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## Dynamics of lake-level fluctuations and economic activity

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This paper examines the relationship between lake level and economic activity in the context of population growth, regional economic conditions, and the seasonal nature of economic activity. Quarterly economic activity in four economic entities (i.e. three municipalities and the county) is examined in a multivariate time series analysis that accounts for the change in population, context of regional unemployment and seasonal variation. The results of the multivariate time series analysis demonstrate that lake level has a negative curvilinear relationship with economic activity. This relationship is limited to the retail trade sector in the nearest municipality, which also has the least diversified economy. Tests show that prior lake levels can forecast retail trade in this limited case, which indicates lake level is causally prior to retail trade.

**Keywords:** water resource management; lake-level dynamics; economic activity of lakes; valuing water amenities; Granger causality

### 1. Introduction

This paper examines the dynamic relationship between lake level in a human-made reservoir and economic activity. This relationship is examined in Montgomery County, Texas, located north of Houston and one of the fastest growing counties in the United States. Montgomery County has historically relied on groundwater as the primary water source, but the Lonestar Groundwater Conservation District determined that groundwater is being overused. Up to 100,000 acre-feet of water from Lake Conroe annually may be used to overcome any groundwater shortages. Lake Conroe is a 21,000-acre reservoir completed in 1973 as a supplemental water supply for the City of Houston. Until the drought of 2011, Lake Conroe was never used for this purpose. As a result, the reservoir has remained at relatively constant lake levels since 1973 – falling below 4 feet below full pool (BFP) only three times in 36 years of lake records (Figure 1). This paper examines the relationship between lake level and economic activity in terms of the historical economic activity and lake-level records. These revealed preferences data are analysed in terms of population growth, regional economic context, and annual seasonal variations.

The current political climate in Texas demonstrates that both political parties agree that water resource allocation is a current and future problem, but neither party can agree or compromise on a solution. Proposed solutions advocate allocating billions of dollars from oil and gas tax revenue or other revenue sources for water-related projects. The purpose of these water-related projects may enable the state to adapt to future drought

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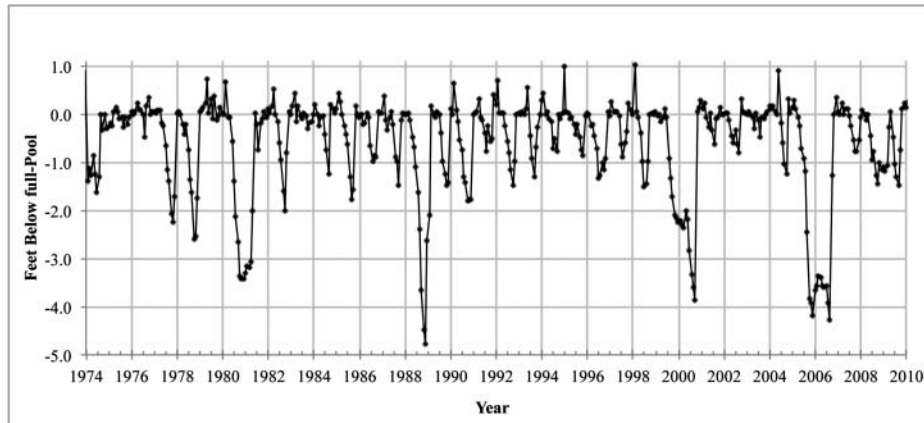


Figure 1. Average monthly lake-level at Lake Conroe 1974-2010.

better, although uncertainty exists regarding specifics of how these funds will be used (Galbraith 2013).

However, the water issues in Texas are not limited solely to drought. Lost in much of the current political debate related to the recent drought is the role of population on limited water resources. This fact means that Texas must manage its limited water resources during a time of seemingly unlimited population growth. Traditionally, mineral-rich Texas is known more for its oil and gas wells. The current situation means that the future of Texas and its ability to grow its population relies as much on the discovery of additional sources of water as on additional sources of oil and gas to fund the search for water.

This paper focuses on the effects of lake-level dynamics on sales tax revenue in four local government entities. While the amenity is located at some distance to each local government entity, the lake-level focus allows for the amenity itself to change. In human managed systems, like reservoirs, this provides additional insight into the impact of environmental management and planning decisions. This approach allows the relative value of the amenity to be estimated. For example, it could be used to estimate the degree of value a view might have depending of the clarity of the view (e.g. shrouded by air pollution), or the relative value of a reservoir as water is released for alternative purposes resulting in various lake levels. This approach has the advantage of focusing on economic activity reflecting the consumer economy, which is very responsive to environmental changes compared to the capital expenditures of property sales. It focuses on the economic and geographic dynamics, with differing spatial patterns and economic conditions with respect to the natural amenity. Finally, the use of time series affords the direct empirical examination of cause (Granger 1969, 1980, 1988).

## 2. Literature review

There are two fundamental methods for valuing the impact of environmental amenities: expressed preferences and revealed preferences. Expressed preferences usually employ surveys asking respondents to express views related to environmental change. These surveys use willingness-to-pay models, contingent valuation analysis or travel cost methods. Revealed preferences employ hedonic models, input-output models, and related linear methods to examine connections between economic activity and lake-level

fluctuations. Hedonic models focus on property values (rather than business activity) based on the availability of residential property data for property analysis. Input-output models quantify the financial value of an amenity in relation to a local economy.

Expressed preferences in the form of contingent value and travel cost method have been used to examine issues related to lake-level fluctuations. Walsh, Aukerman, and Milton (1980) and Cameron (1992) used contingent valuation to estimate losses ranging from \$3 to \$35 per person per day related to low lake levels for reservoirs and fisheries. Four other studies focused on management decisions related to lake levels in reservoirs. Using willingness to pay methods, Cordell and Bergstrom (1993) found users were willing to pay \$51 to \$75 for longer periods of higher lake levels, while Allen (2010) found that recreational users spend an average of \$25 to \$30 a day, for a possible economic loss of nearly 1 million dollars due to lower lake levels. Heller, Clayton, and Throneburg (2005) found that minimal drawdowns have minimal impacts on home values and recreational spending, while Sorte and Buerger (2006) found that lake drawdowns have a localised impact on lakeside businesses that are small in the context of regional economies.

Surveys of recreational users have been used to estimate the value of lake loss and lake level. Fadali and Shaw (1998) found users were willing to pay \$83 per season on average, or \$4 million annually in recreational demand. Hatch and Hanson (2001) found revenue declines as-much-as 47%, even though 63% reported not using the lake. Unlike studies covering current visitation, some expressed preference studies estimate future visitation and associated expenditures. Murray *et al.* (2003) estimated that the impact of delaying drawdown increases revenue ranging from \$5.4 to \$7.5 million. Stable lake levels have been associated with \$7.1 million in economic value, while low lake levels are tied to \$33.5 million in economic losses (LaRue, Shoham, and Wyatt 2011), with the brunt of those losses borne by lakeside businesses.

The disadvantage of expressed preferences lies in the fixed survey nature of the data, which provides feedback for the specific issues under consideration. Unfortunately, expressed preferences provide little insight into past behaviour, much less predicting future behaviour. Nonetheless the survey approaches provide meaningful data for the determination of the value of lake-level fluctuations. The expressed preference surveys confirm that lakefront businesses are impacted the most, the overall impact on the regional economy depends on the importance of the lake as an economic driver, and lowering lake levels has a negative impact that decreases quickly with distance.

### 3. Revealed preferences

The revealed preference literature relies on economic transactions disaggregated in hedonic models. The lack of lakefront business data results in most hedonic models focusing on residential property. For example, in two studies of lakes near Austin, Texas, Lansford and Jones (1995a, 1995b) showed that stable lake levels improve residential property values, with the recreational and aesthetic values increasing by 15–22%. Kashian (2008) estimated that a government ordered drawdown of 2-inches reduces residential property values by 8.5%, showing that even small changes in lake level can have a significant impact on surrounding properties. Cho, Bowler, and Park (2006) found a wide range of increases (\$12–\$4232) associated with being closer to the lake. Loomis and Feldman (2003) revealed significant premiums for lakefront property (\$209,490 on average) that decline with distance from the lake in a curvilinear manner. As lake levels decline, each additional foot of receding shoreline reduces property values by 1%. The wide ranging nature of the model specifications and findings reinforces the uniqueness of

the effects of lake level. Hedonic models provide excellent estimates for a specific geographic area at a given time, but the results are not generalisable, nor can parameter estimates be applied to another area and lake.

A regional approach was used on two lakes in the southeastern US. At Lake Hartwell, on the Georgia-South Carolina border, Allen *et al.* (2010) used the regional dynamic impact model to estimate that a 1 foot decrease in lake level reduced visitors by more than 21,000 (2.5%), and decreased regional economic activity by \$18.8 million. At Lake Lanier, Georgia, the Bleakly Advisory Group (2010) found that lake levels 15.2 feet BFP in 2008 produced 880,000 fewer visitors and a loss of \$90.2 million (i.e. 43.6% of the annual lake impact) or 2.2% of the regional economic activity. These studies indicate that the impact of lower lake levels in the regional economy may be small, but the impact on the local economy may be significant.

The literature reviewed here focused on the literature most relevant to businesses at Lake Conroe. This review highlights some important findings:

- (1) There are not enough businesses near the lake to use hedonic modelling;
- (2) Economic impact models are likely to overstate the effects by including businesses not dependent on lake activity;
- (3) Surveys of local businesses provide examples of significant impacts, but fail to provide compelling data required to determine cause;
- (4) Impact can be significant, but is often confined to properties adjacent to the lake; and
- (5) Lakeside economies are often a small fraction of the regional economy.

#### 4. Data and methods

Lake Conroe is one of the premiere natural amenities in Montgomery County, Texas. First impounded in 1973, Lake Conroe is an earthen dam about 11,300 feet long with a height of approximately 80 feet at the mid-point (TWDB 2003). The original purpose of Lake Conroe was for water supply and irrigation, in addition to being an alternative water supply for Houston. While the lake is referred to as a constant-level lake, past water levels in the lake varied from 205.61 feet above mean-sea-level (MSL) on 17 October 1994 to 196.17 feet on 11 January 1989 (Freese and Nichols 2010). The lake reached a record low of 192.73 feet in December 2011 due to drought conditions. At extreme low levels, the lake becomes treacherous for boaters and many docks are on dry land. The conservation pool of 201 feet has a surface area of approximately 21,000 acres and contains approximately 416,200 acre-feet of water, of which 100,000 acre-feet can be withdrawn annually (TWDB 2003). Each acre-foot used is approximately 325,851 gallons of water, so 100,000 acre-feet per year equals 89 million gallons per day.

Population consistently increased over the study period (Figure 2).<sup>1</sup> During this period Montgomery County grew from more than 75,000 to more than 455,000, while Conroe grew from around 14,000 to 56,000. Willis grew from approximately 1600 to more than 5600, and the City of Montgomery grew from 230 to 620. Based on data from the 2010 Census, these were some of the fastest growing areas of Texas, which grew at a rate of 5.8% per year, while Montgomery County, and the Cities of Conroe, Willis and Montgomery grew at 16.4, 10.8, 9.5 and 7.3% per year, respectively.

Despite the growth in Montgomery County and the cities under study, the lack of growth in water resources is problematic. Historically, Montgomery County has relied solely on groundwater, but the current permitted use exceeds what the aquifers can

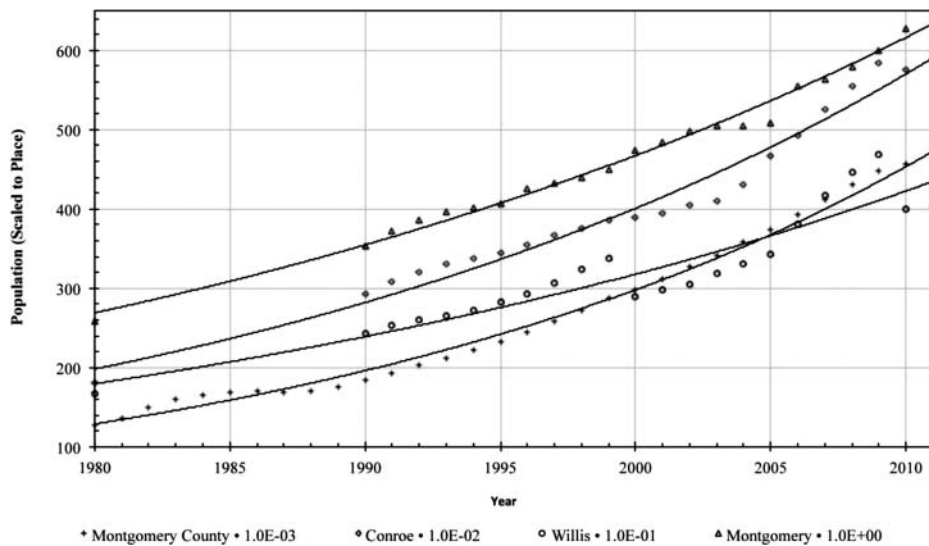


Figure 2. Annual population of Montgomery County and Four Municipalities by year 1980-2010.

replenish annually. The Lone Star Groundwater Conservation District estimates that the county will require 154,000 acre feet of water per year by 2040, but will limit groundwater withdrawal to 64,000 acre feet beginning in 2016 (Thaman and Potok 2006). Lone Star's proposal to make up for the shortfall requires reducing groundwater pumping by 30% of 2009 use by 2016, and develop alternative water sources to make up for lost groundwater production. The use of surface water is problematic for several reasons: (1) The largest single source of surface water in Montgomery County is Lake Conroe with the San Jacinto River Authority (SJRA) and Houston owning Lake Conroe water;<sup>2</sup> (2) surface water must be treated more than groundwater; and (3) surface water requires constructing a distribution system to connect to the existing distribution systems.

Figure 3 shows Lake Conroe and the surrounding area in Montgomery County, including the east-west corridor along SH-105 and the north-south corridor along I-45. The county is the largest governmental entity considered herein. While Lake Conroe extends into Walker County to the north, Montgomery County contains the three municipal entities, both economic corridors and most of the economically-active lakeshore areas.<sup>3</sup> Table 1 presents a comparison of Montgomery County and Conroe, Willis and Montgomery in terms of population, economic activity and geographic location in relation to Lake Conroe. Conroe's size and location at the crossroads of two economic corridors underlies the fact that it also has the most diverse economy of the three cities being studied. Willis has a small population and is relatively close to Lake Conroe, but also largely influenced by the I-45 corridor. The City of Montgomery is clearly the smallest of the populations, and the most isolated from the I-45 economic corridor and much of the SH-105 corridor; its geographic location and economic activity are more closely tied to Lake Conroe and isolated from other influences.

This research examines the relationship between lake levels and economic activity. If a relationship exists, it is thought to be a direct relationship where falling lake levels negatively impact economic activity. Small changes from full pool are expected to have

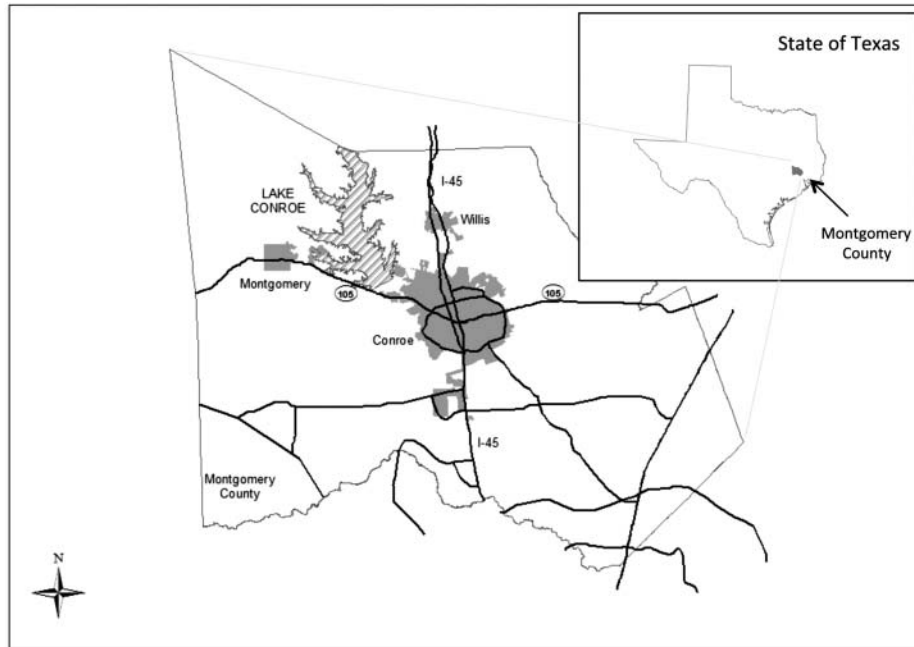


Figure 3. Lake Conroe, Texas Area Map.

Table 1. Comparison of local government entities.

	Montgomery County	Cities of		
		Conroe	Willis	Montgomery
Population 2010	455,761	57,466	3,995	1,377
Retail trade (2010)*	\$2025.8	\$479.4	\$29.4	\$9.9
All industries (2010)*	\$5043.6	\$1615.2	\$42.2	\$11.3
Distance to Lake (mi)				
Center to edge	Contains	6.2	4.2	2.6
Edge to edge	Contains	0.5	2.9	1.5
Distance to corridor (mi)				
I-45	Contains	0.0	0.0	12.1
SH-105	Contains	0.0	6.5	0.0
Elevation (ft above MSL)**				
At airport	245–300	245	300	295
In City	95–381	205	381	295
Area (sq. miles)				
Land	1077.0	52.7	3.3	4.6
Water	1044.0	52.6	3.3	4.5
	33.0	0.1	0.0	0.1

Notes: \*Average quarterly revenue, 2010 (in millions).

\*\*Sources: Federal Aviation Administration, Registered Airports, and Wikipedia, list of Montgomery County Cities.



little to no impact. At some point, as declining lake levels become more apparent, recognisable and impact the activities of people, there will be a shift away from activities associated with the lake, which in turn will impact economic activity. This dynamic leads to two fundamental questions: (1) is there a discernible relationship between lake level and economic activity? and (2) what is the threshold beyond which lake-level impacts become apparent?

Hypothesis 1: There is no discernible relationship between lake level and economic activities.

Hypothesis 2: There is no curvilinear relationship between lake level and economic activity.

In addition it is clear that these impacts are geographically confined and unlikely to have a large spatial impact; but an unanswered question is what is the geographic reach of the impact?

Hypothesis 3: The relationship between lake level and economic activity decays with (geographic) distance.

These impacts are likely to be greatest to the economy proximate to lake-related activities. For example, tourism economies are more likely to be impacted than transportation, unless lake levels are related to transportation activity (e.g. water taxes and navigation). The more directly the economic activity is associated with the lake, the more likely the impact will be detectable.

Hypothesis 4: The relationship between lake level and economic activity is most pronounced in economic sector(s) most closely related to lake activities.

Quarterly data were obtained from the Texas State Comptroller's Office reflecting economic activity in terms of sales tax revenue in the four geographic areas from 1984 to 2010. These data included data from every major sector of the economy, including agriculture, mining, manufacturing, transportation, construction, services, finance, wholesale and retail trade. Data from 1984 to 1996 were classified in terms of SICS; from 1996 to 2010 the data were coded in terms of the NAICS codes. The SICS codes were converted to the NAICS codes based on conversion instructions available from the US Bureau of Labor Statistics. This reconfiguration primarily classified restaurant, hotel and lodging revenues as service rather than retail trade.

The decennial census of the population as mandated by the US Constitution relies on counting people in their residence at the beginning of each decade. Annual population estimates have been developed based on housing stock, births, deaths and migration. The population data for each local government entity was obtained from the US Bureau of the Census. Population census data were used for decennial census years, and all available Bureau of Census estimates of annual population were used to most fully represent recent trends. While no quarterly population estimates are available, data for each entity were fit with an exponential curve, The resulting smooth curve was then adjusted based on the observed differences between the annual estimates and the smoothed curve. While this technique clearly serves to smooth the population estimates, the adjustments maintain some temporal variability thought to be important for this effort.

The regional economic context is represented by the unemployment rate in Texas and Montgomery County. These data were obtained from the Bureau of Labor Statistics'

Local Unemployment Statistics on a monthly basis from 1976 to 2011 for Texas and 1990 to 2011 for Montgomery County. The state and county data are highly correlated ( $r = 0.91$ ) as would be expected, and the county unemployment rate exceeds the state unemployment rate only 0.4% of the time. The monthly Texas unemployment rate data were averaged on a quarterly basis to represent the average quarterly unemployment rate. The Texas data were used to provide context for the local entities. It could be argued that Montgomery County data provide ‘regional’ context for the city analyses, but because Montgomery County has enjoyed historically lower unemployment rates than either Texas or the US as a whole, this would introduce the potential for differential context.

Lake levels at Lake Conroe have been recorded daily at midnight since 1973. These observations are summarised by month as the average monthly lake level. These monthly averages were converted from feet above MSL to feet BFP, where the BFP lake level is equal to full pool (201 MSL) minus the average monthly lake-level elevation observed. The three monthly averages from each quarter between 1974 and 2011 were averaged to obtain the quarterly average lake level. Precipitation data for Conroe, Texas, were extracted from the Monthly Climatological Summary (NOAA 2013).

## 5. Time series regression

Unlike other forms of regression, time series regression allows a statistical test for causality. The protocol developed by Granger (1969, 1980, 1988) uses lagged variables to test for causality in both directions. Prior lags of retail trade and service revenue with current lake level, and prior lags of lake level with current retail trade and service revenue will be tested to support causal interpretation.

Hypotheses 1 and 2 are tested in terms of time series regression of quarterly revenue from retail trade, for the three cities and Montgomery County for continuous quarters since 1984. As the curves in Figure 4 depict, the trends in retail trade revenue in all four local government entities grew exponentially from 1984 to 2010. To account for this trend, the estimated population is included in the base model with retail trade revenue in

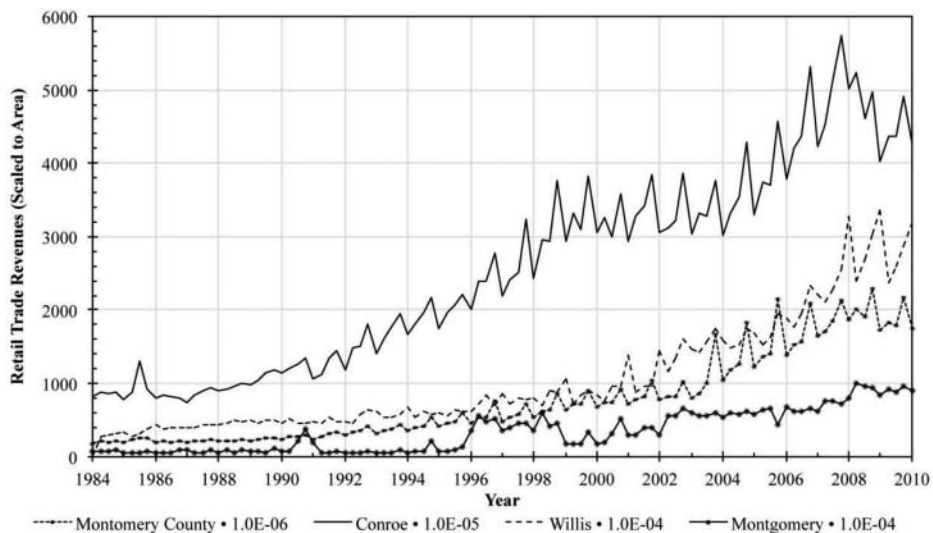


Figure 4. Retail trade revenue in four local entities by Quarter, 1984-2010.

each local government entity. This recognises the inherent fact that population is the fundamental driver of economic activity. In addition, the increasing variability of retail trade revenues is recognisable from the annual variability, indicating that retail trade revenues are subject to non-stationarity (Box, Jenkins, and Reinsel 1994). The economic context of the unemployment rate in the State of Texas is included in the base model to account for these fluctuations. Finally, economic revenue data are known to have seasonal fluctuations. These seasonal fluctuations are accounted for by the inclusion of a seasonal lag, where the revenue one year ago (four quarters) is used as a predictor of the current revenue. Hence, the base model is specified as:

$$y_t = a + \sum b_i x_i + e_t$$

where,  $y_t$  is the local retail trade revenue at time  $t$ ,  $x_1$  is estimated population at time  $t$ ,  $x_2$  is Texas unemployment rate at time  $t$ ,  $x_3$  is the local retail trade revenue at  $t-4$  (one year ago),  $e_t$  is the error term at time  $t$ , and  $i$  varies from one to three. All hypotheses are tested in the context of this base model.

The hypotheses are tested where the base model attempts to account for theoretical influences on the dependent variable of economic activity, rather than isolate the effect of interest from the underlying influences as if they were nuisances (Beck and Katz 1996). Like most time series analyses, ordinary least squares estimation is subject to specification errors associated with serial autocorrelation. To account for this the Prais–Winsten (1954) procedure is employed throughout to account for serial autocorrelation. It represents an improvement on the Cochrane–Orcutt (1949) procedure, which treats each observation as the difference from its antecedent. Unlike Cochrane–Orcutt, Prais–Winsten avoids omitting the first case by transforming the observation by a function of the estimated generalised difference (Curren 2010). The Prais–Winsten procedure in Stata 10.0 was used to conduct these analyses.

The effect of lake level is examined in a linear (Hypothesis 1) and non-linear component (Hypothesis 2). The linear component is predominantly a negative number of feet BFP, while the non-linear component is represented as the feet BFP squared. While these two components are believed to work together (i.e. they are considered together), the amount of time it takes for human behaviour to change because of lake level, and in turn be reflected in revenue data reflecting economic activity, remains uncertain. Hence, lags for each are considered for up to a year. While considering up to a year in lags is arbitrary, lags beyond a year are difficult to envision. The current lake level and lake level squared along with lags of one to four periods were considered. The full model is specified as:

$$y_t = a + \sum b_i x_i + \sum b_j x_j + \sum b_j x_j^2 + e_t$$

where  $y_t$ ,  $x_i$  and  $e_t$  are defined in the base model,  $x_j$  is the lake level in feet BFP, and  $j$  represents time lags zero to four, or  $t$ ,  $t-1$ ,  $t-2$ ,  $t-3$  and  $t-4$ . As there is no conceptual reason to consider the linear and non-linear components operating on different temporal basis, each linear lake level is considered with its non-linear pair. As the hypotheses are directional only negative relationships are considered. The parsimonious model includes the pair that best fits the data.

Hypothesis 3 is considered in terms of the local government entities in which the base- and parsimonious-models are examined. As the distance from the lake increases from the City of Montgomery to the Cities of Willis and Conroe, the effect is expected to

decay. Even though the lake is recognised as a valuable amenity of Montgomery County, it is unlikely that lake levels will be directly associated with discernibly lower economic activity in the county as a whole. Hypothesis 4 is considered in terms of the comparison of the models of retail trade revenues with the models of revenues in the service sector, which is less focused on lake activities. Because the service sector includes professional, scientific and technical services that are not lake-dependent, the connection to lake levels is much more tenuous than the retail sector. The economic distance hypothesis suggests that the more isolated the economic activity is from activities at the lake, the less likely they are to be influenced by the lake levels.

## 6. Findings

The Granger test for causality was conducted on these data. In no case was prior retail trade or service revenue a significant determinant of lake level. The simplified models of retail trade are presented in Table 2. All four models are deemed significant ( $p < 0.001$ ), with 4 and 96 degrees of freedom. Population plays an important positive role in each model. While the specific effect of each person is a complex function of the diversity of the local economy and the specific purchases made in the quarter, each person in Montgomery County, and the Cities of Conroe, Willis and Montgomery, contributes \$12,528, \$2,424, \$1,159 and \$702 to local retail trade per quarter, respectively.

The regional context of Texas, represented by the unemployment rate, shows that this area generally does better than Texas. Each percentage point rise in the current unemployment rate in the state is associated with a decline ranging from \$14.1 to \$0.3 million in local retail trade revenue per quarter for the county and cities. These results are consistent with the idea that the larger the economic base of the local economy, the greater the quarterly impact.

The seasonal nature of retail trade is also a significant contributor to retail trade revenue. The larger, more diverse economies of Montgomery County, Conroe and Willis are most impacted by the seasonal nature of their local economies. That is, retail trade revenues a year ago is a significant predictor of current retail trade. While retail trade a year ago is also an important contributor to current retail trade in the City of Montgomery, each dollar of activity a year ago yields only \$0.34 in current retail trade revenues. This is consistent with the idea that larger, more diverse local economies are more stable than smaller, less diverse local economies. While rainfall in the watershed is inextricably and physically related to lake level ( $r = 0.332$ ), and could theoretically have a shared association with lake level and retail trade, rainfall was not significantly related to retail trade in any model, including all time lags up to a year.

Hypotheses 1 and 2 are examined in the context of this base model of economic activity. Current lake level has an immediate negative impact on the retail trade in the City of Montgomery, but not in the larger more diverse economies of Conroe or Willis or in Montgomery County as a whole. Hypothesis 1 and 2 are rejected for the City of Montgomery model only. A negative curvilinear relationship in the City of Montgomery between current lake level and retail trade is indicated by the statistically significant relationships between lake level (in feet BFP) and lake level squared with retail trade revenue. A 1 foot reduction from 1.5 feet BFP reduces the retail trade revenues in the local economy by \$136,000 a quarter, while a 1 foot reduction from 2.5 feet BFP, reduces retail trade revenue by \$411,000 a quarter. Even when forced into the model, lake level does not play a significant role in any other model. Hypothesis 1 and 2 are rejected only for the closest geographical area. This suggests that as the level of the lake drops the

Table 2. Time series regression of quarterly retail trade in Montgomery County and the Cities of Conroe, Willis, and Montgomery, 1984-2009.

Cochrane-Orcutt transformation	Montgomery County			City of Conroe			City of Willis			City of Montgomery		
	b*	Std Err*	p**	b*	Std Err*	p**	b*	Std Err*	p**	b*	Std Err*	p
Population	699.6	249.7	0.006	2405.7	727.4	0.001	1160.1	325.2	0.001	12444.1	2665.8	0.000
TX Unemployment	-13.900	7.504	0.066	-5.463	2.669	0.043	-0.357	0.125	0.005	-0.452	0.172	0.010
Seasonal Retail Trade	0.947	0.044	0.000	0.847	0.056	0.000	0.922	0.045	0.000	0.342	0.092	0.000
Lake-Level	12.900	22.500	0.568	-1.708	4.988	0.733	-0.594	0.370	0.111	-0.414	0.198	0.040
Lake-Level Squared	7.559	6.165	0.223	-0.365	1.344	0.786	-0.140	0.102	0.173	-0.138	0.053	0.011
Number of obs =		103			103			103			103	
F(4,96) =		809.1			623.1			688.5			31.2	
Prob =		0.000			0.000			0.000			0.000	
R-squared =		0.976			0.970			0.972			0.615	
Adj R-squared =		0.975			0.968			0.971			0.595	

Notes: \*Coefficients and Standard errors for TX Unemployment, Lake Level, and Lake Level Squared are in millions.  
 \*\*Coefficients are not significant when  $p > .05$ .

negative impact on retail trade in the local area increases. Because the empirical evidence is limited to around 4 feet BFP, projections below that lake level are difficult to support. However, the curvilinear nature of the effect makes it clear the impact at 4 feet BFP is greater than that at 3 feet BFP, and that 5 feet BFP is likely to be even worse. The City of Montgomery model is significant ( $p < 0.001$ ), with an adjusted  $R^2$  of 0.601. The best lake level variable is presented, even though it is not significant, for the models in the county as a whole or any of the other cities. These models are significant ( $p < 0.001$ ) and have adjusted  $R^2$ s greater than 0.965, but are not parsimonious in that lake level and lake level squared are forced into the models even though they are not significantly related to retail trade quarterly revenues.

The  $R^2$  for the City of Montgomery model is lower than for the same model in other local economies. This seems to be related to the size and diversity of the local economy. The larger, more diverse economies remain stable throughout the period, while the smaller, less diversified economies have volatility associated with the rise and collapse (or even movement from one local to another local economy) of specialised firms in the area. This may be especially true in the City of Montgomery, as it is located along one (but not two) major transportation corridors. Further exploration of the curvilinear nature of the lake level effect in the City of Montgomery indicates that a semi-log or log-log models explain more variance, but do not reflect the regional effect of unemployment in the State of Texas. Lake level continues to have a similar relationship among economic entities examined with retail sales with the semi-log and log-log models. The quadratic model of lake level depicts the local economy in the context of the region and state economic activity.

The simplified models of service revenues are presented in [Table 3](#). All four models are deemed significant ( $p < 0.001$ ), with 4 and 96 degrees of freedom. Population plays an important positive role in each model.

The regional context of the State of Texas, represented by the unemployment rate in the state, show that this area generally does better than Texas as a whole. Each percentage point rise in the state unemployment rate is associated with a decline in local service revenue per quarter. These results seem to indicate that service revenue varies with available services with no discernible pattern by size or diversity of the local economy.

The seasonal nature of service revenue is also a significant contributor to service revenue in all local economies studied, except the City of Montgomery. The larger more diverse economies of Montgomery County, Conroe and Willis are most impacted by the seasonal nature of their local economies. Service revenues a year ago are a significant predictor of current service revenues, with each dollar of service revenue yielding \$0.76, \$0.34 and \$0.41 in Montgomery County and Conroe and Willis, respectively. In the City of Montgomery, current service revenues are not significantly related to service revenues one year ago. This seems to be consistent with the idea that services are more widely available in diverse economies, but remain more volatile than retail trade and depend to some degree on the services offered and their clientele. For example, a particular professional service (e.g. engineering services) may have a very steady ongoing business based on customers located elsewhere, while another service (e.g. localised waste management) is more closely tied to local demand.

Current lake level has no significant impact on the service sector revenue in any local economy. These findings suggest that the effect of lake level is limited to those sectors of the economy most closely associated with the lake. This result reinforces interviews with service-related businesses ranging from an architecture firm to a law firm to a sign design firm near the lake, all of whom felt that the lake had no impact on their business. The effect associated with the lake is not discernible among the other effects. Hence,

Table 3. Time series regression of quarterly service revenues in Montgomery County and the Cities of Conroe, Willis, and Montgomery, 1984–2009.

Cochrane–Orcutt transformation	Montgomery County			City of Conroe			City of Willis			City of Montgomery		
	b*	Std Err*	p**	b*	Std Err*	p**	b*	Std Err*	p**	b*	Std Err*	p
Population	318.6	114.9	0.007	1051.2	198.4	0.000	166.8	66.1	0.013	3686.2	1514.5	0.017
TX Unemployment rate	-5.815	3.262	0.078	-3.006	0.840	0.001	-0.028	0.032	0.394	-0.121	0.113	0.289
Seasonal Service Revenues	0.759	0.106	0.000	0.341	0.098	0.001	0.408	0.089	0.000	0.144	0.106	0.179
Lake-Level~	-14.500	21.100	0.495	-3.233	2.116	0.130	-0.124	0.055	0.026	-0.103	0.099	0.300
Lake-Level Squared~	-4.935	6.043	0.416	-0.508	0.576	0.380	-0.003	0.015	0.852	-0.016	0.026	0.533
Number of obs =		103			103			103			92	
F (4,96) =		151.9			93.6			234.3			8.9	
Prob =		0.000			0.000			0.000			0.000	
R-squared =		0.886			0.827			0.971			0.337	
Adj R-squared =		0.880			0.818			0.967			0.299	

Notes: \*Coefficients and Standard errors for TX Unemployment, Lake Level, and Lake Level Squared are in millions.

\*\*Coefficients not significant when  $p > .05$ .

~Lake level and Lake level squared are lagged one period for all models except Montgomery County where they are lagged three periods.

Hypothesis 4 cannot be rejected, as lake level and lake level squared have no significant impact on current service revenues or service sector economic activity.

The models of service sector revenue in Montgomery County, Conroe and Willis are relatively robust with adjusted  $R^2$ s ranging from 0.880 to 0.608. The service revenue model for the City of Montgomery is less robust with an adjusted  $R^2$  of 0.345. These models are significant ( $p < 0.001$ ), but are not parsimonious in that lake level and lake level squared are forced into the models even though they are not significantly related to service sector quarterly revenues.

## 7. Discussion, implications and conclusions

There is a tendency to suggest that the impact of changes on an environmental amenity such as Lake Conroe will be both dramatic and widespread. The findings herein suggest Lake Conroe has a clear impact on the local economies, but that these impacts are limited geographically to the areas nearest to the amenity and to those sectors of the economy most closely associated with the amenity. These findings also suggest that the relationship between lake levels and economic activity are causal in that prior lake levels are associated with current retail trade revenues, but prior retail trade revenues are not significantly associated with current lake levels.

Figure 5 presents the impact of lake level on quarterly retail trade revenues. Lake levels do not impact retail trade revenues in Montgomery County or the Cities of Conroe or Willis (i.e. not significantly different than zero, and represented as a solid line for all lake levels at \$0.0 Revenue in Figure 5), but in the City of Montgomery the effect is curvilinear. The impact of lake level is limited in the first 2 feet BFP and becomes more dramatic from 2 to 4 feet BFP. It is difficult to project the impacts for lake levels more than 4 feet BFP as these levels occurred rarely until 2011, occurring only three times in the entire history of the lake when considering monthly averages (c.f. Figure 1). While these data suggest that impact from lower lake levels would increase rather than decrease, the point at which impact approaches a theoretical limit is not clear from these analyses. These findings suggest an

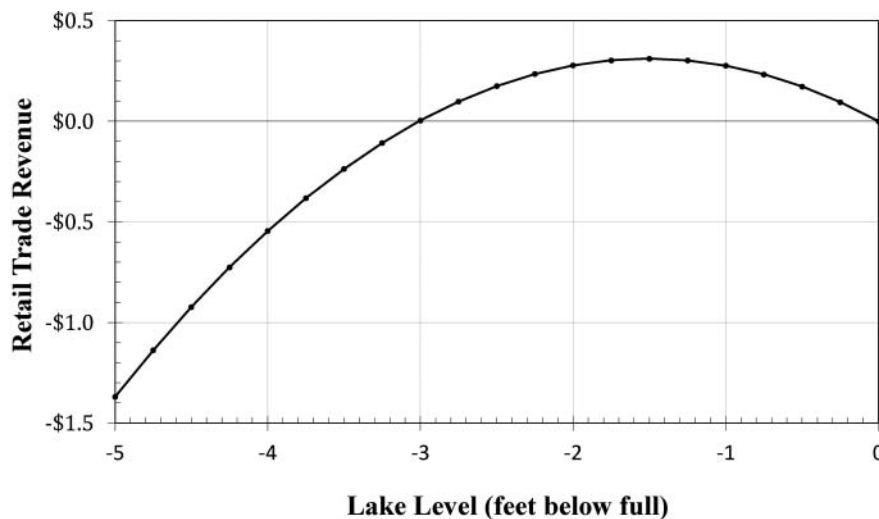


Figure 5. Lake level effect on quarterly retail trade.

Note: Since the lake level effect on retail trade in Montgomery County and the Cities of Conroe and Willis is not significant the effect is effectively zero.



impact of approximately \$418,000 per quarter per foot of lake level decline beyond 2 feet BFP. This amounts to direct impacts of more than \$1.6 million per year in the City of Montgomery for each foot of water in the lake beyond 2 feet BFP.

The results have the relative strength of being based on revealed preferences rather than expressed preferences. Expressed preferences have the disadvantage of being hypothetical, forcing survey respondents to ‘conjure up’ situations for which they may (or may not) have experience and/or expertise. Revealed preferences, such as those herein, have the advantage of reflecting the behaviours and decisions of the past. The present research has the additional advantage that embraces the dynamics of the lake level economy throughout the period, while many revealed preference approaches suppress or at least understate the temporal dimension to represent time periods in a static manner as if all the reflected decisions occurred simultaneously. While the results herein also have the advantage of being dynamic over the time period, they are limited in range to the conditions that have existed in the past. Hence, it is difficult to project results to conditions that have not occurred in history, but they take advantage of reflecting past behaviour which is usually a better predictor of future behaviour than expressed attitudes, beliefs or preferences, which by definition have occurred in the past.

This research is a simple case study of one of many human-made reservoirs that could potentially be studied. The extent to which these results will be unique to this lake or more generalisable to reservoirs in general is uncertain at best. The Texas Water Development Board lists more than 200 lakes and reservoirs in Texas alone (TWDB 2012). If the conditions at Lake Conroe are considered absolutely unique, these results cannot be interpreted for other lakes, but it is unlikely that the conditions at Lake Conroe are completely unique. For example, there are other lakes near metropolitan areas (e.g. Lake Travis near Austin and Lake Ray Hubbard near Dallas), or with similar depths at full pool (e.g. Lake Waco). While it is not the purpose of this paper to identify lakes similar to Lake Conroe, it is clear that the greater the similarity of the lakes and surrounding communities, the more similar the results for that lake would be expected to be to those of Lake Conroe. One relatively conservative approach might be to use the 95% confidence interval to identify a range of potential impacts. Figure 6 presents the

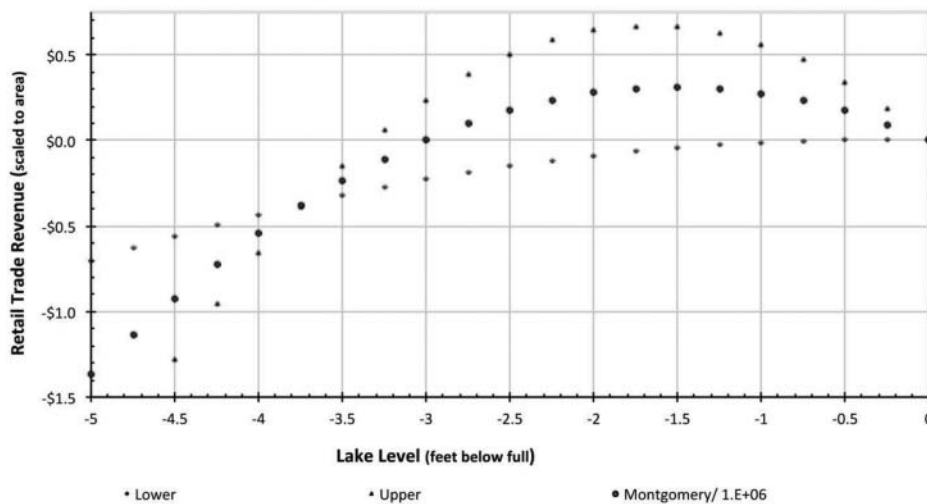


Figure 6. Lake level effect on quarterly retail trade in City of Montgomery with 95% confidence interval.

lake level effect with the 95% confidence interval boundaries for various lake levels from zero to 5 feet BFP. It might be reasonably expected that the impacts of a given lake would be likely to exceed the minimum expected impacts at Lake Conroe. The linear impact of lake level on the local economy in the City of Montgomery has a 95% confidence interval from \$0.020 to \$0.808 million, while the 95% confidence interval for the non-linear component is between \$0.032 to \$0.243 million. This suggests an annual impact between \$.080 and \$3.232 million per foot BFP. If a statewide drought produced lake-level changes below normal, the direct impact on retail trade in the State of Texas would be on the order of \$16 to \$640 million per year per foot BFP.

This research has considered the impact of lake-level fluctuations on economic activity.

These data and subsequent results are applicable to Lake Conroe, which is a reservoir operated by the San Jacinto River Authority. Unlike many of the studies reported in the literature herein, lake levels are regulated. But like many of the studies reviewed, Lake Conroe is unique; it is relatively shallow with small changes in lake-level elevations, resulting in drastically receding shorelines; and the reservoir was originally built as an alternative water supply for the City of Houston, but seldom used for this purpose. The local economies in the area near the lake are also unique. The extent to which these results are replicable around other lakes is not known. It would certainly be anticipated that local economies near deeper lakes, or lakes with other purposes, or lakes more geographically isolated, are likely to respond differently. For example, Lake Conroe has historically been a relatively stable recreational lake that provides the amenity of scenic beauty to local residents, but has been used infrequently as a water supply. Lakes that supply water to local residents or irrigation on an ongoing basis may be accustomed to having low (or volatile) lake levels are likely to be perceived differently. These results also are not relevant for residential property values, although decreased economic activity clearly impacts the market for underlying property.

The analysis here does not explicitly examine the issues surrounding relationships between continued population growth and water use. It is clear that finite potable water resources limit population growth, although these limits can be extended by reducing water use from more than 500 gallons per capita per day to less than 150 gallons per person per day. As Texas approaches a population of 25 million, this would amount to 1.5 million acre feet per day or about 550 million acre feet per year. In theory this would be enough water for about 35 million more people in Texas. While there are many other factors involved in population growth, these simplified calculations show that there is probably ample water in conservation alone to expand the population of Texas moderately. Continued use of water at the current rates and population growth combined clearly raises the prospect of water resource exhaustion, and specifically links population and water use/capacity. As Texas continues to grow, more water sources will be needed to support the growing population, which makes available water a limiting factor for population growth. This prospect far outweighs the near-term potential local economic impact in retail trade based primarily on recreational activities. Resource managers have to balance population growth and water resources in the future. These results help inform management strategies to accommodate continued population growth.

The approach used here has been unique. No literature was discovered that used a time series approach to examine the dynamics of lake-level fluctuations and economic activity. This approach has proved useful in providing insight into the relative size of

impact zones for amenities such as Lake Conroe, and has provided some insight as to the limitations of these effects in local economies. Future research that can document impacts at various distances from lake amenities will enhance insight into the spatial distribution of these impacts. The findings will be strengthened as they are replicated in various places with a variety of circumstances. The approach taken may be expanded in the future to include property sales completed or construction permit applications in the future. Such circumstances would enhance the ability to examine the distance hypothesis for potential thresholds. These results are especially relevant for human-managed lakes, such as reservoirs, but may also be applicable to other natural amenities (e.g. beaches, barrier islands, rivers and forests) with views, habitat and links to recreational activities, especially those with other mutually exclusive competing uses. Additional research will help to provide empirically grounded theory that may provide insight beyond the consideration of lakes.

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### Notes

1. Population is scaled such that each entity is one order of magnitude less than the governmental entity listed to its left.
2. The SJRA has completed an agreement with the City of Houston to use Houston's two-thirds ownership of Lake Conroe water to supply ground water users in Montgomery County who have elected to join SJRA's Groundwater Reduction Plan.
3. The part of the lake that extends into Walker County is surround by the Sam Houston National Forest and hence not developed in the usual sense.

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