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

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**Abstract**

The TVA has long been held in high esteem for its programs designed to reduce malaria mortality and morbidity rates in the Southeast following its establishment in 1933. One reason why the TVA developed the anti malaria programs was that they created large bodies of standing water by damming up the Tennessee River and its tributaries. Given the recent increase in river system management projects around the globe and recurring problems with malaria, the TVA provides insight to the problems associated with large scale dams and water management. Using county level panel data from the Southeast United States, I find that the net effect of the TVA was to increase malaria morbidity and mortality rates following its construction. Using standard statistical life value estimates, I find that between 1933 and 1951, that the TVA cost up to $4.3 billion in hidden malaria cost.

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# 1 Introduction

Recently developing nations have constructed dams for the purposes of water management, electrification, water storage, and irrigation. These dams have significantly improved agricultural production, often at the expense of the removed population (Duflo and Pande 2002). 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 may lead to large outbreaks of waterborne disease. Duflo and Pande provided an excellent study of dams and their effects on agricultural development and rural poverty. However, one measure of rural poverty used in their article, the malaria rate, is likely poorly measured due to infrequent observation. Outbreaks that occur between observations would go unnoticed, making it difficult to identify the true effect of dams on malaria. Furthermore, their study occurs in an era following the eradication of malaria in India where there was widespread use of DDT. During this period, insecticides were still highly effective. Without knowledge of eradication efforts, Duflo and Pande are estimating the net effect of DDT, vector control activities, and dams.

Today, malaria rates are on the rise. 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 malarious regions have incomes that are significantly lower than those living in low intensity areas. These claims have been substantiated by research on the life cycle effects of malaria and malaria eradication. Malaria can lead to reductions in physical stature, and eradication has led to significantly better labor market outcomes for individuals as well as increases in spending (Bleakley 2007, Cutler et al 2010, Hong 2007).

In this paper, I explicitly examine the malaria problem associated with the construction of large scale dams using an exogenous change in the disease environment caused by the formation of the Tennessee Valley Authority (TVA). The TVA was one of many New Deal agencies, formed with the intent of spurring economic activity during the Great Depression. Its primary objective was to control flooding that occurred on the Tennessee River and its major tributaries. To identify the causal effect of a dam on malaria rates, I have collected disease specific mortality and morbidity rates at the county level for two southeastern states, Alabama and Tennessee, where the TVA was primarily located. I use within county variation over time controlling for year specific state level shocks to identify the effect using panel data methods.

The results show that the net effect of the TVA was to increase both morbidity and mortality rates in the counties surrounding the dams. These results are robust to a variety of specifications, accounting for correlation over time and across space. While the net effect of the TVA is positive, I also find evidence that the TVA efforts to combat malaria did reduce malaria rates from the higher baseline. As more dams opened upstream from a county, allowing the TVA to raise and lower water levels in downstream reservoirs, in ways that killed mosquito populations, the malaria rate was reduced. This provides some evidence for the success of one vector control method that will be discussed below.

Point estimates from the differences-in-differences estimation are then used to construct a back of the envelope cost calculation for the cost of mortality and the cost of morbidity. I use outside estimates for the morbidity cost, Value of a Statistical Life (VSL), and the cost of a saved life to estimate the cost of malaria mortality associated with the TVA dam construction. I present two main cost estimates, first, the estimated cost of malaria at TVA dams without the control efforts and secondly the cost including the effect of mosquito control. In the absence of TVA efforts, I estimate the hidden malaria cost to range from $623 million and $6.7 billion.[1] Accounting for the TVA malaria control efforts, the net cost is much lower, ranging from $340 Million and $4.3 Billion.

# 2 Malaria and the TVA

## 2.1 Plasmodium Vivax

The parasite Plasmodium, which is the cause of malaria was first discovered in 1880. Malaria is transmitted when the parasite Plasmodium

> "... 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." [2]

This process can have devastating effects on health. Anemia results from the parasite's destruction of red blood cells. In mild or uncomplicated cases of malaria, cold

[1] The Range of life values range from $1.6 million and $8.6 Million, accounting for the large range

[2] Malaria and its Control in the Tennessee Valley

chills are followed by fever and nausea, and eventually the breaking of the fever. In more complicated cases, blood may appear in one's urine. Pulmonary edema, reduction in blood platelets, and more severe complications may lead to death. Plasmodim Vivax, the variety most prevalent in the United States may remain dormant in the blood for several years, causing complications well after the initial transmission.

## 2.2 Breeding Grounds and Eradication Efforts

The Anopheles mosquito is responsible for the transmission of plasmodium vivax in the United States. These mosquitoes lay their eggs on sitting fresh water, so any idle pool is a potential breeding ground. Sitting water is commonly found along inlets, sink ponds, and swamps. When rivers are flooded to create reservoirs it is unclear whether or not sitting water will increase or decrease. Previous breeding grounds adjacent to the river become flooded and leave larvae susceptible to natural prey. On the other hand, increases in shoreline 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.

Several of the initial mosquito/malaria eradication plans operated with drainage in mind. Following its successful hookworm campaigns, the Rockefeller Foundation and the United States Public Health Service (USPHS) began campaigns to eradicate malaria by forming anti malaria groups within local and state health agencies. Beginning in 1919, the Alabama State Board of Health began inspections within counties to determine the source of the malaria problem. 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. In 1930 the state established a home screening and sealing program. These programs expanded further into the 1930's. In Tennessee, similar efforts were made through the state health agency and the American Red Cross.

Drainage programs received a boost during the Great Depression. The Federal Relief Administration (FERA), the Civilian Works Administration (CWA), and Works Progress Administration (WPA) all assigned relief employees to state health agencies, which had the relief workers build ditches, drain swamps, and spray insecticides. Federal and state control efforts continued through the 1940s through the Malaria Control in War Area's (MCWA) program, which formed the basis of the Centers for Disease Control (CDC). In 1945, local and state agencies received a boost to their eradication efforts when DDT was released from government control during World War II. States, in conjunction with the USPHS mounted a large scale spraying program to kill any anopheles mosquitoes in residential areas. By 1950, eradication was essentially achieved.

## 2.3 The Tennessee Valley Authority

In May of 1933, President Franklin Delano Roosevelt created a new federal agency aimed at developing 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 and existing Army plans for dams at Cove Creek (Norris Dam) and Wheeler Reservoir. 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 including land purchases, transmission lines, and electric generation plants located at the dams.

As these projects were proposed and construction began, concerns grew over the impoundment of large bodies of water. It was estimated that the system of lakes and reservoirs created by the dams would lead to a shoreline 10,000 miles in length covering 600,000 acres of water, creating a large breeding ground for mosquitoes (Derryberry and Gartrell 1952). From the beginning the TVA tried to address concerns about malaria without heavy use of insecticides. The TVA used a variety of techniques ranging from introducing natural predators of mosquito larvae, destruction of habitat through drainage and periodic water fluctuations, brush clearing, larvacides, oiling, and eventually DDT (Gartrell and Ludvik 1954, TVA Annual Report 1945).

Perhaps the TVA's largest effort came through the nearly costless plan to vary the water levels in the reservoirs, as shown in Figure 1. During the winter and early spring months, the TVA would store winter rain water at dams located along upstream tributaries. As the mosquito breeding season approached, the TVA would begin releasing the stored water into downstream reservoirs, raising the water level a few inches. This would flood potential breeding grounds for mosquitoes. The following week, flooding would occur in the next reservoir downstream in the system. This led to a drying along the shoreline in the upstream dam, exposing the mosquito larvae to natural predators. This process of fluctuating the water levels in the reservoirs continued throughout the entire system until the end of the breeding season .

The TVA's efforts involved the largest collection of engineers and experts working to fight malaria in the United States. As malaria rates began to decline, the TVA began to receive praise for its strong efforts. The CDC lists the TVA's accomplishments on its malaria history website.

> "An organized and effective malaria control program stemmed from this new authority in the Tennessee River valley. Malaria affected 30 percent of the population in the region when the TVA was incorporated in 1933... and by 1947, the disease was essentially eliminated. Mosquito breeding sites were reduced by controlling water levels and insecticide applications."

While rates were declining, it is unclear if the TVA was a causal factor, or merely experiencing part of a secular trend, driven in part by the USPHS, WPA, and MCWA. A simple model incorporating the transmission of disease from mosquito to human and back to mosquito accounting for changes in sitting water and control efforts is unlikely to provide satisfying predictions. This is because it is unclear a priori, if the water effect or control effect will dominate. This helps to motivate an empirical model to estimate the net effect of a TVA dam on malaria rates.

# 3 Change in Disease Rates

To identify the causal effect of the TVA on malaria rates in the Southeast United States, I constructed a panel data set from county level disease specific data. The exogeneity of the dams with respect to malaria rates will allow the effect to be identified using within county variation across time, controlling for state wide shocks occurring in specific years. Given the panel nature of the data employed, I am able to control for a variety of features such as county specific shocks, year specific shocks, auto correlation, and correlation across geographic space. One concern that may arise is that the TVA chose dam location sites because they had higher malaria rates. Evidence from the first TVA annual report suggests that the TVA obtained

Army Corps of Engineering project designs and locations for its first two dams. When it began its own reservoir design, it viewed the malaria problem as something to control once construction had begun or was completed. The 1934 TVA annual report states that

> "Health studies and supervision have been undertaken in the regions around construction camps, and studies for malaria elimination are in progress around the reservoirs with a view to preventing increase of malaria when the reservoirs are filled"[3]

## 3.1 Empirical Model of Malaria Rate

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

$$M_{it} = C_i + Y_t + \beta_1 TVA_{it} + \beta_2 Climate_{it} + \beta_3 X + \varepsilon_{it}$$

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 $i$ that did not vary over time. For example, features such as mountains, altitude, latitude, and longitude are are captured by this fixed effect. $Y_t$ is a vector of year fixed effects. The year fixed effects control for nation-wide epidemics and widespread shocks affecting the malaria rate.[4] $TVA_{it}$ is an indicator that equals 1 if county $i$ in year $t$ is located on a completed TVA reservoir. $Climate_{it}$ is a vector of variables constructed from historical climate data and includes monthly average temperatures, monthly precipitation, and an interaction term of the two variables. $X_{it}$ is a vector of time varying county level features, that include the presence of a County Health Organization (CHO) as well as other demographic covariates that help control for key variables, such as population density and percent black in the population.

One key assumption in this estimation framework is that the disease rates in counties that received dams were not on differential trends from counties that did not receive dams. Figure 2 evaluates this claim by showing the average mortality rate in Alabama from 1916 - 1933 by eventual TVA dam status. [5] Counties in blue

[3] TVA Annual Report 1934 p.6

[4] Andrews, Quinby, and Langmuir in 1950 report a nationwide malaria epidemic ranging between the years 1933-1937

[5] The analysis is limited to Alabama due to pre treatment data constraints

represent counties in Alabama that never received a TVA dam and counties in red are those that eventually obtained a TVA dam. Between 1916 and 1933, prior to the creation of the TVA, there is no aparent difference in the mortality rate between the two types of counties.

The impact of a dam can be seen in Figure 3 , which presents a time series of the malaria morbidity rate for two adjacent counties, Limestone County, located on Wheeler Reservoir and Marshall County, which is not on the reservoir. The first vertical line in Figure 3 denotes when construction began at the reservoir, the second denotes the completion of construction. Prior to construction, the morbidity rates in the two counties had similar trends. However, following the beginning of construction, Limestone County, experienced a major increase in the malaria morbidity rate, while Marshall County did not. The increase in Limestone County persists through the completion of construction and remains higher than the initial rate for several years to follow. This comparison is just one example of the kind of differences between counties that help identify the effect of the TVA.[6] While there is a spike following initial construction, in most counties receiving a TVA dam it is not possible to identify when reservoir flooding began. Therefore the TVA variable is restricted to counties being located on completed reservoirs.

If counties experience a spike in the malaria rates when construction begins, rather than when the reservoir is completed, the point estimate of $\beta_1$is downward biased. Other effects will also present potential biases on the coefficient of $\beta_1$. Dams potentially lead to increases in that wealth which in turn could lead to a decrease in the probability of contracting malaria. Dams also change the distribution of the population within the county by removing an at risk population that was living in close proximity to the water. Both the income and population removal affects would lead to downward bias of $\beta_1$. One further complication in the empirical specification is that humans are mobile, possibly leading to spillovers in neighboring regions. This spatial aspect will be examined directly in the robustness checks with the use of spatially weighted regressions.[7]

## 3.2 Malaria Rate Data

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

[6] Effects at other reservoirs are available upon request

[7] Mosquitoes are limited in their flight range to 1 mile, leading any spillovers to be caused by human mobility or regional shocks such as weather events.

health department and from the Vital Statistics of the United States.[8] These state level reports provide the best insight into the prevalence of disease during the period. County level statistics were used by policy makers to make decisions about funding and control efforts. For example, in 1945, when DDT was released to state health agencies, the counties that received DDT were determined by their average mortality rate between 1938 and 1942.[9] While there are some instances of more accurate blood smear surveys in elementary schools, these surveys are few and far between, making the county level statistics the most reliable malaria source during the period. Directly using mortality and morbidity rates has several advantages over previously employed methods. Namely, the probability of infection does not have to be inferred from climate and geographic variables or other crude measures such as the infant mortality rate. It should also be noted that the reported rates may actually be a lower bound estimate of the true prevalence in a county. Reporting of illness only occurred if a person was attended to by a physician. Contemporary malaria experts believed that the true prevalence was between 200 and 400 percent higher than reported rates.[10]

I 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 the monthly average, maximum, and minimum temperatures as well as precipitation data collected at each weather station throughout the country. County level observations were constructed through a triangular interpolation method.[11]

TVA Annual Reports to Congress are used to determine the locations of reservoirs. 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. In the absence of upstream

[8] When crude death rates were reported, they were used as observations, however, in some years, only the raw number of cases of illness and deaths were reported. In raw data years, rates were constructed using county populations interpolated between census years.

[9] Alabama State Board of Health Annual Report 1946 p217

[10] Malaria Control in War Areas 1942.

[11] One obstacle in dealing with this data is that there are far fewer weather stations than there are counties.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, $w_i = \frac{1}{2}(1 - \frac{d_i}{d_1+d+d_3})$ 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.

dams, the water level fluctuation would not be possible, likely creating more stagnation in the reservoir. Reservoirs further downstream are likely to gain the most due to increased control over the water level and flow rates through the reservoir.

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. The opening of a health agency is likely endogenous, however it can be shown that the opening of a CHO and a TVA reservoir are uncorrelated, thus including the presence of a CHO will not bias the estimate for the TVA.[12]

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 impoundment that were affected by the work.

Population characteristics are 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 affected 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 are 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.

[12] Auxiliary regression based evidence is available upon request of the author

## 3.3 Empirical Results

The regression results in Tables 2 and 3 show that there are statistically and economically significant increases in both the mortality and morbidity rate associated with the TVA. Depending on the specification, the TVA increases mortality rates by 3 to 4.4 deaths per 100,000 and increases morbidity rates between 7.1 and 13.9 cases per 10,000. This estimate is the net effect of having a TVA reservoir in the county, taking into account the campaigns financed and implemented by TVA as well as all possible channels through which dams affect malaria.

Column 1 of Table 2 presents the OLS results with the inclusion of county specific fixed effects, the estimated net effect of a TVA reservoir located in a county results in a 4.4 increase in the malaria mortality rate. Specification 2 adds year fixed effects, and specification 3 includes state by year fixed effects. State by year effects may be important to control for changes in the way reporting occurs, or to capture changes within the structure of the state level health agency. Even after controlling for a large portion of variation with the inclusion of various fixed effects, the TVA coefficient remains positive and large. The point estimate represents a forty to fifty percent increase in malaria mortality relative to the sample mean.

As predicted, the number of dams upstream reduces the malaria burden downstream.[13] This is a direct result of the water level fluctuations which are used to expose mosquito larvae to the elements. However, as additional controls are added the statistical significance declines. Other control activities, such as draining and ditching have little effect on mortality rates which is consistent with qualitative evidence. Humphreys (2001) discusses how many of the WPA projects were poorly constructed, leading to stagnate pools of water in drainage ditches.

Table 3 presents the full set of morbidity results. Column 1 presents the results with the inclusion of county fixed effects. Column 2 adds year specific effects and Column 3 includes state by year effects. In each specification, the presence of a TVA reservoir increased morbidity by a statistically significant amount. The upstream dams played a crucial role in mitigating malaria morbidity in downstream reservoirs. While having a reservoir in the county increases rates up to 13.9 cases, having a dam located upstream leads to a 1.7-2.4 reduction in the number of cases. For some locations, this could completely offset the malaria increase caused by the TVA reservoirs. Counties located adjacent to head water dams, such as Norris, received no benefits from the water fluctuations, however, as one moves downstream, there

[13] The results are robust to a variety of functional forms of the number of dams upstream. Including quadratics, cubics, etc does not change the interpretation of the upstream dams

is an increasingly positive effect. A dam such as Ft. Loudon, with only one dam upstream only experienced minor benefits from upstream dams, however, a dam like Pickwick, located in Hardin County, TN, eventually had 11 dams located upstream from it. Its malaria rate fell from a high in 1935 (when construction began) of 122 illnesses per 10,000 to zero by 1951.

Parts of other New Deal programs also seem to have been effective at reducing the morbidity rate. 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 have worked, ditching is associated with increases in the malaria rate. The Tennessee Department of Public Health Biennial Reports related how some of the ditches constructed were of poor design and led to more debris collecting, exacerbating the problem.

## 3.4 Robustness Checks

Results from alternative specifications suggest that the results presented in Table 2 and 3 (Columns 1-3) are robust. The baseline specification assumes that malaria rates were not correlated over time. The plasmodium vivax parasite can live in the blood stream for up to three years, so shocks that occur in the past might have effected rates in the future. Furthermore, there are two potential ways that spatial spillovers may affect the baseline results. Some spatial correlation is induced into the model due to the interpolation of climate data. Because the data are interpolated, data in a given county will be correlated across space with other counties sharing the same weather station observation. To account for this, I adopt a method posed by Cameron, Gelbach, and Miller (2010), which clusters observation along multiple dimensions. The second spatial issue arises from the natural geography. 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 where mosquitoes might breed. This means that if there is a shock in one area, it could affect other cross sectional observations. To account for this, I re-estimate the model using a spatial error model, as posed in Anselin (1988) and LeSage and Pace (2009).

Tests of the fixed effects residuals indicate that auto correlation only persisted for one period. The auto correlation parameter is estimated using the Prais-Winsten procedure with an AR(1) error process. Results from this regression are presented in Table 2 Column 4 for Mortality, and Table 3, Column 4 for morbidity. The estimated net effect of a TVA reservoir, accounting for auto correlation, remains positive and statistically significant.[14] The correlation coefficient across time periods is .295 for mortality and .344 for morbidity.

Results from the Cameron, Gelbach, and Miller (2010) multidimensional clustering are presented in Column 5 of Tables 2 and 3. These regressions are clustered to account for shocks occurring at each of the three weather stations used in the interpolation of the climate variables. After accounting for this error structure, the standard errors change, however, the significance levels of the variables are unchanged, leaving the qualitative interpretation of the TVA projects the same.

Spatial spillover may also influence the rate of malaria transmission. Moran I tests reveal the potential for spatial correlation in the error structure. To account for spatial spillover, I estimate the model with the inclusion of spatially correlated errors. Column 6 of Tables 2 and 3 presents the results of a spatial error model (SEM). In this model, errors occurring in neighboring cross sectional units are weighted by proximity to the $i^{th}$observation.[15] Once this spatial dependence in the errors is taken into account, the results remain unchanged. In all specifications the net effect of the TVA was a large increase in malaria mortality and morbidity.

In the current empirical specifications, it is assumed that reservoir construction does not differentially impact counties. However, epidemiological research suggests that areas that had relatively low malaria rates prior to treatment should experience larger increases in malaria rates than counties that had historically high malaria rates. To determine if there were differential effects of receiving a dam, I modify the empirical specification by interacting the presence of a reservoir with lagged malaria rates. The results from this regression are presented in Table 3, with results mortality results presented in Column 1 and morbidity results presented in Column 2. When this interaction is included in the analysis the TVA reservoir point estimate falls, yet remains positive and statistically significant. The results also show that there were differential effects for counties that had high or low levels of malaria prior to the dams arrivals. If a county had a one point lower death rate, it experienced a .267 increase in the number of deaths per 100,000 individuals when it received a

[14]The Durbin Watson Statistic is 1.37 (1.8 transformed) for mortality and 1.29 (1.9 transformed) for morbidity, which indicates there is little if any auto correlation.

[15]To construct this weighting matrix, I estimate the distance between county seats in kilometers, and use the normalized inverse distance to weight the errors of neighboring counties.

reservoir.[16] The effect is similar using morbidity as the outcome variable of interest, however it is statistically insignificant. In each additional specification the results remain positive and statistically significant.

### 3.5 Placebo Regressions

While the results suggest that the introduction of TVA reservoirs 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 might make it appear as though the TVA was the cause of a malaria rate increase when 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.

Measles has several nice properties for the purpose of this exercise. First and foremost, it is not a waterborne disease. Changes in the water environment should not affect the transmission of measles. Furthermore, it is an airborne virus that infects a large portion of the population. Data for measles morbidity rates come from the Alabama State Board of Health Annual Reports and Tennessee Morbidity Report.

In this setting, I substitute the measles morbidity 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 reservoirs and measles. The full set of results is presented in Table 4. This suggests that when the TVA entered the region, it only raised malaria rates and not morbidity for other major diseases.

## 4 The Cost of the TVA

By combining the results based on the change in malaria rates and external value of life and morbidity estimates I calculate a rough estimate of the dollar cost of the TVA. 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, the cost of malaria is calculated by multiplying the lost income by the TVA coefficient. This will provide a cost per 10,000 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

[16] These results are robust to a number of different lags interacted with the TVA Reservoir variable

total cost associated with morbidity.[17]

There were an additional 7.1 and 13.99 cases per 10,000 individuals in a TVA reservoir county each year. After adjusting the estimates to 2009 dollars; the TVA morbidity costs ranged between $7.4 million 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 $1.7 – $10 million.

Mortality rates also increased as a result of the TVA building a dam. Estimates for this increase range from 3-4.5 deaths per 100,000 per county per year. Costa and Kahn (2004) construct estimates for the value of a statistical life during the 1940's. They find that during the period a life was valued between $1.1 and $1.6 million.[18] Using conservative estimates, a VSL of $1.1 million, and a rise in mortality of 3-4.5 deaths per 100,000, the resulting cost, ignoring the effects of upstream dams is $508 million-1.06 billion. When upstream effects are included in the calculation, the cost falls to $340-826 million in lost life.

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. 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 $8.6 million (year 2009 dollars) to save an infant's life. Using this set of estimates, I find that the TVA malaria cost up to $5.6 billion when upstream effects are ignored and between $565 million and $4.3 billion when upstream effects are used.[19]

# 5 Conclusions

This paper examines the role of large scale reservoir construction on malaria rates in the Southeastern United States using a unique data set collected from state level health publications. The creation of the TVA provided an exogenous change in the disease environment, allowing the identification of the causal effect. The results show

[17] External estimates of malaria morbidity are approximately $45 in the 1930's, however, these are a small fraction of the cost relative to the lost life. Other estimates were constructed using TVA form 970 and appeared in an earlier draft of this paper.

[18] Adjusted to 2009 price level.

[19] Using estimate presented in Viscuzi and Aldy (2003) the range increase upward to $5.8 billion, however these estimates are based on modern VSL's

that the presence of a TVA reservoir led to a large increase in the malaria morbidity and mortality rate. This increase in malaria rates implies a large hidden cost due to illness and the loss of life.

The TVA provides insight into a growing problem around the world today. As more developing 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 tackling the malaria problem in the Southeast, had to take action because of the increases in sitting water in the reservoirs. These increases in sitting water increased the breeding ground for mosquitoes, which ultimately led to an increase in malaria. 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 support that this method reduced the malaria problem. This method can be used at low cost and is easily implemented. A note of caution, the TVA storage reservoirs upstream were typically located in mountainous areas, which are less susceptible to malaria due to their higher elevations and cooler climates. Attempting upstream water storage for mosquito prevention may not work as well in areas with warmer and wetter climates or lower elevations.

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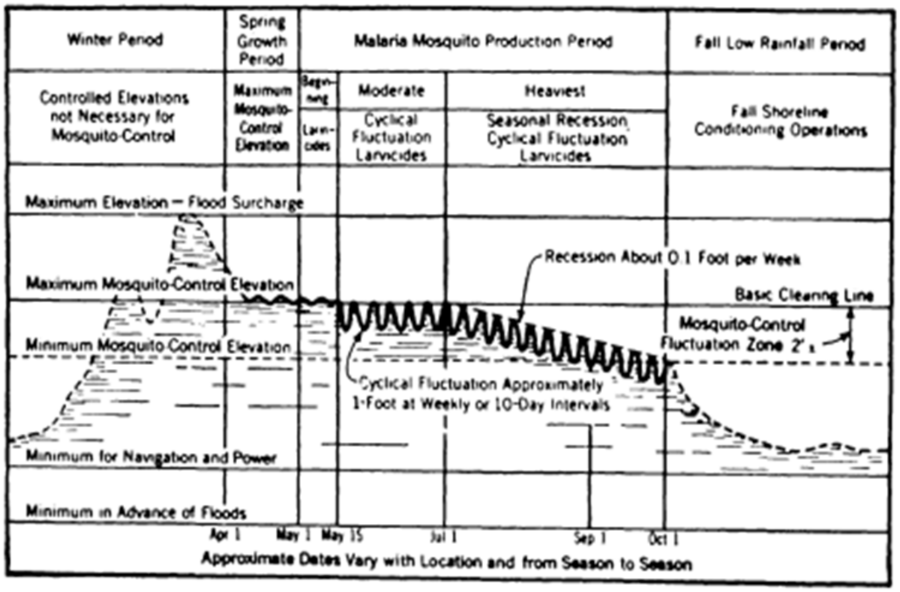
# Tables and Figures

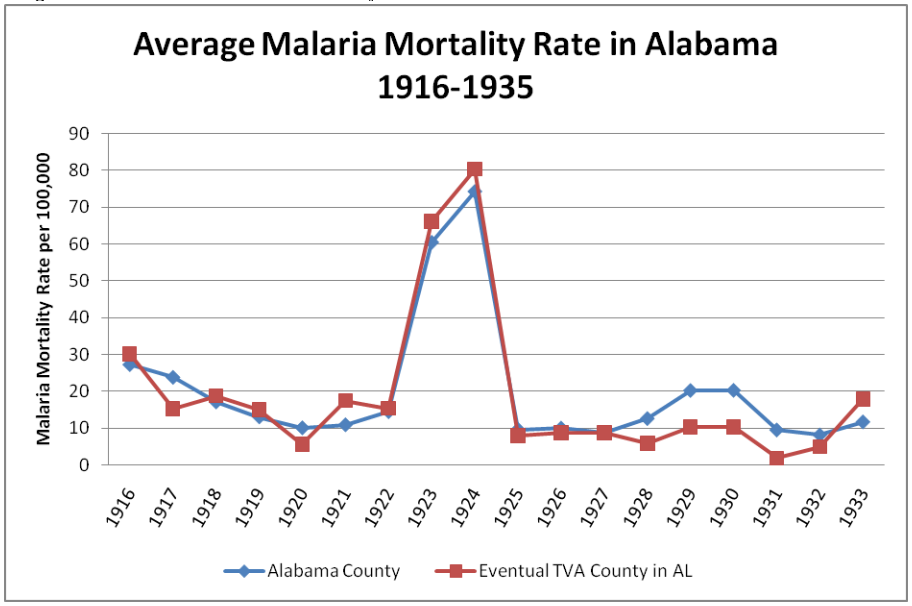
## Figures

Figure 1: Water Level Fluctuations



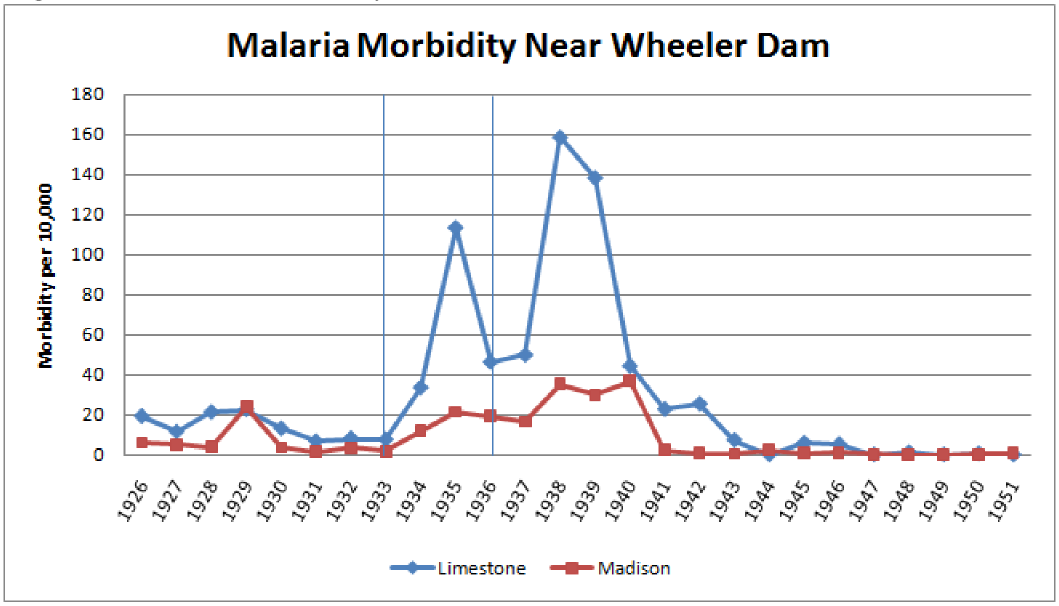

Source: Kitron and Spielman (1989)

Figure 2: Malaria Mortality in Alabama 1916-1935




Source: Alabama State Board of Health Annual Reports 1916-1933

Figure 3: Malaria Morbidity Near Wheeler Reservoir




Source: Alabama State Board of Health Annual Reports 1925-1951

## Tables

**Table 1: Summary Statistics of Malaria Rate**

| Variable | Obs | Mean | Std Dev | Min | Max |
|---|---|---|---|---|---|
| Deaths/100,000 | 3955 | 10.06 | 34.58 | 0 | 1117.46 |
| Morbidity/10,000 | 4530 | 11.6 | 31.55 | 0 | 828.5 |
| TVA Reservoir | 4787 | 0.06 | 0.23 | 0 | 1 |
| County Health Agency | 4312 | 0.61 | 0.49 | 0 | 1 |
| Percent Black | 4785 | 23.05 | 22.65 | 0 | 87.27 |
| Pop. Density | 4787 | 57.98 | 66.51 | 11.09 | 658.86 |
| Percent Urban | 4785 | 14.46 | 18.62 | 0 | 85.48 |
| **Average Temp** | | | | | |
| January | 4787 | 430.3 | 69.64 | 202.87 | 659.2 |
| February | 4787 | 450.83 | 64.46 | 279.76 | 643.74 |
| March | 4787 | 518.22 | 59.01 | 366.18 | 671.75 |
| April | 4787 | 601.64 | 40.24 | 501.45 | 713.66 |
| May | 4787 | 682.45 | 35.51 | 584.48 | 785.79 |
| Jun | 4787 | 759.39 | 31.29 | 663.5 | 834.36 |
| July | 4787 | 784.09 | 26.15 | 677.5 | 860.01 |
| August | 4787 | 776.44 | 29.5 | 681.61 | 855.99 |
| September | 4787 | 725.56 | 40.02 | 620.31 | 844.87 |
| October | 4787 | 622.42 | 44.09 | 513.13 | 779.68 |
| November | 4787 | 504.43 | 48.32 | 393.41 | 658.78 |
| December | 4787 | 436.65 | 59.23 | 287.24 | 630.51 |
| **Precipitation** | | | | | |
| January | 4787 | 530.4 | 321.33 | 31.78 | 2281.33 |
| February | 4787 | 482.75 | 246.02 | 22.34 | 1404.13 |
| March | 4787 | 589.13 | 254.58 | 45.01 | 1821.87 |
| April | 4787 | 449.76 | 225.04 | 50.22 | 1517.81 |
| May | 4787 | 398.51 | 199.71 | 17.65 | 1505.49 |
| Jun | 4787 | 411.98 | 210.52 | 16.77 | 1670.15 |
| July | 4787 | 509.89 | 232.39 | 63.39 | 2221.72 |
| August | 4787 | 417.96 | 206.03 | 25.02 | 1958.03 |
| September | 4787 | 312.76 | 195.5 | 3.37 | 1310.63 |
| October | 4787 | 277.8 | 200.4 | 1.49 | 1316.86 |
| November | 4787 | 384.17 | 251.14 | 1.05 | 1551.56 |
| December | 4787 | 473 | 242.52 | 68.02 | 1715.94 |

Table 2: Malaria Mortality Regression Results

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| TVA Reservoir | 4.409 *** | 3.083 *** | 2.835 *** | 3.413 *** | 3.083 *** | 4.500 *** |
| | (0.914) | (0.795) | (0.594) | (1.262) | (1.157) | (0.857) |
| Number of Dams Upstream | -0.768 ** | -0.274 | -0.307 * | -0.217 | -0.274 | -0.591 *** |
| | (0.329) | (0.360) | (0.169) | (0.242) | (0.273) | (0.167) |
| WPA Ditches | 0.007 | -0.013 | -0.022 | 0.013 | -0.013 | -0.012 |
| | (0.034) | (0.035) | (0.024) | (0.015) | (0.043) | (0.015) |
| WPA Ditch Clearing | 0 | 0.008 | 0.009 | 0.007 | 0.008 | 0.007 |
| | (0.009) | (0.009) | (0.006) | (0.007) | (0.011) | (0.914) |
| WPA Acres Filled | 0.001 | 0.001 | 0.002 | -0.001 | 0.001 | 0.003 |
| | (0.002) | (0.002) | (0.002) | (0.003) | (0.003) | (0.816) |
| | | | | | | |
| Climate Variables | Y | Y | Y | Y | Y | Y |
| County FE | Y | Y | Y | Y | Y | Y |
| Year FE | N | Y | Y | Y | Y | Y |
| State X Year FE | N | N | Y | N | N | N |
| | | | | | | |
| N | 3257 | 3257 | 3257 | 3257 | 3257 | 3257 |

* p<.10, **p<.05, *** p<.01

Note: Spec 4 Accounts for AR(1) error structure

Note: Spec 5 Clusters Error at Weather Station Level

Note: Spec 6 Adjusts for Spatial Correlation in Errors

Table 3: Malaria Morbidity Regression Results

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| TVA Reservoir | 13.991 *** | 11.597 *** | 7.135 *** | 10.358 ** | 11.597 *** | 11.751 *** |
| | (4.003) | (4.237) | (2.267) | (4.347) | (2.716) | (2.620) |
| Number of Dams Upstream | -2.449 *** | -2.222 *** | -1.712 *** | -1.981 ** | -2.222 *** | -2.182 |
| | (0.744) | (0.746) | (0.435) | (0.778) | (0.630) | (0.479) *** |
| WPA Ditches | 0.048 | 0.048 | 0.011 | 0.054 | 0.048 | 0.054 |
| | (0.042) | (0.054) | (0.051) | (0.056) | (0.052) | (0.052) |
| WPA Ditch Clearing | -0.006 | 0.002 | 0.011 | 0.02 | 0.002 | -0.004 |
| | (0.011) | (0.011) | (0.014) | (0.025) | (0.015) | (0.024) |
| WPA Acres Filled | -0.02 *** | -0.022 *** | -0.026 *** | -0.022 ** | -0.022 *** | -0.021 |
| | (0.005) | (0.006) | (0.007) | (0.010) | (0.007) | (0.011) ** |
| Climate Variables | Y | Y | Y | Y | Y | Y |
| County FE | Y | Y | Y | Y | Y | Y |
| Year FE | N | Y | Y | Y | Y | Y |
| State X Year FE | N | N | Y | N | N | N |

* p<.10, **p<.05, *** p<.01

Note: Spec 4 Accounts for AR(1) error structure

Note: Spec 5 Clusters Error at Weather Station Level

Note: Spec 6 Adjusts for Spatial Correlation in Errors

Table 4: Heterogeneous Effects of a TVA Reservoir

| | Mortality | Morbidity |
|---|---|---|
| TVA Reservoir | 2.325 ** | 9.164 ** |
| | (0.916) | (3.984) |
| Malaria Rate $_{t-1}$ | 0.021 | 0.563 *** |
| | (0.030) | (0.134) |
| Malaria Rate $_{t-1}$ x TVA | -0.267 *** | -0.303 |
| | (0.090) | (0.388) |
| Number of Dams Upstream | -0.376 | -2.773 |
| | (0.258) | (0.923) |

* p<.10, **p<.05, *** p<.01

Table 5: Measles Regression Results

| | 1 | | 2 | | 3 | |
|---|---|---|---|---|---|---|
| TVA Reservoir | 3.033 | | 1.516 | | 1.934 | |
| | (3.187) | | (2.888) | | (3.147) | |
| Number of Dams Upstream | -6.691 | ** | -5.009 | * | -4.214 | |
| | (2.583) | | (2.653) | | (2.695) | |
| New CHO | 5.372 | ** | 7.046 | *** | 7.085 | *** |
| | (2.142) | | (2.436) | | (2.384) | |
| CHO | -1.308 | *** | -0.484 | | -0.744 | |
| | (0.462) | | (0.479) | | (0.500) | |
| WPA Ditches | 0.033 | | -0.073 | | -0.113 | * |
| | (0.049) | | (0.053) | | (0.062) | |
| WPA Ditch Clearing | -0.041 | *** | -0.016 | | -0.007 | |
| | (0.011) | | (0.013) | | (0.014) | |
| WPA Acres Filled | 0.018 | | 0.024 | ** | 0.024 | * |
| | (0.011) | | (0.012) | | (0.012) | |
| Pct Black | 0.599 | ** | 0.317 | | 0.314 | |
| | (0.287) | | (0.300) | | (0.308) | |
| Pop Density | -0.113 | | -0.097 | | -0.094 | |
| | (0.072) | | (0.066) | | (0.066) | |
| Pct Urban | -0.653 | *** | -0.114 | | -0.148 | |
| | (0.204) | | (0.228) | | (0.214) | |
| Climate Variables | Y | | Y | | Y | |
| County FE | Y | | Y | | Y | |
| Year FE | N | | Y | | Y | |
| State X Year FE | N | | N | | Y | |

* p<0.10, ** p<0.05, *** p<.01