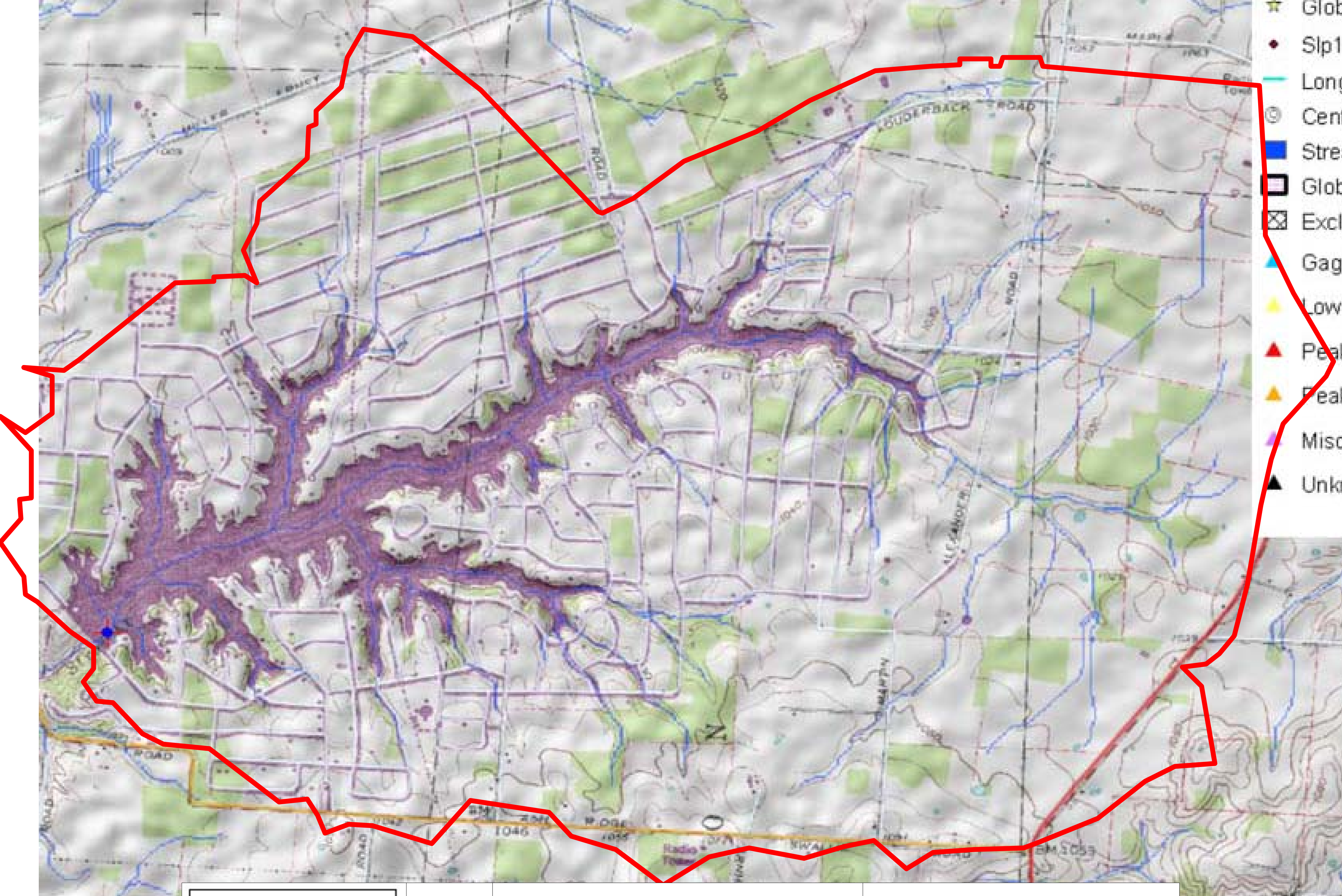
4 RESULTS and DISCUSSION

4.1 Watershed Investigation

The watershed investigation revealed that the majority of Lake Waynoka's watershed lies within the boundaries of the WPOA. The exceptions to this are Straight Creek and Cove 8, which originate beyond the WPOA boundaries (Figure 2). Within the WPOA boundaries, land use is almost exclusively residential single family homes surrounded by lawns and accompanying driveways and two-lane roads. MAD conducted an on-the-ground watershed investigation on July 7, 2011, during which nine lots under construction were observed with no or inadequate sediment and erosion control measures.

The portions of the drainage areas to Straight Creek and the tributary to Cove 8 that lie outside WPOA boundaries were also investigated. Straight Creek's drainage area primarily consists of row-crop agriculture, in corn and soy bean rotation, as well as some tobacco. This drainage area is 18% forested, much of which exists as large woodlots and a smaller portion as narrow riparian corridors. Straight Creek's drainage area also includes part of the newly expanded Eastern Local School District site on U.S. Route 62. The parking lots and buildings on this school site likely make up the majority of impermeable surfaces in Straight Creek's drainage area. Cove 8's drainage area also primarily consists of row-crop agriculture, but has some two-acre and larger residential lots. A small portion (~10%) of the drainage area is forested, mostly consisting of woodlots and narrow riparian corridors. Photographs documenting observations during the investigation are included in Appendix D, photographs 1-35.

A complete listing of observations from our on-the-ground watershed investigation is included in Appendix E.



MAD Scientist & ASSOCIATES LLC	N	Figure 2. Lake Waynoka Watershed Boundary	Source of Image: USGS StreamStats	
		Brown County, OH	Created By: JM	Created: 10-17-11

4.2 Water and Sediment Samples

TOC was assessed in water samples to determine how much organic material is present in the water column. Average TOC values ranged from 3.7 mg/L at the downstream spot in Cove 11 to 23.83 mg/L in the upstream spot in Cove 8 (Figure 3).

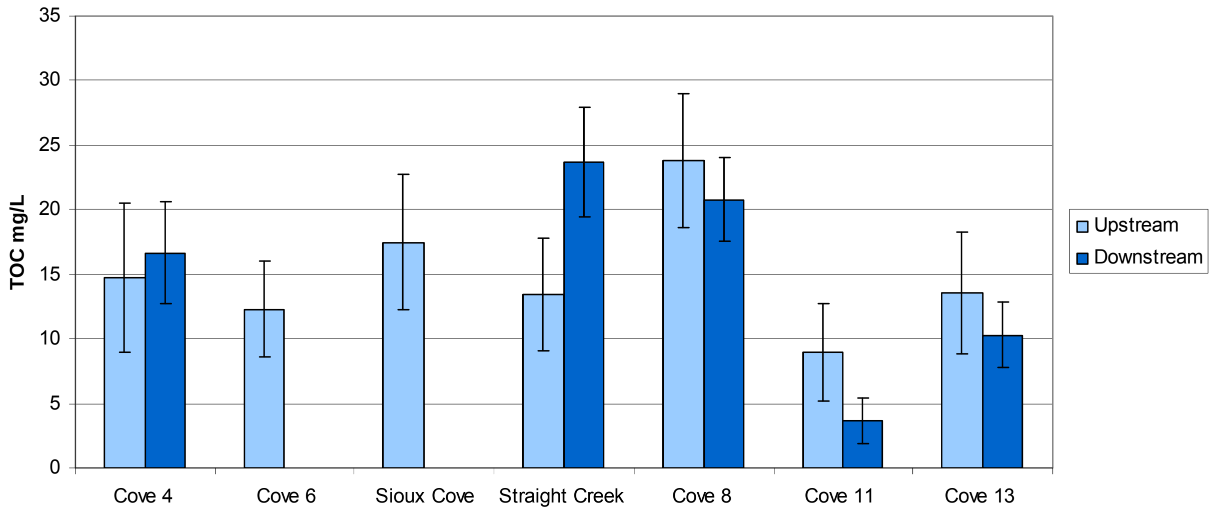
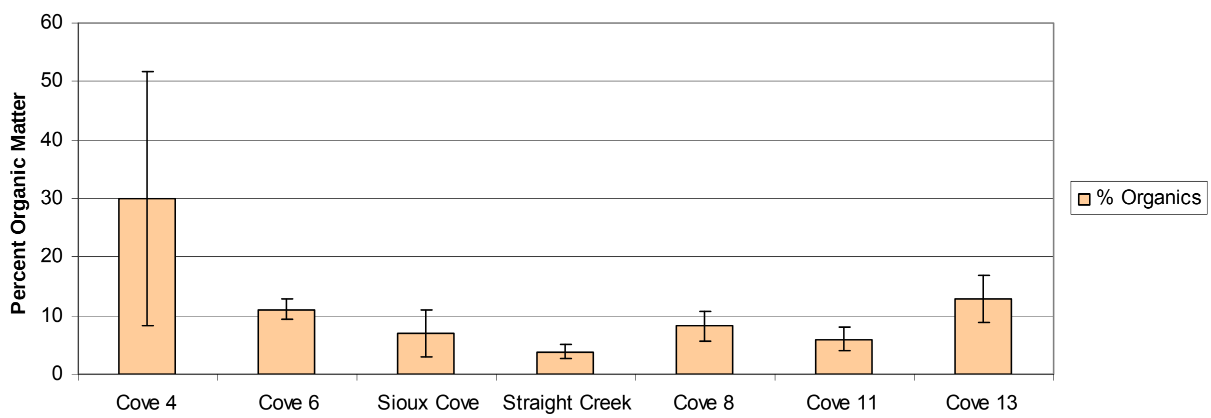


Figure 3. Average TOC values at upstream and downstream locations (±SE) for sampled coves in Lake Waynoka.

The coves did not differ significantly from one another in the amount of TOC that was present in the water column ($p = 0.063$). By comparison, typical summer values for TOC in Minnesota lakes range from 7-14 mg/L (Heiskary and Lindon, 2010) and values from the USEPA's 2007 national lake study averaged 10 mg/L (EPA 841-R009-001a, 2010). This comparison indicates that the values from Lake Waynoka are at the high end of the range for U.S. lakes. The higher amount of TOC may result from algae present in the water column. The clarity of water in Lake Waynoka, although not measured, was observed to be moderately low throughout the summer and the water had a greenish color (Photos 36-37). The upstream Cove 8 sample location had visible algae present on the water surface that likely caused this location to have the highest TOC value (Photos 38-39).

Similar to TOC, the amount of organic matter (OM) present in the sediment samples was assessed to determine how much organic material is accumulating on the bottom of the lake. The percent of OM present in the sediment samples was generally low, with averages ranging from 4% in Straight Creek to 30% in Cove 4 (Figure 4). The sediment sample from the uppermost location of Cove 4 was 73% organic material, consisting of un-decomposed leaves, which made it impossible to actually collect a core sample. Lots of gas bubbles (methane) were released as we attempted to collect the core, indicating that the soils here were anaerobic. These results corresponded with observations made during the winter drawdown that revealed large piles of un-decomposed leaves in Cove 4 (Appendix D, Photos 40-41). Conversely, locations in Cove 4 closer to the main body of the lake were only 8% organic material.



<u>Figure 4</u>. Average percentage of organic matter (±SE) present in Lake Waynoka sediment samples

The much higher amount of OM closer to the head of the cove may result from less boat traffic in this area. Boat traffic aerates the water column, thereby encouraging decomposition of organic material. Thus there should be little accumulation of OM in the ski zone. There is also greater leaf litter input per unit of water surface area in the narrow upper coves than near the lake. Although Cove 4 appeared to have more organic material than other coves, there were no statistically significant differences among the coves in the amount of OM present ($p = 0.208$). The results for TOC and

OM indicate that both of the sampled coves contain approximately the same amount of organic material, both suspended in the water column and accumulated in the sediment.

The amount of TSS present in the water column was determined so that the amount of sediment entering the lake from each cove could be estimated. TSS values range from 5 mg/L at the upstream location in Cove 13 (Red Cloud) to 23 mg/L at the upstream location in Straight Creek (Figure 5). The highest levels of TSS were consistently found in Straight Creek and Cove 8, which are the two tributaries that flow through agricultural areas.

A statistically significant difference exists in the TSS values among the coves ($p = 0.000$) with Straight Creek and Cove 8 having significantly higher TSS values than Coves 11 and 13, which are located at the opposite end of the lake. Straight Creek also has significantly higher TSS than Cove 6 and Sioux cove. Straight Creek and Cove 8 are the largest tributaries to Lake Waynoka with the largest drainage areas, thus it makes sense that these tributaries contribute the most sediment to the lake. No difference exists in the amount of TSS present in upstream and downstream samples ($p = 0.8056$), which suggests that the coves are well mixed from wind and wave action and boat traffic.

Core samples ranged in depth from only one inch to 11 inches, but averaged 5.7 inches. In Straight Creek, it was very challenging to collect a core sample near the head of the cove. The Sludge Judge could be pushed into the sediment to a depth of four feet before hitting hardpan (tight clay). However, the sediment consisted of unconsolidated sand which slid out of the Sludge Judge before the sample could be documented. Interestingly, the upper end of Straight Creek was the only location in which cobbles were found. Closer to the main body of the lake, in Straight Creek cove, the sediment was consolidated and a five-inch core was collected. The large amount of unconsolidated sediment in the upper end of Straight Creek cove was consistent with our observations during the winter drawdown (Photos 42-43) and personal accounts from members of the LAC.

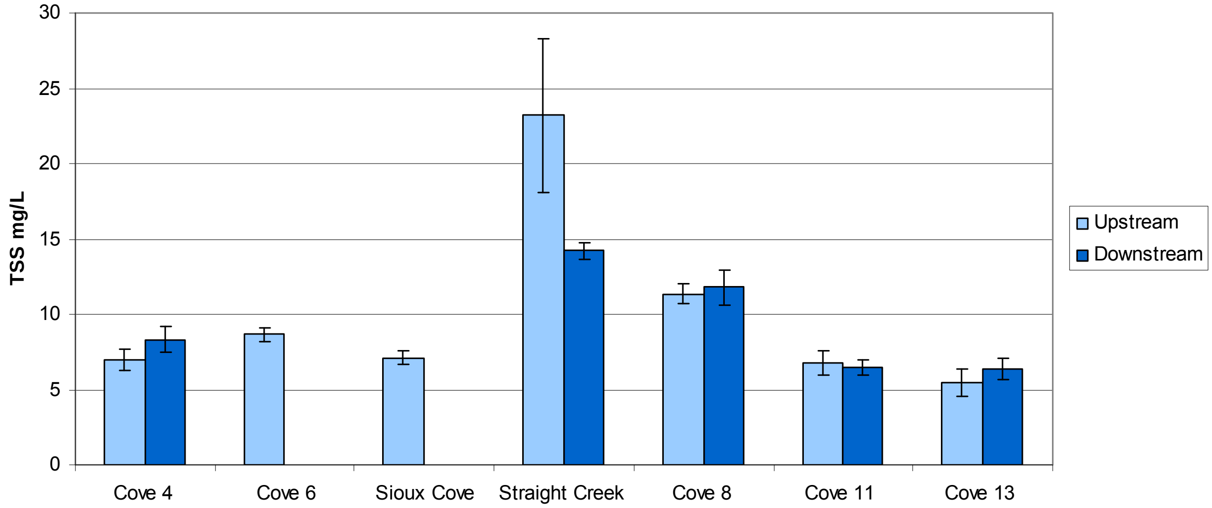


Figure 5. Average TSS values at upstream and downstream locations (±SE) for sampled coves in Lake Waynoka.

Sediment samples observed in the field consisted primarily of sand. To confirm this observation, a particle size analysis was conducted in which samples were sieved into different size classes: fine gravel, very fine gravel, very coarse, coarse, medium, and fine sand, and a catch-all group of the smallest size grains that included very fine-grained sand, silt and clay. The particle size breakdown for each cove was statistically analyzed to determine whether particles tended to be of one size or another. Overall, the coves contain significantly more sand, silt and clay than gravel ($p = 0.000$). On an individual basis, three of the sampled coves, Coves 6, 11 and 13, did not have significant differences amongst the amount of gravel, sand and very fine sand, silt, and clay present ($p > 0.05$). However, four coves did have differences in the distribution of sediment sizes. Sioux Cove and Cove 4 had significantly more of the smallest size grains present than either gravel or sand, and Cove 8 had significantly more of the smallest size grains than gravel ($p = 0.000$, 0.009 and 0.024, respectively) (Appendix D, Photos 44-47). Straight Creek was the only cove with significantly more sand than very fine sand, silt and clay ($p = 0.038$) (Appendix D, Photo 48). A complete list of observations from the sediment sampling is included in Appendix F.

4.3 Stormwater Runoff Rates

The drainage area (land area from which precipitation flows into the tributary) was determined for each of the coves and inlets draining into the lake. Straight Creek's drainage area is approximately four times larger than the drainage area to Cove 8 and five times larger than the drainage area to Cove 4, which has the third largest drainage area (Table 2). Consequently, during a 0.75-inch storm event, Straight Creek contributes 28 times more runoff to Lake Waynoka than Cove 8 and 37 times more runoff than Cove 4 (Figure 6). As the size of the storm increases, this trend remains the same although its magnitude is dampened. For example, during a 1.5-inch storm event, Straight Creek contributes about seven times more runoff to the lake than Cove 8 and almost nine times more runoff than Cove 4. During a one-year storm event (2.5 inch rain) Straight Creek contributes five times more runoff than Cove 8 and seven times more runoff than Cove 4. Thus, as storm events increase in size, the difference in the volume of stormwater runoff amongst the coves becomes smaller.

Calculating these runoff volumes was an important and necessary step to develop an accurate picture of each tributary's contribution to the sediment loading in Lake Waynoka. Using the volume of runoff from each tributary and the measured amount of

Table 2. Lake Waynoka Drainage Areas and Stormwater Runoff Volumes

		3/4" Rain		1.5" Rain		2.5" rain (1-YR Storm)	
Area Name	Drainage Area (Acres)	Runoff Flow (cfs)	Runoff Volume (CF)	Runoff Flow (cfs)	Runoff Volume (CF)	Runoff Flow (cfs)	Runoff Volume (CF)
Cove 4	176.3	0.14	2,806	63.38	115,772	267.31	426,682
Cove 6	99.4	0.08	1,582	35.74	65,273	150.72	240,568
Sioux Cove	8.0	0.01	127	2.88	5,253	12.13	19,362
Straight Creek	921.8	5.84	106,316	72.93	1,009,947	227.59	2,957,502
Cove 8	234.9	0.19	3,738	84.45	154,253	356.17	568,506
Cove 11	29.3	0.02	466	10.53	19,241	44.43	70,912
Cove 13	16.0	0.01	255	5.75	10,507	24.26	38,723

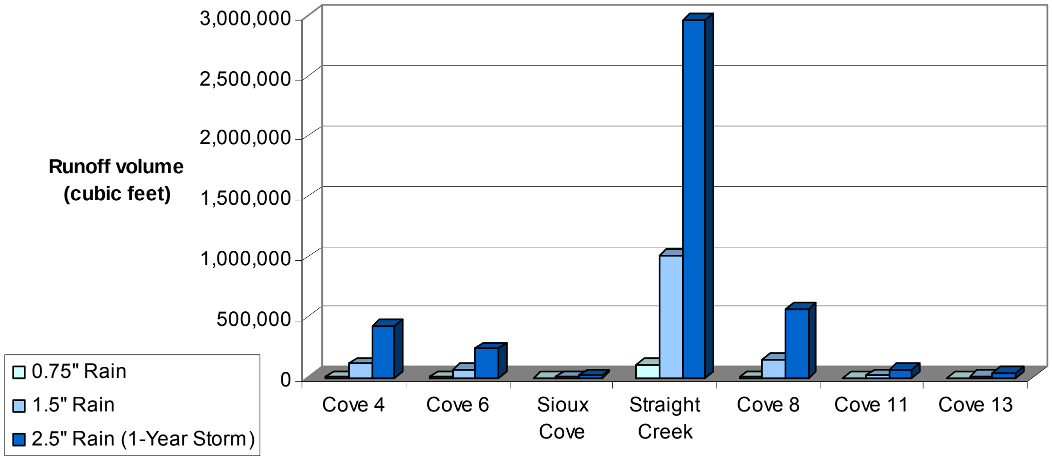


Figure 6. Volume of stormwater runoff entering Lake Waynoka tributaries during 0.75-inch, 1.5-inch and 2.5-inch storm events (NOTE: A 0.75-inch storm is used for water quality calculations by the EPA and a 2.5 inch storm event is considered a storm that has a 99% chance of happening every year)

TSS present in each cove after a storm, we calculated the amount of sediment that is contributed to the lake through each cove (Figure 7). The same trend that exists with runoff volume exists with sediment, whereby the most sediment enters the lake via Straight Creek followed by Cove 8. After a 1.5-inch storm event, Straight Creek contributes eight times more sediment than Cove 8 and 15 times more sediment than Cove 4. As with the runoff volumes, the differences amongst the coves are not as pronounced for larger storm events. After a one-year storm event, Straight Creek contributes six times more sediment than Cove 8 and 12 times more sediment than Cove 4. These results indicate that the amount of sediment a cove contributes to the lake is largely a function of the size of the drainage area.

Noting this relationship, the LAC's energy and resources will be best invested in efforts to curtail sediment loading to the tributaries with the largest drainage areas, with particular emphasis on Straight Creek cove and Cove 8.

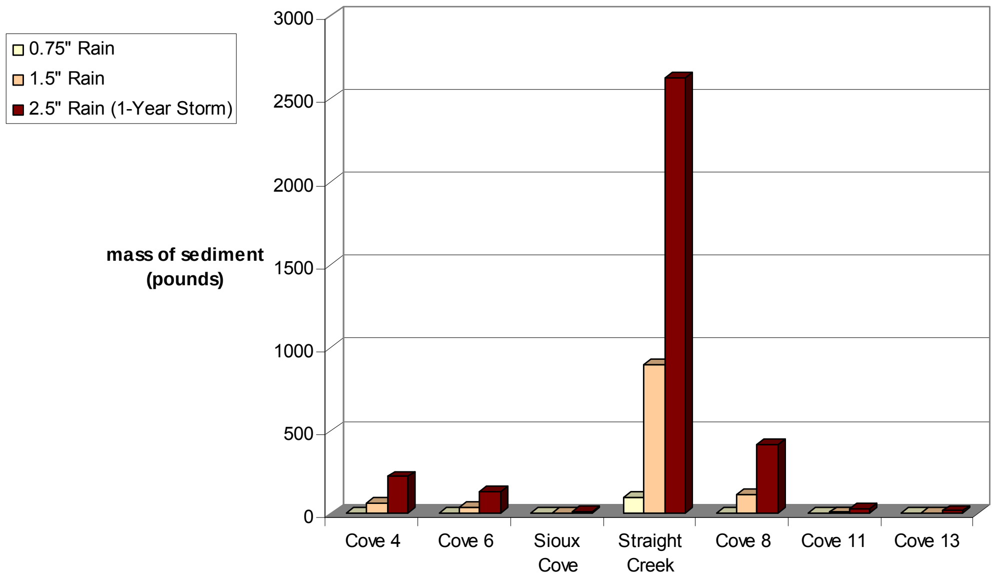


Figure 7. **The mass of sediment that enters Lake Waynoka tributaries during 0.75-inch, 1.5-inch and 2.5-inch storm events**

5 STUDY CONCLUSIONS

Based on LAC accounts, direct observations of the lake during sampling activities, and the study results described in this report, the MAD team has found Lake Waynoka to be relatively stable and in good health. However, certain site enhancements and fine-tuning of WPOA lake management strategies could benefit the lake and its fishery. In addition, a few isolated problem areas requiring attention were identified in the upper coves, particularly at Straight Creek cove.

Straight Creek, which delivers the highest volumes of water and sediment to the lake, presents a specific set of problems that will require engineering solutions: 1) washout behind a wingwall of the Waynoka Drive box culvert, 2) high transport of sediment bed load associated with the proportionally massive volumes of water that flow through this creek, and 3) severe erosion, particularly on the steep south bank of the creek.