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GROUNDWATER MANAGEMENT AND PROTECTION

MADISON COUNTY, ALABAMA

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EXECUTIVE SUMMARY

Madison County's rapidly growing population of approximately one-fourth million residents relies heavily on groundwater for public water supplies. Eight public utilities operate 22 groundwater wells which produce approximately ~~22~~ million gallons per day. The groundwater is produced, primarily, in aquifers of fractured limestone solution channels. The hydrology, land use, rapid growth, and water use patterns combine to make groundwater protection an important issue.

In 1987, representatives from Federal, State, and local governmental agencies, utilities, universities, consulting firms, educators, and private citizens agreed that (1) Madison County should incorporate groundwater protection into its planning and development process, (2) Madison County needs the authority to adopt zoning ordinances and subdivision regulations, and (3) Madison County needs a groundwater management plan. This committee served as the advisory group in the Tennessee Valley Authority's Madison County Groundwater Demonstration and guided the development of this report through recommendations for reconnaissance level groundwater quality surveys, public education efforts, and potential pollution source inventories. The report addresses both immediate and long-term needs for groundwater protection through a three-phased approach which outlines specific actions that Madison County could initiate to safeguard public health and future economic growth of the county. Phase I recommendations include the formation of a technical committee to advise the local governments on groundwater-related matters, continuing efforts to obtain authorization for countywide zoning, and study of the feasibility of various methods

for wellhead protection in Madison County. Phase II focuses on gaining additional technical information through fracture/lineament tracing for the entire county using aerial photography, computerizing the groundwater data which resides in paper files of the many Federal, State, and local governments, and developing additional laboratory capabilities within Madison County. Recommendations for Phase III focus on establishing priorities for public water supplies, dye tracer studies, and/or aquifer testing to adjust initially proposed wellhead protection areas to final form.

GROUNDWATER MANAGEMENT AND PROTECTION
MADISON COUNTY, ALABAMA

INTRODUCTION

Groundwater is extremely important to Madison County (figure 1). Groundwater provides nearly three quarters of the county's drinking water, on average, through private wells and public water supplies; and provides baseflow to surface waters.

In recent years, Madison County has increasingly recognized the need to protect its groundwater resource. No one person, group, or agency can claim credit for identifying this need--it evolved through increased understanding of the relationship between this resource and population growth and economic development.

A supply of usable groundwater is one element of a high quality environment, which can help spur economic development and provide for the needs of a growing population. Without planning protection and understanding of possible consequences, however, economic development and population pressures can cause a gradual degradation of groundwater. In turn, degraded groundwater can hinder industrial recruitment, economic expansion, job creation, land use capability, and residential development, all of which can alter county demographic patterns.

Population growth and economic development increase the need for clean groundwater and also increase the volume and kinds of wastes requiring disposal, and that can lead to problems of groundwater contamination. In addition to problems associated with increases in conventional wastewater and solid wastes, economic and technological progress in recent decades has greatly increased the amounts and types of domestic, agricultural, and industrial chemicals that are used. However,

Figure 1

there has not been comparable progress in identifying the potential long-term effects of these chemicals, in managing them to prevent contamination of groundwater, or in developing treatment technologies for removing them from water that has been contaminated by them.

The challenge for Madison County is to manage growth and economic and technological development in ways that will avoid polluting its groundwater resource. Once groundwater has been contaminated, cleanup is almost always very costly and sometimes impractical or technically infeasible. Therefore, prevention of contamination--not remedial treatment--is the key to continued availability of usable groundwater.

Madison County local governments must become actively involved in groundwater management and protection and cannot simply rely upon state or federal government agencies to manage the resource for them. Although groundwater resources may extend across local, state, or even national boundaries, groundwater is usually considered a local resource. In fact, local communities that depend on the local groundwater resource have the greatest stake in its quality. Most groundwater problems are, by nature, local, in effect, and the main decisions that affect groundwater are local decisions. There are many possibilities for local measures to protect groundwater but implementing them requires a plan.

A plan for Madison County must be the result of a joint effort by local citizens, local governments, utilities, universities, and agencies of local, state, and federal governments. In April 1987, the Tennessee Valley Authority (TVA) convened a local groundwater steering group in Madison County. At the first meeting, the group agreed upon these goals: (1) to seek to incorporate groundwater protection into the

planning and development process for Madison County, (2) to support efforts by Madison County to obtain authority to adopt zoning ordinances and subdivision regulations, and (3) to develop a groundwater management plan for the county.

This report provides essential information needed in developing a plan and is based on the following assumptions: (1) the citizens of Madison County value the environment in which they live and wish to protect it from pollution; (2) continued economic development is necessary for a healthy local economy; and (3) a healthy economy can be sustained and nurtured, without degradation of the groundwater resource, through countywide planning, education, and participation.

GROUNDWATER SYSTEMS AND USAGE IN MADISON COUNTY

Protection of the groundwater resource in Madison County must be based on some fundamental information about where groundwater occurs, how it moves beneath the surface, and where and how it is being used. Pertinent geological data include physical descriptions of rocks underlying Madison County along with the deformational and erosional history associated with them. The following interpretation draws heavily on studies conducted by Malmberg and Sanford and Thomas (1). The geology of Madison County has been reinterpreted since this part of the report was prepared. Interested readers are referred to Raymond and Copeland and Osborne et al. (2).

Geologic Formations

Most of the rock units, or formations, in Madison County were formed in the Paleozoic Era of geologic time. Periods represented include, from oldest to youngest: Ordovician, Silurian, Devonian, Mississippian, and Pennsylvanian. Rocks formed in the Mississippian period constitute the bulk of the formations in Madison County. The Quaternary Era is also represented, although there is a huge time gap between it and the Pennsylvanian period. The formations as they occur in Madison County are described below. A generalized geologic map of the county, based on the work of Malmberg and Sanford, is shown in figure 2.

Sequatchie Formation (Ordovician)

The Sequatchie Formation correlates with similar rocks in the interior basins of Tennessee and Kentucky. While it is usually overlain

Figure 2

BEDROCK GEOLOGY MADISON COUNTY, ALABAMA

LEGEND:

- POTTSVILLE FORMATION
- PENNINGTON FORMATION
- BANGOR LIMESTONE
- HARTSELLE SANDSTONE
- PRIDE MOUNTAIN FORMATION
- MONTEAGLE LIMESTONE
- TUSCUMBIA LIMESTONE
- FORT PAYNE CHERT
- CHATTANOOGA SHALE
- BRASSFIELD LIMESTONE
- SEQUATCHIE FORMATION
- WATER

DATA SOURCE:
GEOLOGY OF MADISON COUNTY, ALABAMA,
BY G. T. MAIMERG AND T. H. SANFORD, JR. 1963

PREPARED FOR: MADISON COUNTY ALABAMA
GROUND-WATER STEERING GROUP
PREPARED BY: TENNESSEE VALLEY AUTHORITY
WATER QUALITY BRANCH, ENGINEERING LABORATORY,
AND GEOGRAPHIC INFORMATION SERVICES

GIS

by the Silurian Brassfield limestone, in certain areas of Madison County it is unconformably overlain by a basal sandstone layer in the Devonian Chattanooga shale. The maximum exposed thickness of this formation in Madison County is on the order of 15 feet.

The Sequatchie consists of very hard, dense, and brittle blue-gray, fossil fragment limestone in beds from 3- to 8-inches thick. Typical weathered surfaces indicate beds of an irregular, knobby blue-black chert which is relatively more resistant to weathering. In some exposures, the chert beds average 3 to 4 inches in thickness. Tan calcareous shale partings that range up to four inches in thickness separate the limestone and chert.

Brassfield Limestone (Silurian)

Exposures of the Brassfield limestone in Madison County are composed predominantly of limestone and some shale, and may be found in four oval-shaped areas along the banks of the Flint River and Hester and Mountain Fork Creeks in the northern part of the county. The Brassfield typically underlies river floodplains and its outcrop pattern is a result of streams eroding down into minor anticlinal (upfolded) structures. Soil and thin alluvium (river sediment) cover many of these rock outcrops so visible exposures of the Brassfield are restricted to streambeds and scattered bluffs along the streams. The maximum exposed thickness of this formation in Madison County is about 30 feet.

While variable with respect to both rock type and thickness, the Brassfield limestone is composed largely of beds of sandstone, shale, and limestone. The thin- to moderately-thick beds of limestone, up to two-feet thick, are interlayered with thin beds of sandstone and shale.

The limestone is dark gray and contains fragmented fossils as well as abundant glauconite and pyrite. The glauconite gives a distinctive greenish color to weathered surfaces. The very fine-grained, quartz-rich sandstone is dark brown, while the friable sandy shale is brownish-green.

Chattanooga Shale (Devonian)

The Chattanooga shale includes sandstone and black shale deposits. It crops out in small areas along Limestone and Tyrone Creeks in the northwest and along the Flint River and Hester and Mountain Fork Creeks in the northcentral part of Madison County. Outcrops, which lie in narrow bands adjacent to outcrops of the Sequatchie and Brassfield limestone formations, are usually limited to streambeds and scattered bluffs or terraces along creek banks. The Chattanooga shale ranges in thickness from 0 to 23 feet.

This dense, black, highly fissile shale gives a pronounced petroliferous odor when it is broken apart with a hammer and is slightly radioactive. Thin bands and nodules of pyrite, and thin bands and lenses of white to dark-gray sandstone are common in the formation. The shale grades downward into a thin basal sandstone member composed of rounded, fine- to coarse-sand grains with some phosphatic and limy material.

Fort Payne Chert (Mississippian)

The Fort Payne chert is exposed in the northwestern part of Madison County over an area of about 50 square miles around Ready Crossroads and along the banks of the Flint River and its tributaries in the central and

northern parts of the county. Along the Flint River, the Fort Payne occurs in steep bluffs 50- to 60-feet high. Areas of outcrop are as much as two miles wide. West of the Flint River, the outcrop areas are characterized by rolling hills with low relief. Few exposures of bedrock are present since most areas are covered by yellow and red clay soils that contain abundant quantities of chert. The thickness of the formation ranges from about 155 to 185 feet.

The Fort Payne chert is composed of light-gray to white or greenish siliceous limestone with irregular zones and nodules of white to dark-gray chert. Thin beds of gray and green shale are present between beds of the siliceous limestone. Unweathered exposures contain as much as 50 percent chert, while extensively weathered areas may be composed entirely of chert. The chert is generally white to blue-gray and usually has a porous texture. Its numerous fracture planes allow it to weather into fine-grained fragments. The upper part of the formation is commonly thin-bedded and weathers to highly fossiliferous, cherty rubble containing abundant crinoid stems. The basal five to six feet is nearly void of chert and consists of green crinoidal limestone, shale, and clay. A bed of green, earthy shale, 15- to 18-inches thick, containing phosphate nodules, is present at the base of the Fort Payne chert where it lies unconformably on the Chattanooga shale.

Tuscumbia Limestone (Mississippian)

Tuscumbia limestone crops out in about half the area of Madison County. In the southeastern part of the county, it crops out in a rectangular area bordered on the north by Brier Fork Creek, on the east

by the Tennessee River, and on the west by the Madison County line. In the east, it crops out in the valley regions extending from Owens Cross-roads in the south to the Tennessee state line. In the northcentral part of the county the formation crops out in an area about three-miles wide and 12-miles long between Brier Fork Creek and the Flint River. Areas of outcrop are characterized by broad rolling hills with low relief and by a mantle of dark-red residual soil. The Tuscumbia is about 200-feet thick in Madison County.

The thin- to thick-bedded, gray, very fossiliferous limestone contains a small amount of gray to white chert which occurs as irregular lenses and nodules. Weathered limestone layers are usually chert-rich and are covered with thick chert-rich rubble.

Monteagle Limestone (Mississippian)

The Monteagle limestone crops out in a belt that extends from Hobbs Island in the southern part of the county northeastward to the town of Gurley. North and west of this outcrop area, the Monteagle is exposed in lower slopes of outlying hills. It ranges in thickness from 200 to 220 feet.

The Monteagle is massive bedded and consists primarily of generally thick, light- to dark-gray beds of oolitic limestone. Near the top of the formation, the limestone is thin-bedded and separated by beds of shale ranging from 2-inches to 5-feet thick. Weathered exposures are nearly white and have smooth, well-rounded surfaces and may contain spherical nodules of pink and gray chert. The nodules in the Monteagle

are readily discernible from the blockier chert of the underlying formations because they often exhibit the original oolitic texture of the formation.

Hartselle Sandstone (Mississippian)

The Hartselle crops out in many places in Madison County. In most places it is decidedly lenticular and it is not uncommon for an outcrop of this formation to pinch out in a very short distance. It ranges in thickness up to 26 feet but is absent in parts of Madison County.

The Hartselle is composed of thin- to thick-bedded, friable to well-cemented sandstones, ranging from white to tan colored quartz sandstones, green calcareous shales, and limestone. Along the Tennessee River, where the formation is 90-feet thick, the sandstone is massively bedded, medium-grained, and friable. On the western slope of Monte Sano, where the Hartselle is 8-feet thick, the sandstone is fine- to medium-grained, crossbedded, and well-cemented. At Bankhead Parkway, leading up the northwestern slope of Monte Sano, it is 16-feet thick and is made up of a series of shales, sandstones, and limestones, with a basal unit of green, very fossiliferous shale.

Bangor Limestone (Mississippian)

The Bangor limestone is exposed in the upland region of the eastern part of Madison County. Outcrops are found on upper slopes of escarpments and on summits and slopes of outliers southwest and northwest of Huntsville. They are usually less than half a mile wide but may extend for many miles in steep, heavily forested slopes around the margins of

the uplands. The limestone, dolomite, and shale formation ranges in thickness from about 400 to 500 feet.

The basal part of the Bangor is generally medium- to massive-bedded, shaly, fossil fragmented limestone with numerous, thin layers of yellow calcareous shale. Frequently, the massive beds of dark-gray fossil fragmented and oolitic limestone contain numerous beds of dolomite and lithographic limestone. The upper 70 feet of the Bangor is composed of interbedded green- to gray-calcareous shales and thin beds of dolomite and limestone.

Pennington Formation (Mississippian)

The Pennington formation, which is the uppermost formation of the Mississippian system in Madison County, includes limestone, dolomite, and shale units. Areas of outcrop in the Pennington, which are characterized by steep bluffs, form narrow bands less than 100-feet wide around the highest outlying remnants of the Cumberland Plateau such as on Monte Sano and Green Mountains east and southeast of Huntsville. The formation is generally 80- to 100-feet thick.

The Pennington is composed of red, green, and purple, earthy shales interbedded with thin layers of limestone. The shales weather readily to red or gray clayey material and are relatively resistant to erosion, forming bluffs that protrude through the mantle of sandstone boulders generally covering the area of outcrop. A massive bed of hard, fossiliferous, light-gray limestone about 20-feet thick occurs near the top of the formation.

Pottsville Formation (Pennsylvanian)

The Pottsville formation, the youngest Paleozoic formation in Madison County, forms a caprock above the thick sequence of underlying sediments of the Mississippian system. Outcrops of the Pottsville formation are restricted to the crests of the outlying remnants of the Cumberland Plateau. They occur only on the highest hills in the eastern half of the county, and extend discontinuously from the Tennessee River in the south to the Tennessee state line in the north. On geologic maps the outcrops appear as irregularly shaped areas, commonly several miles long and generally less than a mile wide, surrounded by banded areas of outcrop of the underlying formations. Characteristic topography of the Pottsville outcrop area includes broad, flat-topped mountains commonly dissected by shallow ravines or gullies. Only the lower part of the Pottsville occurs in Madison County. It is about 200-feet thick.

The Pottsville consists of sandstone, shale, and coal. The basal 25 feet of the formation is composed of tan, brown, and red sandy shales interbedded with sandstone containing limonitic concretions as much as one foot in diameter. A coal seam, about 1-1/2-feet thick overlies the basal shaly part of this formation. Thin- to massive-crossbedded sandstone rests upon the coal bed. The sandstone is composed of fine- to coarse-grained quartz sand with some conglomeratic material in the lower 20 feet. Fresh surfaces are usually white to buff in color, but weather to red, pink, or brown.

Terrace Deposits and Alluvium (Quaternary)

Quaternary deposits of clay, sand, and gravel cap small remnants of terraces and lie unconformably on gently dipping formations of the

Mississippian system in the southeastern part of the county. These gravel deposits cap broad gentle hills which lack vegetation and are scoured by gullies. Most of the gravel is composed of rounded quartz pebbles, but some pebbles consist of well-cemented, fine-grained sandstone.

Recent stream alluvium occurs along the Tennessee and Flint Rivers as well as along some of the larger tributary streams. The alluvial deposits consist largely of lenses of clay, sand, and gravel ranging in thickness from a feather edge to about 30 feet. The sand and gravel are composed primarily of quartz and chert.

Geologic Structure

Madison County lies in both the Cumberland Plateau section and the Highland Rim section of the Appalachian Physiographic Province. Its general structural geology is influenced by a broad upfold, or anticline, called the Nashville Dome, which developed during the Ordovician period. The average inclination, or dip, of about 20 feet per mile from northwest to southeast represents the expected regional dip associated with the Nashville Dome. However, individual upfolds and downfolds, or synclines, are superimposed on the regional inclination. A northward trending synclinal trough passes beneath the city of Huntsville. It is about two-miles wide, and there is about 60 feet of relief between the lower parts of the syncline and the higher areas along the east and west flanks of the structure. The subsurface structure of Madison County is characterized by northwest and northward trending synclines.

Traditionally, these anticlines and synclines are interpreted as folds caused by compressional forces that died out as they entered this area from the more intensely folded and faulted Ridge and Valley section of the province to the east. The anticlines and synclines of the Chattanooga shale, however, likely represent buried elongate hills and valleys. These buried valleys are thought to be important controls on the geohydrology of Madison County.

Interpretation of stratigraphic and structural data suggests that the thin Chattanooga shale was draped over an erosional surface developed on top of the Silurian Brassfield limestone. Subsequently, locally brittle Mississippian limestones compacted over the uneven Chattanooga shale surface and cracked, forming vertical joints that trend northeast to southwest and northwest to southeast. Later enlargement of joints in limestone by solutioning with natural carbonic and humic acids has facilitated groundwater movement down the regional dip. The regional dip of the Chattanooga shale, a key bed in the structural mapping of the area, to the south and southeast may control, to a great extent, the regional groundwater movement.

Geohydrology

The geohydrologic data for Madison County include descriptions of the occurrence, direction, and flow rate of the groundwater. The United States Geological Survey (USGS) determined the four major factors influencing the movement and occurrence of groundwater in Madison County:

- (1) solutionally enlarged fractures in carbonate rocks developed in saturated zones,
- (2) configuration of the basal portion of the aquifers,

particularly the configuration of the Chattanooga shale underlying the Tusculumbia-Fort Payne aquifer, (3) directional permeability and joint-fracture alignment, and (4) relict structure of regolith, forming porous layers of chert rubble in residuum overlying bedrock.

Fortunately, largely through the efforts of the Geological Survey of Alabama (GSA) and the USGS, much more data and analyses of groundwater conditions exist for Madison County than for many other areas. Important references include the 1975 GSA report entitled "Environmental Geology and Hydrology--Huntsville and Madison County, Alabama" and the 1987 USGS report of "Geohydrology and Susceptibility of Major Aquifers to Surface Contamination in Alabama: Area 1."

Both the GSA and USGS publications contain valuable information on the occurrence of groundwater in Madison County. Table 1 summarizes the water-bearing characteristics of the individual formations, modified from the referenced reports. The GSA's hydrologic atlas also contains, among other things, a potentiometric map of the county with inferred groundwater flow directions, confirming the groundwater's general flow direction of north to south. The map, which shows very strong topographic control, was based on water levels in several hundred wells but may be influenced by seasonal fluctuations, variation in precipitation over the years the data may have been collected, well development, and local geology.

Because of their recharge characteristics, sinkholes provide useful data as well. Of particular interest are their locations and orientation. TVA prepared detailed sinkhole and drainage maps of Madison County using aerial photography to locate sinkholes too shallow to appear on

Table 1. Geologic Formations Exposed in Madison County, Alabama,
and Their Water-Bearing Properties (3)

Formation	Thickness (feet)	Description	Water-bearing characteristics
Alluvium and terrace deposits	0-50	Unconsolidated sand, clay, and gravel.	Source of moderate supplies to dug wells.
Pottsville Formation	200	Sandstone, medium to coarse-grained; massive and thin- bedded; some shale and coal near base of formation.	Yields small quantities of water adequate for domestic use, from openings along joints, bedding planes and other fractures. Water high in iron.
Pennington Formation	80-100	Limestone, dolomite, and shale units.	Limestone beds are water bearing. Yields some water to springs. Little importance as an aquifer.
Bargor Limestone	400-500	Limestone, massive, crystalline; some dolomitic limestone layers and shaly beds in upper part.	Yields moderate supplies to springs, primarily at base of formation. Limited development because of slope in outcrop area.
Hartselle Sandstone	0-26	Sandstone, medium to coarse-grained, hard. Locally contains beds of shale and limestone.	Yields some water to springs.
Monteagle Limestone	200-220	Limestone, thick- bedded.	Contains extensive solution cavities supplying moderate quantities of water to wells and springs.
Tuscumbia Limestone	150	Limestone, crystalline, massive-bedded, some cherty layers.	Yields large quantities of water from tubular openings. Source of supply for many wells and springs.

Table 1 (Continued)

Formation	Thickness (feet)	Description	Water-bearing characteristics
Fort Payne Chert	105-185	Limestone, abundant chert, porous.	Yields large quantities of water to many wells that encounter solu- tion channels.
Chattanooga Shale	0-23	Shale, black and hard with much bitumen and pyrite.	Generally impervious; yields some water from joints.
Brassfield Limestone and Sequatchie Formation	0-45	Limestone, cherty; dolomitic limestone; shale; and calcar- eous sandstone.	Yields moderate quantities of mineral- ized water; generally with hydrogen sulfide odor.

topographic maps. While the actual depression contours were incorporated into a computer database, figure 3 shows the sinkholes represented by point symbols, with point size corresponding to relative sinkhole area. Study of sinkhole location and orientation data assisted in determination of the joint orientation as being from northeast to southwest and northwest to southeast.

Patterns of Groundwater Use

Patterns of groundwater use reflect current needs and can help in prediction of future needs. Use patterns help in setting priorities for resource protection when fiscal considerations require it.

Inventory of Public Water Supplies

Madison County is heavily dependent upon groundwater supplies for drinking water. During a one-year period prior to November 1986, eight major water suppliers produced approximately 22 million gallons per day (mgd) of groundwater from 22 wells and springs (table 2). In addition, the City of Madison and the Madison County Water Department both had plans to add a new well to their systems, with the production of each well expected to be over 3 mgd.

Public water suppliers are regulated by the Alabama Department of Environmental Management (ADEM) under authority of the Safe Drinking Water Act (SDWA). ADEM inspects public water supplies, requires testing, and keeps records on water sources and production. Table 3 summarizes data provided by the ADEM Water Supply Branch, 1751 Federal Drive, Montgomery, Alabama, and includes well construction data and approved

Figure 3

Table 2. Madison County--Major Public Groundwater Supplies--Survey Date November 11, 1986

Public water supply	Population served	Groundwater sources(s)	Average production (mgd)	Maximum production (mgd)	Storage capacity (mgd)
Huntsville Utilities ^a	136,710	5	16.596	20	33
Madison Water Works and Sewer Board ^b	9,792	4	0.75	1.0	1.68
Harvest-Monrovia Water Authority	6,387	3	0.9	1.6	1.0
New Hope Water System	3,411	2	0.34	0.95	0.56
Owens Crossroads Water Authority	2,790	2	0.1925	0.225	0.3
Gurley Water System	1,113	2	0.16	0.2	0.4
Triana Water Works	600	1	0.17	0.2	0.06
Madison County Water Department ^c	<u>29,355</u>	<u>3</u>	<u>3.0</u>	<u>4.0</u>	<u>3.1</u>
Totals	190,158	22	22.1085	28.175	40.1

a. Additional source is the Tennessee River. Population served is the total served by the utility. Average production and maximum production is the estimated production from groundwater sources alone. Total combined average and maximum productions were 30.0 and 41.0 mgd respectively.

b. Figures do not include Nolan Drake well, which is being developed to produce 3.2 mgd. Also, a 5-million-gallon storage tank is under construction.

c. Figures do not include Bo Howard well, which is being developed to produce 3.2 mgd.

SOURCE: Alabama Department of Environmental Management

Table 3. Madison County--Major Public Groundwater Supplies
Individual Well/Spring Data

Source	Well depth (ft)	Pumping rate (gpm)	Casing depth (ft)	Drawdown (ft)	Comments
<u>Gurley Water System</u>					
Well 1	110	90	160	70	
Well 2	122	100	59	17	
<u>Harvest-Monrovia Water Authority</u>					
Well 1	110	450	44	1	
Well 2	49	140	39		
Well 3	125	1250	50	9	
<u>Huntsville Utilities</u>					
Brahan Springs	NA	1200	NA	NA	
Williams Well	125	3125	45	7	
Dallas Well	115	2800	32		
Lincoln Well	75	3200	75	11	
Lowe Mill Well	100	1200	67	63	
<u>Madison County Water Department</u>					
Hazel Green Well	96	830			
Cress Well	85	2450			
Esslinger Well	85	280			
Bo Howard Well	114	2200			not in service at time of survey
<u>Madison Water Works and Sewer Board</u>					
Dublin Well		290			encapsulated spring
Gillespie Well	110	300	54		
Lady Ann Well		250			
Schrimsher Well	115	280	71	71	
Nolan Drake Well		2000			not in service at time of survey

Table 3 (Continued)

Source	Well depth (ft)	Pumping rate (gpm)	Casing depth (ft)	Drawdown (ft)	Comments
<u>New Hope Water System</u>					
Well 2	151	260	18		
Well 3	140	270	71	25	
<u>Owens Crossroads Water Authority</u>					
Wells 1 and 2	108	680	50	20	
<u>Triana Water Works</u>					
Well 1	72	150	71	12	

pumping rates. More current information may be available from the individual water suppliers.

Self-Supplied Domestic, Commercial, and Industrial Water Supplies

In 1985, self-supplied domestic users withdrew an average of 0.16 mgd. Self-supplied commercial and industrial supplies accounted for 0.01 mgd and 0.46 mgd, respectively (4).

Agricultural Use of Groundwater

In 1985, Madison County farmers irrigated 1460 acres of cropland. Six hundred acres of turf, ornamentals, and nurseries, while 595 acres of corn and grain sorghum, and 220 acres of cotton were irrigated. Wells were used to irrigate 146 acres with the remainder irrigated by surface supplies (5). Agricultural use of groundwater averaged 0.68 mgd with approximately 95 percent being used for nonirrigation needs (6).

Groundwater-supplied irrigation is negligible in Madison County, although it is apparently of some localized importance to smaller farmers and seems to be increasing. Close proximity of irrigation wells to public water supply wells offers some potential for competition for the resource. Although no major supply problems were encountered during the critical drought period of 1985-87 at Huntsville Utility's Williams Well, nearby irrigation withdrawals were reported to have affected the production of the public supply well.

Water Level Information

Water level information is collected under various local, state, and federal regulatory programs, and in special studies. Local

regulations for well drilling (7) require reporting of well completion data, including water levels, for each well drilled in Madison County. The USGS has a wealth of information on depth to water in Madison County. The information includes records for approximately 1000 wells and is tied to 1:24,000 scale topographic maps. Most of the information is in paper files. The GSA also has at least several hundred water level data points available.

GROUNDWATER QUALITY IN MADISON COUNTY

Knowledge of groundwater quality is important for three reasons:

- (1) for assessing the suitability of the resource for various uses,
- (2) for providing data on aquifer characteristics and groundwater pollution potential, and (3) for defining priority areas for management and possible remedial action in order to protect the public health and welfare.

Sources and Availability of Groundwater Quality Data

Groundwater quality data are available from numerous sources. At least nine federal, state, and local agencies commonly collect groundwater quality data or administer data collection in the region. They include: (1) the USGS; (2) the Alabama Department of Public Health; (3) the United States Department of Agriculture, Soil Conservation Service (USDA, SCS); (4) the Huntsville-Madison County Health Department; (5) ADEM; (6) TVA; (7) the United States Environmental Protection Agency (EPA); (8) the GSA; and (9) the United States Army Corps of Engineers. Much of the information collected, however, represents either background data on commonly occurring minerals or data on coliform bacteria which are collected by local health departments. There are relatively little quality data available on the significant impacts of human activities in the form of heavy metals, organic compounds, or viruses. Much of the water quality data is that which is required of public water supplies in the SDWA.

While all of the information is available, most of the agencies have limited manpower for assembling data from files. Some data may be

unavailable during pending or current litigation. When information is available, there may be problems which limit its usefulness, e.g., poor well log, inadequate sampling parameters or frequencies.

Recent Investigations

Recent investigations in Madison County have primarily been conducted by the Alabama Department of Environmental Management (ADEM), researchers at the University of Alabama in Huntsville, the United States Army, and TVA.

TVA Water Quality Surveys

Water quality surveys initiated by TVA in Madison County have included: (1) a survey of 100 public and private wells for indicator bacteria, nitrates, and chlorides; (2) a bacteriological survey of springs and streams draining Monte Sano Mountain, east of Huntsville; (3) a survey of 11 wells for pollutants regulated under the SDWA; and (4) a survey of cave waters for 128 priority pollutants.

The survey of 100 wells was conducted in 1986 in cooperation with the Huntsville-Madison County Health Department. The Health Department randomly selected sampling locations and collected the samples, while TVA provided laboratory analyses. With 30 percent of the wells testing positive for fecal coliform, bacterial contamination is a concern. Table 4 summarizes the results of the survey and compares them with other random surveys conducted in the Tennessee Valley. Possible sources for bacteria include failing septic tanks and leaking sewer lines, animal waste, and illegal dumps. The average nitrate concentration determined

Table 4. Comparison of Bacteria and Nitrate Data from Three Surveys in the Tennessee Valley

	Average Values			Number of samples
	Fecal coliform (No./100 ml)	Fecal streptococci (No./100 ml)	Nitrate-nitrogen (mg/l)	
McMinn County, Tennessee	0.6	3.7	1.1	124
Madison County, Alabama ^a	5.4	44.6	1.6	100
Sand Mountain, Alabama (8)	8	64.3	5.9	120

a. Cooperative bacteriological survey conducted by the Huntsville-Madison County Health Department and TVA, February, 1986.

from the Madison County survey does not indicate that fertilizers or other nitrate sources have significantly impacted groundwater quality.

In response to concerns from the steering group regarding the potential for groundwater contamination from septic tank usage on Monte Sano Mountain, TVA conducted a bacteriological survey of springs and streams draining the mountain in September 1987. Drought conditions prevailed in sampling, giving excellent baseflow conditions for the survey. The results, summarized in table 5, show significantly higher bacterial concentrations for this survey than for the countywide cooperative bacteriological survey. Bacterial concentrations in the three springs tested were much greater than those found in the countywide cooperative survey.

In the survey of 11 water wells for pollutants regulated under the SDWA, concentrations of metals were found to be generally within drinking water standards. However, dieldrin, a nonregulated pesticide, was detected in a private well several miles north of Huntsville. Use of dieldrin is currently limited to "no effluent discharge" uses, such as deep ground injections for termite control.

In the cave waters survey, three caves were sampled twice each during the period January-May 1987 for 128 priority pollutants. At Shelta Cave, within the Huntsville city limits, heptachlor epoxide was detected on two occasions at concentrations of 0.04 and 0.05 $\mu\text{g}/\text{l}$, while dieldrin was detected at a concentration of 0.10 $\mu\text{g}/\text{l}$ once. Heptachlor epoxide is a degradation product of the pesticide heptachlor which is used only as a termiticide since its ban for all other uses in 1983.

Table 5. Comparison of Bacteria and Nitrate Data--Monte Sano Mountain Bacteriological Survey
(Samples collected by TVA on September 15, 1987 and March 29, 1988)

	Average Values					Number of samples
	Fecal coliform (No./100 ml)	E. coli (No./100 ml)	Fecal streptococci (No./100 ml)	Entero- cocci (No./100 ml)	Nitrate- nitrogen (mg/l)	
Springs	160	196	642	563	0.7	6
Streams	234	252	1078	829	0.5	10
All samples	206	231	914	729	0.6	16

Sanitary Landfill Investigation

Leonard et al. (9) reported contamination of groundwater in monitoring wells downgradient from the Huntsville landfill. Chloride concentrations and chemical oxygen demand were trending upward while the pH was decreasing. The study recommended installation of clay liners and runoff controls as well as more frequent monitoring if the site will continue to be used. New provisions of the Resource Conservation and Recovery Act, Title D, should address some of these recommendations.

Current Investigations

The ADEM, Groundwater Section, is conducting two investigations in which Madison County is involved. They include the Pesticides in Groundwater Project and the Wellhead Protection Project (10).

The Pesticides in Groundwater Project is studying the potential impact of pesticides to groundwaters in agricultural areas. Five private and/or public water supply wells in each of ten designated counties were sampled during the summer of 1989 to detect the presence of pesticides in the groundwater. The wells were selected because of their shallow depths to groundwater and proximity to agricultural lands, thus exhibiting a high potential for contamination. Five wells from Madison County were selected as a part of the project. The groundwater samples from all 50 wells have been analyzed. Chlordane was detected in one Madison County well in August but concentrations were below the health advisory limit (HAL) and the maximum contaminant level (MCL) (11).

In conjunction with the Water Supply Branch of ADEM, a wellhead protection project is being conducted for Mobile, Baldwin, and Madison

Counties. The counties were selected due to their susceptibility to groundwater contamination. The Madison County study is using the fixed radius method for delineating wellhead protection areas for 15 public water supplies. Potential contaminant sources are being identified within a two-mile radius of each well. The potential sources include underground storage tanks, hazardous waste management facilities, solid waste landfills, NPDES facilities, CERCLA sites, and other potential sources. The study will produce 15 maps which inventory potential sources of contamination to groundwater resources in Madison County.

The United States Army has conducted extensive groundwater studies at Redstone Arsenal in the last five years (12).

GROUNDWATER POLLUTION POTENTIAL IN MADISON COUNTY

Virtually all human activities have some potential to contaminate groundwater. The consequences of contamination are varied. Some contaminants may pose an immediate, acute health risk to certain segments of the population. It is possible that citizens may be exposed to pollutants which can create chronic health problems which may not appear for many years. Some residents may merely feel the economic, environmental, and social impacts through loss of livelihood, potential lawsuits from contamination incidents, increased costs of products and services, and loss of desirable surroundings or psychological stress resulting from known or suspected contamination (13).

Table 6 lists numerous potential sources of groundwater pollution (14). While some of the potential pollution sources are not applicable to Madison County, the list serves as a guide for assessment of existing regulatory programs and activities. As a part of this study, certain of these potential pollution sources have been inventoried.

Mapping of Potential Pollution Sources

Aerial photographic interpretation has been used as a cost-effective method for targeting detailed ground-truthing surveys to spot pollution sources. Remote sensing methods were employed by TVA for locating potential abandoned wells, illegal dump sites, abandoned storage tanks, storage tanks in use, agricultural and industrial waste ponds, junkyards, landfills, and old subdivisions. Figure 4 shows the approximate locations of over 1500 potential sources inventoried. Detailed

Table 6. Potential Sources of Groundwater Contamination

<u>CATEGORY I--SOURCES DESIGNED TO DISCHARGE SUBSTANCES</u>	<u>CATEGORY IV--SOURCES DISCHARGING SUBSTANCES AS CONSEQUENCES OF OTHER PLANNED ACTIVITIES</u>
Septic tanks and cesspools Injection wells Land application of waste	Agricultural practices Irrigation practices Pesticide applications Fertilizer applications Animal feeding operations Urban activities De-icing salt applications Urban runoff Percolation of atmospheric pollutants Mining and mine drainage Surface mine-related Underground mine-related
<u>CATEGORY II--SOURCES DESIGNED TO STORE, TREAT, AND/OR DISPOSE OF SUBSTANCES; DISCHARGE THROUGH UNPLANNED RELEASE</u>	<u>CATEGORY V--SOURCES PROVIDING CONDUIT OR INDUCING DISCHARGE THROUGH ALTERED FLOW PATTERNS</u>
Landfills, open dumps, and local disposal Surface impoundments Waste tailings and waste piles Materials stockpiles Containerized storage Aboveground storage tanks Underground storage tanks Containers Miscellaneous Graveyards Animal burial Open burning and detonation sites Radioactive disposal sites	Wells Production wells Monitoring and exploration Wells Construction excavation
<u>CATEGORY III--SOURCES DESIGNED TO RETAIN SUBSTANCES DURING TRANSPORT OR TRANSMISSION</u>	<u>CATEGORY VI--NATURALLY OCCURRING SOURCES WHOSE DISCHARGE IS CREATED AND/OR EXACERBATED BY HUMAN ACTIVITY</u>
Pipelines Materials transport and transfer operations	Groundwater-surface water interactions Natural leaching Salt water intrusion/Brackish Water Upconing

Figure 4

7.5-minute topographic maps showing this information are on file at the Madison County Engineering Department, the Huntsville-Madison County Health Department, and the TVA, Resource Mapping Department.

It must be stressed that there are limitations on the use of the maps without ground-truthing. Since much of the information is gleaned from comparison of 1950 photography to current photography, only features which have changed during that time period may be mapped. Therefore, many more locations may exist. Additionally, some of the sites may not represent actual abandoned facilities.

Analysis of Groundwater Pollution Potential

The USGS briefly summarized the susceptibility of the aquifers in Madison County to contamination and concluded that its major aquifers are recharged throughout their area of outcrop and, consequently, are susceptible to contamination throughout their area of outcrop. Surface contaminants are most likely to contaminate the aquifers in poorly drained areas, sinkholes, and areas highly weathered by solution (15). While most of Madison County is susceptible to groundwater contamination, some areas are more important than others either because they are physically so vulnerable or because the groundwater is such an important source for public water supply.

In order to assess the relative vulnerability of areas of Madison County to groundwater pollution, the DRASTIC Pollution Potential Model (16) was applied to the county. Developed by the National Water Well Association (NWWA) for the EPA, this method consists of

mappable hydrogeologic units superimposed with a rating system which ranks their impact on the area's vulnerability.

DRASTIC Pollution Potential Model

Seven of the most important hydrogeologic factors that control groundwater pollution were identified for the DRASTIC model: Depth to water, net Recharge, Aquifer media, Soil media, Topography, Impact of vadose zone, and hydraulic Conductivity (DRASTIC). The numerical ranking system used for these hydrogeological factors consists of three parts: weights, ranges, and ratings. The sum of the individual ratings multiplied by their respective weights yields a relative numerical value called the DRASTIC index. The numbers are only of value with respect to the study area and are not comparable to DRASTIC indices for other areas.

DRASTIC Application for Madison County (17)

In the Madison County study, existing geologic soils and topographic information was used. The groundwater pollution potential was estimated by choosing the appropriate ranges for each DRASTIC parameter and referring to the hydrogeological settings for guidance. A computer-based Geographical Information System (GIS) combined and integrated the settings and ratings for the spatial analysis.

Map Data Sources--An extensive digital database of mapped and descriptive attribute data was compiled to support development of the DRASTIC Index. USGS Digital Elevation Models (DEMs) were used for topographic elevations. Each of the 22 DEMs consisted of elevation above-sea-level values, recorded to the nearest meter, spaced at

30-meter intervals. Detailed soil mapping units were digitized in 3.75-second by 3.75-second latitude/longitude grid cells from the USDA SCS. Geologic data was taken from existing map sources.

Madison County DRASTIC Ratings--Ratings were assigned to each range of each DRASTIC factor with respect to pollution potential.

The depth to water is the depth from the land surface to the water table in an unconfined aquifer or the depth to the top of a confined aquifer. In general, the greater the depth to water, the greater chance there is that the contaminant will be attenuated or dispersed before reaching the aquifer.

Net recharge is the amount of precipitation that infiltrates the ground surface and eventually reaches the water table. In Madison County, groundwater recharge is thought to be primarily from bedrock aquifer outcroppings in the highlands between streams. The highest recharge rating in DRASTIC is 10 inches per year; however, the net recharge in the southeastern United States is estimated to be greater than 10 inches. All areas were assigned ratings of 8 to 10 reflecting relative groundwater availability (18). Sinkhole areas received the highest ratings.

Aquifer media refers to the consolidated or unconsolidated bedrock which can transmit significant quantities of water. The principal geological formations in Madison County consist of shale, sandstone, and limestone, and are sedimentary in origin. The type of medium determines the transport rate and attenuation of a contaminant through the aquifer. For example, in the southern portion of the county in the Tuscumbia Limestone Formation, groundwater moves quickly through the solution

channels and has a very high pollution potential. However, in the Chattanooga shale found in the northern part of the county, very low quantities of groundwater are present and the formation has a relatively low pollution potential.

Soil is defined as the uppermost part of the regolith where significant biological activity occurs and weathering has produced an aerated zone for the roots of plants. Processes such as contaminant adsorption, biodegradation, and volatilization occur in the soil zone. Different soil characteristics, such as texture, porosity, and permeability, can affect the movement of a contaminant in the soil. Because of the wide range of parent material and topography, a large variety of soil types exist in Madison County.

Topography, in the DRASTIC application, refers to the slope at the ground surface. Less slope results in less surface runoff, greater infiltration and, therefore, greater groundwater pollution potential.

The vadose zone is the unsaturated zone between the soil horizon and the water table. The type of vadose media controls the flow rate, dispersion, and biological and chemical reactions of a pollutant before it enters the water table. The vadose media, which are based on the geological formation, determine the transport rate and attenuation of a contaminant into the aquifer.

The hydraulic conductivity is defined as the ability of the aquifer media to transmit water under a given hydraulic gradient. It can be strongly controlled by the porosity of a geologic formation. In the DRASTIC model, higher hydraulic conductivities are assumed to increase the contaminant transport velocity and thus increase the pollution

potential. Karst limestone and fractured bedrock receive the highest ratings.

The GIS was used to combine the ratings and weights to determine the DRASTIC Index for Madison County as shown in figure 5. Overall, the model results show that Madison County appears to be relatively vulnerable to groundwater pollution. Approximately 37 percent of the county is in the highly vulnerable DRASTIC Index range (greater than 180), another 41 percent is in the moderately vulnerable range (160-179), and the remaining area is in the lower range (less than 159).

Mountain slopes, due to steep topography, thin soil cover, and moderately high depths to groundwater, have a relatively low DRASTIC Index. Mountain flanks have a relatively high pollution potential due to shallow water tables and limited impact of the vadose zone. The solution limestone (karst geology) has the highest index due to the high vadose zone, aquifer media, and hydraulic conductivity ratings. The alternating sandstone, limestone, and shale sequences have moderate indices.

Limitations on the Use of DRASTIC

This index is a screening tool for comparative countywide evaluations with respect to potential for pollution of groundwater. It is only applicable to areas larger than 100 acres. The index is not intended to replace the need for professional expertise and onsite inspections for assessing the pollution potential in specific areas. Its primary use is to help identify areas which are more or less vulnerable than others to contamination, so that limited resources can be directed to areas which are critical to management problems.

Figure 5

**GROUND-WATER POLLUTION POTENTIAL
MADISON COUNTY, ALABAMA**

Deontic index range

RANGE	% OF TOTAL AREA
0 - 79	10.09
80 - 99	0.22
100 - 119	0.33
120 - 139	11.60
140 - 159	7.82
160 - 179	41.28
180 - 199	18.24
200 - 228	19.00
WATER	1.50

1 MILE
1.6 KILOMETERS

PREPARED FOR: MADISON COUNTY ALABAMA
GROUND-WATER STEERING GROUP

PREPARED BY: TENNESSEE VALLEY AUTHORITY
WATER QUALITY BRANCH, ENGINEERING LABORATORY,
AND GEOGRAPHIC INFORMATION SERVICES

GIS

FEBRUARY 29, 1988

INSTITUTIONAL CONTROLS FOR GROUNDWATER PROTECTION

Unlike other basic resources, groundwater is not the primary subject of any law, and there is not a single agency with comprehensive responsibility for assessing, regulating, and protecting groundwater. Instead, there are a variety of federal, state, and local laws and regulations, each of which has some bearing on groundwater protection. In the Tennessee Valley region, more than 60 federal and state agencies are involved in some way with groundwater. Most existing laws that touch upon groundwater deal with point sources of pollution, such as industrial discharges and waste disposal. Point sources continue to be perceived by the public, and consequently by legislative bodies, as the principal threat to water resources. It has become apparent, however, that nonpoint sources can contribute significantly to pollution problems. Nonpoint sources are more difficult to identify, regulate, and mitigate than point sources. The Mining and Nonpoint Source Section of ADEM's Water Division regulates nonpoint sources in Madison County and throughout Alabama. It is involved in delineating nonpoint sources of contamination to groundwater resources (19). Additionally, some agencies such as the TVA, the USDA SCS, and some agricultural extension services have begun to address nonpoint source problems through nonpoint source inventories and priority assessments, demonstration of animal waste management systems, public education, and promotion of voluntary control programs.

Federal Laws and Regulations

Several federal laws contain provisions for control of groundwater pollution. Some of the most significant are the Safe Drinking Water Act (SDWA), the Resource Conservation and Recovery Act (RCRA), and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA or "Superfund").

Safe Drinking Water Act

The SDWA (20) was enacted in 1974 to ensure the safety of public water supplies. It was amended in June 1986 to add new requirements and voluntary programs for protecting the quality of drinking water, including groundwater.

Drinking Water Standards--The SDWA and its 1986 amendments require the EPA to set standards for contaminants in drinking water that may pose a health hazard. The SDWA directs EPA to establish final regulations for 83 chemicals. Drinking water standards are expressed as MCLs. Table 7 shows the the National Primary Drinking Water Standards in effect after passage of the SDWA amendments of 1986.

The SDWA amendments require EPA to regulate an additional 61 substances during the period June 1986 through June 1989. In July 1987, EPA issued Primary Drinking Water Regulations for Synthetic Organic Chemicals (21) and specified additional monitoring requirements for unregulated contaminants. EPA promulgated MCLs for the eight volatile organic chemicals listed in table 8 and specified analytical methods to be used for demonstrating compliance. The same regulations also require public water systems to monitor for the 51 unregulated contaminants listed.

Table 7. National Primary Drinking Water Standards

Constituent	MCL ^a
Arsenic	0.05
Barium	1.00
Cadmium	0.01
Chromium	0.05
Lead	0.05
Mercury	0.002
Nitrate (as N)	10.00
Selenium	0.01
Silver	0.05
Fluoride	4.00
Endrin	0.0002
Lindane	0.004
Toxaphene	0.005
2,4-D	0.1
2,4,5-TP silvex	0.01
Coliform bacteria	<1/100 ml
Total trihalomethanes	0.10
Radionuclides	
Radium 226 and 228 (total)	5 pCi/l
Gross alpha particle activity	15 pCi/l
Gross beta particle activity	4 mrem/yr
Turbidity	1-5 TU

a. (ml = milliliters; TU = units of turbidity; pCi/l = picocuries per liter; and mrem = millirem).

Table 8. Safe Drinking Water Act (40 CFR Parts 141 and 142)
Required Monitoring of Synthetic Organic Chemicals
and Regulated Contaminants

<u>Regulated Contaminants</u>	
Parameter	MCL (µg/l)
Benzene	5
Vinyl chloride	2
Carbon tetrachloride	5
1,2-Dichloroethane	5
Trichloroethylene	5
p-Dichlorobenzene	75
1,1-Dichloroethylene	7
1,1,1-Trichloroethane	200
 <u>Unregulated Contaminants</u>	
Chloroform	Bromodichloromethane
Chlorodibromomethane	Bromoform
trans-1,2-Dichloroethylene	Chlorobenzene
m-Dichlorobenzene	Dichloromethane
cis-1,2-Dichloroethylene	o-Dichlorobenzene
Dibromomethane	1,1-Dichloropropene
Tetrachloroethylene	Toluene
p-Xylene	o-Xylene
m-Xylene	1,1-Dichloroethane
1,2-Dichloropropane	1,1,2,2-Tetrachloroethane
Ethylbenzene	1,3-Dichloropropane
Styrene	Chloromethane
Bromomethane	1,2,3 Trichloropropane
1,1,1,2-Tetrachloroethane	Chloroethane
1,1,2-Trichloroethane	2,2-Dichloropropane
o-Chlorotoluene	p-Chlorotoluene
Bromobenzene	1,3-Dichloropropane
1,2,4-Trimethylbenzene	1,2,4-Trichlorobenzene
1,2,3-Trichlorobenzene	n-Propylbenzene
n-Butylbenzene	Napthalene
Hexachlorobutadiene	1,3,5-Trimethylbenzene
p-Isopropyltoluene	Isopropylbenzene
tert-Butylbenzene	sec-Butylbenzene
Fluorotrichloromethane	Dichlorodifluoromethane
Bromochloromethane	Ethylenedibromide
1,2-Dibromo-3-Chloropropane	

Drinking water standards have implications beyond regulation of public water supplies. Other regulatory programs use drinking water standards as guides for cleanup and protection of groundwater.

Setting standards is a technically difficult issue that integrates the fields of toxicology, chemistry, and economics and other considerations. The SDWA amendments call for EPA to set the MCLs "at the level which no known or anticipated adverse effects on the health of persons occur and which allows an adequate margin of safety." However, final regulatory standards are a compromise between ideal MCL goals and the lowest concentrations achievable by water treatment using "best" available technology.

Underground Injection Regulations--Underground injection is the process of deep well injection of waste. Because this practice has the potential for contaminating drinking water supplies, it is regulated under the SDWA by a permit system. The SDWA amendments specify additional monitoring requirements for deep well injection.

The Underground Injection Control (UIC) Regulations are administered by the Groundwater Section of the ADEM. The UIC program designates five classes of injection wells and requires permits for the wells. The well types include Class I wells which allow for injection of a pollutant beneath the lowest formation that contains an underground source of drinking water within five miles of the well bore. Construction and use of new Class I wells are prohibited in Alabama. Class II wells are for injection of brine or other fluids which are brought to the surface in connection with oil or natural gas production. Class III wells are for injection, which is used for extraction of minerals and energy

resources. Class IV wells are for injection of a hazardous or radioactive waste into or above a formation which contains an underground source of drinking water within five miles of the well bore or into an exempted aquifer. Class IV wells are prohibited nationally and in Alabama. Class V wells are injection wells used to return water used for heating or cooling in a heat pump to the supply aquifer, cesspools, drainage wells for storm runoff, recharge wells, saltwater intrusion wells, certain septic tanks, geothermal wells, and several other types of wells which accept injection of nonsanitary fluids.

In Madison County, the permitted injection wells in the county are Class V wells. They are predominantly wells such as stormwater drainage wells, industrial or multiple dwelling septic tank systems, and nonhazardous wastewater from car washes and laundromats (22).

Sole-Source Aquifer Protection--The sole-source aquifer provisions of SDWA authorize EPA to designate and protect aquifers that serve as the principal drinking water supply for an area. A sole-source aquifer is one that provides 50 percent or more of the drinking water for an area and that, if contaminated, would create a significant hazard to public health.

Any state or local government or other political subdivision or planning entity with jurisdiction over an identified critical protection area may apply for designation of a sole-source aquifer. Applications must include a comprehensive management plan for the aquifer. Approval of a petition involves consideration of (1) whether the aquifer supplies 50 percent or more of the total drinking water, (2) whether the boundaries of the aquifer can be readily defined, and

(3) whether the drinking water supplied by the aquifer can be replaced by water from other sources at reasonable cost.

After a petition for sole source aquifer designation has been approved, federal matching funds may be granted for as much as 50 percent of the cost of developing and implementing the management plan. Total funding authorizations by EPA depend on appropriations to EPA. After an aquifer is designated a sole source, EPA may review the plans for any project in the area and may deny federal financial assistance for any project that could potentially contaminate the aquifer.

Wellhead Protection--The SDWA amendments define a wellhead protection area as "the surface and subsurface area surrounding a water well or wellfield, supplying a public water system, through which contaminants are reasonably likely to move toward and reach such water well or wellfield." The wellhead protection provisions of the SDWA amendments authorize a cost-sharing program that allows states to designate areas where certain types of land use could easily contaminate public groundwater supplies and to plan and implement protective measures within such areas.

The wellhead protection program is a voluntary program. It calls for states to submit plans to EPA by June 1989. In addition to other requirements, each state program must determine the extent of wellhead protection areas, determine all anthropogenic sources of contaminants that may adversely affect public health, describe procedures to protect the water supply from such contamination, and require that potential sources of contamination be evaluated prior to development of new wells.

Once a state wellhead protection program has been approved, EPA may grant 50 to 90 percent funding of the costs for developing and implementing the state plan (total funding authorizations by EPA depend on appropriations to EPA).

Resource Conservation and Recovery Act

The RCRA (23) was enacted in 1976 as an amendment to the Solid Waste Disposal Act to regulate the processing, storage, transportation, and disposal of hazardous wastes and other solid wastes. It requires EPA to issue regulations and standards for management of hazardous wastes.

Subtitle C of RCRA governs hazardous waste from production to disposal. Subtitle C establishes procedures and responsibilities for (1) defining and listing hazardous wastes, (2) tracking these wastes from the point of generation to the point of disposal ("cradle to grave"), (3) assuring that all waste management facilities meet minimum engineering and operating standards through a permit process, (4) assuring that facilities will be properly maintained after their closure, and (5) assuring that operators of hazardous waste management facilities are financially responsible for accidents (24).

The principal groundwater protection provisions of RCRA are requirements for monitoring groundwater at treatment, storage, and disposal facilities (TSDs) and for removing and treating any contamination that is detected (25). It will also eventually require double liners and leachate collection systems for all new and existing land disposal facilities (26). Issuance of a permit for a TSD facility is contingent upon development of an acceptable program for detecting,

evaluating, and correcting groundwater contamination. The monitoring requirements specified in TSD permits are determined on a case-by-case basis, depending on the wastes to be managed at each facility.

In response to directives of RCRA, EPA promulgated a complex series of regulations for hazardous waste management. The EPA maintains a list of hazardous wastes regulated under RCRA which currently contains approximately 450 compounds (27).

The six components of groundwater monitoring programs that EPA deems essential for meeting the goals of RCRA are: (1) characterization of site hydrogeology; (2) location and number of monitoring wells; (3) design, construction, and development of groundwater monitoring wells; (4) design and implementation of a sampling and analysis plan; (5) statistical analysis of monitoring data; and (6) implementation of an assessment plan (28).

Comprehensive Environmental Response, Compensation, and Liability Act

The CERCLA (29) authorizes EPA to perform remedial action at hazardous substance disposal sites, to seek compensation for cleanup from responsible parties, and to take emergency cleanup action on spills of hazardous substances. Groundwater cleanup has been a priority in implementing CERCLA. Of the 541 priority sites listed in January 1986, more than 400 were selected at least in part because of existing or potential contamination of groundwater (30). CERCLA establishes a "superfund" for cleanup or containment of spills or abandoned waste dumps, establishes liability for compensation and authorizes EPA to attempt to recover expenses for cleanup, and calls for mandatory

reporting of spills of hazardous substances in excess of specified quantities.

On October 17, 1986, CERCLA was reauthorized with amendments that strengthen EPA's authority for protecting groundwater. Under the Superfund Amendments and Reauthorization Act (SARA), EPA can order cleanup of leaking underground storage tanks or finance cleanup through a new trust fund. Any person may bring a lawsuit against private parties or the government to enforce compliance. Citizen suits are specially authorized under a "Community Right-to-Know" title that allows recovery of fees for attorneys and expert witnesses (31).

State Laws and Policy

The state of Alabama has enacted three primary environmental laws which address aspects of groundwater protection. They include the Alabama Water Pollution Control Act, the Alabama Solid Waste Act, and the Alabama Hazardous Wastes Management Act (32).

Alabama Water Pollution Control Act

The Alabama Water Pollution Control Act authorizes ADEM to control pollution in state waters, including groundwater. The agency is generally empowered to (1) study and investigate all problems concerned with the improvement and conservation of the waters of the state, (2) conduct investigation and research and design programs to reduce pollution of the state's waters, and (3) propose remedial measures for the abatement of such pollution. Specific directives

for ADEM include: (1) establishment of water quality standards and a permit system for pollutant discharges into waters of the state, (2) a requirement that persons discharging to the state's waters monitor and report activities, and (4) institution of civil action against violators of the Act.

Alabama Solid Waste Act

The Alabama Solid Wastes Act empowers local governments to make solid waste collection and disposal facilities available to the general public in a manner acceptable to ADEM. The regulations, which include specific provisions for groundwater protection and monitoring, cover siting and design standards for facilities. The Act enables the state to enforce Subtitle D of RCRA.

Alabama Hazardous Wastes Management Act

The Alabama Hazardous Wastes Management Act enables the state to enforce Subtitle C of RCRA, regulating TSD facilities. TSD facilities are exempt from groundwater protection requirements if (1) the unit is an engineered structure, (2) does not receive or contain liquid waste or waste containing free liquids, (3) is designed and operated to preclude liquid and precipitation run-on and runoff, (4) has two layers of containment enclosing the waste, (5) has a leak detection system built into each containment layer, (6) has a leak detection monitoring program during the operation, closure, and postclosure periods, and (7) to a reasonable degree of certainty, will not allow hazardous constituents to migrate beyond the outer containment layer through the postclosure care period.

MANAGING GROUNDWATER RESOURCES IN MADISON COUNTY

Madison County's rapidly growing population of approximately one-quarter million relies heavily on groundwater for public water supplies. Eight public utilities operate 22 groundwater wells that produce an average of 22 mgd. The groundwater is produced, primarily, in aquifers of fractured limestone with solution channels. Numerous sinkholes provide direct access of surface waters and waste to the underlying aquifers. The hydrology, land use, rapid growth, and water use patterns of Madison County combine to make groundwater protection an important issue. Local officials, utility managers, and citizens are concerned about potential pollution from pesticides, abandoned wells, failing septic tanks, and industries. The absence of zoning ordinances to guide growth patterns and the multiplicity of local jurisdictions combine to make pollution control difficult.

Many of those concerned about groundwater protection in Madison County have convened a multidisciplinary groundwater steering group to consider groundwater protection issues facing the county and the jurisdictions therein. Beginning in April 1987, representatives from federal, state, and local governmental agencies, utilities, universities, consulting firms, educators, and private citizens have shared views about the need for groundwater protection in Madison County. At the first meeting, the group agreed upon these goals: (1) to seek to incorporate groundwater protection into the planning and development process for Madison County, (2) to support efforts by Madison County to obtain authority to adopt zoning ordinances and subdivision regulations,

and (3) to begin development of a groundwater management plan for the county.

Wellhead Protection for Public Water Supplies

The development of a groundwater management plan for the public water supplies depends greatly on the development of wellhead protection areas (WHPAs). Development and administration of a wellhead protection program can be grouped into two basic interrelated tasks. First, the geographic area to be regulated around each well must be defined. The EPA defines a WHPA as "the surface and subsurface area surrounding a water well or wellfield, supplying a public water system, through which contaminants are reasonably likely to move toward and reach such water well or wellfield" (33). Secondly, the methods for regulating potential sources of pollution within the defined area must be described. These methods depend upon both the nature of the potential pollution sources and the legal mechanisms which may be available to the regulator.

The Safe Drinking Water Act of 1986

The SDWA of 1986 contains important provisions for wellhead protection. It outlines a voluntary program that provides matching funds to participating states. Unfortunately, adequate funding has not been available for widespread implementation. In fact, funding has been made available only to a few states on a demonstration basis. Most wellhead protection programs have been initiated solely under state or local initiative. The EPA has, however, published technical guidelines for delineating WHPAs to assist states and local governments (34).

Methods for Delineation of Wellhead Protection Areas

In Guidelines for the Delineation of Wellhead Protection Areas, the EPA outlined six (6) potential methods for consideration. Each is described briefly, including limitations, here.

1. The Arbitrary Fixed Radii Method involves drawing a circle of specified radius around a well being protected. The distance criteria may be based on very generalized hydrogeologic criteria and/or professional judgment. It is an easy, inexpensive technique which can be used to initially define the WHPA until the need for protection increases or until more detailed data become available. Due to a lack of scientific criteria, the method may over- or under-protect well recharge areas.
2. The Calculated Fixed Radii Method involves drawing a circle for a specified time-of-travel criterion threshold. The time period used is that which allows adequate dilution and dispersion of the contaminants, or allows cleanup of the contamination before it reaches a well. While it is relatively easy to apply and relatively inexpensive, it requires data to define the criteria thresholds. It may, however, be inaccurate, since it does not account for many factors influencing contaminant transport. This is particularly true in areas of heterogeneous and nonisotropic hydrogeology.
3. The Simplified Variable Shapes Method uses standardized geometric forms which are generated using analytical models, with both flow boundaries and time-of-travel used as criteria. The appropriate standardized form is selected based on the basic hydrogeologic parameters and well pumping rates for a given well, and then, the

form is oriented around the well according to groundwater flow patterns. Shapes of the standardized forms are calculated on the basis of the distance to downgradient and lateral extents of the groundwater flow boundaries around the well and then using time-of-travel criterion to calculate the upgradient extent. While the method is easily implemented once the shapes of the standardized forms are calculated, it requires well pumping rates, material type, and direction of groundwater flow. It may not be accurate in heterogeneous geologic settings and conceptual problems occur when the flow directions around the well differ from those inferred from regional or subregional assessments.

4. Analytical Methods involve the use of equations to define groundwater flow and contaminant transport. Site-specific hydrogeological parameters which may be required for each well are transmissivity, porosity, hydraulic gradient, hydraulic conductivity, and saturated thickness of the aquifer. The widely used method, which can be applied by civil engineers and hydrogeologists, incorporates site-specific parameters. It does not, however, generally account for hydrologic boundaries, aquifer heterogeneities, and nonuniform rainfall or evapotranspiration.
5. Hydrogeologic Mapping involves the use of geological, geophysical, and dye tracing methods to establish flow boundaries and time-of-travel criteria. It may also involve mapping of groundwater levels to identify groundwater drainage divides. While it is well suited to areas dominated by highly anisotropic aquifers, such as fractured bedrock and conduit flow karst, it requires specialized expertise in

geologic and geomorphic mapping, extensive data, and significant judgment of what constitutes likely flow boundaries. It may be less suited to delineating a WHPA in large or deep aquifers.

6. Numerical Flow/Transport Models involve the use of computer models that approximate groundwater flow and/or transport equations numerically. They are particularly useful where boundary and hydrogeologic conditions are complex, but require extensive data in these situations. Models potentially provide a high degree of accuracy and can be applied to most types of hydrogeologic settings. They require considerable technical expertise in hydrogeology and modeling, and may be relatively costly.

Delineation of Wellhead Protection Areas for Madison County

Determination of appropriate wellhead protection areas for Madison County's public water wells is made difficult by the heterogeneous nature of the producing aquifers. Karst terrains, such as in Madison County, are characterized by sinkholes, fractured bedrock, and solution channels. Acidic subsurface water, whether naturally occurring or acidic precipitation infiltration, tends to dissolve and enlarge fractures in the soluble limestone units, producing large cavities through which large amounts of water can move at relatively high velocities. Many areas of the county exhibit this type of flow system--for example, the Lincoln Well, in Huntsville, is a large diameter dug well where groundwater can be observed flowing through a large solution cavity. In many other areas, however, groundwater flow through limestone aquifers can be characterized as more diffuse in nature.

Madison County is fortunate to have available much more data and analyses of groundwater conditions than many other areas. For example, the GSA published a hydrologic and environmental atlas in 1974 which contained, among other things, a potentiometric map of the county with inferred groundwater flow directions, confirming the groundwater's general flow direction of north to south. The map, which shows very strong topographic control, was based on water levels in several hundred wells but may be influenced by seasonal fluctuations, variations in precipitation over the years the data may have been collected, well development, and local geology. Local predictions of the direction and rate of groundwater flow is difficult, because flow tends to occur primarily through fractures and solution channels in the soluble limestone formations. Other useful data from both the GSA and the USGS are subject to similar limitations. Consequently, this type of regional analysis does not provide the detailed data necessary to determine the true recharge areas of the public water wells.

The water drawn by a well is usually a combination of water that has infiltrated locally and water that has traveled through the aquifer from a more distant point of recharge. Whatever the source, the water may travel through several media such as clay soils, sand, fractured bedrock, or solution channels. Although it is not always true, it is usually assumed that pollutants that infiltrate over or near the cone of depression (zone of drawdown) of the well are highly likely to travel toward and be drawn into the well in a short time. Pollutants introduced farther upgradient are more likely to be diluted and acted upon by chemical processes. Of course, the solution channels in the limestone

reduce the ability of the aquifer to cleanse pollutants once introduced. This suggests, however, that a combination of methods for the delineation of a WHPA may be appropriate for Madison County.

The highly heterogeneous nature of the limestone aquifers of Madison County render the calculated fixed radius and simplified variable shapes methods inaccurate. Available detailed hydrogeologic data is insufficient at this time to accurately apply analytical methods or numerical models. While the arbitrary fixed radius method has some inherent inaccuracy, it offers potential as an inexpensive, easily applied method to offer protection to the vulnerable area in the immediate vicinity of the well. Hydrogeologic mapping, too, offers potential. While currently available data are insufficient to accurately define the recharge areas, some important data now exists. Hydrogeologic mapping allows the refinement of the WHPAs as the need for more accurate protection increases and/or as more hydrogeologic data become available. A sinkhole protection program would appropriately supplement the initial WHPAs and remain a viable part of a long-term protection strategy.

WPHAs were developed using a three-tiered approach. First, the arbitrary fixed radius method was used with a one-thousand foot radius. Regional potentiometric maps, topographic maps, geologic maps, and detailed sinkhole analysis provided the basis for the delineation for the broader tiers, two and three. Figure 6 illustrates the generalized, initial WHPAs developed in this project for the 22 public water wells in Madison County. The areas shown represent a judgment of the probable recharge areas of the public water wells based on available information.

Figure 6

Each WHPA is shown with three regulatory zones which could be differentially managed based on proximity to the well and the perceived pollution threat. The proposed WHPAs were mapped on standard 7.5 minute topographic maps. The participating federal, state, and local agencies have copies of the maps which should be available for review upon request.

Regulations for Controlling Potential Pollution Sources

While specific recommendations for land use restrictions or performance standards are beyond the scope of this document, several important points should be mentioned. It is possible to delineate multiple areas for protection with differential protection measures in each zone based on the proximity of the area to the wellhead or geohydrologic features which make one area more critical than another area. Challenges to regulations and restrictions will occur from professional developers and/or private citizens who either believe that their property, while within the designated WHPA, is not in the recharge area of the well or spring or that their activity will not adversely affect the quality of the groundwater. Sinkholes, which have been popular dumping grounds in the past, deserve a high degree of protection because of their often direct connection with the groundwater. These concerns have been addressed in other areas through ordinances.

Public Education and Participation

As environmental protection legislation for issues of localized impact such as groundwater protection is addressed, local governments are also faced with the need for public involvement in planning activities.

In order to ensure environmentally sound and technologically feasible input by the public, local governments must be prepared to educate the public in the area of concern. The educational goals must be twofold. The immediate educational goal for the local governments is the education of the adult community. Adult education must be complemented by a long-range goal of educating young people to understand, accept, and welcome their future role in environmental planning.

Local governments have at their disposal many opportunities for providing high quality, low cost groundwater educational programs to the public. The ideal way is to develop programs which fit into existing community information and educational networks, such as garden clubs, 4-H clubs, Scouts, the agricultural extension service, and the classroom. Of course, program topics will vary in different areas. In general, the list of topics is not too long and includes septic tank maintenance, household hazardous waste disposal, animal waste management, and agricultural chemical application. Many resource materials are available for purchase or rental. Appendix A outlines some materials which the TVA has used for groundwater education activities in Madison County and elsewhere.

Recommendations for Implementation

There is an immediate need for protection of groundwater resources in Madison County. Public health and future economic growth of the County depend on a safe public water supply. Although much has been accomplished in gathering data for the delineation of Wellhead Protection Area, much information is still needed. Nevertheless, it is feasible and

may be desirable to immediately implement some protection measures. It would not be wise, however, to begin implementation without a long-term plan which addresses future needs. A phased approach that builds upon available information and adds needed information as funding becomes available, addresses immediate needs while allowing refinement in the future. Several potential implementation actions are listed below.

Phase I Recommendations

1. Seek resolutions in support of groundwater protection from Madison County and municipalities therein. The resolution could sanction the formation of and support a technical committee which will advise the local governments on groundwater related matters.
2. Support the continuing efforts of Madison County to obtain authorization for countywide zoning to provide authority for land use regulations.
3. Create an ordinance or ordinances which define the Wellhead Protection Area for the county's public water supplies and outline appropriate protection measures for the areas. Since challenges to the proposed boundaries of the WHPAs or restrictions on land use will occur, the ordinance should address these. In some areas, ordinances require challengers to provide proof that the proposed activity will either not impact the resource or that the area in question is not within the recharge area of the public water supply. The technical committee could have the responsibility for evaluating geohydrological reports prepared in support of challenges. The local governments should consider using the WHPAs outlined in this document as initial determinations.

Phase II Recommendations

1. Perform fracture/lineament trace for the entire County using aerial photography.
2. Computerize groundwater data which resides in the files of the many federal, state, and local government offices in a form compatible with the Intergraph GIS, since much of the information already available is on the Intergraph system.
3. Consider expanding laboratory analysis capabilities within Madison County.
4. Refine initially determined WHPAs to reflect new information.

Phase III Recommendations

1. Establish public water supply priorities for further refinement of WHPAs based on use and/or suspected problems.
2. Perform dye-tracer studies and/or aquifer testing as funds become available.
3. Adjust WHPAs to "final" form.

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APPENDIX A

The groundwater education resource materials listed here are available from a variety of sources at various prices. Materials which are free and available from TVA while supplies last are marked with an asterisk (*).

Audio-Visual Presentations

"Groundwater," Encyclopaedia Britannica, 18 minutes, 16 mm film.

"Secrets of Limestone Groundwater," Indiana University, 15 minutes, film or video.

"Understanding Ground Water: The Hidden Resource," National Association of Conservation Districts, 24 minutes, slide-tape presentation.

Books

A Citizen's Handbook on Groundwater Protection, by Wendy Gordon, Natural Resources Defense Council, Inc.

Groundwater Protection, The Conservation Foundation.

Brochures/Pamphlets

"Groundwater: A Community Action Guide," Concern, Inc.

"Waste: Choices for Communities," Concern, Inc.

"Groundwater: A Vital Resource--Student Activities," Tennessee Valley Authority.*

Groundwater Fact Sheets, Tennessee Valley Authority.*

"Groundwater: Issues and Answers," American Institute of Professional Geologists.

"Sandcastle Moats and Petunia Bed Holes: A Book About Groundwater," Virginia Water Resources Research Center.

"Hazardous Wastes from Homes," Enterprise for Education.

"Household Hazardous Waste: What You Should & Shouldn't Do," Water Pollution Control Federation.

Brochures/Pamphlets (Continued)

"Groundwater: Why You Should Care," Water Pollution Control Federation.

"Groundwater Protection Begins at the Source!," Tennessee Valley Authority.*

"Cattle Waste Management," Tennessee Valley Authority.*

"Dairy Waste Management," Tennessee Valley Authority.*

"Poultry Waste Management," Tennessee Valley Authority.*

"Swine Waste Management," Tennessee Valley Authority.*

"Owner's Guide for the Home Septic Tank and Soil Absorption System," Alabama Department of Public Health.

"Protecting Our Groundwater," Environmental Protection Agency.

"Toxic Waste: Reduce It--Don't Produce It," Greenpeace.

"Groundwater Pollution Control," National Water Well Association.

"A Homeowner's Guide to Domestic Wells," Virginia Water Resources Research Center.

"A Homeowner's Guide to Septic Systems," Virginia Water Resources Research Center.

"Septic Systems and Groundwater Protection: A Program Manager's Guide and Reference Book," Environmental Protection Agency.

Posters

"Groundwater: A Vital Resource," Tennessee Valley Authority.*

"Groundwater and Land Use in the Water Cycle," originally published by the University of Wisconsin, reprinted by Tennessee Valley Authority.*

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