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2011 Monitoring Data Report

Beebe Lake – *Wright County, MN* *(DOW #86-0023-00)*

- **Rainfall Monitoring**
- **Watershed Runoff Estimates**
- **Lake Level Changes**
- **Lake Surface Temperature**

Prepared for the Beebe Lake Improvement Association (St. Michael, MN) – December 2011

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Introduction

The Lake – Watershed Connection

A lake's watershed is defined as the area that drains to the lake. In simple terms, a raindrop that lands within the boundaries of this watershed flows toward the lake, while any raindrop falling outside the watershed will flow away from the lake (Fig. 1). This is a very important concept for those of us who strive to protect and improve lakes, because the size and characteristics of a lake's watershed dictates how water, nutrients, and pollutants get washed off of the land and into the lake. This impacts many aspects of a lake, including:

- Lake water level
- Lake flushing rate
- Nutrient levels
- Water clarity / algae blooms
- Levels of other pollutants (road salt, pesticides, mercury, etc.)
- Soil entering the lake (sand deltas in lake, reduced lake depth)
- Aquatic plant growth (indirectly)
- Abundance and size of fish (indirectly)

Measuring Runoff

Monitoring the amount of water that flows off of the land ("runoff") in a watershed can be a complicated and costly endeavor, particularly for lakes with large watersheds and many inflow points. Such monitoring typically involves using expensive automated stormwater equipment that records water flow and collects water samples. Although this comprehensive monitoring provides very accurate information about the amount of water and pollutants flowing into a lake, most lake groups can not afford to collect such detailed monitoring data.

A less costly alternative is to monitor rainfall and lake level very accurately with electronic probes. This does not provide direct measurements of what pollutants are in runoff from the watershed, but it does allows us to estimate (1) how much water lands on the watershed during rain storms, and (2) how much of that water flows off of the watershed and into the lake. This is extremely useful information that can be used to predict the effect of rain storms on lake water level and is extremely useful for developing and calibrating watershed computer models.

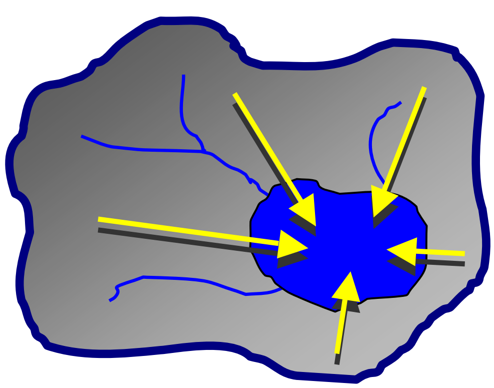


Figure 1. Diagram of a watershed. Any rain falling within the boundary of this lake's watershed flows toward the lake.

Beebe Lake Watershed

Beebe Lake's watershed (Fig. 2) covers roughly 670 acres of land surrounding the lake (~960 acres if the lake is included). The land-use within this watershed is mostly agricultural and open fields, with only a small portion of the watershed (<5%) having impervious surfaces (roads, rooftops, etc.). Soils within the watershed (Fig. 3) are predominantly loam with low to moderate potential for runoff (infiltration rate = 0.6 to 2.0 inches per hour, slopes generally less than 10%; NRCS 2004).

Figure 2. Beebe Lake watershed (MNDNR 2011)

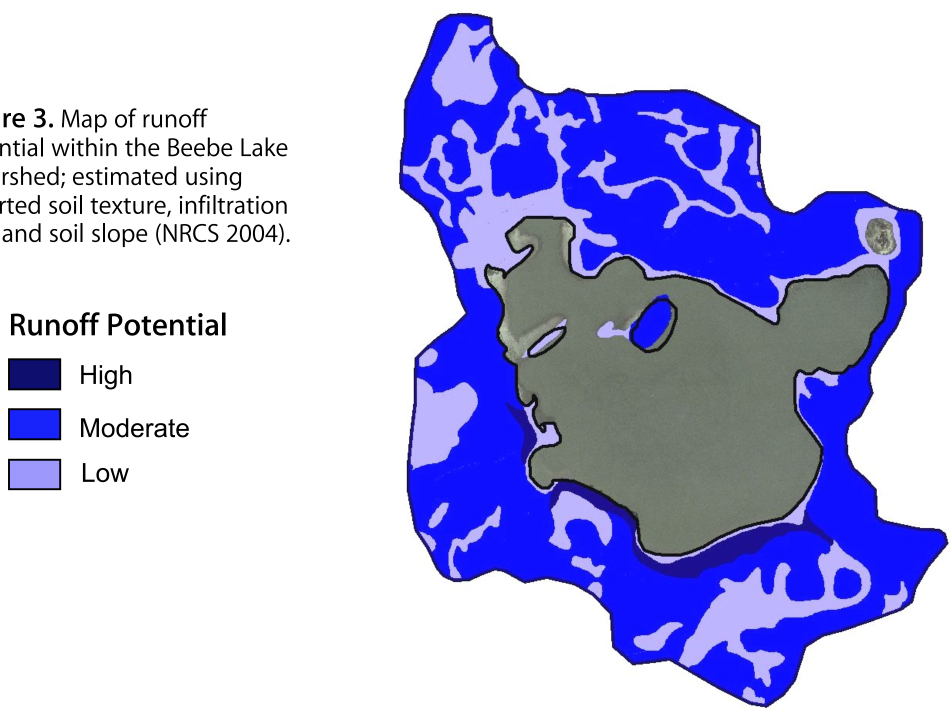


Figure 3. Map of runoff potential within the Beebe Lake watershed; estimated using reported soil texture, infiltration rate, and soil slope (NRCS 2004).

Monitoring and Analysis Methods

Measuring Rainfall

On June 6, 2011, we installed two tipping-bucket rain gauges (model RG3, Onset Computer Corp., Pocasset, MA) in the Beebe Lake watershed (Fig. 4). The locations of these rain gauges were selected based upon permission from landowners, potential for vandalism or theft, and open views of the sky with no obstructions. The rain gauges recorded all rainfall occurring between June 6 and October 13, 2011. These rain gauges use a “tipping bucket” to measure rainfall. This mechanism is calibrated to tip once for each 0.01 inch of rain. The time of each tip is recorded by an electronic data-logger in the rain gauge. This provides an accurate assessment of total rainfall like a standard rain gauge, but allows us to measure rainfall intensity and determine the amount of time between rainfall events. This information is vital for estimating runoff, as intense rainfall and rain falling on soils that are wet from recent rains are much more likely to run off. For example, a 1-inch rain event that occurs over 12 hours (a low-intensity “soaking rain”) will usually have time to soak in and thus does not create much runoff. By comparison, a 1-inch rainfall that occurs in 10 minutes (a high-intensity storm) will usually produce more runoff, even though the amount of rain is the same as in the previous example.

Rainfall can vary dramatically, even over short distances. Long-duration, soaking rains tend to blanket large areas with similar amounts of rain, but thunderstorms tend to drop lots of rain over small swaths of land, leaving other areas dry. Even though the Beebe Lake watershed is fairly small, we needed to measure rainfall at multiple locations to be able to estimate the amount of rain that fell on the entire watershed. Based upon the location of the rain gauges, we divided the watershed into areas that were closest to each rain gauge (Theissen polygons, Fig. 4, Table 1). We then calculated the volume of rain that fell on each portion of the lake and watershed by multiplying the rainfall measured at each rain gauge by the appropriate area (Table 1). We also calculated total rainfall for each rain event (defined as rainfall separated by at least 12 hours without rain), and calculated average rainfall intensity during each rain event (total rainfall ÷ duration of rain event, inches/hour).

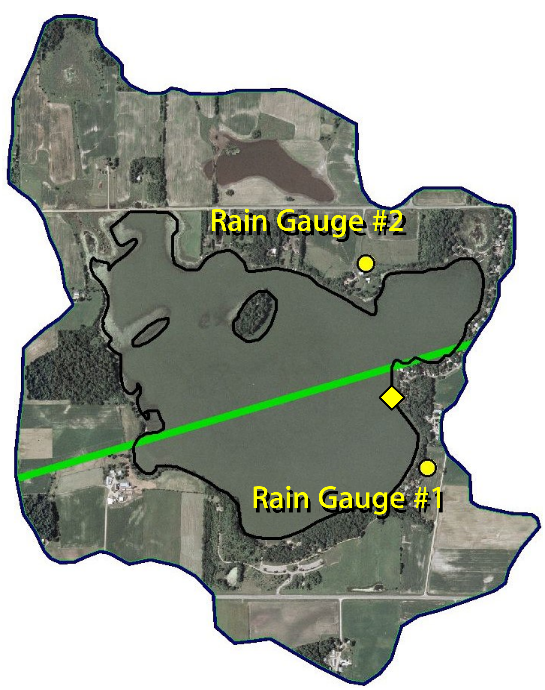


Figure 4. Map of Beebe Lake watershed showing location of the two rain gauges (circles) and the lake level/temperature probe (diamond). The green line indicates the division between portions of the lake and watershed attributed to each rain gauge (Theissen polygons).

Table 1. Delineated areas for Beebe Lake, its watershed, and the portion of each associated with each rain gauge (see Fig. 4). These calculated areas were used to estimate rainfall volume over the entire watershed and lake volume increases associated with each rain event.

	Total *(acres)*	**Rain Gauge #1** *(acres)*	**Rain Gauge #2** *(acres)*
Watershed + Lake	963	384	579
Watershed	667	272	395
Lake	296	112	184

Measuring Lake Level and Temperature

On June 6, 2011, we installed an electronic water level and temperature probe (HOBO 13-ft water level probe, Onset Computer Corp., Pocasset, MA) off the end of a homeowner's dock on the eastern shore (Figs. 4 and 5). The water level probe was suspended ~2 ft below the water surface, inside a perforated PVC pipe. This pipe protected the probe from damage, reduced the growth of algae on the probe, and served as a "stilling well" to reduce water level fluctuations from passing waves. The probe was programmed to record water level (pressure) and water temperature every ten minutes from June 6 through October 13, 2011. A second identical probe was installed out of the water (same location as used for rain gauge #1) to record barometric pressure. Since the water level probe only measures pressure, the data from the second probe were needed to compensate for changes in barometric pressure and thus ensure an accurate water level record.

We downloaded the measurements recorded by the probes and then calibrated and plotted the data using HOBOpro™ software (Onset Computer Corp. 2011). Water depths were calibrated to reflect manual depth gauge readings reported by the Beebe Lake Improvement Association. Using the rainfall data as a guide, we then inspected the water level record to determine how much the lake water level increased immediately following each rain event. In addition, we estimated the rate of evaporation from the lake by determining the rate of lake level decline during extended dry periods (only during periods

Figure 5. Probe used to measure water level and temperature in Beebe Lake (HOBO 13-ft water level probe, Onset Computer Corp.)

Results & Discussion

Rainfall

We recorded 22 separate rain events in 2011 (Figs. 6 and 7). Of these, we were able to determine lake level increase for 14 events. We excluded several small events (<0.1 inch) and combined several events that occurred in close succession (within 24-hours).

Figure 6. Daily total rainfall (area-weighted average of measurements at two rain gauges).

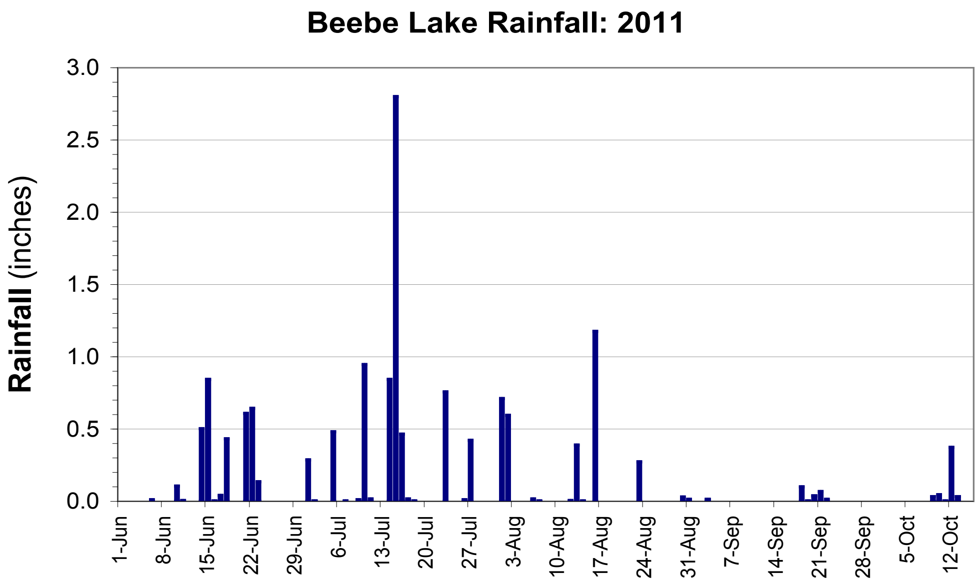
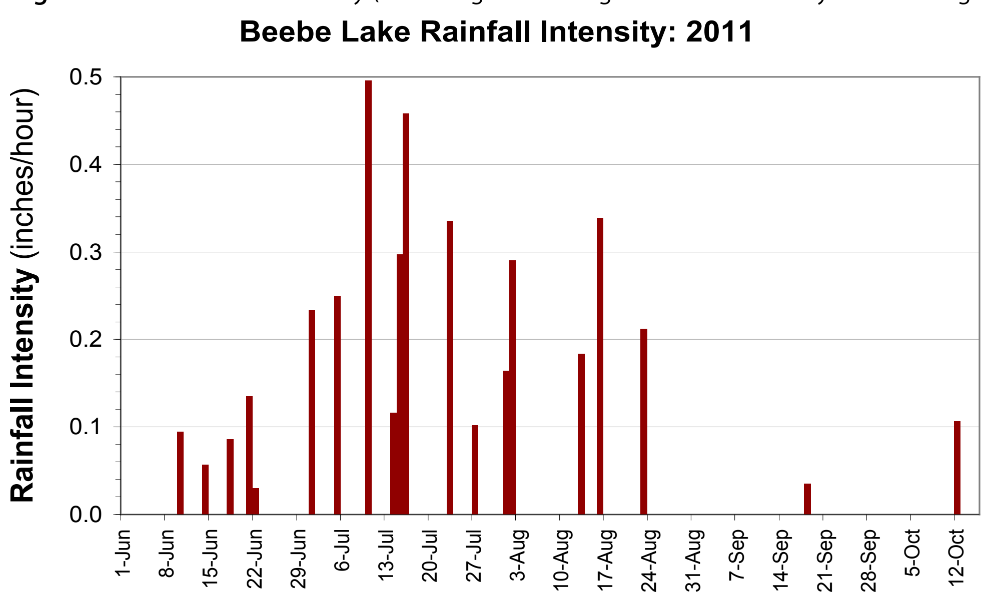


Figure 7. Rainfall event intensity (area-weighted average of rainfall intensity at two rain gauges).



Lake Level and Temperature

Based upon the detailed lake level record, we were able to identify 14 events where the lake level increased appreciably during and immediately after a rain event (Fig. 8). For each event we estimated the amount of lake level increase as shown in Figure 9.

Figure 8. Beebe Lake water level (daily average); elevations calibrated to depth gauge readings.

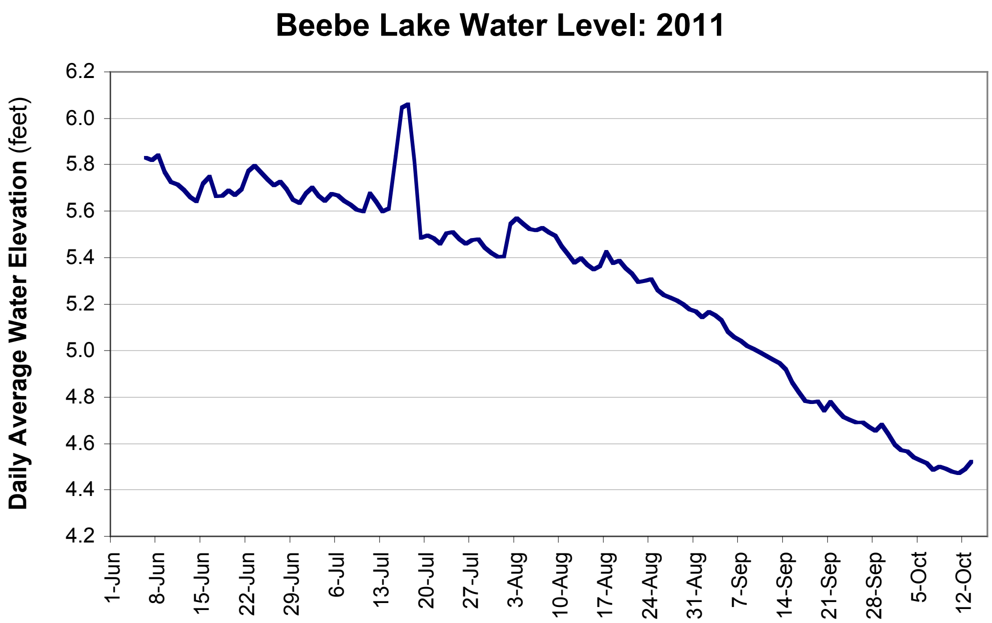


Figure 9. Plot showing method for estimating lake level increase from detailed lake level record (10-minute reading interval). This example shows the increase after ~0.5 inches of rain on 8/2/2011.

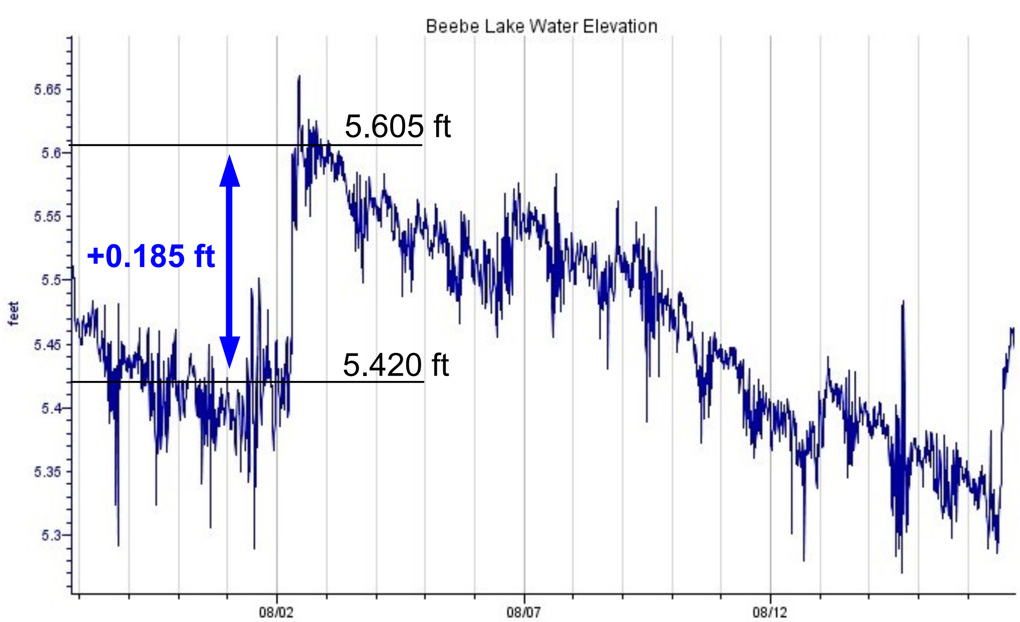
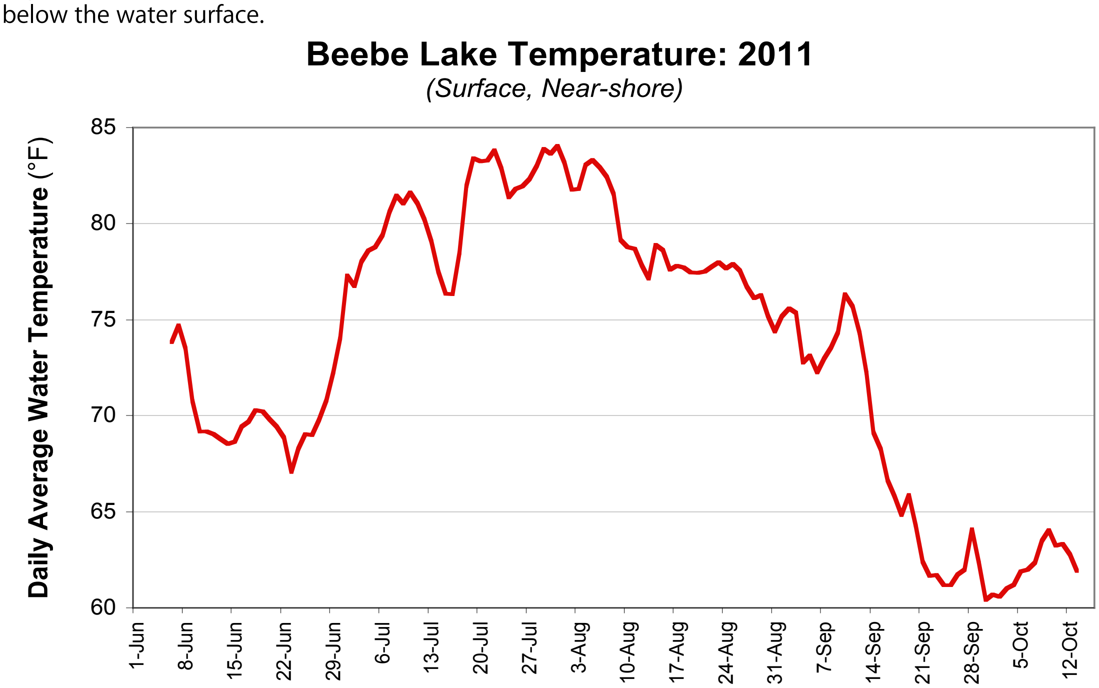


Table 2. Summary of rainfall event characteristics, lake level increase, runoff volume, runoff depth, and runoff coefficient for individual rain events. Listed in decreasing order of runoff volume. *Δ Lake Volume* calculated as [*Δ Lake Level* (in feet) x lake area]. *Runoff Volume* estimated by subtracting direct rainfall to lake [*Rain Depth (in feet)* x lake area] from the calculated *Δ Lake Volume*. Runoff Depth calculated by dividing *Runoff Volume* by the watershed area (land only). Runoff Coefficient calculated as [*Runoff Depth* ÷ *Rain Depth*].

Date	Rain Depth *inches*	Rain Intensity *Inches/hr*	Δ Lake Level *inches*	Δ Lake Volume *acre-ft*	Runoff Volume *acre-ft*	Runoff Depth *inches*	Runoff Coefficient
7/15/11	2.80	0.30	4.80	118.53	49.60	0.89	0.32
7/10/11	0.94	0.50	1.68	41.49	18.02	0.32	0.34
8/16/11	1.18	0.34	1.86	45.93	17.19	0.31	0.26
6/14/11	1.35	0.06	1.80	44.45	11.17	0.20	0.15
7/23/11	0.76	0.34	1.20	29.63	10.96	0.20	0.26
6/22/11	0.77	0.03	1.20	29.63	10.63	0.19	0.25
7/16/11	0.47	0.46	0.84	20.74	9.26	0.17	0.36
7/5/11	0.48	0.25	0.84	20.74	8.98	0.16	0.34
8/13/11	0.38	0.18	0.72	17.78	8.35	0.15	0.39
10/12/11	0.35	0.11	0.60	14.82	6.23	0.11	0.32
6/21/11	0.60	0.14	0.84	20.74	5.83	0.11	0.17
7/27/11	0.43	0.10	0.60	14.82	4.32	0.08	0.18
7/14/11	0.84	0.12	0.96	23.71	2.85	0.05	0.06
6/18/11	0.43	0.09	0.48	11.85	1.20	0.02	0.05

Figure 10. Beebe Lake surface water temperature (daily average); measured nearshore ~2 ft below the water surface.



Predicting Changes in Lake Level

Given the recent issues with high water in Beebe Lake, the following plots should prove useful:

Figure 11 shows the relationship between rainfall depth and runoff depth (dashed blue line). This plot tells us several very useful bits of information: (1) rain events smaller than about 0.15 inches do not produce runoff from the watershed (x-intercept), (2) rainfall depth is a very strong predictor of runoff from the Beebe Lake watershed (R^2=0.85), but other factors, such as rain intensity and soil moisture, also affect runoff (as indicated by the scatter around the dashed blue line).

Figure 12 shows the relationship between rainfall depth and the associated increase in lake level. This relationship is very strong (R^2=0.97), meaning that lake level increase can be very accurately predicted by knowing the rainfall depth. This plot could be used to inform lakeshore homeowners of flooding potential based upon weather forecasts.

In addition, we estimated the rate of lake level decline during extended dry periods in the late summer. These declines suggest that when the lake is at or below its normal water level (no major outflow), the lake drops roughly 0.22 inches per day due to evaporation. This conservative rate of evaporation would also apply to times when outflow was occurring.

Figure 11. Plot showing the relationship between rainfall depth (inches) and watershed runoff (inches). The ratio of these two measurements [*Runoff ÷ Rainfall*] is called the *Runoff Coefficient* and represents the proportion of rain that runs off of the landscape and into the lake (0.3 indicates 30% of the rain runs off).

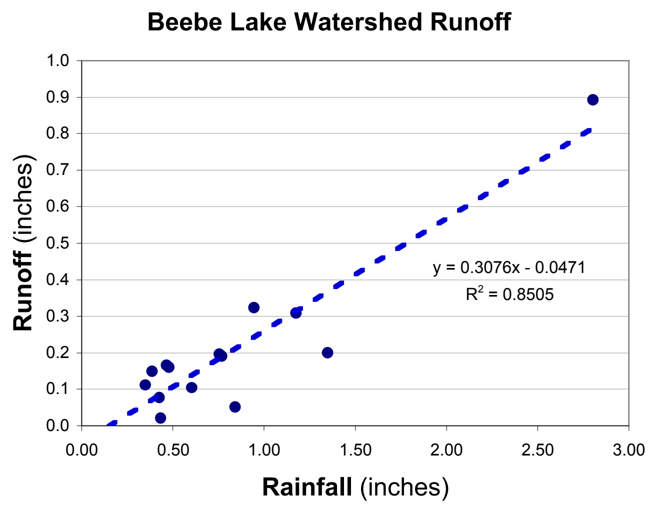
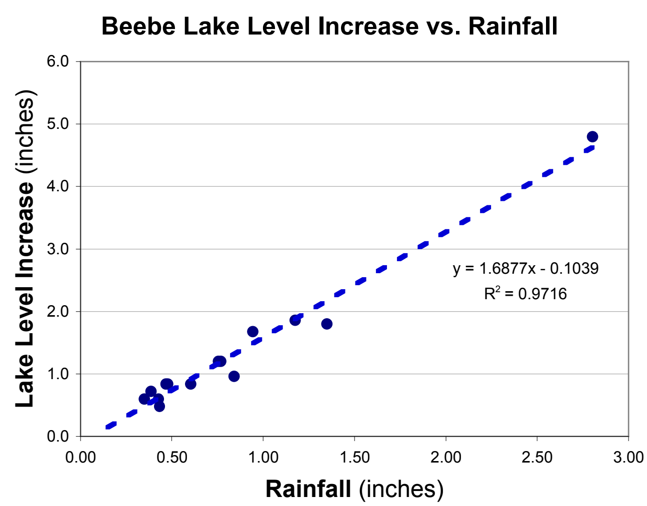


Figure 12. Plot showing the relationship between rainfall depth (inches) and lake level increase (inches). This relationship is very strong, indicating that local rainfall depth is a very good predictor of lake level increase in Beebe Lake.



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