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THE GEOLOGY OF GROUND WATER IN MISSISSIPPI: A COMMENTARY

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In a discussion of economic geology many years ago, I was asked by a professor, "What is any region's most valuable natural resource?" My thoughts immediately turned to pricey resources such as gold, silver, diamonds, and other precious stones, but the correct answer was "water," in particular good drinking water. This resource supplies our next most critical need after we have air to breathe. There are large unpopulated tracts of earth that are desolate because of a lack of water. Even in the humid sub-tropical climate of Mississippi, the Mississippi Department of Environmental Quality has identified "water quantity" as the most pressing issue it will face in the coming years.

Water quantity, and especially the quantity and availability of ground water, has been a hot political issue since Biblical times. The nomadic wanderings of the patriarchs Abraham, Isaac, and Jacob were driven in part by the need for water. The 26th chapter of Genesis tells that Isaac moved to the valley of Gerar to re-dig the wells of his father Abraham, which the Philistines had filled in with dirt. The first well was such a success with flowing water that the herdsmen of Gerar claimed, "The water is ours." Then Isaac dug another well, only to have the herdsmen claim it too. Finally, Isaac moved to another site and dug a well that no one quarreled over, and so he named it Rehoboth, meaning (in Isaac's expanded explanation) "At last the Lord has made room for us, and we shall be fruitful in the land."

Potable water is as important to being "fruitful in the land" today as it was in Isaac's time. This was especially true for early settlements in Mississippi. In 1811, Silas Dinsmoor, Choctaw Agent for Mississippi between 1802 and 1816, built an Agency house at Ridgeland, Mississippi, near the intersection of Agency Road and the Natchez Trace right-of-way. This house measured 72 by 30 feet and was scandalously large for an Agency house of its time. To provide for the large water supply needed by the Agency's many guests, Dinsmoor began digging a well in late 1811 and early 1812 (Elliot, 1998) and dug to a depth of 172 feet in the stiff Yazoo Clay before abandoning the project as a dry hole.

Even if Dinsmoor had dug his well twice as deep, it would still have been dry, because the Yazoo Clay is as much as 400 feet thick in the Ridgeland area. The Agency later dug an additional cistern to supplement their water supply. Today cisterns of old home sites dot the landscape of the Jackson Prairie, a physiographic province across central Mississippi developed on the Yazoo Clay. Similar cisterns dot the landscape of the Black Prairie, a physiographic province developed on the Cretaceous chalk belt of northeastern Mississippi. On cold winter mornings, cisterns of the Jackson Prairie, along Kickapoo Road west of Ridgeland, can be located by their wispy vapors, the ghosts of long-forgotten home sites, now only an extension of the rolling fields.

Cisterns have been used since ancient times in areas where ground-water resources were very deep or absent. They generally have a narrow neck at the surface and expand below to a large cylinder or basin to catch the rainwater funneled from the roof of a house. The cistern with which I am most familiar is a relic in my in-law's 3-acre yard in northwestern Hinds County. The modest brick, well-like upper structure and concrete covering at the surface hide a huge cavity below, a deep cylindrical cavity that looks like an intercontinental ballistic missile silo. This dark abyss was built large enough to store rainwater from wet months to be used in the dry months or, even worse, in dry years. Before drinking the water, it was best to sieve out the "wiggly worms" through a cloth. Even so, not much could be done about the coliform bacteria from bird droppings and other sources. This water would not pass our Health Department standards of today.

Thanks to modern drilling techniques my in-laws (who never used the cistern) have an 800-foot deep water well in the Cockfield Formation. This well is over 40 years old and still provides crystal-clear water, which, according to a recent test by an industrial laboratory, has a pH of 8.29 (8.3 to 8.5 is ideal, meaning no CO_2 and no corrosion), low iron and manganese, and no coliform bacteria. Much of Mississippi is blessed with good ground water, and, unlike desert areas were there is little rainfall, Mississippi's ground water is a renewable resource thanks to the state's average rain accumulations of some 50 to 68 inches a year.

One myth I've heard from some water-well owners in Hinds County, and which they apparently heard from their well driller, is that their ground water comes from an underground river that flows south from Michigan. This myth conjures up images of a cavernous earth much like that in Jules Verne's novel *Journey to the Center of the Earth* with subterranean rivers connecting distant points. To the contrary, well water from the Cockfield of northwestern Hinds County flows slowly through the pore spaces of sands, or aquifers, within the formation. At a regional dip of about 20 feet per mile, my in-laws' 800-foot deep Cockfield aquifer rises to the surface some 40 miles to the north-northeast around Pickens, Mississippi. Uphill from my in-laws' well is a deeper commercial well at Camp Kickapoo owned by the North Hinds Water Association. This well pumps water from the Kosciusko Formation, also known as the Sparta (a name having no relation to the fictional Mississippi town of television lore) aquifer, at a depth of 1,500 feet. While both the Cockfield and Sparta aquifers produce good water, the Sparta produces more of it and is tapped for large commercial wells. As judged by the regional dip, the recharge area for the Sparta well at Camp Kickapoo is some 60 or more miles to the north-northeast along the Big Black River north of Durant.

Connecting geologic formations and aquifers to their surface exposures and recharge areas is part of the Surface Geology Mapping Program of the Mississippi Department of Environmental Quality's Office of Geology. Such information is critical to any model of ground-water flow and to the protection of the state's ground-water supplies. Neither my in-laws nor North Hinds Water Association wants a landfill sited on the recharge area of their ground water. The hydrology of these formations is often more complex than the models used to predict their flow. Models may treat formations as homogeneous units when, in reality, they are a composite of interconnected sands, the skeletal elements of ancient river, delta, and marine environments. The Cockfield and Sparta formations of northwestern Hinds County contain, not one, but two aquifer sands near their base. These sands represent the river-channel and distributary-mouth bar sands of ancient delta systems (Dockery, 1976).

Ancient Tertiary delta systems, such as that of the Sparta and Cockfield aquifers, tend to be sandier updip (to the north) where fluvial facies dominate. This is the case for the Hatchetigbee Formation of the upper Wilcox Group, which merges with sands of the Meridian Formation of the Claiborne Group in central Mississippi to form the Meridian-upper Wilcox aquifer. Northward near the Tennessee line, the Meridian-upper Wilcox aquifer merges with sands of the overlying Tallahatta, Winona, Zilpha, and Sparta formations (Arthur and Taylor, 1998, p. I10, table 1) to form a single thick aquifer unit named the Memphis Sand.

The City of Memphis uses the Memphis Sand aquifer, and to a lesser degree the Fort Pillow Sand aquifer below, as its sole water supply, and boasts the best drinking water of any large metropolitan city. According to a brochure by the Memphis Light, Gas and Water Division, the Memphis well field contains 170 wells, each capable of producing three million gallons of water per day. In all, a total of about 196 million gallons of water per day is pumped from the Memphis aquifer in southwestern Tennessee, of which approximately 60% (about 118 million gallons per day) is used by the City of Memphis. A regional ground-water model by the U. S. Geological Survey (USGS) indicates that this pumpage has increased the ground-water flow from Mississippi into the Memphis well fields (Mississippi Water Resources Management Planning Council, 1995, p. 18).

The general structural geology of the state determines the distribution of Mississippi's ground-water supplies. South of Interstate 20, formations dip to the south and have surface exposures, or outcrop belts, that trend east-west. North of Interstate 20, a structural trough known as the Mississippi Embayment changes the dip toward the west and causes formations to trend north-south along their outcrop belts.

In Cretaceous outcrops of northeastern Mississippi, geology and well-water/spring-water availability are responsible for an interesting pattern of settlement. Here the Black Prairie is a region of excellent farm lands but few towns due perhaps to the lack of a shallow aquifer for ground water. Beginning at Tupelo and continuing north into Tennessee is a north-south geologic boundary marking the edge of the Black Prairie and the top of an aquifer known as the Coffee Sand. Also beginning at Tupelo, and continuing northward along the contact of the Demopolis Chalk, which forms the Black Prairie, and the Coffee Sand are the towns of Tupelo, Saltillo, Guntown, Baldwin, Frankstown, Booneville, Rienzi, and Corinth. All these towns and U.S Highway 45, which connects them, are situated between farm land to the west and an aquifer to the east. As these towns have grown, they have tapped even deeper Cretacous aquifers, including the Eutaw-McShan aquifer (Everett and Jennings, 1994; Strom and Mallory, 1995) and the Gordo aquifer of the Tuscaloosa Formation (Phillips and Hoffmann, 1994). At Corinth, where the city sits on a Paleozoic structural high and the Tuscaloosa is absent, wells pump more than a million gallons of water a day from fractured Paleozoic basement rocks (Jennings, 1994).

The Demopolis-Coffee Sand contact is exposed at several places along U.S. Highway 45 between Tupelo and Corinth. One notable site is at Frankstown where highway excavations in 1990 for the Frankstown bypass encountered so many fossil shark teeth at the Demopolis-Coffee Sand contact that fossil collectors from distant states came to collect them. These fossils generated such publicity that Booneville High School was awarded a National Science Foundation grant (the first ever awarded to a high school) to use the site as a project in teaching their students earth science. The site and Booneville High School made national news on an ABC Sunday evening newscast. Fossils from this site are illustrated in Circular 4 of the Office of Geology (Manning and Dockery, 1992). Today, the geologic boundary that spawned a corridor of towns is remembered, not for its ground water, but for its fossils, as attested by an eight-foot-high granite monument at a roadside park just off U.S Highway 45 at Frankstown.

Another geologic boundary and associated water supply, which is perhaps responsible for a string of towns, is the famous Cretaceous-Tertiary Boundary, also known as the K-T Boundary. Here in the Tertiary, some 400 feet of Porters Creek Clay are separated from thick deposits of Cretaceous chalk below by a sand at the base of the Clayton Formation. The thickness of the basal Clayton sand is quite variable. The origin of this sand has been attributed to such novel processes as deposition in the tidal wave that followed the asteroid impact that killed off the dinosaurs (that impact crater is believed to exist under Yucatan Peninsula). Whatever its mode of deposition, the Clayton sand is a source for shallow ground water and feeds springs along a narrow strip that connects Starkville, Houston, Pontotoc, New Albany, Ripley, and Walnut. It is interesting to note that the name for Oktibbeha County, which contains Starkville, derives its name from an Indian word which means “pure water,” while Noxubee County to the southeast comes from a word meaning “stinking water” (Schmitz et al., 1999).

Towns and other developments are no longer restricted to sites with a shallow water table accessible to hand-dug wells, but there are other limits to how deep water wells can be drilled. Water salinity increases with depth, and the base of fresh water (water containing less than 1,000 parts per million of dissolved solids) varies between a few hundred feet deep in northeastern Tishomingo County to greater than 3,000 feet deep in various places such as parts of Grenada and Yalobusha counties, Smith and Jasper counties, and Pearl River County (Newcomb, 1965).

The depth to the base of fresh water poses a problem along a west-northwest to south-southeast zone of central Mississippi just south of the Yazoo Clay outcrop belt. Here, surficial Miocene aquifers are too shallow to supply commercial quantities of water, and the Eocene Sparta aquifer is near to the base of the fresh water interval; also, water color is often a problem. This poses problems for parts of Wayne County where the base of fresh water is less than 1,000 feet deep. The City of Waynesboro once relied on a shallow lenticular Oligocene aquifer, known as the Waynesboro Sand, for its ground water (Johnson, 1982). To solve its need for more water, the city drilled a well north of town into the Sparta, where the aquifer was at a shallower depth, and built a pipeline to carry the water to town.

Terry, Mississippi, is also situated south of the Yazoo Clay outcrop belt and faces a similar problem to that of Waynesboro. The town water supply comes from the Oligocene Forest Hill Formation, a formation with channel sands that are better developed in some places than in others. For this area, the South Hinds County Water Association has recently drilled a 2,000-foot-deep well to tap an additional water supply in the Sparta aquifer.

Jackson, Mississippi, is situated atop the Jackson Dome where ground-water supplies in the Cockfield and Sparta aquifers can be accessed by wells at a shallower depth but where water levels have less draw-down space. Though these aquifers do not presently supply the total needs of the City of Jackson, they are used by surrounding communities and industries, including such specialty needs as the water bottled by the Mississippi Bottled Water Company.

Challenges today in modeling ground-water supplies exist in the Mississippi “Delta” and in the Miocene aquifers of southern Mississippi. In the “Delta,” the Mississippi River alluvial aquifer is commonly in hydrologic connection with the Cockfield and Sparta aquifers. For this area, mapping the Eocene “bedrock” below the alluvium is important in the hydrologic investigations currently under study by the MDEQ Office of Land and Water Resources (see Jennings, 2001). The base of the alluvial aquifer is irregular, and, in places, the alluvium fills in deep holes left by the ancient course of the Mississippi River, as shown by the mapping work of Saucier (1994). This irregular surface makes mapping of the Eocene subcrop more difficult.

Recharge of the alluvial aquifer comes from several sources, including the Mississippi River along its western boundary. However, recharge from the river is possible only when the river is higher than the water level of the alluvium (Bryant and Dowdy, 1998). Potentiometric maps constructed for the Mississippi River Valley alluvial aquifer (Bryant-Byrd, 2002) confirm that the river is not a major source of recharge as once thought. A more significant source of recharge comes from the truncated Tertiary aquifer sands along the bluff line. These aquifers are in contact with the alluvium and supply it with a constant flow of ground water. Subcropping Tertiary sands are a potential source of recharge for the alluvial aquifer during the irrigation season in the summer months. Rain-swollen, interior streams may also provide a minor periodic source of recharge (Bryant, 1995).

The water temperature of the alluvial aquifer is near the mean annual temperature, ranging from 63 F in DeSoto County to 66.5 F at Vicksburg (Brown, 1947, p. 56). In contrast, Brown (1947, p. 33) noted that a deep “Delta” well at Glen Allen in Washington County produced water from the Eocene Meridian Sand at 1,746 to 1,786 feet at a temperature of 98.7 F and suggested that the heat might come from the buried volcanic terrain of the Sharkey Platform. In Jackson, Mississippi, above the northwest flank of the buried Jackson Volcano, water-supply wells for Duke Energy’s “make up water supply” for the cooling tower of its power plant on Beasley Road encountered water above 100 F in the Meridian Sand at 1,600 feet. A pumping test on the Duke North America #2 Hinds (by Bill Oakley on May 18, 2000), after pumping for 24 hours at 720 gallons per minute from an interval screened at 1,605 to 1,690 feet, showed the water to be as hot as a hot summer’s day with a temperature of 39.12 C or 102.4 F.

The problem posed by the Miocene sections of southern Mississippi is that they comprise a monotonous sequence of sands and clays, which lack fossiliferous marine units and are difficult to subdivide into formations and aquifers. In central and northern Mississippi, fossiliferous marine formations provide diagnostic fossils, or guide fossils, which aid in field mapping. In southern Mississippi where marine fossils are largely absent, geologic mapping progresses by the tedious connecting of sand body to sand body as interpreted on oil well and water well geophysical logs and the projection of these sands to the surface. This problem is being studied by both the Office of Geology's Surface Mapping Program and the Office of Land and Water Resources. If the independent mapping of these offices, one for the purpose of surface geologic maps and one for the purpose of ground-water models, agree, then the Miocene maps of both offices will have considerable credibility.

Disconformably overlying the Miocene of southern Mississippi are the graveliferous sands of the Pliocene Citronelle Formation. The Citronelle provides the shallow ground-water needs of southern Mississippi, is responsible for many of the state's springs, and supplies gravel resources. Many towns owe their existence to Citronelle springs, and some show this by their name. Crystal Springs is such a town and is also one of the major suppliers of gravel in the state. Most rivers and streams in southern Mississippi are spring fed from the Citronelle Formation, and gravels from the Citronelle are reworked as gravel bars along their course. One evidence of a Pliocene age for the Citronelle Formation is its elevation. What was once deposited in a river bottom in the Pliocene now caps the highest hills with its basal contact at an elevation of 400 feet above sea level and its upper surface extending to elevations of over 600 feet in Jasper County and at the junction of Simpson, Jefferson Davis, and Covington counties. Situated on the Citronelle Formation just north of McComb, an old railroad town in Pike County, is the Town of Summit, which derived its name for being one of the highest points along the railroad between Jackson and New Orleans (Brieger, 1980, p. 397).

Another Pliocene shallow aquifer, known informally as pre-loess terrace deposits, feeds spring-fed streams in western Mississippi along the Mississippi River valley wall and onto the alluvial plain. This aquifer is also graveliferous and is responsible for the gravel bars in western streams and for gravel resources extending from Natchez to Memphis, Tennessee. The pre-loess terrace deposits are similar to gravels at the base of the present Mississippi River Alluvial Plain and probably represent a time in the Pliocene when the course of the combined Mississippi and Ohio rivers flowed at a higher level. After the Pleistocene-Recent Mississippi River Alluvial Plain was down cut to its present level, the old Pliocene terrace was left perched on the eastern valley wall where its water table drained into local creeks and streams. These clear-water streams served as a water supply for many early settlements along the bluff line, including such places as Natchez, where it is called the Natchez aquifer (Boswell and Bednar, 1985), Vicksburg, Satartia, Yazoo City, and Charleston. North of Charleston, a string of Mississippi towns lies along the center of the loess and pre-loess terrace exposure belt. These towns direct the path of U.S Highway 51 and Interstate 55 to Memphis, Tennessee (also a bluff-line town), and include Oakland, Enid, Pope, Courtland, Batesville, Sardis, Como, Senatobia, Coldwater, Hernando, Nesbit, and Southaven. Today their water supply is derived from deep Paleocene and Eocene aquifers in the Claiborne and Wilcox groups.

Pliocene aquifers also provide fresh water for Mississippi's barrier islands and are potential fresh-water sources even at sea. The upper Graham Ferry aquifer provides fresh water for Ship Island with two wells at 436 and 480 feet and for Horn Island with one well at 835 feet (Stewart and Everett, 2002, in press). Brown et al. (1944, p. 52) noted the hydrostatic head at Horn Island to be 49 feet above sea level. In 1928 during prohibition, the Isle of Caprice Amusement and Development Company completed a flowing well (Harrison Co. well #203 of Brown et al., 1944) to a depth of 867 feet in the Graham Ferry aquifer for their popular gambling and sunbathing resort at the Isle of Caprice (originally Dog Island, 11 miles southeast of Biloxi between Horn and Ship islands). When the resort and island were reduced to a sand shoal below sea level in 1932, all that remained above the Gulf waters was the flowing well head, which provided a source of fresh water for local vessels until it corroded and collapsed in the 1970s (Rucker and Snowden, 1988).

Geophysical log analysis of the Sapphire #1 State of Mississippi oil exploration well, an offshore well drilled three miles south of Ship Island, indicates fresh water at a depth of 1,800 feet in the lower Graham Ferry aquifer. The presence of fresh water lenses below the Gulf of Mexico is a testament to the driving force of hydraulic heads generated in the Pliocene hills of southern Mississippi. However, this fresh water may also be a relic of the last ice age some 11,000 years ago when much of today's shallow Gulf sea floor was dry ground.

Mississippi was once a resort destination for places touted for their mineral water. One such place was Cooper's Wells just south of the intersection of Highway 18 and Midway Road in Hinds County between Jackson and Raymond. Dug to 100 feet in the Miocene Catahoula Formation, the well water was unpleasant to taste and smell but was believed to have curative properties. Though there is nothing there today, in Antebellum times this resort was called the "Saratoga of the South" and had a hotel that could accommodate over 800 guests. Jefferson Davis and Governor Foote debated for the Governor's race at Cooper's Wells in front of thousands of people (Hinds County Gazette, 1999; Drake, 2000). Other health resorts and "watering places" included **St. Roch Mineral Springs** at Bay St. Louis in Hancock County, **Mineral Springs** and **Marble Springs** at Ocean Springs in Jackson County, **Stafford Springs** and **Ward Springs** at Heidelberg in Smith County, **Waukaway Springs** in Jasper County, **Allison's Wells** near Canton in Madison County, **Ramsey Springs** near Wiggins in Stone County, **Castalian Springs** near Durant in Holmes County, and **Rawls Springs** and **Mammoth Springs** near Hattiesburg in Forrest County (Bisnette, 1996). Allison's Wells was also famous for its black-tie restaurant and art colony before it burned down in 1963 (Fontaine, 1981).

While the total number of water wells in Mississippi is not known, the following are some interesting statistics provided by Pat Phillips of the Mississippi Office of Land and Water Resources. There are about 80,000 water wells in the U. S. Geological Survey (USGS) files. The Mississippi Office of Land and Water Resources (OLWR) has records on an additional 45,000 wells not tracked by the USGS for a total of 125,000 Mississippi water wells on file. Of these wells, some 18,300 are permitted by OLWR, 11,500 (or most) of which are irrigation wells in the Delta. More water is pumped from the Mississippi River Valley alluvial aquifer for agricultural purposes than is pumped from all other aquifers (and for all other usages) combined. According to Arthur (2001, p. 36), the average annual pumpage rate from the alluvial aquifer used in the USGS calibrated model for a period between 1988 and 1996 was about 1.27 billion gallons per day. This is a huge volume of water when compared to public and industrial water withdrawal from all aquifers in northeastern Mississippi, which Strom (1998, p. 27) calculated at 76 million gallons a day for the year 1995. According to the Mississippi Water Resources Management Planning Council (1995, p. 7), irrigation and aquaculture (catfish ponds) account for 80% of ground-water pumpage in the state.

Other interesting ground-water facts include:

1. The deepest and hottest water well in Mississippi is the Choctaw Generation, Inc. #2 Test Production Well in Section 35, T. 18 N., R. 10 E., Choctaw County, which produces water with less than 400 ppm of chlorides at 3,000 gallons per minute from the Coker-Massive Sand aquifer at a screened interval of 2,830-3,170 feet below the surface. The water temperature of this well is 120 F.

2. The well with the highest hydrostatic head is one screened at 1,735 feet below surface in the Merdian-Upper Wilcox aquifer at Eden in Yazoo County (USGS Yazoo County well #B103), which had an initial static water level of 143 feet above land surface when it was completed in December of 1954 (Hoffmann and Gregory, 2000, p. 5). When this high-pressured well was placed on line, leaks appeared throughout the water system (Hoffmann, personal communication).

3. The highest volume wells in the state are four wells at the Grand Gulf Nuclear Power Plant in Claiborne County owned by System Energy Resources, Inc. These are Ranney wells with horizontally-drilled screened intervals at the base of the Mississippi River alluvial aquifer, extending over 2,000 feet under the Mississippi River. Each well is rated at 10,000 gallons per minute or 14.4 million gallons per day.

4. Ground water supplies the needs of more than 90% of Mississippi's population and constitutes over 80% of all fresh water used in the state (Mississippi Water Resources Management Planning Council, 1995, p. 12).

5. In the year 1990, 2.7 billion gallons of ground water was pumped per day in Mississippi, of which 66% was used for irrigation, 15% was used for aquaculture, and only 11% was used for public water supplies (Johnson, 1994, p. 11). In other words, more ground water was used in Mississippi for catfish than for people (i.e. public water supplies).

6. The lower Cretaceous aquifer of northeastern Mississippi (Boswell et al., 1965, p. 11) is the only significant fresh-water aquifer not presently used in the state.

In conclusion, ground-water supplies, which played such a colorful role in shaping Mississippi's historic past, hold the keys to the state's future.

ACKNOWLEDGMENTS

Thanks are extended to John Marble of the Mississippi Office of Geology and Jim Hoffmann, Steve Jennings, Lindsey Stewart, Pat Phillips, and Celeste Evans of the Mississippi Office of Land and Water Resources for their help with this paper.

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GROUND-WATER TRIVIA TEST

1. Of the 18,300 water wells permitted by the Mississippi Office of Land and Water Resources (OLWR), how many are irrigation wells in the Delta? a. 8,500, b. 11,500, c. 13,500.

2. The total number of water wells on record in the combined U. S. Geological Survey and OLWR data bases is: a. 85,000, b. 95,00, c. 125,000.

3. An amount equal to one third of all fresh water produced in Mississippi is produced from the Mississippi River alluvial aquifer for agricultural purposes. a. True, b. False.

4. The estimated average gallons-per-day pumped from the Mississippi River alluvial aquifer for the period of 1988 to 1996 is: a. 527 million, b. 927 million, c. 1.27 billion.

5. The deepest water well in Mississippi has its screen set at what depth below surface level? a. 2,000 feet, b. 3,000 feet, c. 4,000 feet.

6. The hottest water well in Mississippi has a water temperature of: a. 120 F., b. 130 F., c. 140 F.

7. The water well with the highest hydrostatic head in Mississippi was measured with a static head of how many feet above surface level? a. 84 feet, b. 123 feet, c. 143 feet.

8. The well with the largest potential flow in Mississippi is rated at how many gallons per minute? a. 8,000, b. 10,000, c. 12,000.

9. Ground water supplies the water needs for what percentage of Mississippi's

population? a. 70%, b. 80%, c. 90%.

10. In 1990, more ground water was used in Mississippi for catfish than for people (i.e. public water supplies). a. True, b. False.

Answers: 1 (b), 2 (c), 3 (b), 4 (c), 5 (b), 6 (a), 7 (c), 8 (b), 9 (c), 10 (a)

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