A Dam Problem: TVA's Fight Against Malaria 1926-1951

By

Carl Kitchens

Abstract:

The TVA has long been held in high esteem for being the responsible for the reduction in malaria mortality and morbidity rates in the Southeast following its establishment in 1933. Given the recent increase in river system management projects around the globe and a recurring malaria problem, the TVA provides insight to the problems associated with large scale water management. I find, using county level panel data, that the TVA increased the malaria morbidity and mortality rates following its construction.

I would like to thank Price Fishback for providing assistance in the collection of data and for helpful comments as the drafts have progressed. I would also like to thank the University of Arizona: Department of Economics for financial support to collect data. Additional thanks to Ron Oaxaca for helpful comments and to participants in the Economic History Seminar. Additional support has been provided by the Economic History Association Travel Grant.

1. Introduction

Recently in developing nations there has been a major push in dam construction for the purposes of water management, electrification, water storage, and irrigation. China has experienced some of the largest building projects in the world, most notably, Three Gorges Dam. It is only one project in a larger effort to control the Yangtze River. In South Africa and Lesotho, large projects are being constructed and planned for the near future. One of the major environmental concerns when dams are constructed is that they impound a large body of water. In mild and tropical climates, this impoundment of water may lead to large outbreaks of malaria. Despite large-scale efforts to eradicate malaria, between one and three million people die annually from malaria or malaria related illnesses. Over 300 million are infected annually (Sachs 2002). The World Health Organization reports that people living in highly malarias regions have incomes that are significantly lower than those living in low intensity areas. Speculation for the high rates of modern infection include shifts in population centers and practices in agriculture, which are relying more and more on the construction of dams for irrigation and water management.[1]

As a means of examining the impact of large dam projects and malaria eradication efforts, I examine the impact of the Tennessee Valley Authority on the extent of malaria in the Tennessee River Valley during the period from 1926 through 1951. The TVA is one of the world's largest dam projects. Like modern dams, the TVA was built to improve navigation, flood control, and to produce electricity. In the building process the TVA flooded large areas in a place rife with problems with mosquitoes and malaria. Aware of the potential danger, the TVA

---

[1] Today there are renewed efforts being made to eradicate malaria worldwide. Many of the programs are designed to reduce the contact with the disease by using insecticide treated bed nets in the home. The Gates Foundation has made malaria eradication one of its highest priorities, and has funded various programs from the bed nets and vaccine research, to other technologies that adopt missile defense technologies to discriminate between male and female mosquitoes in the air. In 2007 and 2008, the Gates Foundation spent over $3 Billion on World Health initiatives (Gates Foundation Annual Report 2008).

embarked on a major malaria eradication program. In their annual reports the TVA trumpeted their eradication efforts with implications that the disease rate declined. My goal is to address the impact of the TVA on the extent of malaria during this period. Was the potential rise in malaria rates from creating large bodies of still water overcome by the TVA's efforts to eradicate the disease?

The paper also contributes to the literature on disease eradication efforts by private charities and governments at all levels. Infectious disease lowers incomes by reducing people's ability to sustain work effort (Acemoglu and Johnson 2007). Private charities and governments at all levels have attempted to eradicate infectious diseases like malaria, hookworm, and typhoid. These programs typically target the most disease ridden areas, causing an endogeneity problem. This paper uses an exogenous change in the eradication effort that came from the creation of the TVA. The TVA was created as a part of the New Deal to control the Tennessee River and electrify the South. Within county variation over time will be used to identify the causal effect of the TVA. The data employed in this paper will allow new estimates income loss attributable to malaria to be calculated. After changes in malaria rates have and income loss have been identified, I use those estimates to create a back of the envelope calculation. I find that the TVA was very costly in terms of lost income from both morbidity and mortality. Had the TVA not been able to reduce the malaria problem through fluctuating pool elevation in the reservoir system, increased malaria morbidity and mortality would have cost between $740 million and $7.5 billion, where the major discrepancy is based on range of estimates for the value of a statistical life (VSL). Because the TVA was partially successful in reducing the problem through water level fluctuation, I find that the true cost to be between $140 Million and $2 Billion. Again with differences due to the range of VSL estimates.

Malaria and the Tennessee Valley

The Parasite, Its Lifecycle, and Effects

The parasite that is the cause of malaria, Plasmodium, was first discovered in 1880. The discovery of this parasite led to the discoverer, Laveran, being awarded the Nobel Prize in 1907. Following the discovery of the parasite, British doctors in India proved that the disease was transmitted by mosquitoes. This discovery, by Sir Ronald Ross, was awarded its own Nobel

Prize in 1902. These official discoveries solidified long held beliefs that mosquitoes were the transmitters of the disease.

A detailed description of the lifecycle is provided in the TVA publication “Malaria and Its Control in the Tennessee Valley.”

> “…the parasite is injected into the human blood stream by the bite of an infected mosquito. Shortly thereafter the parasite enters a red blood cell and begins to grow and multiply until from 16 to 24 new parasites are formed. The red cell then bursts, freeing the parasites which soon enter other red cells to undergo similar development. This phase is known as the asexual cycle.”

The lifecycle continues when a female mosquito bites an infected human host, the parasite transfers through a blood meal; the developed sex cells of the parasite bury themselves in the stomach of the mosquito and multiply. The cycle continues when an uninfected human is bit. It is possible for the parasite to remain dormant for an extended period of time, up to three years. If either the human population or the mosquito population can remain uninfected for this period of time, then the disease will become eradicated until reintroduction of the parasite from outside sources.

The disease has a long history in South America and Africa, locals in Peru discovered early on that chewing the bark of certain trees would reduce the ailments associated with malaria. The indigenous cinchona tree bark, contained quinine, which is the primary medicine used to combat the effects. In Africa, humans adapted by a genetic mutation, sickle cell, which prevents the parasite from multiplying within the red blood cell host.

While malaria is rarely deadly, the CDC lists several of the effects from contraction. The most basic symptom associated with malaria is anemia, which is a direct result of the parasite’s destruction of red blood cells. In mild or uncomplicated cases of malaria, cold chills are followed by fever and nausea, and eventually the breaking of the fever. In more complicated cases, blood mat appear in one’s urine, pulmonary edema, reduction in blood platelets, and more severe complications leading to one’s death may exist. Because of the common symptoms presented, it is often difficult to diagnose malaria in a patient. However, once the fever is sustained, the pattern of sweats and chills made malaria easily identifiable to doctors.

The Mosquito’s Lifecycle and Home

In the southeast United States, the species of mosquito responsible for the transmission of Plasmodium is the Anopheles mosquito. Its lifecycle is described in four stages, egg, larvae, pupa, and adult. Egg are laid at the end of February or early March. As a result, the mosquito populations may be susceptible to weather shocks occurring in those months. The mosquitoes do not mature until later in the spring when temperatures increase to average near 70 degrees Fahrenheit. While the temperature is above this threshold, breeding activity flourishes. Adult females can live for up to two months and will lay eggs multiple times during the season. Mosquitoes lay their eggs on sitting water, so any idle pool is potentially a breeding ground. The breeding season tails off following the first hard freeze of the fall (TVA Malaria and Its Control).

Sitting water is commonly found along inlets, sink ponds, and swamps. Vegetation is needed for the larvae to feed, so any plant growth will only increase the rate of survival for the larvae. When rivers are flooded to create reservoirs, the overall effect is unclear. Previous breeding grounds adjacent to the river become flooded and susceptible to natural prey such as fish. However, the shoreline is increased, which may create larger breeding grounds, particularly if vegetation is abundant. If shorelines are cleared prior to flooding, suitable breeding grounds may become scarce, reducing the mosquito population and the transmission of malaria.

Early Eradication Efforts

The first major campaigns to eradicate endemic disease in the United States came at the turn of the 20th century. Federal, state, and private organizations banded together to fight hookworm in the southeastern states. This campaign extended into the 1920’s until hookworm was believed to be eradicated. Following the successful hookworm campaign, the Rockefeller Foundation’s International Health Board, The United States Public Health Service, and state health agencies turned their attention to other infectious diseases that plagued the population. In the Southeast, Malaria was a major problem, infecting over 30% of the population as late as 1930. The Rockefeller Foundation had great success initially in reducing malaria at experiment stations located in Mississippi and Arkansas in cooperation with the US Public Health Service. Experiment stations were quickly adopted in other southern states.

Beginning in 1919, the Alabama State Board of Health began inspections within counties to determine the source of the malaria problem. After two inspections, the number of inspections expanded quickly. By 1921, over 20 counties participated in inspections and the U.S. Public Health Service provided the state a malarial engineer. Very quickly programs were established in urban areas. In 1923 the first rural malarial campaigns began and five engineers began working on malaria relief projects. Most of the early projects focused on drainage or studies to pinpoint the source of mosquito vectors within the county. Not until 1930 did the state establish a home screening and sealing program. These programs expanded further into the 1930's.

The Tennessee Department of Public Heath describes similar activities related to surveying, drainage, and screening homes. Tennessee was particularly active in home screening. Reports also state that the American Red Cross provided funds for the construction of screened doors and windows in 1926. These were assembled in high schools as a part of vocational education. Other major projects were started near Memphis in 1923. State and local efforts continued through the 1930's and were aided by labor provided by New Deal agencies.

During the Great Depression a variety of agencies were created to create jobs for unemployed workers. Many of these agencies provided labor to local health agencies to carry out proposed projects, including the Federal Emergency Relief Administration (FERA) and its local agencies the Tennessee Emergency Relief Administration (TERA) and the Alabama Relief Administration (ARA), the Civilian Works Administration (CWA) , and the Works Progress Administration (WPA). Most of these projects focused on labor intensive efforts, such as building drainage systems, clearing existing drainage facilities, or by excavating dirt. Each of the above agencies contributed in some way to fight malaria problem.

Following World War II, health agencies received a major boost to the malaria fight when DDT was released to the public. The use of DDT as an insecticide was discovered in 1939, but because of WWII, all of its production was allocated to the military. It proved to be an effective killer of mosquitoes, leading to a reduction in malaria morbidity. By 1950, malaria had been almost completely eradicated in the United States. However, DDT has its own set of environmental problems, and its use has since been reduced.

The Tennessee Valley Authority

In May of 1933, President Franklin Delano Roosevelt created a new federal agency that would be regional in scope, and was aimed at developing what was deemed a lagging Southern economy. The Tennessee Valley Authority was chartered as a federal corporation that would assume control of the Tennessee River and its tributaries.

The primary goals outlined in the charter included a general provision to improve the economy in the Tennessee Valley. The first director of the TVA, Arthur Morgan, quickly established plans for a series of dams and reservoirs to line the Tennessee River and its major tributaries. The plans were to expand upon an existing US Army Corps of Engineering project, Wilson Dam in Muscle Shoals, Alabama. In the first six years of existence, the TVA expanded rapidly. By 1939, the TVA had received over $3.68 billion in federal appropriations. By 1945 cumulative appropriations exceeded $9.9 billion. Most of the money was spent for dam construction, and related expenses: land purchases, transmission lines, and electric generation plants located at the dams.

As these projects were proposed and construction began, concerns grew over the impoundage of large bodies of water. It was estimated that the system of lakes and reservoirs would create a shoreline 10,000 miles in length covering 600,000 acres of water, creating a large breeding ground for mosquitoes (Derryberry and Gartrell 1952). Malaria was already a problem in the region, and any increase in sitting water would potentially increase its severity. From the beginning the TVA tried to address the malaria concerns without heavy use of insecticides. The TVA used a variety of techniques from introducing natural predators of mosquito larvae, destruction of habitat through drainage and periodic water fluctuations, brush clearing, larvacides, and oiling (Gartrell and Ludvik 1954). The TVA would eventually have the option of DDT, which was used experimentally in 1943 and 1944. The earliest uses of DDT were in conjunction with the Office of Malaria Control in War Areas. General spraying of DDT began at the close of the war (1945 TVA Annual Report to Congress).

The TVA initially tried to combat malaria with sound design of the reservoir and precise timing to fill the reservoir. If an existing construction plan did not facilitate the TVA's objective, it was altered to meet the updated needs of the project (although it did not change the location of construction). Bishop (1936) details how construction plans at Wheeler Dam were altered to allow the for water level fluctuation. The construction teams also spent long hours clearing brush along the proposed reservoirs perimeter to prevent the creating of breeding grounds upon impoundage. The agency also made efforts not to flood its reservoirs during peak mosquito breeding seasons.

Perhaps the largest effort made by the TVA came through a near costless plan to vary the water levels in the reservoirs. During the winter and early spring months, the TVA would store water at dams located along upstream tributaries, and slowly raise the water level in the river reservoirs. This would flood potential breeding grounds for mosquitoes. Then, during the primary breeding season of spring and summer, the TVA would fluctuate the water levels in the reservoir, slowly lowering the water levels, drying out potential breeding grounds for the mosquito larvae. The water levels in the reservoirs would continue to drop during the summer and into the fall until winter, when the process began its cycle. An illustration of this procedure was provided by Kitron and Spielman (1989), and is presented in Figure 1.

Once the reservoirs were flooded, the agency routinely patrolled its reservoirs looking for large patches of mosquito larvae; it would then dump oil into the reservoir to reduce the prevalence of the breeding, which was standard during this time period. For each acre sprayed with oil by plane, it was estimated that the cost was only $1.22, and only slightly higher if applied by boat. The TVA estimated the cost of each case of malaria at $40 (although it provides no methodology for this calculation) and found that it could screen houses and make them mosquito proof for less than the estimated cost of the disease. Screening efforts were made at some of the most susceptible project locations within a mile of the reservoirs shore (Malaria Control in the TN Valley). Over a three year period 1936-1938, it was estimated that the cost of malaria in the Tennessee Valley was over $18 million in year 2000 dollars.

Many researchers (Bishop 1936, 1934, Gartrell 1954, Kitron 1989) have claimed that the TVA is responsible for the decline in malaria rates witnessed between 1930 and 1950. The CDC lists the TVA's accomplishments on its malaria website. Humphreys describes the TVA as follows "The history of the TVA …is a saga of heroic deeds well done, which really did bring untold benefits to the people while preserving their health" (Humphreys). It remains to be seen if the TVA is the source of the improved conditions, or is part of a larger trend initiated by efforts of the Rockefeller Foundation, the US Public Health Service, and local health officials.

A Simple Susceptible-Infected-Removed (S-I-R) Model of Malaria Transmission

Borrowing from the literature pertaining to the spread of epidemiological disease, I develop simple comparative statics to determine how the disease profile will change due to changes in the epidemiological environment caused by the TVA's damming of the Tennessee River. The model I adopt is a differential equations model named the Susceptible - Infected – Removed (SIR). Typically these models are used to determine if a disease will be endemic or will fade out as time progresses, based on the flow of births and deaths, and the fraction of individuals that become ill upon contact with an infected individual. For a detailed description of the model see Allen (2008), Bauer (1990), Newman (2002).

The SIR model works as follows, there is a fraction of the population, α, that is infected by a disease and a fraction of the population β, that is susceptible to the disease, there is also a third group that has immunity and is a $1-\alpha-\beta$ fraction of the population. The model assumes that the population is closed with respect to time, and that the probability of new infection is proportional to the product of infected and susceptible individuals. Formally, Pr(New Case) = $a\alpha\beta$, where a is $a>0$.

While typically the model examines the dynamics of convergence to disease free or epidemiological nightmare, I am interested in explaining how changes in initial conditions change the probability of infection in the following time periods. I modify this model in the following way to adapt it for the transmission of malaria, I assume that the fraction of the population that is infected, α, is a function of the number of mosquitoes, and that the number of mosquitoes is a function of epidemiological characteristics such as, climate (c) , sitting water (w) , and anti-malarial (k) efforts such as ditching and spraying. Formally, $\alpha = f(m),\ m = g(\text{c,w,k})$. Assumptions on the functional forms are as follows, f is increasing in m; g is increasing in w and decreasing in k. Substituting, the Pr(New Case) = $a\beta f(g(\text{c,w,k}))$.

To predict the effects of the TVA, two partial derivatives must be examined. First, the TVA fought hard to limit the increase in the mosquito population by ditching spraying, fluctuating water levels, etc. By assumptions made on the functional form, an increase in anti-malarial efforts leads to fewer mosquitoes, making the partial derivative negative.

$$\frac{\partial \Pr\ (New\ Case)}{\partial k} = a\beta \frac{\partial f}{\partial m}\frac{\partial m}{\partial g}\frac{\partial g}{\partial k} < 0$$

Also, the TVA changed the shape of the Tennessee River by constructing reservoirs. These reservoirs vastly increased the amount of sitting water and increased the shoreline of the river. This effect in the SIR model can be represented by a change in w, leading to the following partial derivative, which by assumption of the model leads to an increase in the malaria rate.

$$\frac{\partial \Pr\ (New\ Case)}{\partial w} = a\beta \frac{\partial f}{\partial m}\frac{\partial m}{\partial g}\frac{\partial g}{\partial w} > 0$$

Whether or not the actual malaria rate increased will depend on the magnitudes of each of the partial derivatives. A priori, there is no way to determine which is larger in magnitude. To fully evaluate the effect that the TVA had on malaria rates, an empirical investigation must proceed.

Related Work on Infectious Disease

Several recent works have focused on infectious disease, primarily by examining either hookworm or malaria. Work by Brinkley (1997) focused on the incidence of hookworm in the southeast between 1860 and 1880. Brinkley finds that a higher rate of hookworm infection in 1880 led to decreased wealth measured by per capita agricultural output. Bleakley (2007b) also examined the effects of hookworm. Bleakley found that the Rockefeller Foundation's hookworm eradication campaign between 1910-1915, led to individuals obtaining higher levels of schooling, higher labor participation rates, and increased literacy.

Other work deals specifically with malaria. Hong (2007) examines health outcomes for Union soldiers during the American Civil War. By using the height of Union soldiers as a proxy for health status, Hong finds that individuals conscripted from highly malarious areas are on average 1.1 inches shorter than soldiers who hail from malaria free areas. To control for the probability of contracting malaria, Hong develops a malaria index by using epidemiological factors such as climate to determine the probability than an individual has contracted malaria. Bleakley (2007a) uses this index to perform similar analysis found in Bleakley (2007b). In this work, Bleakley finds that individuals who were exposed to higher levels of malaria eradication efforts had better economic outcomes later in life, as measured by income and literacy rates.

Furthermore, the results show that the impacts were largest for children who had not yet made their human capital investments.

Broader impact studies have been performed by economist at the World Health Organization (WHO). Sachs (2003) examines the relationship between malarial risk and incomes after conditioning on the quality of governmental institutions using data from the WHO. Sachs finds that after controlling for governmental institution quality that areas that experience high levels of malarial exposure risk still have lower levels of income. This link shows that even with stable governments, disease ridden areas may have lower potential incomes unless the diseases can be managed. Another paper by Sachs (2001) measures the income gap experienced by areas with high levels of malaria. The author finds that areas with high levels of malaria experience significantly lower levels of income than malaria free countries.

2. Change in Malaria Rates

To identify the causal effect of the TVA on malaria rates in the Southeast United States, time variation within the county will be utilized in both the malaria morbidity and mortality rates, as well as in the completion of TVA projects. The TVA provides an exogenous change in malaria control policies in the county. The TVA transformed the Tennessee River from a freely flowing river to a series of dams and reservoirs. By the end of the sample period, any county located on the Tennessee River was associated with a TVA dam. In many ways, the timing of the projects is also exogenous. The first projects initiated by the TVA used reservoir plans developed by the US Army Corps of Engineers, and as time moved forward, the TVA developed its own construction plans. While the location of these later dams is endogenously determined, by the close of construction in 1944, all counties along the Tennessee River were located on a reservoir. Construction continued through the 1970's on dams located on minor tributaries.

Variation in climate variables will play a critical role in determining whether or not the parasite can survive. The parasite thrives in warm, moist climates, creating natural variation across counties. There is also substantial variation in the number of county health organizations (CHO) operating in a given year. Many of these organizations became operational during the hookworm eradication campaigns, however, some may have opened in response to increased problems with malaria in the county, or infectious diseases in general. Because of this endogeneity, estimation of the impact of a CHO will likely have to be addressed by using an instrumental variables approach.

Empirical Model of Malaria Rate

To identify the causal effect of the TVA on the affected counties, I specify the following baseline empirical model.

$$(1)\quad M_{it} = \alpha_i C_i + \alpha_t Y_t + \beta_1 TVA_{it} + \beta_2 CHO_{it} + \beta_3 Climate_{it} + \beta X_{it} + \varepsilon_{it}$$

Where M_{it} is either the mortality rate per 100,000 people or the morbidity rate per 10,000 people in county i in year t. The vector C_i represents a set of county fixed effects to control for unobservable characteristics that are specific to county i and do not vary over time. For example, features such as mountains, altitude, latitude, and longitude are fixed. Y_t is a vector of year fixed effects. The year fixed effect controls for nation-wide epidemics that occurred in the 1933-1937 time frame reported by Andrews, Quinby, and Langmuir in 1950 as well as other national shocks occurring in year t. TVA_{it} is an indicator that equals 1 if county i, in year t, is located on a TVA constructed reservoir. $Climate_{it}$ is a vector of variables constructed from historical climate data and include monthly average temperatures and monthly precipitation. CHO_{it} is a vector of indicator variables describing the presence of a County Health Organization. The first variables takes the value of one if a CHO opens in the year, and the second variable takes the value of one if a CHO is in operation. X_{it} is a vector of demographic covariates that will help control for key variables such as population density, percent black in the population.

Malaria Rate Data Sources

To gain insight into the TVA's effects on malaria in the region, I use county level data that allows me to compare and contrast the experiences with malaria for counties in the Tennessee Valley and counties outside the Tennessee Valley. Data has been collected from a variety of state and federal sources. Morbidity and mortality for Alabama and Tennessee come from publications of the state's public health department. In years when rates were provided, they are used as observations. In some early publications, crude death and sick counts were reported; these were transformed to rates using population data. Annual population estimates are derived from interpolating the decennial census.

Using morbidity data has several advantages over mortality data, however both sets of data have advantages over previously implemented methods. Hong (2007) notes that mortality data is not a good indicator of the prevalence of disease, especially malaria, which has a high infection rate, but typically a very low mortality rate. Because of the chronic, rather than deadly nature of the disease, mortality data may lead to a large undercounting of the prevalence of the disease. The morbidity data from Alabama and Tennessee will allow me to explore with a high level of accuracy the impact of the TVA on malaria. Both morbidity and mortality provide direct measures of the diseases prevalence. I will not have to implement models that estimate the probability of contraction based on climatic and geographic variables commonly mentioned in the epidemiology literature.

While I will do not use climate data to develop propensity models, I will use monthly climate variables to control for random weather shocks that would affect malaria rates. To control for this, I have collected the Historic Climatology Networks Monthly Weather data from 1895-2009. This data contains average, maximum, and minimum temperatures as well as precipitation data collected at each weather station throughout the country. One obstacle in dealing with this data is that there are far fewer weather stations than there are counties. For example, Alabama only has six weather stations. In order to create observations for each county-year, the following procedure was used. The latitude and longitude of each county seat and weather station is used to determine the distance between a given station and county seat. This is performed for each county-weather station pair in the country. The three stations with the smallest distance are then used to triangulate the weather in the given location. Each weather station is weighted according to its distance from the county seat, where the weight,

$$w_i = \frac{1}{2}(1 - \frac{d_i}{d_1 + d_2 + d_3})$$

and d_i is the distance in kilometers. In some cases weather stations in bordering states are used. When climate data is missing, observations are constructed by interpolating between years, at the same station in the same month.

TVA Annual Reports to Congress are used to determine the locations of reservoirs. An indicator variable takes the value of one if the county-year observation was located on a TVA reservoir, and is zero otherwise. There is both cross sectional and time variation in this variable, as the projects came online at different times within the sample.

While most of TVA's anti malaria efforts, such as spraying, are unobservable, one variable of interest, water level fluctuation, is observable. To proxy for the water fluctuations from upstream storage reservoirs downstream through the system, I have created a variable that counts the number of reservoirs located upstream from each reservoir county. Reservoirs far downstream are likely to gain the most due to increased control over the water level and flow rates through the reservoir. The process depicted in Figure 1 can only proceed if there is a system of reservoirs.

In both Alabama and Tennessee the State Board of Health had active offices at the county level. Starting in 1919 Alabama began establishing county offices, and by 1937 had set up an office in every county in the state. These local offices were faced with a variety of diseases to fight, as well as other concerns such as infant mortality. Malaria, typhoid, syphilis, and other communicable diseases were at the forefront of importance for the local authorities.

Other New Deal agency work is accounted for by a set of three variables: New Feet, Old Feet, and Acres Excavated. Alabama's State Board of Health reported annual progress in counties where federal relief agency labor was used. The reports detail the new linear feet trenched, the number of existing linear feet of trench that was cleared, and the acreage of the water impoundments that were affected by the work.

Population characteristic data has been compiled from the Census of Population and from the State Vital statistic reports. Combining the population and area data provides a measure of the population density per square mile. In the early years of the malaria campaigns, state agencies focused on urban areas, recognizing that a large portion of the population could be impacted by malaria fighting efforts. Because malaria is transferred from human to human through mosquito bites, counties that have higher population densities may be more susceptible to transmission of the disease.

Census data will also be used to determine the percentage of the population that was African American. There are two arguments in the literature assessing the importance of blacks pertaining to malaria. The first relies on sickle cell anemia, which would suggest that blacks should have a lower infection rate. The second argument focuses on the poverty of southern blacks. Blacks may have to live on land closer to swamps and mosquito breeding grounds due to their low income status in the south, putting them at higher risk for contracting malaria. It is unclear if sickle cell or poverty will play the dominating role.

To highlight the importance of DDT in the eradication of malaria, I have included an indicator variable in that equals 1 if the year is after 1944 and zero otherwise. I use 1944 because at the close of WWII, DDT was made available to the public and was no longer strictly produced for military purposes. This is effectively a trend variable to observe the trend following the introduction of DDT. While it is not a causal effect, the trend is informative. This variable only appears in the specification that includes county fixed effects because it is a linear combination of the year fixed effects.

Summary Statistics: Malaria Rates

To provide a sense for the changes in morbidity and mortality over time and space, detailed maps for Alabama and Tennessee are provided in appendices A-D. By visual inspection, it is difficult to tell what effect the TVA has on the region. In both states, mortality and morbidity are reduced over the sample period in all counties. It appears as though over time, the morbidity and mortality rates are steadily decreasing through World War II. The sharp drop following the end of the war was likely caused by the introduction of DDT in 1945. Summary statistics are provided in Table I, and detail morbidity, mortality, climatic variables, the presence of a CHO, WPA project, and other demographics.

At the beginning the sample, infection rates were very high, the maximum value recorded in the sample is 8284 cases per 100,000 people, however by the end of the sample, most counties reported having zero cases of malaria. For the entire time series, the average number of cases reported per year was 116 per 100,000. Mortality data reveals a similar story; the highest reported mortality rate for a single county year was 1117 deaths per 100,000, with an average over the period of 10 deaths per 100,000. This trend in malaria rates may have led some scholars in the past to view the decline as causal evidence.

The TVA was present in very few counties, primarily along the Tennessee River and some of its major tributaries such as the Ocoee, Clinch, and Powell Rivers. 6.5 percent of county-years in the sample were located on a TVA reservoir. Other New Deal programs, such as the WPA began their work in 1935, and had very high variation in the work performed. In some counties, the WPA constructed over 1,000,000 linear feet of ditches, or as little as one foot. Similarly, dirt excavation by the TVA ranged from 0 to over 2100 acres of dirt excavated in a county-year.

CHOs were located in over two thirds of all county-years, with rapid increases occurring throughout the 1930's. As previously mentioned, every county in Alabama had a local office by the mid 1930's. Tennessee also had a similar increase of local offices, but eventually developed a regional approach to the rural health problem.

Raw correlations show a positive relationship between a larger black population and malaria mortality and morbidity rates. This runs counter to the idea that the black population may have experienced a lower incidence of malaria due to sickle cell anemia. This positive relationship may suggest that income discrepancies dominate any benefits from sickle cell anemia. The raw correlations also reveal a negative relationship between urbanization and malaria rates. It is likely that cities had better infrastructure to deal with sitting water than rural areas. A similar relationship exists between population density and malaria rates.

Empirical Results: Malaria Rate

In this subsection, I will discuss the regression results detailing the TVA's net effect of the TVA efforts against malaria in the southeast. I find that there are statistically and economically significant increases in both the mortality and morbidity rate associated with the TVA. Depending on the specification, I find that the TVA increases mortality rates by .9 to 4.22 deaths per 100,000. Furthermore, I find that the TVA increases morbidity rates between 2.57 and 13.99 cases per 10,000. The full mortality results are presented in Table 2 and the morbidity results are presented in Table 3. It should be noted that this estimate is a net effect of having a TVA reservoir in the county, taking into account the campaigns financed and implemented by TVA.

While the TVA appears to have increased the rates of morbidity and mortality in counties located on reservoirs, there is some hope that the TVA prevented the rates from being worse than they would have been without their efforts. The variable detailing the number of reservoirs upstream has a negative and statistically significant coefficient. This supports the narrative evidence that the TVA's water level fluctuation program was successful. When upstream dams released water to downstream reservoirs, breeding grounds were flooded. However, the combined effect of being on a TVA reservoir and having multiple dams upstream still leads to a positive net effect.

Parts of other New Deal programs also seem to have been effective against malaria. The combined efforts by the CWA, FERA, and WPA to excavate dirt to fill and drain swamps led to a statistically significant reduction in the malaria morbidity rate. For every acre of dirt excavated or filled, the resulting reduction in the malaria rate is .02 per 10,000. While excavation appears to work, ditching results in increases in the malaria rate. Commentary provided in the Tennessee Department of Public Health Biennial Reports discuss how some of the ditches constructed were of poor design and would lead to more debris collecting, exacerbating the problem (Humphreys).

The availability of DDT also has the expected sign. When DDT was included in the county fixed effects specification, morbidity was reduced by 16.55 cases per 10,000. The coefficient was statistically significant at the 1% level. Furthermore, DDT reduced mortality however the point estimate is statistically insignificant. It is likely that DDT helped prevent people from becoming sick with malaria, but conditional on being sick, DDT does little to prevent death.

Several of the variables have signs that should be expected. Areas with higher population densities experience higher infection rates. More urbanized areas experience lower levels of malaria, which is likely due to the early efforts of the CHOs. Counties with a larger proportion of blacks also witness higher levels of infection. This may indicate that the income discrepancies between races more than offset any benefits from sickle cell anemia.

Interestingly, an increase in average monthly temperature does not always result in increased infection rates. With respect to the breeding cycle, this may make some sense. Conditional on precipitation, warmer spring and summer months matter little provided that the average daily high is above the survival threshold of the mosquito. Increases in monthly precipitation do not unambiguously lead to increases in malaria. In some months one would suspect increased moisture to lead to more malaria, the point estimates are negative, such as the month of March.

In both the mortality and morbidity specifications, the coefficient of the CHO is positive. This is likely due to endogeneity. Counties that opened up offices likely would have experienced large gains by educating the population about health practices. In this case, the CHO is not the variable of interest. If CHO are uncorrelated with the TVA, then the estimates of the TVA parameter will still be consistent. This point will be discussed at length momentarily.

Additional Specifications

Due to the nature of the parasite transmission, it is possible that there is serial correlation in the error term. It has been reported that the parasite can live in the body for a year, and in some extremes, up to three years. A simple test suggested by Wooldridge (2002) of regressing the residuals on the lagged residuals reveals that there is potentially serial correlation in the baseline model fixed effects model. To control for this, I specify that the error structure takes on an AR(1) process. I also include the restriction that the correlation over time $\rho,$ is the same across all counties. Intuitively this restriction is plausible, because the autocorrelation is likely due to the transmission mechanism, not county specific features. The model to estimate is described by equation (2), where all covariates are the same as in equation (1). To estimate (2), I implement a Prais -Winsten Feasible Generalized Least Squares (FGLS) iterative approach.

$$(2)\ M_{it} = \alpha_i C_i + \alpha_t Y_t + \beta_1 TVA_{it} + \beta_2 CHO_{it} + \beta_3 Climate_{it} + \beta X_{it} + \rho \varepsilon_{it-1} + \varepsilon_{it}$$

Regression results indicate that a small degree of positive serial correlation is present in the model. The Durbin Watson Statistic is 1.37 for mortality and 1.29 for morbidity. The correlation coefficient across time periods is .295 for mortality and .344 for morbidity. Full results of the specification are presented in Tables 2 for mortality and in Table 3 for morbidity. After controlling for serial correlation, the TVA still appears to have caused a significant increase in both mortality and morbidity.

Another potential concern about the fixed effects results are related to the interpolated county level climate variables. Because these variables are derived from regional weather stations, there is a common component in the error term across counties sharing the same weather station. This type of correlation would normally be solved by clustering on the weather station used in the interpolation. In this case, I interpolate the climate variables by using the three nearest weather stations, which implies that all three portions of the error must be accounted for. A new method developed in Cameron, Gelbach and Miller (2010), addresses this issue directly. In their paper, the authors develop a method to cluster on multiple dimensions. Using their method, the equation to estimate is

$$(3)\ M_{itqrs} = \alpha_i C_i + \alpha_t Y_t + \beta_1 TVA_{itqrs} + \beta_2 CHO_{itqrs} + \beta_3 Climate_{itqrs} + \beta X_{itqrs} + \varepsilon_{itqrs}$$

Where, *q*,*r*, and *s* represent the weather station used to interpolate the climate variables. The results from this specification are reported in Table 2 and 3. Once the observations are clustered by the weather station, efficiency improves for morbidity.

Spatial Correlation

One further complication is that conditional on county fixed effects and year fixed effects, differences in regional geography could be driving the results. There is a general downward slope from the eastern portion of the sample to the west as water drains towards the Mississippi River. Counties further east, or upstream, may experience improved natural drainage across counties, leading to less sitting water for mosquitoes to breed. Restated, as the topography flattens moving towards the Mississippi River, one would expect to see higher rates of malaria due to a lack of drainage. I test for spatial correlation in the errors by using a Moran I test on the OLS fixed effects residuals, both for morbidity and mortality. The Moran I Test Statistic for morbidity is 1.18 (in the absence of spatially interpolated climate data), which implies that the null of no spatial correlation cannot be rejected. However, when examining the mortality residuals, the Moran I test statistic is 4.13, which shows that for mortality, there may be some degree of spatial autocorrelation. This spatial correlation is accounted for by the following model

$$(4)\ M_{it} = \alpha_i C_i + \alpha_t Y_t + \beta_1 TVA_{it} + \beta_2 CHO_{it} + \beta X_{it} + \lambda W_{ij} \varepsilon_{jt} + \varepsilon_{it}$$

Where λ is the correlation between the errors of county i and j, weighted by the inverse of their distance depicted in matrix, W_{ij}.

Further testing, using a LaGrange multiplier test suggests that spatial lags should also be included in the analysis. In other words, neighboring counties morbidity and mortality rates affect the rate in the given county. In the absence of spatial correlation in the error, the model would be described as follows.

$$(5)\ M_{it} = pW_{ij}M_{jt} + \alpha_i C_i + \alpha_t Y_t + \beta_1 TVA_{it} + \beta_2 CHO_{it} + \beta X_{it} + \varepsilon_{it}$$

In this specification, M_{jt} is the malaria rate in neighboring county j, weighted by its distance from county I, where p estimates the correlation coefficient between the two counties. However, because both spatial lags and spatial errors should be included in the model, a more general framework needs to be adopted to account for both the error structure and the spatially lagged dependent variable.

$$(6)\ M_{it} = pW_{ij}M_{jt} + \alpha_i C_i + \alpha_t Y_t + \beta_1 TVA_{it} + \beta_2 CHO_{it} + \beta X_{it} + \lambda W_{ij}\varepsilon_{jt} + \varepsilon_{it}$$

The specifications in Equation 4-6 are all variations of the problem that has recently been studied by Lee and Yu (2010). They develop a quasi maximum likelihood estimation procedure for spatially correlated panel data, including both spatial lags and spatially correlated errors. I implement their method to estimate the coefficients.

Results of the estimation procedure are presented in Tables 2 and 3. The point estimates of both mortality and morbidity fall yet remain positive and statistically significant. When spatial lags and spatial errors are included the mortality estimate falls to 2.52 deaths per 100,000 people. Morbidity also remains positive with a statistically significant estimate of 7.23 increased cases per 10,000 people.

In this model, the direct effect of having a reservoir in the county is captured by the estimate of β_1, however; the total impact of a reservoir is the sum of the direct effect and effects on neighboring counties. The estimated correlation coefficient, p is statistically insignificant, therefore it is difficult to say that the total impact is different than the estimated direct effect.

County Health Organizations

As previously noted, if it is possible to show that there is no correlation between the TVA and the presence of a CHO, the endogeneity problem will not bias the estimates of the coefficient of interest, TVA. To test this hypothesis, I run auxiliary regression of a new CHO on the TVA and all other covariates. Results of this specification are presented in Table 4. The results show that there is no statistically significant correlation between the TVA and the CHO's. From a historical perspective, this makes a lot of sense. Most of the CHO's were opening between 1910 and 1930, so there would be little or no influence by the TVA because it was not in existence.

While uncorrelated with the TVA, the CHO is still of importance in the overall explanation for the rapid decline in morbidity and mortality. First and foremost the CHO's were leaders in distributing literature about infectious disease, spraying, ditching and disease eradication efforts. The CHO primarily spread literature through elementary education and public lectures teaching cleanliness. It seems unlikely that the CHO increased morbidity rates.

Ideally a 2SLS procedure would be adopted to control for the endogenous opening of a CHO, however, at this time, I have been unable to collect the data needed for proper instrumentation. Several different ideas have been considered as instruments, primarily looking for links between other public spending and health spending, such as state highway expenditures, education spending, and spending on prisoners.

Placebo Regressions

While the results suggest that the TVA increased malaria rates, it may be possible that the entire disease profile is endogenously changing in the counties where the TVA is located. An entire shift in the disease profile would make it appear as though the TVA was the cause of malaria rate increase, when in fact; the change in rates was due to an exogenous factor. To examine this hypothesis, I re-estimate the model using data pertaining to a different disease.

There are a few potential problems with this idea; the first is that several diseases may be correlated with malaria. Water borne illnesses will clearly be affected by the altered environment, while other diseases are correlated due to medical practices. Syphilis, for example is not directly related to malaria, however, doctors discovered that it could be treated by injecting patients with malaria. A case of syphilis prior to penicillin would almost surely result in death, while injecting the patient with malaria led to minor symptoms such as fever and chills.

Another complication is that there were major advances in modern medicine, which may make it difficult to distinguish changes in the environment induced by the TVA and the results of these advances, such as penicillin. To get around this issue, I avoid bacteria based illnesses and instead use virus based illness. One illness in particular, Measles has several nice properties for the purpose of this exercise. It is an airborne virus that cyclically infects a large portion of the population. Additionally, a vaccine was not developed until the 1960's, well after the end of the sample period in this study. This will remove any complications associated with a major shift in the treatment of the virus. Because of the nature of its transmission and the state of medical technology during the sample period, measles is an ideal candidate to see if the TVA had effects on the greater disease profile in a county. Data for measles morbidity rates come from the Alabama State Board of Health Annual Reports and Tennessee Morbidity Report. The same procedures were used to adjust raw case numbers into rates as defined previously.

In this setting, I substitute the measles morbidly rate in place of the malaria morbidity rate in equations (1) , (2), and and re-estimate the models. Regression results show that there is no statistically significant link between the TVA and measles. The full set of results is presented in Table 5. This suggests that when the TVA entered the region, it only affected malaria rates to change, and not another set of diseases.

The Cost of Malaria

By using sample data collected by the TVA I am able to identify the effect that malaria has on income. Survey data was collected to detail the living situations of families living in reservoir areas. These families represent the people that the TVA projects were designed to aid. In order to identify the cost of malaria, variation across households will identify the cost of each case of malaria. Household income is determined by features such as human capital, physical capital, land, and health status. I specify the following linear income regression, where Y is the income of the family, which is composed of: farm profits, income from children, value of home consumption, and wages.

$$Y_i = \beta_0 + \beta_1 Malaria_i + \beta X_i + \varepsilon_i$$

The variable of interest in this specification is the reported number of malaria infections within the family in the year 1936. Other covariates control for measures of human and physical capital. Physical capital is measured by land, which is defined as the number of acres in production in 1935; the value of farm implements, such as tractors, plows, disc harrows, etc, and by the value of livestock animals. I also control for occupation with an indicator variable that is one if the family is in farming and zero otherwise. Within farming, there are five sub categories day laborer, share cropper, share tenant, cash farmer, and in kind farmer. Human capital is further measured by the size of the family, age of the husband, age of the wife, education of the husband, education of the wife, an interaction between the education levels of the husband and wife, and the race of the family.

It should also be noted that the occurrence of malaria in the current period may be endogenously determined with previous income levels. Individuals with higher levels of income may be able to invest in malaria prevention. Purchasing door and window screens for the home, insecticide spray, and by sealing cracks in the home can lead to reductions in the probability of infection. I will use an instrumental variables approach to control for this source of endogeneity, using variables related to the family's water source, however the available instruments appear weak in the empirical exercise.

Malaria's Cost Data Sources

The data used to identify the effect of malaria on income is derived from a survey performed by the TVA, TVA Form 970, prior to land purchases at each reservoir site. The TVA surveyed each family that lived on the land to be flooded by the TVA project. The survey was detailed in nature so that the TVA would be able to assist in the relocation of the family to a new property and form detailed estimates of the property's value come time to purchase. Data were collected on standard demographics, such as age, race, education, family size, occupation, religion, as well as more detailed information pertaining to the family farm. Data collected details the acreage of various crops planted over the previous two years, the possession and value of farm implements, a detailed summary of the sources of the family income, as well as the value of goods produced for home consumption.

Summary Statistics: Malaria's Cost

The Guntersville Reservoir was quite normal in terms of the malaria infection rate in the time period. Of the 490 families for which data has been entered, 161 (32%) reported having at least one case of malaria in the home. The differences between the infected and healthy are mixed. Families which had at least one family member contract malaria are similarly distributed along several dimensions: age, family size, whether or not the family farms, value of farm equipment, livestock value, and acres in production. However, the families differ in several respects, individuals who did not contract malaria were much more likely to have possessions which are signs of wealth; these include telephones, automobiles, and radios. The healthy population also has slightly more education than the infected, is more likely to be a property owner, and is more likely to be African American. Perhaps the most striking difference between the groups is the percentage of those infected who are share croppers. There is some narrative evidence for this increase in exposure: typically sharecroppers resided on the most marginal land on the farm. These locations were often times adjacent to swamps, which put the share cropping families at higher risk to contract the disease (Humphreys).

In aggregate, the people living near the Guntersville Reservoir were very poor. Annual incomes for the cross section ranged from $88 to $8,000, with the average household having $798. Families that did not become exposed to malaria had an average income $70 higher than those that were exposed. When home consumption crops are excluded, this difference increases to $75. The average farm operated 39 acres, with the largest farm operating 650 acres. Education was quite low, with men averaging a 5th grade education, and women averaging a 6th grade education. Men who were not exposed had over half a year of additional schooling. The average age of men was 45 years old, and the average woman was 41 years old. On average, the family had 4.3 children. The average home experienced .78 cases of malaria; however the variability was very high; one family reported twelve cases in the year. Conditional on having at least one case of malaria, the infected household averaged over two cases in the year. A set of full summary statistics is available in Table 5.

Raw correlations reveal the expected relationships. Income is negatively correlated with malaria. Malaria is positively correlated to family size. Other relationships present the expected signs; farm capital is positively correlated with income, as is education, and family size. Any variable that is associated with wealth is negatively correlated with malaria.

Malaria Cost Results

In this section I will present the primary regression results of the household production function to determine the per case cost of malaria. I find that when a household is infected with a case of malaria, that there is a statistically significant drop in income. However, this affect is reduced when a county fixed effect is included in the specification. Furthermore, when an interaction term between the county and malaria is included, the effect becomes insignificant at traditional levels of confidence.

Results are presented in Table 7. It is seen that when county effects are ignored, that an increase in malaria results in a$35-$38 reduction of income. To put this in perspective, this reduction represents a 4.7 percent reduction in income per case of malaria in the family. When crops grown for home consumption are excluded from the measure of income, the reduction in income attributable to malaria is $42 per case. This provides some insight into the household. When malaria hits a home, they are more likely to substitute from production that is tradable in the market, in favor of goods that can be consumed in the household. Provided that the average household that is infected has over two cases within the year, the average reduction in income is $70-$84, which is close to 10% of annual household income.

So far the potential endogeneity has been ignored. Households with higher levels of wealth may have been more likely to invest in malaria reducing goods. If income in previous periods is negatively correlated with malaria today and income across time periods is positively correlated, then there is a negative bias, the OLS estimate likely overestimates the true cost. To control for this endogeneity, I attempt to instrument by using variables related to a family's water source. If the family has its own water source on site, it may be more prone to contracting malaria due to possible sitting water. This would create a body of stagnate water adjacent to the home, which is the ideal breeding ground for mosquitoes. It is also important to know how close to the house the water source is, so as an additional instrument, I include the distance between the water source and the home. The further the water source is located from the home, the less likely that malaria transmission occurs. The water source is likely uncorrelated with income, the availability of a well, cistern, or plumbing on location have to do with the natural features of the property. Furthermore, the distance from the home to the water source is not likely correlated with income. Additionally, I include and interaction between the presence of a water source and its distance from the home.

First Stage regression results indicate that having a water source at home reduces the likelihood of contracting malaria, and is statistically significant. The negative coefficient of the in site water source may indicate that there are other health benefits, such as sanitary water, making one less susceptible to other diseases that interact with malaria. The further away from the home that the water source is located, the less likely one is to contract the disease. The results from the first stage also indicate that the collection of instruments are weak, as reported by the F-Statistic, which is 2.3. In the second stage, the cost of malaria increases to $150 per case, which is larger in magnitude than expected given the predicted direction of the OLS bias. This is likely due to the weak instruments and small sample size. I plan to continue searching for possible instruments that will have explanatory power, and will also explore the use of matching estimators.

3. The Total Malaria Cost of the TVA

Initially I expected to follow in the footsteps of previous researchers and find that the TVA reduced malaria morbidity and mortality, my results indicate that the presence of a TVA reservoir led to more malaria. By combining the results based on the change in malaria rates and the results from the income regression, I will make a simple back of the envelope calculation. If I assume that the loss of income is the same in all counties with a TVA reservoir and that this loss is constant over time, then I can calculate the cost of malaria associated with the TVA by multiplying the lost income by the TVA coefficient. This will provide a cost per 100,000 people, I then can adjust this figure by using the interpolated annual population in the county. I do this for each county year, and then sum to derive the total cost associated with morbidity. It should be noted that the cost point estimates I use come from the OLS specifications, and may be overstating the true cost of morbidity.

This calculation leads to the following result: each case of malaria reported in the TVA survey data led to a 4.7 percent reduction in income. To put this into perspective, an additional case of malaria in the home is equivalent to a loss of 2.5 weeks of work. When the TVA impounded water at the dams, increases in the morbidity rate followed. Using the point estimates outlined above, the TVA increased morbidity by between 10.35 and 13.99 cases per 10,000 individuals in a county each year. After inflating the estimates to 2009 dollars; the TVA costs between $7.4 and $13 million in lost income over the sample period. Dams upstream were found to reduce the prevalence of malaria in a given county, working through the water level fluctuation channel. When upstream dams are included in the calculation, the cost of morbidity falls to $1.5 – $5.5 million.

Mortality rates also increased as a result of the TVA building a dam. Estimates for this increase range from 4.09-4.5 deaths per 100,000 per county per year. Viscuzi and Aldy (2003) provide a survey of recent value of a statistical life (VSL) literature. Their survey details a range of common VSL's ranging from a low of $1.25 million, to a high of $11.5 million per life, after adjusting to 2009 dollars. Using the range of estimates provided, per county per year cost may be determined. Using conservative estimates, a VSL of $1.25 million, and the in mortality of .9 per 100,000, the resulting cost per county is $1.125 million per year. Using the higher estimated VSL and change in mortality rate, a cost of $50.6 million per year is inflicted on counties residing on a TVA reservoir. Using both sets of conservative estimates, I find that the TVA cost individuals over $740 million during the sample period. When the larger point estimates and values of a VSL are implemented, this total jumps substantially to over $7.5 billion in lost income. This difference is almost entirely attributable to the value placed on a life. Once again the effects of upstream dams must be included in the calculation. When included, the estimated range of cost falls to $139 million - $2 billion.

One point of contention over the use of standard VSL estimates is that the estimated VSL is based on the expected lifetime earnings of an individual. Using modern estimates are likely to overestimate the true cost because life expectancies and per capita incomes have increased from the 1930's and 1950's to today. As an alternative measure to these estimates, I will use Fishback, Haines, and Kantor's (2007) estimate of the cost of a life saved during the New Deal. In their study, the authors estimate the effect that New Deal programs had on the infant mortality rates and other causes of death. They find that it cost between $1.9 million and $8.5 million (year 2000 dollars) to save an infant's life. Using this set of estimates, I find that the TVA cost between $216 million and $1.5 billion.

Conclusions

The TVA provides insight into a growing problem around the world today. As more and more nations begin to construct large water management programs, increased sitting water is liable to create increased rates of infectious disease. The TVA, which was long held in esteem for supposedly decreasing the malaria problem in the Southeast, was in fact a major contributor to the long standing problem. Almost certainly the problem would have been more severe had the TVA not made an attempt to control the disease by spraying, ditching, and fluctuation of the water level in the reservoirs. Specific attention should be given to the method of raising and lowering the water levels from reservoir to reservoir. There is at least some support that this method reduced the malaria problem. This method is low cost and easily implemented, providing that a series of reservoirs exist. A note of caution to this point though, the storage reservoirs upstream were typically located in mountainous areas. These areas are less susceptible to malaria due to their higher elevations and cooler climates. Attempting upstream water storage for mosquito prevention may not work in areas with warmer and wetter climates or lower elevations.

There is also support for the work carried out by the WPA and other agencies during the period to drain and fill swamps. The policy of draining and filling swamps may run into implementation problems today due to changes in attitude towards the preservation of wetlands. While effective at preventing mosquito vectors from breeding, the preservation of other rare or endangered species specific to wetlands may be more valuable to society than reducing the incidence of malaria within the population.

Furthermore, DDT proves its effectiveness at reducing the malaria problem. While it is not environmentally friendly, it was effective at killing any insect that was a nuisance to man. It provided the largest drop in malaria rates of any of the methods explored in this paper. In developing nations, it may be worthwhile to explore its use if the environmental costs do not exceed the benefits from its use.

At this point it is difficult to thoroughly discuss the role of the CHO due to a lack of valid instruments, however, other researchers have found evidence of the CHO’s reducing the prevalence of disease. It is likely that their efforts against malaria were also successful. Precise estimation of the CHO’s role in malaria eradication remains as a focus of future research.

In the case of malaria, the TVA has increased the burden on the population it was intended to help. In calculating the total cost of the TVA, official reports to the government fail to include indirect cost associated with an increased disease profile in its service area. In future research, it may be important to examine the effectiveness of specific TVA anti-malarial programs, such as oiling, spraying, and introducing natural predators to the environment. These programs may provide an opportunity to explore more environmentally friendly methods than DDT.

Sources:

1. Acemoglu, Daron. Johnson Simon. Disease and Development: The Effect of Life Expectancy on Economic Growth. Journal of Political Economics. 2007.
2. Alabama State Board of Health Annual Report. 1916-1924, 1926-1946, 1948-1951
3. Alabama Bureau of Vital Statistics Report. 1929, 1931-1940

4. Allen, Linda. An Introduction to Stochastic Epidemic Models. Springer. 2008
5. Andrews, Quinby, Langmuir. Malaria Eradication in the United States. American Journal of Public Health. 1950.
6. Bishop, E. L. The TVA's New Deal in Health. . Am J Public Health 1934
7. Bishop, E. L. Malaria-Control Activities of the Tennessee Valley Authority. Public Health Reports (1896-1970), Vol. 51, No. 29 (Jul. 17, 1936), pp. 970-975
8. Bleakley, Hoyt. Malaria Eradication in the Americas: A retrospective Analysis of Childhood Exposure. NBER Working Paper 2007.
9. Bleakley, Hoyt. Disease and Development: Evidence from Hookworm Eradication in the American South. Quarterly Journal of Economics. 2007.

10. Brauer, F. Models for the Spread of Universally Fatal Diseases. Journal of Mathematical Biology. 1990
11. Derryberry, OM. Gartrell, FE. Trends in Malaria Control Program of the Tennessee Valley Authority. The American Journal of Tropical Medicine and Hygiene. 1952.
12. Fishback, Price V. Haines, Michael. Kantor, Shawn. Births, Deaths and New Deal Relief During The Great Depression. The Review of Economics and Statistics. 2007.
13. Gallup, John. Sachs, Jeffrey. The Economic Burden of Malaria. The American Society of Tropical Medicine and Hygiene. 2001.
14. Gartrell, FE.Ludvik, GF. The Role of Insecticides in the TVA Malaria Control Program. The American Journal of Tropical Medicine and Hygiene. 1954.
15. Hong, SC. The Burden of Early Exposure to Malaria in the United States 1850-1860: Malnutrition and Immune Disorders. Journal of Economic History. 2007.
16. Kitron, Uriel. Spielman, Andrew. Suppression of Transmission of Malaria through Source Reduction: Antianopheline Measures Applied in Israel, the United States, and Italy. Reviews of Infectious Diseases 1989.
17. Lee, Lung Fei and Yu, Jihai. "Estimation of Spatial Autoregressive Panel Data Models With Fixed Effects" Journal of Econometrics 2010
18. Moore, Michael. Viscusi, W. Kip. Compensation Mechanisms for Job Risks: Wages, Workers' Compensation, and Product Liability. 1990
19. Morgan, Arthur. The Making of the TVA. 1974

20. Newman, MEJ. Spread of Endemic Diseases on Networks. Physical Review 2002.
21. Sachs, Jeffrey. Malaney, Pia. The Economic and Social Burden of Malaria. Nature 2002.
22. Sachs , Jeffrey. Institutions Don't Rule: Direct Effects of Geography on Per Capita Income. NBER WP #9490. 2003.
23. Tennessee Department of Public Health. Annual Bulletin of Vital Statistics 1927-1951
24. U.S. Historic Climatology Network. Monthly Data 1895-2009.
25. Viscusi, W Kip. Aldy, Joseph. The Value of a Statistical Life: A Critical Review of Market Estimates Throughout the World. The Journal of Risk and Uncertainty. 2003.

26. Wooldridge, Jeffrey. Econometric Analysis of Cross Section and Panel Data. 2002. p176

Figure 1: TVA Water Fluctuation Procedure

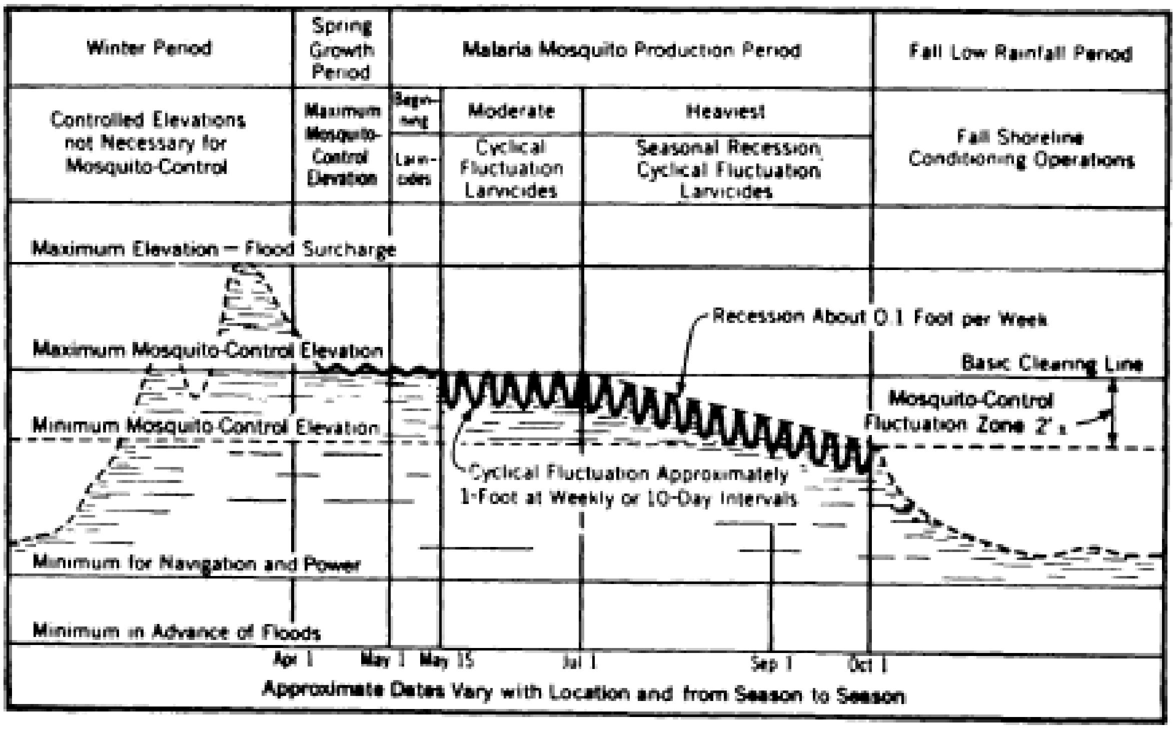


Table 1: Summary Statistics of Malaria Rate

Variable	Obs	Mean	Std Dev	Min	Max
Deaths/100,000	3955.00	10.06	34.58	0.00	1117.46
Morbidity/10,000	4530.00	11.60	31.55	0.00	828.50
TVA Reservoir	4787.00	0.06	0.23	0.00	1.00
County Health Agency	4312.00	0.61	0.49	0.00	1.00
Percent Black	4785.00	23.05	22.65	0.00	87.27
Pop. Density	4787.00	57.98	66.51	11.09	658.86
Percent Urban	4785.00	14.46	18.62	0.00	85.48
Average Temp					
January	4787.00	430.30	69.64	202.87	659.20
February	4787.00	450.83	64.46	279.76	643.74
March	4787.00	518.22	59.01	366.18	671.75
April	4787.00	601.64	40.24	501.45	713.66
May	4787.00	682.45	35.51	584.48	785.79
Jun	4787.00	759.39	31.29	663.50	834.36
July	4787.00	784.09	26.15	677.50	860.01
August	4787.00	776.44	29.50	681.61	855.99
September	4787.00	725.56	40.02	620.31	844.87
October	4787.00	622.42	44.09	513.13	779.68
November	4787.00	504.43	48.32	393.41	658.78
December	4787.00	436.65	59.23	287.24	630.51
Precipitation					
January	4787.00	530.40	321.33	31.78	2281.33
February	4787.00	482.75	246.02	22.34	1404.13
March	4787.00	589.13	254.58	45.01	1821.87
April	4787.00	449.76	225.04	50.22	1517.81
May	4787.00	398.51	199.71	17.65	1505.49
Jun	4787.00	411.98	210.52	16.77	1670.15
July	4787.00	509.89	232.39	63.39	2221.72
August	4787.00	417.96	206.03	25.02	1958.03
September	4787.00	312.76	195.50	3.37	1310.63
October	4787.00	277.80	200.40	1.49	1316.86
November	4787.00	384.17	251.14	1.05	1551.56
December	4787.00	473.00	242.52	68.02	1715.94

Table 2: Malaria Mortality Results

	OLS		County FE		county fe, Year FE		County FE, Year FE, AR(1)		County FE, Year FE, Multi dim clustering	
	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
TVA Reservoir	**1.143**	**(0.416)**	**4.091**	**0.759682**	**4.221**	**(0.715)**	**4.525**	**(1.312)**	**4.221**	**(1.049)**
# Dams Upstream	0.131	(0.130)	-0.846	(0.659)	-0.913	(0.596)	**-0.848**	**(0.331)**	-0.913	(0.620)
Post 1945 FE	-	-	-1.785	(1.307)	-	-	-	-	-	-
New CHO	0.897	(1.145)	0.544	(0.958)	0.501	(1.025)	0.230	(0.772)	0.501	(1.123)
CHO	0.161	(0.392)	-0.449	(0.731)	0.094	(0.737)	-0.005	(0.674)	0.094	(0.768)
WPA Ditches (1000 ft)	0.000	(0.014)	-0.037	(0.040)	-0.031	(0.041)	-0.004	(0.016)	-0.031	(0.047)
WPA clearing (1000 ft)	**-0.008**	**(0.004)**	0.009	(0.010)	0.013	(0.011)	0.009	(0.007)	0.013	(0.013)
WPA Acres Filled	0.001	(0.002)	0.000	(0.003)	0.000	(0.002)	-0.001	(0.003)	0.000	(0.003)
% black	**0.171**	**(0.017)**	0.496	(0.372)	0.358	(0.335)	**0.335**	**(0.170)**	0.358	(0.365)
Pop Density	**-0.006**	**(0.003)**	0.013	(0.031)	0.020	(0.027)	0.016	(0.016)	0.020	(0.030)
% Urban	**-0.031**	**(0.016)**	-0.068	(0.078)	-0.046	(0.070)	-0.040	(0.063)	-0.046	(0.077)
Climate	Yes		Yes		Yes		Yes		Yes	
County FE	No		Yes		Yes		Yes		Yes	
Year FE	No		No		Yes		Yes		Yes	

Table 2 Continued

	Spatial Error Model		Spatial Lag Model		Spatial Error and Lag	
	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
TVA Reservoir	**2.529**	**(0.616)**	**2.759**	**(0.603)**	**2.527**	**(0.616)**
# Dams Upstream	-0.153	(0.124)	-0.194	(0.122)	-0.153	(0.124)
New CHO	1.026	(0.818)	0.951	(0.808)	1.027	(0.818)
CHO	-0.469	(0.325)	-0.395	(0.318)	-0.467	(0.326)
WPA Ditches (1000 ft)	**0.024**	**(0.017)**	**0.027**	**(0.016)**	0.024	(0.017)
WPA clearing (1000 ft)	-0.011	(0.008)	-0.011	(0.008)	-0.011	(0.008)
WPA Acres Filled	0.004	(0.003)	0.003	(0.003)	0.004	(0.003)
% black	**0.111**	**(0.009)**	**0.115**	**(0.008)**	**0.111**	**(0.009)**
Pop Density	-0.003	(0.003)	-0.002	(0.003)	-0.003	(0.003)
% Urban	-0.018	(0.010)	**-0.020**	**(0.010)**	**-0.018**	**(0.010)**
p	-		0.087		-0.003	
lambda	0.165		-		0.168	
Climate	YES		YES		YES	
County FE	YES		YES		YES	
Year FE	YES		YES		YES	

Table 3 Morbidity Results

	OLS		County FE		County FE, Year FE		County FE, Year FE, AR(1)		County FE, Year FE, Mult Dim Clustering	
	Coef	Std. Err.	Coef	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
TVA Reservoir	**6.984**	**(1.517)**	**13.991**	**(4.003)**	**11.597**	**(2.280)**	**10.358**	**(4.347)**	**11.597**	**(2.716)**
# Dams Upstream	**-0.483**	**(0.236)**	**-2.449**	**(0.744)**	**-2.222**	**(0.420)**	**-1.981**	**(0.778)**	**-2.222**	**(0.630)**
Post 1945 FE			**-16.548**	**(3.102)**						
New CHO	**16.534**	**(8.645)**	2.095	(2.124)	**14.719**	**(7.876)**	**14.827**	**(2.824)**	14.719	(10.576)
CHO	**5.619**	**(0.971)**	**16.968**	**(8.640)**	**4.722**	**(1.567)**	**4.797**	**(2.478)**	**4.722**	**(2.203)**
WPA Ditches (1000 ft)	**0.356**	**(0.068)**	0.048	(0.042)	0.048	(0.051)	0.054	(0.056)	0.048	(0.052)
WPA clearing (1000 ft)	0.006	(0.006)	-0.006	(0.011)	0.002	(0.013)	0.020	(0.025)	0.002	(0.015)
WPA Acres Filled	**-0.240**	**(0.033)**	**-0.020**	**(0.005)**	**-0.022**	**(0.007)**	**-0.022**	**(0.010)**	**-0.022**	**(0.007)**
% black	**0.095**	**(0.049)**	0.578	(0.388)	0.261	(0.161)	0.357	(0.329)	0.261	(0.359)
Pop Density	-0.012	(0.012)	0.077	(0.054)	**0.086**	**(0.023)**	**0.106**	**(0.057)**	**0.086**	**(0.048)**
% Urban	**-0.015**	**(0.006)**	0.001	(0.178)	**0.211**	**(0.087)**	0.099	(0.189)	0.211	(0.223)
Climate	Yes		Yes		Yes		Yes		Yes	
County FE	Yes		Yes		Yes		Yes		Yes	
Year FE	No		No		Yes		Yes		Yes	

Table 3 Continued

	Spatial Error Model		Spatial Lag Model		Spatial Error and Lag	
	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
TVA Reservoir	**7.231**	**(2.101)**	**6.633**	**(2.048)**	**7.231**	**(2.102)**
# Dams Upstream	-0.187	(0.423)	-0.134	(0.413)	-0.185	(0.423)
New CHO	**12.429**	**(2.792)**	**12.332**	**(2.741)**	**12.432**	**(2.792)**
CHO	**7.241**	**(1.102)**	**7.256**	**(1.079)**	**7.245**	**(1.106)**
WPA Ditches (1000 ft)	0.082	(0.057)	0.071	(0.056)	0.082	(0.057)
WPA clearing (1000 ft)	-0.027	(0.027)	-0.013	(0.026)	-0.027	(0.027)
WPA Acres Filled	-0.015	(0.012)	-0.016	(0.012)	-0.015	(0.012)
% black	**0.303**	**(0.029)**	0.301	(0.028)	0.303	(0.029)
Pop Density	0.000	(0.009)	0.004	(0.009)	0.000	(0.009)
% Urban	**-0.193**	**(0.036)**	**-0.203**	**(0.035)**	**-0.193**	**(0.036)**
p	-0.005		-		-0.005	
lambda	**-**		-0.010		-0.008	
Climate	YES		YES		YES	
County FE	YES		YES		YES	
Year FE	YES		YES		YES	

Table 4: CHO Auxiliary Regression

Var	Coef	Std Err	Var	Coef	Std Err
TVA	-0.01	(0.013)	Apr Pcp	**0.00**	**(0.000)**
WPA New Ditches	0.00	(0.000)	May Pcp	0.00	(0.000)
WPA Old Ditches	0.00	(0.000)	Jun Pcp	0.00	(0.001)
WPA Excavation	0.00	(0.000)	Jul Pcp	0.00	(0.001)
Percent Black	**0.00**	**(0.001)**	Aug Pcp	**0.00**	**(0.000)**
Pop Density	0.00	(0.000)	Spe Pcp	0.00	(0.000)
Percent Urban	**0.00**	**(0.001)**	Oct Pcp	0.00	(0.000)
Jan Temp	**0.00**	**(0.000)**	Nov Pcp	**0.00**	**(0.000)**
Feb Temp	0.00	(0.000)	Dec Pcp	0.00	(0.000)
Mar Temp	0.00	(0.000)	Jan Int	0.00	(0.000)
Apr Temp	0.00	(0.000)	Feb Int	0.00	(0.000)
May Temp	**0.00**	**(0.001)**	Mar Int	**0.00**	**(0.000)**
Jun Temp	**0.00**	**(0.001)**	Apr Int	**0.00**	**(0.000)**
Jul Temp	0.00	(0.001)	May Int	0.00	(0.000)
Aug Temp	0.00	(0.001)	Jun Int	0.00	(0.000)
Sep Temp	0.00	(0.001)	Jul Int	0.00	(0.000)
Oct Temp	0.00	(0.000)	Aug Int	0.00	(0.000)
Nov Temp	0.00	(0.000)	Sep Int	0.00	(0.000)
Dec Temp	0.00	(0.000)	Oct Int	0.00	(0.000)
Jan Pcp	**0.00**	**(0.000)**	Nov Int	**0.00**	**(0.000)**
Feb Pcp	0.00	(0.000)	Dec Int	0.00	(0.000)
Mar Pcp	**0.00**	**(0.000)**	Constant	**-1.68**	**(0.680)**

Table 5 Measles Morbidity Results

	County FE		County FE, Year FE		County FE, Year FE AR(1)		Multi Dim Clustering	
	Coef	Std Err.	Coef	Std Err.	Coef	Std Err.	Coef	Std Err.
TVA Reservoir	2.247	(3.942)	1.606	(3.977)	1.119	(3.682)	1.606	(4.798)
# Dams Upstream	-1.198	(0.702)	-0.654	(0.697)	-0.671	(0.651)	-0.654	(0.577)
New CHO	-6.459	(2.732)	-4.775	(2.759)	-4.941	(2.666)	-4.775	(3.032)
CHO	5.093	(2.366)	7.334	(2.682)	7.581	(2.490)	7.334	(2.493)
WPA Ditches (1000 ft)	0.053	(0.054)	-0.077	(0.061)	-0.091	(0.061)	-0.077	(0.105)
WPA clearing (1000 ft)	-0.042	(0.015)	-0.012	(0.015)	-0.011	(0.016)	-0.012	(0.030)
WPA Acres Filled	0.017	(0.012)	0.023	(0.012)	0.026	(0.013)	0.023	(0.024)
% black	0.640	(0.304)	0.324	(0.341)	0.342	(0.305)	0.324	(0.246)
Pop Density	-0.124	(0.064)	-0.095	(0.063)	-0.108	(0.061)	-0.095	(0.069)
% Urban	-0.711	(0.214)	-0.153	(0.245)	-0.132	(0.226)	-0.153	(0.163)
Climate	Yes		Yes		Yes		Yes	
County FE	Yes		Yes		Yes		Yes	
Year FE	No		Yes		Yes		Yes	

Table 6: Summary Statistics of TVA Form 970- Guntersville Reservoir

	Total Population		Healthy		Infected		
Variable	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	T-Test
Farmer	0.90	(0.300)	0.90	(0.304)	0.91	(0.292)	-0.33
Well Water	0.69	(0.462)	0.68	(0.466)	0.71	(0.453)	-0.71
Cistern Water	0.01	(0.119)	0.02	(0.122)	0.01	(0.111)	0.24
Spring Water	0.27	(0.444)	0.27	(0.447)	0.25	(0.437)	0.48
Other Water	0.02	(0.154)	0.03	(0.171)	0.01	(0.111)	1.20
Water On Cite	0.78	(0.413)	0.79	(0.405)	0.76	(0.430)	0.93
Water Distance	75.09	(125.552)	73.34	(133.118)	78.68	(108.655)	-0.44
Telephone	0.02	(0.127)	**0.02**	**(0.154)**	**0.00**	**(0.000)**	**1.99**
Automobile	0.31	(0.464)	**0.34**	**(0.474)**	**0.26**	**(0.440)**	**1.74**
Piano	0.06	(0.240)	0.07	(0.255)	0.04	(0.205)	1.13
Phonograph	0.29	(0.455)	0.29	(0.454)	0.30	(0.459)	-0.19
Sewing Machine	0.74	(0.440)	0.75	(0.436)	0.72	(0.450)	0.61
Organ	0.13	(0.341)	0.15	(0.359)	0.10	(0.300)	1.58
Radio	0.18	(0.389)	**0.21**	**(0.407)**	**0.14**	**(0.345)**	**1.93**
White	0.94	(0.232)	**0.93**	**(0.260)**	**0.98**	**(0.156)**	**-2.15**
Husband Age	43.86	(17.458)	44.69	(17.440)	42.16	(17.425)	1.51
Husband Education	5.58	(3.411)	**5.78**	**(3.424)**	**5.17**	**(3.358)**	**1.87**
Wife Age	37.35	(29.457)	37.84	(34.188)	36.36	(15.829)	0.52
Wife Education	5.85	(3.469)	5.91	(3.543)	5.71	(3.318)	0.61
Property Owner	0.49	(0.500)	**0.52**	**(0.500)**	**0.43**	**(0.497)**	**1.77**
Day Laborer	0.04	(0.207)	0.04	(0.202)	0.05	(0.218)	-0.37
Share Cropper	0.10	(0.305)	**0.08**	**(0.279)**	**0.14**	**(0.351)**	**-1.99**
Share Tenant	0.25	(0.431)	0.23	(0.421)	0.28	(0.450)	-1.21
1936 Acres	37.89	(54.105)	36.39	(58.582)	40.98	(43.483)	-0.88
Animal Value	402.66	(436.373)	400.26	(436.479)	407.59	(437.474)	-0.17
Farm Equip Value	207.50	(394.331)	213.59	(418.027)	194.99	(341.369)	0.49
Home Consumption	236.83	(131.743)	235.08	(131.409)	240.42	(132.763)	-0.42
No. of Children	4.34	(3.391)	4.19	(3.358)	4.65	(3.449)	-1.39
N	492		331		161		

Table 7: Malaria Cost Results

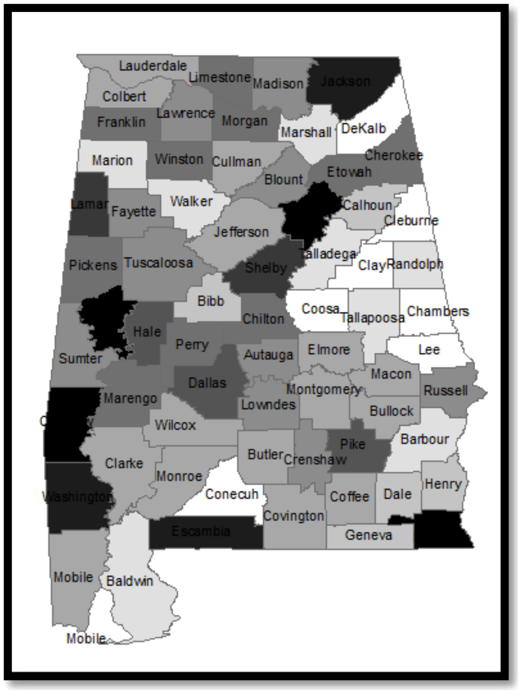
	Total Income		Net of In Home Consumption		Total Income County FE		Net Consumption County FE	
	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
Cases of Malaria	**-38.40**	**(19.043)**	**-42.22**	**(18.762)**	**-30.33**	(18.781)	**-34.86**	**(18.550)**
Farm	**-449.72**	**(199.335)**	**-511.57**	**(199.141)**	**-442.36**	**(197.458)**	**-504.86**	**(197.183)**
Race	**138.06**	**(64.299)**	**99.83**	**(60.730)**	**115.32**	**(62.716)**	79.07	(60.338)
Husband Age	2.05	(1.515)	1.64	(1.490)	2.24	(1.550)	1.81	(1.528)
Husband Education	**-25.07**	**(15.334)**	**-28.41**	**(14.427)**	**-27.14**	**(15.567)**	**-30.29**	**(14.643)**
Wife Age	-0.60	(0.582)	-0.65	(0.575)	-0.44	(0.599)	-0.51	(0.595)
Wife Education	22.78	(23.788)	16.15	(23.625)	19.25	(23.220)	12.93	(23.035)
Family Education	**4.70**	**(2.535)**	**5.21**	**(2.466)**	**5.18**	**(2.503)**	**5.65**	**(2.431)**
Laborer	26.43	(106.154)	149.00	(107.016)	33.17	(107.372)	155.15	(108.394)
Cropper	104.45	(89.039)	**148.11**	**(89.854)**	120.50	(91.928)	**162.77**	**(93.627)**
Share Tenant	**-249.78**	**(57.085)**	**-223.44**	**(55.453)**	**-243.66**	**(56.892)**	**-217.85**	**(55.400)**
Livestock Value	**0.63**	**(0.333)**	0.53	(0.335)	**0.66**	**(0.335)**	**0.56**	**(0.338)**
Farm Implement Value	**1.00**	**(0.310)**	**1.04**	**(0.295)**	**0.98**	**(0.311)**	**1.02**	**(0.297)**
Children	**30.58**	**(8.671)**	**18.66**	**(8.184)**	**29.48**	**(8.985)**	**17.65**	**(8.497)**
Acres	1.31	(1.855)	1.03	(1.810)	1.31	(1.830)	1.04	(1.786)
Constant	**260.41**	**(147.702)**	**253.97**	**(143.023)**	193.21	(150.267)	192.64	(146.086)
N	492		492		492		492	
R Square	0.51		0.48		0.51		0.48	

Table 8: 2SLS Malaria Cost

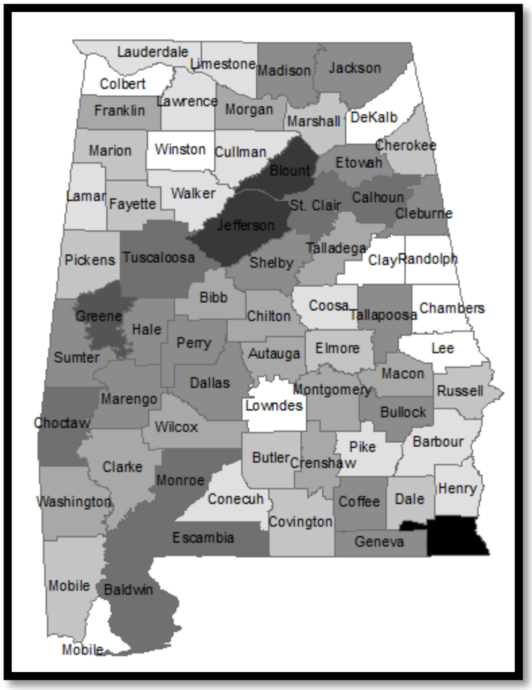
1st Stage Results			2nd Stage Results		
malaria	Coef.	Std. Err.	Income	Coef.	Std. Err.
Yds. From House	0.00	(0.001)	Cases Malaria	-150.81	(247.960)
On Cite	**-0.49**	**(0.249)**	Farm	**-429.62**	**(134.880)**
Yds x On Cite	0.00	(0.002)	Radio	**273.00**	**(129.445)**
Farm	-0.15	(0.259)	White	209.00	(129.440)
Radio	**-0.34**	**(0.197)**	Hus. Age	2.24	(2.611)
White	**0.77**	**(0.294)**	Hus. Education	-34.01	(23.272)
Hus. Age	**0.00**	**(0.005)**	Wife Age	-1.20	(1.291)
Hus. Education	-0.05	(0.038)	Wife Education	22.46	(20.739)
Wife Age	0.00	(0.003)	Hus Ed x Wife Ed	**4.61**	**(2.657)**
Wife Education	-0.01	(0.041)	Laborer	60.56	(177.947)
Hus Ed x Wife Ed	0.00	(0.005)	Cropper	183.21	(220.148)
Laborer	0.11	(0.353)	Share Ten.	**-196.17**	**(109.892)**
Cropper	**0.71**	**(0.256)**	Livestock Value	**0.57**	**(0.150)**
Share Ten.	0.25	(0.177)	Machine Value	**0.95**	**(0.141)**
Livestock Value	0.00	(0.000)	No. Children	**36.72**	**(20.922)**
Machine Value	0.00	(0.000)	Acres 1935	1.54	(1.034)
No. Children	**0.07**	**(0.023)**	Constant	258.14	(212.867)
Acres 1935	0.00	(0.002)			
Constant	0.51	(0.459)			

Appendix A: Alabama Morbidity Maps 1916-1950

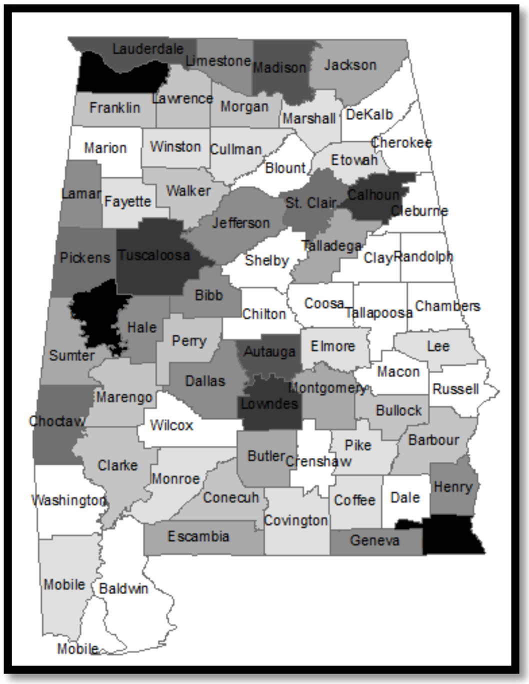
AL 1916 Morbidity/10,000



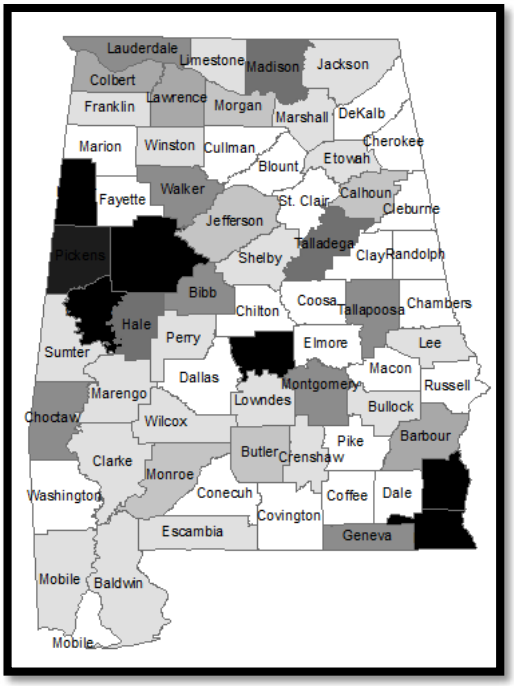
AL 1917 Morbidity/10,000



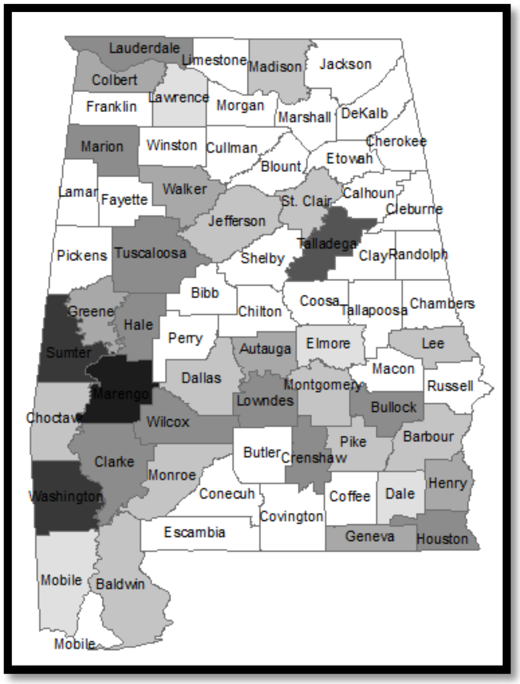
AL 1918 Morbidity/10,000



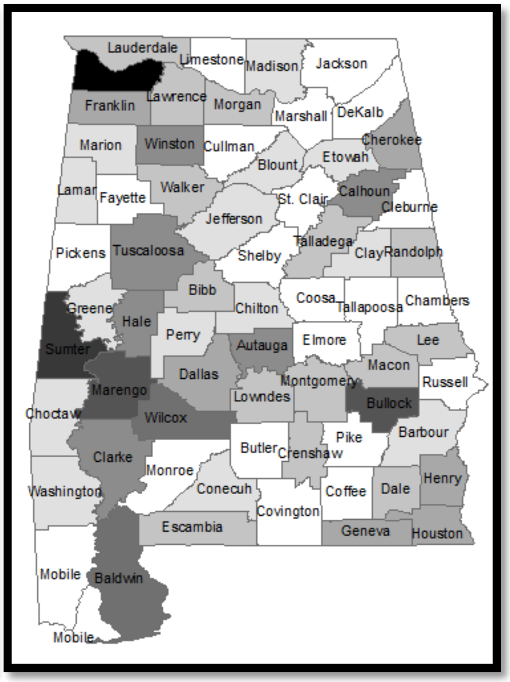
AL 1919 Morbidity/10,000



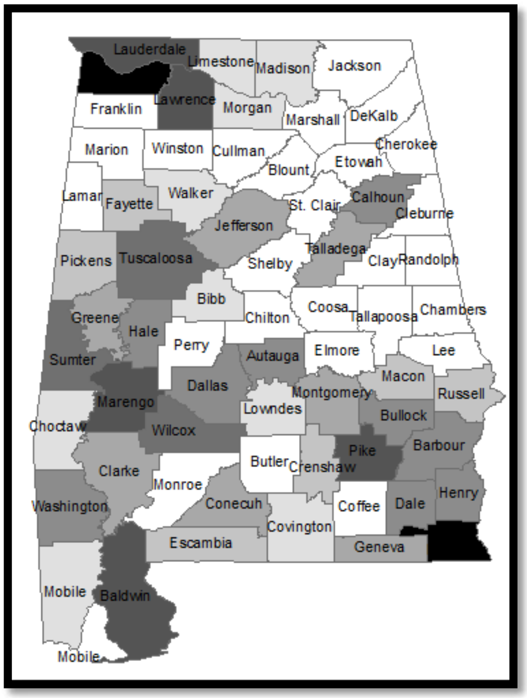
AL 1920 Morbidity/10,000



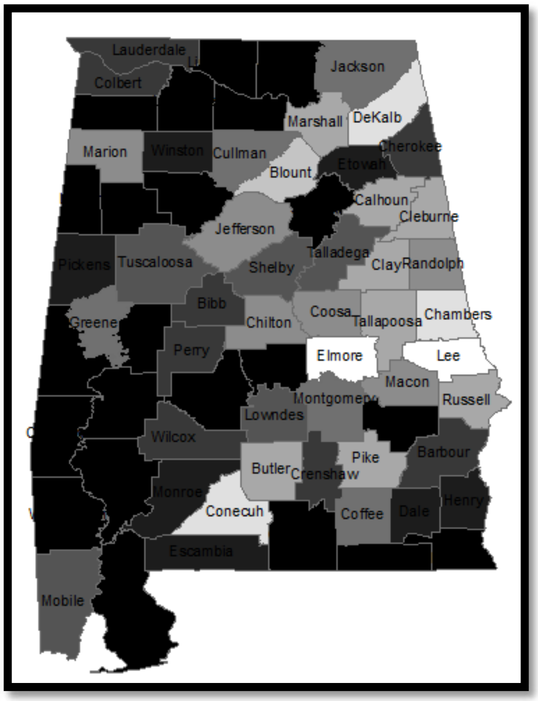
AL 1921 Morbidity/10,000



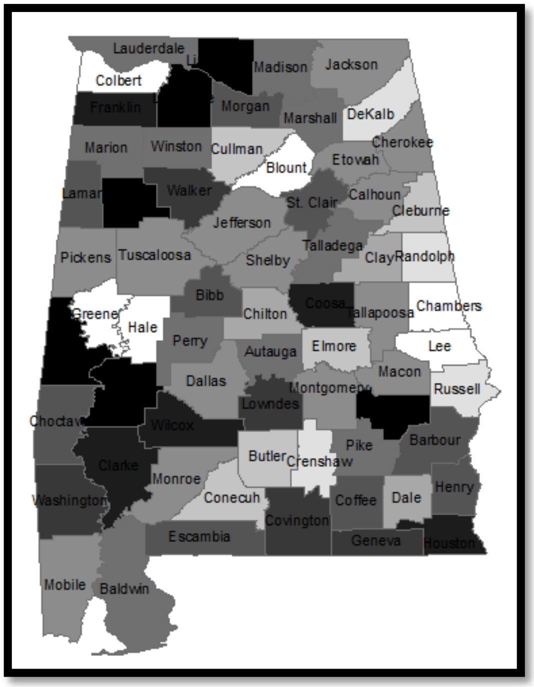
AL 1922 Morbidity/10,000



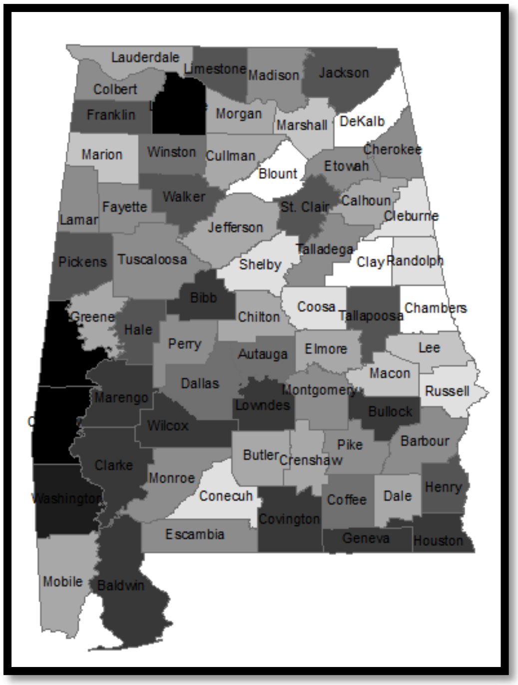
AL 1923 Morbidity/10,000



AL 1924 Morbidity/10,000

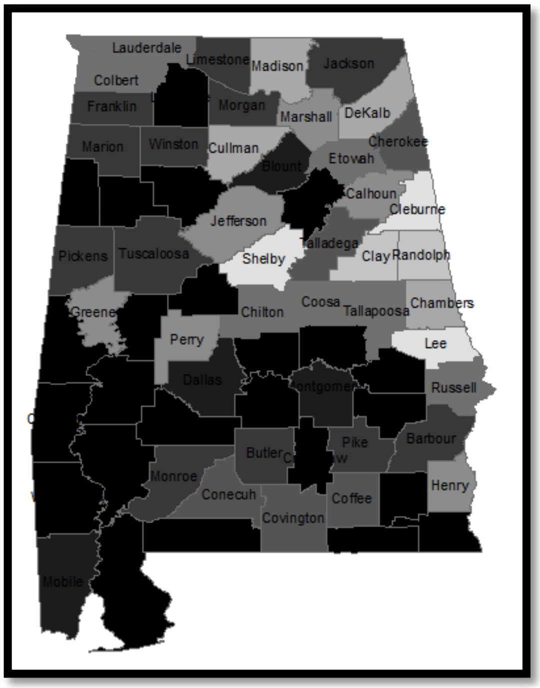


AL 1926 Morbidity/ 10,000

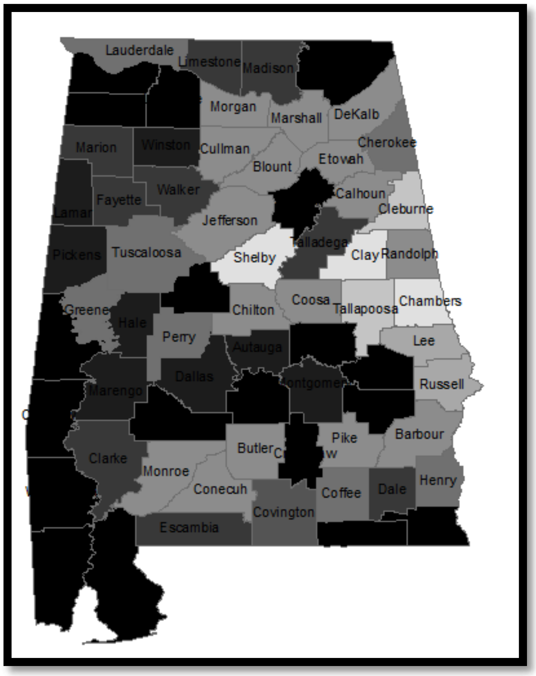


AL 1927 Morbidity/ 10,000

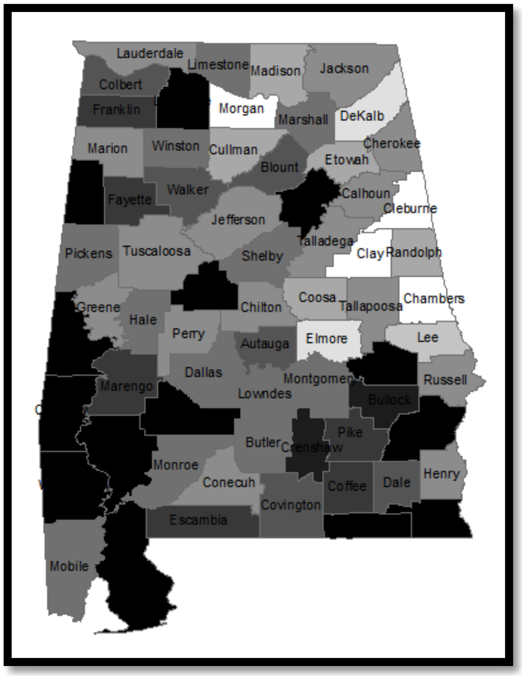
AL 1928 Morbidity/ 10,000



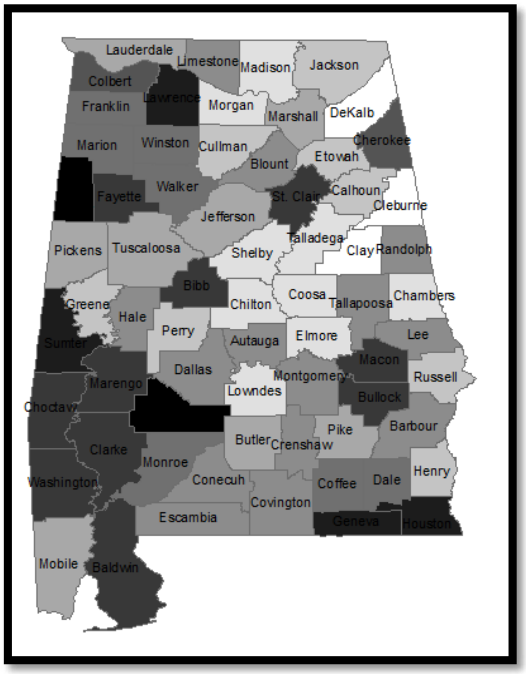
AL 1929 Morbidity/ 10,000



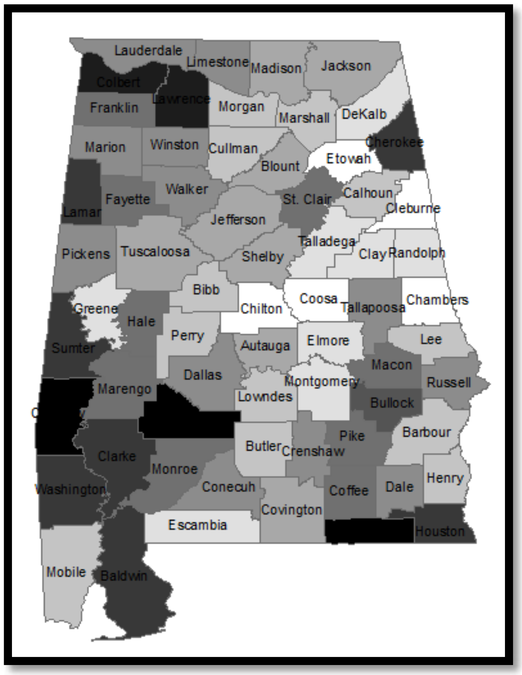
AL 1930 Morbidity/ 10,000



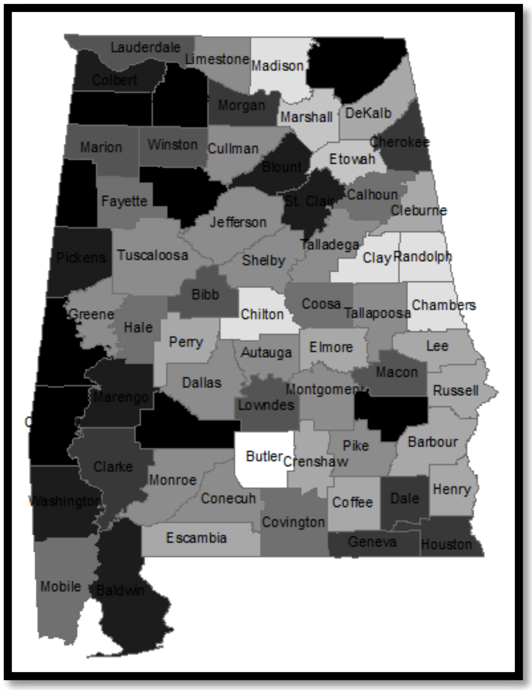
AL 1931 Morbidity/ 10,000



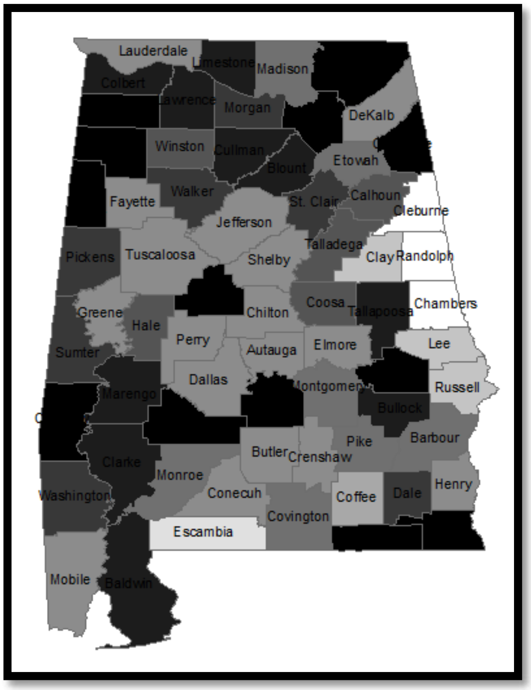
AL 1932 Morbidity/ 10,000



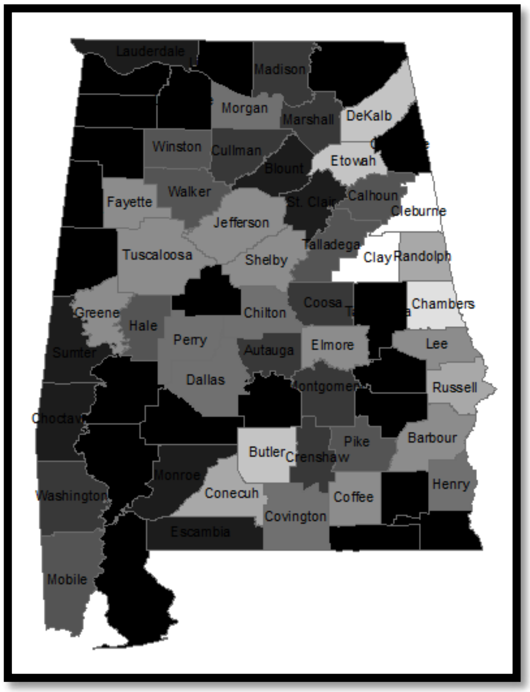
AL 1933 Morbidity/ 10,000



AL 1934 Morbidity/ 10,000

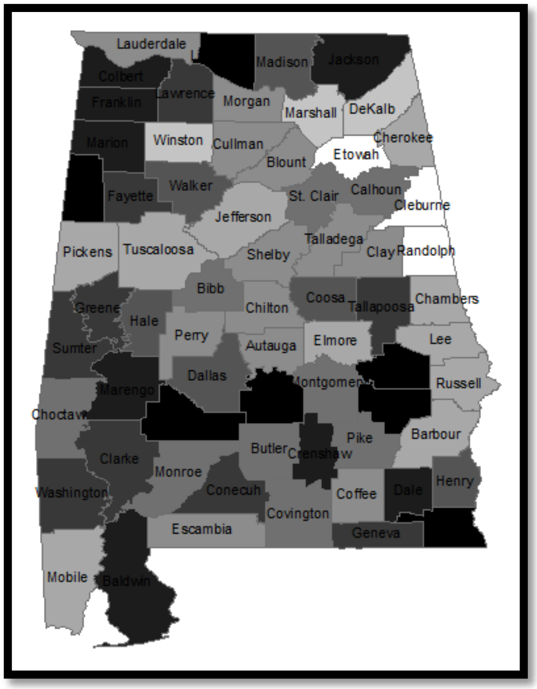


AL 1935 Morbidity/ 10,000

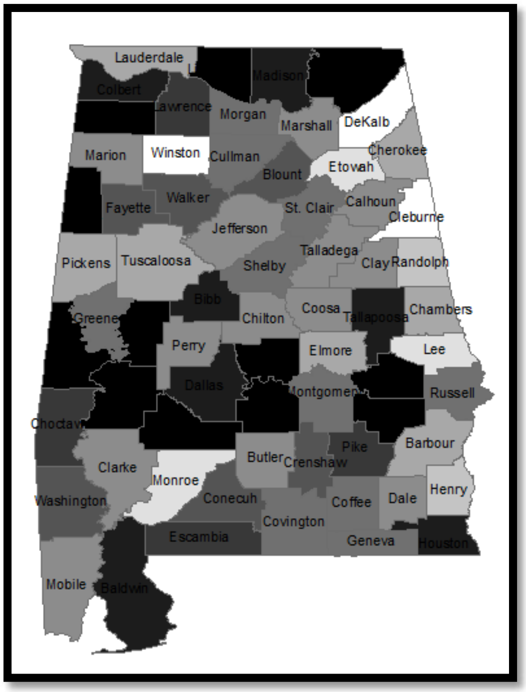


AL 1936 Morbidity/ 10,000

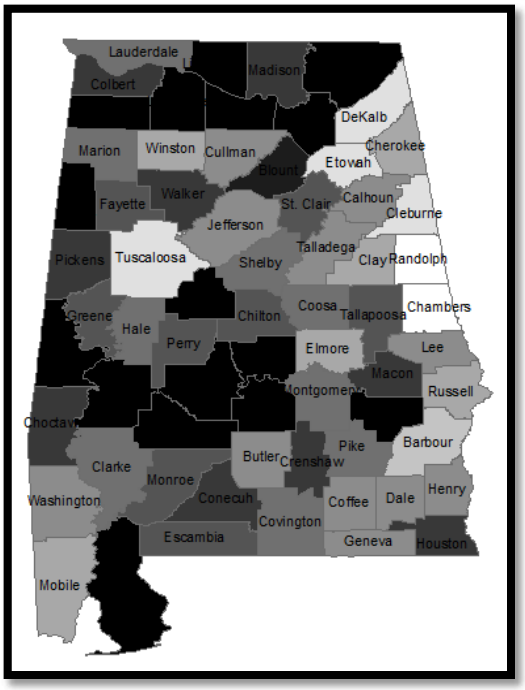
AL 1937 Morbidity/ 10,000



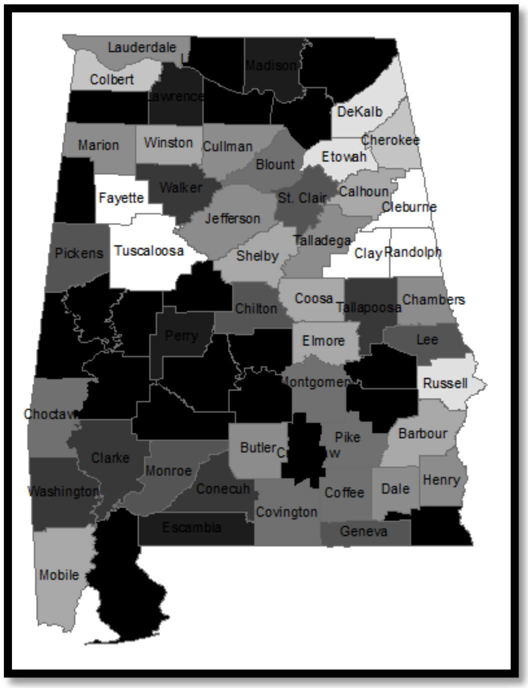
AL 1938 Morbidity/ 10,000



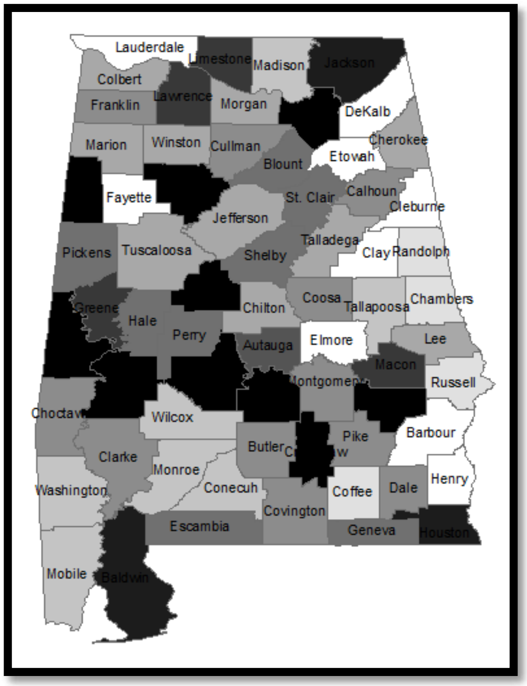
AL 1939 Morbidity/ 10,000



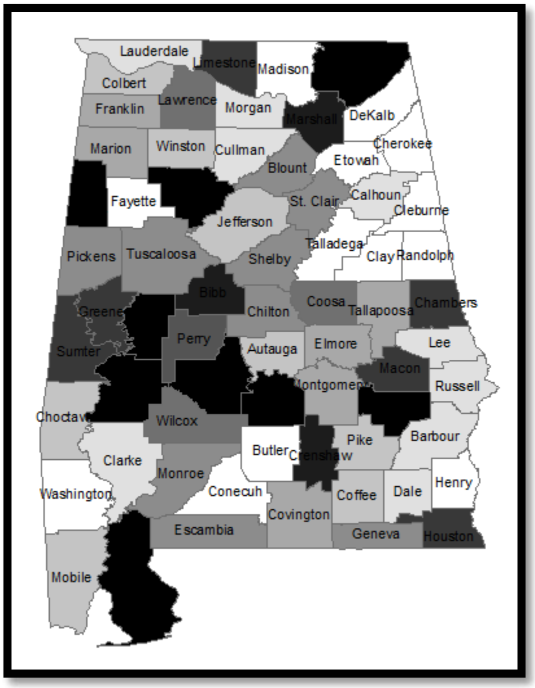
AL 1940 Morbidity/ 10,000



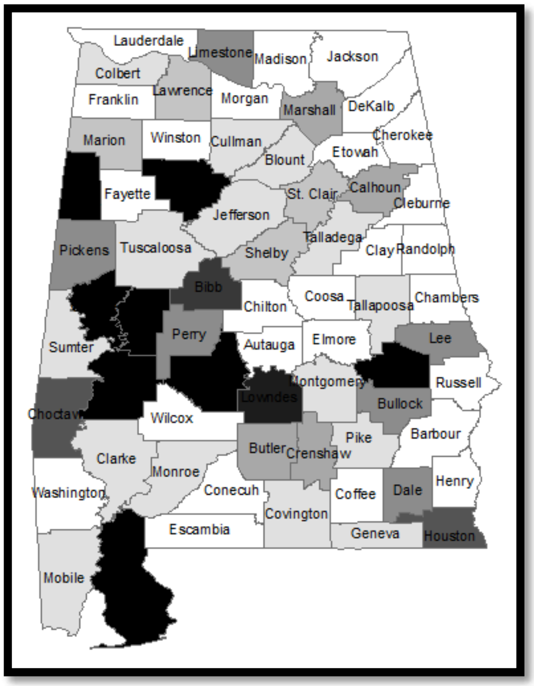
AL 1941 Morbidity/ 10,000



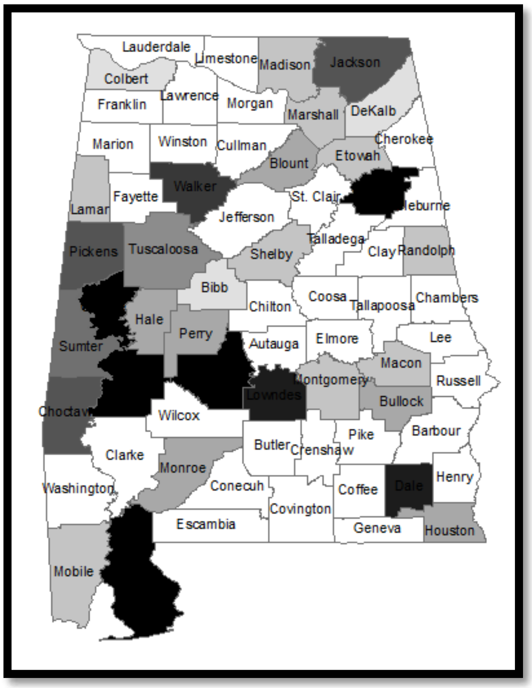
AL 1942 Morbidity/ 10,000



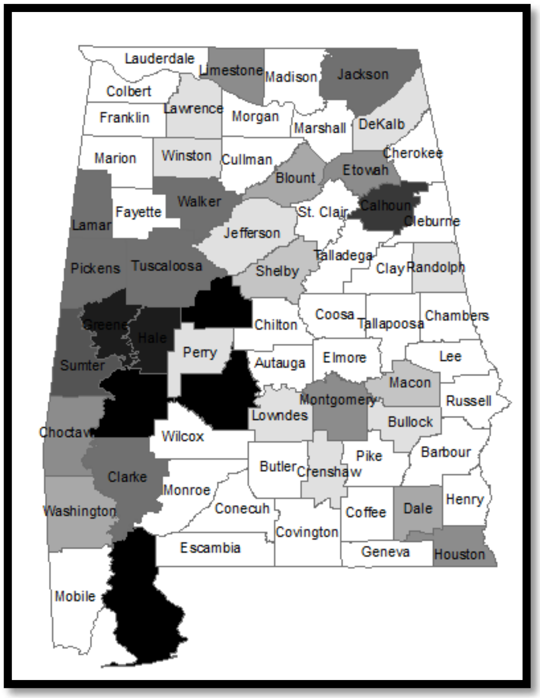
AL 1943 Morbidity/ 10,000



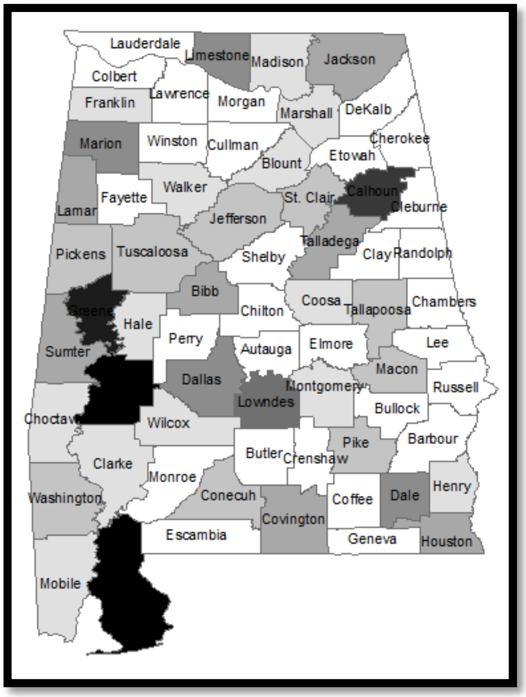
AL 1944 Morbidity/ 10,000



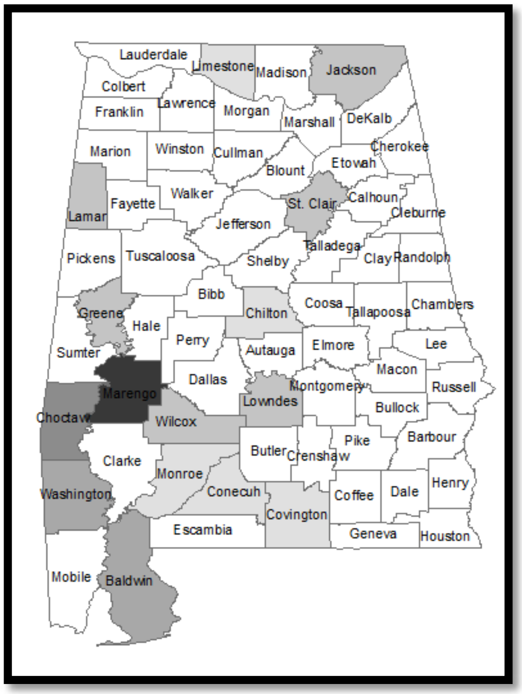
AL 1945 Morbidity/ 10,000



AL 1946 Morbidity/ 10,000



AL 1948 Morbidity/ 10,000



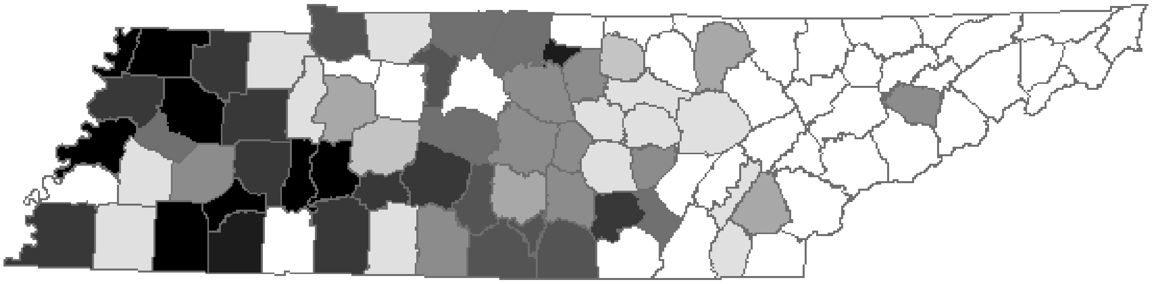
AL 1949 Morbidity/ 10,000

AL 1950 Morbidity/ 10,000

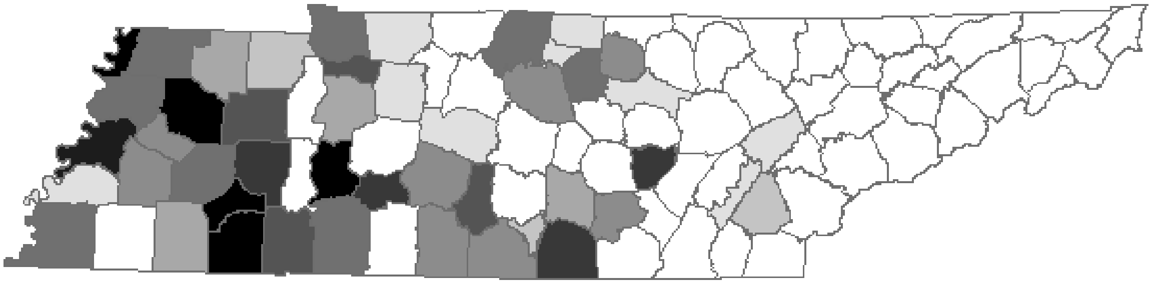
Grey Scale:
Bins
0-1
1-2
2-3
3-5
5-10
10-15
15-20
20-30
30-40
40+

Appendix B: Tennessee Morbidity Maps 1929-1949

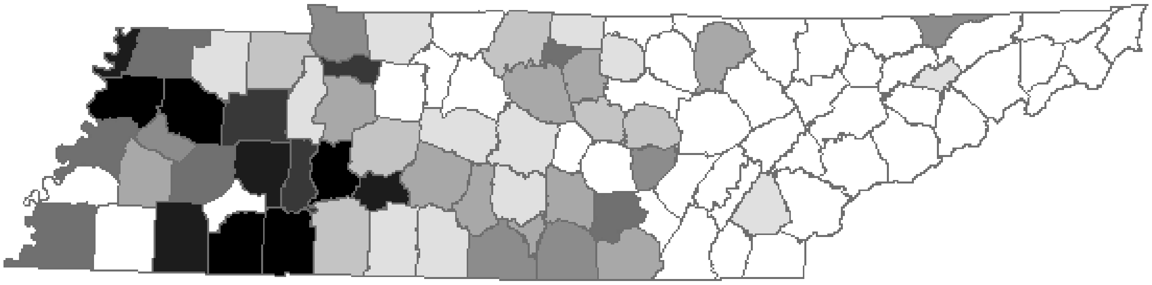
TN 1929 Morbidity/10,000



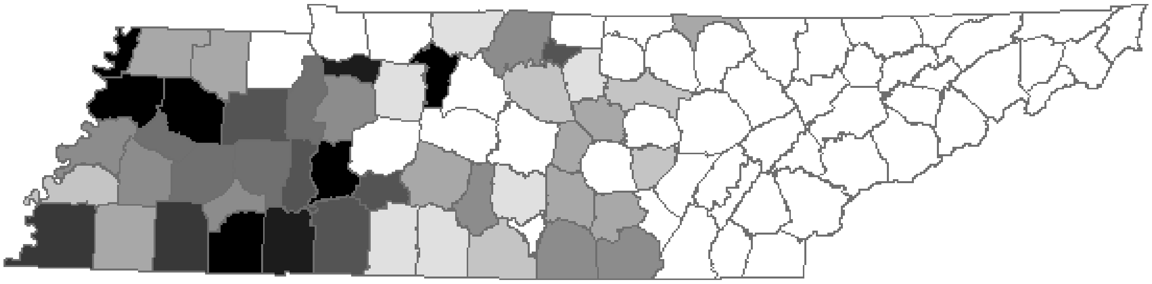
TN 1930 Morbidity/10,000



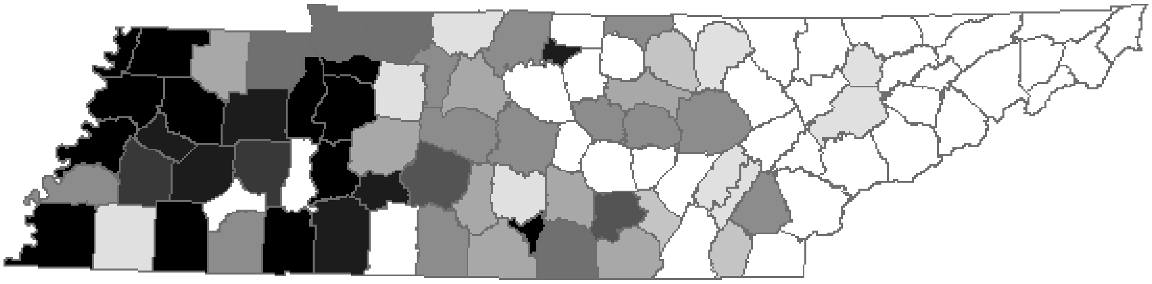
TN 1931 Morbidity/10,000



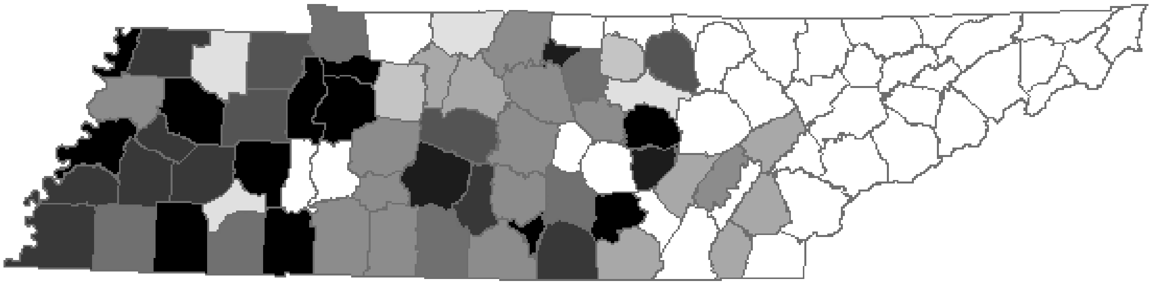
TN 1932 Morbidity/10,000



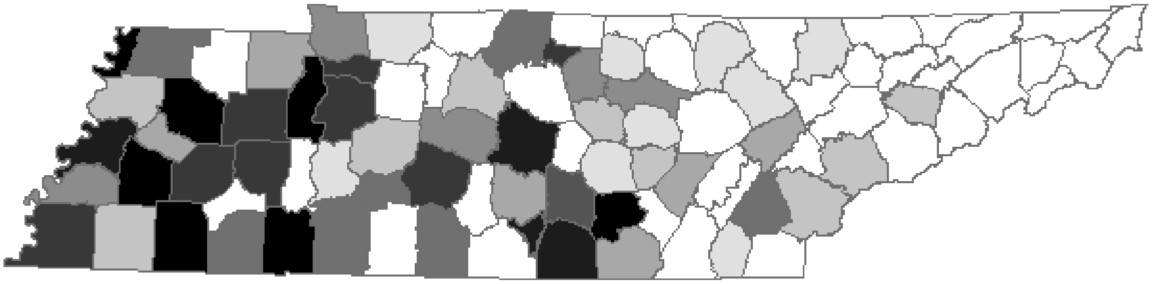
TN 1933 Morbidity/10,000



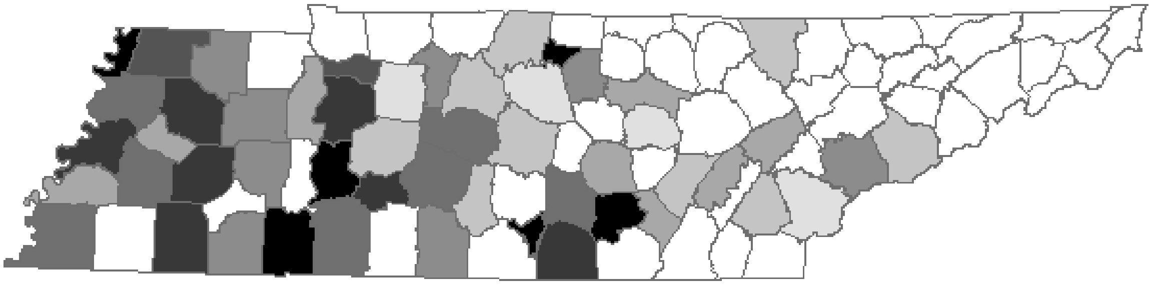
TN 1934 Morbidity/10,000



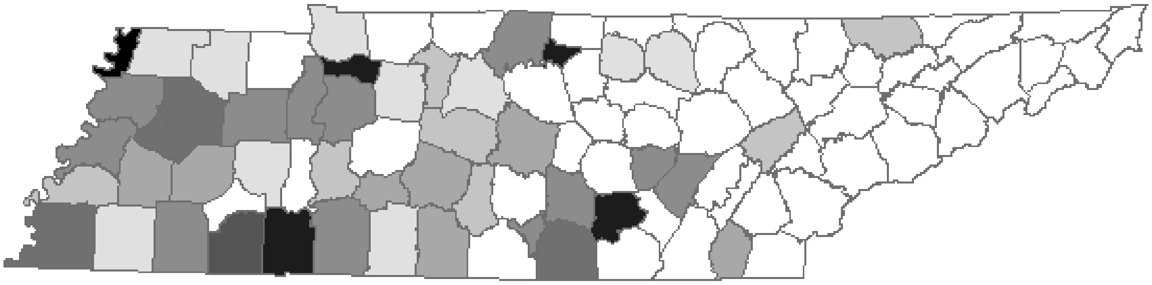
TN 1935 Morbidity/10,000



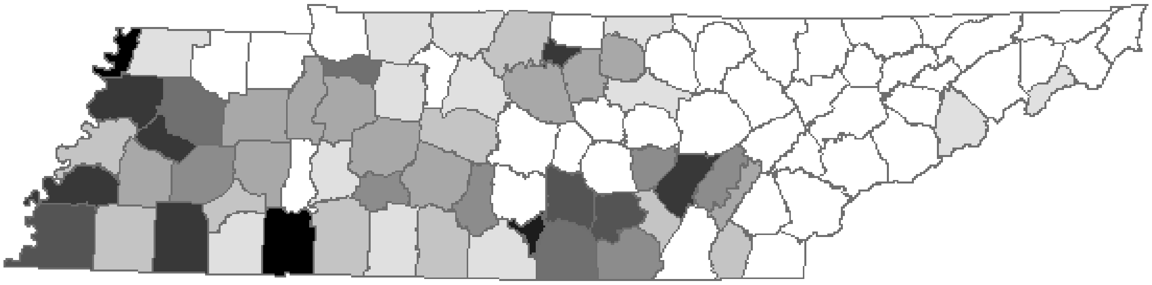
TN 1936 Morbidity/10,000



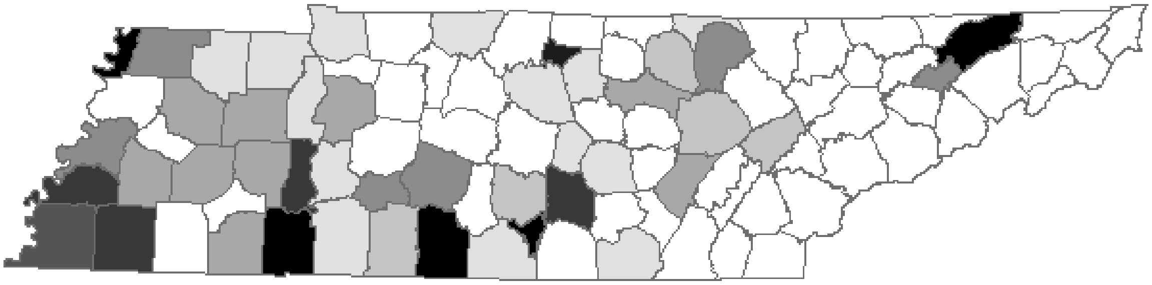
TN 1937 Morbidity/10,000



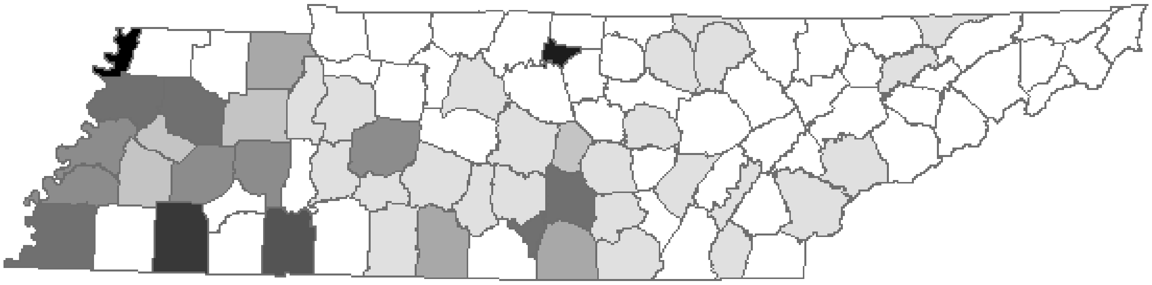
TN 1938 Morbidity/10,000



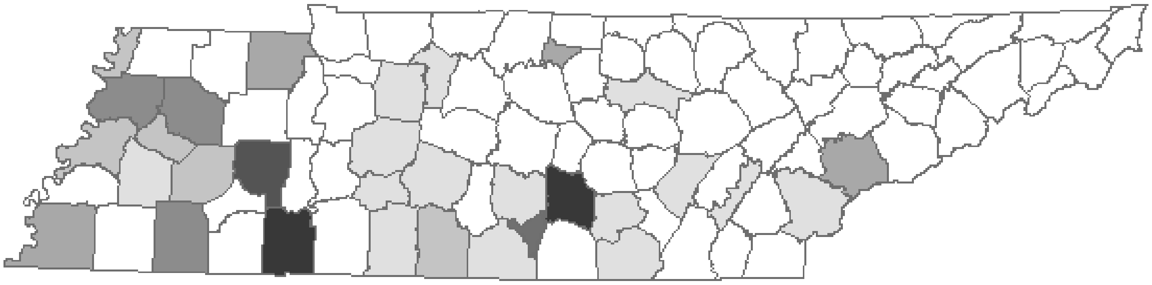
TN 1939 Morbidity/10,000



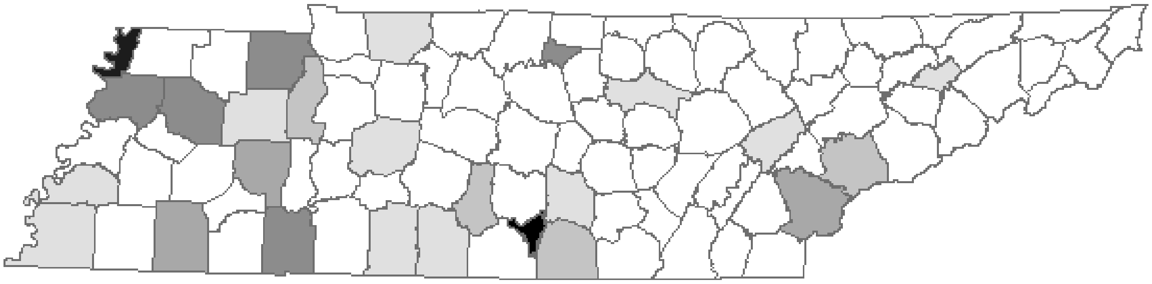
TN 1940 Morbidity/10,000



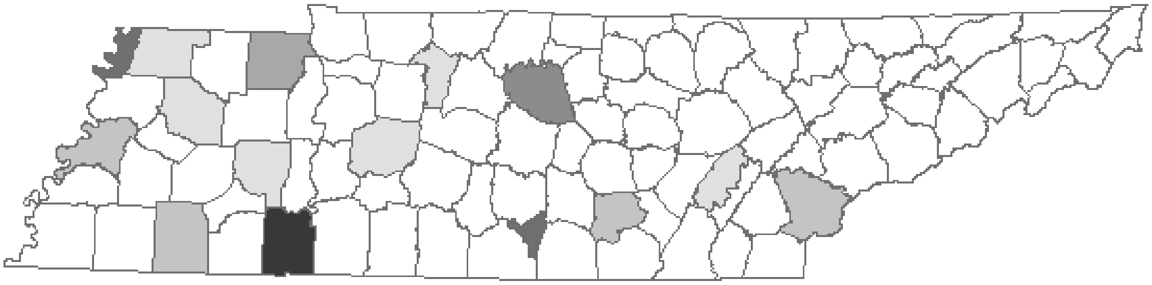
TN 1941 Morbidity/10,000



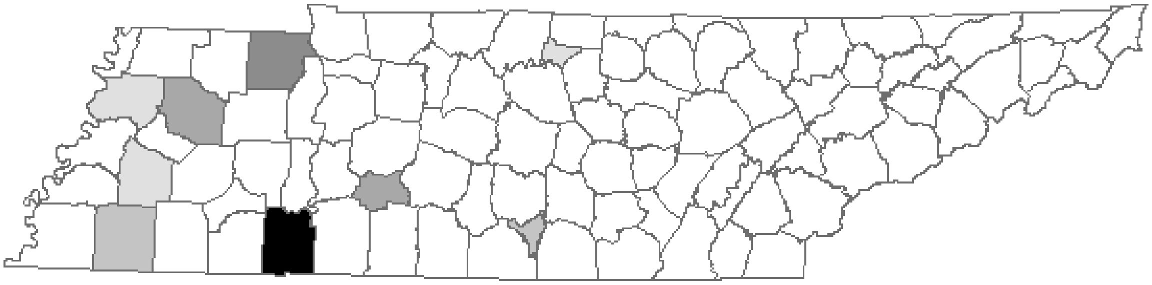
TN 1942 Morbidity/10,000



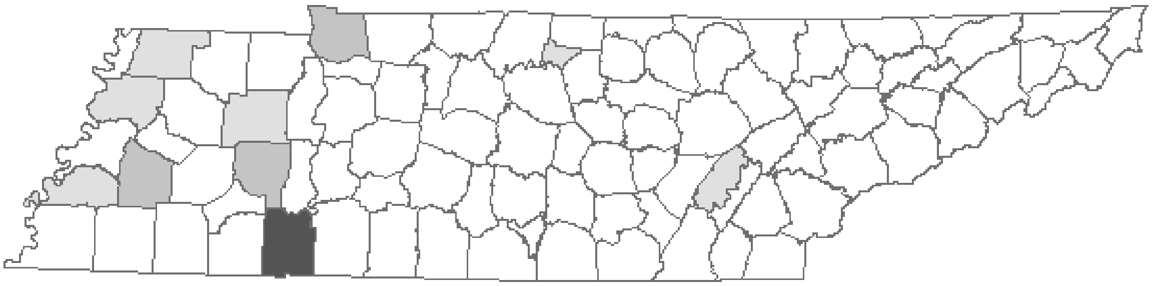
TN 1943 Morbidity/10,000



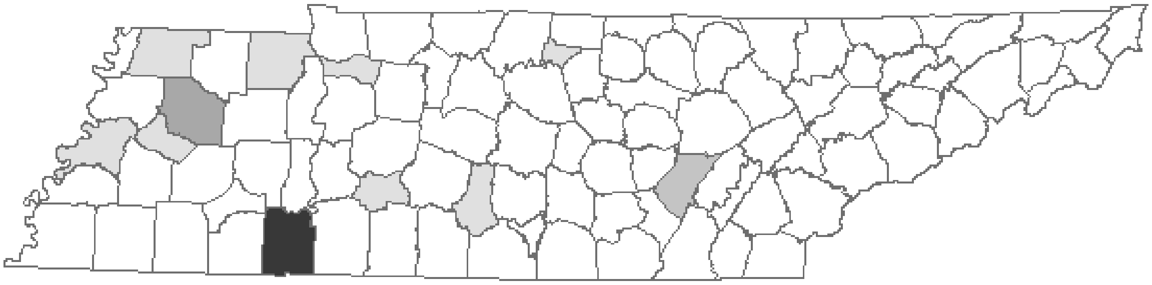
TN 1944 Morbidity/ 10,000



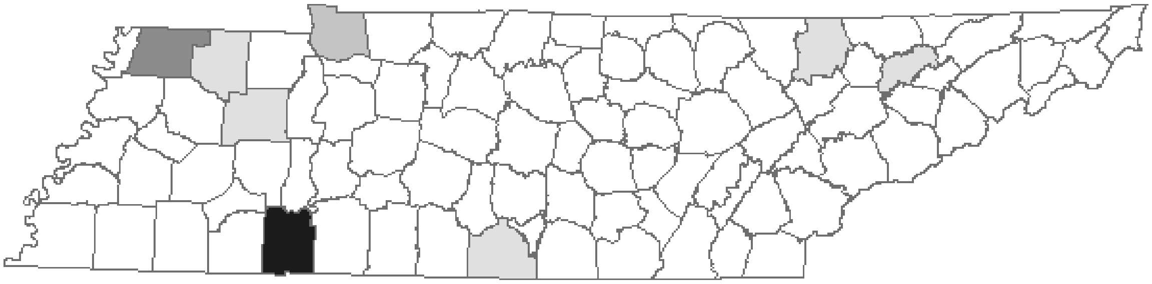
TN 1945 Morbidity/ 10,000



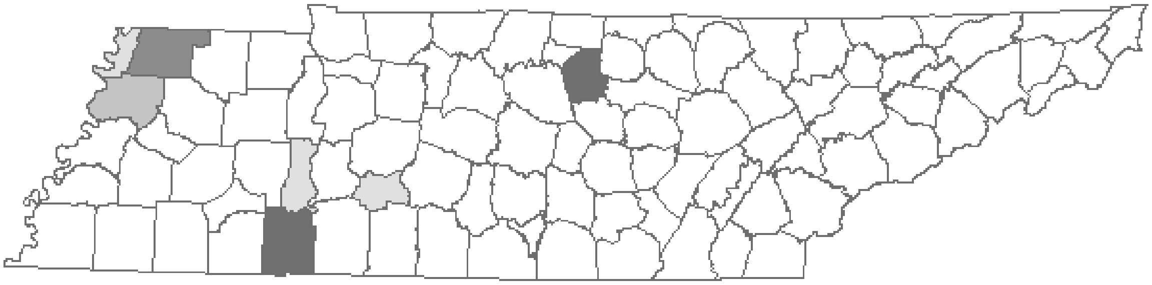
TN 1946 Morbidity/ 10,000



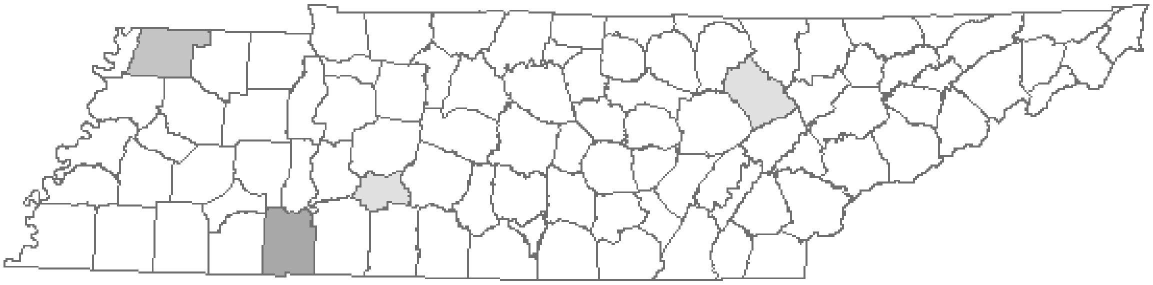
TN 1947 Morbidity/ 10,000



TN 1948 Morbidity/ 10,000

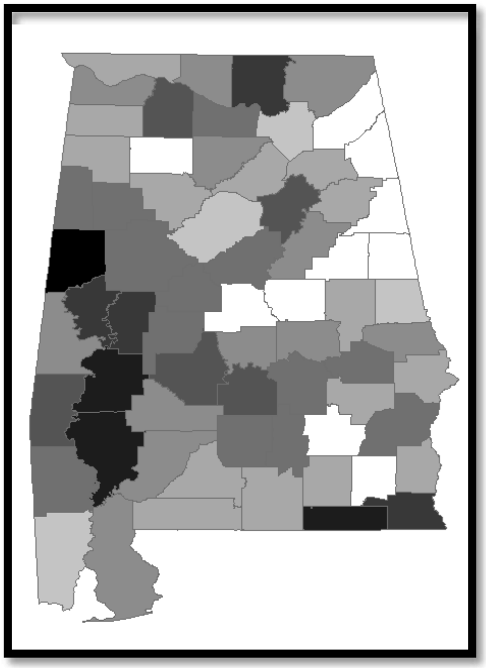


TN 1949 Morbidity/ 10,000

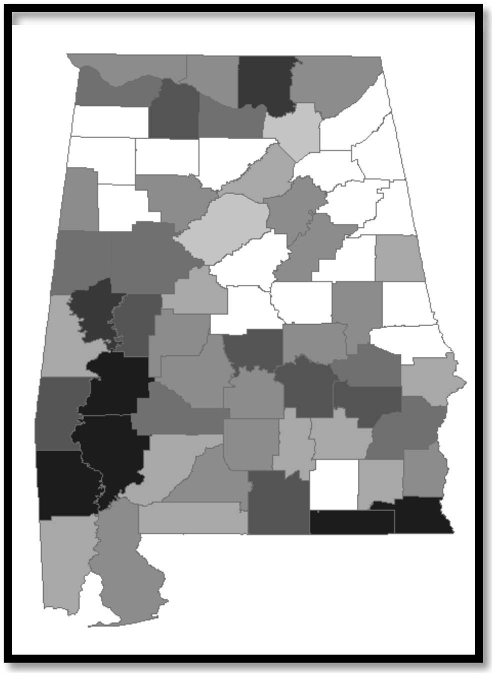


Appendix C: Alabama Mortality Maps 1926-1940

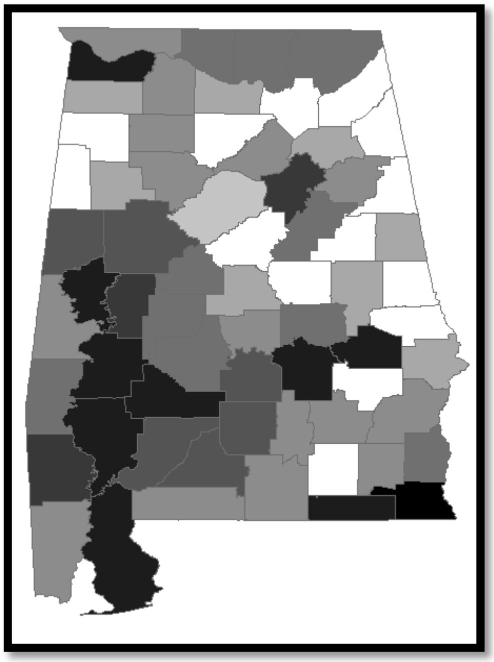
AL Mortality 1926



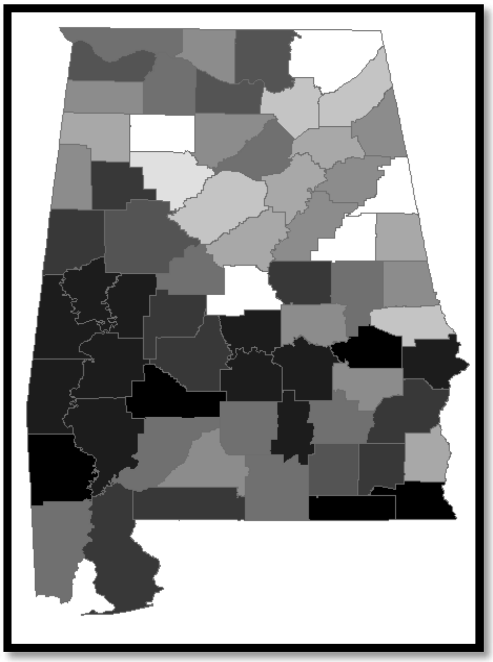
AL Mortality 1927



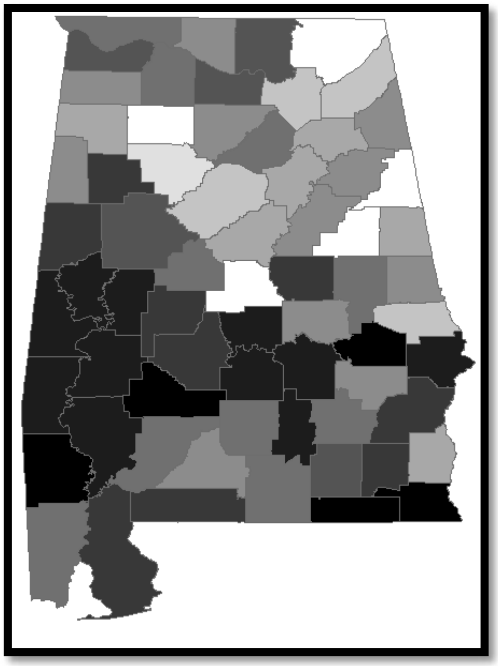
AL Mortality 1928



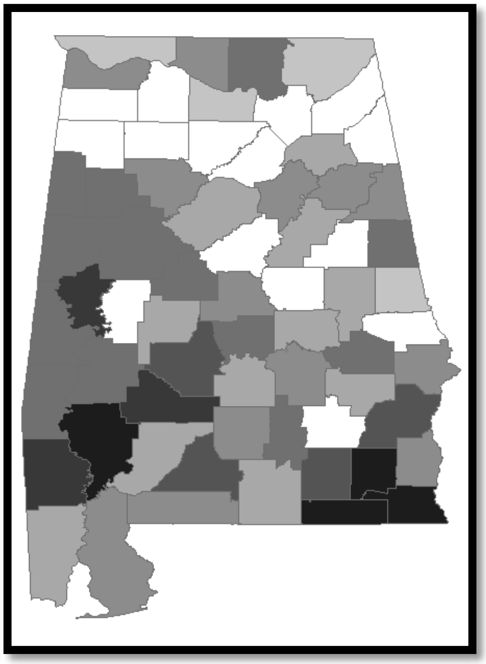
AL Mortality 1929



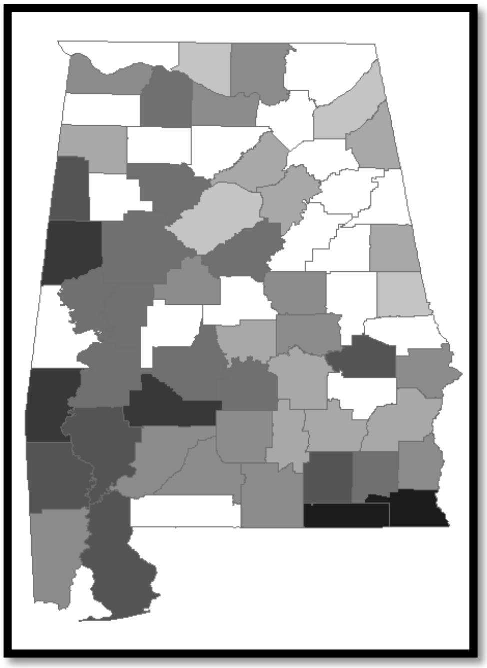
AL Mortality 1930



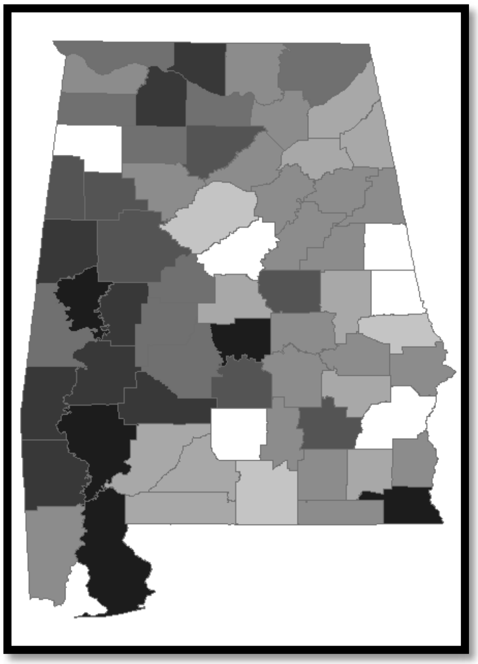
AL Mortality 1931



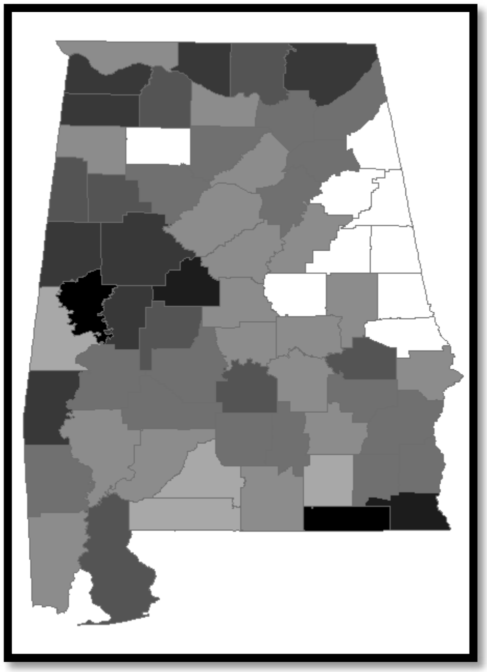
AL Mortality 1932



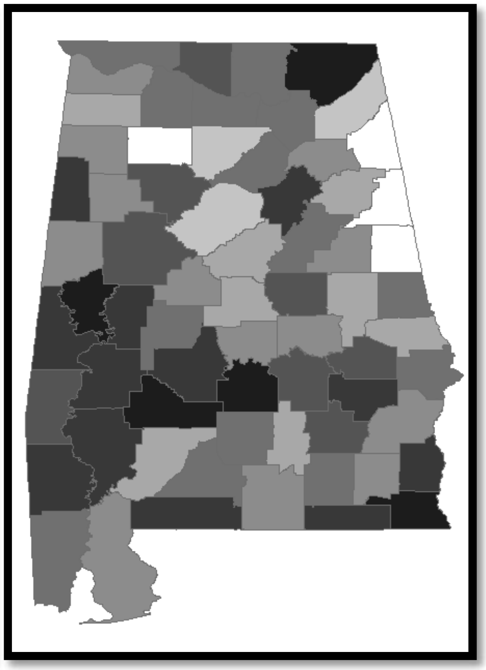
AL Mortality 1933



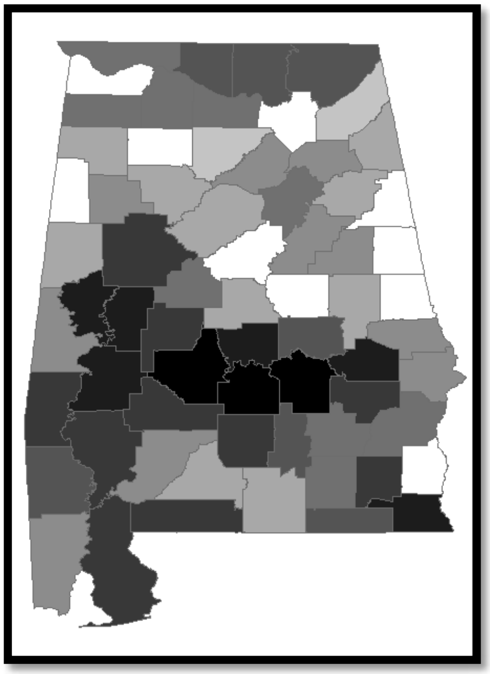
AL Mortality 1934



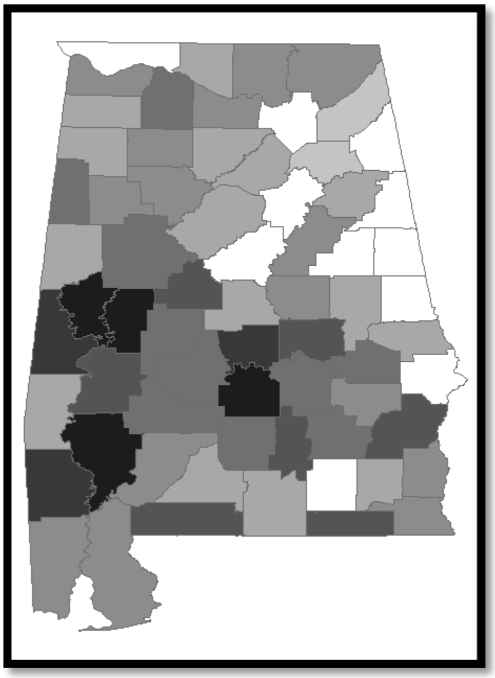
AL Mortality 1935



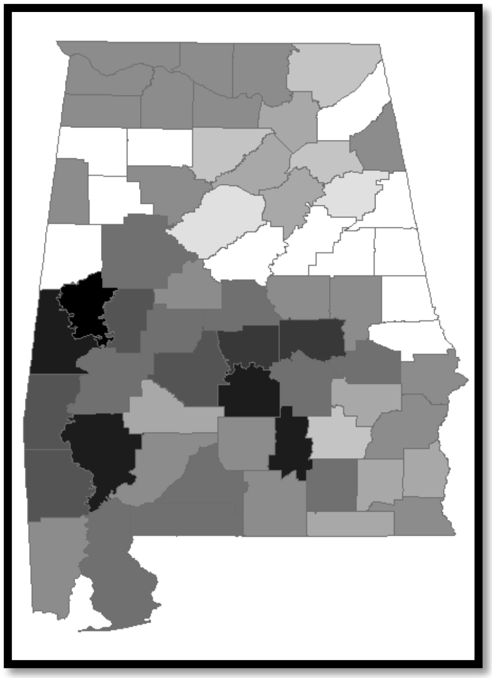
AL Mortality 1936



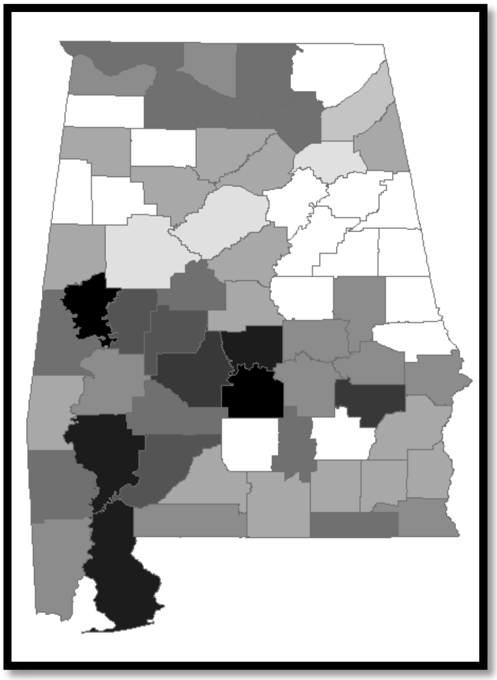
AL Mortality 1937



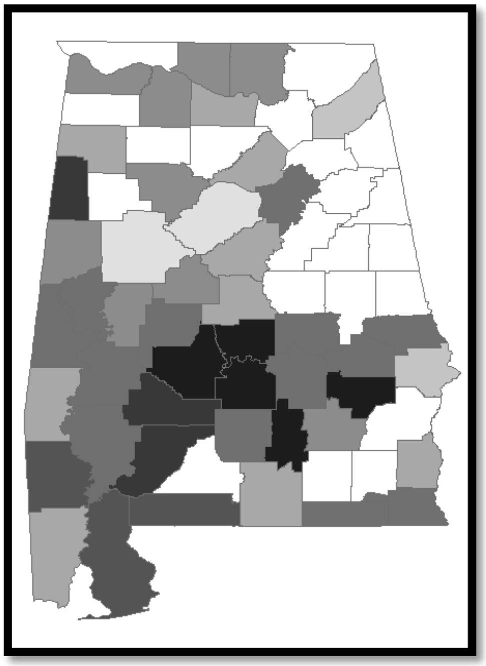
AL Mortality 1938



AL Mortality 1939

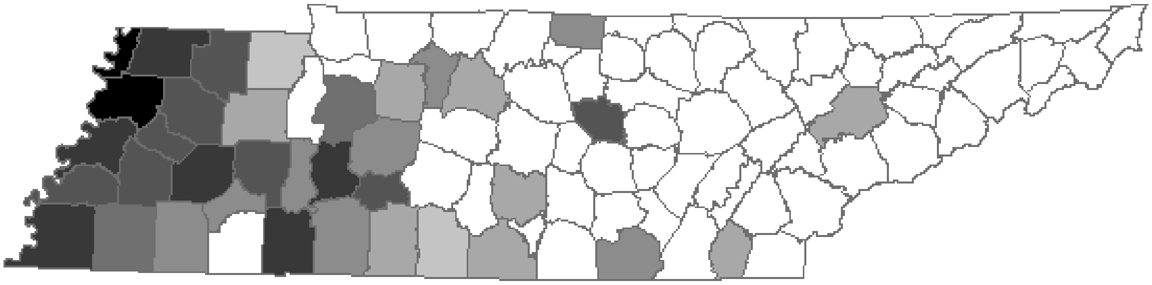


AL Mortality 1940

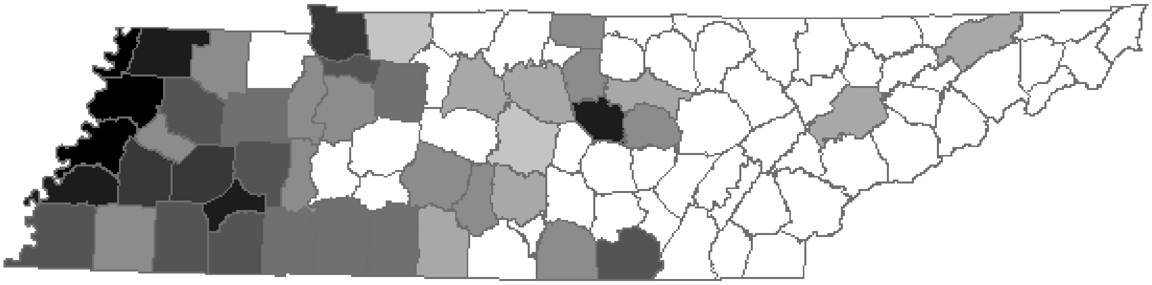


Appendix D: Tennessee Mortality Maps 1927-1946

TN 1927 Mortality/100,000

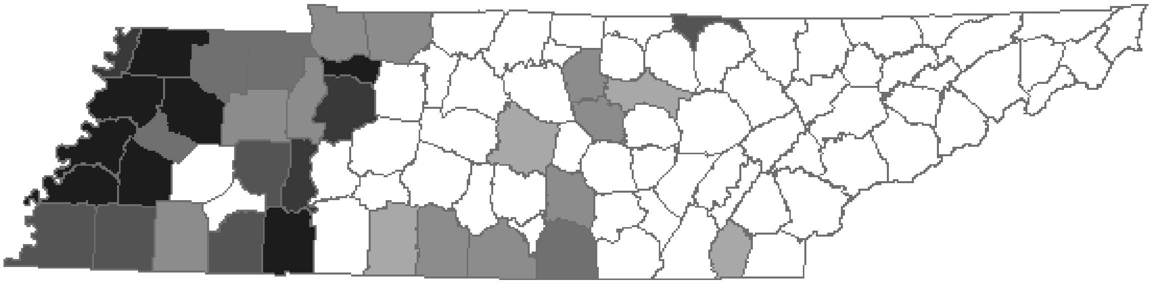


TN 1928 Mortality/100,000

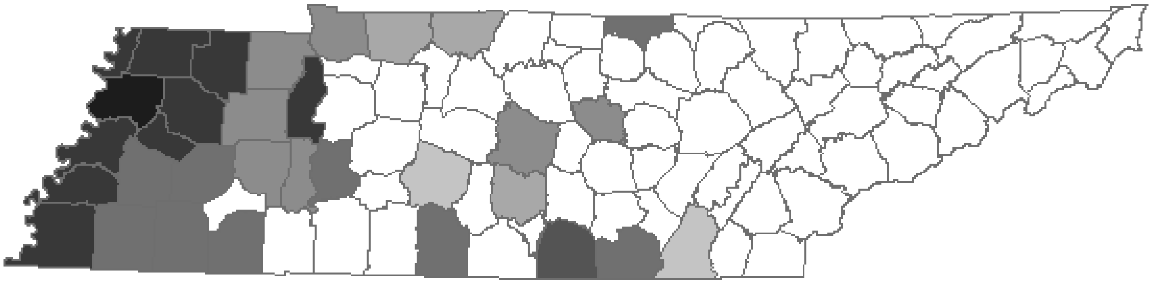


TN 1929

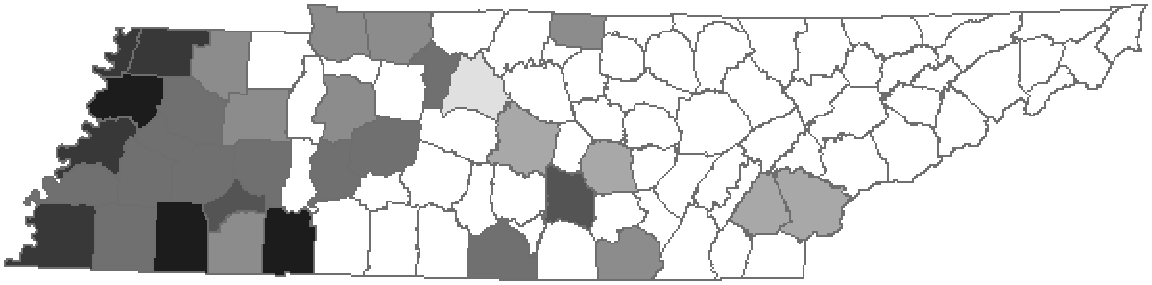
Mortality/100,000



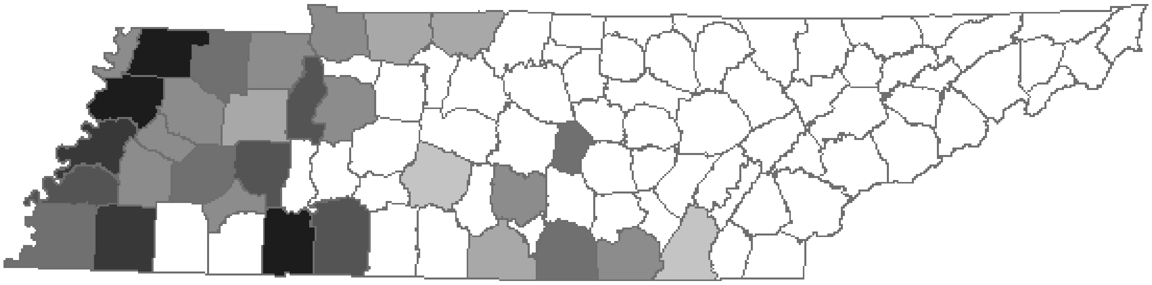
TN 1930 Mortality/100,000



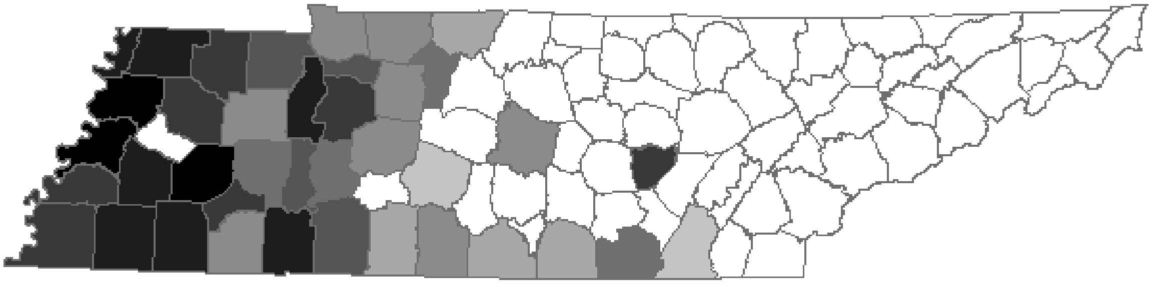
TN 1931 Mortality/100,000



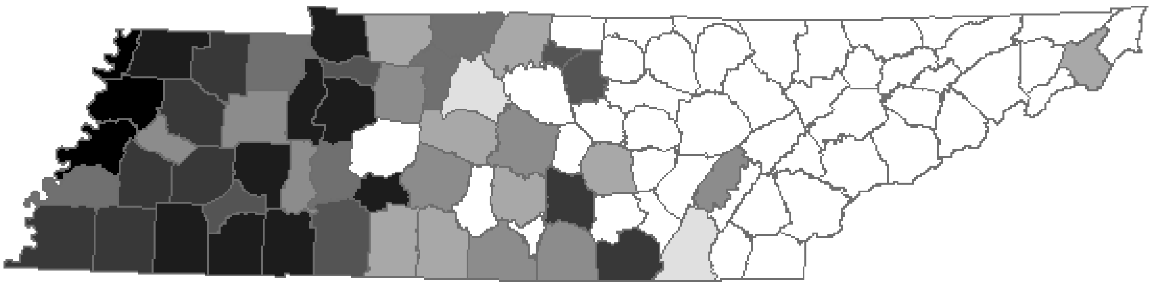
TN 1932 Mortality/100,000



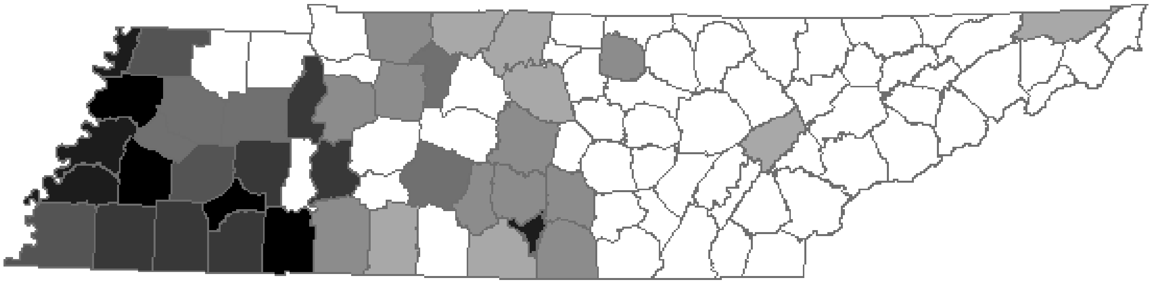
TN 1933 Mortality/100,000



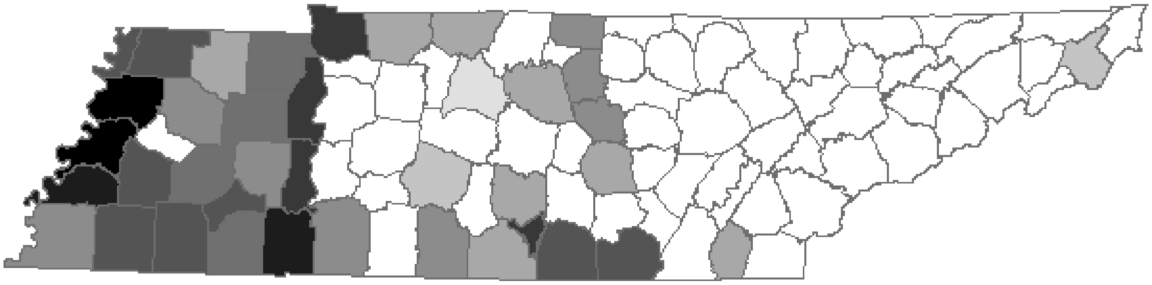
TN 1934 Mortality/100,000



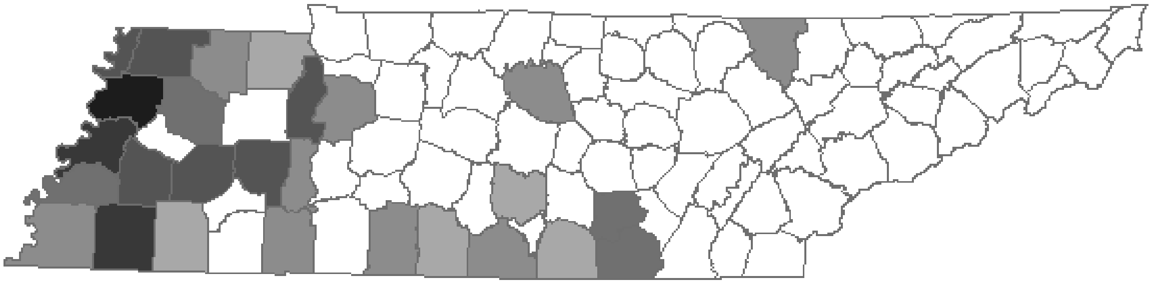
TN 1935 Mortality/100,000



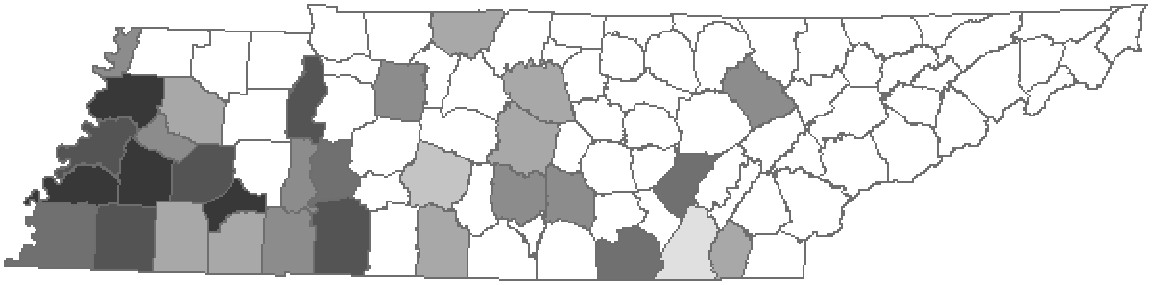
TN 1936 Mortality/100,000



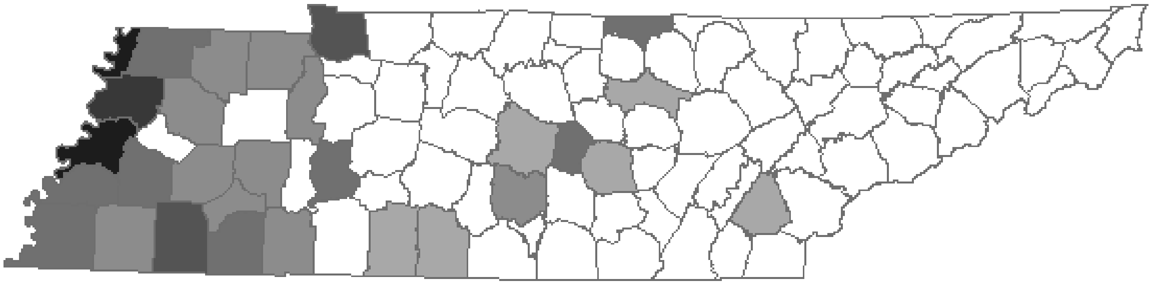
TN 1937 Mortality/100,000



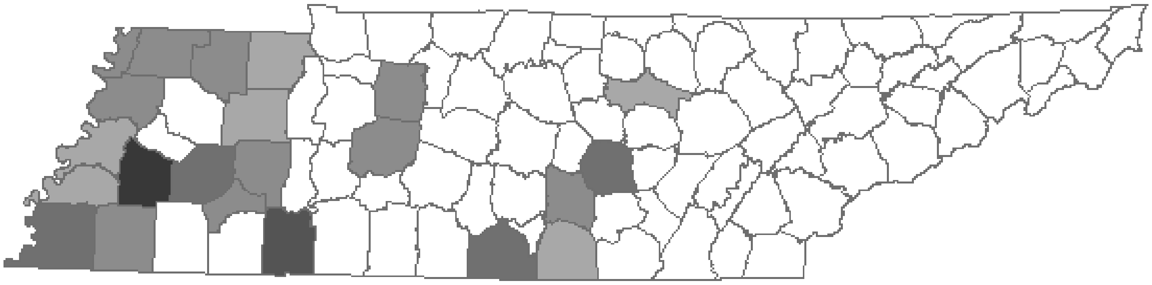
TN 1938 Mortality/100,000



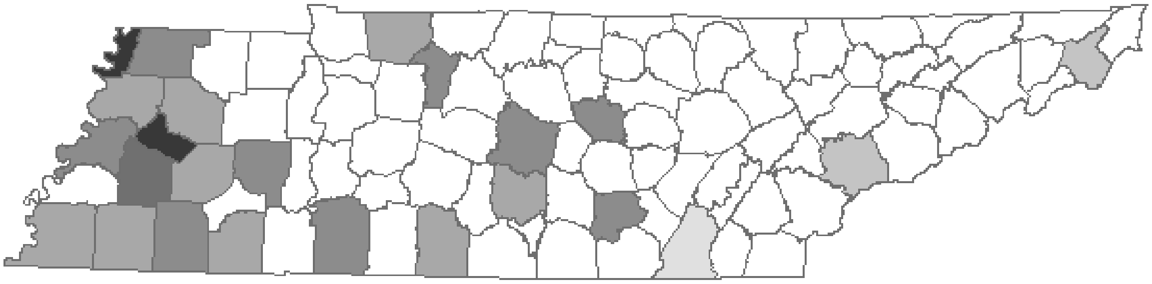
TN 1939 Mortality/100,000



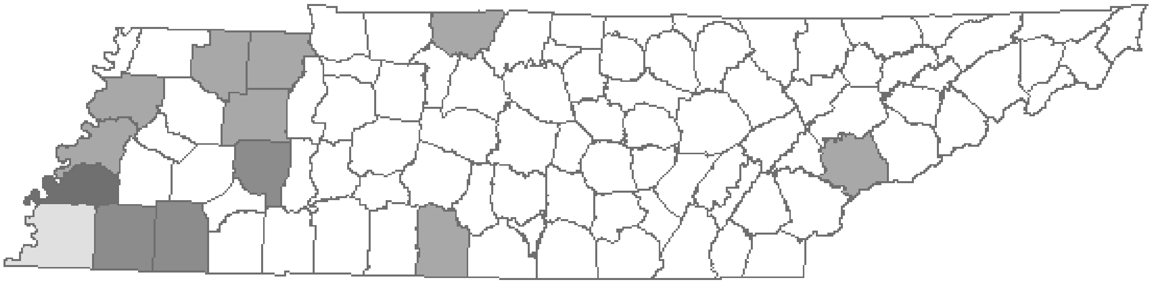
TN 1940 Mortality/100,000



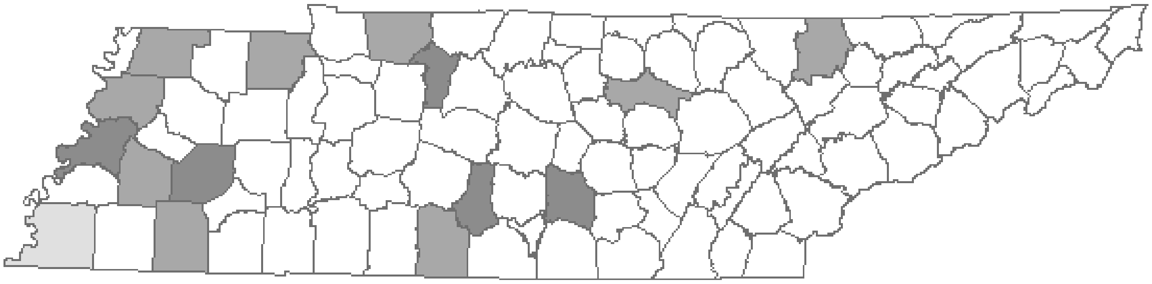
TN 1941 Mortality/100,000



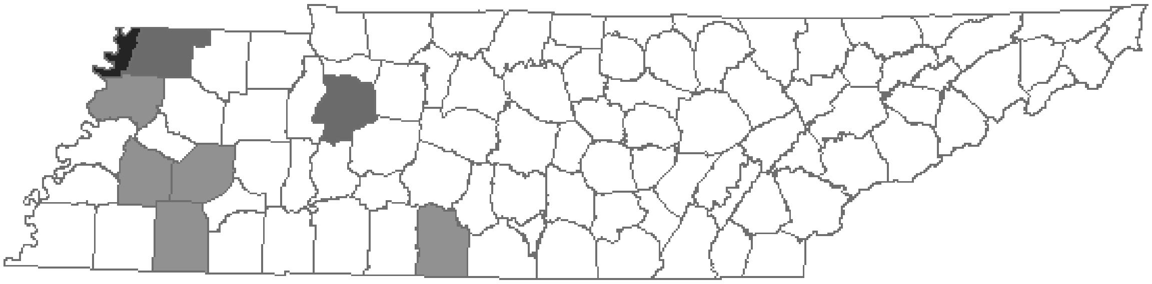
TN 1942Mortality/100,000



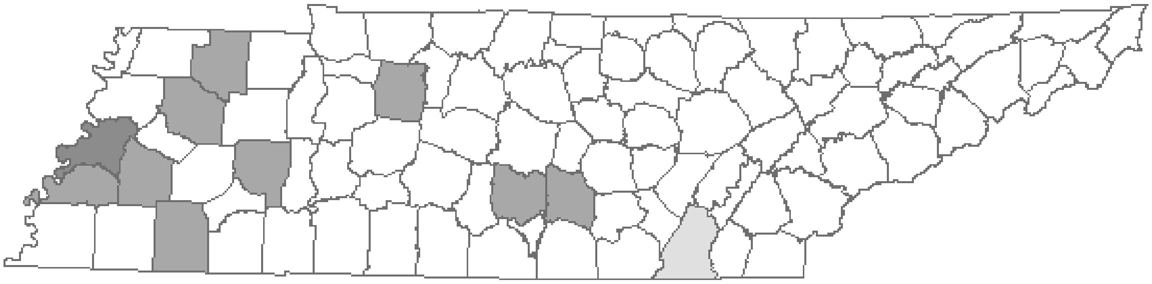
TN 1943 Mortality/100,000



TN 1944 Mortality/100,000



TN 1945 Mortality/100,000



TN 1946 Mortality/100,000