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Development of residential lakeshore properties can have several effects on aquatic ecosystems including the thinning of littoral coarse woody habitat. Previous studies have shown that reduction of littoral coarse woody habitat negatively affects largemouth bass (*Micropterus salmoides*) growth rates. In order to validate these results and attempt to find the mechanism through which bass growth rates are reduced, we surveyed 16 lakes in Vilas, County Wisconsin on a gradient of conductivity and development. Regressions of size-specific growth rates with lake area ($p < .01$) and maximum depth ($p < .05$) were negatively correlated and significant. A negative correlation was observed between mean largemouth bass (*Micropterus salmoides*) growth rate and development, between lake categories of low development low conductivity and high development high conductivity, although this trend was not statistically significant. Our research confirms that extensive residential lakeshore development may reduce the growth rates of bass as demonstrated by Schindler (2000).



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**COVER SHEET**

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# Determining the Impacts of Residential Lakeshore Development and Various Physical Factors on Largemouth Bass (*Micropterus salmoides*) Growth Rates

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**Abstract**

Development of residential lakeshore properties can have several effects on aquatic ecosystems including the thinning of littoral coarse woody habitat. Previous studies have shown that reduction of littoral coarse woody habitat related to development negatively affects largemouth bass (*Micropterus salmoides*) growth rates. In order to validate these results and attempt to find the mechanism through which bass growth rates are reduced, we surveyed 16 lakes in Vilas, County Wisconsin on a gradient of conductivity and development. Length and weight were recorded and scales were removed from 28 – 30 bass in each lake. Regressions of size-specific growth rates with lake area ($p < .05$) and lake perimeter ($p < .05$) were positively correlated and significant. A negative correlation was observed between mean largemouth bass (*Micropterus salmoides*) growth rate and development, between lake categories undeveloped and low development, and a positive correlation was observed between lake categories low development and high development, although these trends were not statistically significant. Our research raises questions about the complexity of the effect extensive residential lakeshore development has on growth rates of largemouth bass (*Micropterus salmoides*) and proposes the roles lake area and lake perimeter play in the mechanism through which development affects growth rates.

**Introduction**

The popularity of angling largemouth bass (*Micropterus salmoides*) grew during the 1980’s as more anglers started viewing bass as a sport fish and the demand for the ability to catch larger bass in higher abundances grew. At present, bass fishing represents an increasingly popular sport (both recreationally and competitively) and makes up a large component of the fishing-related economy in the United States and around the world. The increased demand to maintain and produce desirable fisheries has increased the importance of understanding how bass growth rates are affected.

Though not statistically significant, Schindler (2000) found that largemouth bass (*Micropterus salmoides*) growth rates were higher in lakes with low levels of development than in lakes with high levels of development. This result is in contrast to studies that suggest residential lakeshore development will increase nutrient loading and the production capacity of a lake, and in turn fish growth rates (Hanson and Leggett 1982). As demonstrated by Schindler (2000), the effect of development on growth rates is possibly associated with the negative correlation shown to exist between residential lakeshore development and abundance of coarse woody habitat (Christensen et al. 1996 and Marburg et al. 2006). The importance of this relationship was validated by Sass (2006) in demonstrating that CWH plays a large role in sustaining desirable fisheries through top-down effects of predators on prey and bottom-up effects of decreasing primary and secondary productivity. However, the mechanism that influences bass growth rates through residential development has not been demonstrated (Schindler 2000).

We attempted to identify the mechanism through which residential lakeshore development affects bass growth rates, and to validate the findings of a negative correlation between residential lakeshore development and Largemouth bass (*Micropterus salmoides*) growth rates as seen by Schindler (2000). We surveyed 16 lakes in Vilas County, Wisconsin that were on a gradient of development and conductivity.

Length and weight measurements and scales were collected from 28 - 30 Largemouth bass (*Micropterus salmoides*) in each lake in order to determine growth rates. We tested for an effect of development (buildings/km), conductivity (µS/cm), secchi depth (feet), logs/km, total unfiltered P( µgrams/liter), percent of wetland shoreline, lake perimeter (km), percent macrophyte coverage, lake area (hectare), and lake maximum depth (m) on bass growth rates.

## Methods

### *Study Area*

We surveyed 16 lakes located in Vilas County, Wisconsin from June – August 2006. Lakes selected varied on a gradient of conductivity (range = 11 – 179.5 µS/cm; mean = 79.4 µS/cm) and development (range = 0 – 38.9 houses/km; mean = 11.6 houses/km) (Figure 1), and were subdivided into categories of undeveloped, low development, and high development as described by Christensen et al. 1996. (Schindler et al. 2000) Conductivity was selected as a predictor of landscape position. Lake size ranged from 8.1 ha – 402.2 ha and averaged 118.7 ha. All lakes were previously sampled by the University of Wisconsin-Madison Trout Lake Station staff from 2001 – 2004. Data collected by the Trout Lake Station staff included, but was not limited to development (buildings/km), conductivity (µS/cm), secchi depth (feet), logs/km, total unfiltered P( µgrams/liter), percent of wetland shoreline, lake perimeter (km), percent macrophyte coverage, lake area (hectare), and lake maximum depth (m) (unpublished data) (Figure 2). Largemouth bass (*Micropterus salmoides*) were present in all lakes.

Camp Lake, Little Rock Lake, and Day Lake only permit electric motors. Little Rock Lake was closed to public access and fishing in 1985 (Swenson 2002) and was divided into a treatment (northern) and reference (southern) basin by two poly-vinyl chloride (PVC) curtains during 1985 in preparation for a whole-lake acidification study. Camp Lake is naturally divided into a treatment and reference basin and is connected by a shallow beaver channel (< .3m). To avoid possible confounding effects of past studies done on the treatment basins of these two lakes, we only sampled their reference basins.

*Fish Sampling*

From June – August 2006, the 16 lakes were sampled for largemouth bass by angling and electroshocking. Lakes were sampled by angling if conductivity was not sufficient for productive electroshocking. Sampling typically started at the boat landing and continued around the lake until 30 largemouth bass (*Micropterus salmoides*) were captured, however, areas thought to contain bass were targeted on lakes larger then 200 hectare.

Upon completion of the sampling event, we measured each captured bass for mass and total length. Several scales were removed from behind a depressed pectoral fin for age and growth determination. All bass were released back to the lake following data collection. If 30 bass were not captured during the sampling period, a second sampling period took place. In order to avoid replication of data, bass sampled were examined for scale loss due to previous sampling and compared to the length and weight of all other bass caught in the lake. The methods of photographing, reading, and determining growth of scales are outlined in Sass (2006). Determination of growth rate for each fish was determined by the Fraser-Lee method (Carlander 1982) and is detailed in Schindler (2000).

*Statistical Analysis*

In order to account for possible size-specific effects of length on growth rate, we performed a polynomial least squares regression of the growth rate (mm/yr) ($\log_{10}$ transformed) on the length (mm) of every fish (Schindler et al. 2000); growth rate could not be determined on five bass that were less than one year of age. We then calculated estimates of size specific growth rates (180 mm, 215 mm, 245 mm, 275 mm, and 310 mm) for each lake. Specific sizes were chosen in order to increase the number of lakes that growth rates were interpolated from: Little John and Camp (reference basin) were the only lakes with non-interpolated growth rates. Within each size-specific length category, univariate linear regressions were used to determine if size specific growth rates were influenced by development (buildings/km), conductivity (µS/cm), secchi depth (feet), logs/km, total unfiltered P( µgrams/liter), percent of wetland shoreline, lake perimeter (km), percent macrophyte coverage, lake area (hectare), or lake maximum depth (m). Mean growth rate ($\log_{10}$ transformed) for all lake categories (undeveloped, low development, and high development) were determined by averaging growth rate ($\log_{10}$ transformed) for each size specific class (180 mm, 215 mm, 245 mm, 275 mm, and 310 mm) for each lake and then averaging the mean growth rate ($\log_{10}$ transformed) within each category. Mean growth rate ($\log_{10}$ transformed) within each category was then plotted against mean development (Figure 3).

**Results**

A total of 478 largemouth bass (*Micropterus salmoides*) were sampled in our study: 30 bass from each lake and 28 bass from Moon Lake (Figure 2). Sizes of bass ranged from 58 – 420 mm, and age ranged from less than 1 to over 16.

A polynomial least squares regression of growth rate (mm/yr) ($log_{10}$ transformed) on the length (mm) of every bass within each lake yielded $R^2$ values ranging from .266 – .832; regressions were statistically significant ($p < .05$) for each lake. Univariate regressions of estimates of size specific growth rates (180 mm, 215 mm, 245 mm, 275 mm, and 310 mm) against development, conductivity, secchi depth, logs/km, total unfiltered P, percent of wetland shoreline, lake perimeter, percent macrophyte coverage, lake area, and lake maximum depth were only significant and positively correlated for lake area ($p < .05$) (Figure 4) and lake perimeter ($p < .05$) (Figure 5) and size-specific for 310 mm bass. Though not statistically significant, a negative correlation was observed between mean largemouth bass (*Micropterus salmoides*) growth rate ($log_{10}$ transformed) and development between the lake categories no development and low development, and a positive correlation was noted between lake categories low development and high development (Figure 3).

**Discussion**

Our results showed a size-specific (310 mm) positive correlation between growth rates of largemouth bass (*Micropterus salmoides*) and lake area and lake perimeter. These results are in contrast to Keskinen and Marjomaki (2003), who found growth of pikeperch (*Sander lucioperca*) to be negatively correlated with lake area and positively correlated with total phosphorous and water color. This is also in contrast to the results seen by Schindler et al. (2000), who found no significant effects of lake area on bass growth rates in their 9 study lakes. It is possible that increasing the number of study lakes to 16 allowed us to detect the effects of lake area and perimeter on bass growth rates. While it has been suggested that growth rates would be higher in smaller lakes because they tend to be eutrophic as opposed to larger lakes which tend to be oligotrophic (Keskinen and Marjomaki 2003, Bonvechio and Bonvechio 2006), we did not see a correlation between total unfiltered phosphorous and growth rates, suggesting that the relationship between lake area and perimeter and growth rates was not related to productivity.

Analysis of the relationship between lakeshore development and size-specific growth rates did not show a significant correlation. However, a negative trend in growth rates was seen between undeveloped lakes and lakes with high development and a positive trend was noted between lakes with low development and lakes with high development (Figure 3). The initial decrease in growth rates with increasing development is consistent with Schindler (2000) however the increase in growth rates from low development to high development is not. It is possible that effects of development on species in lower trophic positions such as bluegill sunfish (*Lepomis macrochirus*) (Schindler et al. 2000) are more evident than on apex and keystone species (Carpenter and Kitchell 1993) such as largemouth bass (*Micropterus salmoides*). Reasons for the effects of development on bass growth rates, as demonstrated by Sass et al. 2006, include the possibility that removal of coarse woody habitat allows for bass to consume all of their energy favorable prey and force themselves to follow the optimal foraging tenets (Werner and Hall 1974), resulting in decreased growth rates. In larger lakes were prey such as yellow perch (*Perca flavescens*) are more abundant, largemouth bass may show increases in growth rates as coarse woody habitat decreases because foraging rates are sustained as encounters with prey increase.

The negative correlation between bass growth rates and development was also possibly confounded by Camp, Little Rock, and Day Lake all having a ban on gas motors. These regulations may reduce angling pressure in these lakes and increase largemouth bass (*Micropterus salmoides*) reproductive success (Ostrand et al. 2004, Kieffer et al. 1995) by limiting the number of anglers targeting vulnerable spawning bass (Suski and Philipp 2004). In turn growth rates of juvenile bass may be higher in these lakes. However this conclusion needs to be validated because decreased angling pressure can also increase population abundances, negatively affecting growth rates (Schindler et al. 1997, Post et al. 1998). Alternatively, increased angling pressure can decrease population abundances and competition, causing increases in growth rates (Goedde and Coble 1981). For this reason we suggest that future studies looking to understand the effects of development on growth rates, incorporate angling pressure into their analysis.

Our research confirms the possibility demonstrated by Schindler (2000) that extensive residential lakeshore development may reduce the growth rates of largemouth bass (*Micropterus salmoides*), however, predator-prey interactions may also benefit the apex predator as a result of development reducing the preys' habitat. Future studies trying to find the mechanism through which development effects growth rates, should incorporate diet analysis and food web modeling into data collection

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**Figure Legend**

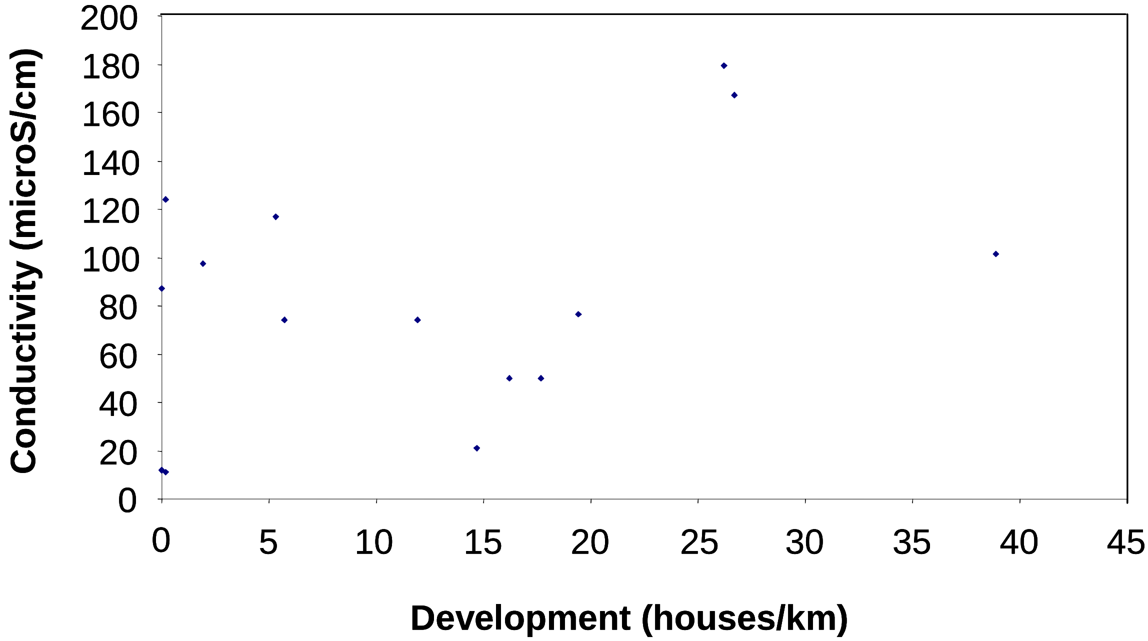
**Figure 1.** 16 sample lakes distributed on a gradient of conductivity (micros/cm) and development (buildings/km).

**Figure 2.** Summary of the 16 lakes sampled, physical characteristics, and number of largemouth bass (*Micropterus salmoides*) sampled.

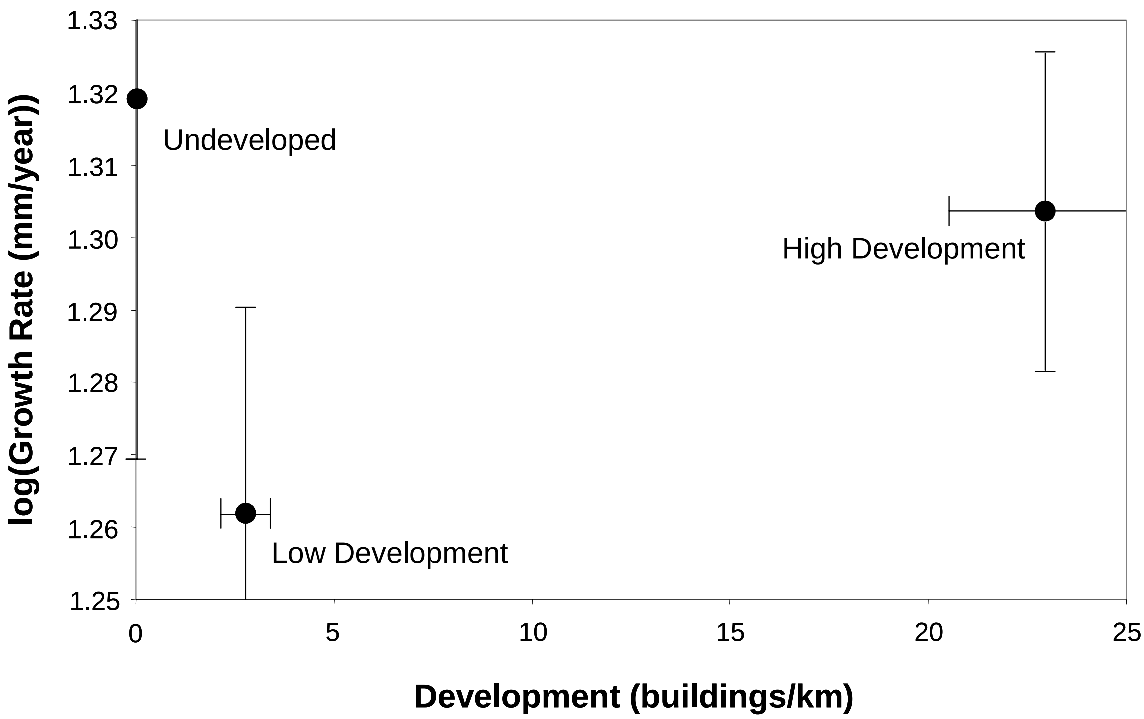
**Figure 3.** Mean growth rate ($\log_{10}$ transformed) (mm/year) of largemouth bass (*Micropterus salmoides*) plotted against mean development for three categories of lakes: undeveloped, low development (< 10 buildings/km), and high development (> 10 buildings/km). Error bars represent one standard deviation.

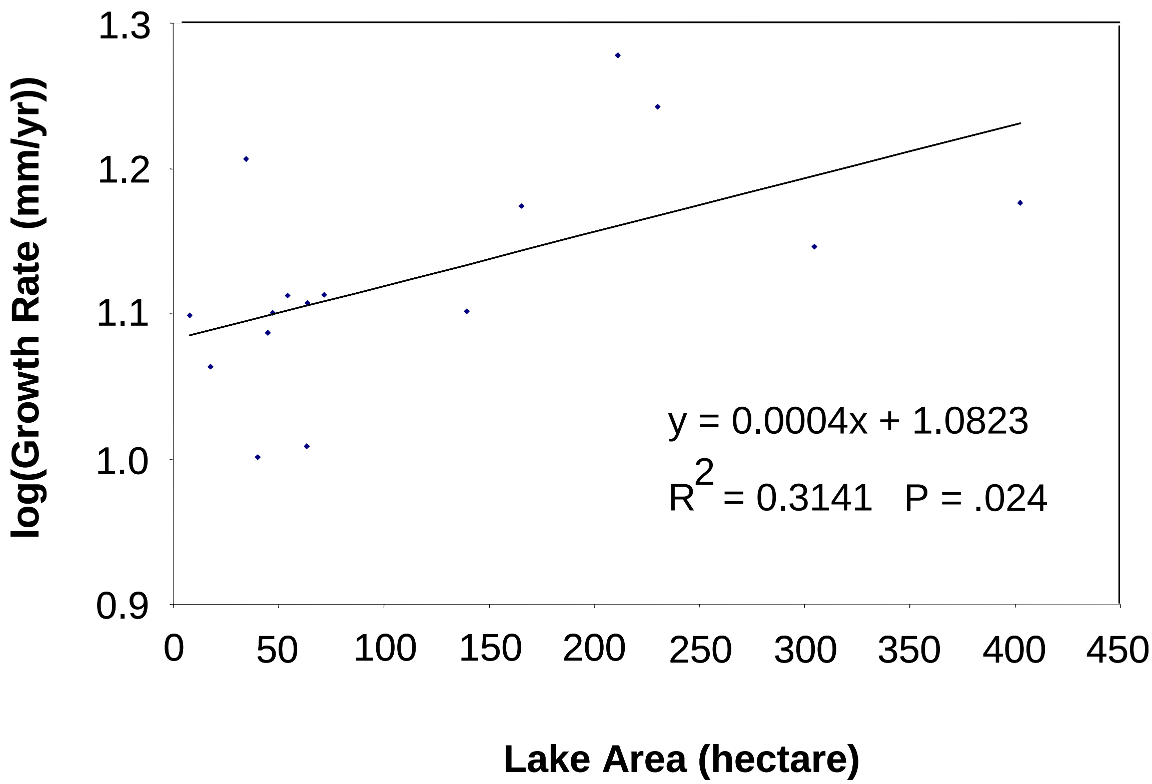
**Figure 4**. Linear regression of the growth rate (mm/yr) ($\log_{10}$ transformed) versus lake area (hectare).

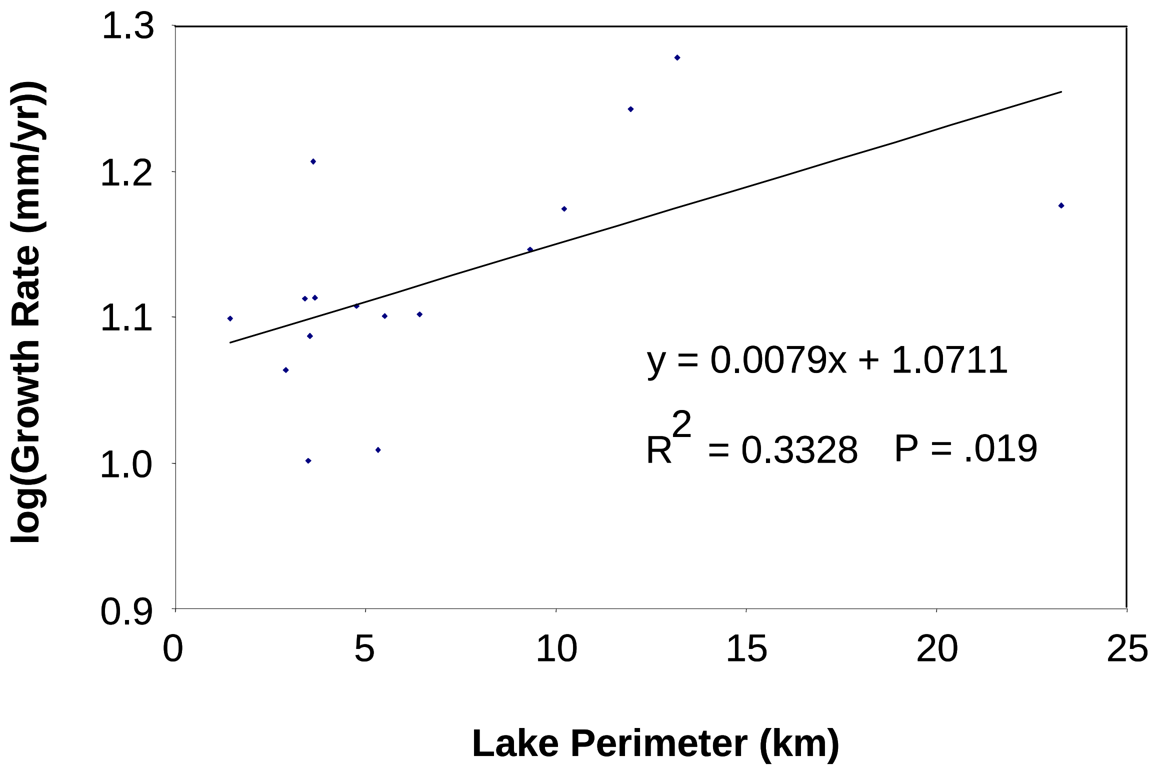
**Figure 5.** Linear regression of the growth rate (mm/yr) ($\log_{10}$ transformed) versus lake perimeter (km).


Conductivity (microS/cm)
200
180
160
140
120
100
80
60
40
20
0
0
5
10
15
20
25
30
35
40
45
Development (houses/km)

| Lake | Largemouth Bass (n) | % Marcrophyte Coverage | Lake Perimeter (km) | % of Wetland Shoreline | Total P unfiltered | Buildings per km | Logs/km | Lake Area (hectare) | Lake Maximum Depth | Secchi Depth | Conductivity (microS/cm) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Allequash | 30 | 36.4 | 10.2 | 36.9 | 15 | 0.0 | 40.0 | 165.3 | 24 | 3.55 | 87 |
| Camp Reference Basin | 30 | 75.9 | 2.9 | 0.0 | 5 | 0.0 | 20.0 | 17.6 | 31 | 4.50 | 12 |
| Little Rock South Basin | 30 | 45.6 | 1.4 | 0.0 | Unknown | 0.0 | 125.0 | 8.1 | 10 | 6.63 | 12 |
| Day | 30 | 14.1 | 5.5 | 0.0 | 28 | 0.2 | 125.0 | 47.3 | 48 | 8.25 | 11 |
| Round | 30 | 67.8 | 3.7 | 34.1 | 17 | 0.3 | 20.0 | 71.5 | 25 | 2.13 | 124 |
| Little John | 30 | 50.7 | 5.3 | 0.0 | 15 | 2.1 | 25.0 | 63.4 | 19 | 2.18 | 98 |
| Little Crooked | 30 | 69 | 4.8 | 11.5 | 12 | 5.5 | 22.5 | 63.8 | 20 | 2.25 | 117 |
| White Sand | 30 | 27.7 | 9.3 | 19.1 | 5 | 5.8 | 12.5 | 304.6 | 71 | 4.88 | 74 |
| Upper Buckatabon | 30 | 72.1 | 13.2 | 12.0 | 17 | 12.6 | 20.0 | 211.4 | 47 | 3.25 | 74 |
| Moon | 28 | 34.9 | 3.4 | 26.5 | 7 | 15.0 | 22.5 | 54.4 | 38 | 4.00 | 21 |
| Found | 30 | 77.8 | 6.4 | 2.2 | 14 | 16.6 | 35.0 | 139.3 | 21 | 2.40 | 50 |
| Black Oak | 30 | 36.4 | 12.0 | 15.7 | 5 | 18.0 | 5.0 | 230.1 | 85 | 5.25 | 50 |
| Little St. Germain | 30 | 24.4 | 23.3 | 2.7 | 16 | 19.8 | 30.0 | 402.2 | 53 | 3.63 | 77 |
| Johnson | 30 | 68.5 | 3.6 | 0.0 | 10 | 26.2 | 2.5 | 34.7 | 42 | 3.70 | 180 |
| Brandy | 30 | 72.5 | 3.5 | 0.0 | 9 | 30.1 | 0.0 | 45.1 | 44 | 2.63 | 167 |
| Arrowhead | 30 | 39.3 | 3.5 | 3.0 | 10 | 45.8 | 2.5 | 40.1 | 43 | 4.40 | 102 |


1.33
1.32
1.31
1.30
1.29
1.28
1.27
1.26
1.25
log(Growth Rate (mm/year))
Undeveloped
High Development
Low Development
0
5
10
15
20
25
Development (buildings/km)


1.3
1.2
1.1
1.0
0.9
log(Growth Rate (mm/yr))
0
50
100
150
200
250
300
350
400
450
Lake Area (hectare)
y = 0.0004x + 1.0823
R2 = 0.3141 P = .024


1.3
1.2
1.1
1.0
0.9
log(Growth Rate (mm/yr))
0
5
10
15
20
25
Lake Perimeter (km)
y = 0.0079x + 1.0711
R2 = 0.3328 P = .019