Wolf Bay Watershed Literature Review

The proceeding literature review represents the combined efforts of the Volkert/AllenES team to assimilate all pertinent scientific information that could be used in the formulation of a Watershed Management Plan for the Wolf Bay Watershed. Thirteen different sources were reviewed and summarized to compile the following literature review.

Watershed Characterization

Worldwide, more than 40% of the population lives within 60 miles of the coast. The continental US coastal zone represents 17% of the land area but contains greater than 50% of the population (Alabama Coastal Foundation, 2005). Alabama and other southeastern states of the south Atlantic-Gulf region are the fastest growing areas in the United States. As population, agricultural, and industrial centers have expanded along sea coasts, demands for freshwater resources have resulted in widespread water depletion and contamination in coastal regions. Inevitable water supply and quality problems arise from population growth, underscoring the need to protect water resources from degradation (Lee et al., 2007). The implications of this growth, both short-term and long-term, indicate that management of growth with regard to resource protection will be a challenge in the Wolf Bay watershed (Wolf Bay Plan, 2005).

The Wolf Bay watershed is located in the southeastern part of Baldwin County, Alabama between Perdido Bay to the east and Mobile Bay to the west. The watershed is located within the jurisdictions of Baldwin County, Foley, Elberta, Gulf Shores and Orange Beach municipalities (Alabama Water Watch, 2007). However, our focus for this study will be on the northern portion of the watershed which includes only Baldwin County and the towns of Foley and Elberta. Baldwin County is among the fastest growing areas in Alabama showing a 43% increase in population from 1990-2000. From 2010 to 2016, Baldwin County experienced a 14.4% population increase compared to just a 1.7% growth rate for the rest of the state during the same period. Much of the growth is due to the City of Foley’s population rise of 20.5% from 2010 to 2016 (Alabama Water Watch, 2007; US Census, 2016; Cook, 2017). This rapid expansion of urban/suburban development contributes both point source and nonpoint source pollutants to tributary systems and to Wolf Bay. Pollutants include eroded soils from construction sites, an increase in the volume of municipal wastewater discharge, lawn chemicals, and oil from parking lots (Alabama Water Watch, 2007).

For the scope of this project, the three northern sub-watersheds of the Wolf Bay Watershed that will be analyzed include the Sandy/Wolf Creek watershed that consists of 15,199 acres (23.75 square miles), Miflin Creek watershed that contains 8,427 acres (13.17 square miles), and the Graham Bayou watershed that has an area of 12,670 acres (19.8 square miles). The major tributaries that make up these sub-watersheds include Wolf Creek, Sandy Creek, Miflin Creek, Graham Bayou, Owens Bayou, and Hammock Creek. Stream channels in the northern parts of the watershed, including the headwaters of Wolf, Sandy, and Miflin Creeks, are characterized by relatively high elevation (maximum 100 ft. MSL), with topography that decreases in relief from north (upstream) to south (downstream) towards Wolf Bay (Cook, 2017). The southern edges of these tributaries experience daily tidal fluctuations of up to two feet. Wolf Bay itself flows into the Intracoastal Waterway which flows into either Perdido or Mobile Bay depending on winds and tides, and ultimately into the Gulf of Mexico (Alabama Water Watch, 2007).

Land use within the watershed includes forests (23%), agriculture (27%), urban/suburban (27%), wetlands/water (16%) and other uses (7%) (www.mobilebaynep.com)*. Since 1992, urban/suburban land use increased from 4% to 27% while agricultural area has declined from 46% to 27% and forests declined from 32% to 23% of the watershed. Within the agriculture sector, there has been a significant shift from row crops to sod farms (Alabama Water Watch, 2007). A characteristic of this watershed is that overland flow during precipitation events is minimal and only a small percentage of precipitation is discharged to the surface streams with the majority of the water infiltrating the subsurface aquifers immediately (Lee et al.). The aquifer in the Wolf Bay watershed is the Miocene/Pliocene Aquifer which is comprised of over 500 feet of inter-layered sands, gravels and clays. Baldwin County is unique in that the entire county serves as the recharge area (Wolf Bay Plan, 2005). However, the increase in urban/suburban land use and associated impermeable surfaces has reduced the amount of freshwater infiltration to the aquifer. This fact is especially pertinent in consideration that groundwater pumping for municipal, irrigation, and industrial use has increased six-fold since 1966. These increasing groundwater withdrawals along the coast of Baldwin County could lead to invasion of seawater in to freshwater-bearing aquifers (Lee et al., 2007).

Wolf Bay serves as a nursery ground for many types of commercially and recreationally important species of fish, crab, shrimp, and other organisms. Additionally, the United States Fish and Wildlife Service has documented several species listed as threatened or endangered including Florida manatee (*Trichechus manatus latirostris*), Alabama red-bellied turtle (*Pseudemys alabamensis*), Gulf Sturgeon (*Acipenser oxyrinchus desotoi*), American bald eagle (*Haliaeetus leucocephalus*), wood stork (*Mycteria americana*), and the red cockaded woodpecker (*Picoides borealis*) (www.mobilebaynep.com). Imperiled habitats within the watershed include Gulf Coast Pitcher Plant Bogs, Atlantic White Cedar Swamps, and Long Leaf Pine Savannahs (Wolf Bay Plan, 2005).

Wolf Bay Watershed Watch (WBWW) began the process of obtaining an "Outstanding Alabama Water" (OAW) classification for Wolf Bay in 2001. In April 2007, the bay was granted OAW status by ADEM which classifies it as the highest of seven levels of waterbody classifications established by ADEM. Wolf Bay was one of five waterbodies statewide and was the first bay in Alabama to attain OAW classification. Under OAW classification, the bay is protected by higher water quality standards including more stringent restrictions on wastewater discharges and toxic substances in the bay, a higher minimum dissolved oxygen level, and a lower level of acceptable year-round pathogen concentration (Alabama Water Watch, 2007). The classification extends from the Intracoastal Waterway to Moccasin Bayou (www.mobilebaynep.com). The waterbody is also classified for swimming, fish and wildlife, and shellfish harvesting (Hydro Engineering Solutions, 2013).

Baldwin County has a mild but humid climate with average annual rainfall of around 61 inches (Hydro Engineering Solutions, 2013). In the contiguous United States, this region is second only to the Pacific Northwest in total annual rainfall with the frequency of thunderstorms over coastal Alabama being surpassed only by the Florida peninsula (Wolf Bay Plan, 2005). The summer months are typically the wettest with the winter typically being the driest months. Annual rainfall is generally well distributed although significant rain events can be experienced due to proximity to the coast and exposure to hurricanes and tropical storms. Since 1995, six hurricanes have impacted Baldwin County with precipitation amounts ranging from 2 to 24 inches. The average high and low temperatures are 77 degrees and 55 degrees, respectively. The warmest month is July with the coldest month being January (Hydro Engineering Solutions, 2013).

Discharge

In 2013, Hydro Engineering Solutions conducted a watershed study on Wolf Bay for the Baldwin County Commission and Highway Department. The purpose of the study was to gain an understanding of the watershed and determine its sensitivity to land use changes in areas that are expecting growth in the future. The study projected that the main area of future development was to occur along the Foley Beach Express and that the Wolf Creek and Sandy Creek basins were the two sub-watersheds that would experience the most impact from this development. Results indicate that additional development around the municipalities of Foley and Elberta will increase peak discharges downstream if they are not detained and that development of each area will cause a negative impact to the local reach downstream. Without detention, peak discharges will occur earlier and increase discharge in local streams leading to the bay although it will not have an effect on the discharge at the outlet of the bay itself. The existing regional ponds are not sufficient to handle discharge increases at the outlet of Wolf Bay and local detention needs to be employed in the upper portions of the watershed. Protections from in-stream erosion can be accomplished by using local detention on smaller, more frequent rain events which will protect against stream degradation that could occur with increased runoff. The study used a drainage area of 56.06 square miles and determined that the 100-year peak discharge was 10,620 cfs.

Wang et al. (2014) predicted a slight increase in precipitation with high flows expected to increase and low flows expect to decrease. Monthly average streamflow and surface runoff were projected to increase in spring and summer but especially in fall. Land use/land cover change does not have a significant effect on monthly average streamflow, but would affect partitioning of streamflow, causing higher surface runoff and lower baseflow.

Sediment

When rainfall totals are high, the combination of flood runoff, erosion, and the destruction of trees and buildings along the shoreline results in the transport of large amounts of sediment and debris into parts of the Wolf Bay watershed and into Wolf Bay itself (Wolf Bay Plan, 2005). In 2005, Alabama Soil and Water Conservation reported that urban land use in the watershed consisted of 14,000 acres, or 22% of the total land use. However, 63% of measured sedimentation in the watershed (240,000 tons) originated from developing urban land. In comparison, forest land, which comprises 53% of the watershed, contributes under 3% of total sedimentation, while agriculture uses 10% of the land and contributes less than 1% of total sedimentation (Lee et al., 2007).

Cook (2017) found that concentrations of total suspended sediments (TSS) obtained from periodic water grab samples were highest at Sandy Creek at Baldwin Road (929 tons/year) and Wolf Creek at Swift Church Road (861 tons/year). For comparison, the next highest concentration was only 460 tons/year. It was also noted that, although the Wolf Creek sampling site on Swift Church Road is downstream from the Wolf Creek site on Doc McDuffie Road, the suspended sediment load is 8.7 times larger at the Doc McDuffie Road location. This is due to the proximity of the downstream sampling point to the reach of Wolf Creek with tidal influence. When sediment loads were normalized to negate the influence of drainage area size and stream discharge, the east and west unnamed tributaries to Sandy Creek had the largest suspended sediment loads in the Wolf Bay watershed.

Bed sediment loads are composed of particles that are too large or too dense to be carried in suspension by stream flow. The sample site on Wolf Creek at Doc McDuffie Road showed bed sediment loads (10,471 tons/year) that were 6 times larger than the next largest load. Even after normalization relative to drainage area, Wolf Creek at McDuffie Road had more than twice the load of the next largest. These results are due to excessive upstream erosion which contributes a disproportionately large amount of bed sediment (Cook, 2017).

For total sediment loads, data normalized to negate the influence of drainage area size and stream discharge showed that Wolf Creek at Doc McDuffie Road exhibited the highest levels of total sediment load. The west and east unnamed tributaries of Sandy Creek had the next highest amounts but were still half that of the Wolf Creek at Doc McDuffie Road site. On average, bed sediment makes up 72% of the total sediment loads for streams with measurable suspended and bed sediment (Cook, 2017).

Without human impact, watershed erosion rates, called the geologic erosion rate, would be 64 t/mi^2/yr (Maidment, 1993). Normalized sediment loads show that 9 of 13 monitored watersheds were from 1.1 to 34.9 times greater than the geologic erosion rate (Cook, 2017).

Turbidity

Sampling conducted from 2004-2007 showed an increasing trend in turbidity in Wolf Bay. It was suggested that the upward trend was likely from a combination of eroded soils washing off the watershed into the bay and increased levels of nutrients flowing into the bay which stimulated the growth of algae (Alabama Water Watch, 2007).

Cook (2017) found average turbidity among 14 sampling points within the Wolf Bay watershed showed that the unnamed tributary at US Highway 98, Wolf Creek at Swift Church Road and another sampling point on the unnamed tributary at US Highway 98 exhibited the highest turbidity (110, 77 and 75 NTUs, respectively). Although land-use data indicates that watersheds with dominant urban development and/or agriculture are more likely to exhibit higher turbidity concentrations in streams, that was not necessarily the finding in this case. The Wolf Creek sampling point off Poplar Street in Foley had the highest percentage of residential development (84.8%) but showed average turbidity in the lower 40 NTU range. Average turbidity for all Wolf Bay watershed sites exceeded the ADEM standard of 9.7 NTU by 3 to 24 times (Cook, 2017).

Residents report that, following rain events, Sandy Creek turns a milky color. While the exact cause is unknown, it is believed that the increase in development has led to an increase in the erosion rate which has uncovered a white clay layer within the stream. Another common complaint is the turbidity of Wolf Creek. Much of the land under construction in the town of Foley drains into Wolf Creek which could be the cause. Foley recently passed an ordinance requiring low impact development which will reduce runoff into streams. This coupled with the required water quality component of treating the first flush should result in better water quality (Wolf Bay Watershed Watch, 2017).

Water Chemistry

pH

Monitoring by the WBWW showed an increase in alkalinity and pH from 1998-2000. Scientists believe this trend can be attributed to the drought cycle occurring at that time (Alabama Coastal Foundation, 2005). Since the drought subsided 10 years of data shows a trend that the water in Wolf Bay is becoming more acidic. In 2011, a salt layer was detected ¾ of a mile up Sandy Creek. In 2016, it was detected a full mile up the creek (Singleton, 2016).

Nutrients

Excessive nutrient enrichment can cause blooms of algae and associated bacteria that can cause taste and odor problems in drinking water and decrease oxygen concentration to eutrophic levels. Certain toxins can also be produced during blooms of particular algal species (Cook, 2017). In 2012, ADEM collected water quality samples from designated sampling points in Miflin Creek, Sandy Creek, Wolf Creek and Wolf Bay during the growing season of March-October. Mean total nitrogen values at the Wolf Creek station were the lowest since 2005 but were the highest among all stations sampled. Cook (2017) found the highest total nitrogen concentrations in sampling locations in Miflin and Sandy Creek. Both of these watersheds are dominated by row crop and turf agricultural land use. The ADEM reference concentration for total nitrogen was exceeded in 83% of samples collected.

Total phosphorous values at the Wolf Creek site increased from 2005-2008 but were lower from 2009-2012. Total phosphorous values were still highest for the Wolf Creek site compared to other sites in the 2012 sampling. Cook (2017) found that two of the Wolf Creek monitoring sites exhibited the highest levels of phosphorous among 14 sample sites throughout the watershed. It was also noted that 10 of the 14 sites had average phosphorous concentrations above the 0.04 mg/L reference established by ADEM (Cook, 2017).

Relatively large average concentrations and loadings of nitrogen and phosphorus in most of the monitored Wolf Bay watershed streams originate from sources related to urban, residential and agricultural land use that dominate specific parts of the watershed (Cook, 2017).

Dissolved Oxygen

Biological processes, oxidation and sediment loads all contribute to depletion of dissolved oxygen (DO) in surface water. DO concentrations in the Wolf Bay watershed are significantly affected by water temperature, stream discharge, concentrations of organic material in the water and oxygen-consuming plants. The ADEM reference standard for dissolved oxygen is 5.0 mg/L although the Wolf Bay watershed is held to a higher standard of 6.94 mg/L due to its OWA status (Cook, 2017).

In the summer of 2000, citizen data documented a sharp decline in DO in Wolf Creek that was likely due to low flows and stagnancy caused by drought. Data also indicated that DO levels increased to around 6-9 ppm later in the year when water temperatures decreased, and flow increased (Alabama Water Watch, 2002). Growing season averages in 2005 and 2006 indicated poor water quality of 2.2 ppm in Wolf Creek headwaters in the City of Foley but recovered to 7.7 ppm downstream where the creek empties into Wolf Bay. The low oxygen levels were believed to be the result of contributions of spring water (which is devoid of oxygen) and discharge from waste water treatment plants which depletes DO as organic matter decomposes (AWW, 2007). In 2010, the headwaters of Wolf Creek continued to consistently display extremely low oxygen. To address the issue, the City of Foley partnered with the Mobile Bay National Estuary Program (MBNEP) to perform a natural stream restoration in 2010. Since then, the stream has returned to normal ranges for oxygen (Wolf Bay Watershed Watch, 2017).

Sampling in 2012 showed DO concentrations in Miflin Creek were below the ADEM criteria limit of 5 mg/L in June, August and October. DO concentrations in Wolf Bay were below the criteria in June and July. Sandy Creek was below the criteria for all months sampled. All samples in Wolf Creek were above the ADEM criteria (ADEM, 2014).

Cook (2017) measured DO at 14 monitoring sites throughout the Wolf Bay watershed from December 2106 through August 2017. During that time, the sampling site at Elberta Creek at Baldwin County Road 83 had the lowest average DO at 6.3 mg/L. Conversely, the sampling point on the unnamed tributary to Sandy Creek at US Highway 90 had the highest average DO at 8.6 mg/L. Twelve of the 14 sites had measured DO values less than the ADEM reference standard of 6.94 mg/L.

Pathogens

There are no permitted point source discharges directly into Wolf Bay; however, a local wastewater treatment plant does discharge into Wolf Creek (Alabama Coastal Foundation, 2005). Bacteriological monitoring showed that Wolf Creek had unsafe levels of *E. coli* (above 600 colonies/100 mL of water) from 1999-2002. Levels returned to “safe for frequent human contact” (less than 200 colonies/100 mL of water) after April of 2003 (Alabama Watershed Watch, 2007). Riviera Utilities is working on permitting a major upgrade to their wastewater treatment plant located on Wolf Creek. This upgrade should reduce occurrences of overflows from the plant. North Hammock Creek has had cows removed from accessing the stream and a septic tank workshop was held to provide homes a free pump out voucher to prevent future septic tank failures (Wolf Bay Watershed Watch, 2017).

Cook (2017) collected samples during a low discharge event on August 3, 2017. The samples were taken during low flow due to the fact that bacteria concentrations in streams at low flow are more likely to represent point sources, including municipal and industrial wastewater discharge and sewer line leaks, where impacts of runoff are minimized. Wolf Creek at Swift Church Road and Wolf Creek at Doc McDuffie Road had the highest most probable number of *E. coli* colonies (mpn) for the low discharge event. The numbers recorded are relatively low for surface water and most likely do not represent any particular pathogen point source. It was noted however that, when correlated to watershed area, the sampling site at Elberta Creek at Baldwin County Road 83 exhibited relatively high bacteria counts and may represent a source of pathogens above background levels.

Conductance

Generally, specific conductance (SC) was relatively low due to no significant contaminant sources in the watershed and most SC measurements were made immediately after precipitation events. Fluctuations of SC in streams with tidal influence correspond to tidal cycles with relatively high SC at high tide due to salt water and relatively low SC due to fresh water at low tide or at times of large rainfall volumes. Median measured SC for all Wolf Bay watershed sites exceeded the ADEM standard of 20.4 mS/cm (Cook, 2017).

Conclusion

Cook (2017) concluded that when all parameters are considered with respect to water quality and potential remediation and restoration, watersheds upstream from Wolf Creek sites at Doc McDuffie Road and Swift Church Road and the unnamed tributaries to Sandy Creek from sites along US Highway 98 have the highest degree of impairment and should be considered primary targets for remediation and restoration.

** Cook (2017) states that forest (including forested wetlands) are the most dominant land use/land cover type in the Wolf Bay watershed. Agriculture is the second largest land use/land cover and* *dominates the headwaters and areas of higher elevations. Developed land is listed as covering about 16% of the watershed.*

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