THE FRESH-SALINE WATER INTERFACE IN KENTUCKY

By H.T. Hopkins
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Kentucky Geological Survey
University of Kentucky

In cooperation with
United States Geological Survey
Department of the Interior
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INTRODUCTION

Water, both fresh and slightly saline, is a valuable natural resource of Kentucky. Present development has been largely limited to the shallow fresh ground water and to water from surface streams; the deeper fresh and slightly saline ground water has remained virtually undeveloped. Fresh and slightly saline water is found at depths ranging from less than 100 feet to more than 2,000 feet below land surface in Kentucky. Increased water needs of the future will require use of the deeper ground water for public, industrial, domestic, and agricultural supplies.

VIEW MAP (16.4 Mb)

Purpose and Scope

This report is intended primarily to delineate the fresh-saline water interface, the common boundary between fresh water and saline water, on a suitable base map of Kentucky (approximate scale, 1 inch = 8 miles). The map affords a ready means of determining the availability of fresh and saline water throughout the State and, specifically, the minimum depth of a saline water at a particular point or for a more general area.

The text presents the general geology, the geohydrologic controls and their relationship to the interface, and the general chemical characteristics of the water above and below the interface for each physiographic region.

Definitions and Uses of Fresh and Saline Water

The definitions of fresh water and saline water as used in this report are based on the concentration of dissolved mineral matter (total dissolved solids) stated in parts per million. Water having a total dissolved-solids concentration of less than 1,000 ppm is classified as fresh, and water having a total dissolved-solids concentration of 1,000 ppm or more is classified as saline. Saline water in this report refers to water containing from 1,000 to 3,000 ppm total dissolved solids, unless otherwise stated.

The occurrence of saline water in a geologic formation may be due to one or more of the following causes: Retention in the rock formation of the salty water entrapped at the time the formation was deposited (connate water); solution of salt from the formation itself, or from adjacent formations; and entrance of salt water into the formation after it was deposited and subsequently exposed to the ocean or another source of salt water.[1]

Saline water has been used for domestic and commercial purposes since the first settlers arrived in Kentucky. The famous Upper and Lower Blue Lick Springs in Nicholas County in the north-eastern part of the Blue Grass region were used by the Indians and early settlers as a source of salt for curing and seasoning food. Later settlers bottled and sold water from these springs for medicinal purposes. Chemical analyses made in 1850 of water from the Lower Blue Lick Spring showed the total dissolved solids to be 10,296 ppm and the cholorides 5,462 ppm. Water from the Upper Blue Lick Spring has similar concentrations.

The search for brines suitable for supplying industrial chemicals such as magnesium, sodium, potassium, chloride, fluoride, bromide, and iodide, to name a few, has been conducted since shortly after the Commonwealth was settled.

The fresh water above the interface is used throughout the State for public, industrial, agricultural, and small domestic supplies, whereas the slightly saline water just below the interface is virtually unused. This slightly saline water can be used without treatment for specific agricultural purposes and with treatment for public, industrial, and domestic supplies.

A partial list of the more common chemical constituents in drinking water and the limiting concentrations of each, as recommended by the U.S. Public Health Service (1962), is as follows: Total dissolved solids should not exceed 500 ppm, but if water of such quality is not available, water having more than 500 ppm but less than 1,000 ppm may be used; chloride, 250 ppm; fluoride, 1.5 ppm; iron, 0.3 ppm; manganese, 0.5 ppm; sulfate, 250 ppm; and nitrate, 45 ppm.

No set classification is available for hardness. However, the general classification for hardness as calcium carbonate, used by the U.S. Geological Survey, is as follows: 60 ppm or less is soft water, 61 to 120 ppm moderately hard water, 121 to 180 ppm is hard water, and more than 180 ppm is very hard water.

Agricultural uses of saline water include irrigating crops and watering livestock. All crops can be irrigated with water having total dissolved solids less than 525 ppm; most fruit and vegetable crops, except strawberries, apricots, green beans, celery, and radishes, and most forage crops such as burnet, red clover, white Dutch clover, and ladine clover commonly grown in Kentucky, may be irrigated with water containing up to 1,400 ppm total dissolved solids.[2]

Livestock can tolerate water of substantially poorer quality than would be acceptable for human use. The following table gives the recommended upper limits for dissolved solids in water to be consumed by different farm animals, as quoted in the 1963 report of the California Water Pollution Control Board.

Upper limits of dissolved-solids concentration in water to be consumed by livestock

	ppm		ppm
Poultry	2,860	Cattle (dairy)	7,150
Pigs	4,290	Cattle (beef)	10,000
Horses	6,435	Adult sheep	12,900

Requirements for dissolved-solids content of water used for industrial purposes may vary widely; for example, water for low-pressure boilers may contain total dissolved solids ranging from 500 to 2,500 ppm, according to the design of the boiler, whereas high-pressure boilers may require water with total dissolved

[1] Krieger, R.A., Hatchett, J.L., and Poole, J.L., 1957, Preliminary survey of the saline-water resources of the United States: U.S. Geol. Survey Water-Supply Paper 1374.

[2] California State Water Quality Control Board Water-Quality Criteria Pub. 3-A, 1963.

solids of less than 100 ppm. Generally, water that meets drinking-water standards is acceptable for most industrial processes.

One of the more important potential uses of saline water is as a source of raw water for desalination. Mapping of the interface has shown the occurrence of saline water throughout the State and is in itself an approximation of its availability. Desalination is most economical when the raw water used is only slightly saline. Water with 1,000 to 3,000 ppm total dissolved solids occurs immediately below the interface throughout the State. Special reference is made to the Knox Dolomite underlying part of the Blue Grass region as a potential source of saline water suitable for desalination.

The Fresh-Saline Water Interface

The fresh-saline water interface is the physical boundary above which water is classified as fresh and below which water is classified as saline. The interface is not a plane but a zone of varying thickness ranging from less than 100 feet throughout most of Kentucky to more than 500 feet in parts of the Blue Grass region. The chemical change within this zone is gradational rather than abrupt and is best detected by chemical analysis. The depth of the interface ranges from less than 200 feet below land surface in many areas of the State to more than 2,000 feet below land surface in several areas in the western and southeastern parts of the State.

Aquifers containing saline water are found above the fresh water in the lows centered in Muhlenberg County in the Western Coal Field region and Bell County in the Eastern Coal Field region; however, they are not important as sources of water. Similarly, less saline waters are found well below the fresh-saline water interface in parts of the Knox Dolomites underlying the Blue Grass region.

Source of Data

Most of the data used in this report were taken from the files of the Ground Water Branch offices of the U. S. Geological Survey in Kentucky. Some data were obtained from the files of the Lexington and Henderson offices of the Kentucky Geological Survey.

Chemical analyses used in preparing the map were made primarily by the U.S. Geological Survey's Water Quality Laboratory at Columbus, Ohio. Copies of these analyses are available for examination in the Louisville Ground Water Branch office.

Use of the Map

The altitude of the fresh-saline water interface with reference to mean sea level is shown on the map by means of contours drawn at intervals of 100 feet. Thus, the map can be used to indicate the availability and maximum depth of fresh water. The maximum depth of fresh water or the minimum depth to saline water at a particular site is found by subtracting the altitude of the contour representing the interface nearest the site from the altitude of the land surface. The land-surface altitude can be determined from topographic maps, available for the entire State, Interpolation between contours should not be less than one-fourth the contour interval, that is, 25 feet.

In using the map to indicate the availability of fresh water, it is evident that the shallowest depths of the interface, ranging from 25 to 350 feet below land surface, occur in the Blue Grass and Mississippian Plateau regions, and that within these areas the best sources of fresh water are found adjacent to surface streams. The greatest depths of fresh water are in the Jackson Purchase, Western Coal Field, and Eastern Coal Field regions where the interface ranges from 200 to more than 2,000 feet below land surface. Thus, slightly saline water is to be found at minimum depths in the Blue Grass and Mississippian Plateau regions, and at maximum depths below the deeper fresh water in the Jackson Purchase, Western Coal Field, and Eastern Coal Field regions.

JACKSON PURCHASE REGION

General Geology

The Jackson Purchase region is in the extreme northeastern part of the Mississippi Embayment. The embayment was formed by subsidence of the Paleozoic rocks during the Cretaceous Period, and is filled with unconsolidated sediments of Cretaceous and younger ages. The sediments lie unconformably on the truncated Paleozoic rocks and thicken progressively from the east and north toward the southwest, where their total thickness exceeds 2,200 feet within the area covered by this report. The southwest dip of the Cretaceous and Tertiary deposits, excluding the upper gravels of Pliocene(?) age, ranges from 20 to 30 feet to the mile. The Pliocene(?) and Quaternary deposits are essentially flat lying.

The Paleozoic rocks and Cretaceous sands, clays, and gravels crop out in a narrow belt along the eastern border of the region adjacent to the Tennessee River (Kentucky Lake) and its tributaries. In this area the Paleozoic rocks dip to the east and northeast toward the Eastern Interior Coal Basin (McFarlan, 1943), referred to as the Western Coal Field in Kentucky. Tertiary sands, clays, and gravel overlying the Cretaceous sediments have few outcrops, generally being overlain by alluvium and (or) loess of Quaternary age. The alluvium consists of sand, clay, and gravel.

Along the western and northern parts of the region Tertiary sands, clays, and gravels overlying the Cretaceous sediments are overlain by alluvium and loess of Quaternary age. The alluvium consists of sand, clay, and gravel and makes up the flood plains of the Ohio, Mississippi, and Tennessee Rivers and their tributaries. Along the smaller streams, the alluvium is generally fine sand, silt, and clay. Thick deposits of loess occur on the Mississippi River bluffs but they gradually become thin away from the river.

A fuller discussion of the type and thickness of sediments has been given by MacCary and Lambert (1962) and in the series of hydrologic investigations atlases being prepared for each 7 ½-minute topographic quadrangle in the Jackson Purchase region.

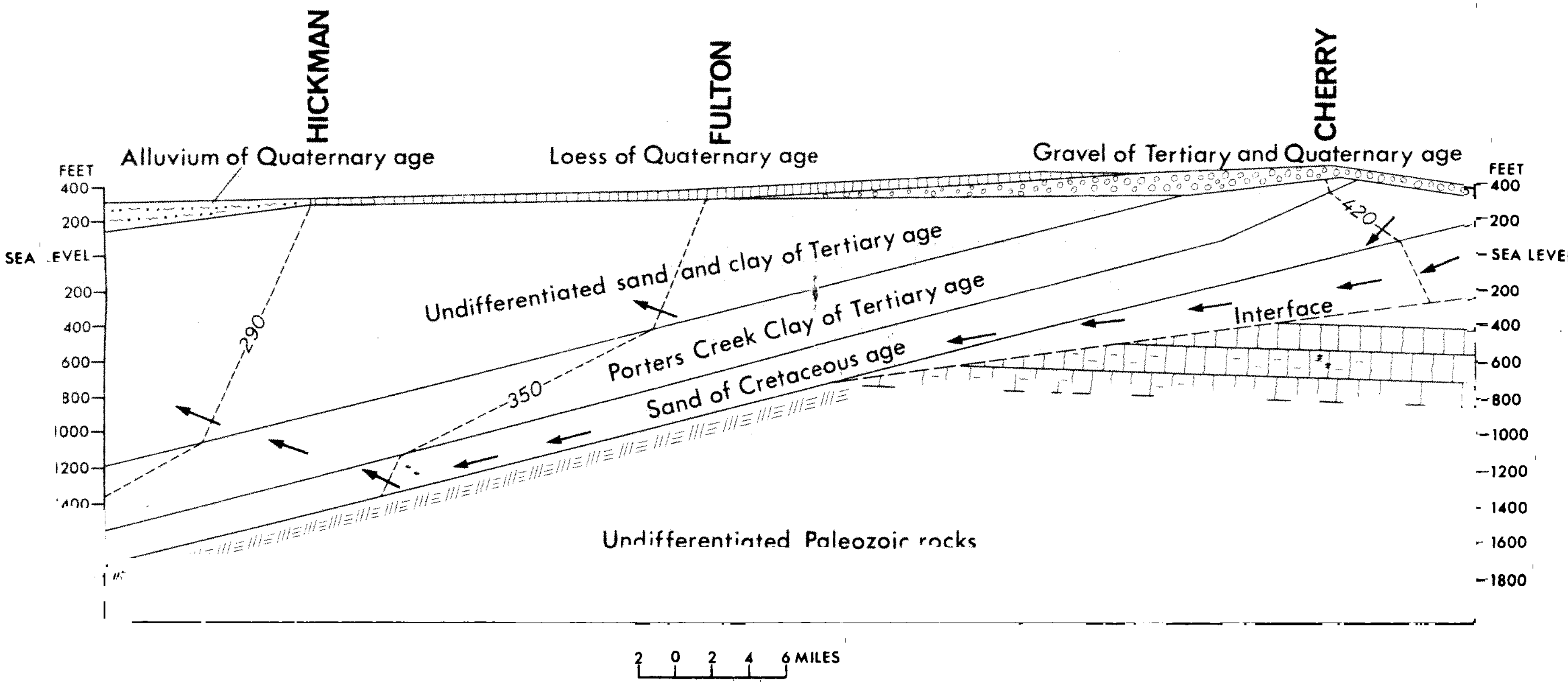
Geohydrologic Controls and their Relation to the Interface

The major control on the depth of the interface is the depth of the Paleozoic rock underlying the Cretaceous and younger sediments within the Mississippi Embayment trough.

The interface coincides with the contact of the Cretaceous and Paleozoic rocks in the embayment trough beneath the altitude of 700 feet below mean sea level. Above this altitude, the interface has a much more gradual gradient than the Cretaceous-Paleozoic contact and is entirely within the Paleozoic rocks. The Paleozoic rocks in which the interface lies dip slightly to the north and northeast toward the Mississippian Plateau and the Eastern Interior Coal Basin.

The Cretaceous and Paleozoic rocks are hydraulically interconnected, and water moves across their contact as a result of the hydraulic gradient, or pressure head. The hydraulic gradient is the ratio of the difference in water level between two points to the linear distance *measured along the aquifer* (not to the horizontal distance between the two points).

A generalized geologic section showing the probable flow of water in the Cretaceous and Paleozoic rocks is shown at the end of the text. In the eastern part of the section, the water moves from the overlying sands of Cretaceous age into the undifferentiated Paleozoic rocks. In the vicinity of Farmington, the direction of flow is from the undifferentiated Paleozoic rocks to the sands of Cretaceous age. Below the altitude of 700 feet below mean sea level the water moves, as shown by the equipotential lines, from the sands of Cretaceous age into the overlying undifferentiated sand and clay of Tertiary age, where a sharp decrease in the hydraulic head results from the discharge of ground water to the Mississippi River on the west. Saline water does not move across from the Paleozoic rocks to the sands of Cretaceous age below the



Generalized geologic section showing the flow of water across the Cretaceous-Paleozoic contact and in the unconsolidated sediments of Cretaceous and younger ages above the interface, Jackson Purchase region. Arrows indicate the direction of ground-water flow across the equipotential lines.

altitude of 700 feet, because the hydraulic head in the sands is equal to, or slightly greater than, that in the Paleozoic rocks. The interface is therefore placed at the contact of these units below the altitude of 700 feet.

Quality of Water

Above the interface, ground water ranges from a sodium bicarbonate to a calcium magnesium bicarbonate type, and below the interface the water is a calcium magnesium bicarbonate type. The change in chemical quality from fresh to saline water near the interface is characterized by a sharp increase in chloride, hardness, and iron.

A partial list of the chemical constituents found in water above the interface is shown in the following table:

	Range (*in ppm)*		*Remarks*
	From	To	
Total dissolved solids	30	350	Generally less than 200 ppm in Cretaceous and younger rocks.
Hardness as $CaCO_3$	50	300	Generally less than 100 ppm in Cretaceous and younger rocks.
Chloride (C1)	2	50	Generally less than 10 ppm in Cretaceous and younger rocks.
Fluoride (F)	.1	1.7	Generally less than 0.3 ppm.
Iron (Fe) and Manganese (Mn)	.1	7.8	Generally less than 0.3 ppm.
Nitrate (NO_3)[3]	.1	30	Nitrate in excess of 100 ppm has been recorded in shallow waters.
Sulfate (SO_4)	.1	38	Generally less than 10 ppm.

[3] There is evidence that more than 45 ppm of nitrate in water may cause methemoglobinemia in infants (blue babies) (U.S. Public Health Service, 1962).

MISSISSIPPIAN PLATEAU REGION

General Geology

The Mississippian Plateau region forms an arcuate belt around the Western Coal Field region extending from the central to the western parts of the State. It is bounded on the west by the Jackson Purchase region, on the south by the Kentucky-Tennessee line, on the east by the Eastern Coal Field and Blue Grass regions, and on the north by the Western Coal Field region and the Ohio River.

The region is subdivided into two major plateau areas separated by the south-facing Dripping Springs escarpment. The inner and higher Mammoth Cave plateau lies to the north of the escarpment, and the lower Pennyroyal plateau lies to the south.

Both of these plateaus are underlain by Paleozoic rocks of Mississippian age. The Pennyroyal plateau is underlain by relatively pure limestone, which is fine to coarse grained, cherty in parts, thin to thick bedded, predominantly thick bedded, with some thin- to medium-shaly beds. The rocks underlying the Mammoth Cave plateau are limestone and shale. The limestone is fine to coarse grained, thin to thick bedded, and locally arenaceous; the shale occurs in fine to medium beds, mostly as parting and lenses. Capping the rocks are sandstone, siltstone, and conglomerate of Late Mississippian and Early Pennsylvanian ages.

The predominantly thick-bedded limestone underlying the Pennyroyal plateau is readily soluble in ground water. Solution by percolating ground water has developed a vast subsurface drainage system. Sinkholes are numerous on the surface of the plateau. A similar subsurface drainage pattern is developed in the deeper limestone underlying the more arenaceous Late Mississippian and Pennsylvanian surface rocks of the Mammoth Cave plateau. Relatively few sinkholes are developed in the arenaceous rocks, but springs are common, especially along the face of the Dripping Springs escarpment.

Unconsolidated deposits of gravel, sand, clay, and silt of Cretaceous and Quaternary ages occur as alluvium, or they mantle the Paleozoic rocks, as in the Between-The Lakes area in the western part of the region.

The major structural feature of the region is the Cincinnati Arch, which transects the eastern part in a north-northeasterly direction. Rocks on the west side of the arch dip to the west and north toward the Eastern Interior Coal Basin, and rocks on the east side dip to the east and south toward the Eastern Coal Field region. The dips average 30 feet to the mile, but may be as much as 70 feet to the mile.

Geohydrologic Controls and their Relation to the Interface

The major controls on the position of the interface are the regional structure (the Cincinnati Arch and the resulting dip of the rocks away from the arch), the composition of the underlying rocks, and the surface and subsurface drainage patterns. The drainage patterns and rock composition are the more significant controls and tend to mask the influence of the regional structure.

In the Pennyroyal plateau the large number of sinkholes, lost rivers, and springs and the few surface streams show that the dominant drainage of this plateau is subsurface. Percolating ground water in the underlying relatively pure, thick-bedded limestone has developed an intricate subsurface drainage system by solution along joint systems, fractures, and bedding planes. The discharge of ground water from this subsurface system occurs as springs and seeps along the valleys of the Green River and its tributaries, the Barren, Nolin, and Rough Rivers, and the Cumberland River and its tributaries, the Little and Red Rivers. These rivers, by solution and abrasion of the underlying limestone, have incised their valleys from less than 100 feet to more than 300 feet below the uplands in their respective basins. The entrenchment of these streams has created a hydraulic gradient that is greater than the regional hydraulic gradient approximating the average dip of the underlying limestone, and the ground-water flow is locally toward the stream. The interrelation between subsurface drainage and surface streams is reflected in the development of the solution openings. In the intervalley areas, the large solution openings are found above the altitude of the present valley floor; in the stream valleys they are found at depths as great as 100 feet below the altitude of the valley floors.

The depth of the interface beneath the Pennyroyal plateau is coincident with the maximum depth of large solution openings and is essentially a subdued reflection of the topography of the plateau. Thus, fresh water on this plateau is found at a lower altitude adjacent to the major rivers than under the ridges. For example, in Metcalfe County, water from a well bottomed at an altitude of 822 feet on a ridge has dissolved solids of 780 ppm, and a well bottomed 41 feet lower at altitude 781 feet on the same ridge has slightly saline water with dissolved solids of 1,750 ppm. A spring discharging at an altitude of 680 feet adjacent to South Fork has dissolved solids of only 270 ppm, and a well bottomed at an altitude of 646 feet in the valley of South Fork yields water containing 705 ppm dissolved solids. The higher dissolved-solids content at the well bottomed at altitude 781 feet is the result of either ground water moving through smaller openings at reduced velocity, thereby providing a longer period of contact and a resulting increased solution of the limestone, or the contribution of residual salts of connate water below.

On the Mammoth Cave plateau, the surface features indicative of subsurface drainage, such as sinkholes and lost rivers, are not so common as on the Pennyroyal plateau. The surface rocks on the Mammoth Cave plateau are more arenaceous and less soluble than those on the Pennyroyal plateau. However, the formations underlying these surface rocks are readily soluble, and subsurface solution openings have been developed to depths coincident with those on the adjoining Pennyroyal plateau. The resulting gradient of the interface, therefore, is relatively uniform downdip beneath the Pennyroyal and Mammoth Cave plateaus.

The interface is deepest below the valleys of the Green River and its tributaries, which have maintained their courses from the Pennyroyal plateau by deep entrenchment of their valleys across the Dripping Springs escarpment and Mammoth Cave plateau. This deep entrenchment creates locally a greater hydraulic gradient for ground-water movement than the regional hydraulic gradient approximating the average dip of the rocks underlying the intervalley areas. Therefore, the maximum depth of large solution openings and of the interface is below these valleys, as in the Pennyroyal plateau.

The Mammoth Cave area is an excellent example of the relation between the subsurface and surface drainage systems. In this area the Green River is entrenched approximately 350 feet below the upland surface. Several major cavern levels are developed in the upland both above and at the present elevation of the Green River. Each of the successively higher levels of cavern originally discharged to the downward-cutting Green River in much the same manner as Echo River does today.

Echo River flows through the cavern complex in a series of large openings, partly navigable by small boat, at an elevation approximately equal to the present level of the Green River. They hydraulic gradient of the water table between Echo River in the cave and the Green River outside the cave is less than 0.3 foot per mile except at rising and falling stages of the Green River. At flood peaks, the levels are approximately equal in the Green River and in the cave.

This low gradient of the water table toward the Green River is reflected in the gradient of the interface in this immediate area. Solution of the relatively pure limestone underlying the part of the plateau away from the river has kept pace with the downward cutting of the river; thus, the depth of development of solution openings has been more uniform and the gradient of the interface toward the river is less than in surrounding areas of the plateau and on the adjoining Pennyroyal plateau.

Two areas on the Mammoth Cave plateau where the position of the interface is of special interest are in southeast Breckinridge County and central Grayson County.

The area in southeast Breckinridge County shows the interface approximately 200 feet above that in the surrounding area. This high results from the solution by circulating ground water of sulfate (919 ppm) from thin beds of gypsum common in the rocks underlying the area. In this area, water containing less than 1,000 ppm total dissolved solids can be obtained by deepening wells to an altitude of 500 feet above sea level and sealing off the zone yielding high-sulfate water.

The low in the interface, indicated by a well bottomed at an altitude of 275 feet below mean sea level in central Grayson County, results from the deep circulation of fresh water along the faults and fractures associated with the Shawneetown-Rough Creek fault system. Depression contours have not been drawn around this well because of insufficient data on the areal extent of the low. Drillers' logs, the only source of information available, are inconclusive for outlining the area.

Quality of Water

The water is a calcium magnesium type immediately above the interface and a sodium bicarbonate type below the interface. The change in chemical quality from fresh to saline water near the interface is characterized by a sharp increase in chloride, hardness, and iron.

A partial list of the chemical constituents found in water above the interface is shown in the following table:

	Range (*in ppm*)		*Remarks*
	From	*To*	
Total dissolved solids	55	980	Generally range from 250 to 650 ppm.
Hardness as $CaCO_3$	67	550	Generally range from 125 to 225 ppm.
Chloride (C1)	10	250	Generally less than 10 ppm.
Fluoride (F)	.1	.3	Commonly exceeds 0.3 ppm in the fluorspar area in the northwestern part of the region.
Iron (Fe) and Manganese (Mn)	.1	.3	
Nitrate (NO_3)[4]	.1	160	Generally less than 20 ppm.
Sulfate (SO_4)	10	350	Generally less than 25 ppm.

[4] There is evidence that more than 45 ppm of nitrate in water may cause methemoglobinemia in infants (blue babies) (U.S. Public Health Service, 1962).

WESTERN COAL FIELD REGION

General Geology

The Western Coal Field region is bounded on the south, east, and west by the inner edge of the U-shaped Mammoth Cave plateau of the Mississippian Plateau region and on the north by the Ohio River.

The use of the term Western Coal Field is restricted to Kentucky to describe the southernmost extension of the Eastern Interior Coal Basin, a structural basin centered in Illinois. The dip of the Paleozoic rocks in the adjoining Mississippian Plateau region as well as those in the Western Coal Field region is toward the center of this structural basin.

Two major structural features are present: faulting on the south limb of the Moorman syncline, which extends northwestward from Butler County in the southeast through Union County in the northwest; and the Shawneetown-Rough Creek fault zone, which enters Ohio County in the east from the Mississippian Plateau and extends west across Union County. Displacement along this latter fault system exceeds 1,000 feet in places.

The rocks range in age from Paleozoic to Recent. The Paleozoic rocks, exposed over most of the area, are sandstone, siltstone, and shale, with relatively thin beds of limestone, dolomite, and coal. The Quaternary deposits consist of unconsolidated silt, clay, sand, and gravel making up the alluvium of the Ohio River and its tributaries, the Green and Tradewater Rivers. Loess deposits consisting of fine silt and sand occur along the bluffs to the Ohio, Most of the region is a rolling upland ranging from 400 to 500 feet above mean sea level. A belt of rugged hills concentric to the Mammoth Cave plateau lies along the east, south, and southwestern parts of the region, and a series of hills resulting from displacements along the Shawneetown-Rough Creek fault system crosses the region from east to west.

Geohydrologic Controls and their Relation to the Interface

The predominant influences on the depth of the interface in the Western Coal Field region are faulting along the south limb of the Moorman syncline and the Shawneetown-Rough Creek fault zone. North of the Shawneetown-Rough Creek fault zone the depth of the interface is related to the overall dip of rocks toward the center of the Eastern Interior Coal Basin, the rock composition, and the surface drainage pattern.

Along the southern border of this region, there is a pronounced depression in the interface with a maximum depth of 400 feet below mean sea level. This exceeds the normal depth of the interface by 600 feet in the part of the Western Coal Field to the north and by 1,000 feet in the part of the Mississippian Plateau region to the south. However, residual connate water may be confined above the fresh water in sandstone lenses and beds of limited areal extent between fault blocks.

This depression is related to the fault system lying to the south of the axis of the Moorman syncline. The axis of this depression trends east-west with a slight bow to the north from near Central City in Muhlenberg County to a point southwest of St. Charles in Hopkins County. A maximum structural displacement of 1,800 feet occurs in the area from the southern part of Muhlenberg County north to the axis of the Moorman syncline (Rose, 1963). Ground water moves toward this low from the outcrop area of the basal Pennsylvanian sandstones through joint systems, bedding planes, interstitial openings, and along fault planes.

In the northern and central parts of this region the interface lies between 200 and 550 feet below land surface. North of the Shawneetown-Rough Creek fault system, the rocks generally dip northward toward the center of the Eastern Interior Coal Basin, and the interface descends along this dip into Illinois and Indiana at the north bank of the Ohio River. The interface is between 50 and 100 feet below the bottom of the alluvial deposits of the Ohio River. Ground-water flow in the Pennsylvanian rocks underlying this area is along joint systems and bedding planes with some flow through interstitial openings. In the unconsolidated Ohio River alluvium, the flow occurs entirely in interstitial openings.

The interface immediately adjacent to the Mississippian Plateau region on the east and west reflects the local surface drainage pattern. The streams flowing across the limestone and dolomite of this area influence the position of the interface in the same manner as that described for the adjoining Mississippian Plateau region.

Quality of Water

The water above the interface ranges from a sodium bicarbonate to a calcium magnesium bicarbonate type; below the interface the water is generally a sodium bicarbonate or sodium chloride type. The change in chemical quality from fresh to saline water near the interface is characterized by a sharp increase in sodium and chloride.

A partial list of the chemical constituents found in water above the interface is shown in the following table:

	Range (*in ppm*)		*Remarks*
	From	To	
Total dissolved solids	100	990	Generally range between 400 and 750 ppm.
Hardness as $CaCO_3$	5	550	Generally range between 100 and 300 ppm.
Chloride (C1)	3	185	Generally less than 50 ppm.
Fluoride (F)	.1	2.8	Frequently exceeds 0.3 ppm.
Iron (Fe) and Manganese (Mn)	.1	.3	
Magnesium (Mg)	.1	70	Generally less than 35 ppm.
Nitrate (NO_3)[5]	.1	90	Generally less than 10 ppm.
Sodium (Na)	1.0	335	Generally less than 50 ppm.
Sulfate (SO_4)	.2	430	Generally less than 50 ppm.

[5] There is evidence that more than 45 ppm of nitrate in water may cause methemoglobinemia in infants (blue babies) (U.S. Public Health Service, 1962).

BLUE GRASS REGION

General Geology

The Blue Grass Region lies in the north-central part of the State. It is bounded on the west and south by the Pennyroyal plateau of the Mississippian Plateau region, on the east by the Eastern Coal Field region, and on the north by the Ohio River.

The topography is gently rolling to rugged, varying with the composition of the underlying rocks.

The rocks of this region are of Paleozoic and Quaternary ages. The Paleozoic rocks form a broad structural dome and crop out as a series of concentric exposures, with the oldest rock exposed in the central part of the region. The oldest Paleozoic rocks underlie the Inner Blue Grass area, a gently rolling upland in the central part of the region. The rocks are thin- to thick-bedded limestones and thin-bedded shales. Surface and subsurface solution openings are common in these rocks. Encircling the area is the Eden Shale belt, a series of shales with interbedded thin limestone layers. Solution openings are not common; however, erosion has produced a relatively rugged topography. Encircling the Eden Shale belt is the Outer Blue Grass area, a gently rolling area underlain by Silurian and Devonian rocks. The Silurian rocks are limestone with interbedded shale; the Devonian rocks are shale and limestone with interbedded siltstone. Subsurface and surface solution openings are common in the limestone and siltstone beds.

The outer perimeter of the Blue Grass region is a series of erosional remnants of the adjoining Mississippian Plateau and Eastern Coal Field regions, referred to as the Knobs area. The Knobs are formed of Mississippian and Pennsylvanian rocks overlying Silurian and Devonian rocks. The Mississippian rocks are limestones and siltstones with some shale beds; the Pennsylvanian rocks are sandy limestones and sandstones which form the cap rocks in the Knobs adjacent to the Eastern Coal Field region and the southeastern part of the Mississippian Plateau region. The Silurian and Devonian rocks are similar to those in the Outer Blue Grass area.

The Quaternary rocks are unconsolidated gravel, sand, silt, and clay overlying the Paleozoic rocks throughout the region. In the Ohio River valley the Quaternary deposits are more than 100 feet thick in places and are excellent sources of ground water. In the valleys of the Licking, Kentucky, and Salt Rivers these deposits are less than 50 feet thick except near the confluence of these rivers with the Ohio River, where they are more than 50 but generally less than 100 feet thick.

The Jessamine Dome, centered in Jessamine County along the axis of the Cincinnati Arch, is the dominating structural feature of this region. The dip of the rocks away from the Jessamine Dome averages 20 to 30 feet to the mile to the east and west and about 10 feet to the mile to the north and south.

Two prominent faults are present – the Kentucky River fault system and the West Hickman fault. The Kentucky River fault system extends northeast from Lincoln County in the south-central part of the region to Mt. Sterling in Montgomery County. The West Hickman fault trends northeast form the Kentucky River fault system in Jessamine County to Maysville in Mason County.

Geohydrologic Controls and their Relation to the Interface

The major controls on the position of the interface are the regional structure (the Jessamine Dome and the resulting dip of the rocks away from this dome), the composition of the underlying rocks, and the surface and subsurface drainage patterns.

In this region, as in the Mississippian Plateau region, the influence of the surface drainage patterns is most important and tends to mask the influence of the structure and composition of the underlying rocks.

The overall direction of flow of the major surface streams, the Salt, Kentucky, and Licking Rivers and their tributaries, is downdip toward the Ohio River on the north and west flanks of the Jessamine Dome. However, the direction of flow of the Kentucky and Licking Rivers is updip in the upstream parts of their courses on the south and southeast flanks of the Jessamine Dome. The Salt River drains the western part of the area, the Kentucky the central part, and the Licking River the eastern part. The valleys of these streams are seldom entrenched more than 200 feet below the adjoining uplands except along the Kentucky River. In the central part of the area, the Kentucky River and its tributaries are entrenched more than 350 feet below the adjoining upland across the Cincinnati Arch. Faulting has altered locally the direction of flow of the Kentucky River from northwest to southwest in southern Clark, Fayette, and Jessamine Counties. Flow to the northwest is resumed in southern Jessamine County.

The Ohio River may be entrenched as much as 400 feet but generally is entrenched between 200 and 300 feet below the upland. The gentle slopes of valley walls, rising above broad flood plains of the river, give this valley a more subdued appearance than those of its tributaries draining the Blue Grass region.

The subsurface drainage to these rivers and the depth of the interface varies with the composition and solubility of the underlying rocks. The more soluble rocks underlie the central Inner Blue Grass area; immediately adjacent to this area lie the least soluble rocks, the Eden Shale belt. The rocks underlying the Outer Blue Grass and Knobs areas are intermediate in solubility between the inner two areas.

In the Inner Blue Grass area, sinkholes, lost river, and springs show the presence of a well-developed subsurface drainage system. Water moving beneath the uplands moves down the dip of the rocks away from the Jessamine Dome. The flow of water is through openings developed by solution and abrasion in limestone beds that are underlain by shale and siltstone beds. The shale and siltstone beds are relatively impermeable, and thus retard the downward movement of water. However, water does move through these impermeable beds locally to a lower limestone unit through openings developed by faulting, by intersecting joint systems, or by solution where the formation is thin or limy.

On the uplands are several water-bearing zones containing fresh water generally to depths less than 200 feet. Below this depth the water is saline. As the water moves from the shallow to the deeper zones, it moves through progressively smaller openings for progressively longer periods of time, thereby altering its chemical quality from fresh to saline by solution of salt from the rocks or from the residual salts of connate water in the deeper formations. In this region the alteration of chemical quality is most often reflected by a sharp increase in hardness and chloride.

Near the Kentucky River gorge the interface is found at progressively lower depths than in the upland. In the upland the interface is generally above an altitude of 800 feet, whereas in the Kentucky River gorge it is generally at an altitude of 500 feet or less. The Kentucky River gorge provides the lowest point for ground-water discharge in the Inner Blue Grass region. Along the gorge the hydraulic gradient toward the river is greater than the regional gradient, which approximates the dip of the rocks away from the Jessamine Dome, with the result that locally ground water will move toward the river rather than downdip. The fresh water moving from the upland toward the river has, by solution and abrasion, developed relatively large openings in the limestone underlying the gorge to an altitude lower than 400 feet.

The same general shape and slope of the interface in the gorge of the Kentucky River is also reported beneath the valleys of its tributaries, but the interface is not so deep in the tributaries.

In the northern part of the Inner Blue Grass region the interface is generally more than 150 feet below land surface and commonly exceeds 200 feet. In the vicinity of the Kentucky River fault system in the southern part of the area, high concentrations of chloride are common at depths greater than 100 feet below land surface, except in the valley of the Kentucky River and the immediate vicinity of Herrington Lake, where the interface is at depths more than 150 feet below land surface. The chlorides are derived from the mixing of residual connate water with circulating fresh ground water and (or) possibly by the upward movement of connate water along fault planes.

Generally, the change in chemical quality as the interface is approached from above is an increase in hardness and chloride concentration; however, sharp increases in the concentration of iron and sulfate may also occur.

In the adjoining Eden Shale belt there is little subsurface drainage. The underlying rocks, shales with interbedded thin limestones, are not readily soluble in ground water and therefore few subsurface solution openings are developed. There are some springs in the area, but their yields are generally small and not sustained throughout the year.

The interface in this area is commonly at depths of less than 100 feet below land surface on the upland and less than 75 feet below land surface in the stream valleys. Generally, deterioration of chemical quality near the interface is reflected by an increase in sulfate, chloride, and iron.

In the Outer Blue Grass and Knobs areas adjoining the Eden Shale belt the small number of sinkholes and low-yielding springs shows that the subsurface drainage system is poorly developed. The predominance of shale and of limestone with interbedded shale inhibits the development of a major subsurface drainage system by solution.

The poor development of the subsurface drainage system provides a minimum of ground-water storage at shallow depths for discharge to the small streams of the area. Thus, many of the tributaries of the larger streams have no apparent flow during the period from mid-July to November. However, ground water moves as underflow toward the deeper valleys of the Salt, Kentucky, and Licking Rivers during the periods of no apparent flow in their tributaries. The gradient of the interface is steepest toward the Kentucky River. In the Outer Blue Grass area the interface is generally less than 75 feet below land surface in the upland but may be as much as 165 feet below land surface in the valleys.

In the Knobs area underlain by Silurian and Mississippian rocks, the interface is generally less than 75 feet below land surface. In the area underlain by the Devonian shale, the interface is generally less than 65 feet, but it may be as much as 165 feet below land surface in the valleys of the Licking and Kentucky Rivers.

It should be noted that relatively high concentrations of chloride, frequently exceeding 100 ppm and sometimes as much as 240 ppm, are common in water containing less than 1,000 total dissolved solids in the Outer Blue Grass and Knobs areas. The change in chemical quality downward toward the interface is reflected by an increase in chloride, sulfate, iron, and frequently manganese.

Quality of Water

The water above the interface ranges from a calcium magnesium bicarbonate type to a sodium chloride type, and that below the interface generally is a sodium bicarbonate or sodium chloride type. The change in chemical quality from fresh to saline water near the interface is characterized by a sharp increase in chloride, sulfate, hardness, and occasionally iron.

A partial list of the chemical constituents found in water above the interface is shown in the following table:

	Range (*in ppm*)		*Remarks*
	From	To	
Total dissolved solids	250	980	Generally range from 450 to 800 ppm.
Hardness as $CaCO_3$	50	980	Generally range from 250 to 600

			ppm.
Chloride (C1)	2	340	Generally less than 75 ppm.
Fluoride (F)	.1	8.4	Frequently exceeds 0.3 ppm.
Iron (Fe) and Manganese (Mn)	.1	9.1	Frequently exceeds 0.3 ppm.
Magnesium (Mg)	2.9	44	Generally less than 20 ppm.
Nitrate (NO_3)[6]	.1	70	Generally less than 10 ppm.
Sodium (Na)	8	200	Generally less than 10 ppm.
Sulfate (SO_4)	.4	520	Generally less than 100 ppm. Sulfate in excess of 150 ppm is common to the area underlain by the Devonian shale and Eden Group.

The Knox Dolomite is of special interest as a future source of saline water suitable for conversion to fresh water by the desalination process. This formation underlies the entire State, but in the Blue Grass region the upper part of the formation contains water with total dissolved solids ranging from 1,500 ppm to 10,000 ppm. The total solids are generally less than 3,500 ppm in the central and northern parts of the region, but they increase to the southeast, south, and west, where the formation is oil bearing. The Knox Dolomite is from 700 to 1,000 feet below land surface, or from 500 to 900 feet below the interface in the Blue Grass region. Wells finished in the Knox Dolomite are shown on the map by open circles.

Present data on the chemical quality of water and yields of wells in the Knox Dolomite are inconclusive to evaluate the potential of this formation as a source of saline water. Future studies of this formation on a Statewide basis are intended.

[6] There is evidence that more than 45 ppm of nitrate in water may cause methemoglobinemia in infants (blue babies) (U.S. Public Health Service, 1962).

EASTERN COAL FIELD REGION

General Geology

The Eastern Coal Field region is in the southeastern part of the State. It is bounded on the west by the Mississippian Plateau region, on the north by the Blue Grass region, and on the northeast, east, southeast, and south by the States of Ohio, West Virginia, Virginia, and Tennessee, respectively.

The topography is that of an intricately dissected upland. The region is subdivided into three areas for ease of discussion: the Cumberland Plateau section, the Kanawha section, and the Cumberland Mountain section (Price and others, 1962). The latter section includes Pine Mountain and the intervening Middlesboro syncline.

The Cumberland Plateau section lies in a belt 5 to 30 miles wide along the western edge of the region. It is a broad, gently rolling upland intricately dissected adjacent to the Mississippian Plateau and Blue Grass regions.

The section is underlain by sandstone, siltstone, shale, and coal of Pennsylvanian age. The sandstone is thin to thick bedded and locally crossbedded; the siltstone and shale ranges from thin shale partings to thin-bedded siltstone; coal beds are from 0 to 48 inches in thickness and locally beds up to 120 inches are reported. Rocks of Mississippian age similar to those in the adjoining Knobs area are exposed in the valleys of the Cumberland, Kentucky, and Licking Rivers.

The Kanawha section is the largest section, covering the entire central and northern parts of the region. It is an intricately dissected plateau with the tributaries of the major streams, the Cumberland, Kentucky, Licking, Big Sandy, and Little Sandy Rivers, entrenched in steep narrow valleys.

The section is underlain by Paleozoic rocks of Pennsylvanian and Mississippian ages. Siltstone and limestone of Mississippian age are exposed in the valleys in the northern part of the area. The siltstones contain fine-grained interbedded sandstones with irregularly interbedded shale; the limestones are finely to coarsely crystalline and contain abundant chert nodules in places. The Pennsylvanian rocks in the northern part of the area are sandstone, siltstone, and shale, and include some coal beds. The sandstone is quartzose, thick bedded to massive, and crossbedded; the siltstone is fine grained and interbedded with minor amounts of thin green shale. In the southern part of the area, the Pennsylvanian rocks are sandstone, siltstone, shale, limestone and coal. The sandstone is fine to medium grained, locally coarse grained, thick bedded, and crossbedded; shale, siltstone, and limestone are commonly interbedded. The limestone may be present as lenses or as beds generally not more than 2 feet thick; coal may be present in beds more than 6 feet thick.

The Cumberland Mountain section lies along the southeast edge of the area. This section consists of two parallel ridges, Pine Mountain and Cumberland Mountain, and an intervening valley, the Middlesboro syncline. It is an intricately dissected area similar to that of the Kanawha section.

The area is underlain by Paleozoic rocks ranging in age from Devonian to Pennsylvanian. Devonian and Mississippian rocks are exposed along the Pine Mountain and Rocky Face faults. The Devonian rock exposed is the Chattanooga Shale, a grayish-black, carbonaceous, pyritic shale, ranging from 250 to 300 feet in thickness.

The Mississippian rocks are sandstone, limestone, and shale. The sandstone beds are chiefly in the upper sections immediately underlying the Pennsylvanian rocks. The sandstone is fine to medium grained, crossbedded, and conglomeratic; shale with thin limestone beds is common. The limestone underlies the upper sandy beds and is medium to coarsely crystalline, medium to thick bedded. The shale occurs as thin to medium beds in the limestone sections. A thick lower unit overlying the Chattanooga Shale contains a few siltstone and sandstone beds.

The Pennsylvanian rocks are sandstone, siltstone, shale, and coal, similar to those described for the southern part of the Kanawha section.

The difference in the composition of the underlying rocks causes variations in the type of subsurface openings through which ground water flows. In sandstone, siltstone, shale, and coal the major ground-water flow is along joint systems, fractures, and bedding planes. However, there is some flow through intergranular spaces. In limestones the major ground-water flow is through openings enlarged by solution along joint systems, fractures, and bedding planes.

The major structural features of the region are the Irvine-Paint Creek uplift, the Eastern Kentucky syncline, and the Cumberland Mountain overthrust. The Irvine-Paint Creek uplift is a series of folds and faults trending east-west from Wolfe County to Lawrence County. The Eastern Kentucky syncline is a broad basin lying between the Irvine-Paint Creek uplift and the Cumberland Mountain overthrust. The Cumberland Mountain overthrust lies along the southeast border of the region. The Pine Mountain fault separates this area from the adjoining Eastern Kentucky syncline area.

Geohydrologic Controls and their Relation to the Interface

The major controls of the depth of the interface are the regional structure (Irvine-Paint Creek uplift, Eastern Kentucky syncline, and the Cumberland Mountain overthrust), the composition of the underlying rocks, and the surface and subsurface drainage patterns.

In this region the surface drainage does not exert as strong an influence on the position of the interface as in the Blue Grass and Mississippian Plateau regions. However, in the part of the Eastern Coal Field north of the Irvine-Paint Creek uplift soluble limestone of Mississippian age is exposed in the valleys of the Little and Big Sandy Rivers and Tygarts Creek, and it controls in part the position of the interface. Mississippian limestones are similarly exposed in the valleys of the Cumberland, Kentucky, and Licking Rivers adjacent to the Mississippian Plateau and Blue Grass regions. Solution openings developed in these limestones underlying the valleys contain water with less than 1,000 ppm total dissolved solids at depths greater than 100 feet, whereas on the upland, water with total dissolved solids of 1,000 ppm or more is found at, or just below, the contact of the Mississippian and Pennsylvanian rocks. In the upland areas interbedded shales near the contact of the rocks of Mississippian and Pennsylvanian ages retard the downward flow of water to the underlying Mississippian rocks, inhibiting the development of large solution openings and the flushing of residual connate water. Water below this contact shows a sharp increase in hardness and chloride caused by solution of limestone and mixing with residual connate water. Near the streams underlain by Mississippian rocks, the development of large solution openings and flushing of connate water occur at greater depths than beneath the upland area, and thus fresh water is found at maximum depths within the valleys.

In the eastern part of the Cumberland Mountain section and the area of the Kanawha section south of the Irvine-Paint Creek uplift, the major influence on the depth of the interface is the Eastern Kentucky syncline. The Pennsylvanian rocks within this structure thicken progressively from their outcrop area adjacent to the Mississippian Plateau and Blue Grass regions toward the southeast. Ground water moves through these Pennsylvanian rocks primarily in small openings along joint systems, fractures, and bedding planes; some flow occurs through the interstitial openings of the medium- and coarse-grained sandstone. There are no large solution openings characteristic of the Mississippian Plateau and Blue Grass regions. Because of the higher permeability, the numerous points of discharge as springs and seeps, and the limited solubility of the Pennsylvanian rocks, the quality of water is not readily altered and the interface is relatively deep beneath the upland, resulting in more gentle gradients toward streams throughout the region.

The interface shows three prominent lows in the outcrop areas of the Pennsylvanian rocks along the northwest edge of the Eastern Kentucky syncline. The westermost low, in parts of Knox and Laurel Counties, is separated from the central low in part of Breathitt and Owsley Counties by a local structure, the Rockcastle uplift. The axis of the Rockcastle uplift trends northeast from just south of London in Laurel

County to south-central Owsley County. The central low is, in turn, separated form the northernmost low in parts of Magoffin and Johnson Counties by the Irvine-Paint Creek uplift, which trends east-west across the Eastern Coal Field region. These three areas form natural hydraulic lows toward which water moves from the outcrop area to the northwest and from adjacent structural highs. The maximum depth of the interface in each area is defined by the Pennsylvanian sandstones which lie just above the contact with Mississippian rocks. Water in the underlying Mississippian rocks is characterized by a sharp increase in chloride, hardness, and total dissolved solids. The total dissolved solids generally increase from less than 1,000 ppm to more than several thousand parts per million immediately below the interface.

The Pennsylvanian sandstones southeast of these lows also have high concentrations of chloride; however, the exact position of the interface within these sands is not known in detail and is to be the subject of a future study.

In the Cumberland Mountain section the major influence on the depth of the interface is rock structure (the Pine Mountain overthrust block and the Middlesboro basin) and related faulting.

The maximum known depth of the interface in the Eastern Coal Field region occurs in the Middlesboro basin, a down-faulted area in south-central Bell County. The Middlesboro basin, being topographically lower than adjoining areas, is essentially a hydraulic low. Water moves toward this low from the outcorp area of Pennsylvanian rocks which are topographically higher and dip toward the basin. Fault planes intercept the flow and provide a route for deep circulation of fresh water. In this basin the interface is shown on the map at a minimum depth of 1,500 feet below land surface at an altitude of 400 feet below mean sea level. However, water form this depth contains less than 200 ppm total dissolved solids and unconfirmed reports of several oil and gas tests in the area have indicated fresh water at depths as great as 9,000 feet below land surface. On this latter basis, it is believed that the maximum depth of the interface in the Middlesboro basin is about 2,000 feet below land surface, or 1,000 feet below mean sea level.

Northeast of the Middlesboro basin the interface reflects the topography of the Pine Mountain thrust block, Cumberland Mountain, and the Middlesboro syncline lying between them. Ground water moves southeastward from Pine Mountain and northwestward from Cumberland Mountain to the Middlesboro syncline and then southwest along the plunge of the axis of this syncline to the Middlesboro basin. The interface slopes gently toward the Kanawha section to the northwest from the crest of Pine Mountain and rather steeply to the southeast toward the Middlesboro syncline. At the northeast end of the Middlesboro syncline near the crest of Black Mountain the interface rises to its highest point in the State.

The location of the interface in this area is based on information given for each well shown on the map and on reports of saline water from well-inventory schedules completed by U.S. Geological Survey personnel. The information from well-inventory schedules is not shown on the map because it is limited to statements concerning taste, odor, and color of water.

Quality of Water

The water above the interface ranges from a calcium magnesium bicarbonate type to a sodium bicarbonate type. Below the interface it is generally a sodium bicarbonate or sodium chloride type. The change in chemical quality from fresh to saline water near the interface is characterized by a sharp increase in chloride, hardness, and iron.

A partial list of the chemical constituents found in water above the interface is shown in the following table:

	Range (*in ppm)*		*Remarks*
	From	To	
Total dissolved solids	200	930	Generally range from 250 and 450 ppm.
Hardness as $CaCO_3$	25	450	Generally less than 150 ppm.
Chloride (C1)	2	330	Generally range from 50 to 150 ppm.
Fluoride (F)	.1	2.6	Frequently exceeds 0.3 ppm.
Iron (Fe) and Manganese (Mn)	.1	33.0	Frequently exceeds 0.3 ppm.
Magnesium (Mg)	.9	26.0	Generally less than 20 ppm.
Nitrate (NO_3)[7]	.1	37	Generally less than 10 ppm.
Sodium (Na)	.1	300	
Sulfate (SO_4)	.2	380	High-sulfate content is common in water draining from some deep mines and strip mine spoil piles.

[7] There is evidence that more than 45 ppm of nitrate in water may cause methemoglobinemia in infants (blue babies) (U.S. Public Health Service, 1962).

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KENTUCKY GEOLOGICAL SURVEY
University of Kentucky
IN COOPERATION WITH
UNITED STATES GEOLOGICAL SURVEY
Department of the Interior
1966

FRESH-SALINE WATER INTERFACE MAP OF KENTUCKY

By H.T. HOPKINS
U.S. Geological Survey

Scale 1:500,000
1 inch equals approximately 8 miles

Physiographic regions and major structural features of Kentucky

EXPLANATION

Hydrology

Well

Wells finished in the Knox dolomite equivalent are shown with open circles. The only Knox wells shown are in the Blue Grass region.

Spring

668-54 — Total dissolved solids, in parts per million — Chloride concentration, in parts per million

770 — Depth of well, in feet below land surface

370 — Altitude of bottom of well or outlet of spring, in feet referred to mean sea level

Two sets of figures may be shown for one well symbol indicating two analyses of different depths or analyses from two wells less than 100 feet apart

800 — Interface contour

Shows altitude of the base of fresh water throughout the State. Dashed where approximately located. Contour interval, 100 feet. Datum is mean sea level.

Physiography (structure)

Jackson Purchase region
Rocks of Mesozoic and Tertiary age

Mississippian Plateau region
Rocks of Mississippian age

Western Coal Field region
Rocks of Pennsylvanian age

Blue Grass region
Rocks of Ordovician, Silurian, and Devonian age

Eastern Coal Field region
Rocks of Pennsylvanian age
(Along Pine Mountain fault rocks are of Devonian and Mississippian age)

Boundary between physiographic or geologic units
Dashed where inferred

Thrust fault
Barbs on upper plate

Geologic Section

Sand

Clay

Gravel

Limestone

Sandstone

Shale

Contact

Fault

Geology generalized from Geologic Map of Kentucky
by W. R. Jillson, scale 1:500,000
(Kentucky Geological Survey, ser. 6, 1929)

GEOLOGIC SECTION FROM NEAR BARDWELL, CARLISLE COUNTY, TO NEAR CATLETTSBURG, BOYD COUNTY

Horizontal scale same as map

DRAFTED BY ROGER B POTTS