Buffalo River Watershed
Lakes Eutrophication Modeling

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BUFFALO - RED RIVER WATERSHED DISTRICT

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1.0 INTRODUCTION

This report summarizes the in-lake water quality modeling efforts for lakes in the Buffalo River Watershed (BRW) as described in Tasks 10 and 11 of the Minnesota Pollution Control Agency (MPCA) contract #B55092: Buffalo River Watershed Approach Plan (WRAP) Phase II.

The overall goal of this analysis was to establish the loading capacities to the lakes in the BRW providing information for future management of their water quality. Results of the lake modeling include the predicted average amount of nutrient load reduction required to meet current water quality lake eutrophication standards in each lake.

The in-lake water quality modeling utilizes a modified version of the BATHTUB model called CNET. CNET models were created for eighteen individual lakes in the BRW, including a special case of five lakes in the Sand-Axberg Chain-of-Lakes located in the north-central portion of the watershed. In addition, the five "example" lakes developed under Task 9 of this project (HEI 2011a), were also modeled. This report covers the development and use of the CNET models and provides a summary of the predicted distributions of mean annual total phosphorus (TP), chlorophyll-*a* (Chl-*a*), and Secchi disk depths in the lakes.

The CNET models were calibrated to the assumed average condition in each lake using the average observed in-lake water quality condition and watershed inputs (flow and TP loading) from thirteen years (1997-2009) simulated in the BRW Soil and Water Assessment Tool (SWAT) model. Following calibration, the models were used for stochastic simulations using Crystal Ball, a Monte Carlo simulator. The stochastic simulations result in distributions of in-lake eutrophication conditions based on statistical distributions of input parameters. The stochastic modeling approach reflects the variability in model parameters inherent in natural systems (e.g., climate) and allows for a more realistic prediction of long-term water quality condition. Finally, load reduction scenarios were developed for each lake to estimate the required load reduction needed to meet current lake eutrophication water quality standards.

2.0 LAKE INFORMATION

2.1 THE BUFFALO RIVER WATERSHED

The BRW (HUC 09020106) (**Figure 1**), located in northwest Minnesota, comprises an area of 1,100 square miles. Other watersheds bordering it are the Wild Rice River (north), Pelican River (east), and Cormorant Lakes (east). The western and southern boundaries of the watershed are areas that drain directly to the Red River of the North, of which the Buffalo River is a tributary. The BRW lies in portions of Clay, Becker, Wilkin, and Otter Tail Counties.

The land-use of the BRW is primarily agricultural, with forested areas, lakes, and wetlands present in the eastern portion of the watershed. Small municipalities are scattered throughout the area.

The BRW transects three Level 3 eco-regions. Eco-regions are areas defined by the United States Environmental Protection Agency (USEPA) as relatively homogenous areas characterized by distinctive regional ecological factors, such as soils, natural vegetation, land use, and topography. The three eco-regions in the BRW are the Lake Agassiz Plain (LA), the North Central Hardwood Forests (NCHF), and the Northern Lakes and Forests (NLF). The majority of the watershed is located in the LA eco-region (composing the western half) with the lesser, central portion of the watershed in the NCHF eco-region. Less than 5% of the watershed is located in the NLF eco-region, located in the far eastern tip .

According to the Minnesota Department of Natural Resources (MN DNR) 24 k GIS data layer, 302 lakes (defined as waterbodies with a surface area greater than 10 acres) and 1,870 smaller ponds exist within the BRW. Approximately 40% of the BRW lakes are considered to be shallow for regulatory purposes (waterbodies with a maximum depth of less than 15 feet or 80% or more littoral area), with the remaining considered deep. One hundred and twelve of the lakes are named.

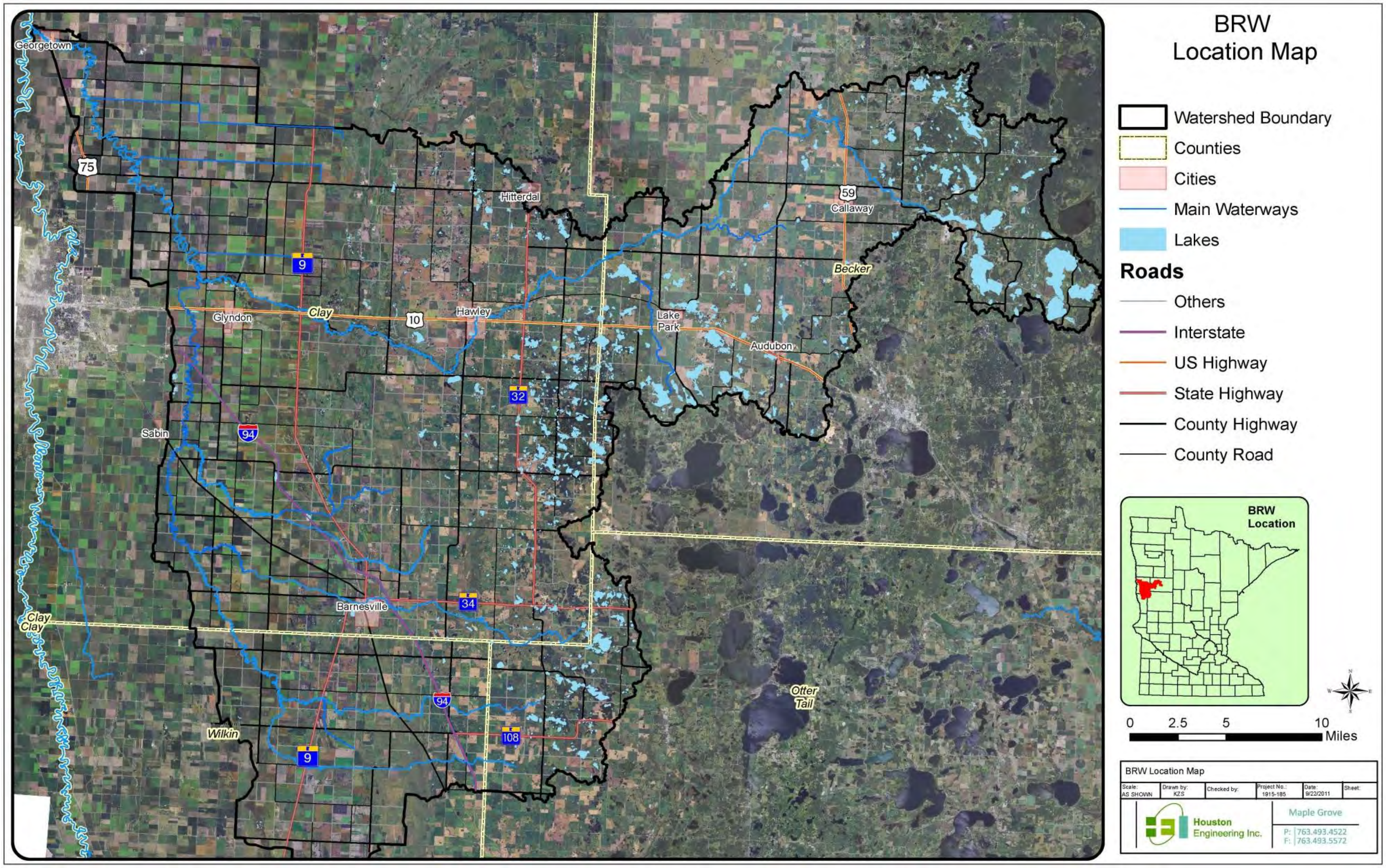

Figure 1. Location of the Buffalo River Watershed (HEI 2011b).

2.2 THE LAKES

Eighteen BRW lakes were identified for in-lake water quality modeling. Sixteen of these lakes are considered impaired for excess nutrients and listed on the MPCA's 2012 303(d) List; the other two lakes being modeled are non-impaired lakes within the Sand-Axberg Chain (it was requested that the whole Sand-Axberg Chain be modeled under this effort). In addition, five "example" lakes were developed under Task 9 of this project and are simulated with in-lake models; these models were developed to represent lakes in the BRW, in general, and to inform future restoration activities. The modeled lakes are listed in **Table 1; Figure 2** shows the location of the 16 impaired lakes and the Sand-Axberg Chain. Also shown in **Table 1** is each lake's name, the MN DNR lake ID, the county where the lake is located, the Buffalo Red-River Watershed District (BRRWD) planning region, the level 3 eco-region, and the lake type (shallow or deep).

Table 1: General Information on Modeled Lakes in the BRW.

Lake Name	Lake ID	County	Planning Region	Eco-Region[2]	Lake Type
Axberg[1,3]	03066000	Becker	Mainstem	NCHF	Shallow
Boyer	03057900	Becker	Mainstem	NCHF	Deep
Forget-me-not	03062400	Becker	Mainstem	NCHF	Shallow
Gottenberg	03052800	Becker	Mainstem	NCHF	Shallow
Gourd	03063500	Becker	Mainstem	NCHF	Shallow
Jacobs	56103900	Otter Tail	Southern	NCHF	Deep
Lime	03064600	Becker	Mainstem	NCHF	Shallow
Maria	14009900	Clay	Mainstem	LA	Shallow
Marshall	03052600	Becker	Mainstem	NCHF	Deep
Mission	03047100	Becker	Lakes	NCHF	Shallow
North Tamarac	03024102	Becker	Lakes	NLF	Shallow
Sand (Stump)[1]	03065900	Becker	Mainstem	NCHF	Deep
Sorenson (Lee)[1]	03062500	Becker	Mainstem	NCHF	Shallow
Stakke	03063100	Becker	Mainstem	NCHF	Shallow
Stinking	03064700	Becker	Mainstem	LA	Shallow
Talac[1]	03061900	Becker	Mainstem	NCHF	Shallow
West Labelle (Duck)	03064500	Becker	Mainstem	NCHF	Shallow
Yort (Sand)[1,3]	03061800	Becker	Mainstem	NCHF	Shallow
LA-Deep	Example	Multiple	Multiple	LA	Deep
LA-Shallow	Example	Multiple	Multiple	LA	Shallow
NCHF-Deep	Example	Multiple	Multiple	NCHF	Deep
NCHF-Shallow	Example	Multiple	Multiple	NCHF	Shallow
NLF-Shallow	Example	Becker	Lakes	NLF	Shallow

[1]-Part of the Sand-Axberg Chain of Lakes
[2]-LA = Lake Agassiz Plain; NCHF = North Central Hardwood Forest; NLF = Northern Lakes and Forests
[3]-Not listed as impaired.

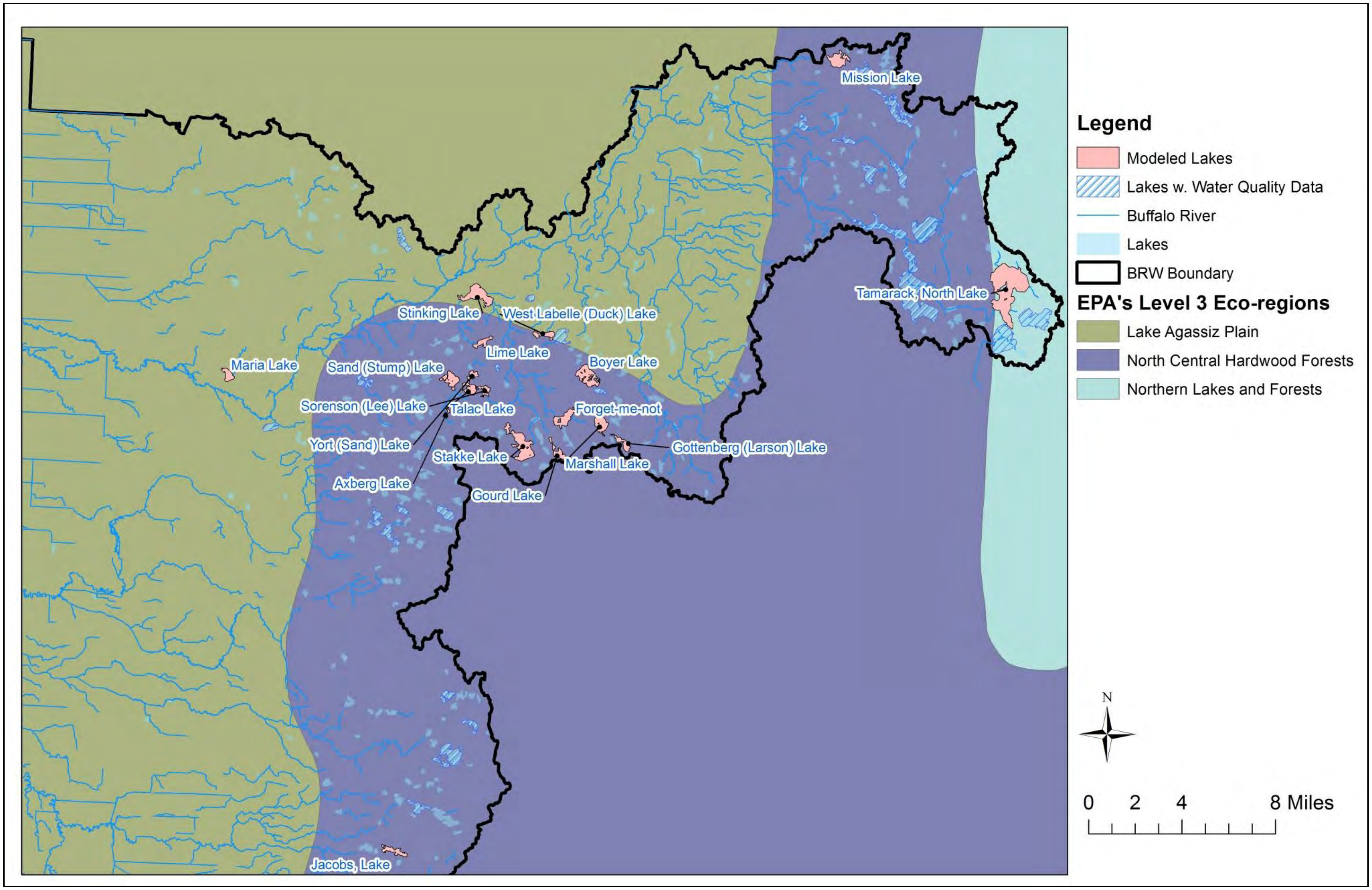

Figure 2. Modeled Lakes of the Buffalo River Watershed.

SAND-AXBERG CHAIN-OF-LAKES

The Sand-Axberg Chain represents a special case in the BRW and, as such, all five of the lakes (three of which are listed as impaired) were modeled in this effort. The Sand-Axberg Chain has been a topic of concern by local citizens and the MPCA for a number of years. The Chain has a long history of anthropogenic impacts, including a basin created in the northwest section of Axberg Lake for use in storing poultry manure and the eventual re-routing of flow from and around this waterbody (HEI, 2012). In 1997, the hydrology of the Sand-Axberg Chain was changed significantly as large amounts of precipitation caused extensive flooding that connected previously closed basins (Paakh, 2011). The current flow pattern (post-1997 flood) is assumed correct for the lake modeling and is shown in **Figure 3.**

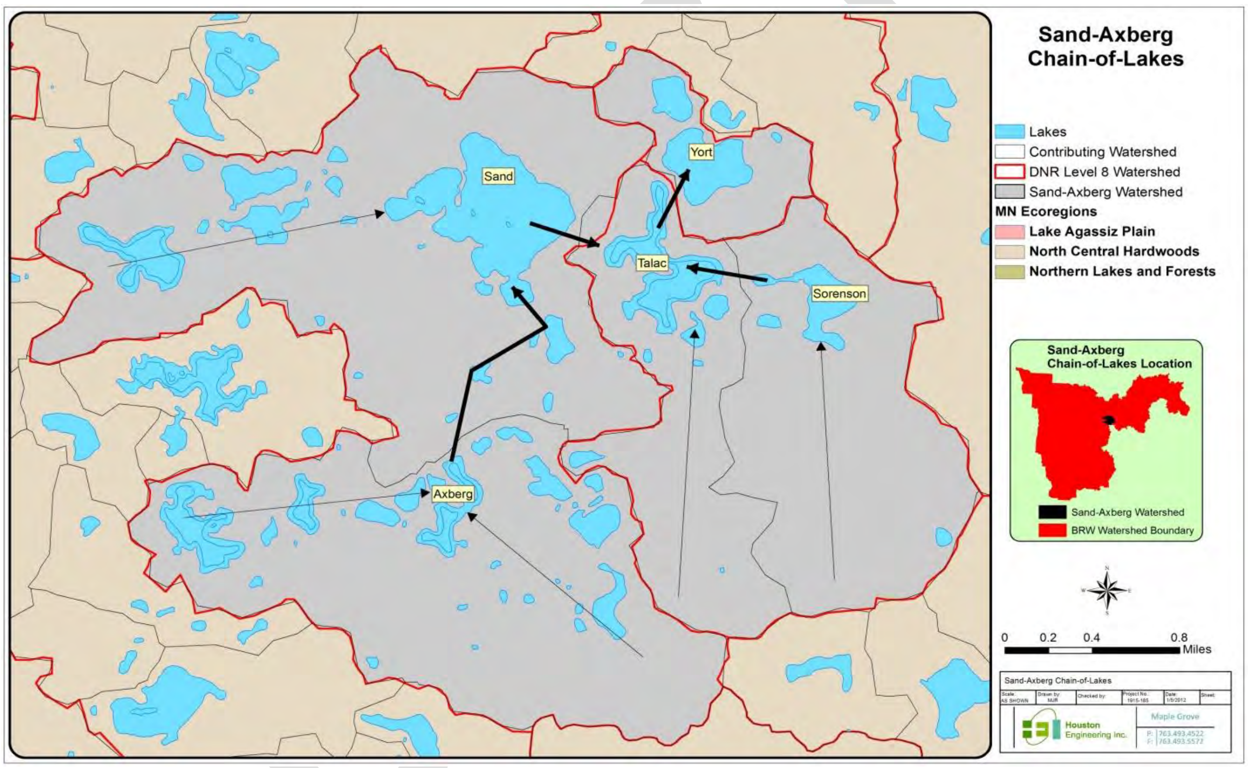

Figure 3. Sand-Axberg Chain. Bold arrows indicate direction of flow between lakes. Non-bold arrows indicate overland flow direction within lake's watershed.

EXAMPLE LAKES

In addition to the eighteen individual lakes being modeled, five "example" lakes are also being modeled. The "example" lakes were developed to represent the over 300 lakes within the BRW, dividing them into five classes based on the eco-region they lie within and whether they're considered shallow or deep (for regulatory purposes). The classification of the lakes in the BRW was performed as part of Task 9 of this project and is detailed in a report completed in 2011 (HEI, 2011). The five lake classifications used for the "example" lakes follow the lake classifications used for water quality assessment: LA-Deep, LA-Shallow, NCHF-Deep, NCHF-Shallow, and NLF-Shallow. Lakes within each class are expected to have a similar eutrophication response to fluctuations in watershed loading and, as such, these simulated responses can be used to inform future lake management for lakes that are not explicitly modeled as part of this project.

2. 3 LAKE MORPHOLOGY

The required inputs to the CNET model, for each lake simulated, include basic morphology characteristics such as: surface area, mean depth, contributing drainage area, and total drainage area. **Table 2** shows the required morphometric characteristics for the modeled lakes in the BRW. The characteristics are in the international system of units (SI) (i.e., the metric system), as required by the CNET model. For the purposes of this report, contributing drainage area is defined as the area that contributes water directly to the lake via overland flow and total drainage area is the total area that contributes water to the lake (including areas that drain into the lake through upstream waters, for example). The difference between total drainage area and contributing drainage area is the area that contributes water as tributary flows.

The primary data sources used for lake morphometric characteristics (**Table 2**) were the MN DNR LakeFinder website (http://www.dnr.state.mn.us/lakefind/index.html) and the MN DNR Geographic Information Systems (GIS) online data deli (http://deli.dnr.state.mn.us). For the individual lakes, most morphometric characteristics were found using the DNR Lake Finder website (**Table 2**). For the "example" lakes, average characteristics were used from lakes within each class that have water quality data associated with them (HEI, 2011).

Not all of the required morphometric characteristics were available for all of the BRW lakes. If mean depth was not available, but maximum depth was, a regression relationship was used to estimate mean depth from maximum depth (HEI, 2011a). If surface area was not available, areas were estimated using the areas in the 24k MN DNR lake data layer. The drainage area of the contributing watershed (**Table 2**) to each lake was defined using the MN DNR level 8 auto-catchments. Each lake's contributing drainage area was defined as the lake's direct contributing sub-catchment and upstream contributing sub-catchments. Any upstream tributary drainage areas were defined by the sub-basins layer used to develop the BRW SWAT model. All morphometric characteristics for the BRW lakes, the lakes used to develop the "example" lakes, and a detail description of the methods used to summarize the morphometric characteristics can be found in previous reports (HEI, 2011a&b).

Table 2: Morphometric Characteristics of Modeled BRW Lakes.

Lake Name	Surface Area (km^2)	Mean Depth (m)	Contributing Drainage Area (km^2)	Total Drainage Area (km^2)
Axberg	0.134	2.70	6.31	6.31
Boyer	1.549	3.98	8.44	8.44
Forget-me-not	1.461	1.22	8.59	8.59
Gottenberg	0.467	1.49	2.87	2.87
Gourd	0.473	1.35	1.47	1.47
Jacobs	0.540	2.66	12.54	12.54
Lime	0.397	1.35	4.73	27.86
Maria	0.436	1.49	5.42	12.34
Marshall	0.747	3.25	2.15	2.15
Mission	0.986	1.22	3.51	3.51
North Tamarac	5.887	2.66	19.41	36.44
Sand (Stump)	0.805	4.60	7.54	14.85
Sorenson (Lee)	0.316	1.40	3.76	3.76
Stakke	1.821	2.13	12.30	12.30
Stinking	1.497	1.20	32.61	62.26
Talac	0.554	3.40	2.44	21.88
West Labelle (Duck)	0.452	1.93	1.66	1.66
Yort (Sand)	0.235	1.50	0.93	22.81
LA-Deep	0.620	4.40	2.69	2.69
LA-Shallow	0.770	1.50	4.16	4.16
NCHF-Deep	0.740	4.80	3.84	3.84
NCHF-Shallow	0.890	1.80	3.84	3.84
NLF-Shallow	3.400	2.30	5.46	5.46

2.4 In-Lake Water Quality

Water quality data for lakes in the BRW were obtained from MPCA personnel for the time period through 2011 (the year that the last assessment was completed in this watershed). The average water quality conditions for the eighteen lakes and five “example” lakes for the most current assessment period (2002-2011) are given in **Table 3**. For purposes of this study, the average water quality condition is defined as the mean of all available data. It should be noted that the only data available for Axberg Lake are from 2000; given that no water quality data are available for this waterbody during the time period of the study, an exception was made to allow for the lake to be modeled. In addition to the average water quality conditions, **Table 3** shows the observation period and the number of observations for each lake eutrophication parameter used in computing the average condition. The average water quality conditions provided in **Table 3** were used to calibration the CNET models.

For the five "example" lakes, average water quality conditions were estimated from lakes with water quality data that are the same type (shallow vs. deep) and in the same eco-region. See HEI (2011a) for a complete list of the lakes used to develop the "example" lakes.

Table 3: Average Observed Water Quality Condition in Modeled Lakes

Lake Name	Observation Period	TP		Chl-*a*		Secchi Disk Depth	
		# of Obs	Mean (ug/L)	# of Obs	Mean (ug/L)	# of Obs	Mean (m)
Axberg	2000	4	230.2	4	98.2	4	0.48
Boyer	2008-2009	11	54.4	11	23.7	11	2.37
Forget-me-not	2009-2010	12	82.4	12	27.4	12	0.94
Gottenberg	2009-2010	12	68.0	12	33.8	12	0.81
Gourd	2009-2010	12	113.3	12	53.9	12	0.58
Jacobs	2009-2010	12	86.8	12	37.5	11	1.93
Lime	2009-2010	12	137.7	12	63.4	12	0.85
Maria	2009-2010	12	199.2	12	55.5	12	1.05
Marshall	2008-2009	12	41.8	12	20.5	11	1.85
Mission	2009-2010	12	120.3	12	75.6	12	0.58
North Tamarac	2005, 2007-2010	21	34.2	21	12.9	67	1.7
Sand (Stump)	2002-2008	29	168.5	29	24.8	29	2.2
Sorenson (Lee)	2002-2006, 2008	27	218	27	46.9	27	1.36
Stakke	2008-2009	10	64.8	9	29.8	9	1.48
Stinking	2009-2010	12	308.6	12	95.8	12	0.66
Talac	2002-2006, 2008	29	118.4	29	34.4	29	2.06
West Labelle (Duck)	2009-2010	12	89.3	12	41.1	12	1.29
Yort (Sand)	2002	3	82.6	3	8.67	3	1.07
LA-Deep	Varies	Varies	41.5	Varies	15.5	Varies	2.02
LA-Shallow	Varies	Varies	168.4	Varies	55.5	Varies	1.14
NCHF-Deep	Varies	Varies	49.7	Varies	13.2	Varies	5.18
NCHF-Shallow	Varies	Varies	108	Varies	37	Varies	2.13
NLF-Shallow	Varies	Varies	27.9	Varies	8.8	Varies	1.95

2.5 WATER QUALITY STANDARDS

Lake eutrophication standards are written to protect lakes as a function of their protected use. The lakes of the BRW are considered Class 2B waters, which are protected for aquatic recreation. The MPCA considers a lake impaired when TP and a least one of the response variables (Chl-*a* or Secchi depth) exceed the standards (MPCA 2010).

Minnesota's lake water quality standards were developed by depth classification and eco-region and are listed in **Table 4**. The eco-regions in the BRW include the NLF, NCHF, and LA.

Currently the MPCA does not have specific numeric water quality standard for the LA eco-region but rather lakes within this area are assessed on a case-by-case basis. In practice, when assessing a lake in the LA eco-region, the MPCA considers the land use within the lake's total contributing lakeshed and compares that land use to typical values seen in the other eco-regions (as summarized in Heiskary and Wilson 2005). The numeric criteria of whichever eco-region's land use characteristics most closely match those of the lake in question are then applied for determining impairment. In the lakes of the BRW, this analysis has typically resulted in the Northern Glaciated Plains (NGP)/Western Cornbelt Plains (WCP) eco-regions' criteria being used for assessment purposes. The water quality standards for the NGP and WCP are included in **Table 12**. The water quality standards in **Table 4** provide target concentrations when determine the surface water load reduction needed to meet the water quality standards.

Table 4. MN's Eutrophication Water Quality Standards (Heiskary and Wilson 2005).

Eco-region	TP (ppb)	Chl-*a* (ppb)	Secchi Disk Depth (m) [2]
Northern Lakes and Forest	30	9	2
North Central Hardwood Forest[1]			
- Deep lakes and reservoirs	40	14	1.4
- Shallow Lakes	60	20	1
Northern Glaciated Plains[1]			
- Deep lakes and reservoirs	65	22	0.9
- Shallow Lakes	90	30	0.7
Western Cornbelt Plains[1]			
- Deep lakes and reservoirs	65	22	0.9
- Shallow Lakes	90	30	0.7

[1]: Deep lakes are classified as having a maximum depth greater than 15 feet whereas shallow lakes have a maximum depth less than 15 feet or greater than 80% of the lake is part of the littoral zone.
[2]: Standard for Secchi disk depth is the minimum transparency value (i.e., values must be greater than the standard)

2.6 Water Budget

A water budget is an accounting of the amount of water entering and leaving a lake over a given time period. The time period used for modeling the lakes of the BRW in this study is annual. The amount of water moving in and out of a system varies from year-to-year, dictated primarily by the seasonal precipitation occurring in the area. The water budget is important to quantify because different sources of water can contain different quantities of pollutants and the amount of water entering and leaving the lake determines the hydraulic residence time, which impacts the lake's eutrophication response. The water budget is also important because it is used during hydrologic and water quality modeling for model calibration and validation purposes. A water budget accounts for "gains" in water to the lake (i.e., precipitation, surface water runoff, tributary inflow, and groundwater inflow) as well as "losses" (i.e., evaporation, surface outflow, and groundwater outflow). Each of these affects the volume of water in the lake (storage).

The water budget components accounted for in this study are: **Precipitation**, , is the amount of water entering the lake directly from precipitation landing on the lake's surface; **Contributing drainage inflow**, the water flowing to the lake from the contributing drainage area, including both surface and groundwater inputs; **Tributary inflow**, the amount of water flowing into the lake from upstream basins, usually from stream sources;; **Evaporation**, the water leaving the surface of the lake through evaporative processes; **Surface outflow**, the water leaving the lake through surface outlets (usually a stream); and **Storage**, the change in the water stored in the lake due to lake level increases or decreases.

The average annual water budgets for the modeled lakes of the BRW were calculated using climate and flow data from the BRW SWAT model (HEI, 2013). Contributing drainage area inflows were computed using the WYLD model parameter, which summarizes the total amount of water leaving an area over time. Further discussion on the outputs from the BRW SWAT model is provided in **Section 3.1**. CNET is a steady-state model, assuming no change in average lake storage during a time step. As such, the simulated change in storage term was assumed to be zero in the models created. The water budgets for the modeled lakes of the BRW are shown in **Table 5**, using units of acre-feet per year (ac-ft/yr). Tributary flow tends to be the dominant water budget component for lakes with upstream connections. Two lakes (Boyer Lake and Mission Lake) are closed basin lakes, with very little outflow.

Table 5. Average Annual Water Budgets for the Modeled BRW Lakes.

Lake Name	Inflows (ac-ft/yr)			Outflows (ac-ft/yr)	
	Precipitation	Contributing Drainage Inflow	Tributary Inflow	Evaporation	Outflow
Axberg	86	1,075	0	104	1,057
Boyer	836	68	0	904	1
Forget-me-not	574	1,386	0	657	1,303
Gottenberg	266	297	321	353	531
Gourd	307	252	0	417	142
Jacobs	301	30	142	330	143
Lime	273	748	3,769	312	4,478
Maria	239	537	1,116	274	1,619
Marshall	470	321	0	626	166
Mission	512	220	0	731	1
North Tamarac	3,096	3,472	3,023	3,643	5,947
Sand (Stump)	517	1,285	1,057	628	2,230
Sorenson (Lee)	203	688	0	227	663
Stakke	1,227	2,015	0	1,492	1,750
Stinking	966	5,703	4,532	970	10,232
Talac	356	446	2,894	400	3,296
West Labelle (Duck)	285	17	131	301	132
Yort (Sand)	151	181	3,296	199	3,428
LA-Deep	392	507	0	451	448
LA-Shallow	469	333	0	522	280
NCHF-Deep	446	196	0	550	92
NCHF-Shallow	533	317	0	632	218
NLF-Shallow	1,790	1,212	0	2,106	896

2.7 Total Phosphorus Nutrient Balance

Similar to a water budget, a TP nutrient balance accounts for the amount of TP entering and exiting a lake over a given time period. Nutrient amounts are expressed as loads, in units of mass per time, or for the purposes of this study, kilograms per year (kg/yr). The nutrient loads are estimated by considering the concentration of TP in the water and the amount of water entering and exiting the lake over the time period. The TP balance accounts for both “gains” (e.g., surface water runoff) as well as “losses” (e.g., outflows) from the lake.

The typical TP balance for a lake accounts for loading from the contributing drainage area, tributary loading, atmospheric deposition, internal loading, sedimentation/retention, and outflow.

Given that no information is available on internal loading of TP for the BRW lakes, this term was lumped into the modeling error for this study. Each of the TP balance components is discussed in more detail below.

In the case of the BRW lakes, TP balances were calculated using the CNET model with inputs from the BRW SWAT model results. The average annual TP balances, as calculated by the CNET models, are provided in **Table 6**. Most lakes in the BRW retain (sedimentation in **Table 6**) a large portion of the TP loaded into them.

Table 6. Average Annual TP Nutrient Mass Balances for BRW Lakes.

Lake Name	Gains (kg/yr)			Losses (kg/yr)	
	Atmospheric Deposition	Contributing Drainage Area Load	Tributary Load	Sedimentation	Outflow Load
Axberg	4	3,368	0	3,073	300
Boyer	40	41	0	81	0
Forget-me-not	27	836	0	731	133
Gottenberg	14	100	0	188	44
Gourd	15	80	0	74	20
Jacobs	16	16	91	107	15
Lime	13	881	7,194	7,328	760
Maria	13	1,791	703	2,109	399
Marshall	22	120	0	134	9
Mission	30	111	0	141	0
North Tamarac	177	83	52	60	251
Sand (Stump)	24	4,025	300	3,831	519
Sorenson (Lee)	9	321	0	152	178
Stakke	59	1,021	0	933	147
Stinking	46	8,012	5,344	9,510	3,893
Talac	17	208	697	411	510
West Labelle (Duck)	14	6	52	57	15
Yort (Sand)	7	84	510	252	349
LA-Deep	19	317	0	313	23
LA-Shallow	23	367	0	332	58
NCHF-Deep	22	13	0	29	6
NCHF-Shallow	27	170	0	168	29
NLF-Shallow	51	31	0	52	30

2.7.1 Contributing Drainage Area Loading

The amount of TP entering each lake from its contributing drainage area was estimated using the outputs of the BRW SWAT model. SEDP, ORGP, and SOLP values for the sub-basins containing each lake were extracted from the model and summed together to compute the total TP loading from that sub-basin. The percent of the sub-basin that is considered contributing drainage area to the lake was then multiplied by the sub-basin TP loading value to estimate the amount of TP entering the lake from this source. The resultant average annual contributing drainage area loadings for each lake, in kg/yr, are given in **Table 6**.

2.7.2 Tributary Loading

TP entering a lake, from upstream lakes and/or sub-basins, and transported by a stream or river is known as tributary loading. This loading is the portion of the TP balance stemming from upstream areas and was estimated using reach outputs from the BRW SWAT model. Not all lakes in the BRW have tributary loading. For the special case of the Sand-Axberg Chain, where one lake feeds directly into another, tributary flows and loadings for the downstream lakes (e.g., Sand Lake) were taken as the outflow and load s from the upstream lake (e.g., Axberg lake) as computed in the CNET model. In reality, the outflow from one lake may travel a short distance before entering the next lake and in-stream processes may impacted the nutrients (nutrient up-take or sedimentation); but at the average annual time scale, this impact was assumed negligible. The annual average tributary loadings, in kg/yr, for lakes with tributary flows are given in **Table 6**.

2.7.3 Atmospheric Loading

The rates of atmospheric deposition of TP onto each of the simulated lakes were set equal to those used in the Minnesota Lake Eutrophication Analysis Procedure (MINLEAP) modeling program. MINLEAP is a program developed by Wilson and Walker (1989) to provide predictive techniques to assess common lake problems based on eco-region. The lakes in the NCHF eco-region, including the lakes in the Sand-Axberg Chain, and the LA eco-region use an estimated mean annual atmospheric deposition load of 30 kg/km^2/year and lakes in the NLF eco-region have an estimated mean annual atmospheric load of 15 kg/km^2/year (HEI 2011b).

The average annual atmospheric depositions, in kg/yr, are shown in **Table 6**.

2.7.4 Internal Loading of TP

Internal loading is the re-release of TP from sediments, usually due to anoxic conditions (dissolved oxygen concentrations < 2.0 mg/L) near the bed of the lake. Internal phosphorus loading can be a substantial part of the mass balance in a lake, especially in lakes with a history of high phosphorus loads. If a lake has a long history of high phosphorus concentrations, it is possible to have internal loading rates higher than external loads. Internal loading is usually quantified by taking sediment cores from the lake bed and analyzed in a laboratory. No such studies or data are available for lakes in the BRW.

Since no information on internal loading is available for these lakes, and to limit additional uncertainty in the analyses, the internal loading component of the TP balance was ignored. As such, any errors associated with ignoring internal loading are lumped into the CNET calibration coefficients.

2.7.5 Retained Mass & Error

Other in-lake processes (sedimentation, nutrient uptake, etc.) were not explicitly accounted for in the TP balances, but rather lumped into a retained mass and error term (sedimentation in **Table 6**). The retained mass and error term is the difference between TP inputs and TP outputs (i.e., retained mass + error = TP inputs – TP outputs). The average annual sedimentation loadings, in kg/yr, are given in **Table 6**.

2.7.6 Surface Outflow Loading

The amount of TP exiting each lake through surface water outflow is known as surface outflow load and was calculated (by CNET) by taking the in-lake TP concentration and applying it to the lake's outflow. The average annual surface water outflow loadings computed for each of the lakes simulated, in kg/yr, are given in **Table 6**.

3.0 MODEL DEVELOPMENT AND APPLICATION

3.1 Watershed Modeling

Minimal observed runoff data is available in the BRW. For those lakes that did have observed data available, it was analyzed and determined insufficient for estimating long-term hydrologic and TP budgets for the purposes of this project. Given the lack of observed data, results of the BRW SWAT model (HEI 2013), developed under Task 3 of this project, were used to develop inputs to the CNET models. The hydrologic/ TP budget components taken from the SWAT model include precipitation, potential evapotranspiration (assumed to be equal to evaporation), contributing drainage area runoff volume, contributing drainage area TP load, tributary flow, and tributary TP load. Data from the BRW SWAT model are available from 1995 through 2009 for daily, monthly, and annual timescales at the sub-basin scale.

SWAT model results for sub-basin parameters are reported on a per unit area basis, e.g. surface TP loading is reported as kilograms per hectare per year. To estimate sub-basin parameters from these data, annual hydrology and TP loadings were extracted from the SWAT model for sub-basins where the modeled lakes are located. In addition, results from any reaches upstream of the contributing sub-basins (i.e., upstream tributaries to the lakes) were also extracted. To use the outputs form SWAT in CNET, a few transformations were needed. For precipitation and evaporation, CNET uses per unit area values and only required a unit transformation from millimeters to meters per year. For the contributing drainage areas contributions (surface water flow and loading), CNET requires absolute values (i.e. volume and mass). Since the outputs from SWAT are given in units per area, the surface water flows and surface water loadings output were multiplied by the contributing drainage area's area, giving a total contributing drainage area's volume/mass.

Table 7 contains a summary of the contributing drainage area feeding into each lake, the SWAT sub-basin that each modeled lake lies within, as well as any SWAT reaches that are tributary to the lake. For the Sand-Axberg Chain, the upstream lakes, themselves, are listed.

For the "example" lakes, average, representative hydrologic and loading conditions had to be found for each lake class. To do this, each of the BRW lakes that were used to develop the "example" lakes (i.e., lakes with water quality data) were identified (HEI 2011b). The SWAT sub-basins that contain these lakes were then also identified and categorized by "example" lake class. These SWAT sub-basins are shown in **Figure 3**. The annual SWAT output for each of the sub-basins were summarized and averaged by "example" lake class, providing an average annual hydrologic and loading condition for each class of "example" lakes. For modeling purposes, it was assumed that no upstream reaches flow into the drainage areas of the "example" lakes.

Table 7: SWAT Sub-Basin IDs and Reach IDs for Modeled BRW Lakes.

Lake Name	Contributing Drainage Area (km^2)	SWAT model	SWAT Contributing Sub-basin ID	SWAT Tributary Reaches ID/ Lake
Axberg	6.31	Mainstem	26	N/A
Boyer	8.44	Mainstem	37	N/A
Forget-me-not	8.59	Mainstem	33	N/A
Gottenberg	2.87	Mainstem	39	38
Gourd	1.47	Mainstem	32	N/A
Jacobs	12.54	Sbranch	76	75
Lime	4.73	Mainstem	29	28
Maria	5.42	Mainstem	10	11
Marshall	2.15	Mainstem	38	N/A
Mission	3.51	Mainstem	57	N/A
North Tamarac	19.41	Mainstem	79	80, 81, 83
Sand (Stump)	7.54	Mainstem	26	Axberg
Sorenson (Lee)	3.76	Mainstem	27	N/A
Stakke	12.30	Mainstem	30	N/A
Stinking	32.61	Mainstem	31	30, 32, 34
Talac	2.44	Mainstem	27	Sorenson/Sand
West Labelle (Duck)	1.66	Mainstem	35	36
Yort (Sand)	0.93	Mainstem	28	Talac
LA-Deep	2.69	Both	Multiple	N/A
LA-Shallow	4.16	Both	Multiple	N/A
NCHF-Deep	3.84	Both	Multiple	N/A
NCHF-Shallow	3.84	Both	Multiple	N/A
NLF-Shallow	5.46	Mainstem	Multiple	N/A

The average annual hydrology and TP loadings, from the SWAT model, for the eighteen individual lakes and five "example" lakes are given in **Tables 5 and 6**; results are shown as absolute volumes/loads as calculated by the CNET models. The values in **Tables 5 and 6** are average annual values (1997-2009); year-by-year summaries of these data are contained in **Appendix A**.

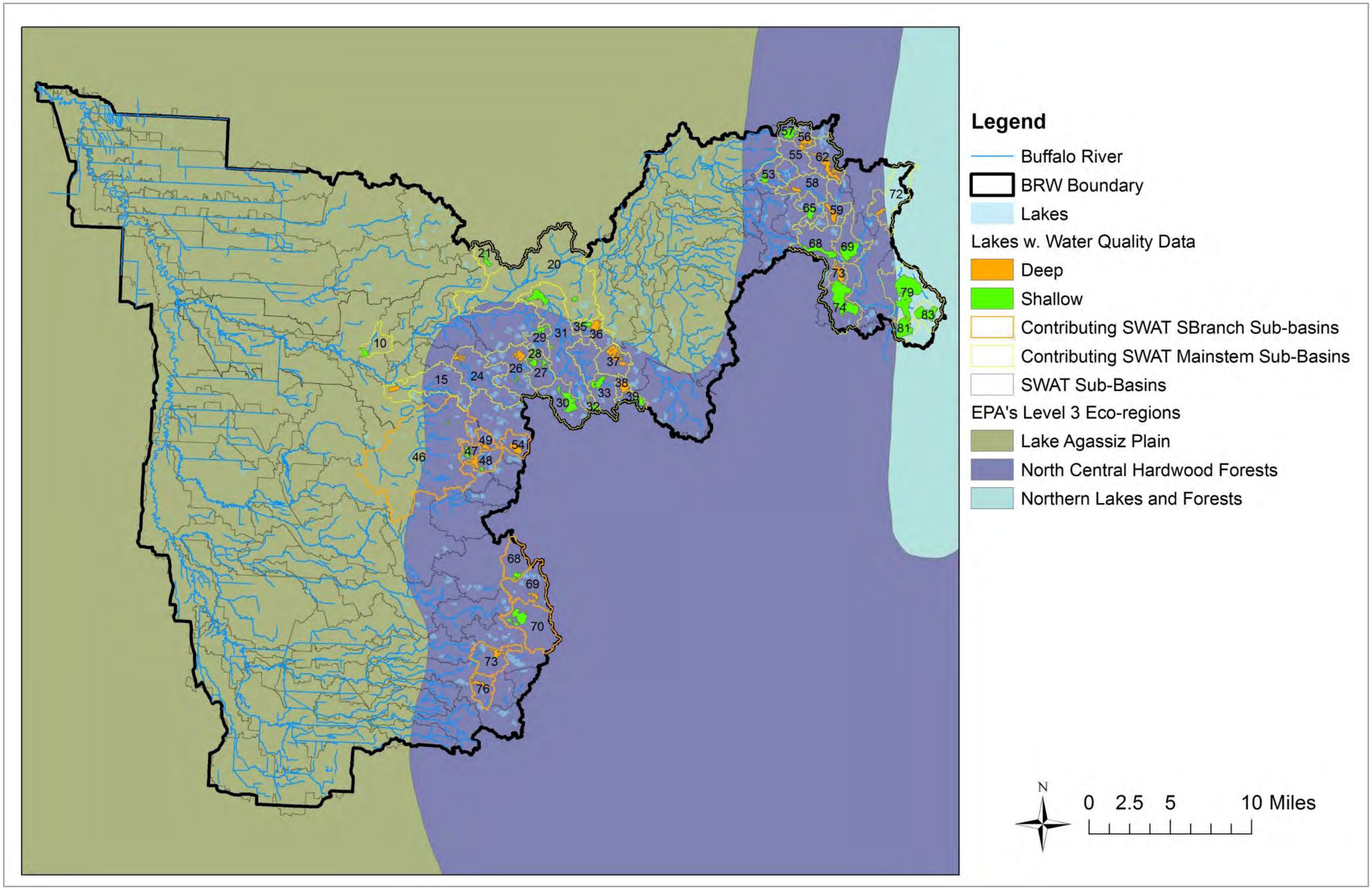

Figure 4: SWAT Sub-basins Contributing to BRW Lakes with Water Quality Data.

3.2 Lake Modeling

In-lake water quality was simulated using the CNET program. CNET is a spreadsheet version of the BATHTUB model currently available as a “beta” version from Dr. William W. Walker (URL: http://wwwalker.net/bathtub/index.htm). Similar to BATHTUB, CNET is a steady-state model that simulates eutrophication-related water quality conditions in lakes and reservoirs. The primary modification to the CNET model completed during this effort was to implement a Monte Carlo approach, which allowed selected modeling inputs to vary, based upon known or assumed statistical distributions, and to be reflected in the forecast results. The Monte Carlo approach generates a statistical distribution of the annual mean TP and Chl-*a* concentrations, and Secchi disk depth, reflecting the uncertainty in the model parameters and normal variability in inputs (e.g., annual TP load from surface runoff) as well as correlation among inputs (e.g., runoff and load). Crystal Ball (a proprietary software developed by Oracle; http://www.oracle.com/appserver/business-intelligence/crystalball/crystalball.html) was used to perform the Monte Carlo simulations.

The following sections cover the calibration and stochastic set-up of the CNET models.

3.2.1 Model Calibration

Prior to completing the Monte Carlo modeling analysis, the CNET models were calibrated for the average condition, using the average (1997-2009) annual water budget and TP mass balance inputs (**Tables 5 and 6**) and calibrated to the average observed water quality conditions (**Table 3**). The period 1997-2009 for the SWAT data was used instead of the complete SWAT modeling period (1995-2009) because of the 1997 flood, which change the flow pattern of the Sand-Axberg Chain. It should be noted, the average in-lake water quality conditions from the observed data are assumed to represent the lakes’ responses to the average hydrology and TP loadings from the SWAT model even though their time periods typically don’t match. This assumption may not actually be the case but is considered the best option for modeling these lakes with the available data. It may/will contribute to errors and uncertainty in the models.

All available data was used in calibrating the CNET models; therefore, no model validations were performed. While this is not an ideal approach, the limited amount of data available in the BRW was best used to compute a longer term average condition for in-lake water quality and watershed hydrology/loading, leading to more realistic inputs for the CNET models. Again, the lack of data for model validation may contribute to uncertainty in the results.

The CNET model relies on numerous sub-models for computing eutrophication dynamics with a lake, providing the ability to simulate eutrophication dynamics in lakes with differing in-lake processes. The first step in calibrating the CNET models was to select the best (sub-) model for simulating in-lake TP, Chl-*a*, and Secchi depths. The best (sub-) models were determined by finding the best-fit, i.e., the model with its calibration coefficient closest to 1.

The selected models varied from lake to lake; the following were used in the BRW lakes:

- Total Phosphorus Models
    - Model 4: Canfield & Bachman (1981), Reservoirs
    - Model 5: Vollenweider (1976), Northern Lakes
    - Model 7: First-Order Settling
    - Model 8: Canfield & Bachman (1981), Natural Lakes
    - Model 9: Canfield & Bachman (1981), Reservoirs + Lakes
- Chl-*a* Models
    - Model 2: P, Light, Flushing
    - Model 4: P, Linear
    - Model 5: P, Exponential, Jones & Bachman (1976)
- Secchi Disk Models
    - Model 1: Secchi vs Chl-*a* and Turbidity
    - Model 3: Secchi vs Total P, CE Reserviors
    - Model 4: Calson TSI (1977), Lakes

Full descriptions of each (sub-) model can be found in the BATHUB documentation (Walker 1996).

Table 8 shows the eutrophication models used for each lake (listed by model number) and the associated calibration coefficients. The most common TP model used was model 8, followed by 4, 9, and 7; the least common used was model 5. TP calibration coefficients ranged from 0.3 for North Tamarac to 2.84 for Lime Lake. The most common Chl-*a* model used was model 2, followed by 4 with the least common is 5. The Chl-*a* calibration coefficients ranged from 0.33 for Stinking Lake to 1.735 for Axberg Lake. The most common Secchi disk model was model 1, followed by 4 with the least common being 3. The Secchi disk calibration coefficients ranged from 0.515 for Stinking Lake to 2.15 for "example" Lake NCHF-Shallow.

Most of the models have calibration coefficients within the expected range (0.7 – 1.3). Some of the calibration coefficients listed in **Table 8** are outside of the expected range, with some being significantly higher/lower. These higher/lower than expected calibration coefficients are likely cause by a combination of multiple factors: (1) lack of extensive observed in-lake water quality data; (2) uncertainty within the SWAT model results; (3) the assumption that the mean annual loading (from 1997-2009) correlates to the mean observed in-lake water quality data (often only available for two years); and/or (4) lack of internal loading data. The quality of each lake's CNET model calibration (i.e., the final values of the calibration coefficients) was taken into account when interpreting the results of the modeling, including the recommended TP load reductions.

Table 8: Selected Eutrophication Models and Calibration Coefficients for the Modeled Lakes.

Lake Name	TP		Chl-*a*		Secchi Disk	
	Model #	Calibration Coefficient	Model #	Calibration Coefficient	Model #	Calibration Coefficient
Axberg	4	1.48	2	1.34	1	0.95
Boyer	7	1.12	5	0.85	1	1.59
Forget-me-not	4	1.38	4	1.03	1	0.64
Gottenberg	4	1.15	5	0.89	1	0.75
Gourd	8	0.635	2	0.635	3	1.18
Jacobs	8	0.69	2	0.91	1	1.95
Lime	4	2.84	4	0.87	2	0.87
Maria	9	1.35	4	0.99	1	1.54
Marshall	9	1.1	5	1.1	1	1.1
Mission	7	1.19	2	0.98	1	1.15
North Tamarac	7	0.3	5	0.91	4	1.21
Sand (Stump)	9	0.88	2	0.76	1	1.65
Sorenson (Lee)	5	1.17	2	0.51	1	1.94
Stakke	9	1.29	1	0.82	1	1.22
Stinking	9	0.983	2	0.83	1	1.62
Talac	5	1.19	2	0.83	1	1.92
West Labelle (Duck)	8	0.6	2	0.83	1	1.43
Yort (Sand)	4	0.92	4	0.37	4	1.84
LA-Deep	4	1.45	2	0.83	1	0.93
LA-Shallow	8	0.84	2	0.655	1	1.65
NCHF-Deep	8	0.36	2	0.65	1	2.13
NCHF-Shallow	8	0.655	2	0.64	1	2.15
NLF-Shallow	8	0.52	2	0.55	1	0.58

Table 9 shows the average water quality observations and the simulated eutrophication parameters for each modeled lake. All of the simulated values are within a few percentile of the observed average value, as would be expected for a calibrated model.

Table 9: Observed and Simulated Mean Eutrophication Parameters for Calibration of BRW CNET Models.

Lake Name	TP (ug/L)		Chl-*a* (ug/L)		Secchi Disk (m)	
	Observed	Modeled	Observed	Modeled	Observed	Modeled
Axberg	226.8	227.3	75.8	75.7	0.48	0.48
Boyer	54.4	54.5	23.7	23.6	2.37	2.37
Forget-me-not	82.4	82.6	27.4	23.8	0.94	0.95
Gottenberg	68	67.3	33.8	33.6	0.81	0.81
Gourd	113.3	113.2	53.9	54.2	0.58	0.58
Jacobs	86.8	87.1	37.5	37.3	1.93	1.92
Lime	137.7	137.7	63.4	63.1	0.85	0.85
Maria	199.2	200.0	55.5	55.4	1.05	1.05
Marshall	41.8	41.6	20.5	20.6	1.85	1.85
Mission	120.3	119.7	75.6	75.6	0.58	0.58
North Tamarac	34.2	34.2	12.9	12.8	1.7	1.7
Sand (Stump)	188.1	188.5	27.4	27.5	2.15	2.15
Sorenson (Lee)	217.7	218.2	50.4	50.7	1.44	1.44
Stakke	64.8	64.2	29.8	29.9	1.48	1.47
Stinking	308.6	308.6	95.8	96	0.66	0.65
Talac	125.8	125.6	34	34	2.07	2.07
West Labelle (Duck)	89.3	89.2	41.1	41.1	1.29	1.29
Yort (Sand)	82.6	82.6	8.67	8.6	1.07	1.07
LA-Deep	41.5	41.3	15.5	15.3	2.02	2.01
LA-Shallow	168.4	168	55.5	55.7	1.14	1.12
NCHF-Deep	49.7	49.4	13.2	13.2	5.18	5.2
NCHF-Shallow	108	109.1	37	37.5	2.13	2.11
NLF-Shallow	27.9	27.1	8.8	8.3	1.9	2.01

3.2.2 Stochastic Simulations

Once the lake models were calibrated, Monte Carlo or “stochastic” simulation was performed. Stochastic modeling is an approach where model input values (e.g., precipitation) used in the equations to compute the in-lake mean concentration of TP and Chl-*a* and Secchi disk depth, are allowed to vary according to their observed statistical distribution and therefore their probability of occurrence. This allows the effect of parameter uncertainty and normal variability in the inputs (e.g., amount of surface runoff and nutrient load, which varies annually depending upon the amount of precipitation) to be quantified when computing the in-lake mean concentration of TP and Chl-*a* and Secchi disk depth.

Using the Crystal Ball software allowed for multiple probabilistic model computations. Many trial values (1,000 trials in this case) were generated with each trial representing a different permutation of model input values within the bounds established by the statistical distributions. The many trials resulted in a computed distribution of expected in-lake water quality for each lake rather than a single, deterministic output that was based upon only one possible combination of model inputs. Select inputs, primarily those components of the water budget or TP mass balance, were allowed to vary during the Monte Carlo simulation. The selected inputs are precipitation, evaporation, atmospheric deposition, contributing drainage inflow, and contributing drainage area TP loading. In addition, tributary inflow and TP loadings were varied for those lakes that were simulated with these inputs.

Crystal Ball was used to develop the model input statistical distributions based on the previously mentioned SWAT hydrologic and TP loading annual values for the period 1995-2009. It should be noted that the period 1995-2009 was used instead of the period used to calibrate the CNET models (1997-2009) in order to extend the available dataset. Crystal Ball was used to choose the distribution based on the best fit of the data. **Tables 10 an d 11** show the "best fit" distributions.

In addition to the distributions, correlation coefficients were used to account for links between certain hydrologic and loading parameters, e.g. contributing drainage inflow is driven by (and, therefore, correlated to) precipitation. The correlation coefficients used in the Monte Carlo simulations are shown in **Table 12**; these values were computed using Microsoft Excel. Only a weak correlation, if any, existed between precipitation and evaporation; as such, this correlation was ignored. Contributing drainage inflow was correlated to contributing drainage area loading to account for more loading with increased flow. It was assumed that atmospheric deposition is directly linked to precipitation; as such, a correlation coefficient of 1.0 was assigned to these variables. This was based on assumptions that: (1) all atmospheric deposition of TP is wet deposition; (2) the deposition is driven solely by precipitation; and (3) deposition varies from year-to-year with precipitation. Contributing drainage inflow and contributing drainage area TP loading showed a strong positive correlation to precipitation. Contributing drainage area TP loading usually showed a strong positive correlation with contributing drainage inflow. **Table 11** shows the correlation coefficients for tributary inflow and TP loadings at the relevant lakes. Tributary inflow and TP loadings were correlated to each other and precipitation. It is notable that lakes in the Sand-Axberg Chain were linked together and outflows from upstream lakes were used as inflows into downstream lakes. Therefore, tributary inflows and TP loadings were not varied as a statistical distribution, since they varied as a function of each model run.

When appropriate, the model input statistical distributions were truncated to prevent erroneous values and/or modeling errors, e.g. negative TP loading rates. These truncations included: minimum values of precipitation, maximum values of evaporation, minimum values of contributing drainage inflow and TP loading, and minimum values of tributary flow and TP loading. The minimum or maximum allowable values were set to the minimum or maximum values during the period of record (1995-2009) used to construct the distribution.

Table 10: Statistical Distributions used for Monte Carlo Simulations in BRW Lakes.

Lake	Precipitation	Evaporation	Atmospheric Loading	Contributing Drainage Inflow	Contributing Drainage Area Loading
Axberg	Gamma	Logistic	Gamma	Max Extreme	Max Extreme
Boyer	Logistic	Min Extreme	Logistic	Lognormal	Max Extreme
Forget-me-not	Logistic	Logistic	Logistic	Gamma	Gamma
Gottenberg	Logistic	Min Extreme	Logistic	Lognormal	Max Extreme
Gourd	Logistic	Logistic	Logistic	Lognormal	Lognormal
Jacobs	Beta	Min Extreme	Beta	Logistic	Logistic
Lime	Logistic	Logistic	Logistic	Beta	Lognormal
Maria	Beta	Weibull	Beta	Max Extreme	Exponential
Marshall	Logistic	Min Extreme	Logistic	Gamma	Lognormal
Mission	Weibull	Min Extreme	Weibull	Lognormal	Beta
North Tamarac	Logistic	Min Extreme	Logistic	Logistic	Gamma
Sand (Stump)	Gamma	Logistic	Gamma	Max Extreme	Max Extreme
Sorenson (Lee)	Gamma	Logistic	Gamma	Lognormal	Gamma
Stakke	Logistic	Logistic	Logistic	Beta	Gamma
Stinking	Logistic	Weibull	Logistic	Beta	Max Extreme
Talac	Gamma	Logistic	Gamma	Lognormal	Gamma
West Labelle (Duck)	Logistic	Min Extreme	Logistic	Lognormal	Lognormal
Yort (Sand)	Gamma	Logistic	Gamma	Beta	Max Extreme
LA-Deep	Logistic	Weibull	Logistic	Beta	Lognormal
LA-Shallow	Beta	Weibull	Beta	Max Extreme	Lognormal
NCHF-Deep	Weibull	Min Extreme	Weibull	Lognormal	Lognormal
NCHF-Shallow	Logistic	Logistic	Logistic	Beta	Exponential
NLF-Shallow	Logistic	Min Extreme	Logistic	Lognormal	Exponential

Table 11: Statistical Distributions and Correlation Coefficients for Tributary Inflow and TP Loading for Relevant BRW Lakes.

Lake	Distribution		Correlation Coefficient		
	Tributary Flow	Tributary Loading	Precip: Tributary Flow	Precip: Tributary Loading	Trib Flow: Tributary Loading
Gottenberg	Gamma	Lognormal	0.63	0.54	0.9
Lime	Lognormal	Max Extreme	0.76	0.74	0.82
Maria	Beta	Gamma	0.55	0.44	0.89
North Tamarac	Logistic	Logistic	0.79	0.76	0.85
Stinking	Beta	Gamma	0.76	0.46	0.7
West Labelle (Duck)	Lognormal	Exponential	0.73	0.57	0.91

Table 12: Correlation Coefficients for Monte Carlo Simulation of BRW Lakes.

Lake	Precip: Atmospheric Deposition	Precip: Contributing Drainage Inflow	Precip: Contributing Drainage Area Loading	Contributing Drainage Inflow: Contributing Drainage Area Loading
Boyer Lake	1	0.7	0.73	0.91
Forget-me-not	1	0.76	0.36	0.69
Gottenberg	1	0.57	0.31	0.64
Gourd	1	0.79	0.73	0.91
Jacobs	1	0.57	0.46	0.87
Lime	1	0.8	0.73	0.9
Maria	1	0.62	0.48	0.76
Marshall	1	0.77	0.69	0.89
Mission	1	0.23	0.5	0.7
North Tamarac	1	0.77	0.72	0.79
Stakke	1	0.74	0.4	0.67
Stinking	1	0.78	0.81	0.84
West Labelle (Duck)	1	0.8	0.69	0.9
Axberg	1	0.75	0.73	0.76
Sand (Stump)	1	0.75	0.73	0.76
Sorenson (Lee)	1	0.77	0.37	0.68
Talac	1	0.77	0.37	0.68
Yort (Sand)	1	0.77	0.78	0.84
LA-Deep	1	0.79	0.46	0.77
LA-Shallow	1	0.78	0.68	0.92
NCHF-Deep	1	0.57	0.54	0.9
NCHF-Shallow	1	0.66	0.68	0.84
NLF-Shallow	1	0.84	0.76	0.79

4.0 EUTROPHICATION RESPONSE, LOADING CAPACITY, & RECOMMENDED REDUCTIONS

4.1 LOAD REDUCTION SCENARIOS

The purpose of this CNET modeling is to determine the loading scenario(s) under which applicable water quality standards (**Table 4**) will be met in the BRW lakes and water quality conditions will improve. For the load reduction scenarios, TP loadings were reduced incrementally within the CNET model and assumed to come from the both the contributing drainage area and tributary loadings. If the lake had a tributary loading, the loading from the tributary was assumed to have the same reduction as the contributing drainage area.

Each CNET model started with the calibrated average condition (i.e., the current condition) and a set of standard reductions: 20% load reduction, 40% load reduction, 60% load reduction, 80% load reduction, and 90% load reduction. After the models were run using the general load reduction scenarios, the reductions were refined to find the necessary load reduction to meet the TP water quality standard for each individual lake. This approach is consistent with MPCA guidance (MPCA, 2007), which assumes that if a lake meets the State's TP water quality standard that Chl-*a* and Secchi depth within the system will respond accordingly and eventually also reach the State-defined goals (even if the results of the CNET modeling do not predict this result). This approach assumes that data collected and extensively analyzed by the MPCA during standards development provides a more accurate estimate of how lakes will respond when moved from an impaired to unimpaired state than the relationships that exist within the CNET program. This reduction process was applied to all eighteen individual lakes and the five example lakes. It should be noted that some of the "example" lakes are not impaired; in those cases, the general load reductions were used to see how the lakes would react to changes in loading. Results of the load reduction scenarios are discussed in **Section 4.2;** figures showing the effects of the reductions by lake can be found in **Appendix A**.

Given the special nature of the Sand-Axberg Chain, additional load reduction scenarios were investigated for those waterbodies. In addition to the standard load reduction approach mentioned above, scenarios were also used that assumed that all tributary inflows meet the water quality standard. Contributing drainage area loading was then reduced to find the required reduction if the waters upstream of the lake meet the water quality standard.

4.2 Eutrophication Response

Figure 5 shows an example of the frequency distribution of TP concentrations for Forget-Me-Not Lake resulting from its Monte Carlo simulation. **Table 13** shows the numeric values used to construct **Figure 5**. **Figure 5** and **Table 13** show the results of incrementally reducing loads within the CNET model. The reduced loads were assumed to come from contributing drainage area loading and any tributary loading. Each line in **Figure 5** represents a different loading scenario and the red dashed line represents the TP water quality standard target. It is assumed the lake will meet the water quality standard if the in-lake TP concentrations are lower than the water quality standard 50% of the time.

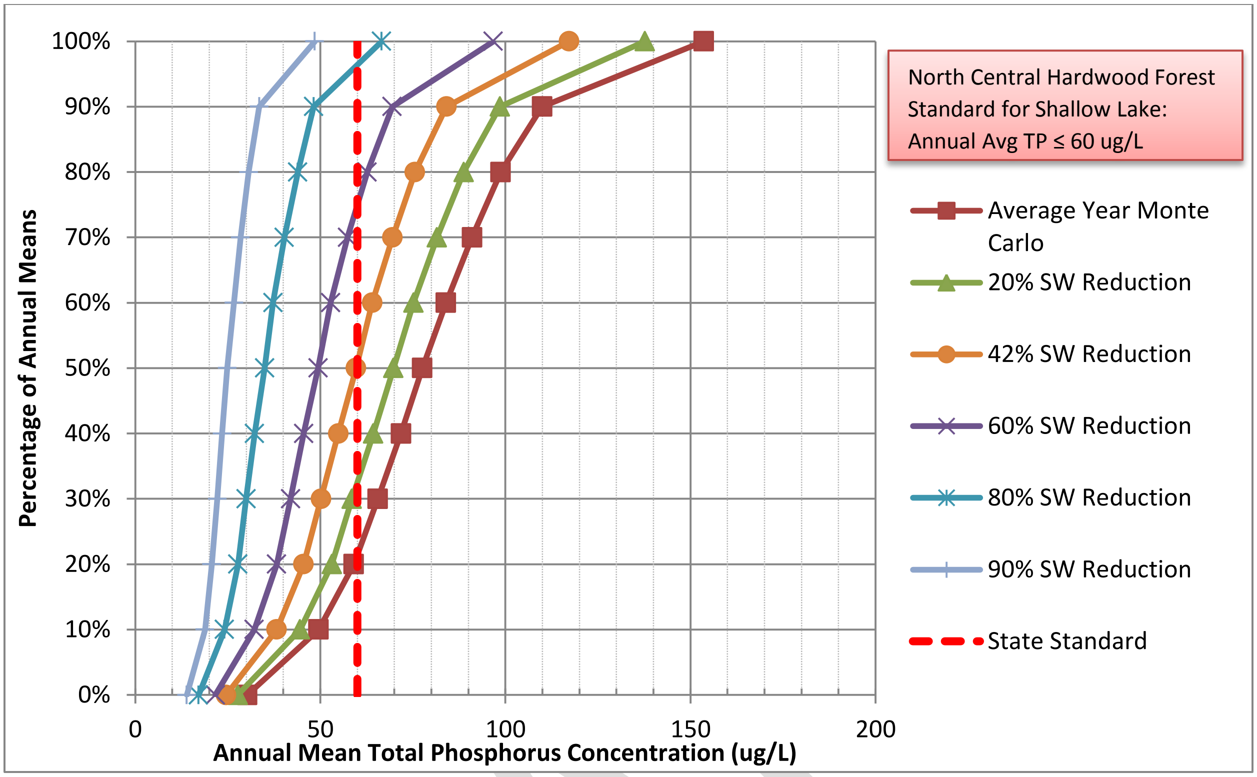

Figure 5. Example of the Frequency Distribution of Mean Annual TP Concentrations Resulting from Select Load Reduction Scenarios (Forget-Me-Not Lake).

For Forget-Me-Not Lake, the average initial in-lake TP concentration is 78.8 µg/L and the TP loading is 865 kg/yr. **Figure 5** and **Table 13** show a reduction of 42% is needed to meet the water quality standard of 60 µg/L 50% of the time. This results in a load reduction of 363 kg/yr, an allowable annual load of 502 kg/yr, and an in-lake TP concentration of 59.7 µg/L (**Table 13**).

Table 13. Example of Monte Carlo Simulation TP Loading Reduction Results (Forget-Me-Not Lake).

Non-Exceedance Percentile	Average Year Monte Carlo	20% Reduction	42% Reduction	60% Reduction	80% Reduction	90% Reduction
Load	865 kg	692 kg	502 kg	346 kg	173 kg	87 kg
Mean	78.8	70.7	60.4	50.3	35.7	25.7
0%	30.3	27.7	24.5	21.6	17.1	13.9
10%	49.6	44.5	38.2	32.2	24.1	18.9
20%	59.1	53.1	45.5	38.2	27.8	20.7
30%	65.5	58.6	50.2	42.0	29.9	22.2
40%	71.8	64.3	54.8	45.5	32.2	23.5
50%	77.5	69.8	59.7	49.4	35.0	24.8
60%	83.9	75.2	64.0	52.8	37.2	26.7
70%	91.0	81.5	69.5	57.4	40.3	28.4
80%	98.7	88.7	75.6	62.7	43.9	30.6
90%	109.9	98.5	84.1	69.4	48.2	33.5
100%	153.6	137.7	117.2	96.7	66.6	48.5

The results of the CNET modeling and load reduction scenarios for all of the lakes are summarized in **Table 14**. **Table 14** includes the specific TP water quality standard that applies to the individual lake, the simulated initial TP concentration and loading into the lake (excluding atmospheric deposition) as estimated by the average condition, the percent load reduction require to meet the TP water quality standard, the absolute load reduction (in kilograms per year) required to meet the TP water quality standard, and the loading capacity of the lake (i.e., the TP loading when the water quality standard is met) excluding atmospheric load. Atmospheric deposition was subtracted from the total TP load (for this portion of the reporting) because it cannot be physically reduced.. These results will inform load allocations to meet water quality standards. Outputs for each individual lake are provided in **Appendix A**. It is important to note that the simulated initial mean TP concentration values presented in **Table 14** are those computed under the Monte Carlo simulations. In most cases, these values will be slightly less than those that were observed and to which the models were calibrated (shown in **Table 10**), due to the fact that the values in **Table 14** are based on distributions of model inputs and not limited by the observed dataset. In addition, the CNET models were calibrated to the average condition for 1997-2009 and the distribution for the stochastic simulations are based on 1995-2009(to extend the dataset). 1995 and 1996 had slightly lower than average precipitation, lowering the average concentrations. The fact that these simulated values are lower than the observed data is accounted for when developing load reduction recommendations by applying a margin of safety.

The required load reductions for the modeled individual lakes ranged from 0% to 93% with a group median of 55% and an average of 50%. The lakes with larger drainage basins (e.g., Jacobs, Lime, and Stinking) tended to require higher load reductions than lakes with smaller drainage basins (e.g., Gottenberg, Gourd, and Marshall). Lakes with the highest absolute load (e.g., Axberg, Lime, Sand , and Stinking) tend to require higher relative load reductions and lakes with lower absolute loads tend to have lower relative load reductions. A few lakes do not follow this trend. Gourd Lake has a relatively low absolute TP load (87 kg/yr) but needs a high relative load reduction (60%). It should be noted, Gourd Lake has a relatively small drainage basin. Stakke Lake has a higher absolute load (1,026 kg/yr) but requires minimal relative load reduction. Some lakes are influence by upstream lakes. For example, Lime Lake has a large drainage area and is downstream of the Sand-Axberg Chain. Most of the loading (~90%) into Lime Lake is from tributary sources.

Table 14: Results of the Load Reduction Scenarios for BRW Lakes.

Lake Name	TP Standard (ug/L)	Simulated Initial Mean In-Lake TP Conc. (ug/L)	Initial TP Load[1] (kg/yr)	TP Load Reduction (%)	Absolute TP Load Reduction (kg)	Loading Capacity (kg/yr)
Axberg	60	214.4	3,232	92%	2,973	259
Boyer	40	54.5	44	45%	17.6	26.4
Forget-me-not	60	78.8	865	42%	363	502
Gottenberg	60	66.2	234	15%	35	199
Gourd	60	106.3	87	68%	59	28
Jacobs	40	76.9	99	78%	77	22
Lime	60	133.4	8,513	80%	6,810	1,703
Maria	90	190.7	2,607	72%	1,877	730
Marshall	40	39.4	126	0%	0	126
Mission	60	117	116	60%	70	46
North Tamarac	30	34.1	138	28%	39	99
Sand (Stump)	40	177.4	4,268	93%	3,969	299
Sorenson (Lee)	60	215.9	316	73%	230	85
Stakke	60	61.5	1,055	3%	32	1,023
Stinking	90	302.1	13,827	84%	11,615	2,212
Talac	60	122.9	901	52%	469	433
West Labelle (Duck)	60	83.9	62	45%	28	34
Yort (Sand)	60	79.9	589	32%	188	401
LA-Deep	65	39	321	0%	0	321
LA-Shallow	90	158.3	381	70%	266	144
NCHF-Deep	40	48.3	13	80%	10	3
NCHF-Shallow	60	107.0	178	71%	127	52
NLF-Shallow	30	27.4	32	0%	0	32

[1]TP Load consists of contributing drainage area load and tributary load, i.e. no atmospheric load.

A few lakes show no load reduction is required to meet the TP water quality standard. These lakes include Marshall Lake, LA-Deep, and NLF-Shallow. Marshall Lake has an average observed TP concentration (41.8 µg/L) close to its TP water quality standard (40 µg/L) and the simulated initial mean TP concentration in the lake is slightly lower than the standard (39.4 ug/L). As mentioned above, this is due to the stochastic nature of the Monte Carlo approach and is accounted for in the recommended load reductions. In the case of LA-Deep and NLF-Shallow lakes, the observed data in these "example" lakes show that, on average, these classes of lakes in the BRW are not violating water quality standards. As such, the load reduction exercise is used to provide insight on how such lakes may respond to changes in TP loading and also in developing protection strategies.

In addition to the load reduction scenarios that were presented above (and summarized in Table 13), a special set of scenarios were developed for the Sand-Axberg Chain. Given the high priority and unique nature of these lakes, a scenario was developed to consider the necessary reduction in contributing drainage area loading to each lake, if the upstream lakes met the water quality standards. The results of this special case for the Sand-Axberg Chain are shown in **Table 15**. It should be noted that Axberg and Sorenson Lakes do not have any upstream lakes flow into them and the results are the same as shown in **Table 14**. It should also be noted that the initial TP loading for Sand, Talac, and Yort Lakes in **Table 15** is different than that in **Table 14** since the tributary loading is reduced to meet the water quality standard.

Table 15: Results of the Load Reduction Scenarios using Monte Carlo Simulation for Sand-Axberg Chain with Tributary Flows meeting Water Quality Standards.

Lake Name	TP Standard (ug/L)	Simulated Initial Mean In-Lake TP Conc. with Tributary Meeting Standard (ug/L)	Initial TP Loading (kg/yr)	Load Reduction (%)	Absolute Load Reduction (kg)	Loading Capacity (kg/yr)
Axberg	60	214.4	3,232	92%	2,973	259
Sand (Stump)	40	173.8	4,201	95%	3,930	271
Sorenson (Lee)	60	215.9	316	73%	230	85
Talac	60	61	410	0%	0	410
Yort (Sand)	60	51.5	318	0%	0	318

Results of this analysis show that Talac and Yort Lakes would require no load reduction from their contributing drainage area if the upstream lakes met the water quality standards. Results for Sand (Stump) Lake in **Table 15** show a lower initial TP concentration but a slightly higher required load reduction than results in **Table 14**. This seems contrary to the expected result since the tributary flows are meeting the water quality standard. This happens because when the tributary loads are reduced by 93% (as shown in **Table 14**), the resultant tributary TP concentration is less than 60 ug/L (the water quality standard for the upstream lake). Therefore, setting the tributary inflow to have a TP concentration of 60 ug/L requires additional reduction in contributing drainage area loading to meet the water quality standard in Sand (Stump) Lake (**Table 15**). A complete set of results for this special case for the Sand-Axberg Chain are provided in **Appendix A**.

4.3 Recommended Load Reductions

Section 4.2 describes the load reduction scenarios that were simulated in the BRW CNET models to compute the loading capacity (excluding atmospheric loading) of the studied lakes. Results of that analysis can also be used to compute total maximum daily loads (TMDLs) for the impaired lakes. As discussed above, using the Monte Carlo approach for simulating in-lake water quality in the BRW lakes resulted in slightly lower mean in-lake TP concentrations than those that were computed from observed data. On average, the difference between the stochastically-simulated and observed values is 4.1%. To account for this difference in computing TMDLs and recommending load reductions for the impaired lakes, a 5% margin of safety (MOS) was applied to the analysis. **Table 16** summarizes the results of this work, presenting the absolute and percent load reduction needed to achieve the TP water quality standard minus a 5% MOS in each impaired lake and presenting the computed TMDL (in kilograms per year) based on this result.

Table 16: Recommended Load Reductions and TMDLs for Impaired BRW Lakes.

Lake Name	TP Standard - 5% MOS (ug/L)	Load Reduction (%)	Absolute Load Reduction (kg)	TMDL (kg/yr)
Boyer	38	52%	23	21
Forget-me-not	57	47%	407	458
Gottenberg	57	22%	51	183
Gourd	57	72%	63	24
Jacobs	38	82%	81	18
Lime	57	82%	6,981	1,532
Maria	86	74%	1,929	678
Marshall	38	1%	1.3	125
Mission	57	63%	73	43
North Tamarac	29	35%	48	90
Sand (Stump)	38	94%	4,012	256
Sorenson (Lee)	57	74%	234	82
Stakke	57	8%	84	971
Stinking	86	85%	11,753	2,074
Talac	57	55%	496	406
West Labelle (Duck)	57	49%	30	32

5.0 SUMMARY OF RESULTS

Eighteen individual lakes and five “example” lakes were modeled under Tasks 10 and 11 of Phase II of the BRW WRAP project. The purpose of this lake modeling effort was to inform the development of TMDLs and load allocations for sixteen impaired lakes, and to inform restoration and protections strategy development for two additional lakes in the Sand-Axberg Chain and the lakes of the BRW, in general.

Twenty-three CNET models were created to simulate in-lake eutrophication dynamics in the BRW lakes. The models were calibrated to observed average conditions based on available in-lake data and simulated watershed loading values, taken from a SWAT model of the area. Stochastic simulations were used to compute the expected in-lake response to reductions in watershed loading and to compute loading capacities and TMDLs for each of the impacted lakes. Results showed that, on average, TP loading to the lakes addressed in this report will need to be reduced by 56% to meet the water quality standards. The lowest percent reduction required is estimated at 1%, while the highest required is 94%.

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APPENDIX A

(In separate file)

A.1 Axberg Lake

Table A.1.1. Annual BRW SWAT outputs (1995-2009) for Axberg Lake.

Year	Precipitation (m/yr)	Evaporation (m/yr)	Contributing Drainage Inflow (hm^3/yr)	Contributing Drainage Area Load (kg/yr)	Tributary Flow (hm^3/yr)	Tributary Loading (kg/yr)
1995	0.661	0.792	0.548	376	0.0	0.0
1996	0.691	0.889	0.941	2631	0.0	0.0
1997	0.911	0.923	1.931	4717	0.0	0.0
1998	0.879	1.009	1.883	2365	0.0	0.0
1999	0.775	0.972	1.072	2734	0.0	0.0
2000	0.805	0.974	0.659	924	0.0	0.0
2001	0.762	0.942	1.639	1849	0.0	0.0
2002	0.717	0.932	1.007	3208	0.0	0.0
2003	0.538	1.068	0.272	215	0.0	0.0
2004	0.791	0.956	0.768	608	0.0	0.0
2005	0.910	0.996	1.316	5289	0.0	0.0
2006	0.685	1.038	1.214	3630	0.0	0.0
2007	0.692	0.944	1.235	1986	0.0	0.0
2008	1.022	0.850	2.146	10382	0.0	0.0
2009	0.802	0.892	2.089	5884	0.0	0.0
Average	**0.776**	**0.945**	**1.25**	**3120**	**0.0**	**0.0**

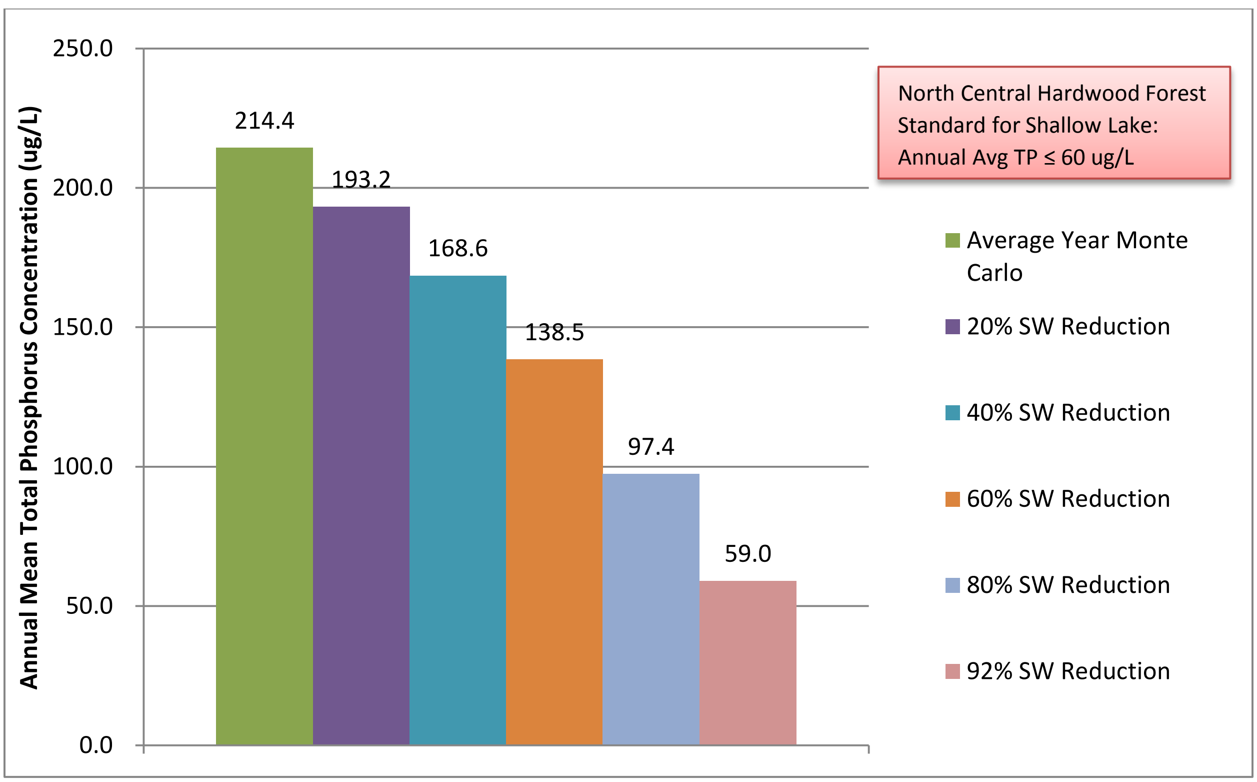

Figure A.1.1. Axberg Lake Annual Mean TP Concentrations under Select Load Reduction Scenarios.

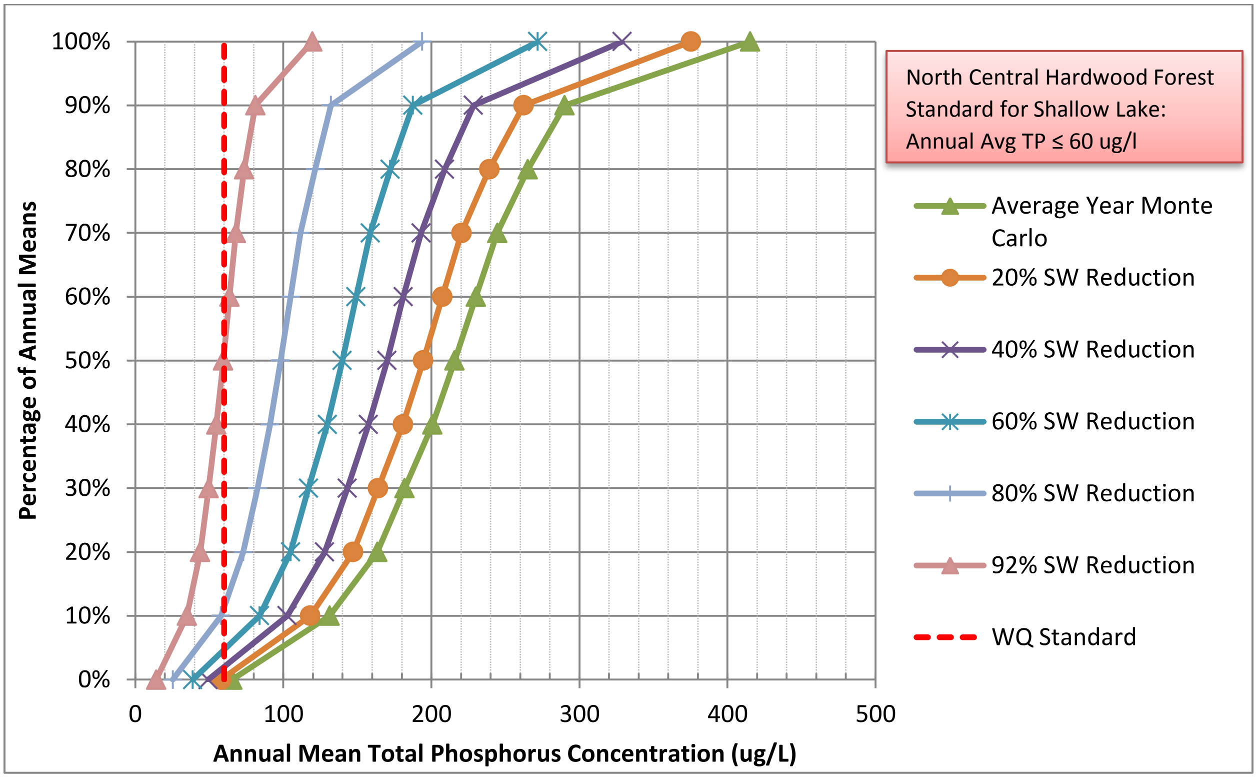

Figure A.1.2. Axberg Lake Frequency Distribution of Annual Mean TP Concentrations Resulting from Select Load Reduction Scenarios.

Table A.1.2. Data used to Produce the Annual Mean TP Frequency Distribution (Figure A.1.2) for Axberg Lake.

Non-Exceedance Percentile	Average Year Monte Carlo	20% Reductio n	40% Reductio n	60% Reductio n	80% Reductio n	92% Reductio n
Load	3,232 kg	2,586 kg	1,939 kg	1,293 kg	647 kg	259 kg
Mean	214.4	193.2	168.6	138.5	97.4	59.0
0%	65.6	58.0	49.3	38.9	25.4	14.1
10%	131.3	118.2	102.7	84.0	57.9	34.9
20%	163.5	147.1	127.9	105.0	73.0	43.9
30%	181.9	164.0	143.3	117.1	82.6	49.6
40%	200.8	180.8	157.6	129.8	91.0	54.8
50%	215.7	194.5	170.1	139.9	98.2	59.4
60%	230.1	207.4	181.0	149.2	105.0	63.6
70%	244.6	220.4	193.1	158.8	111.6	68.0
80%	265.3	239.1	209.0	172.3	121.6	73.6
90%	290.1	262.3	228.5	187.5	132.2	81.1
100%	415.4	375.4	328.9	271.9	193.7	119.6

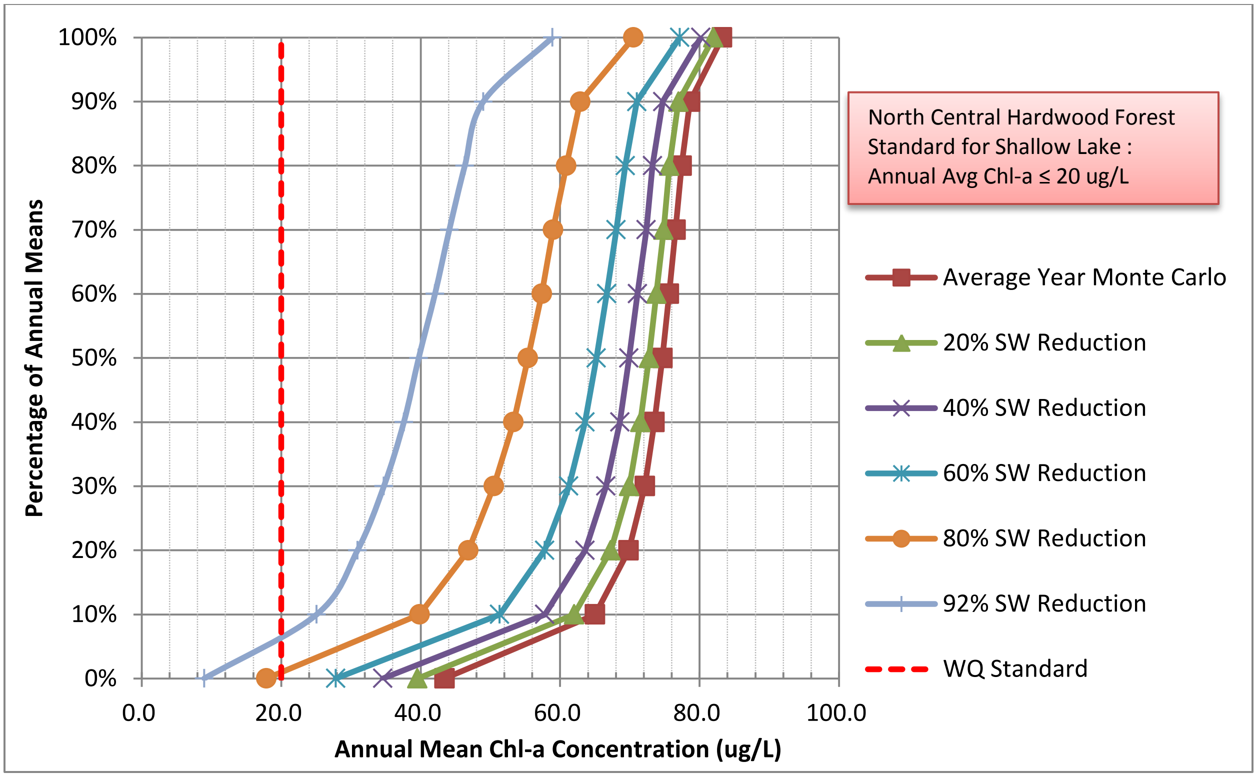

Figure A.1.3. Axberg Lake Frequency Distribution of Annual Mean Chl-*a* Concentrations Resulting from Select Load Reduction Scenarios.

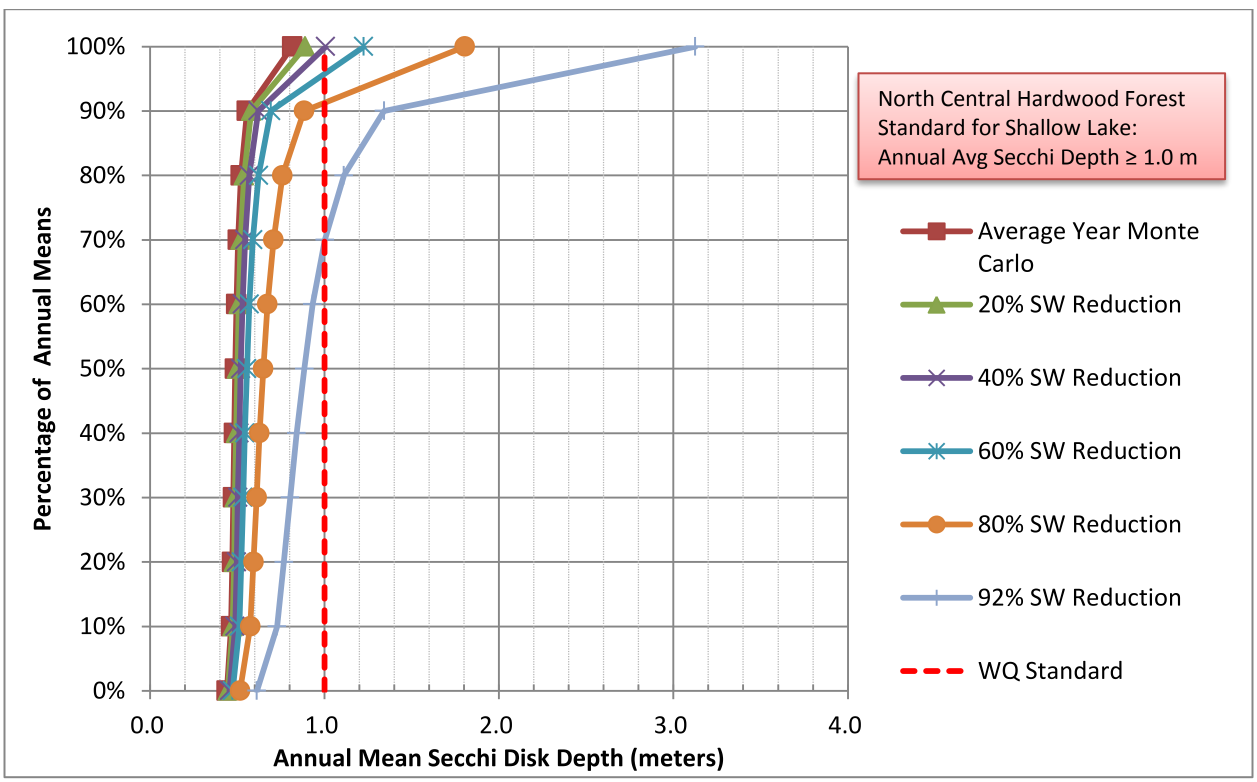

Figure A.1.4. Axberg Lake Frequency Distribution of Annual Mean Secchi Disk Depths Resulting from Select Load Reduction Scenarios.

A.2 Boyer Lake

Table A.2.1. Annual BRW SWAT outputs (1995-2009) for Boyer Lake.

Year	Precipitation (m/yr)	Evaporation (m/yr)	Contributing Drainage Inflow (hm^3/yr)	Contributing Drainage Area Load (kg/yr)	Tributary Flow (hm^3/yr)	Tributary Loading (kg/yr)
1995	0.661	0.787	0.04	8.4	0.0	0.0
1996	0.691	0.875	0.07	48.4	0.0	0.0
1997	0.911	0.919	0.18	117.4	0.0	0.0
1998	0.879	1.003	0.13	47.4	0.0	0.0
1999	0.775	1.013	0.07	32.9	0.0	0.0
2000	0.805	1.032	0.04	11.8	0.0	0.0
2001	0.762	1.022	0.09	31.2	0.0	0.0
2002	0.717	0.973	0.06	30.4	0.0	0.0
2003	0.538	1.085	0.02	3.4	0.0	0.0
2004	0.791	0.983	0.05	13.5	0.0	0.0
2005	0.910	1.027	0.08	48.9	0.0	0.0
2006	0.685	1.058	0.08	42.2	0.0	0.0
2007	0.692	0.957	0.09	23.6	0.0	0.0
2008	1.022	0.897	0.14	99.5	0.0	0.0
2009	0.802	0.922	0.14	61.6	0.0	0.0
Average	**0.776**	**0.970**	**0.08**	**41.3**	**0.0**	**0.0**

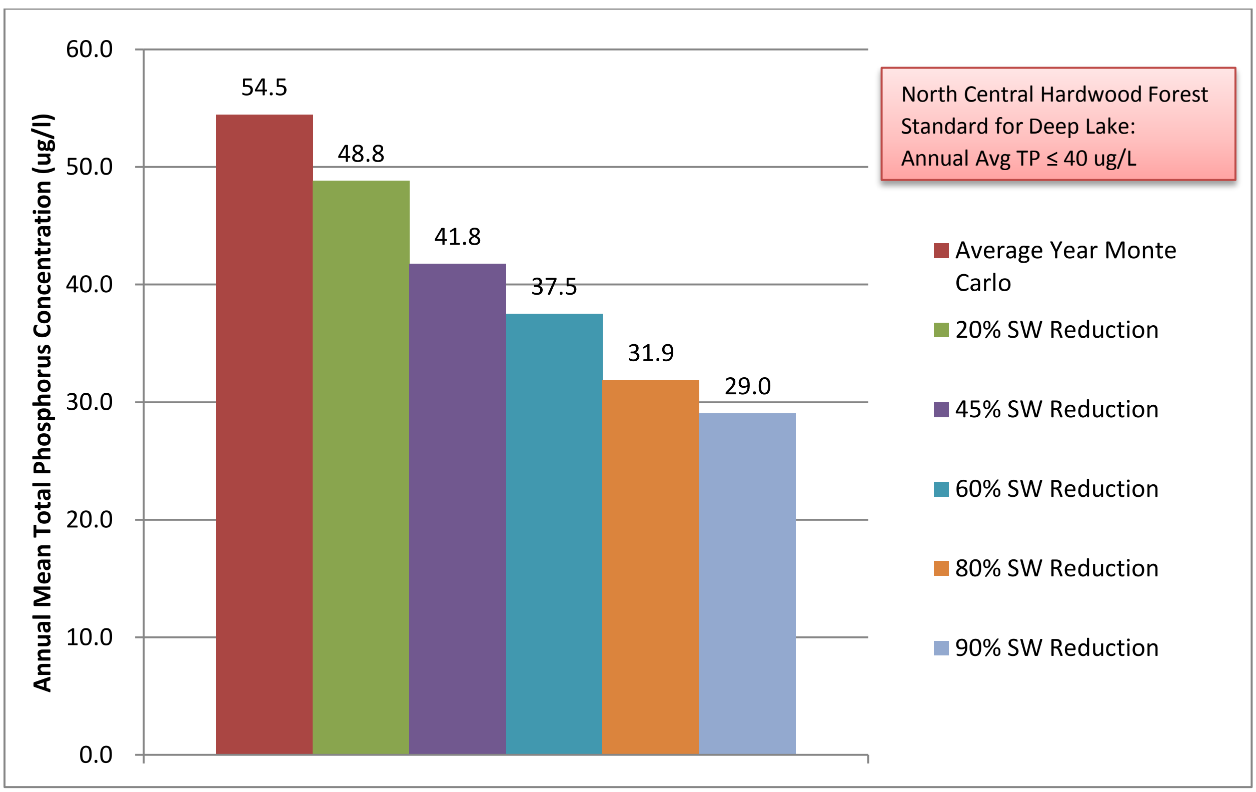

Figure A.2.1. Boyer Lake Annual Mean TP Concentrations under Select Load Reduction Scenarios.

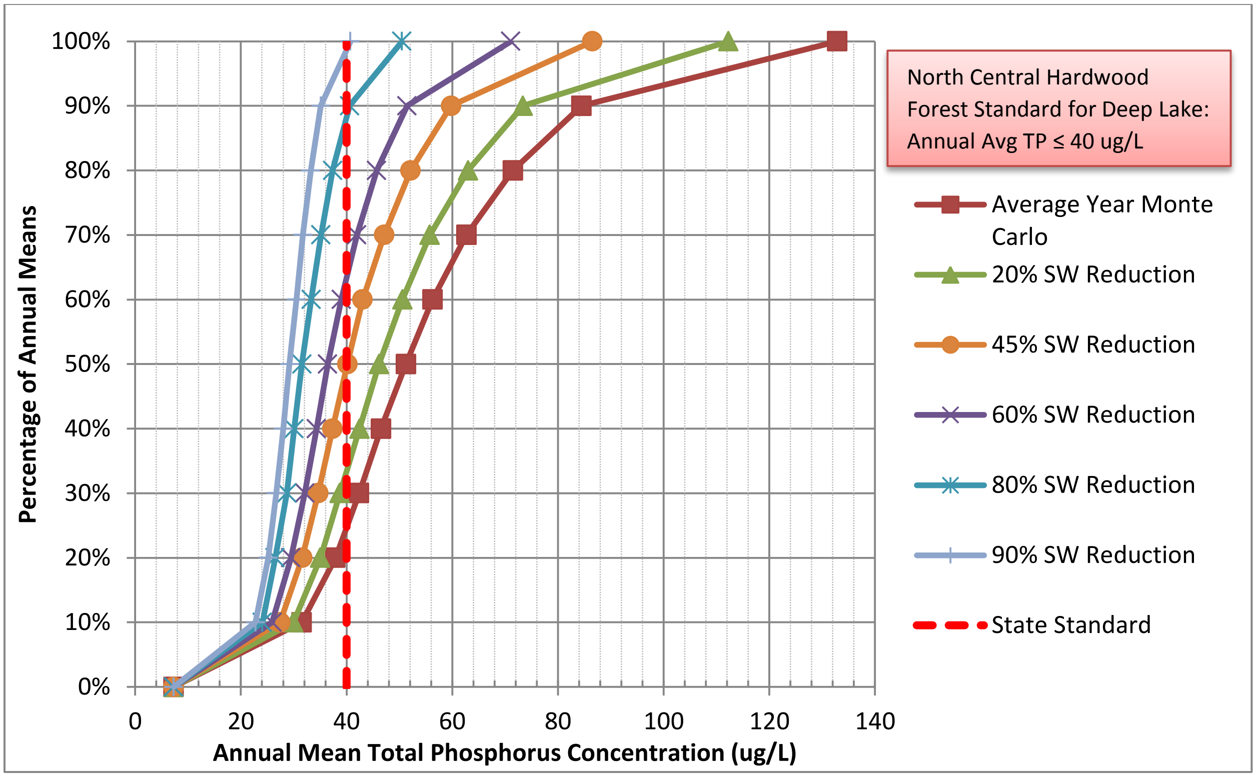

Figure A.2.2. Boyer Lake Frequency Distribution of Annual Mean TP Concentrations Resulting from Select Load Reduction Scenarios.

Table A.2.2. Data used to Produce the Annual Mean TP Concentrations (ug/L) Frequency Distribution (Figure A.2.2) for Boyer Lake.

Non-Exceedance Percentile	Average Year Monte Carlo	20% Reductio n	45% Reductio n	60% Reductio n	80% Reductio n	90% Reductio n
Load	43.6 kg	34.9 kg	24.0 kg	17.4 kg	8.7 kg	4.4 kg
Mean	54.5	48.8	41.8	37.5	31.9	29.0
0%	7.3	7.3	7.3	7.3	7.3	7.3
10%	31.5	30.0	27.4	25.9	24.1	22.8
20%	37.9	35.0	31.6	29.5	26.5	25.2
30%	42.4	38.7	34.6	32.1	28.7	26.7
40%	46.5	42.5	37.3	34.3	30.1	28.0
50%	51.3	46.2	40.2	36.4	31.6	29.2
60%	56.3	50.6	43.0	39.0	33.3	30.5
70%	62.7	55.8	47.1	41.9	35.2	31.8
80%	71.5	63.0	52.1	45.7	37.4	33.2
90%	84.5	73.4	59.8	51.5	40.6	35.1
100%	132.9	112.3	86.5	71.1	50.5	40.7

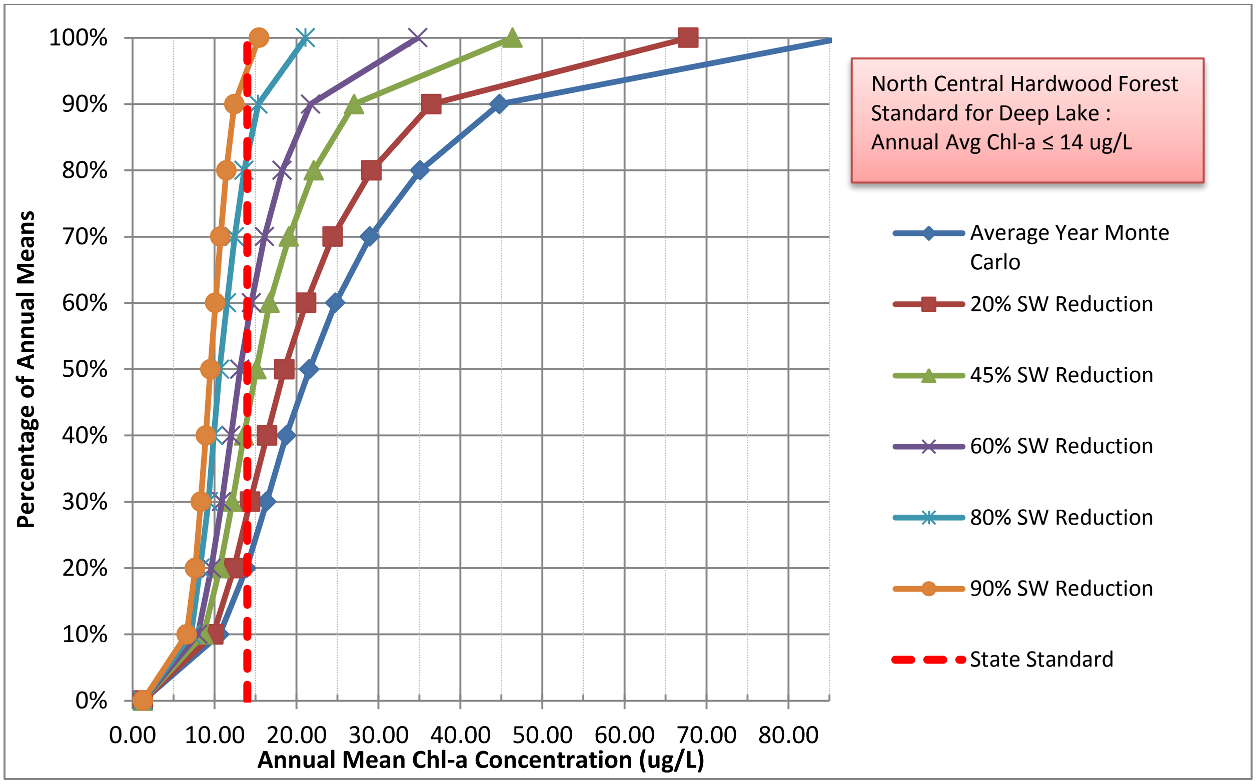

Figure A.2.3. Boyer Lake Frequency Distribution of Annual Mean Chl-*a* Concentrations Resulting from Select Load Reduction Scenarios.

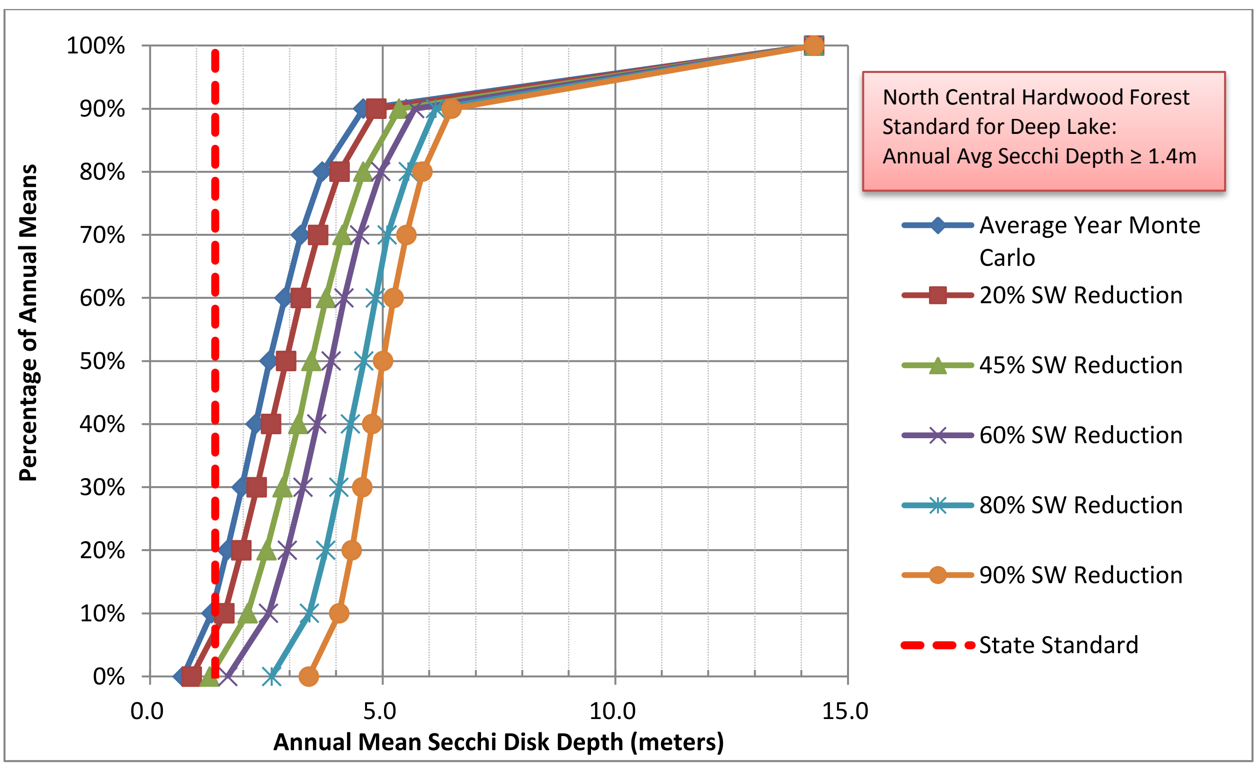

Figure A.2.4. Boyer Lake Frequency Distribution of Annual Mean Secchi Disk Depths Resulting from Select Load Reduction Scenarios.

A.3 Forget-Me-Not Lake

Table A.3.1. Annual BRW SWAT outputs (1995-2009) for Forget-Me-Not Lake.

Year	Precipitation (m/yr)	Evaporation (m/yr)	Contributing Drainage Inflow (hm^3/yr)	Contributing Drainage Area Load (kg/yr)	Tributary Flow (hm^3/yr)	Tributary Loading (kg/yr)
1995	0.661	0.747	0.69	519	0.0	0.0
1996	0.691	0.836	1.26	722	0.0	0.0
1997	0.911	0.864	2.92	1,331	0.0	0.0
1998	0.879	0.952	2.50	1,890	0.0	0.0
1999	0.775	0.913	1.59	675	0.0	0.0
2000	0.805	0.918	1.06	228	0.0	0.0
2001	0.762	0.884	2.20	2,020	0.0	0.0
2002	0.717	0.875	1.12	326	0.0	0.0
2003	0.538	1.007	0.46	46	0.0	0.0
2004	0.791	0.899	0.84	461	0.0	0.0
2005	0.910	0.937	1.82	589	0.0	0.0
2006	0.685	0.975	1.64	649	0.0	0.0
2007	0.692	0.886	1.67	1,208	0.0	0.0
2008	1.021	0.794	3.03	811	0.0	0.0
2009	0.802	0.834	2.84	1,063	0.0	0.0
Average	**0.776**	**0.888**	**1.71**	**836**	**0.0**	**0.0**

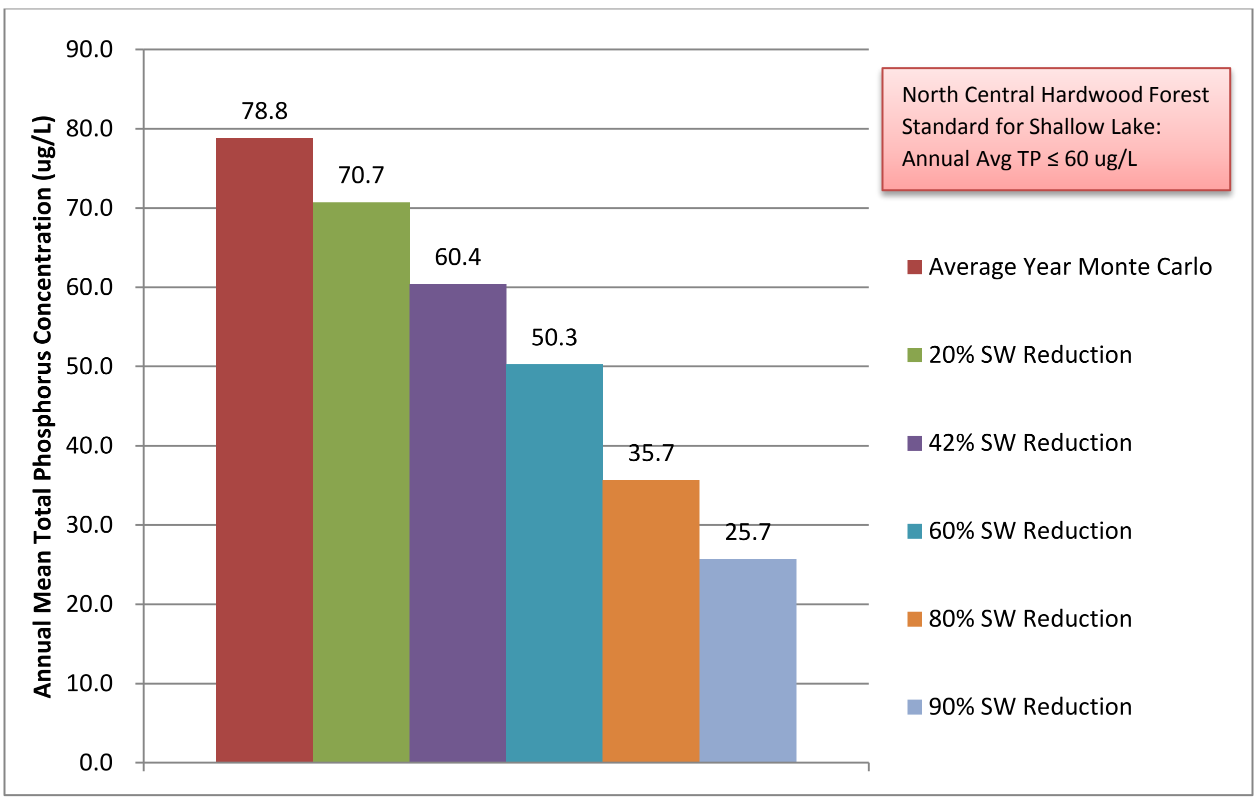

Figure A.3.1. Forget-Me-Not Lake Annual Mean TP Concentrations under Select Load Reduction Scenarios.

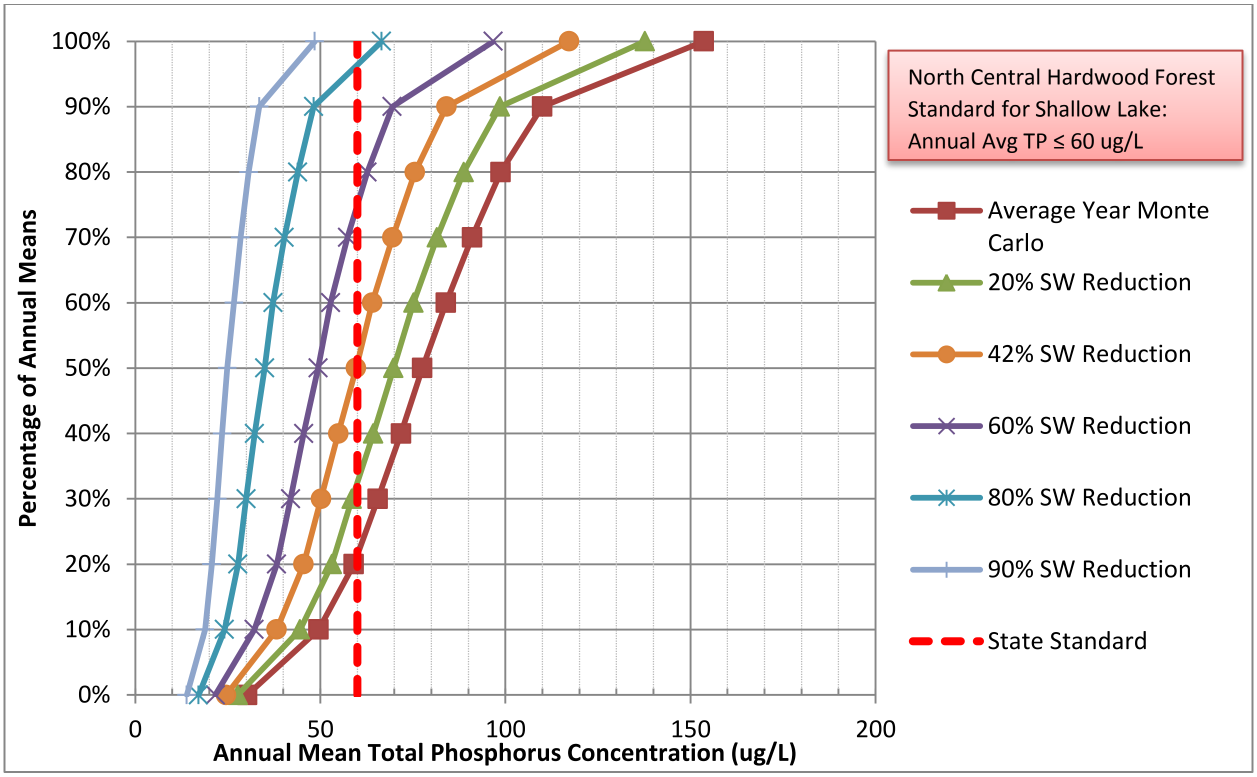

Figure A.3.2. Forget-Me-Not Lake Frequency Distribution of Annual Mean TP Concentrations Resulting from Select Load Reduction Scenarios.

Table A.3.2. Data used to Produce the Annual Mean TP Concentrations (ug/L) Frequency Distribution (Figure A.3.2) for Forget-Me-Not Lake.

Non-Exceedance Percentile	Average Year Monte Carlo	20% Reduction	42% Reduction	60% Reduction	80% Reduction	90% Reduction
Load	865 kg	692 kg	502 kg	346 kg	173 kg	87 kg
Mean	78.8	70.7	60.4	50.3	35.7	25.7
0%	30.3	27.7	24.5	21.6	17.1	13.9
10%	49.6	44.5	38.2	32.2	24.1	18.9
20%	59.1	53.1	45.5	38.2	27.8	20.7
30%	65.5	58.6	50.2	42.0	29.9	22.2
40%	71.8	64.3	54.8	45.5	32.2	23.5
50%	77.5	69.8	59.7	49.4	35.0	24.8
60%	83.9	75.2	64.0	52.8	37.2	26.7
70%	91.0	81.5	69.5	57.4	40.3	28.4
80%	98.7	88.7	75.6	62.7	43.9	30.6
90%	109.9	98.5	84.1	69.4	48.2	33.5
100%	153.6	137.7	117.2	96.7	66.6	48.5

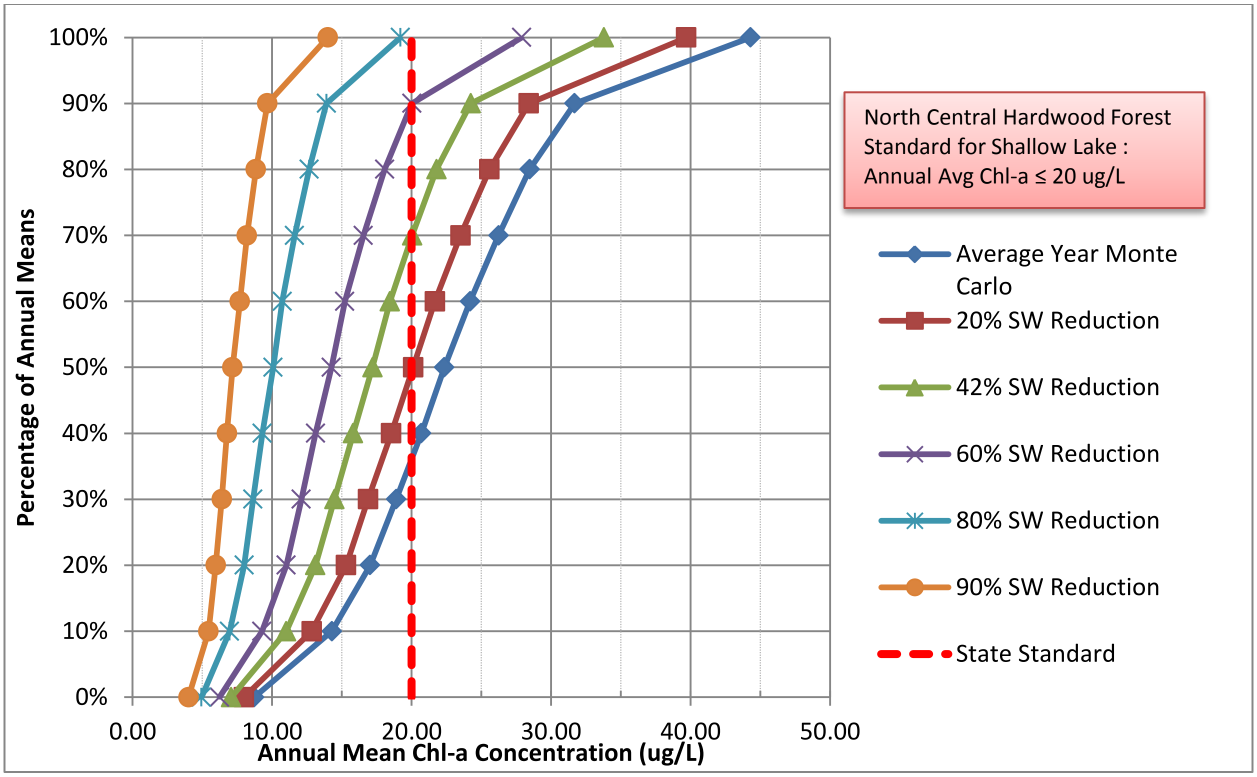

Figure A.3.3. Forget-Me-Not Lake Frequency Distribution of Annual Mean Chl-*a* Concentrations Resulting from Select Load Reduction Scenarios.

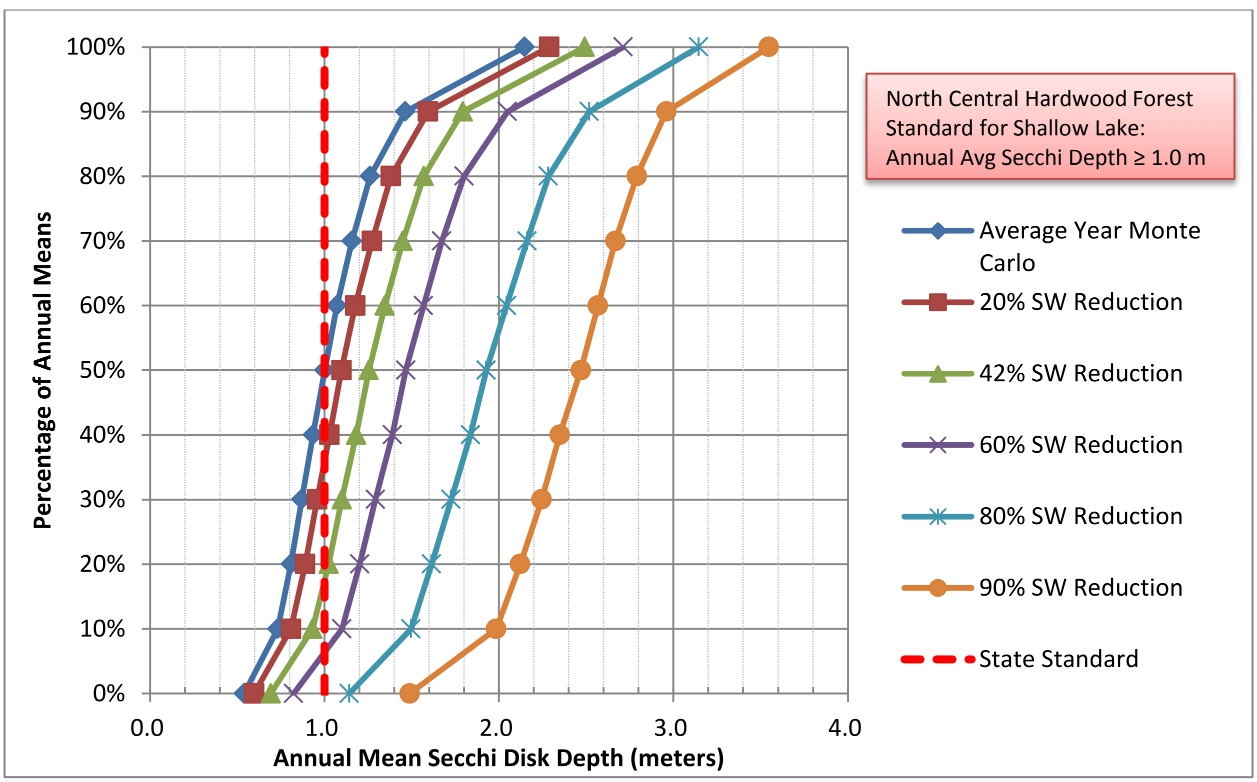

Figure A.3.4. Forget-Me-Not Lake Frequency Distribution of Annual Mean Secchi Disk Depths Resulting from Select Load Reduction Scenarios.

A.4 Gottenberg Lake

Table A.4.1. Annual BRW SWAT outputs (1995-2009) for Gottenberg Lake.

Year	Precipitation (m/yr)	Evaporation (m/yr)	Contributing Drainage Inflow (hm^3/yr)	Contributing Drainage Area Load (kg/yr)	Tributary Flow (hm^3/yr)	Tributary Loading (kg/yr)
1995	0.671	0.794	0.12	76	0.2	46.8
1996	0.681	0.885	0.37	220	0.3	65.2
1997	0.732	0.926	0.50	123	0.7	319.6
1998	0.805	1.005	0.35	113	0.6	102.2
1999	0.626	0.972	0.31	45	0.4	43.9
2000	0.743	0.971	0.24	38	0.2	38.9
2001	0.609	0.941	0.33	122	0.4	116.5
2002	0.658	0.934	0.21	10	0.3	98.8
2003	0.467	1.063	0.15	12	0.1	9.2
2004	0.800	0.953	0.24	95	0.2	36.9
2005	0.707	1.002	0.30	42	0.4	131.1
2006	0.644	1.035	0.34	52	0.4	131.7
2007	0.699	0.870	0.53	259	0.4	125.2
2008	0.897	0.796	0.62	81	0.7	299.9
2009	0.802	0.808	0.89	212	0.7	210.7
Average	**0.703**	**0.930**	**0.37**	**100**	**0.4**	**118.4**

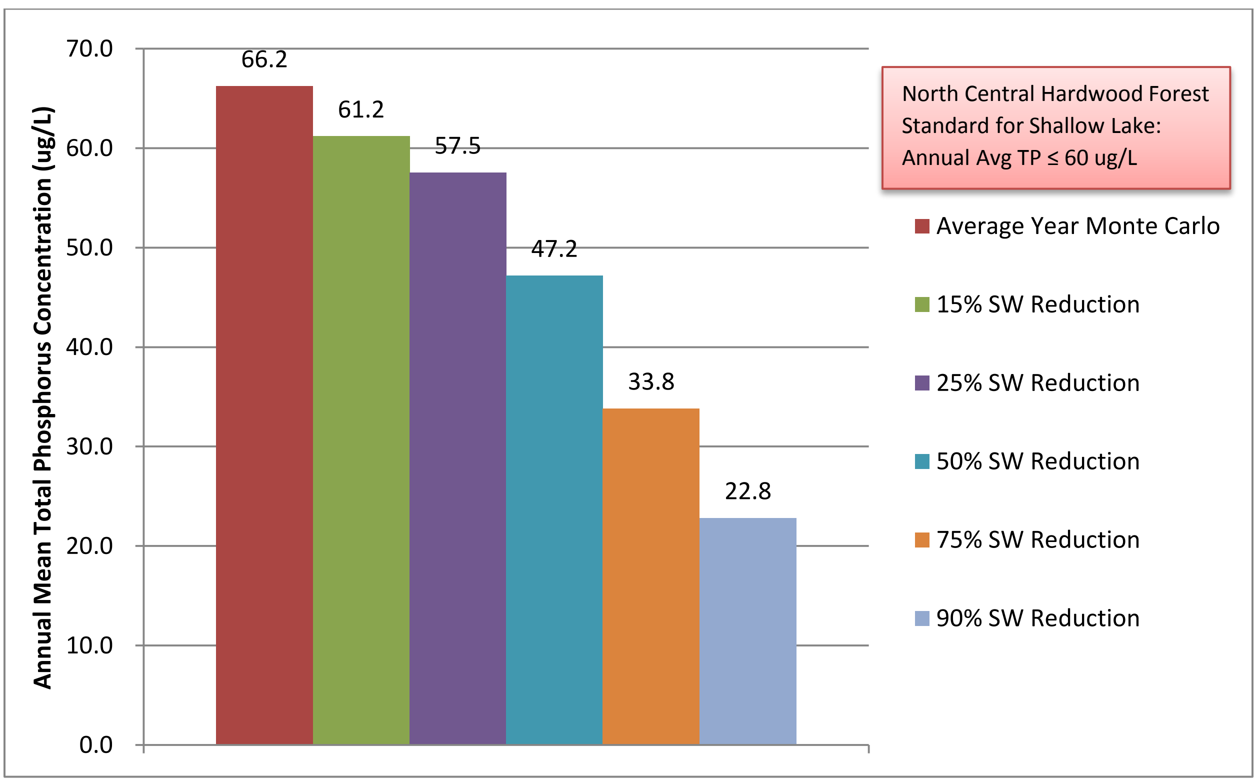

Figure A.4.1. Gottenberg Lake Annual Mean TP Concentrations under Select Load Reduction Scenarios.

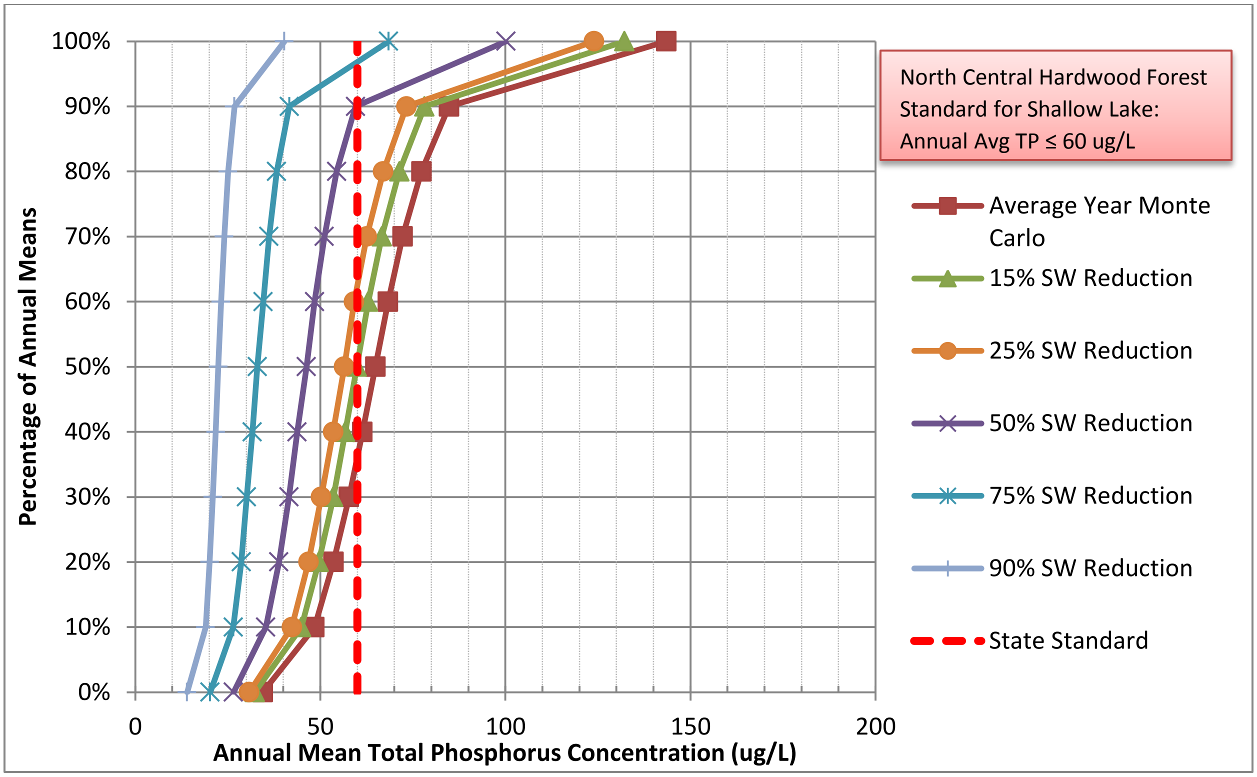

Figure A.4.2. Gottenberg Lake Frequency Distribution of Annual Mean TP Concentrations Resulting from Select Load Reduction Scenarios.

Table A.4.2. Data used to Produce the Annual Mean TP Concentrations (ug/L) Frequency Distribution (Figure A.4.2) for Gottenberg Lake.

Non-Exceedance Percentile	Average Year Monte Carlo	15% Reduction	25% Reduction	50% Reduction	75% Reduction	90% Reduction
Load	234.1 kg	199.0 kg	175.6 kg	117.1 kg	58.5 kg	23.4 kg
Mean	66.2	61.2	57.5	47.2	33.8	22.8
0%	34.5	32.3	30.8	26.5	20.2	14.0
10%	48.4	44.9	42.3	35.3	26.5	19.0
20%	53.6	49.6	46.8	38.8	28.7	20.1
30%	57.8	53.5	50.2	41.6	30.1	21.0
40%	61.4	56.7	53.5	43.7	31.6	21.7
50%	64.9	59.9	56.5	46.3	33.0	22.4
60%	68.3	62.9	59.1	48.4	34.6	23.2
70%	72.2	66.6	62.6	51.1	36.1	24.0
80%	77.3	71.4	67.0	54.4	38.2	25.1
90%	84.8	78.2	73.3	59.5	41.6	26.8
100%	143.5	132.1	123.9	100.2	68.5	40.3

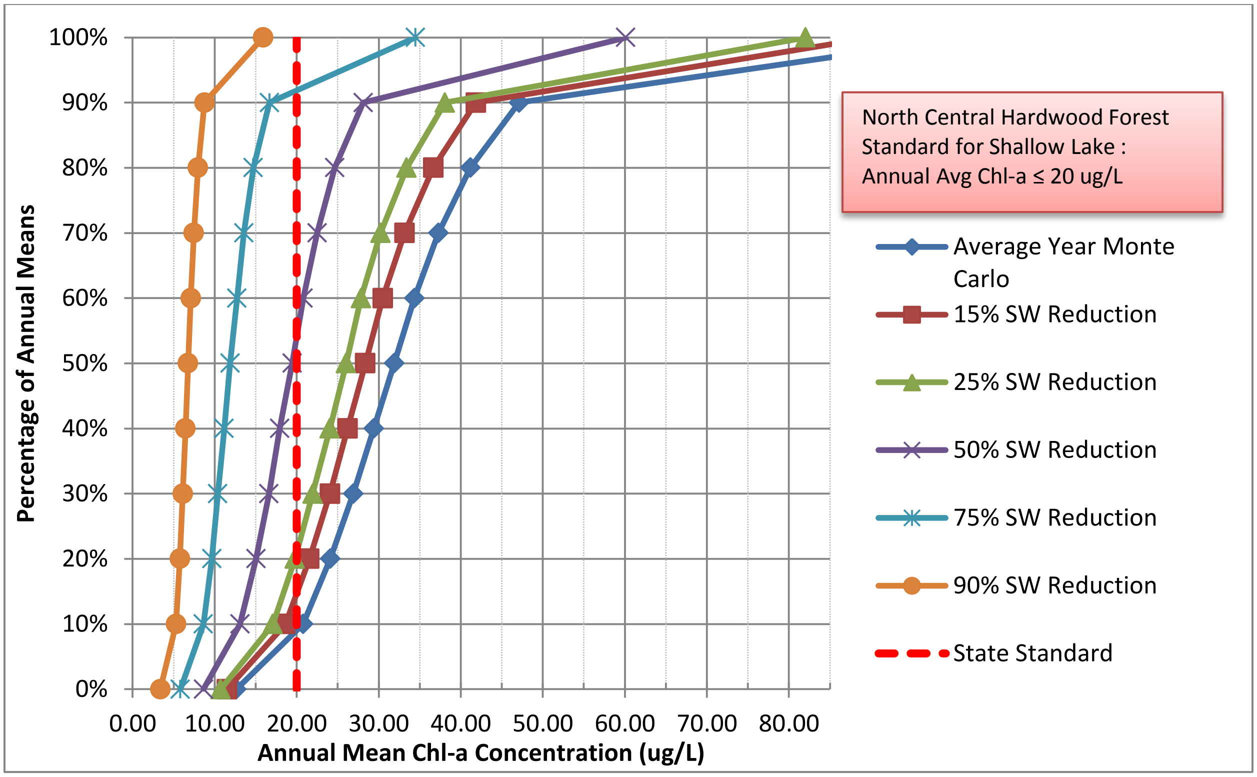

Figure A.4.3 Gottenberg Lake Frequency Distribution of Annual Mean Chl-*a* Concentrations Resulting from Select Load Reduction Scenarios.

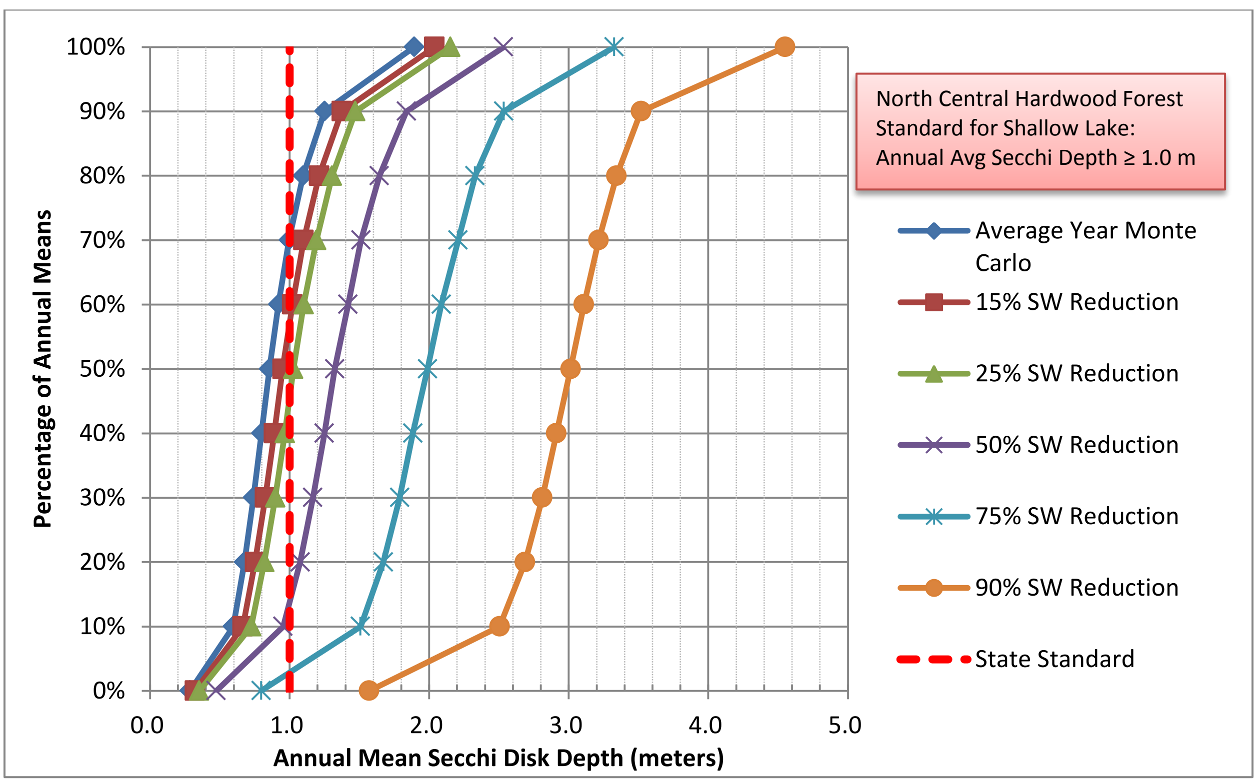

Figure A.4.4. Gottenberg Lake Frequency Distribution of Annual Mean Secchi Disk Depths Resulting from Select Load Reduction Scenarios.

A.5 Gourd Lake

Table A.5.1. Annual BRW SWAT outputs (1995-2009) for Gourd Lake.

Year	Precipitation (m/yr)	Evaporation (m/yr)	Contributing Drainage Inflow (hm^3/yr)	Contributing Drainage Area Load (kg/yr)	Tributary Flow (hm^3/yr)	Tributary Loading (kg/yr)
1995	0.661	0.878	0.13	27	0.0	0.0
1996	0.691	0.991	0.25	37	0.0	0.0
1997	0.911	1.034	0.49	187	0.0	0.0
1998	0.879	1.119	0.41	62	0.0	0.0
1999	0.775	1.085	0.31	31	0.0	0.0
2000	0.805	1.081	0.20	36	0.0	0.0
2001	0.762	1.050	0.37	116	0.0	0.0
2002	0.717	1.040	0.27	64	0.0	0.0
2003	0.538	1.183	0.10	7	0.0	0.0
2004	0.791	1.064	0.16	24	0.0	0.0
2005	0.910	1.110	0.34	100	0.0	0.0
2006	0.685	1.158	0.30	89	0.0	0.0
2007	0.692	1.054	0.27	59	0.0	0.0
2008	1.022	0.956	0.56	215	0.0	0.0
2009	0.802	1.003	0.50	138	0.0	0.0
Average	**0.776**	**1.054**	**0.31**	**80**	**0.0**	**0.0**

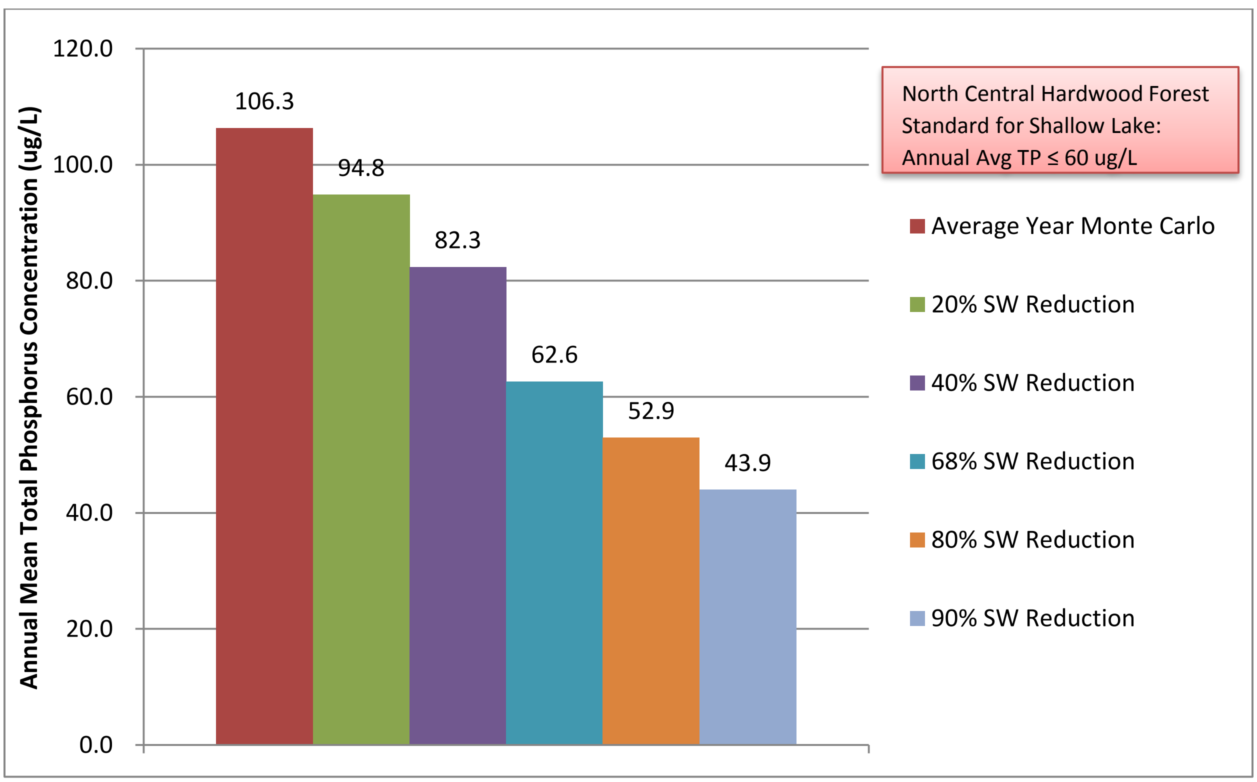

Figure A.5.1. Gourd Lake Annual Mean TP Concentrations under Select Load Reduction Scenarios.

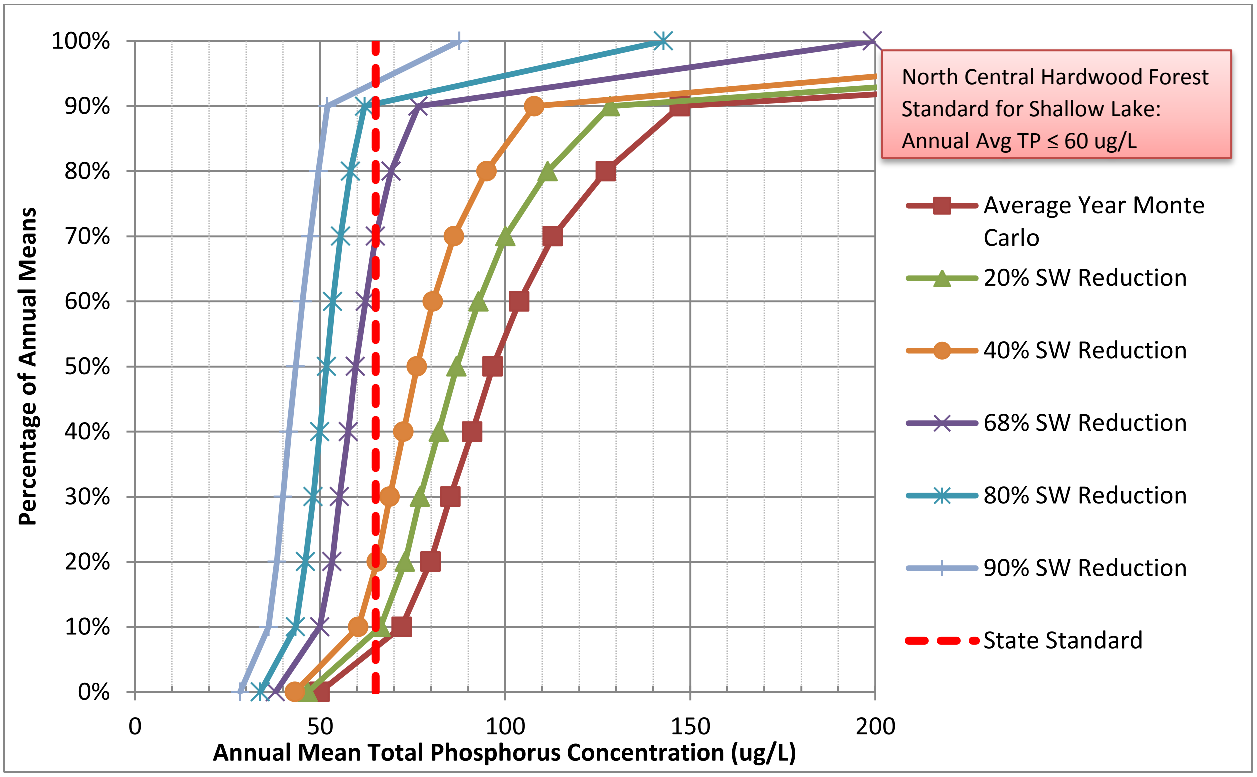

Figure A.5.2. Gourd Lake Frequency Distribution of Annual Mean TP Concentrations Resulting from Select Load Reduction Scenarios.

Table A.5.2. Data used to Produce the Annual Mean TP Concentrations (ug/L) Frequency Distribution (Figure A.5.2) for Gourd Lake.

Non-Exceedance Percentile	Average Year Monte Carlo	20% Reductio n	40% Reductio n	68% Reductio n	80% Reductio n	90% Reductio n
Load	86.8 kg	69.4 kg	52.1 kg	27.8 kg	17.4 kg	8.7 kg
Mean	106.3	94.8	82.3	62.6	52.9	43.9
0%	49.9	46.6	43.2	37.9	33.9	28.4
10%	72.0	66.3	60.3	49.9	43.4	36.1
20%	79.8	73.0	65.3	53.2	46.0	38.3
30%	85.2	77.0	68.8	55.3	48.2	40.0
40%	91.1	82.1	72.5	57.6	49.9	41.6
50%	96.7	86.9	76.2	59.6	51.8	43.4
60%	103.9	92.9	80.5	62.2	53.4	45.2
70%	112.9	100.1	86.2	65.0	55.6	47.4
80%	127.2	111.5	95.0	69.2	58.2	49.6
90%	147.2	128.3	107.9	76.5	62.0	52.0
100%	438.9	377.1	309.5	199.3	142.8	87.6

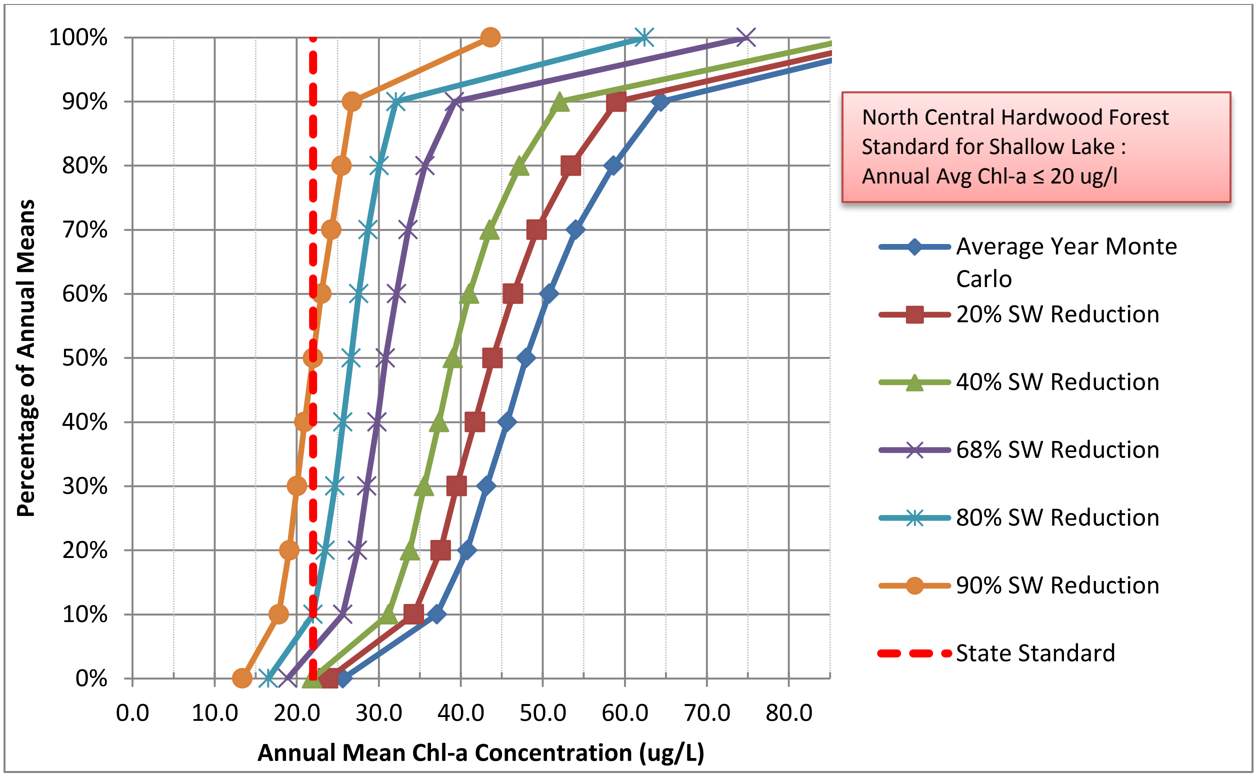

Figure A.5.3 Gourd Lake Frequency Distribution of Annual Mean Chl-*a* Concentrations Resulting from Select Load Reduction Scenarios.

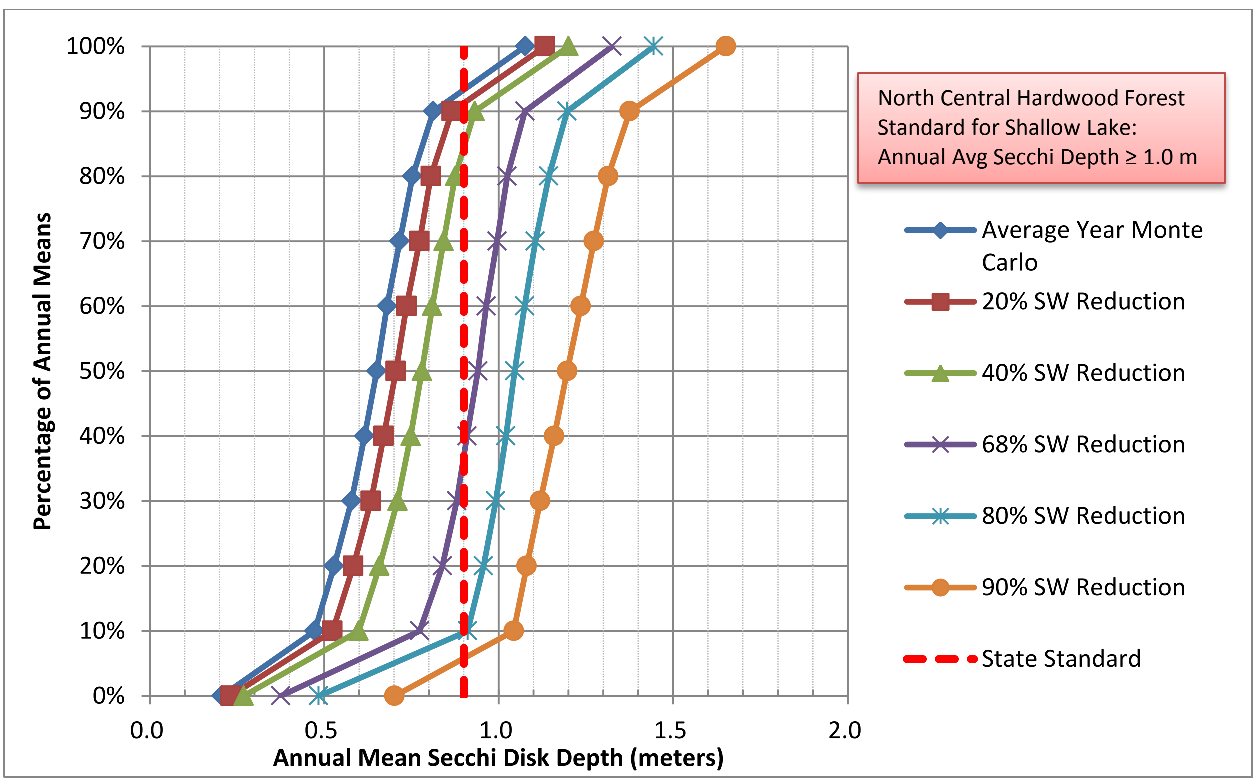

Figure A.5.4. Gourd Lake Frequency Distribution of Annual Mean Secchi Disk Depths Resulting from Select Load Reduction Scenarios.

A.6 Jacobs Lake

Table A.6.1. Annual BRW SWAT outputs (1995-2009) for Lake Jacobs.

Year	Precipitation (m/yr)	Evaporation (m/yr)	Contributing Drainage Inflow (hm^3/yr)	Contributing Drainage Area Load (kg/yr)	Tributary Flow (hm^3/yr)	Tributary Loading (kg/yr)
1995	0.638	0.746	0.024	9.4	0.08	33.3
1996	0.592	0.831	0.038	20.5	0.12	40.4
1997	0.779	0.864	0.051	15.8	0.63	531.9
1998	0.916	0.940	0.085	35.2	0.62	182.8
1999	0.652	0.907	0.034	12.9	0.11	29.6
2000	0.736	0.917	0.014	2.3	0.05	20.0
2001	0.659	0.877	0.040	8.2	0.11	69.7
2002	0.522	0.870	0.016	9.4	0.05	24.5
2003	0.575	0.998	0.010	1.2	0.06	58.7
2004	0.807	0.891	0.029	18.8	0.09	28.8
2005	0.818	0.933	0.035	17.0	0.14	75.2
2006	0.529	0.967	0.037	21.1	0.13	95.2
2007	0.760	0.779	0.058	32.2	0.16	54.1
2008	0.782	0.731	0.036	15.8	0.14	72.1
2009	0.545	0.784	0.041	16.4	0.12	43.2
Average	**0.687**	**0.869**	**0.037**	**15.7**	**0.17**	**90.6**

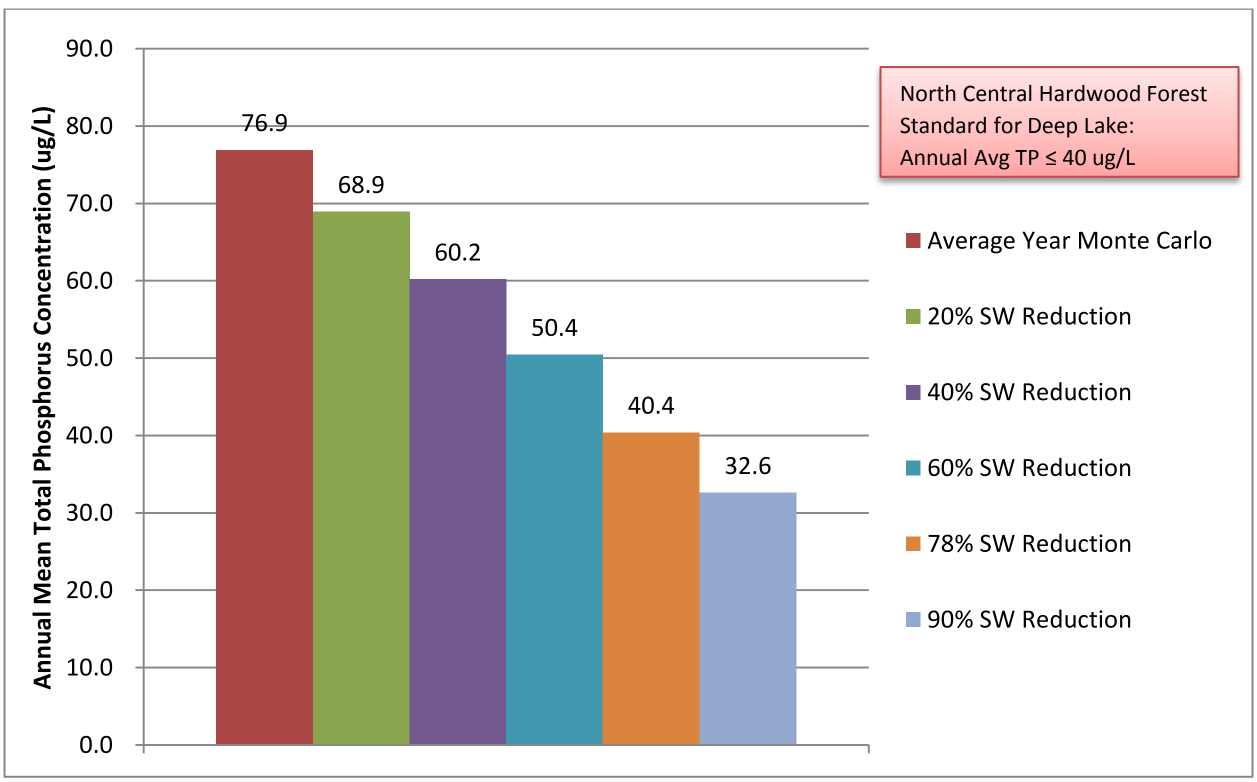

Figure A.6.1. Lake Jacobs Annual Mean TP Concentrations under Select Load Reduction Scenarios.

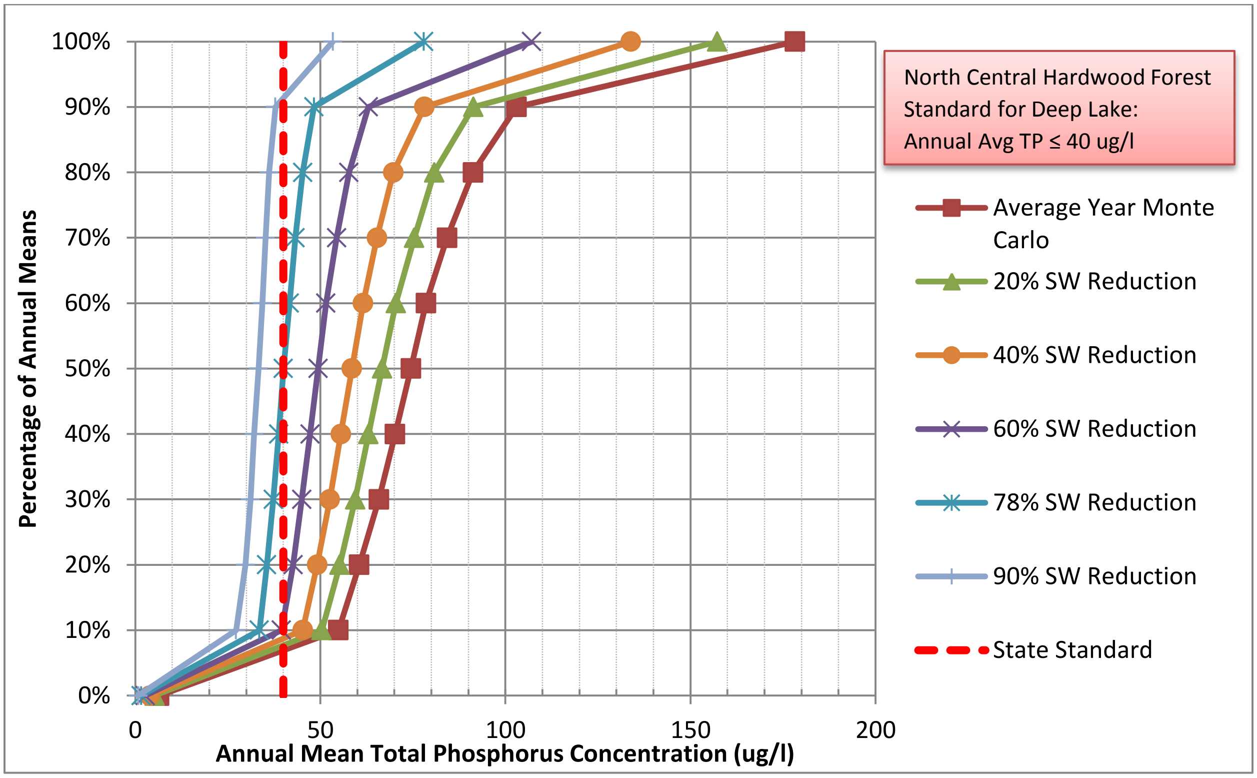

Figure A.6.2. Lake Jacobs Frequency Distribution of Annual Mean TP Concentrations Resulting from Select Load Reduction Scenarios.

Table A.6.2. Data used to Produce the Annual Mean TP Concentrations (ug/L) Frequency Distribution (Figure A.6.2) for Lake Jacobs.

Non-Exceedance Percentile	Average Year Monte Carlo	20% Reductio n	40% Reductio n	60% Reductio n	78% Reductio n	90% Reductio n
Load	98.5 kg	78.8 kg	59.1 kg	39.4 kg	21.7 kg	9.9 kg
Mean	76.9	68.9	60.2	50.4	40.4	32.6
0%	6.5	5.2	4.0	2.7	1.6	0.8
10%	54.9	50.4	45.3	39.5	33.5	27.2
20%	60.5	55.2	49.2	42.6	35.5	29.8
30%	65.8	59.4	52.6	45.0	37.3	31.1
40%	70.2	63.0	55.6	47.2	38.8	32.1
50%	74.5	66.7	58.5	49.4	40.0	33.3
60%	78.6	70.4	61.6	51.5	41.6	34.4
70%	84.3	75.4	65.3	54.4	43.2	35.2
80%	91.3	80.8	69.7	57.8	45.2	36.1
90%	103.0	91.4	78.1	63.0	48.3	37.9
100%	178.2	157.2	133.9	107.1	78.0	53.4

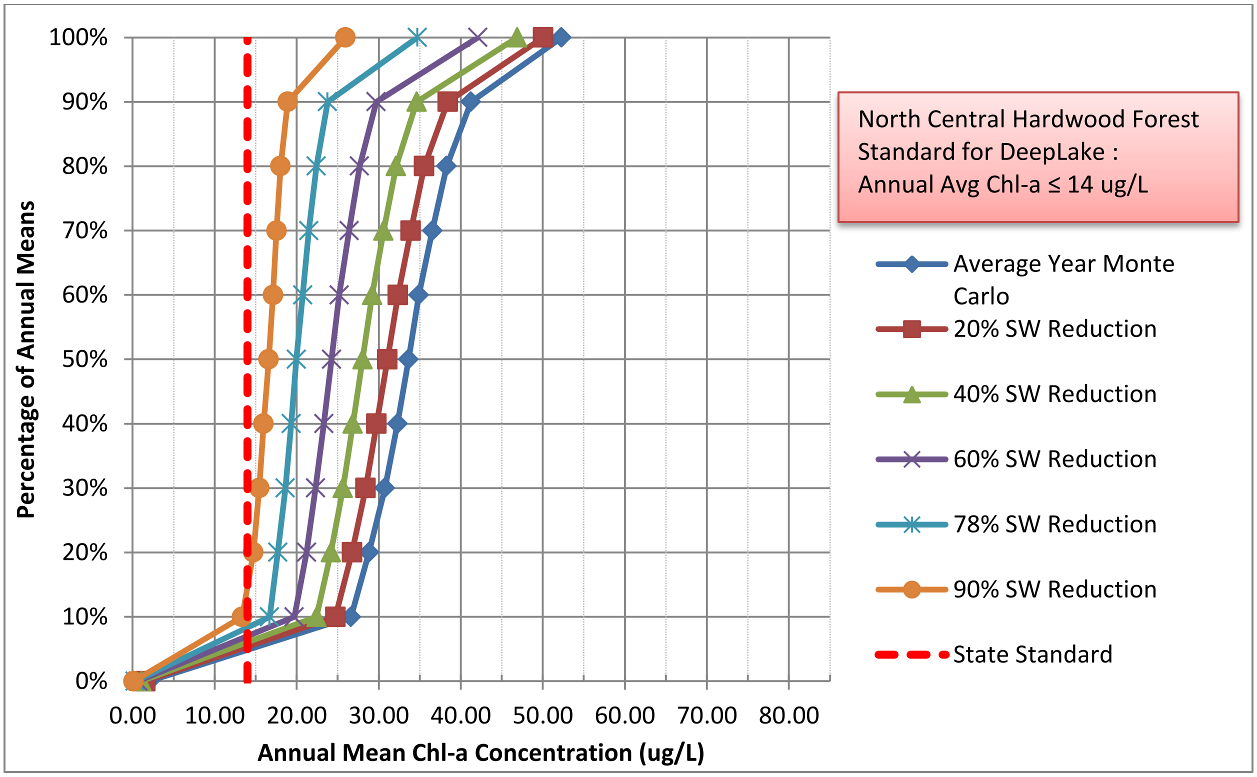

Figure A.6.3 Lake Jacobs Frequency Distribution of Annual Mean Chl-*a* Concentrations Resulting from Select Load Reduction Scenarios.

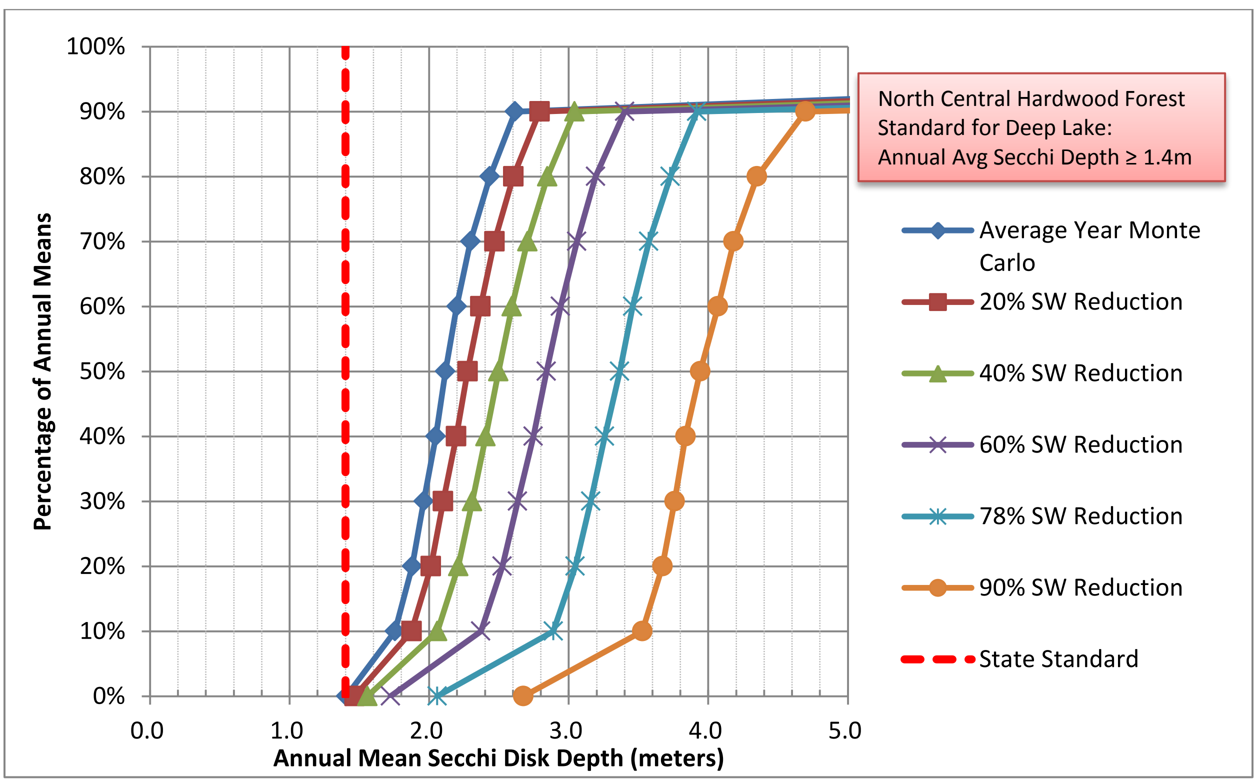

Figure A.6.4. Lake Jacobs Frequency Distribution of Annual Mean Secchi Disk Depths Resulting from Select Load Reduction Scenarios.

A.7 Lime Lake

Table A.7.1. Annual BRW SWAT outputs (1995-2009) for Lime Lake.

Year	Precipitation (m/yr)	Evaporation (m/yr)	Contributing Drainage Inflow (hm^3/yr)	Contributing Drainage Area Load (kg/yr)	Tributary Flow (hm^3/yr)	Tributary Loading (kg/yr)
1995	0.661	0.745	0.31	281	1.8	1,040
1996	0.691	0.834	0.75	437	3.3	6,296
1997	0.911	0.862	1.53	2,073	7.2	11,292
1998	0.879	0.950	1.24	663	6.9	6,362
1999	0.775	0.911	0.92	336	4.2	5,969
2000	0.805	0.916	0.53	404	2.7	2,040
2001	0.762	0.882	1.11	1,271	6.0	5,338
2002	0.717	0.873	0.79	694	3.7	6,694
2003	0.537	1.005	0.21	74	1.2	421
2004	0.791	0.897	0.45	233	2.8	1,471
2005	0.910	0.935	1.07	1,106	5.0	11,183
2006	0.685	0.973	0.85	1,077	4.6	8,373
2007	0.692	0.884	0.78	643	4.6	4,973
2008	1.021	0.792	1.80	2,464	8.1	22,695
2009	0.802	0.832	1.49	1,463	7.8	13,760
Average	**0.776**	**0.886**	**0.92**	**881**	**4.6**	**7,194**

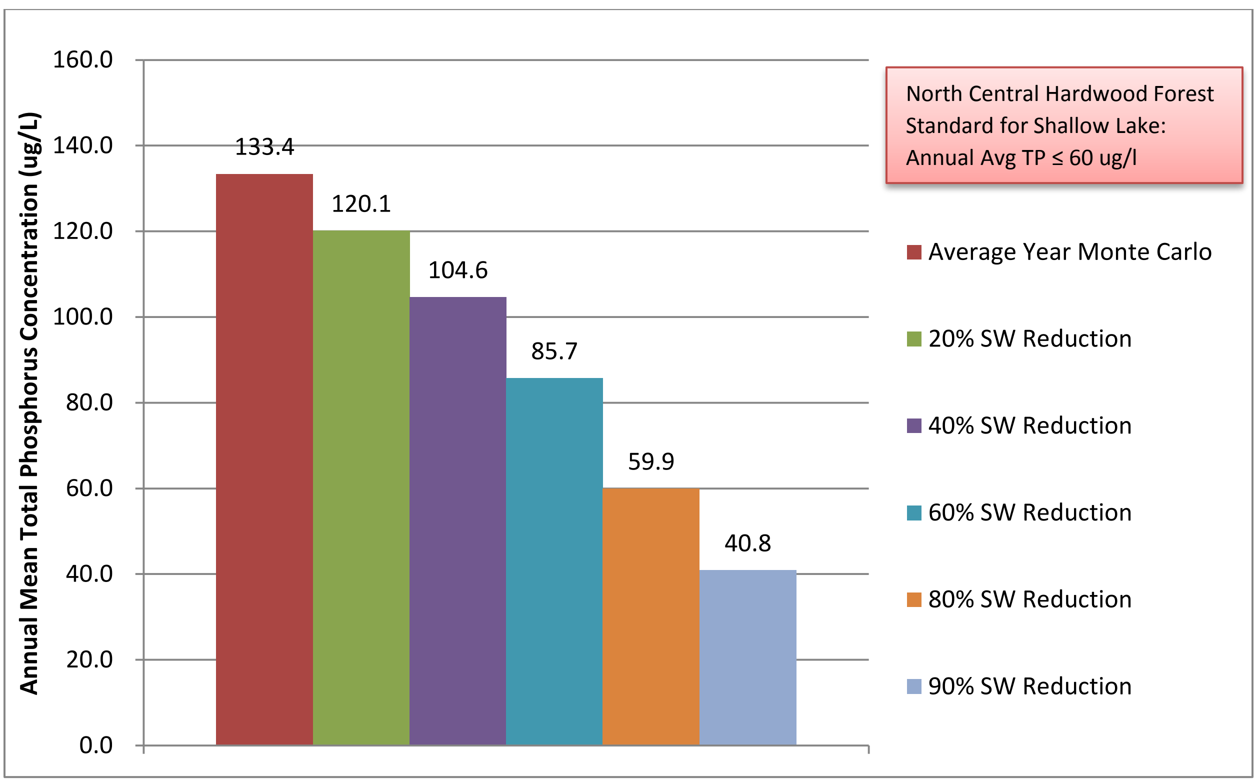

Figure A.7.1. Lime Lake Annual Mean TP Concentrations under Select Load Reduction Scenarios.

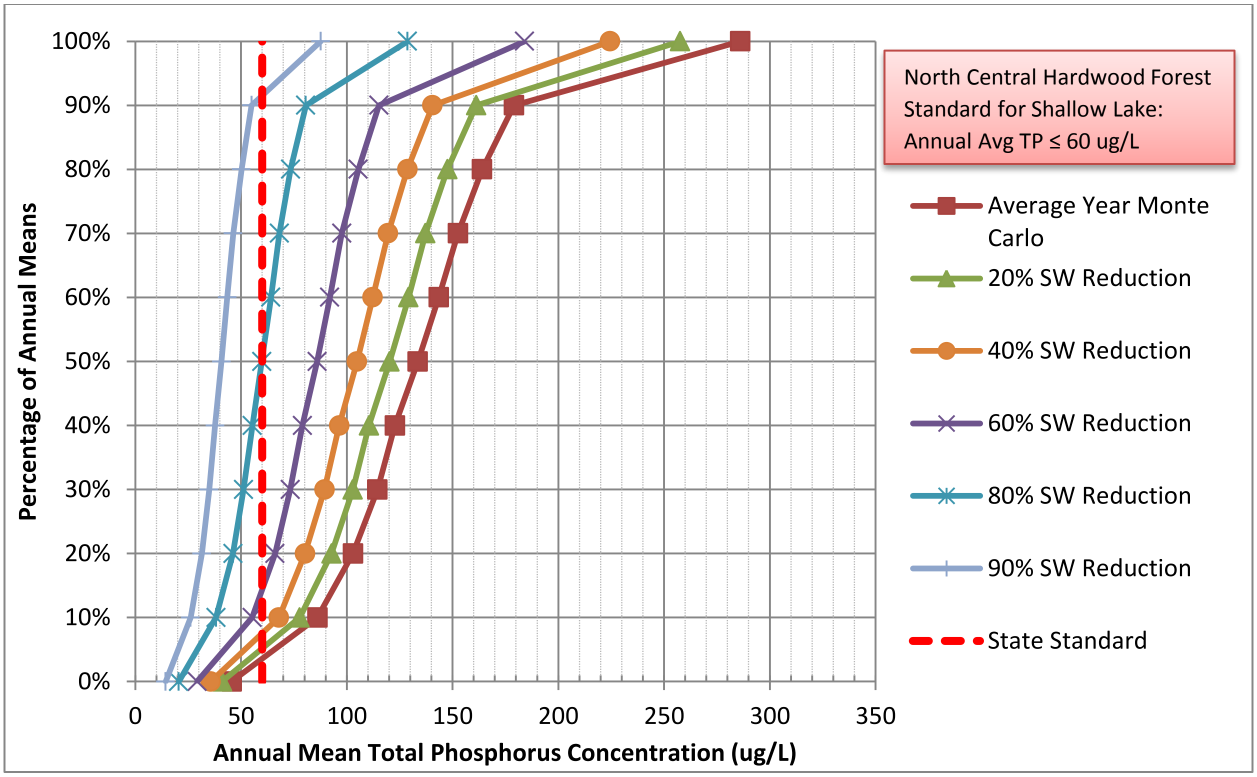

Figure A.7.2. Lime Lake Frequency Distribution of Annual Mean TP Concentrations Resulting from Select Load Reduction Scenarios.

Table A.7.2. Data used to Produce the Annual Mean TP Concentrations (ug/L) Frequency Distribution (Figure A.7.2) for Lime Lake.

Non-Exceedance Percentile	Average Year Monte Carlo	20% Reduction	40% Reduction	60% Reduction	80% Reduction	90% Reduction
Load	8,513 kg	6,810 kg	5,108 kg	3,405 kg	1,703 kg	8,51 kg
Mean	133.4	120.1	104.6	85.7	59.9	40.8
0%	45.6	41.0	35.7	29.3	20.6	14.3
10%	86.1	77.7	68.0	55.3	38.2	26.1
20%	103.0	92.8	80.3	66.1	46.2	31.5
30%	114.5	102.9	89.5	73.3	51.2	35.0
40%	122.8	110.5	96.4	79.1	55.4	37.8
50%	133.6	120.3	104.9	86.0	59.9	40.7
60%	143.5	129.2	112.3	92.0	64.1	43.5
70%	152.6	137.2	119.5	97.7	68.2	46.3
80%	164.0	147.6	128.7	105.4	73.5	50.2
90%	179.0	161.2	140.5	115.2	80.6	55.0
100%	286.1	257.6	224.6	184.1	128.7	87.7

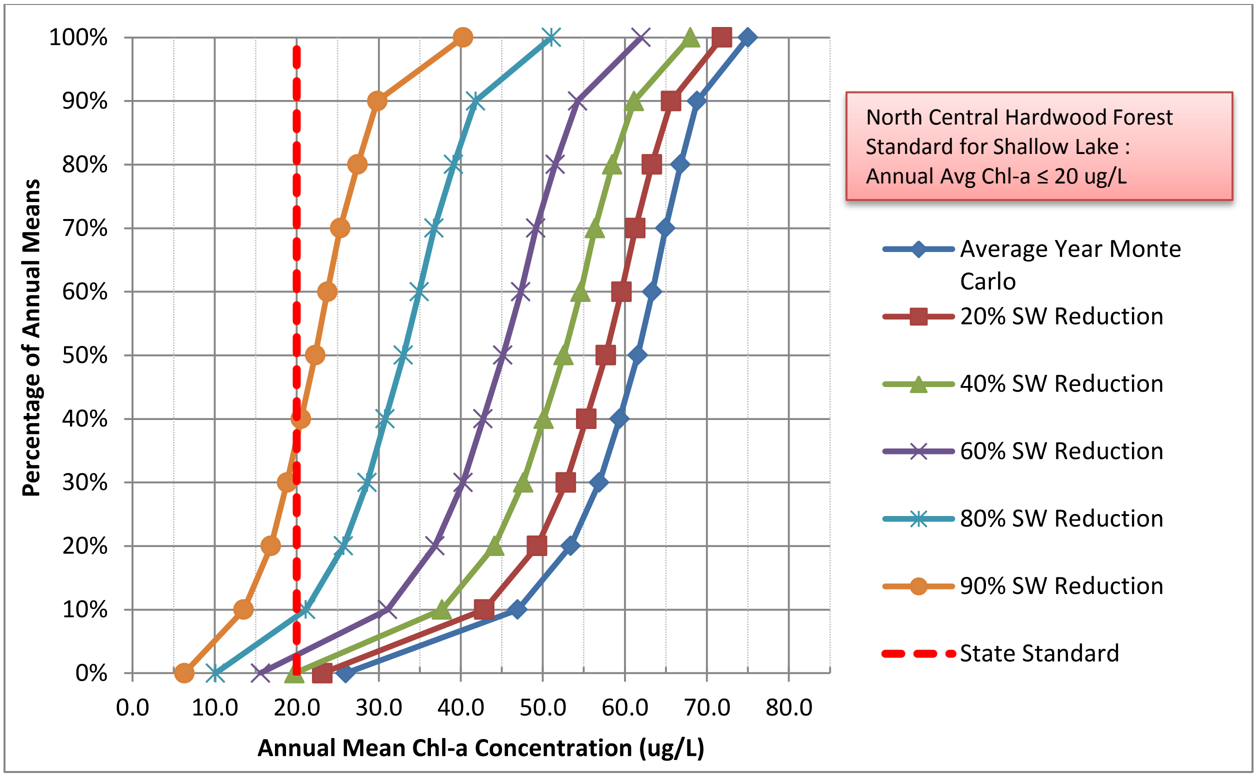

Figure A.7.3 Lime Lake Frequency Distribution of Annual Mean Chl-*a* Concentrations Resulting from Select Load Reduction Scenarios.

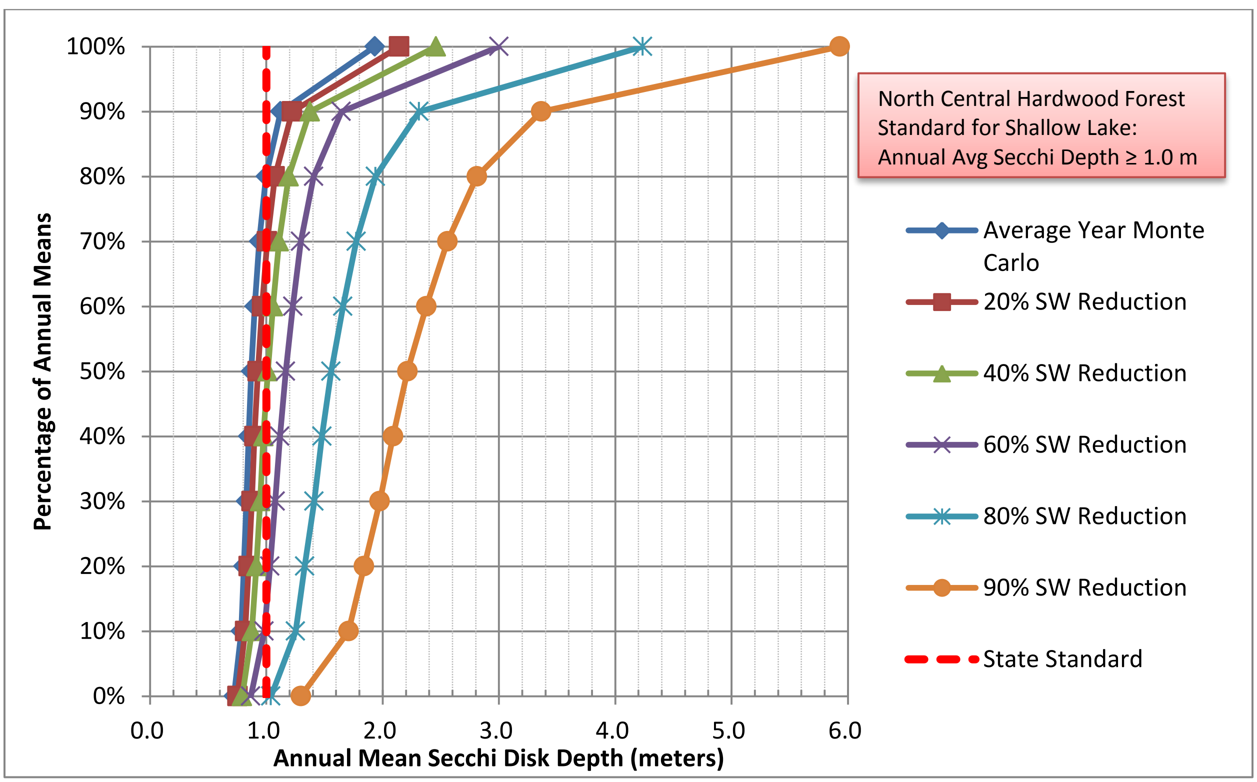

Figure A.7.4. Lime Lake Frequency Distribution of Annual Mean Secchi Disk Depths Resulting from Select Load Reduction Scenarios.

A.8 Maria Lake

Table A.8.1. Annual BRW SWAT outputs (1995-2009) for Maria Lake.

Year	Precipitation (m/yr)	Evaporation (m/yr)	Contributing Drainage Inflow (hm^3/yr)	Contributing Drainage Area Load (kg/yr)	Tributary Flow (hm^3/yr)	Tributary Loading (kg/yr)
1995	0.606	0.667	0.24	139	0.5	230.8
1996	0.520	0.733	0.71	2,434	1.2	419.3
1997	0.863	0.738	1.19	4,299	2.3	1860.8
1998	0.872	0.841	1.81	2,914	1.9	608.8
1999	0.679	0.797	0.53	1,015	1.4	268.7
2000	0.727	0.820	0.35	517	0.8	401.1
2001	0.549	0.794	0.69	608	1.5	857.8
2002	0.605	0.789	0.25	955	1.2	502.1
2003	0.512	0.892	0.07	183	0.3	64.5
2004	0.823	0.801	0.52	951	0.8	236.5
2005	0.720	0.842	0.56	1,778	1.6	760.3
2006	0.542	0.874	0.49	2,148	1.2	792.5
2007	0.651	0.714	0.61	1,262	1.2	666.8
2008	0.788	0.676	0.71	2,997	2.6	1535.0
2009	0.703	0.640	1.20	4,672	2.1	1343.6
Average	**0.677**	**0.775**	**0.66**	**1,791**	**1.4**	**703.2**

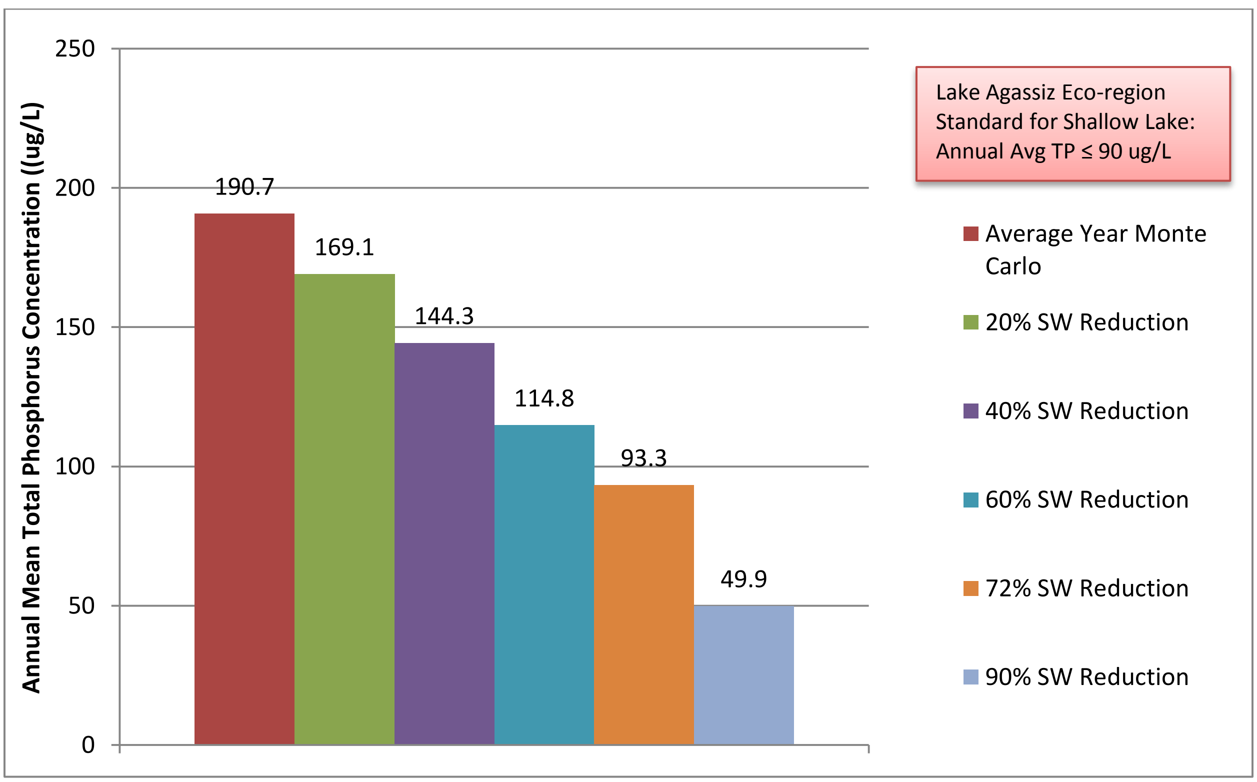

Figure A.8.1. Maria Lake Annual Mean TP Concentrations under Select Load Reduction Scenarios.

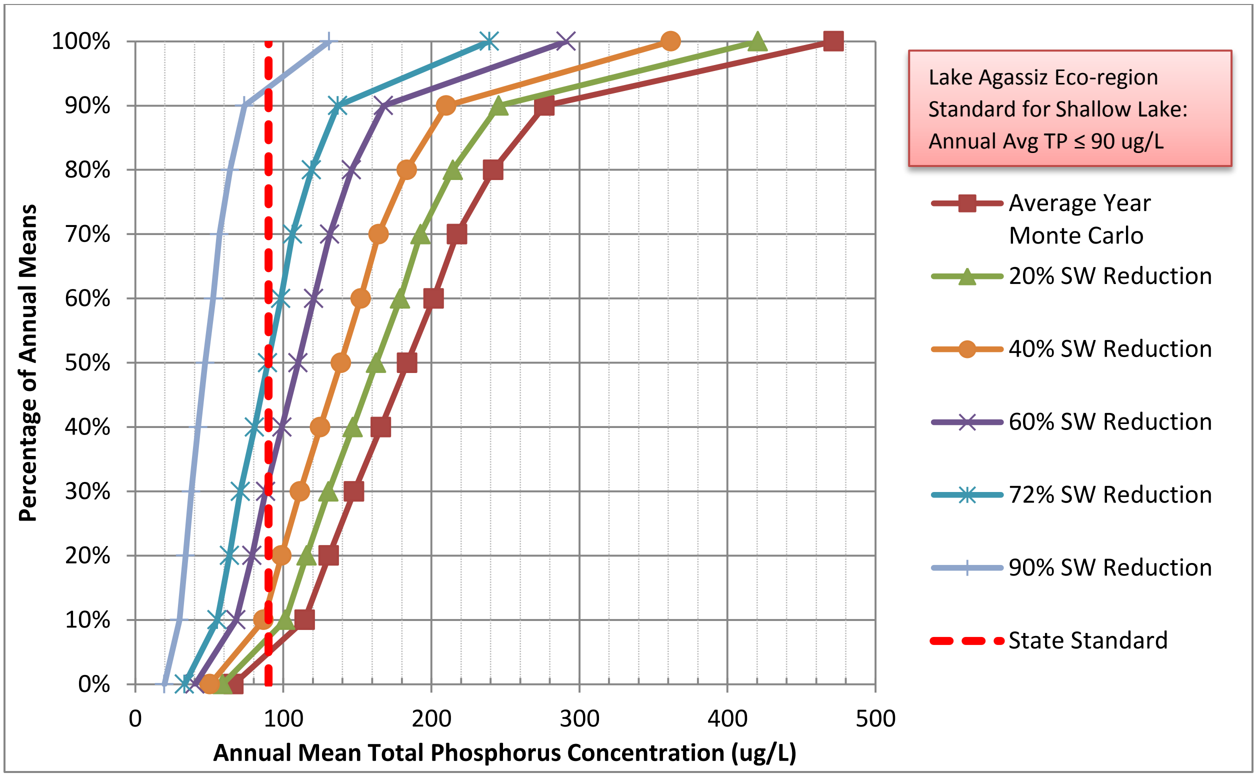

Figure A.8.2. Maria Lake Frequency Distribution of Annual Mean TP Concentrations Resulting from Select Load Reduction Scenarios.

Table A.8.2. Data used to Produce the Annual Mean TP Concentrations (ug/L) Frequency Distribution (Figure A.8.2) for Maria Lake.

Non-Exceedance Percentile	Average Year Monte Carlo	20% Reduction	40% Reduction	60% Reduction	72% Reduction	90% Reduction
Load	2,607 kg	2,086 kg	1,564 kg	1,043 kg	730 kg	261 kg
Mean	190.7	169.1	144.3	114.8	93.3	49.9
0%	66.4	58.9	50.4	40.4	33.3	19.7
10%	114.4	101.4	86.6	68.1	55.4	29.8
20%	130.7	115.7	98.7	78.8	63.7	33.9
30%	147.8	130.6	111.3	88.1	71.0	37.8
40%	166.0	146.9	124.9	99.1	80.6	42.5
50%	183.8	162.8	138.8	110.0	89.5	47.2
60%	201.6	179.0	152.3	120.6	98.3	52.6
70%	217.4	192.7	164.4	131.4	106.2	56.9
80%	241.9	214.5	183.4	146.1	119.1	63.9
90%	276.5	245.4	210.1	167.7	136.7	73.6
100%	471.8	420.6	361.8	291.2	239.2	131.0

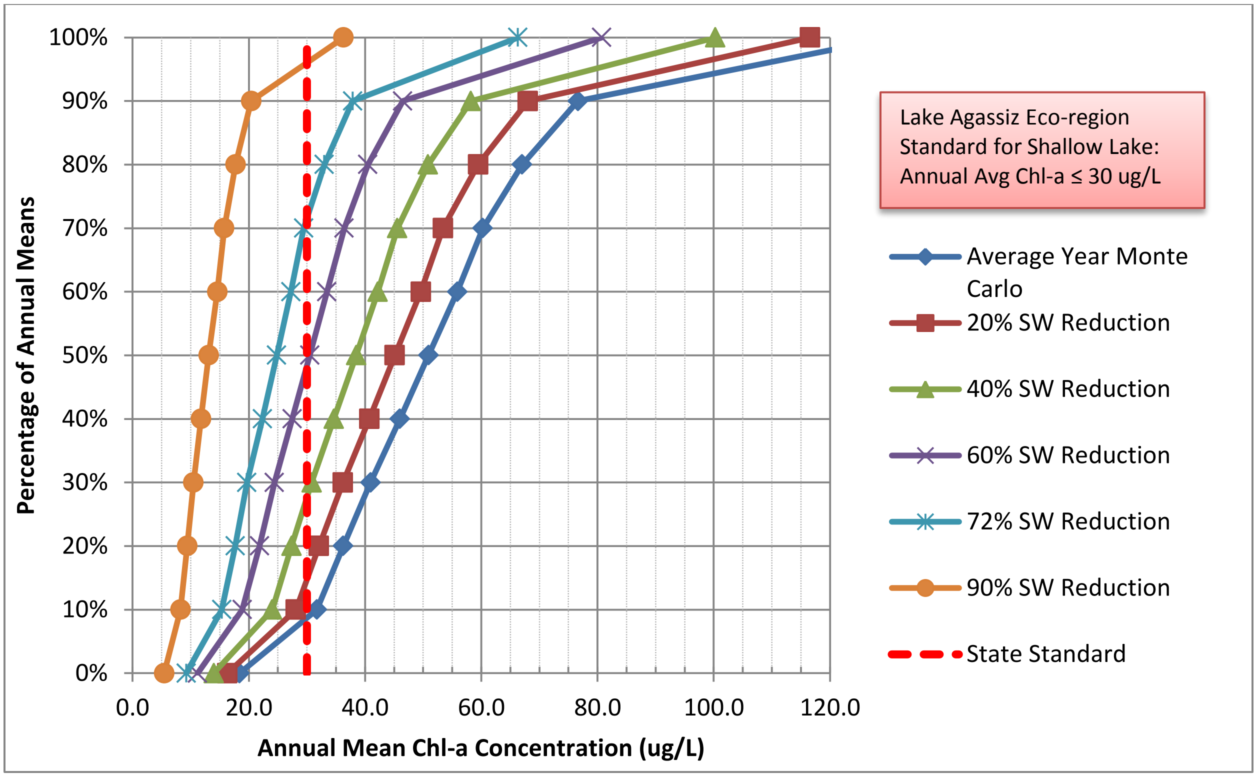

Figure A.8.3 Maria Lake Frequency Distribution of Annual Mean Chl-*a* Concentrations Resulting from Select Load Reduction Scenarios.

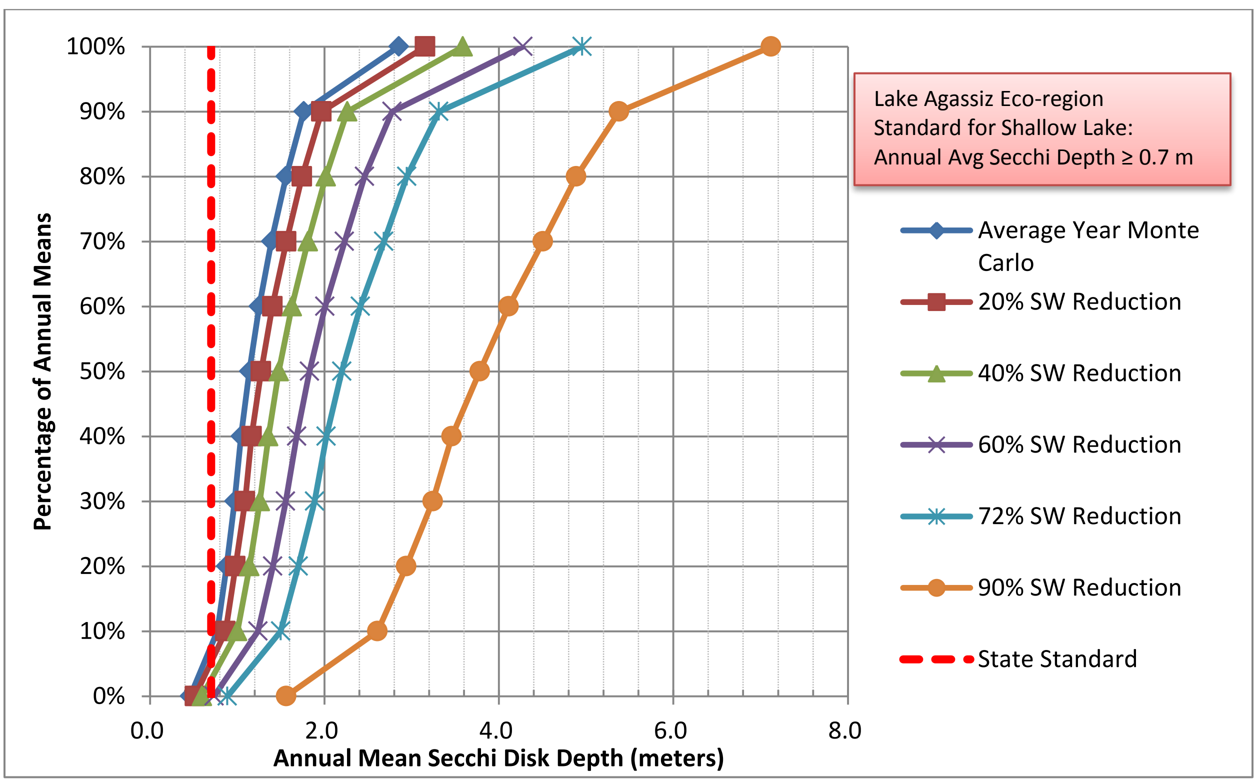

Figure A.8.4 Maria Lake Frequency Distribution of Annual Mean Secchi Disk Depths Resulting from Select Load Reduction Scenarios.

A.9 Marshall Lake

Table A.9.1. Annual BRW SWAT outputs (1995-2009) for Marshall Lake.

Year	Precipitation (m/yr)	Evaporation (m/yr)	Contributing Drainage Inflow (hm^3/yr)	Contributing Drainage Area Load (kg/yr)	Tributary Flow (hm^3/yr)	Tributary Loading (kg/yr)
1995	0.661	0.835	0.15	51	0.0	0.0
1996	0.691	0.933	0.35	62	0.0	0.0
1997	0.911	0.982	0.71	320	0.0	0.0
1998	0.879	1.066	0.58	103	0.0	0.0
1999	0.775	1.078	0.37	45	0.0	0.0
2000	0.805	1.095	0.19	43	0.0	0.0
2001	0.762	1.085	0.39	118	0.0	0.0
2002	0.717	1.036	0.32	100	0.0	0.0
2003	0.538	1.151	0.08	12	0.0	0.0
2004	0.792	1.047	0.20	39	0.0	0.0
2005	0.910	1.092	0.43	134	0.0	0.0
2006	0.685	1.127	0.37	136	0.0	0.0
2007	0.692	1.021	0.39	130	0.0	0.0
2008	1.022	0.959	0.74	303	0.0	0.0
2009	0.803	0.986	0.67	210	0.0	0.0
Average	**0.776**	**1.033**	**0.40**	**120**	**0.0**	**0.0**

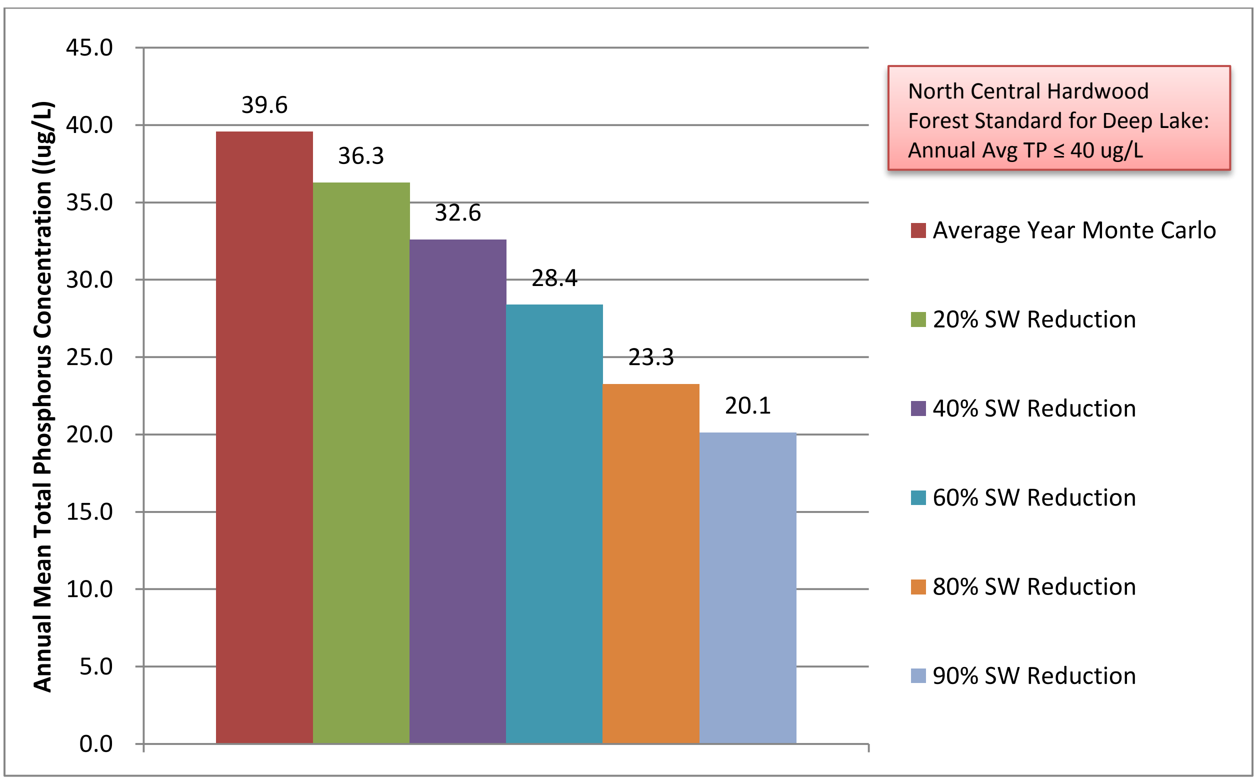

Figure A.9.1. Marshall Lake Annual Mean TP Concentrations under Select Load Reduction Scenarios.

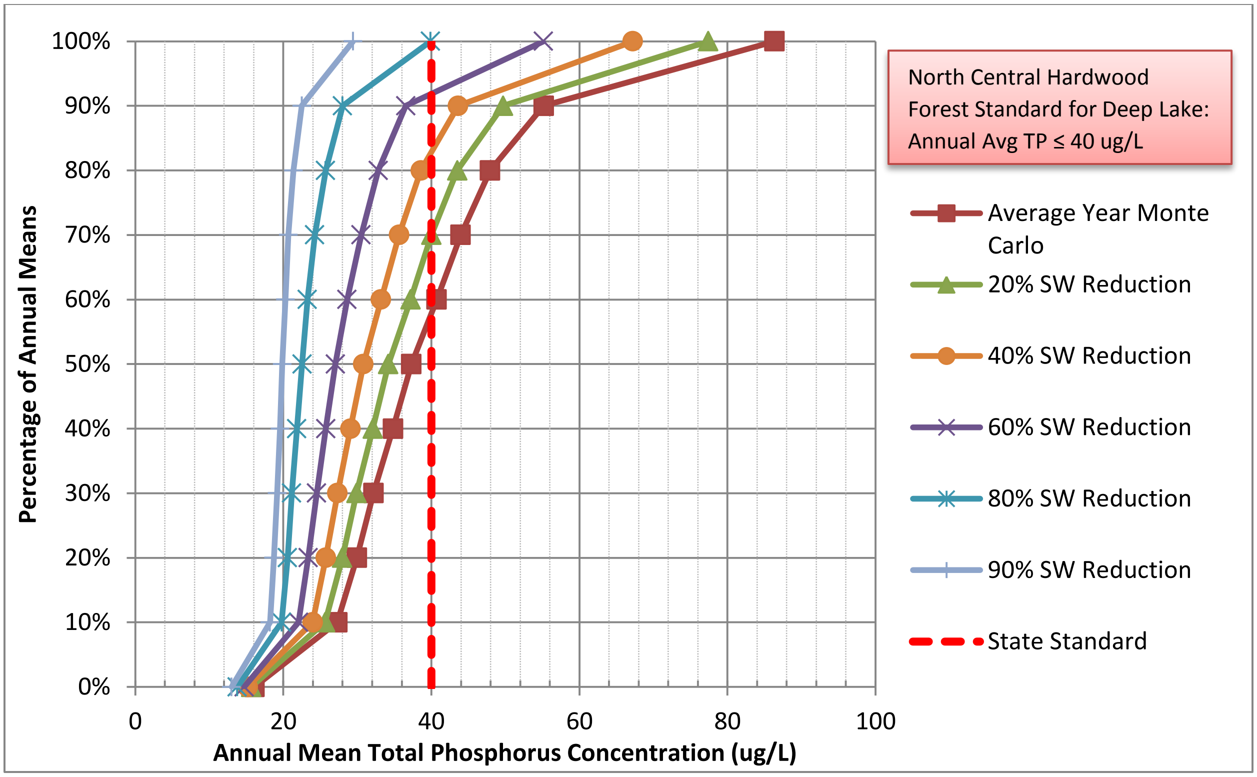

Figure A.9.2. Marshall Lake Frequency Distribution of Annual Mean TP Concentrations Resulting from Select Load Reduction Scenarios.

Table A.9.2. Data used to Produce the Annual Mean TP Concentrations (ug/L) Frequency Distribution (Figure A.9.2) for Marshall Lake.

Non-Exceedance Percentile	Average Year Monte Carlo	20% Reduction	40% Reduction	60% Reduction	80% Reduction	90% Reduction
Load	126.3 kg	101. kg	75.8 kg	50.5 kg	25.3 kg	12.6 kg
Mean	39.6	36.3	32.6	28.4	23.3	20.1
0%	16.1	15.7	15.2	14.7	13.8	13.0
10%	27.3	25.7	24.0	22.1	19.8	18.2
20%	29.9	28.0	25.7	23.4	20.6	18.7
30%	32.2	29.9	27.3	24.5	21.1	19.2
40%	34.8	32.1	29.1	25.7	21.8	19.6
50%	37.3	34.2	30.8	27.0	22.5	19.9
60%	40.7	37.2	33.2	28.6	23.3	20.3
70%	44.0	40.0	35.6	30.5	24.2	20.7
80%	47.9	43.5	38.6	32.8	25.7	21.4
90%	55.2	49.7	43.6	36.6	28.0	22.5
100%	86.4	77.4	67.2	55.1	39.9	29.4

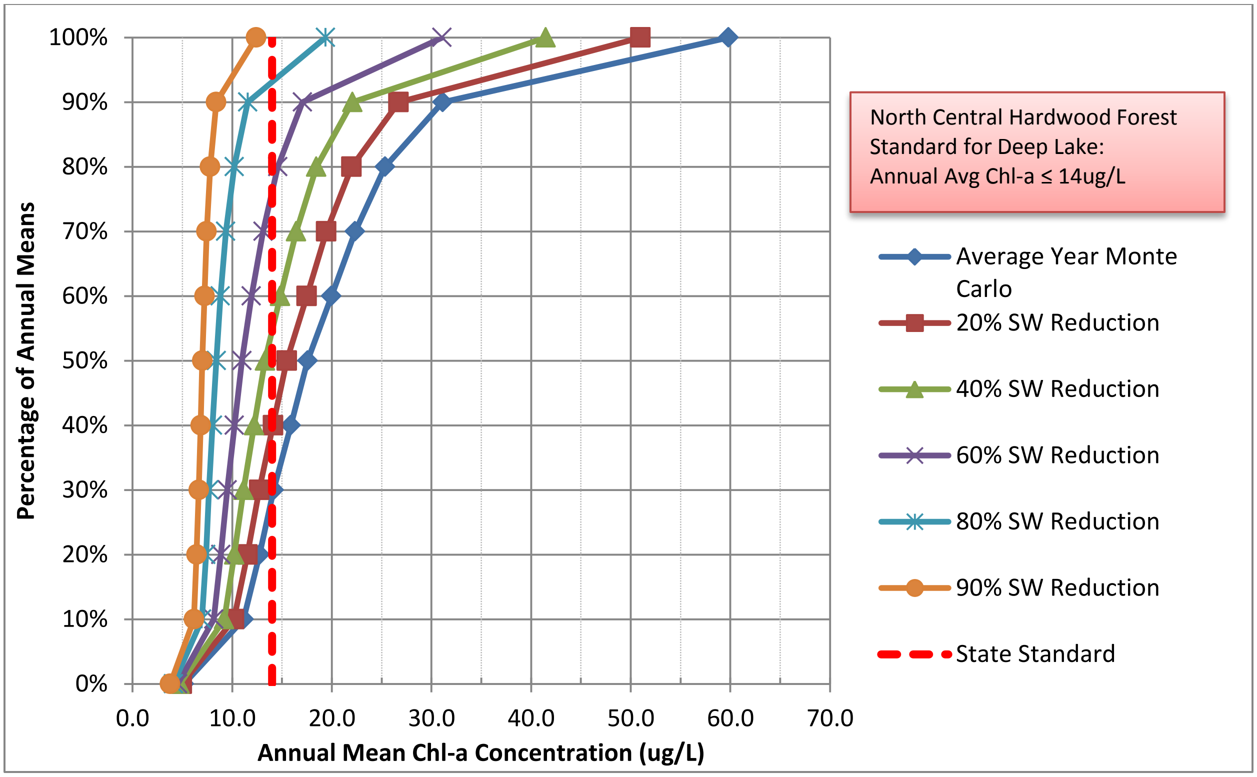

Figure A.9.3 Marshall Lake Frequency Distribution of Annual Mean Chl-*a* Concentrations Resulting from Select Load Reduction Scenarios.

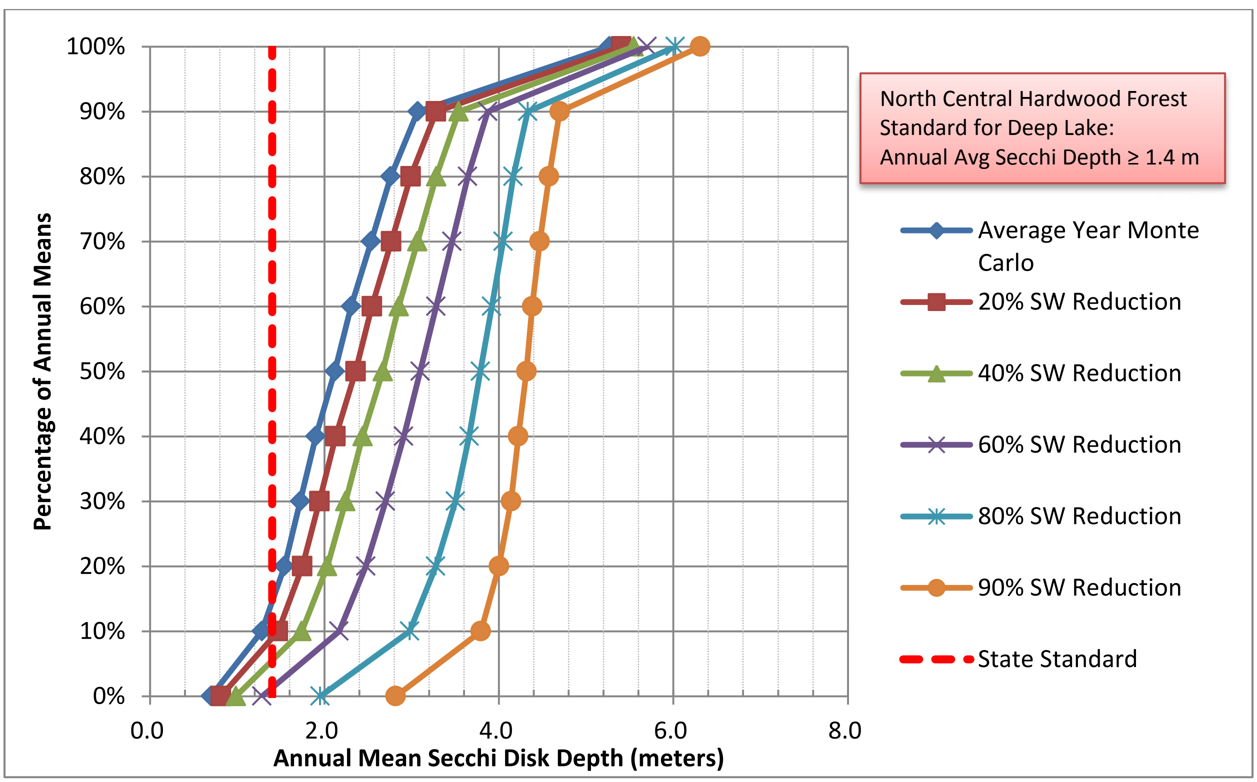

Figure A.9.4. Marshall Lake Frequency Distribution of Annual Mean Secchi Disk Depths Resulting from Select Load Reduction Scenarios.

A.10 Mission Lake

Table A.10.1. Annual BRW SWAT outputs (1995-2009) for Mission Lake.

Year	Precipitation (m/yr)	Evaporation (m/yr)	Contributing Drainage Inflow (hm^3/yr)	Contributing Drainage Area Load (kg/yr)	Tributary Flow (hm^3/yr)	Tributary Loading (kg/yr)
1995	0.580	0.824	0.24	132	0.0	0.0
1996	0.558	0.922	0.25	124	0.0	0.0
1997	0.639	0.981	0.29	64	0.0	0.0
1998	0.752	1.052	0.21	120	0.0	0.0
1999	0.797	1.063	0.46	176	0.0	0.0
2000	0.695	1.080	0.20	18	0.0	0.0
2001	0.630	1.069	0.35	198	0.0	0.0
2002	0.585	1.025	0.12	11	0.0	0.0
2003	0.415	1.134	0.03	2	0.0	0.0
2004	0.811	1.030	0.11	105	0.0	0.0
2005	0.694	1.073	0.36	207	0.0	0.0
2006	0.587	1.110	0.28	78	0.0	0.0
2007	0.673	0.948	0.24	90	0.0	0.0
2008	0.730	0.838	0.47	275	0.0	0.0
2009	0.463	0.904	0.44	65	0.0	0.0
Average	**0.641**	**1.004**	**0.27**	**111**	**0.0**	**0.0**

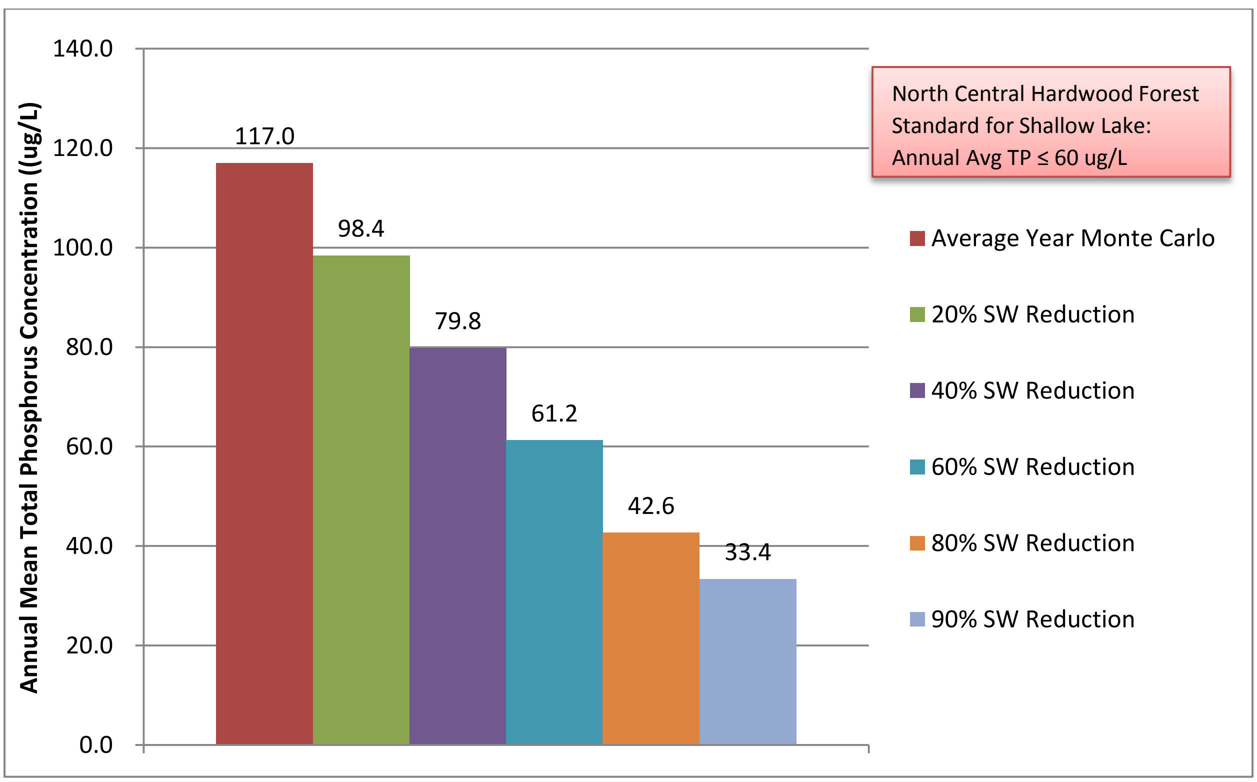

Figure A.10.1. Mission Lake Annual Mean TP Concentrations under Select Load Reduction Scenarios.

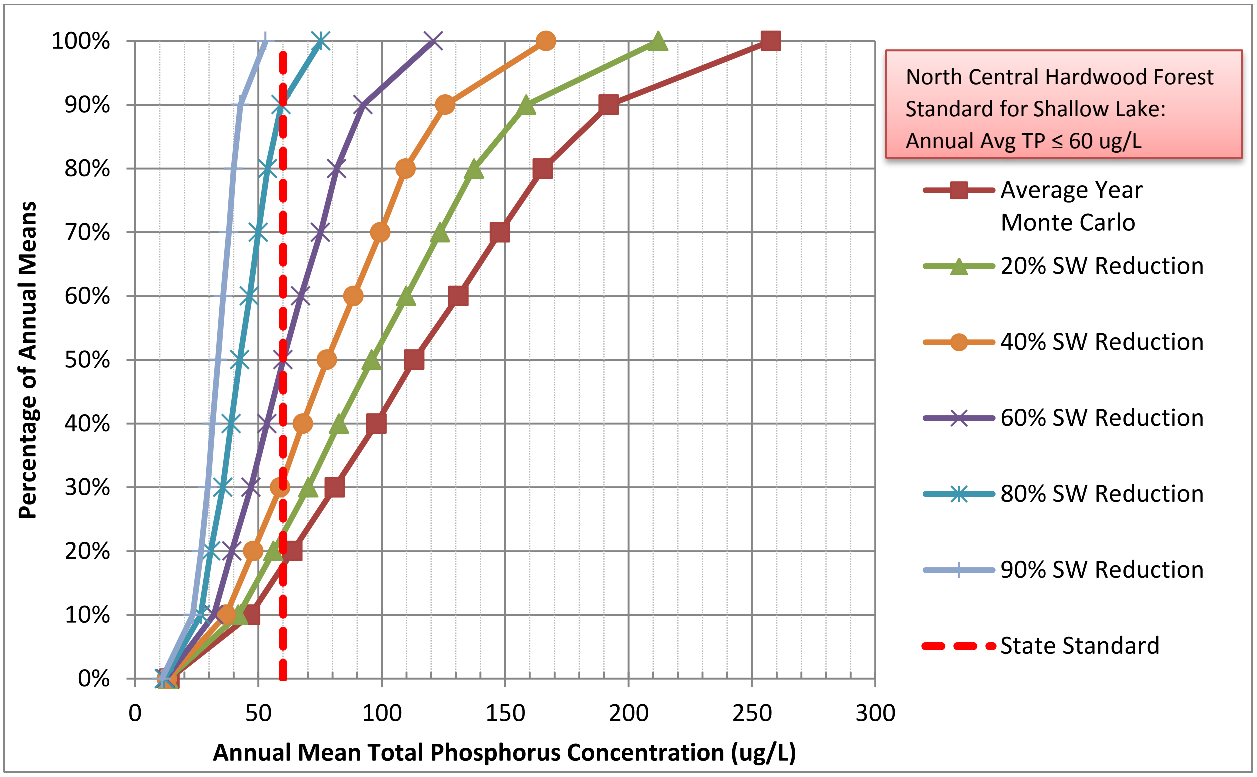

Figure A.10.2. Mission Lake Frequency Distribution of Annual Mean TP Concentrations Resulting from Select Load Reduction Scenarios.

Table A.10.2. Data used to Produce the Annual Mean TP Concentrations (ug/L) Frequency Distribution (Figure A.10.2) for Mission Lake.

Non-Exceedance Percentile	Average Year Monte Carlo	20% Reduction	40% Reduction	60% Reduction	80% Reduction	90% Reduction
Load	115.7 kg	92.6 kg	69.4 kg	46.3 kg	23.1 kg	11.6 kg
Mean	117.0	98.4	79.8	61.2	42.6	33.4
0%	14.0	13.4	12.9	12.4	11.9	10.9
10%	46.7	41.9	36.8	31.9	26.6	23.4
20%	63.8	56.2	47.9	39.2	30.7	26.8
30%	81.0	70.2	58.9	47.0	35.6	29.4
40%	97.9	82.7	68.0	53.5	39.0	31.4
50%	113.1	95.9	77.8	60.1	42.5	33.6
60%	131.1	110.0	88.6	67.2	46.5	35.7
70%	147.9	123.7	99.5	75.2	50.0	38.0
80%	165.4	137.4	109.7	81.8	53.8	40.0
90%	192.1	158.6	125.8	92.5	59.3	42.7
100%	257.8	212.2	166.6	120.9	75.3	52.9

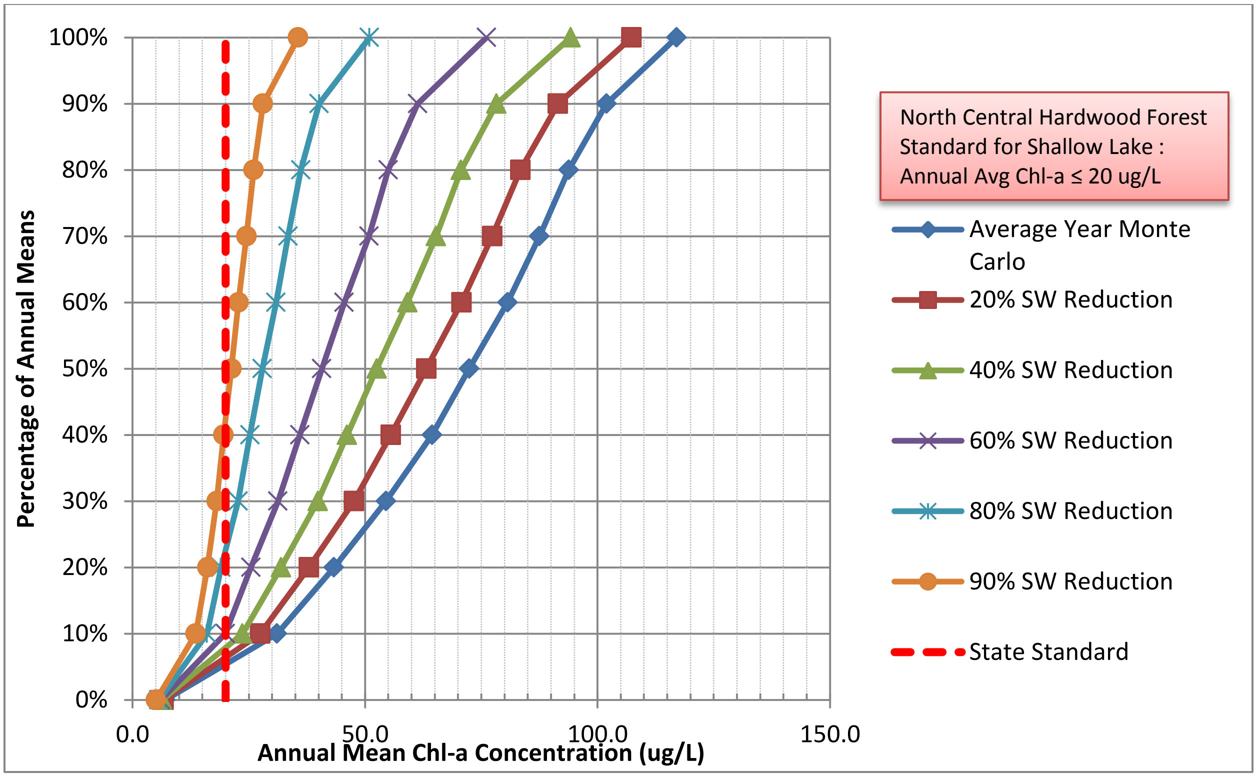

Figure A.10.3 Mission Lake Frequency Distribution of Annual Mean Chl-*a* Concentrations Resulting from Select Load Reduction Scenarios.

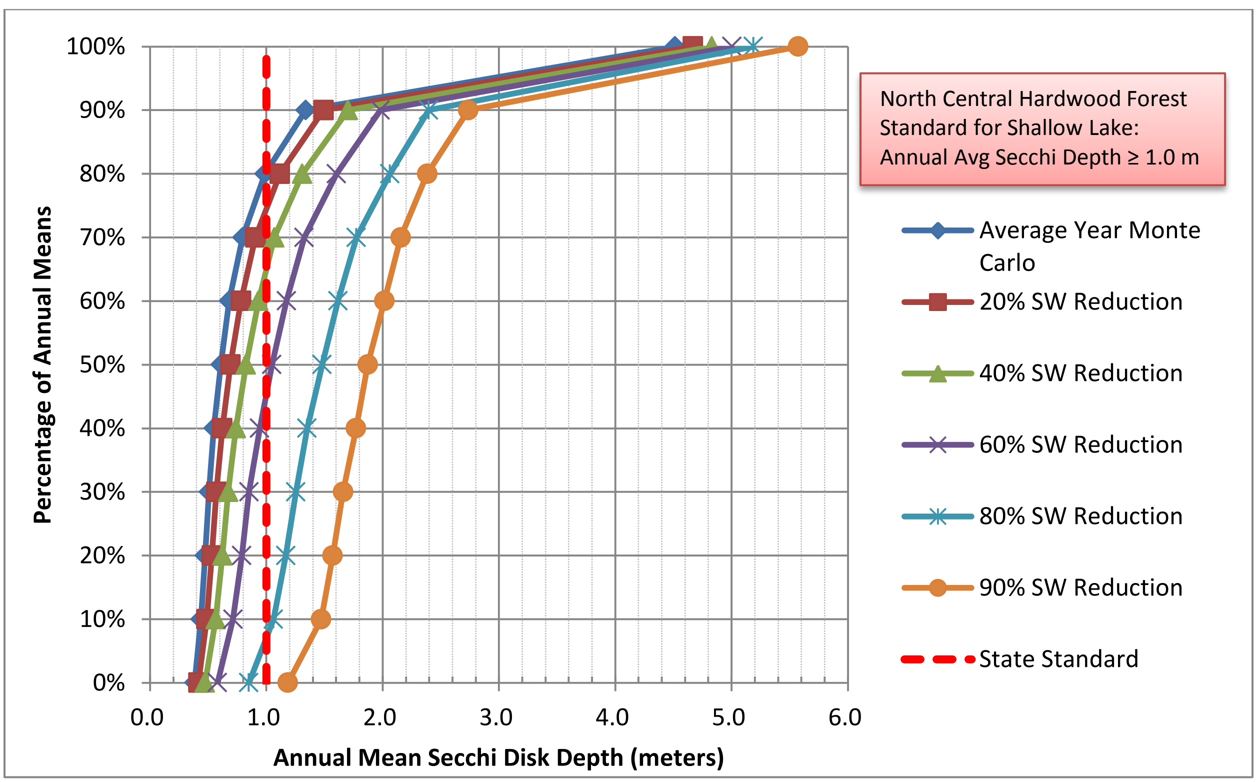

Figure A.10.4. Mission Lake Frequency Distribution of Annual Mean Secchi Disk Depths Resulting from Select Load Reduction Scenarios.

A.11 North Tamarac Lake

Table A.11.1. Annual BRW SWAT outputs (1995-2009) for North Tamarac Lake.

Year	Precipitation (m/yr)	Evaporation (m/yr)	Contributing Drainage Inflow (hm^3/yr)	Contributing Drainage Area Load (kg/yr)	Tributary Flow (hm^3/yr)	Tributary Loading (kg/yr)
1995	0.580	0.637	3.82	60	3.3	38.5
1996	0.558	0.699	3.66	58	3.1	32.2
1997	0.638	0.739	4.35	87	3.8	50.6
1998	0.752	0.809	4.52	82	3.9	53.9
1999	0.797	0.810	6.01	118	5.2	74.4
2000	0.695	0.839	4.29	60	3.6	43.9
2001	0.630	0.825	4.50	68	3.9	46.8
2002	0.585	0.787	3.57	43	3.1	28.1
2003	0.415	0.876	2.54	17	2.1	11.5
2004	0.811	0.783	4.19	124	3.8	82.2
2005	0.694	0.821	4.50	78	4.0	46.0
2006	0.586	0.841	4.25	82	3.7	56.0
2007	0.673	0.709	4.19	91	3.7	56.1
2008	0.730	0.621	5.19	157	4.6	91.7
2009	0.582	0.650	4.62	114	4.1	70.2
Average	**0.648**	**0.763**	**4.28**	**83**	**3.7**	**52.1**

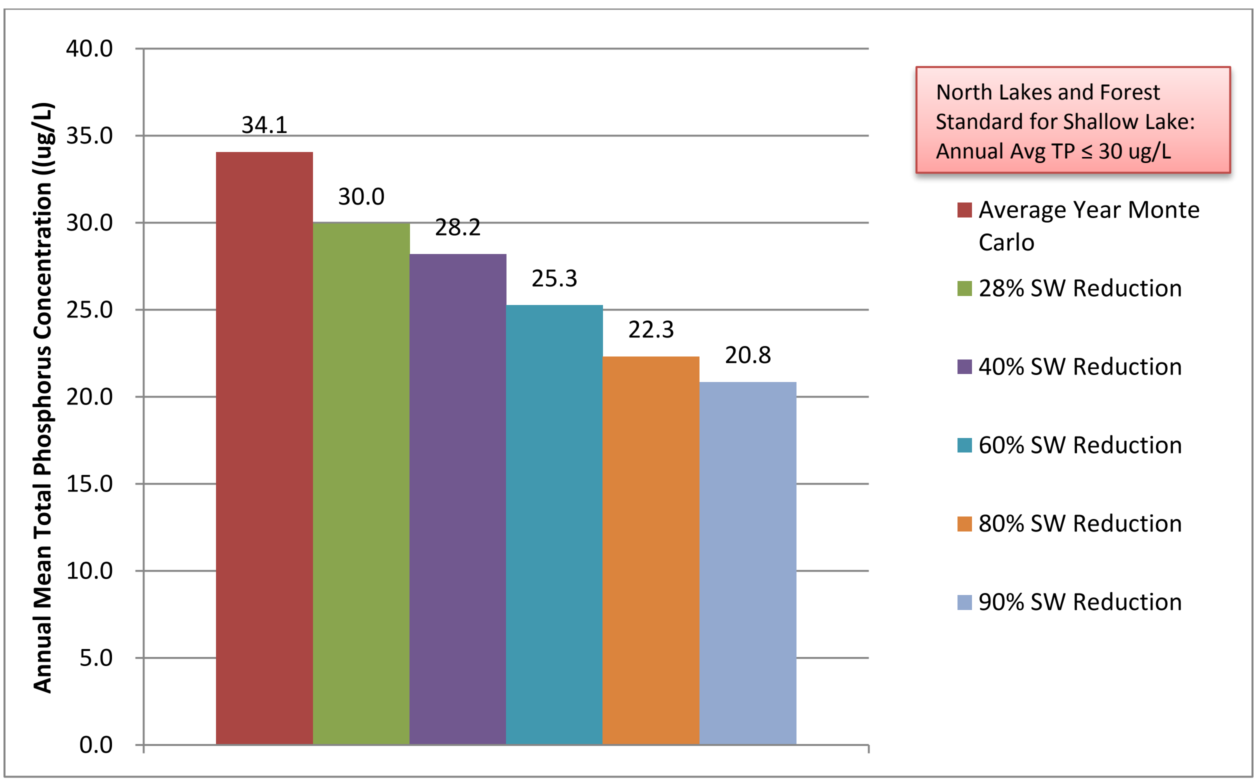

Figure A.11.1. North Tamarac Lake Annual Mean TP Concentrations under Select Load Reduction Scenarios.

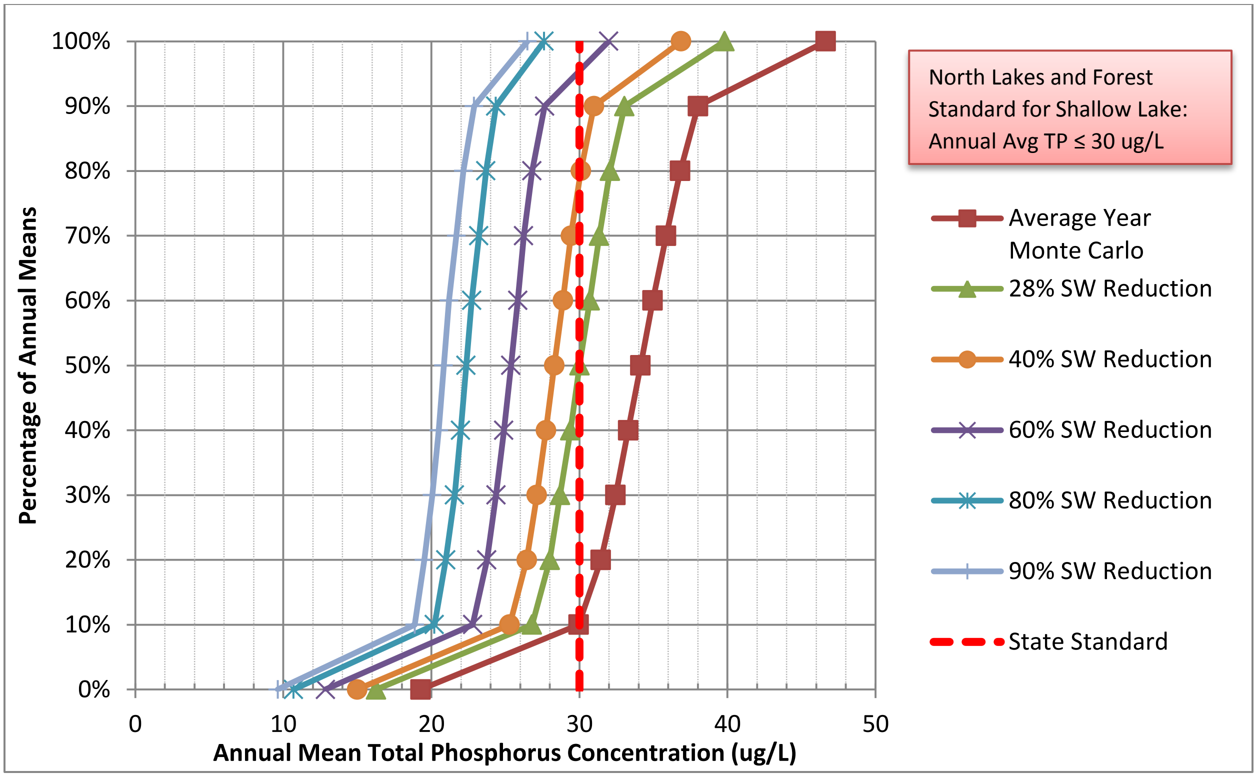

Figure A.11.2. North Tamarac Lake Frequency Distribution of Annual Mean TP Concentrations Resulting from Select Load Reduction Scenarios.

Table A.11.2. Data used to Produce the Annual Mean TP Concentrations (ug/L) Frequency Distribution (Figure A.11.2) for North Tamarac Lake.

Non-Exceedance Percentile	Average Year Monte Carlo	28% Reduction	40% Reduction	60% Reduction	80% Reduction	90% Reduction
Load	138.4 kg	99.7 kg	83.1 kg	55.4 kg	27.7 kg	13.8 kg
Mean	34.1	30.0	28.2	25.3	22.3	20.8
0%	19.3	16.3	15.0	12.8	10.7	9.6
10%	29.9	26.8	25.3	22.8	20.2	18.9
20%	31.4	28.0	26.4	23.8	21.0	19.5
30%	32.4	28.7	27.1	24.4	21.6	20.1
40%	33.3	29.4	27.7	24.9	22.0	20.5
50%	34.1	30.0	28.3	25.4	22.3	20.8
60%	35.0	30.7	28.9	25.8	22.7	21.2
70%	35.9	31.3	29.4	26.2	23.2	21.7
80%	36.8	32.1	30.1	26.8	23.7	22.2
90%	38.0	33.0	31.0	27.7	24.4	22.9
100%	46.6	39.8	36.9	32.0	27.6	26.5

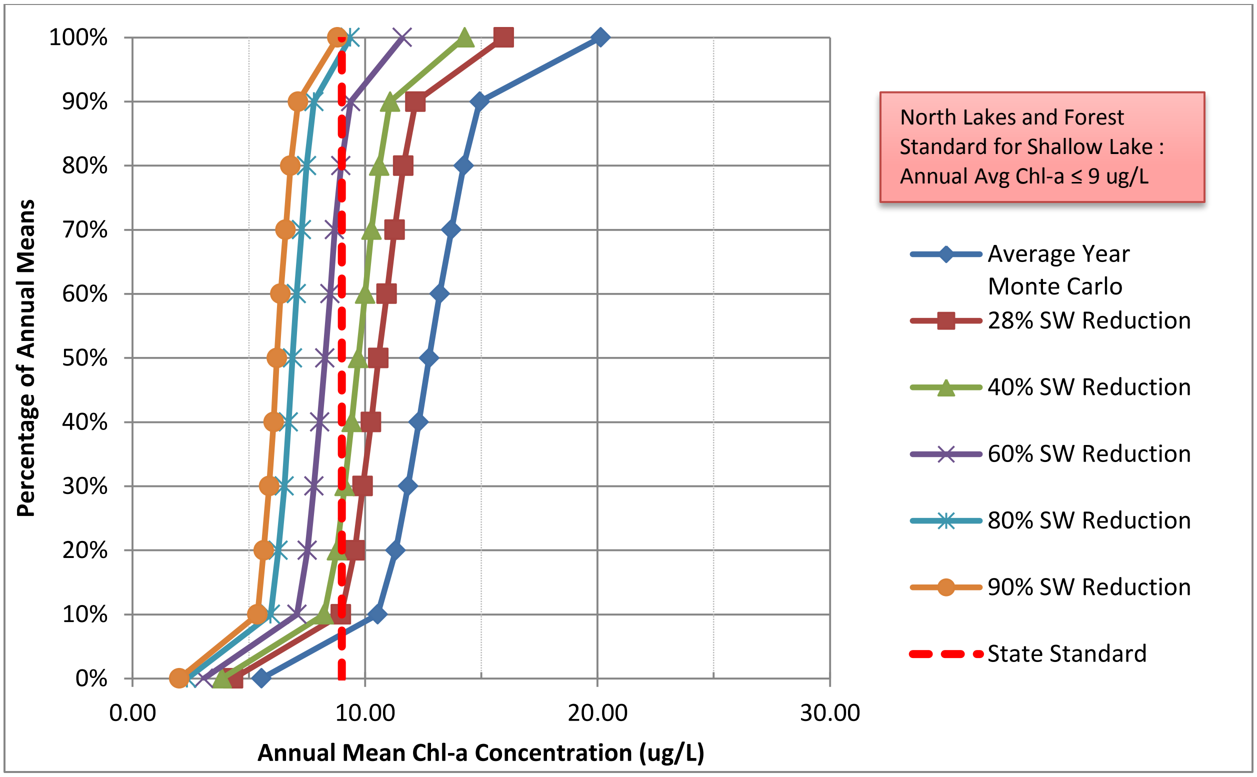

Figure A.11.3 North Tamarac Lake Frequency Distribution of Annual Mean Chl-*a* Concentrations Resulting from Select Load Reduction Scenarios.

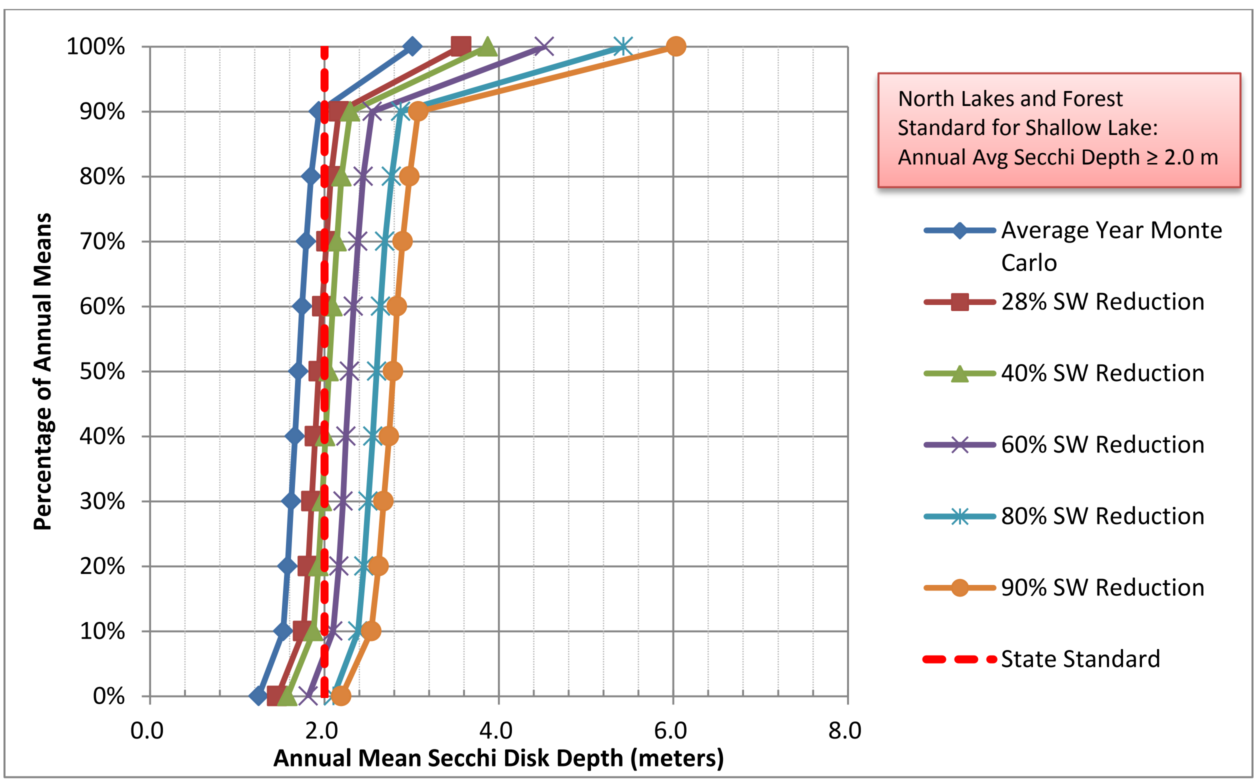

Figure A.11.4. North Tamarac Lake Frequency Distribution of Annual Mean Secchi Disk Depths Resulting from Select Load Reduction Scenarios.

A.12 Sand (Stump) Lake

Table A.12.1. Annual BRW SWAT outputs (1995-2009) for Sand (Stump) Lake.

Year	Precipitation (m/yr)	Evaporation (m/yr)	Contributing Drainage Inflow (hm^3/yr)	Contributing Drainage Area Load (kg/yr)	Tributary Flow (hm^3/yr)	Tributary Loading (kg/yr)
1995	0.661	0.792	0.655	449	0.53	48
1996	0.691	0.889	1.124	3,144	0.91	192
1997	0.911	0.923	2.307	5,637	1.93	493
1998	0.879	1.009	2.250	2,826	1.87	343
1999	0.775	0.972	1.281	3,267	1.05	220
2000	0.805	0.974	0.787	1,105	0.64	85
2001	0.762	0.942	1.958	2,209	1.61	268
2002	0.717	0.932	1.204	3,833	0.98	223
2003	0.538	1.068	0.325	256	0.20	15
2004	0.791	0.956	0.918	727	0.75	81
2005	0.910	0.996	1.573	6,320	1.30	364
2006	0.685	1.038	1.451	4,337	1.17	277
2007	0.692	0.944	1.476	2,373	1.20	215
2008	1.022	0.850	2.564	12,406	2.17	789
2009	0.802	0.892	2.496	7,032	2.08	584
Average	**0.776**	**0.945**	**1.49**	**3,728**	**1.2**	**280**

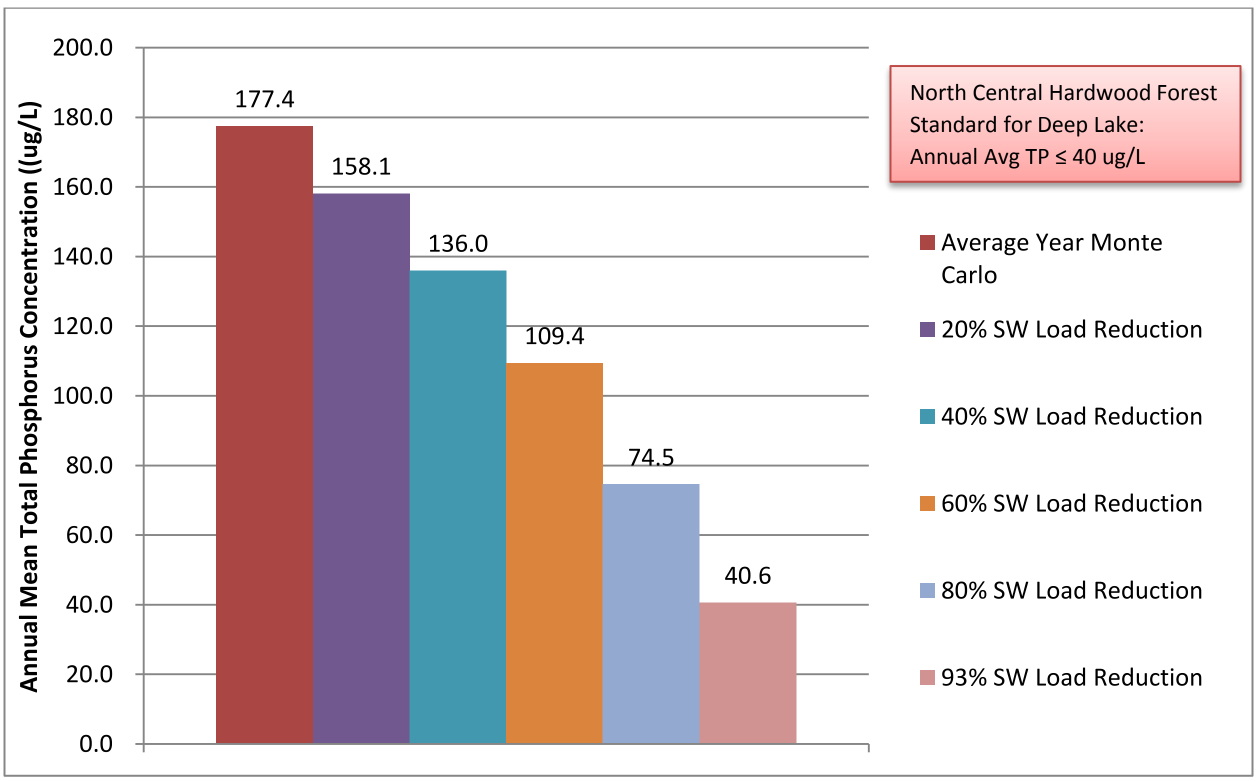

Figure A.12.1. Sand (Stump) Lake Annual Mean TP Concentrations under Select Load Reduction Scenarios.

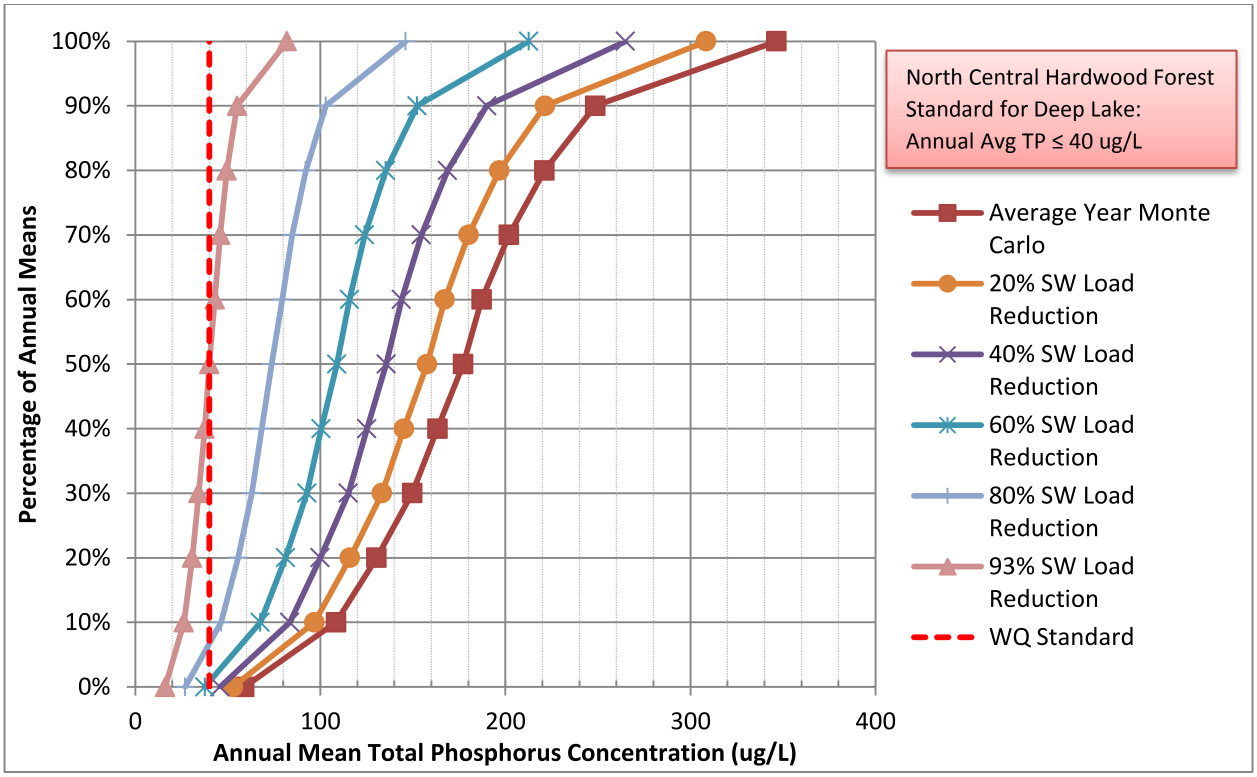

Figure A.12.2. Sand (Stump) Lake Frequency Distribution of Annual Mean TP Concentrations Resulting from Select Load Reduction Scenarios.

Table A.12.2. Data used to Produce the Annual Mean TP Concentrations (ug/L) Frequency Distribution (Figure A.12.2) for Sand (Stump) Lake.

Non-Exceedance Percentile	Average Year Monte Carlo	20% Reduction	40% Reduction	60% Reduction	80% Reduction	93% Reduction
Load	4267.6 kg	3414.1 kg	2560.6 kg	1707. kg	853.5 kg	298.7 kg
Mean	177.4	158.1	136.0	109.4	74.5	40.6
0%	58.9	52.8	45.8	37.6	27.0	16.2
10%	108.5	96.9	83.5	67.6	46.5	26.3
20%	130.4	116.0	100.0	81.1	55.5	30.8
30%	149.7	133.3	115.1	92.8	63.0	34.2
40%	163.3	145.1	125.2	100.5	68.3	37.5
50%	177.2	157.7	135.6	108.9	73.7	40.0
60%	187.1	167.2	143.9	115.8	79.4	42.9
70%	202.0	180.1	154.6	124.0	84.7	45.9
80%	221.2	196.8	168.8	135.4	92.1	49.5
90%	248.5	221.4	190.0	152.3	102.9	55.1
100%	346.5	308.5	264.9	212.6	146.1	82.0

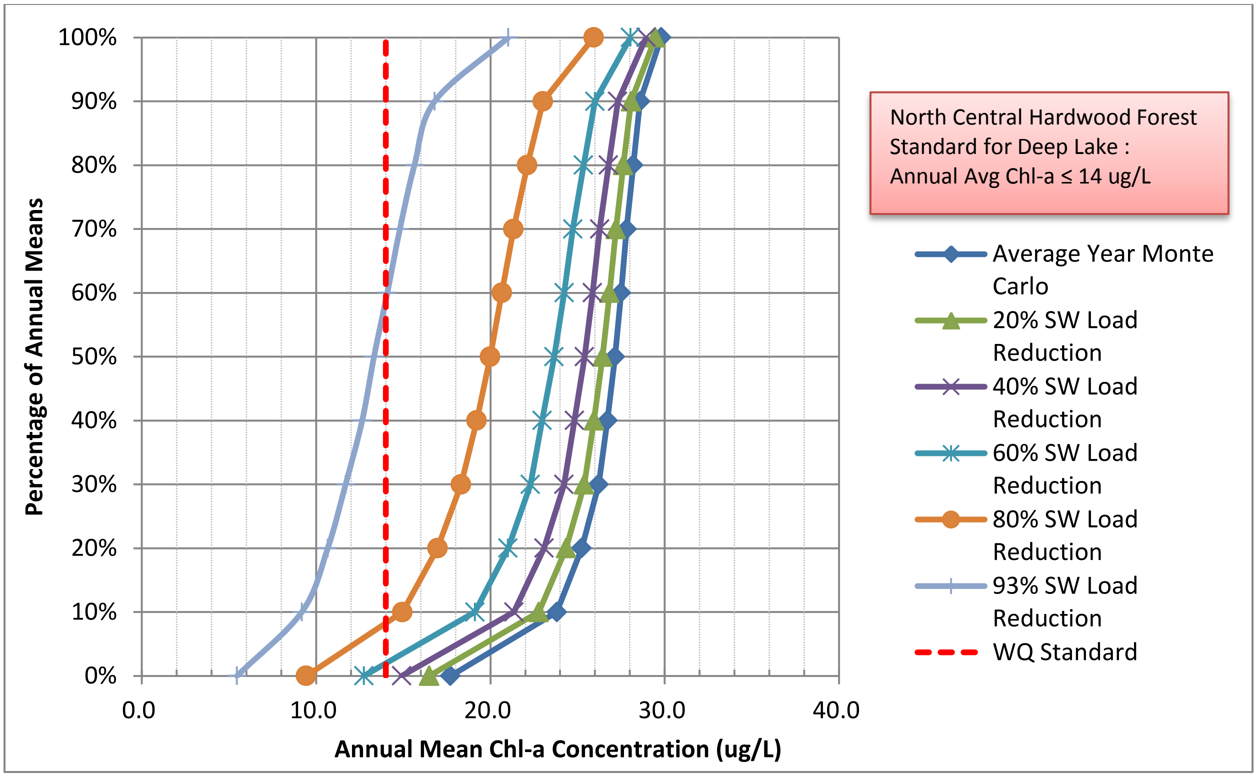

Figure A.12.3 Sand (Stump) Lake Frequency Distribution of Annual Mean Chl-*a* Concentrations Resulting from Select Load Reduction Scenarios.

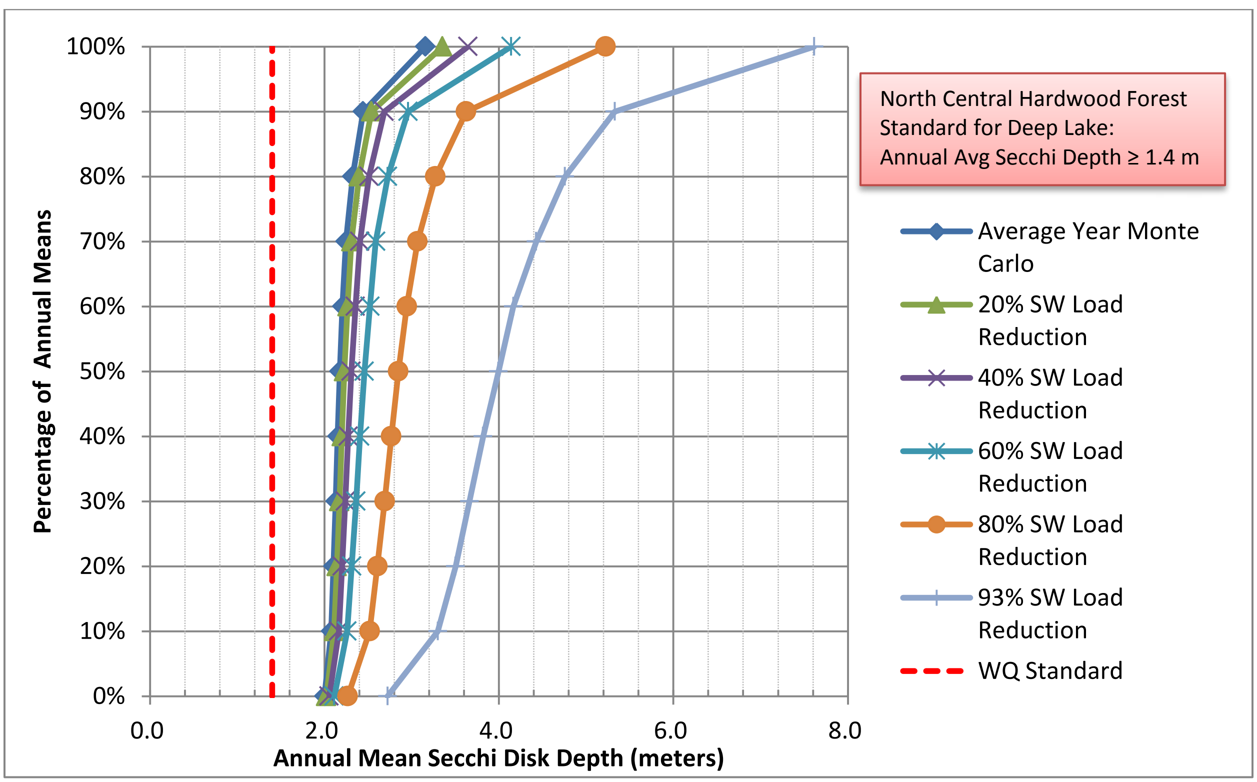

Figure A.12.4. Sand (Stump) Lake Frequency Distribution of Annual Mean Secchi Disk Depths Resulting from Select Load Reduction Scenarios.

The following figures are results from the Monte Carlo Simulation under load reduction scenarios for Sand (Stump) Lake where tributary flows are meeting the water quality standard of the upstream lakes (Axberg lake).

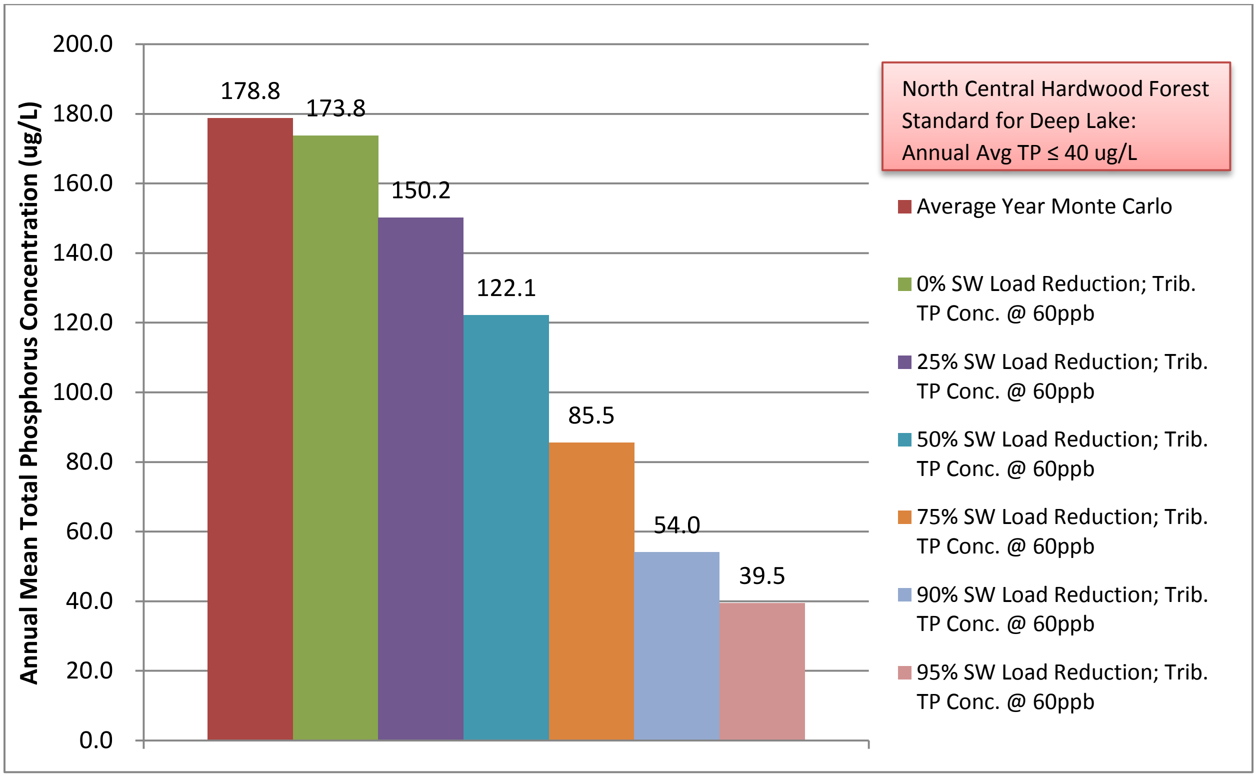

Figure A.12.5. Sand (Stump) Lake Annual Mean TP Concentrations under Select Load Reduction Scenarios with Tributary TP Concentrations at 60 ug/L (Water Quality Standard for Axberg Lake).

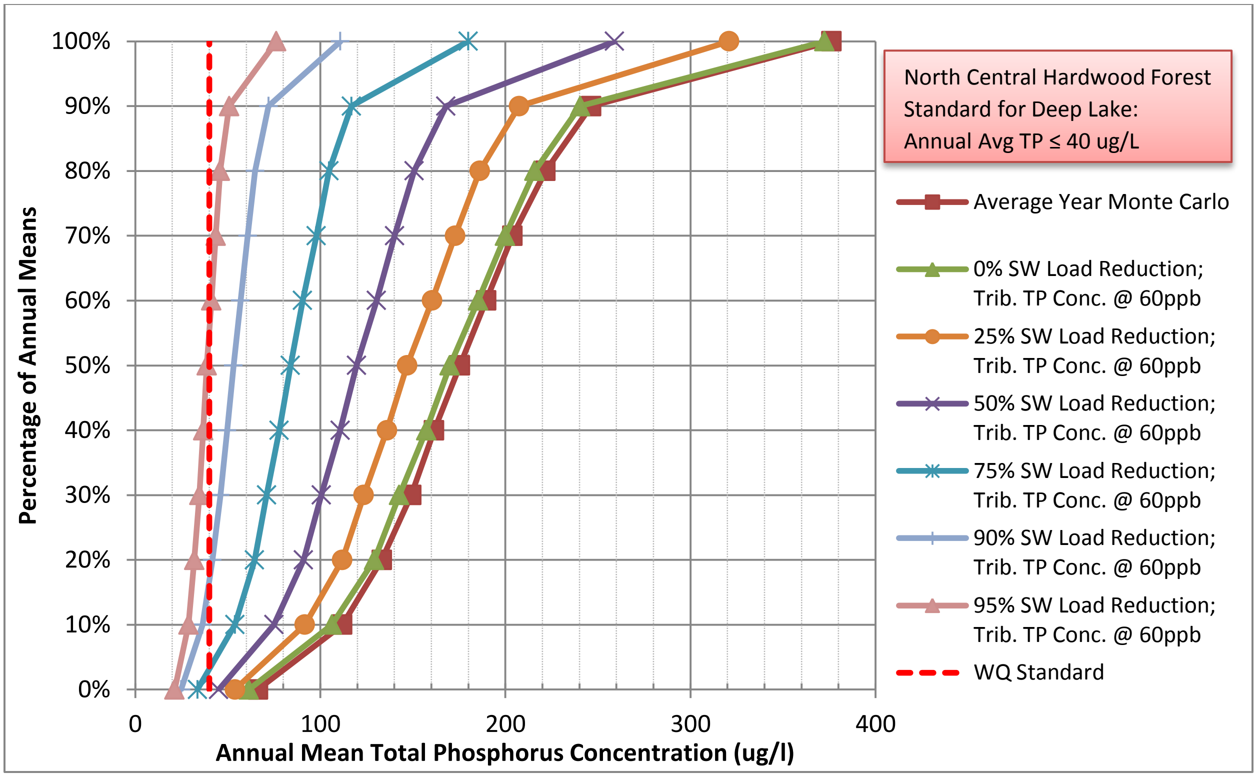

Figure A.12.6. Sand (Stump) Lake Frequency Distribution of Annual Mean TP Concentrations Resulting from Select Load Reduction Scenarios with Tributary TP Concentrations at 60 ug/L (Water Quality Standard for Axberg Lake).

Table A.12.2. Data used to Produce the Annual Mean TP Concentrations (ug/L) Frequency Distribution (Figure A.12.6) for Sand (Stump) Lake with Tributary TP Concentrations at 60 ug/L.

Non-Exceedance Percentile	Average Year Monte Carlo	0% Reduction; Trib. TP Conc. @ 60ppb	25% Reduction; Trib. TP Conc. @ 60ppb	50% Reduction; Trib. TP Conc. @ 60ppb	75% Reduction; Trib. TP Conc. @ 60ppb	90% Reduction; Trib. TP Conc. @ 60ppb	95% Reduction; Trib. TP Conc. @ 60ppb
Load	4,201 kg	3,989kg	3,011 kg	2,033 kg	1,054 kg	467 kg	271 kg
Mean	178.8	173.8	150.2	122.1	85.5	54.0	39.5
0%	66.3	61.4	53.8	45.1	33.6	24.8	21.2
10%	111.8	106.2	91.6	74.9	53.9	36.3	28.8
20%	133.3	129.2	111.8	91.0	64.5	41.7	31.9
30%	149.2	142.7	123.4	100.5	71.0	46.0	34.6
40%	161.5	157.2	136.0	110.8	77.8	49.6	36.8
50%	175.4	169.9	146.9	119.5	83.8	53.1	38.6
60%	189.6	185.3	160.4	130.4	90.4	56.9	41.1
70%	203.9	199.8	172.8	140.1	97.8	60.8	43.5
80%	221.6	215.8	186.2	150.7	104.7	64.7	45.8
90%	246.3	240.4	207.4	167.9	116.8	72.0	50.8
100%	376.2	372.4	320.9	259.0	179.9	110.9	76.2

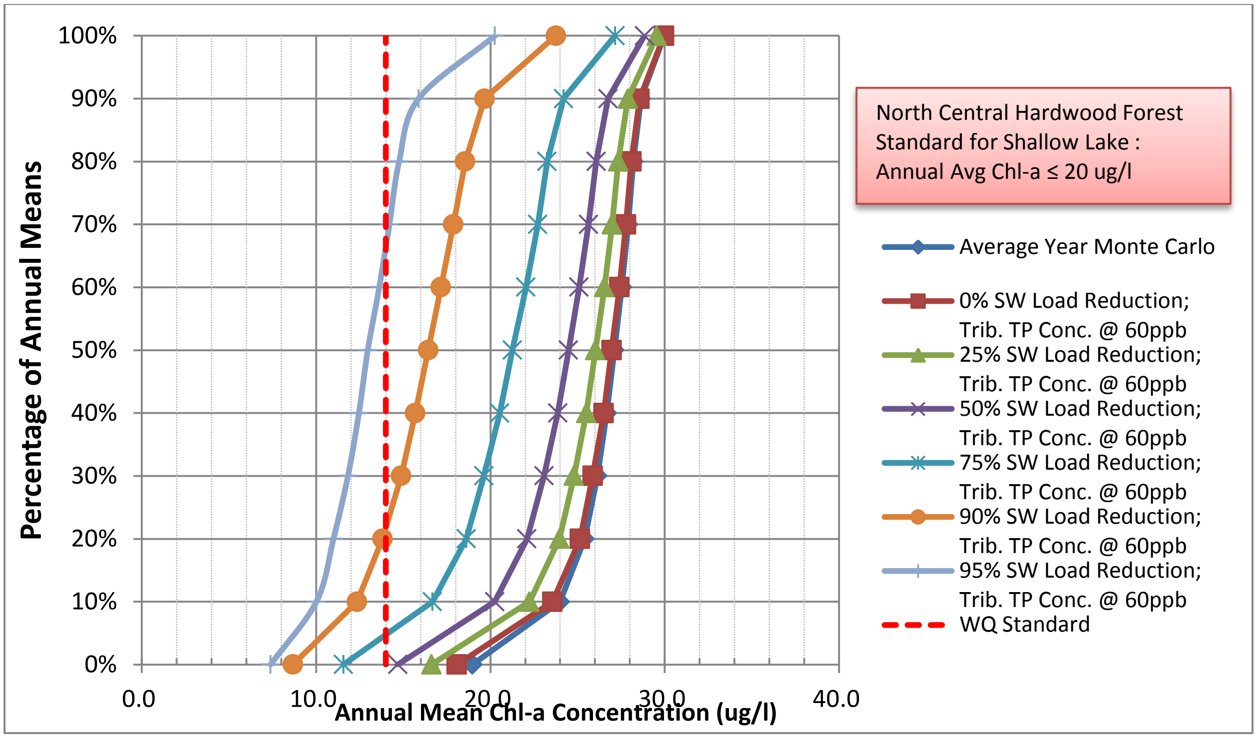

Figure A.12.7 Sand (Stump) Lake Frequency Distribution of Annual Mean Chl-*a* Concentrations Resulting from Select Load Reduction Scenarios with Tributary TP Concentrations at 60 ug/L (Water Quality Standard for Axberg Lake).

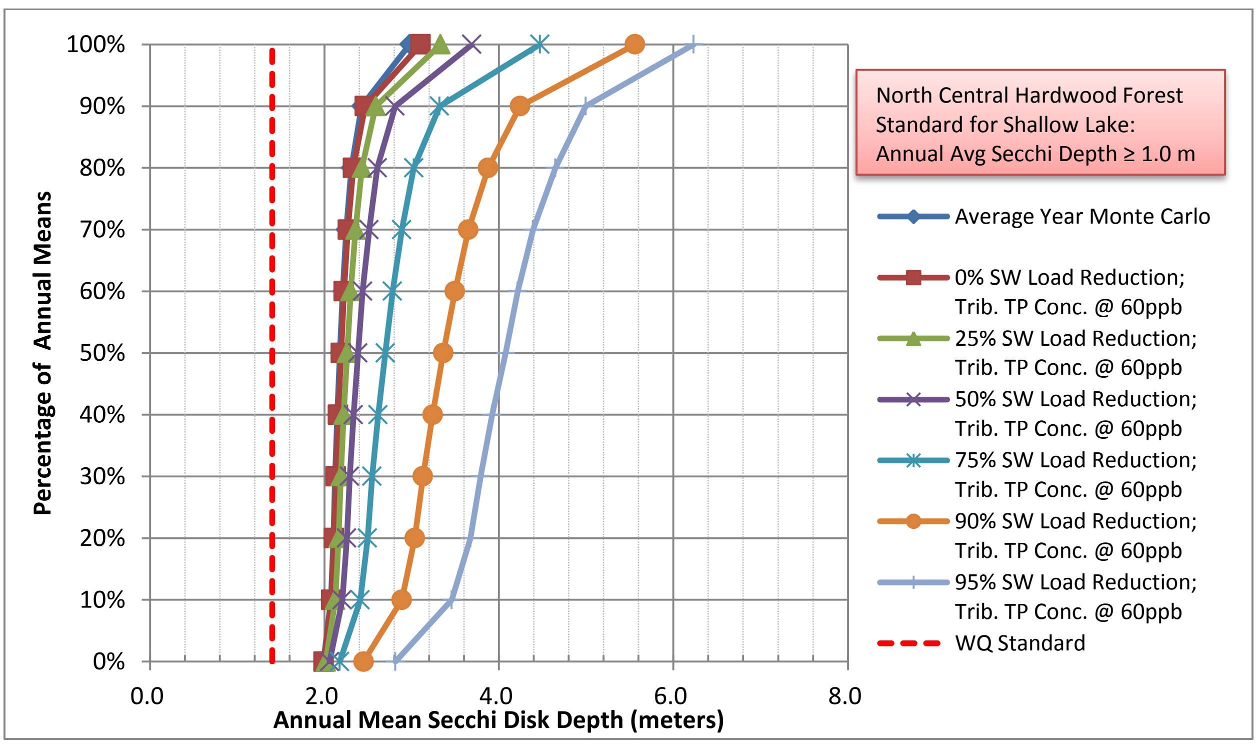

Figure A.12.8. Sand (Stump) Lake Frequency Distribution of Annual Mean Secchi Disk Depths Resulting from Select Load Reduction Scenarios with Tributary TP Concentrations at 60 ug/L (Water Quality Standard for Axberg Lake).

A.13 Sorenson (Lee) Lake

Table A.13.1. Annual BRW SWAT outputs (1995-2009) for Sorenson (Lee) Lake.

Year	Precipitation (m/yr)	Evaporation (m/yr)	Contributing Drainage Inflow (hm^3/yr)	Contributing Drainage Area Load (kg/yr)	Tributary Flow (hm^3/yr)	Tributary Loading (kg/yr)
1995	0.661	0.735	0.231	188	0.0	0.0
1996	0.691	0.823	0.508	262	0.0	0.0
1997	0.911	0.850	1.237	463	0.0	0.0
1998	0.879	0.937	1.125	693	0.0	0.0
1999	0.775	0.898	0.763	248	0.0	0.0
2000	0.805	0.904	0.520	83	0.0	0.0
2001	0.762	0.870	0.987	714	0.0	0.0
2002	0.717	0.861	0.580	116	0.0	0.0
2003	0.538	0.993	0.264	18	0.0	0.0
2004	0.791	0.885	0.458	177	0.0	0.0
2005	0.910	0.922	0.842	206	0.0	0.0
2006	0.685	0.960	0.779	234	0.0	0.0
2007	0.692	0.872	0.762	457	0.0	0.0
2008	1.022	0.780	1.395	319	0.0	0.0
2009	0.802	0.819	1.322	443	0.0	0.0
Average	**0.776**	**0.874**	**0.78**	**308**	**0.0**	**0.0**

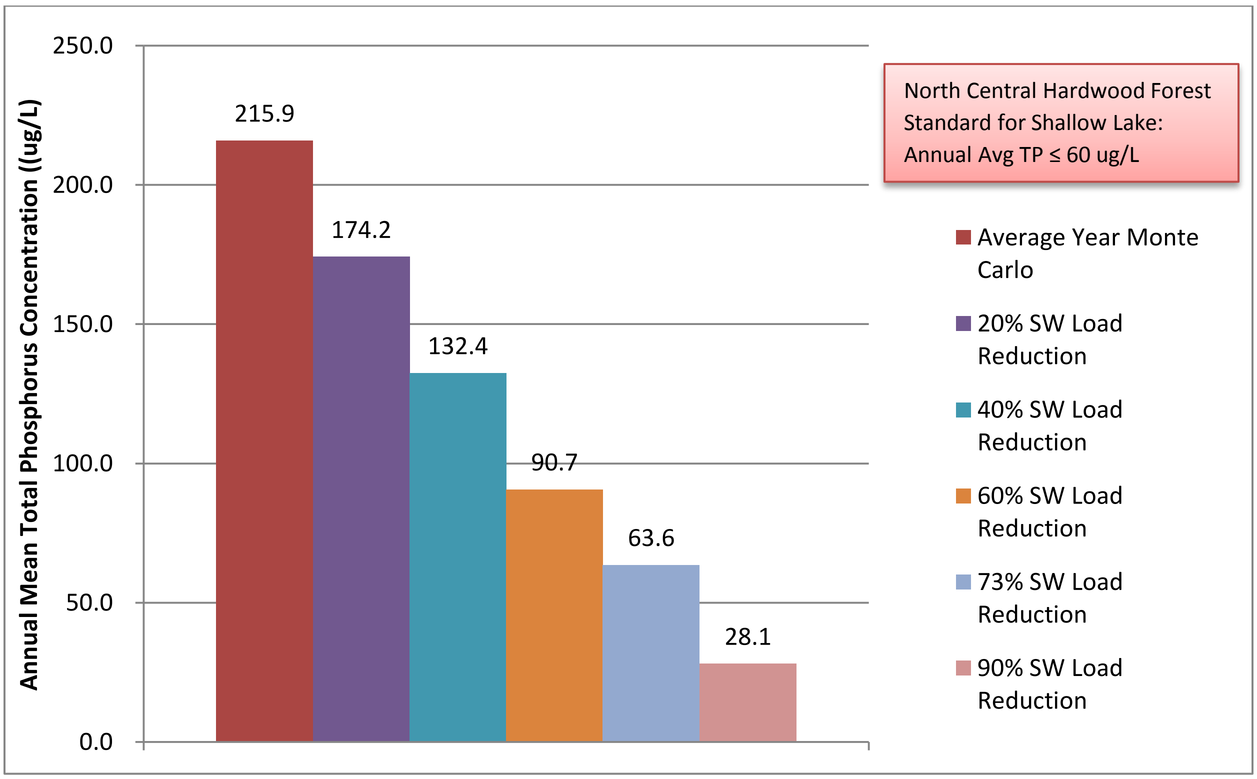

Figure A.13.1. Sorenson (Lee) Lake Annual Mean TP Concentrations under Select Load Reduction Scenarios.

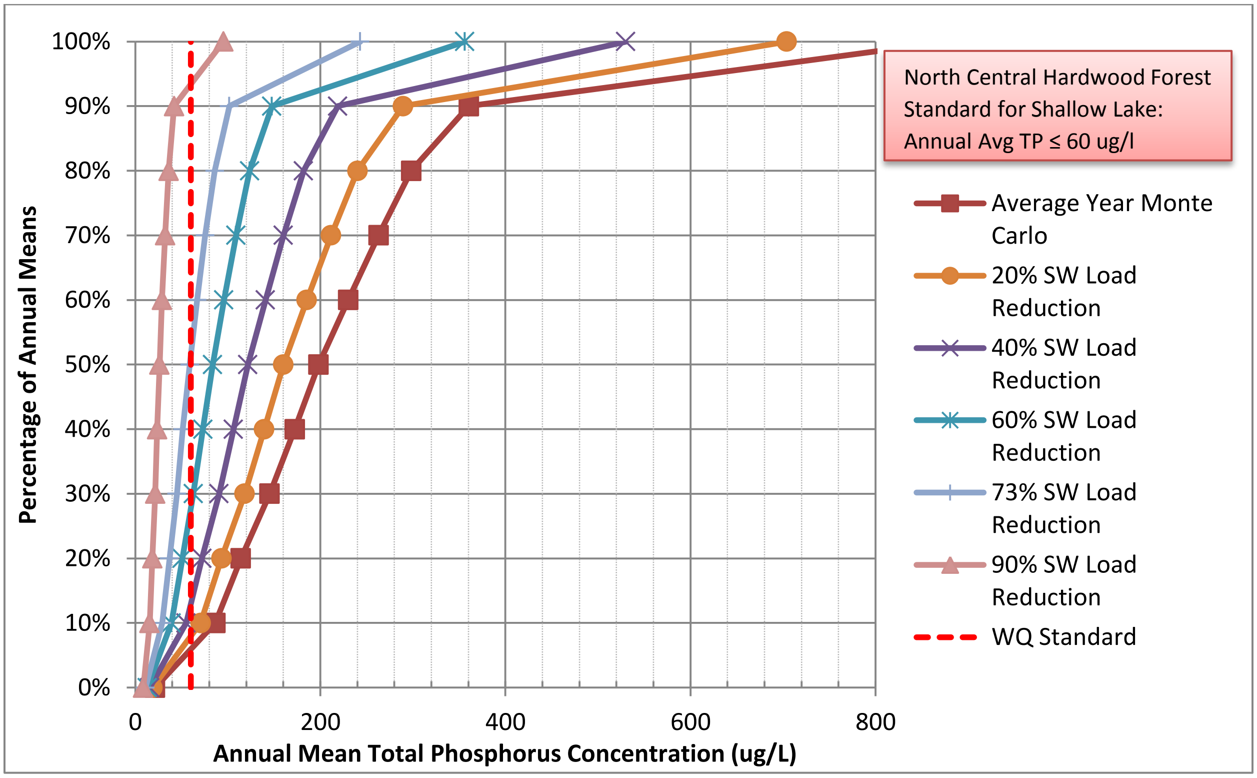

Figure A.13.2. Sorenson (Lee) Lake Frequency Distribution of Annual Mean TP Concentrations Resulting from Select Load Reduction Scenarios.

Table A.13.2. Data used to Produce the Annual Mean TP Concentrations (ug/L) Frequency Distribution (Figure A.13.2) for Sorenson (Lee) Lake.

Non-Exceedance Percentile	Average Year Monte Carlo	20% Reduction	40% Reduction	60% Reduction	73% Reduction	90% Reduction
Load	315.7 kg	252.6 kg	189.4 kg	126.3 kg	85.2 kg	31.6 kg
Mean	215.9	174.2	132.4	90.7	63.6	28.1
0%	21.4	18.6	15.8	12.9	11.1	8.7
10%	86.5	70.6	54.9	39.1	29.0	15.6
20%	114.0	93.2	72.1	50.7	37.0	18.5
30%	145.3	118.2	90.7	62.7	44.9	21.6
40%	172.3	139.3	106.2	73.1	51.4	23.7
50%	198.1	160.1	121.7	83.7	59.0	26.3
60%	230.2	185.3	140.7	95.9	66.8	28.9
70%	263.0	211.7	160.1	108.9	75.6	32.3
80%	298.3	240.1	181.8	123.6	85.8	36.2
90%	360.6	289.5	219.0	147.6	101.7	42.0
100%	878.1	704.2	530.2	356.2	243.1	95.2

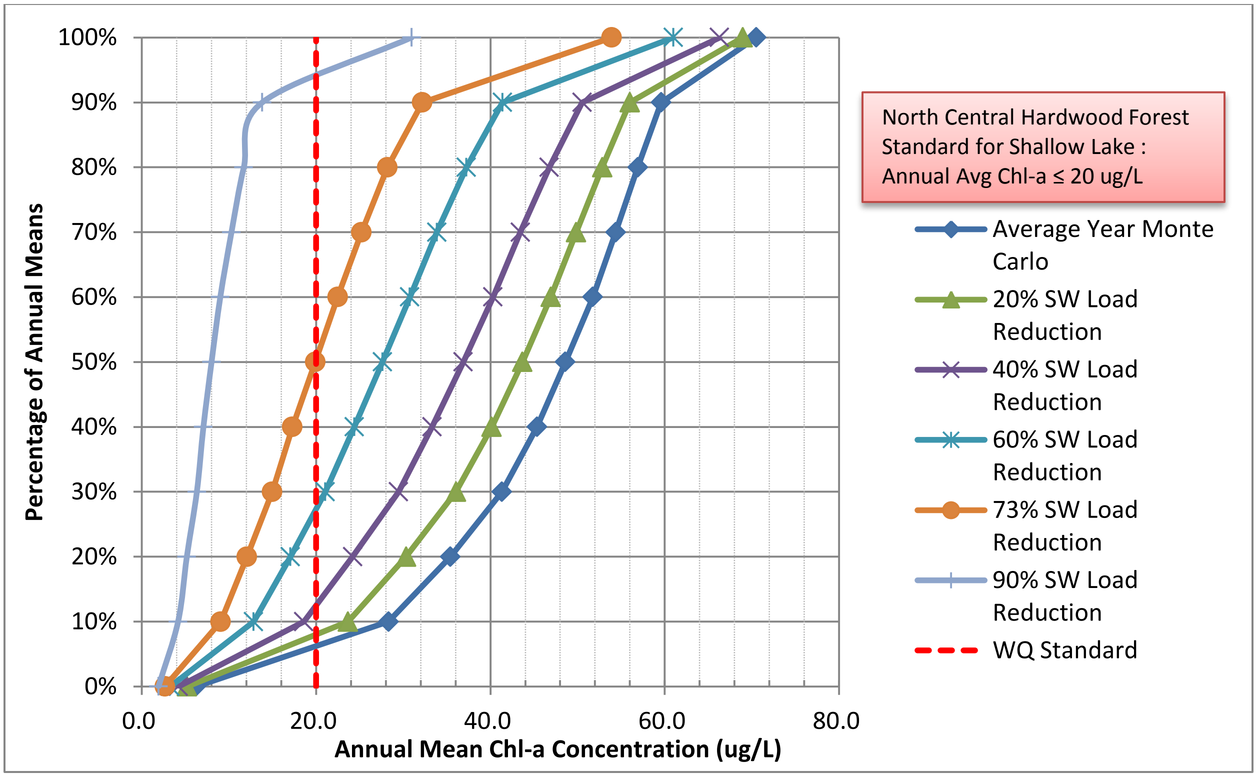

Figure A.13.3 Sorenson (Lee) Lake Frequency Distribution of Annual Mean Chl-*a* Concentrations Resulting from Select Load Reduction Scenarios.

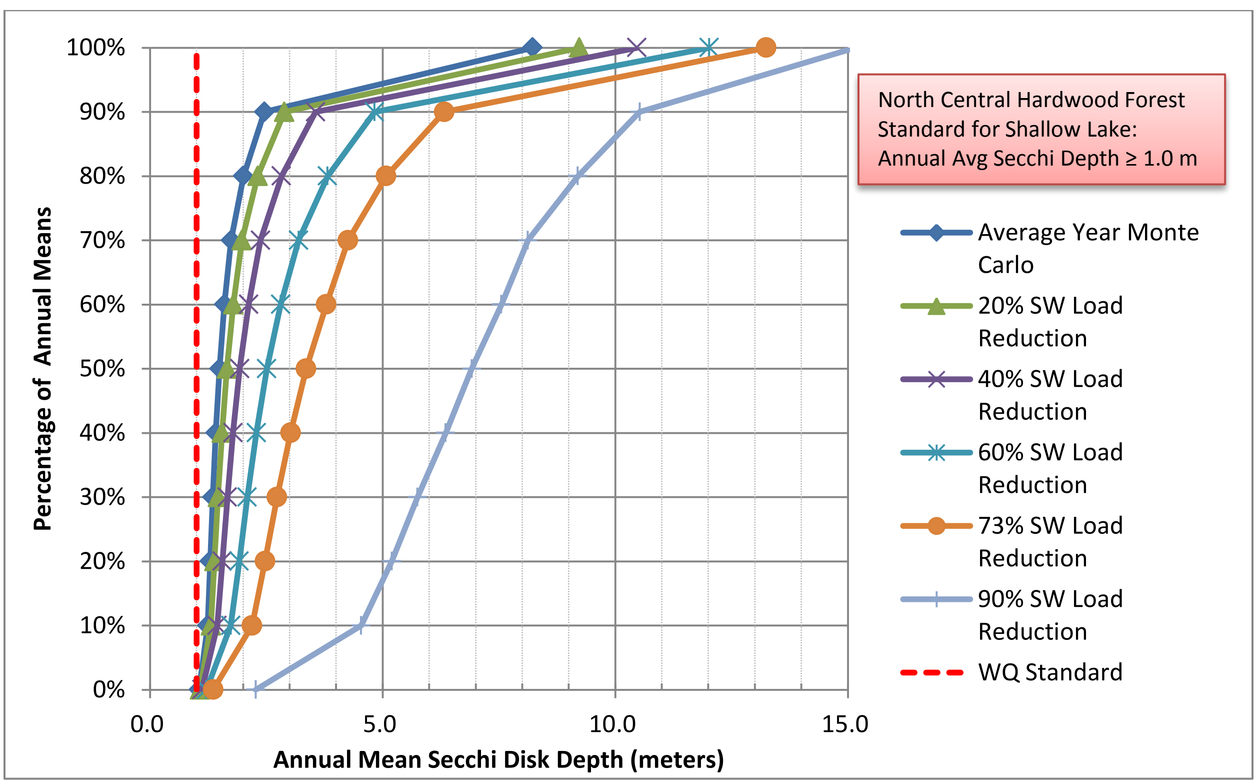

Figure A.13.4. Sorenson (Lee) Lake Frequency Distribution of Annual Mean Secchi Disk Depths Resulting from Select Load Reduction Scenarios.

A.14 Stakke Lake

Table A.14.1. Annual BRW SWAT outputs (1995-2009) for Stakke Lake.

Year	Precipitation (m/yr)	Evaporation (m/yr)	Contributing Drainage Inflow (hm^3/yr)	Contributing Drainage Area Load (kg/yr)	Tributary Flow (hm^3/yr)	Tributary Loading (kg/yr)
1995	0.661	0.790	0.77	647	0.0	0.0
1996	0.691	0.888	1.62	884	0.0	0.0
1997	0.911	0.921	3.90	1,911	0.0	0.0
1998	0.879	1.007	3.59	2,398	0.0	0.0
1999	0.775	0.970	2.32	792	0.0	0.0
2000	0.805	0.973	1.66	250	0.0	0.0
2001	0.762	0.940	3.15	2,369	0.0	0.0
2002	0.717	0.930	1.81	383	0.0	0.0
2003	0.538	1.066	0.86	47	0.0	0.0
2004	0.791	0.954	1.32	577	0.0	0.0
2005	0.910	0.994	2.63	823	0.0	0.0
2006	0.685	1.036	2.59	779	0.0	0.0
2007	0.692	0.942	2.45	1,269	0.0	0.0
2008	1.022	0.848	4.33	868	0.0	0.0
2009	0.802	0.890	4.26	1,320	0.0	0.0
Average	**0.776**	**0.943**	**2.48**	**1,021**	**0.0**	**0.0**

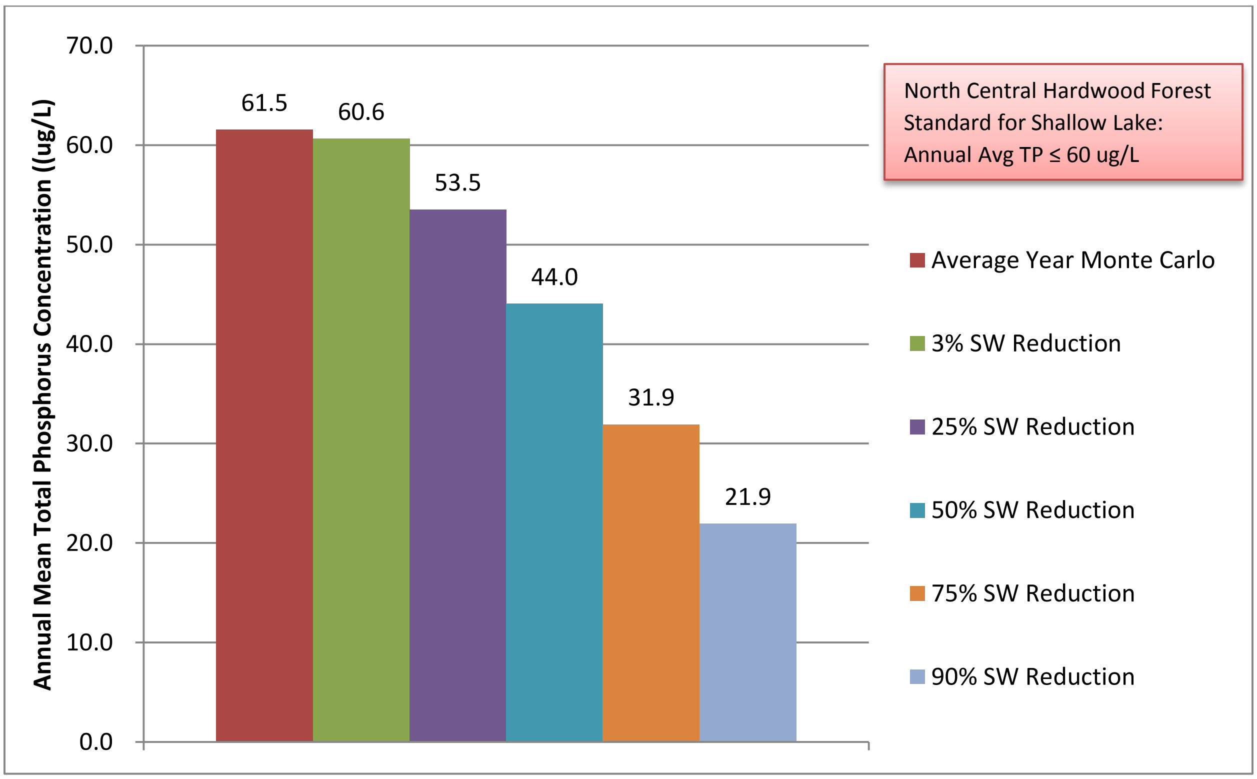

Figure A.14.1. Stakke Lake Annual Mean TP Concentrations under Select Load Reduction Scenarios.

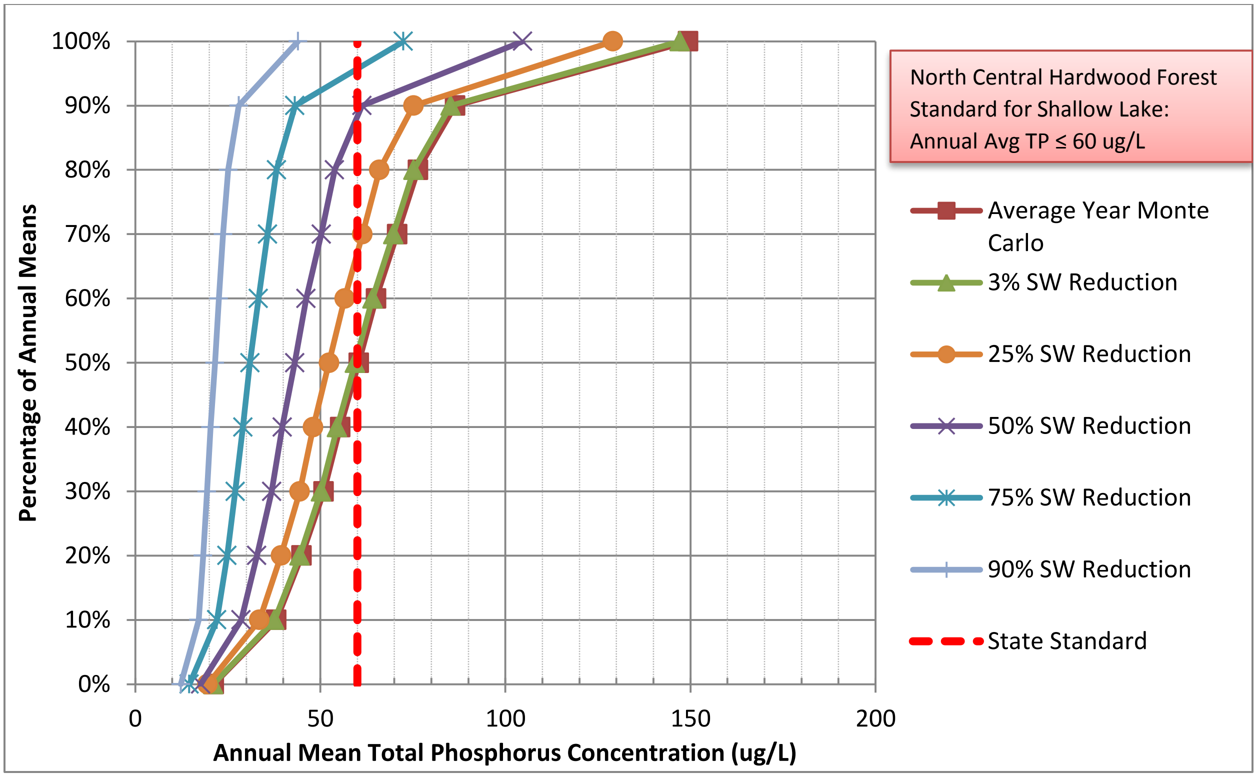

Figure A.14.2. Stakke Lake Frequency Distribution of Annual Mean TP Concentrations Resulting from Select Load Reduction Scenarios.

Table A.14.2. Data used to Produce the Annual Mean TP Concentrations (ug/L) Frequency Distribution (Figure A.14.2) for Stakke Lake.

Non-Exceedance Percentile	Average Year Monte Carlo	3% Reduction	25% Reduction	50% Reduction	75% Reduction	90% Reduction
Load	1,055 kg	1,023 kg	791 kg	527 kg	264 kg	106 kg
Mean	61.5	60.6	53.5	44.0	31.9	21.9
0%	21.2	21.0	19.5	17.7	14.6	12.3
10%	38.1	37.6	33.5	28.6	22.0	17.1
20%	45.0	44.4	39.4	32.9	24.8	18.3
30%	50.9	50.2	44.4	36.9	27.0	19.4
40%	55.4	54.5	48.1	39.7	29.1	20.4
50%	60.4	59.4	52.4	43.1	31.0	21.5
60%	65.1	64.1	56.6	46.2	33.3	22.6
70%	70.7	69.7	61.4	50.3	35.8	23.7
80%	76.4	75.2	65.9	53.8	38.2	25.1
90%	86.4	85.2	75.2	61.2	43.1	28.0
100%	149.4	147.1	129.1	104.7	72.4	44.0

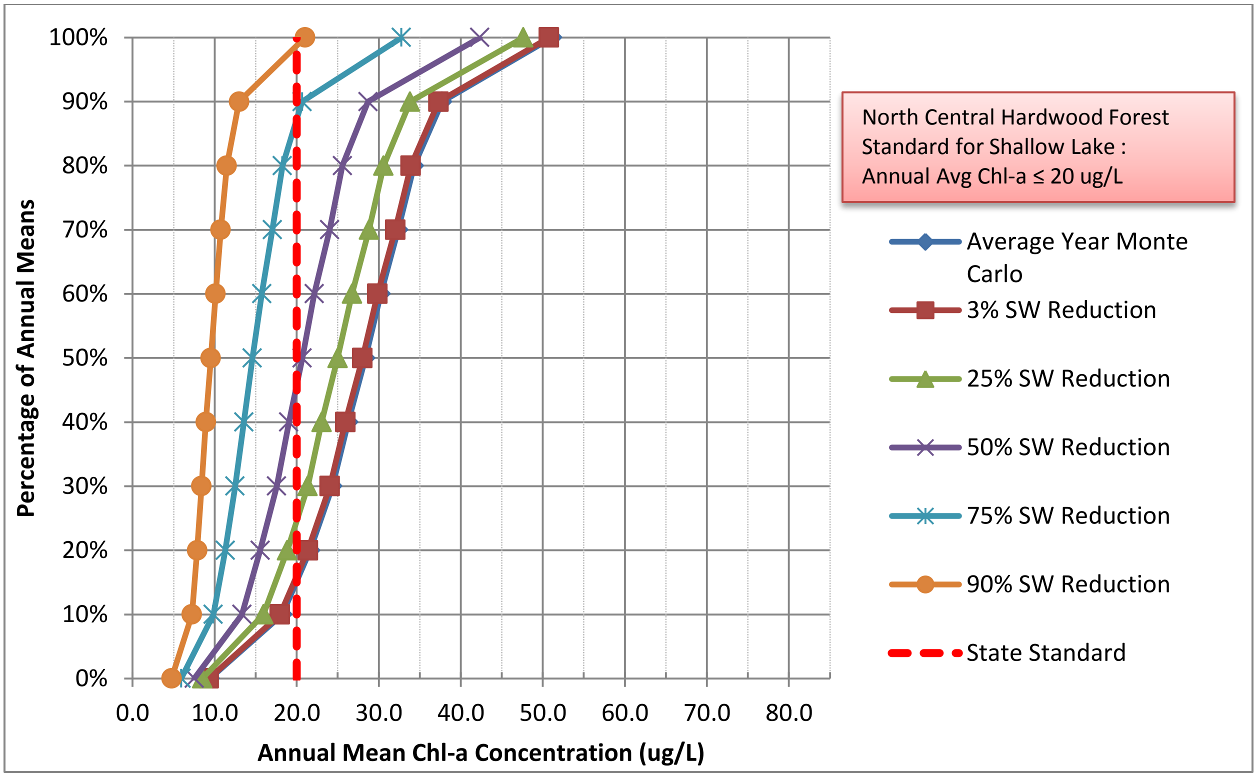

Figure A.14.3 Stakke Lake Frequency Distribution of Annual Mean Chl-*a* Concentrations Resulting from Select Load Reduction Scenarios.

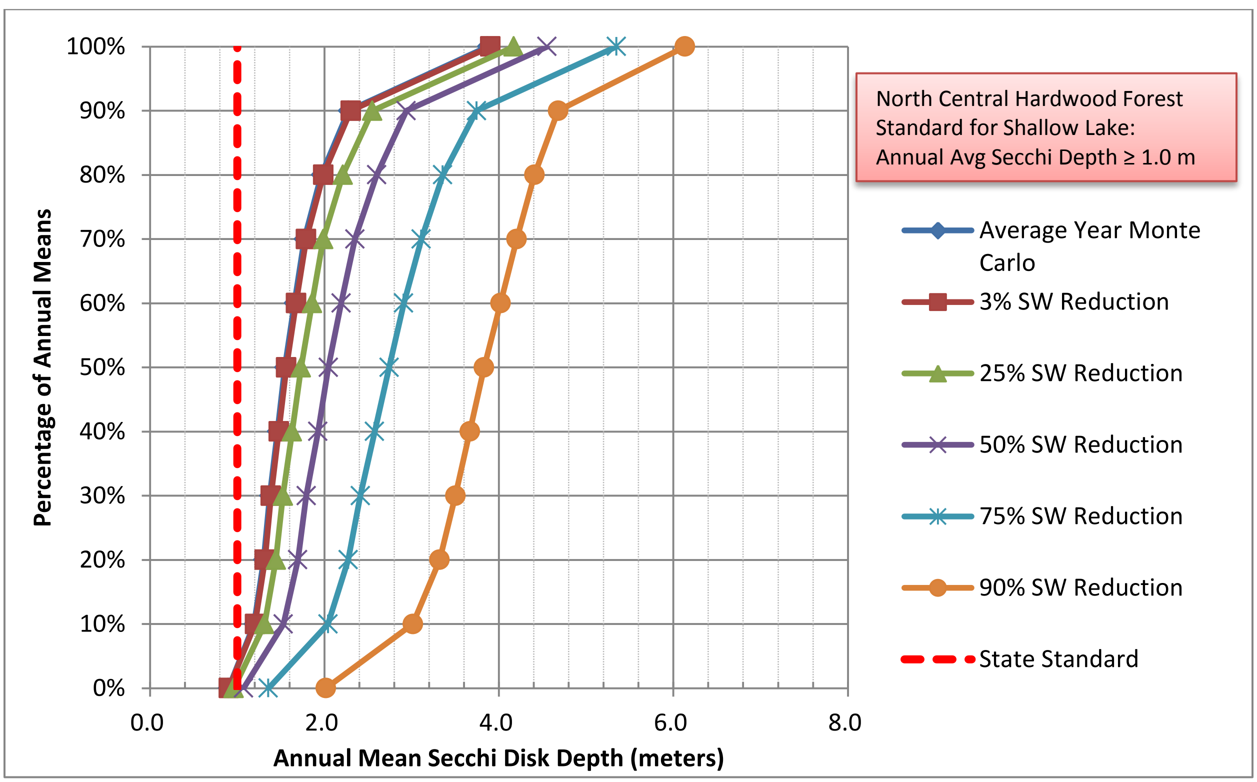

Figure A.14.4. Stakke Lake Frequency Distribution of Annual Mean Secchi Disk Depths Resulting from Select Load Reduction Scenarios.

A.15 Stinking Lake

Table A.15.1. Annual BRW SWAT outputs (1995-2009) for Stinking Lake.

Year	Precipitation (m/yr)	Evaporation (m/yr)	Contributing Drainage Inflow (hm^3/yr)	Contributing Drainage Area Load (kg/yr)	Tributary Flow (hm^3/yr)	Tributary Loading (kg/yr)
1995	0.661	0.660	3.96	1,865	1.6	2,700
1996	0.691	0.733	5.63	7,802	3.5	4,335
1997	0.911	0.752	10.54	12,739	9.7	6,484
1998	0.879	0.842	10.45	10,266	8.4	13,163
1999	0.775	0.799	6.05	6,672	5.1	4,333
2000	0.805	0.811	3.32	2,726	3.4	1,264
2001	0.762	0.775	9.49	7,293	7.3	12,128
2002	0.717	0.766	5.70	7,093	3.6	2,448
2003	0.538	0.891	1.57	494	1.4	269
2004	0.791	0.790	4.61	3,049	2.3	3,478
2005	0.910	0.823	8.53	12,600	6.1	4,534
2006	0.685	0.854	5.92	9,557	5.4	3,304
2007	0.692	0.775	7.21	5,149	5.5	7,627
2008	1.022	0.686	11.85	22,558	10.5	7,187
2009	0.802	0.722	10.64	10,320	9.8	6,911
Average	**0.776**	**0.779**	**7.03**	**8,012**	**5.6**	**5,344**

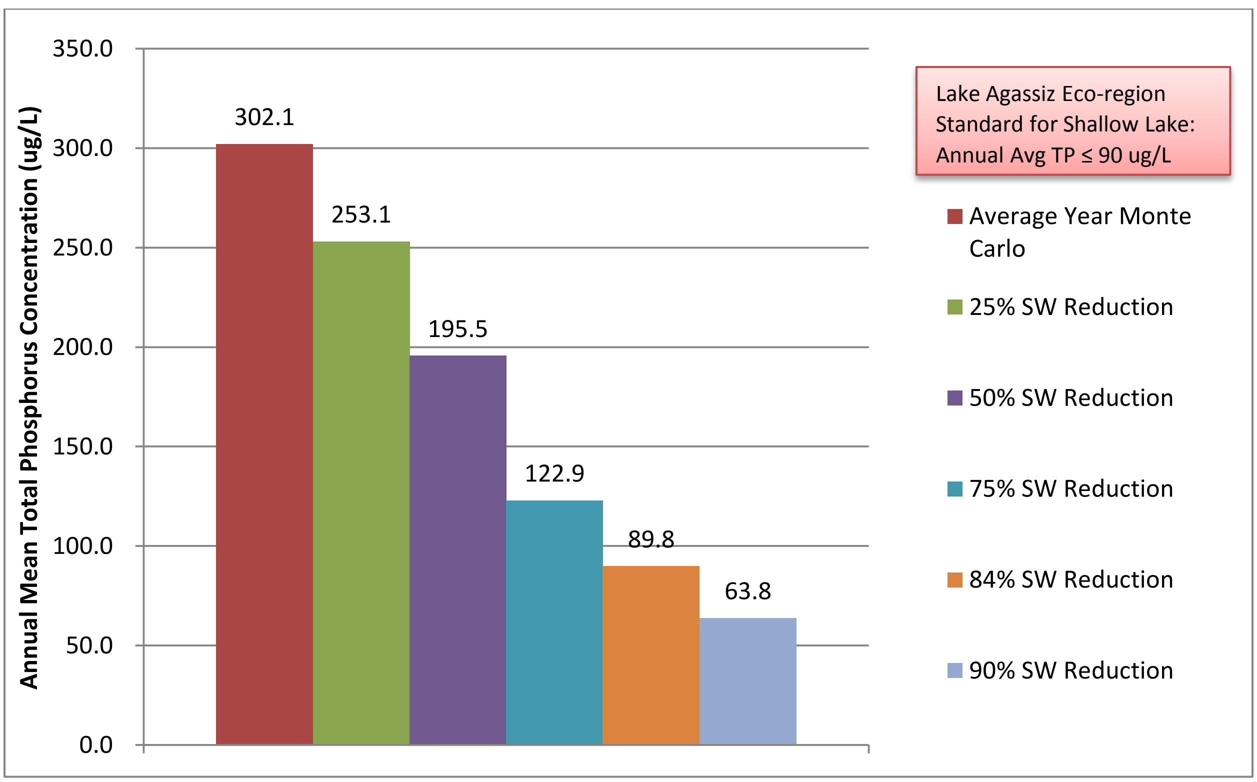

Figure A.15.1. Stinking Lake Annual Mean TP Concentrations under Select Load Reduction Scenarios.

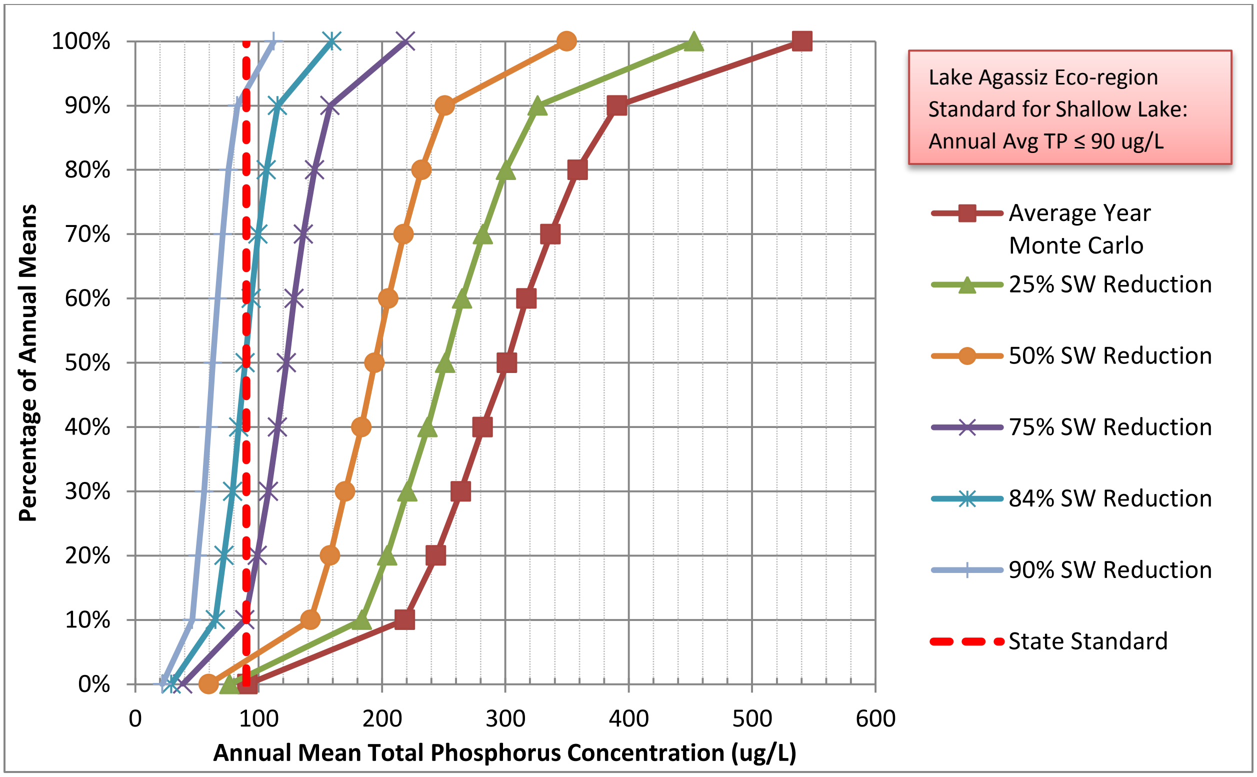

Figure A.15.2. Stinking Lake Frequency Distribution of Annual Mean TP Concentrations Resulting from Select Load Reduction Scenarios.

Table A.15.2. Data used to Produce the Annual Mean TP Concentrations (ug/L) Frequency Distribution (Figure A.15.2) for Stinking Lake.

Non-Exceedance Percentile	Average Year Monte Carlo	25% Reduction	50% Reduction	75% Reduction	84% Reduction	90% Reduction
Load	13,827 kg	10,370 kg	6,913 kg	3,457 kg	2,212 kg	1,383 kg
Mean	302.1	253.1	195.5	122.9	89.8	63.8
0%	90.9	76.4	59.5	38.5	29.1	21.9
10%	218.6	183.7	142.1	88.8	64.9	46.2
20%	243.9	204.2	157.9	98.9	72.0	50.9
30%	263.9	220.6	170.2	108.0	79.0	55.9
40%	281.6	237.1	183.4	115.4	83.9	59.6
50%	301.4	251.2	194.1	122.6	89.1	62.9
60%	317.1	265.0	205.2	128.8	94.0	66.7
70%	336.7	282.0	217.6	136.3	99.6	70.9
80%	358.5	300.4	232.0	145.3	106.3	75.6
90%	390.5	326.3	251.1	158.0	115.4	82.7
100%	540.8	453.1	349.9	219.1	159.3	112.3

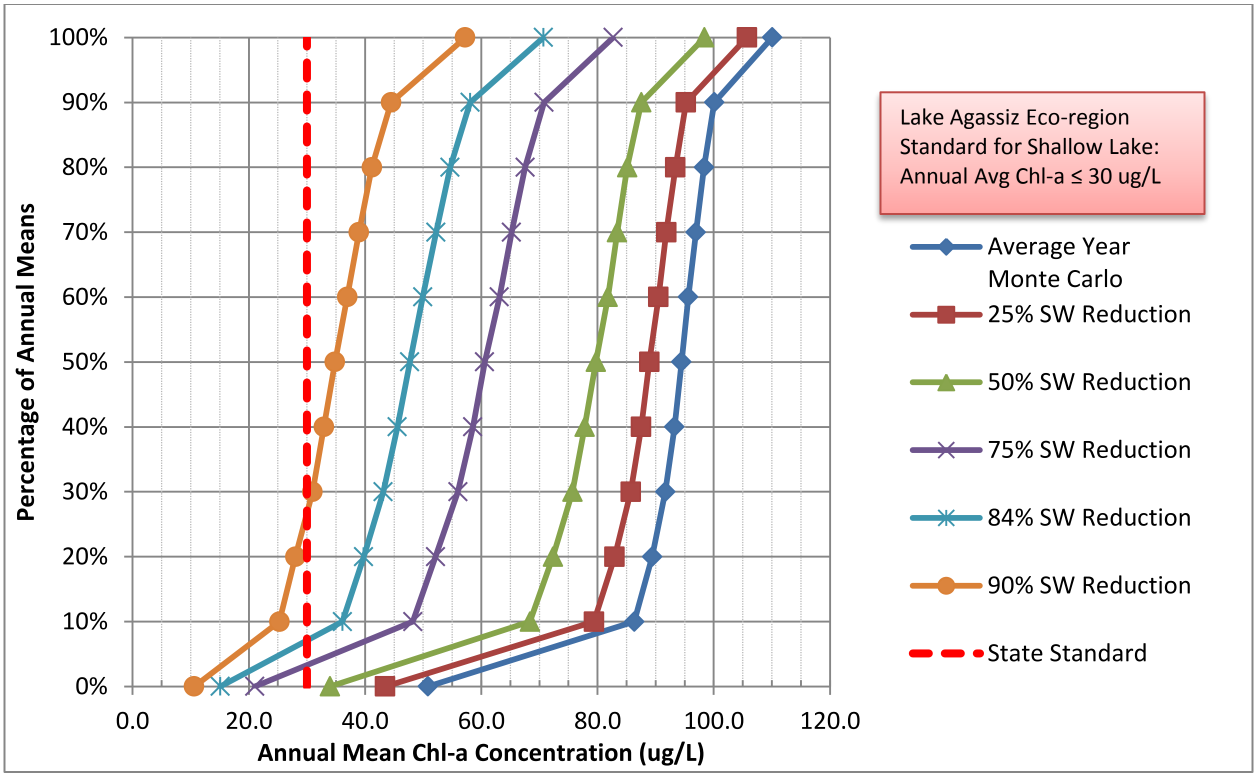

Figure A.15.3 Stinking Lake Frequency Distribution of Annual Mean Chl-*a* Concentrations Resulting from Select Load Reduction Scenarios.

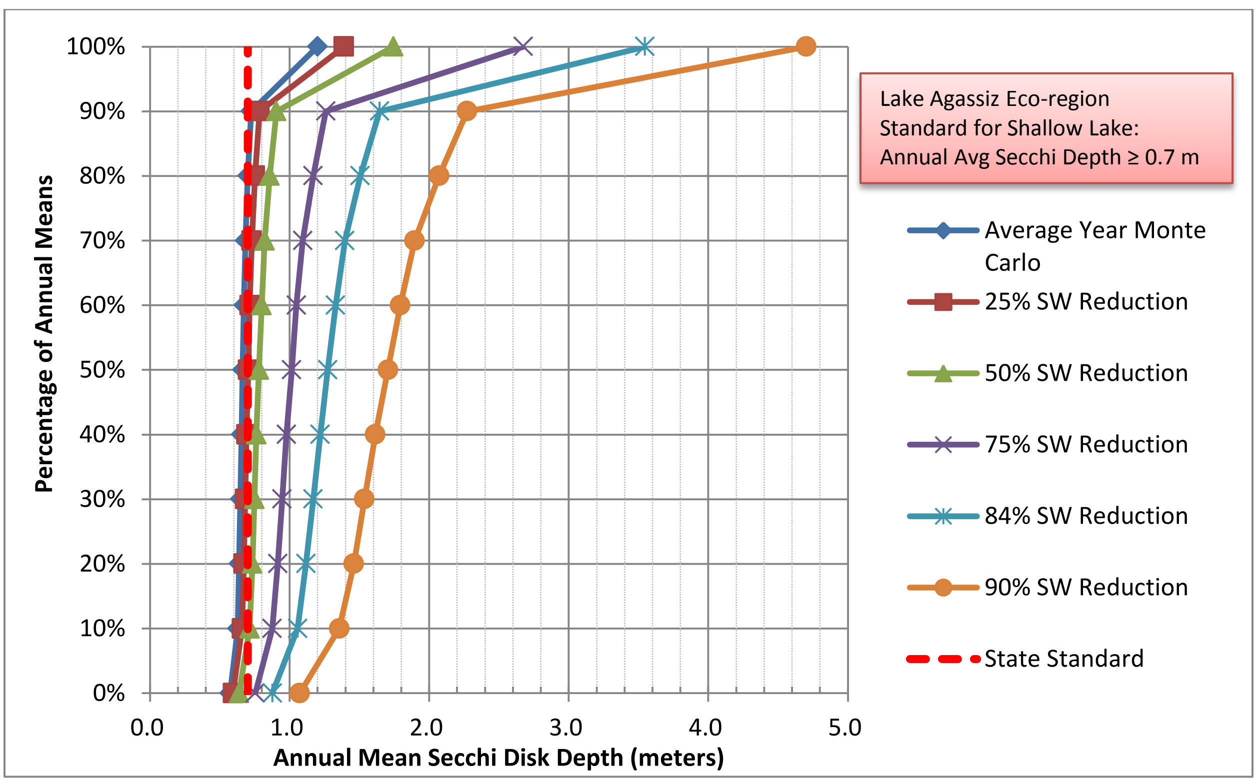

Figure A.15.4. Stinking Lake Frequency Distribution of Annual Mean Secchi Disk Depths Resulting from Select Load Reduction Scenarios.

A.16 Talac Lake

Table A.16.1. Annual BRW SWAT outputs (1995-2009) for Talac Lake.

Year	Precipitation (m/yr)	Evaporation (m/yr)	Contributing Drainage Inflow (hm^3/yr)	Contributing Drainage Area Load (kg/yr)	Tributary Flow (hm^3/yr)	Tributary Loading (kg/yr)
1995	0.661	0.735	0.150	122	1.29	148
1996	0.691	0.823	0.329	170	2.34	450
1997	0.911	0.850	0.800	300	5.48	1,184
1998	0.879	0.937	0.728	449	5.12	1,012
1999	0.775	0.898	0.494	161	2.89	512
2000	0.805	0.904	0.337	54	1.78	182
2001	0.762	0.870	0.639	462	4.38	870
2002	0.717	0.861	0.376	75	2.54	440
2003	0.538	0.993	0.171	11	0.32	20
2004	0.791	0.885	0.296	114	1.96	217
2005	0.910	0.922	0.545	134	3.65	777
2006	0.685	0.960	0.504	152	3.02	589
2007	0.692	0.872	0.493	296	3.18	605
2008	1.022	0.780	0.903	206	6.34	1,726
2009	0.802	0.819	0.856	287	5.82	1,339
Average	**0.776**	**0.874**	**0.51**	**199**	**3.34**	**671**

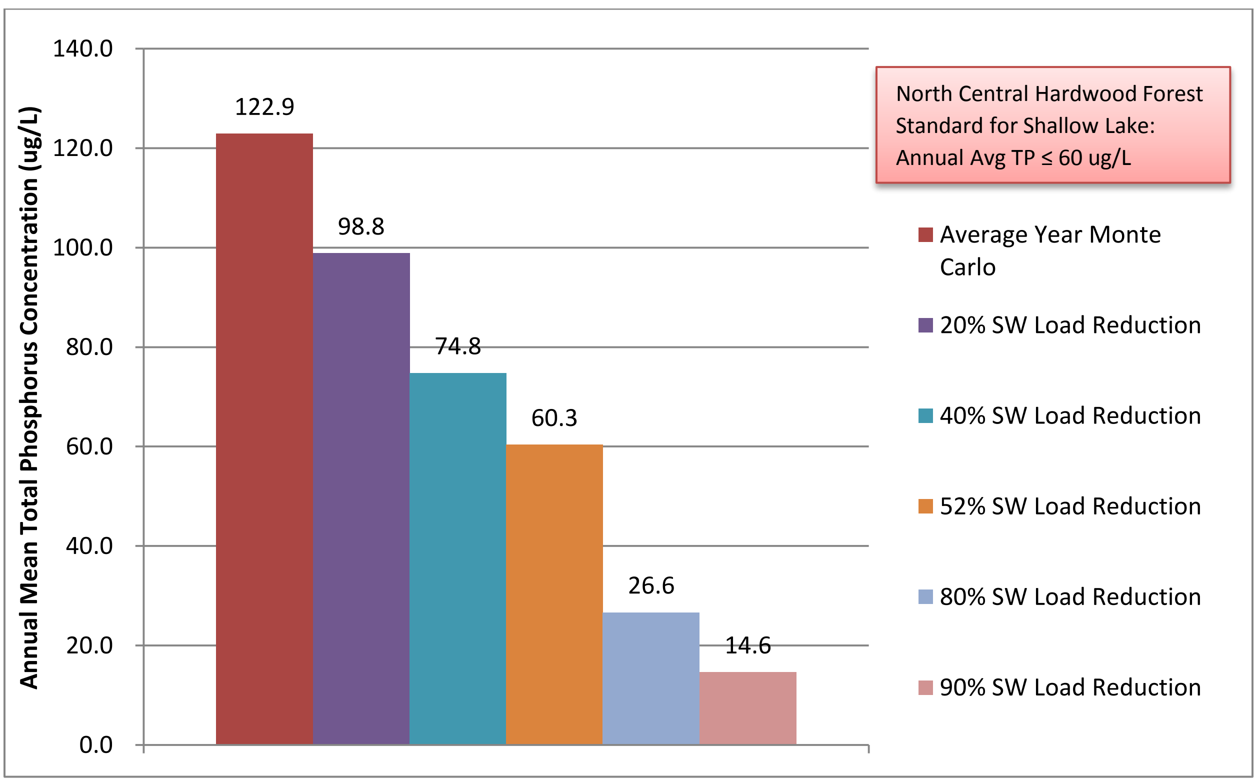

Figure A.16.1. Talac Lake Annual Mean TP Concentrations under Select Load Reduction Scenarios.

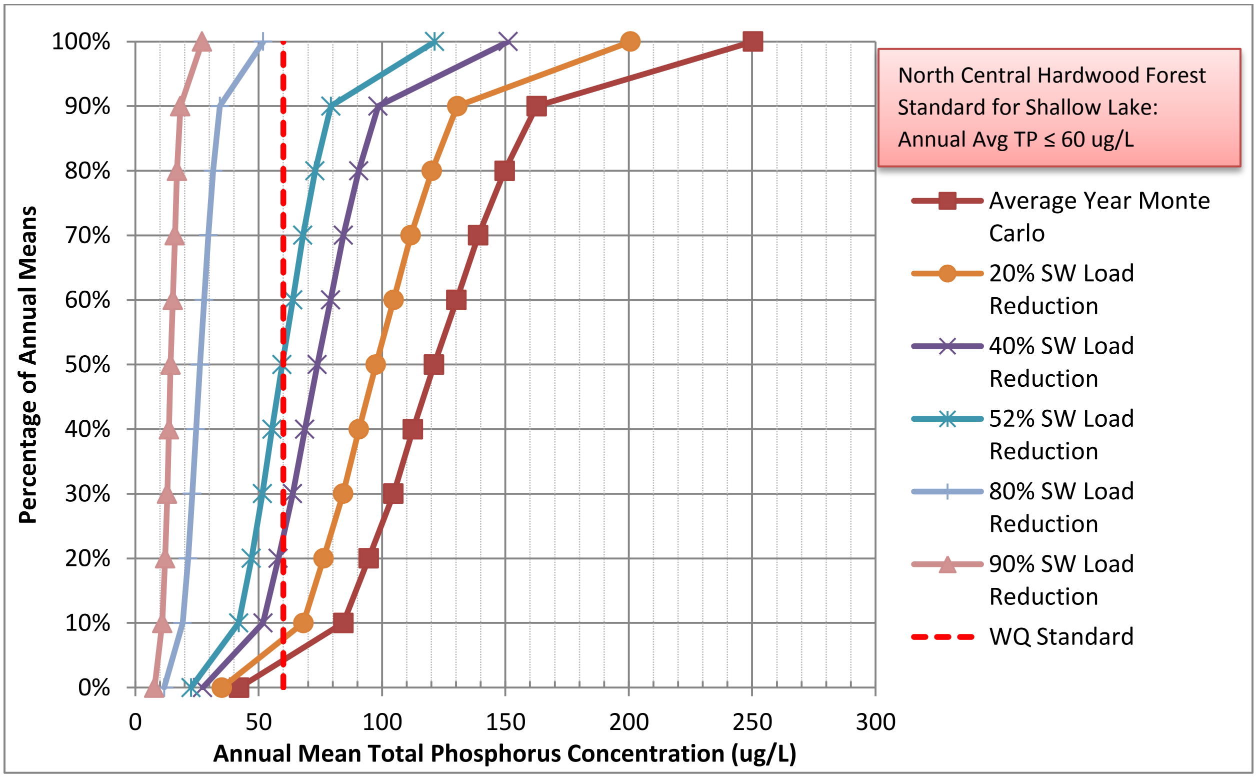

Figure A.16.2. Talac Lake Frequency Distribution of Annual Mean TP Concentrations Resulting from Select Load Reduction Scenarios.

Table A.16.2. Data used to Produce the Annual Mean TP Concentrations (ug/L) Frequency Distribution (Figure A.16.2) for Talac Lake.

Non-Exceedance Percentile	Average Year Monte Carlo	20% Reduction	40% Reduction	52% Reduction	80% Reduction	90% Reduction
Load	901.4 kg	721.1 kg	540.8 kg	432.7 kg	180.3 kg	90.1 kg
Mean	122.9	98.8	74.8	60.3	26.6	14.6
0%	42.2	35.1	27.3	22.6	11.7	7.8
10%	84.4	68.1	51.8	41.9	19.2	11.0
20%	94.6	76.3	58.0	47.1	21.4	12.1
30%	104.7	84.2	63.8	51.6	23.1	13.0
40%	112.6	90.7	68.7	55.4	24.6	13.7
50%	121.1	97.5	73.8	59.5	26.2	14.3
60%	130.2	104.7	79.2	63.8	27.9	15.2
70%	139.0	111.7	84.4	67.9	29.7	16.0
80%	149.7	120.2	90.6	72.9	31.6	16.9
90%	162.7	130.5	98.5	79.3	34.3	18.3
100%	250.4	200.8	151.1	121.4	51.9	27.1

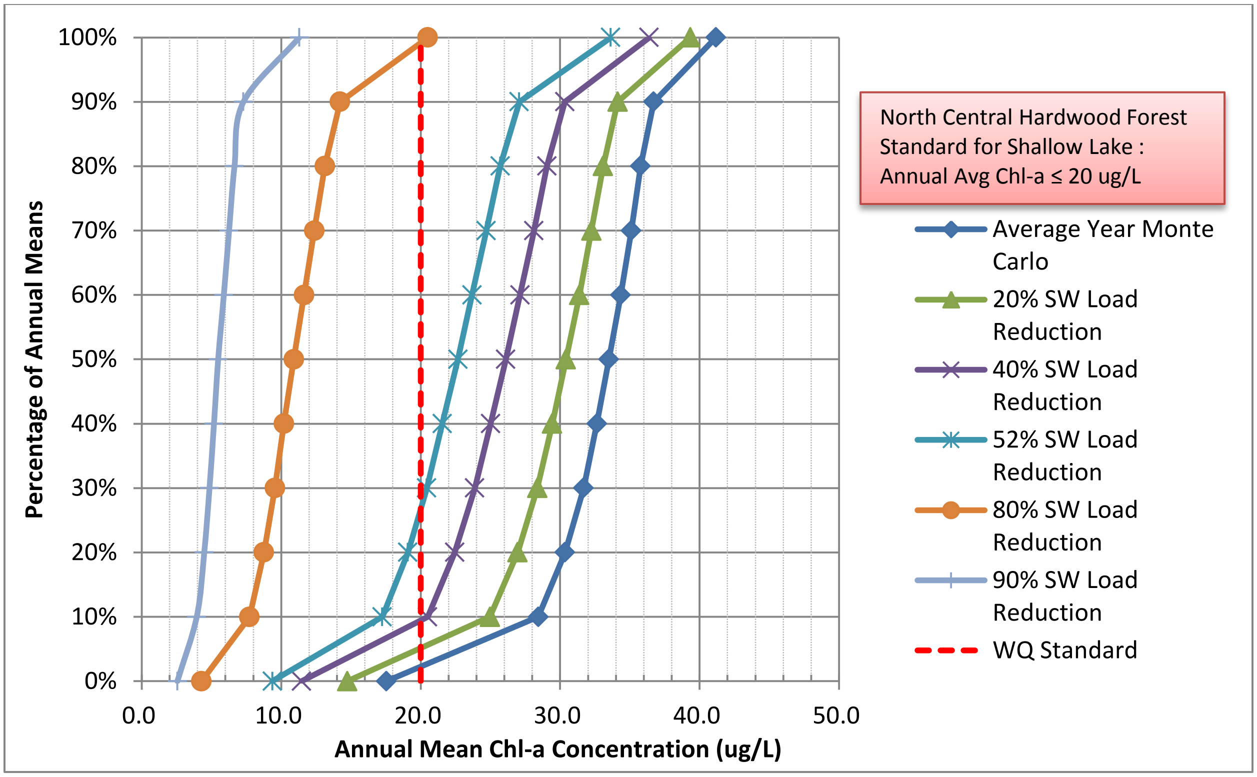

Figure A.16.3 Talac Lake Frequency Distribution of Annual Mean Chl-*a* Concentrations Resulting from Select Load Reduction Scenarios.

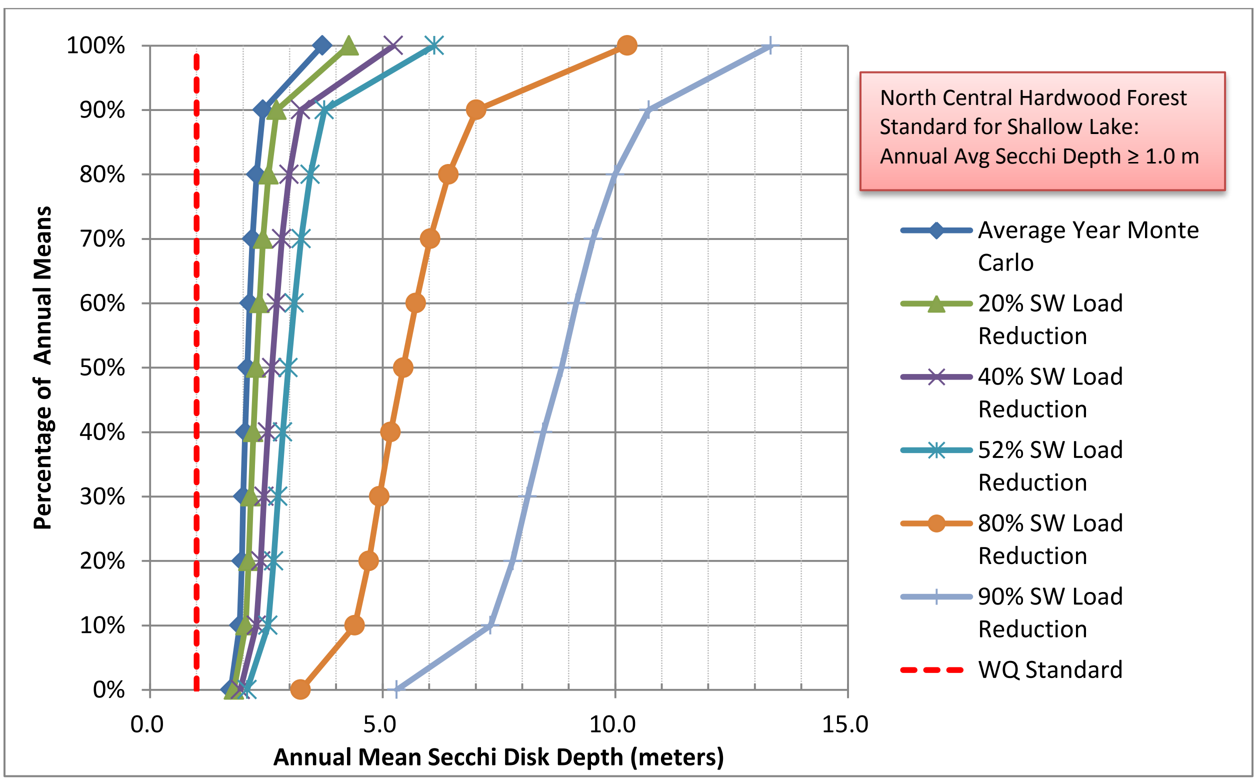

Figure A.16.4. Talac Lake Frequency Distribution of Annual Mean Secchi Disk Depths Resulting from Select Load Reduction Scenarios.

The following figures are results from the Monte Carlo Simulation under load reduction scenarios for Talac Lake where tributary flows are meeting the water quality standard of the upstream lakes (Sand (Stump) Lake and Sorenson (Lee) Lake).

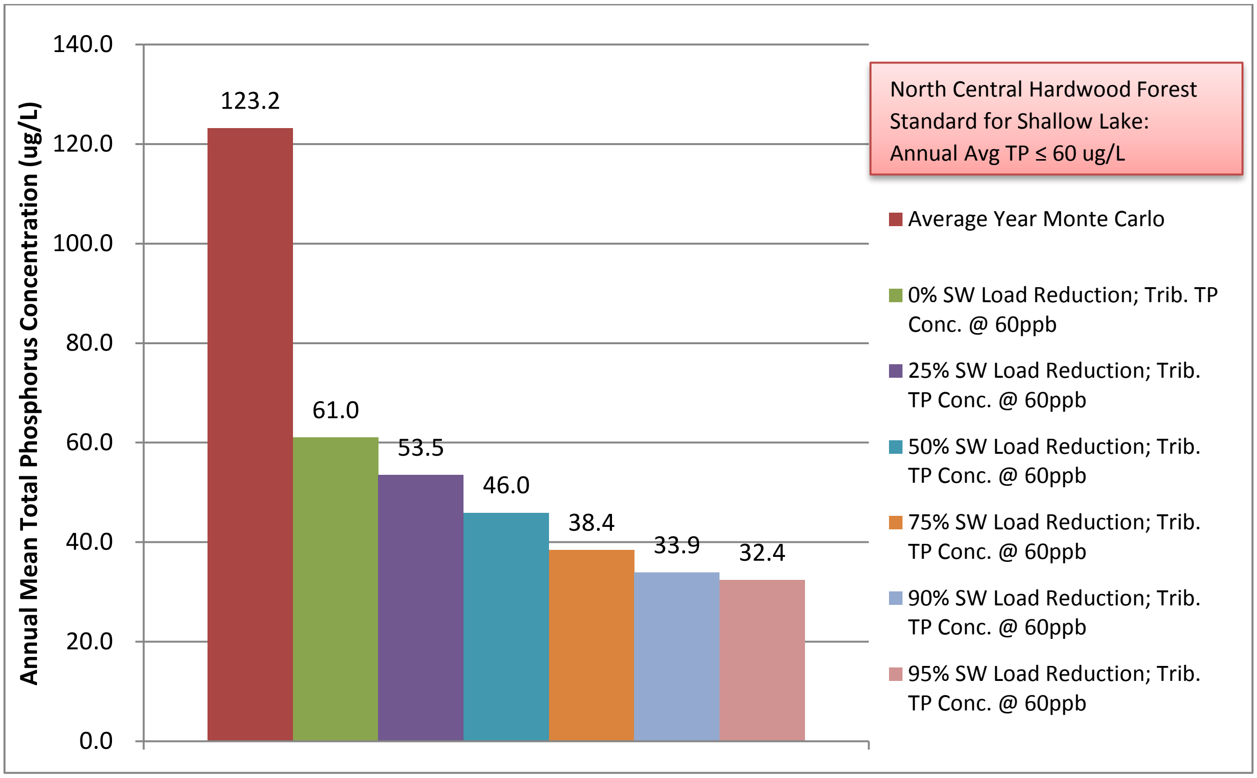

Figure A.16.5. Talac Lake Annual Mean TP Concentrations under Select Load Reduction Scenarios where Tributary Inflows Meet Water Quality Standards (60 ug/L).

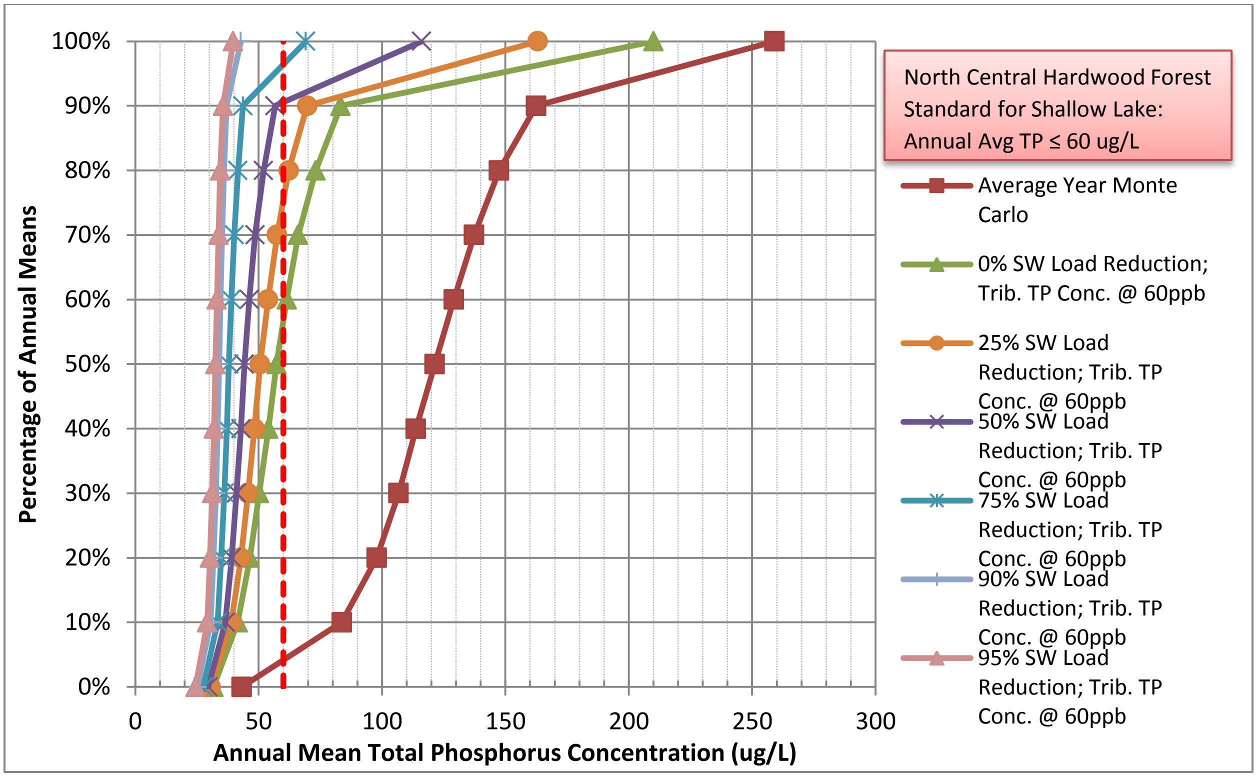

Figure A.16.6. Talac Lake Frequency Distribution of Annual Mean TP Concentrations Resulting from Select Load Reduction Scenarios where Tributary Inflows Meet Water Quality Standards (60 ug/L).

Table A.16.3. Data used to Produce the Annual Mean TP Concentrations (ug/L) Frequency Distribution (Figure A.16.2) for Talac Lake where Tributary Inflows Meet Water Quality Standards (60 ug/L).

Non-Exceedance Percentile	Average Year Monte Carlo	0% Reduction; Trib. TP Conc. @ 60ppb	25% Reduction; Trib. TP Conc. @ 60ppb	50% Reduction; Trib. TP Conc. @ 60ppb	75% Reduction; Trib. TP Conc. @ 60ppb	90% Reduction; Trib. TP Conc. @ 60ppb	95% Reduction; Trib. TP Conc. @ 60ppb
Load	916 kg	916 kg	687 kg	343 kg	86 kg	8.6 kg	0.4 kg
Mean	123.2	61.0	53.5	46.0	38.4	33.9	32.4
0%	43.2	31.7	30.6	29.5	27.6	25.2	24.4
10%	83.7	41.6	39.0	36.5	33.4	30.5	29.2
20%	97.8	46.4	42.8	39.0	34.8	31.7	30.3
30%	106.7	50.2	45.7	41.0	36.1	32.7	31.2
40%	113.7	53.9	48.3	42.8	37.1	33.4	31.9
50%	121.4	57.3	50.6	44.2	37.9	34.0	32.5
60%	129.1	61.4	53.8	46.2	38.9	34.6	33.0
70%	137.3	66.0	57.4	48.6	40.1	35.2	33.8
80%	147.4	73.1	62.2	52.0	41.6	36.0	34.4
90%	162.5	83.2	69.7	56.7	43.6	37.1	35.6
100%	259.1	210.0	163.1	116.1	69.1	42.8	39.7

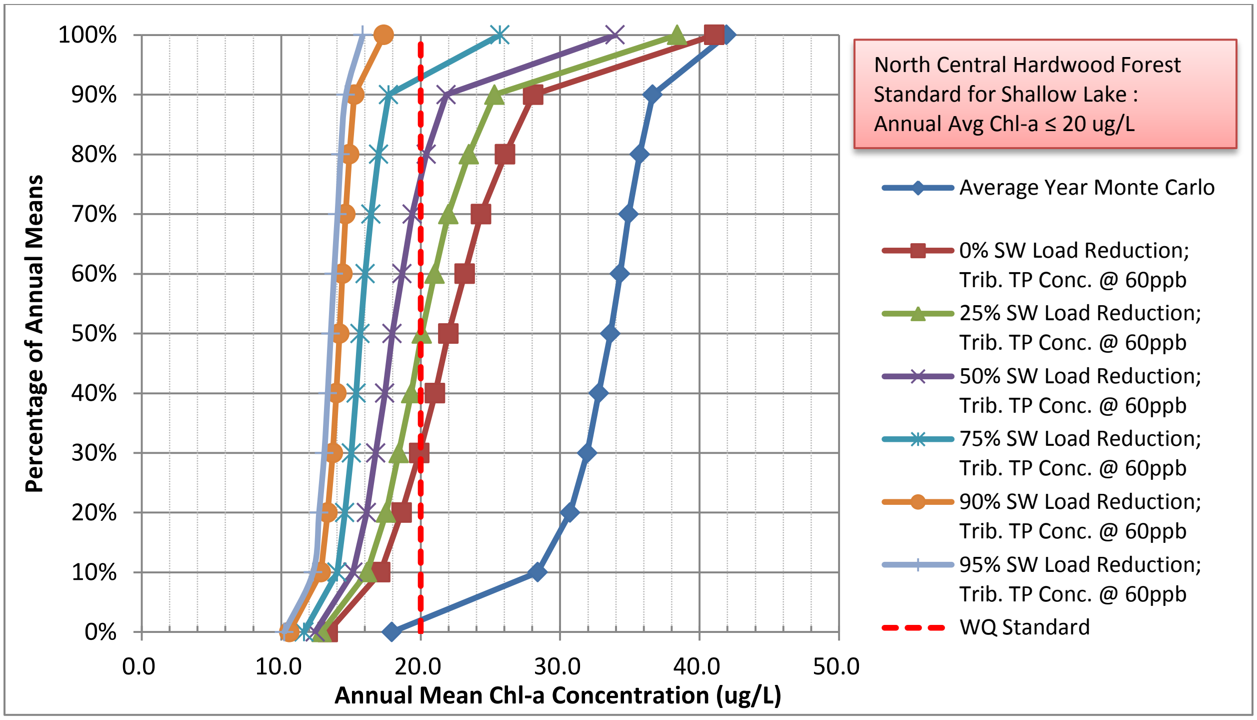

Figure A.16.7 Talac Lake Frequency Distribution of Annual Mean Chl-*a* Concentrations Resulting from Select Load Reduction Scenarios where Tributary Inflows Meet Water Quality Standards (60 ug/L).

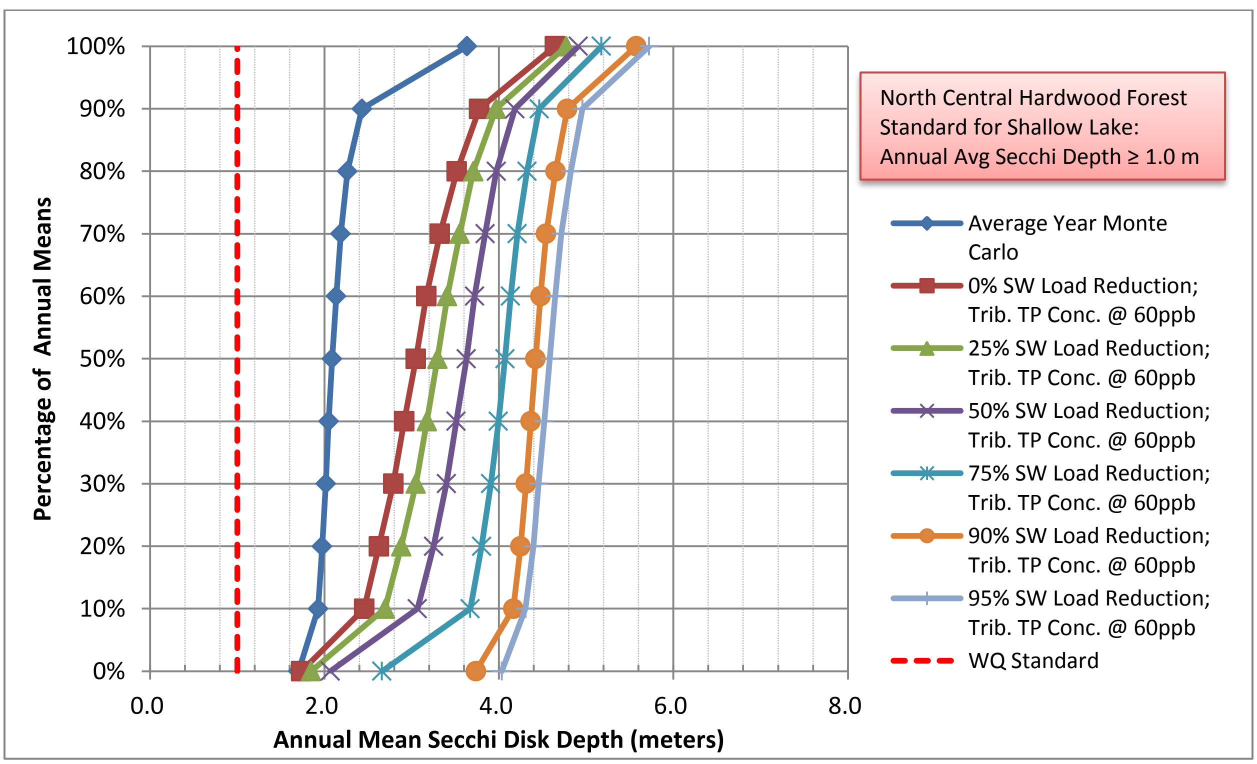

Figure A.16.8. Talac Lake Frequency Distribution of Annual Mean Secchi Disk Depths Resulting from Select Load Reduction Scenarios where Tributary Inflows Meet WQ Standards (60 ug/L).

A.17 West Labelle (Duck) Lake

Table A.17.1. Annual BRW SWAT outputs (1995-2009) for West Labelle (Duck) Lake.

Year	Precipitation (m/yr)	Evaporation (m/yr)	Contributing Drainage Inflow (hm^3/yr)	Contributing Drainage Area Load (kg/yr)	Tributary Flow (hm^3/yr)	Tributary Loading (kg/yr)
1995	0.662	0.778	0.009	2.0	0.08	11.2
1996	0.691	0.865	0.017	3.0	0.13	81.6
1997	0.912	0.908	0.032	15.3	0.31	165.6
1998	0.879	0.991	0.028	4.8	0.24	77.4
1999	0.775	1.001	0.020	1.7	0.14	22.2
2000	0.805	1.021	0.014	1.8	0.08	7.5
2001	0.762	1.010	0.021	5.5	0.17	50.6
2002	0.718	0.962	0.018	4.6	0.12	26.8
2003	0.538	1.072	0.010	0.5	0.05	1.6
2004	0.792	0.971	0.015	2.2	0.09	13.0
2005	0.910	1.016	0.025	6.8	0.17	39.7
2006	0.685	1.045	0.021	6.8	0.15	46.6
2007	0.692	0.945	0.021	6.3	0.17	42.9
2008	1.022	0.885	0.036	15.1	0.27	94.9
2009	0.803	0.910	0.032	11.5	0.26	99.4
Average	**0.777**	**0.959**	**0.021**	**5.9**	**0.16**	**52.1**

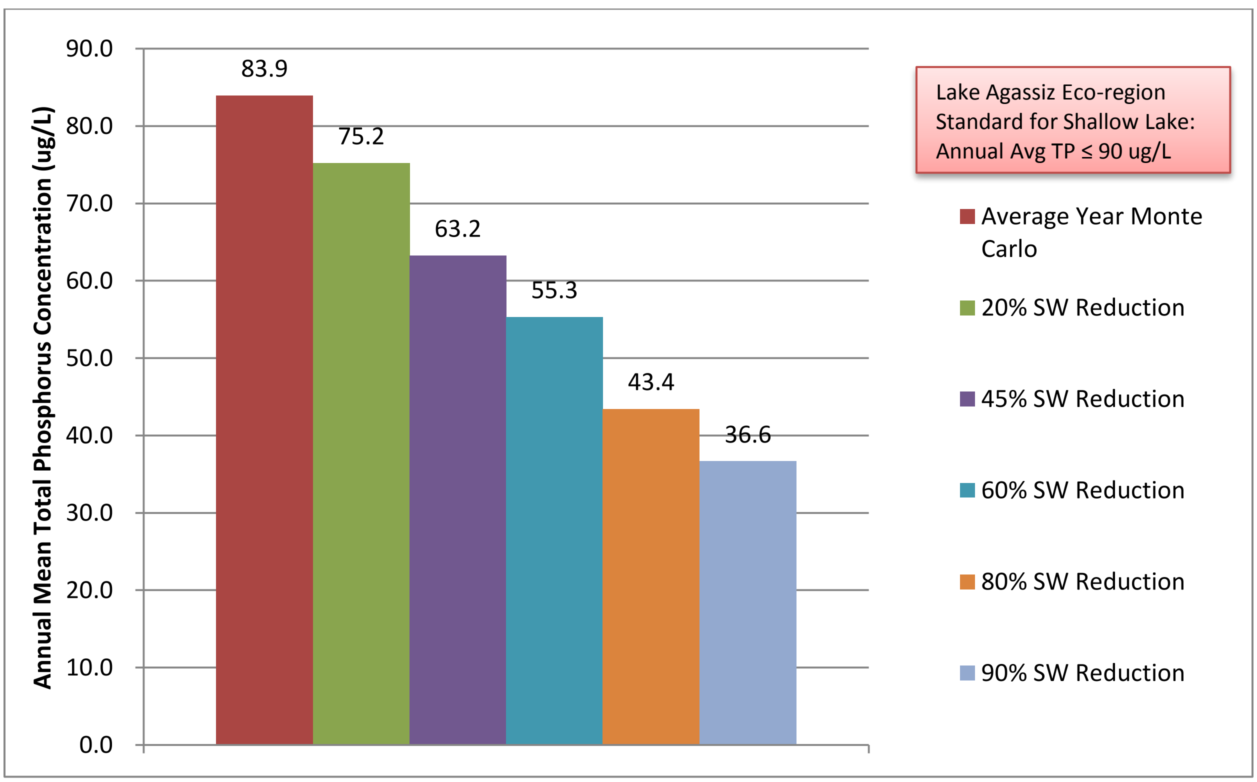

Figure A.17.1. West Labelle (Duck) Lake Annual Mean TP Concentrations under Select Load Reduction Scenarios.

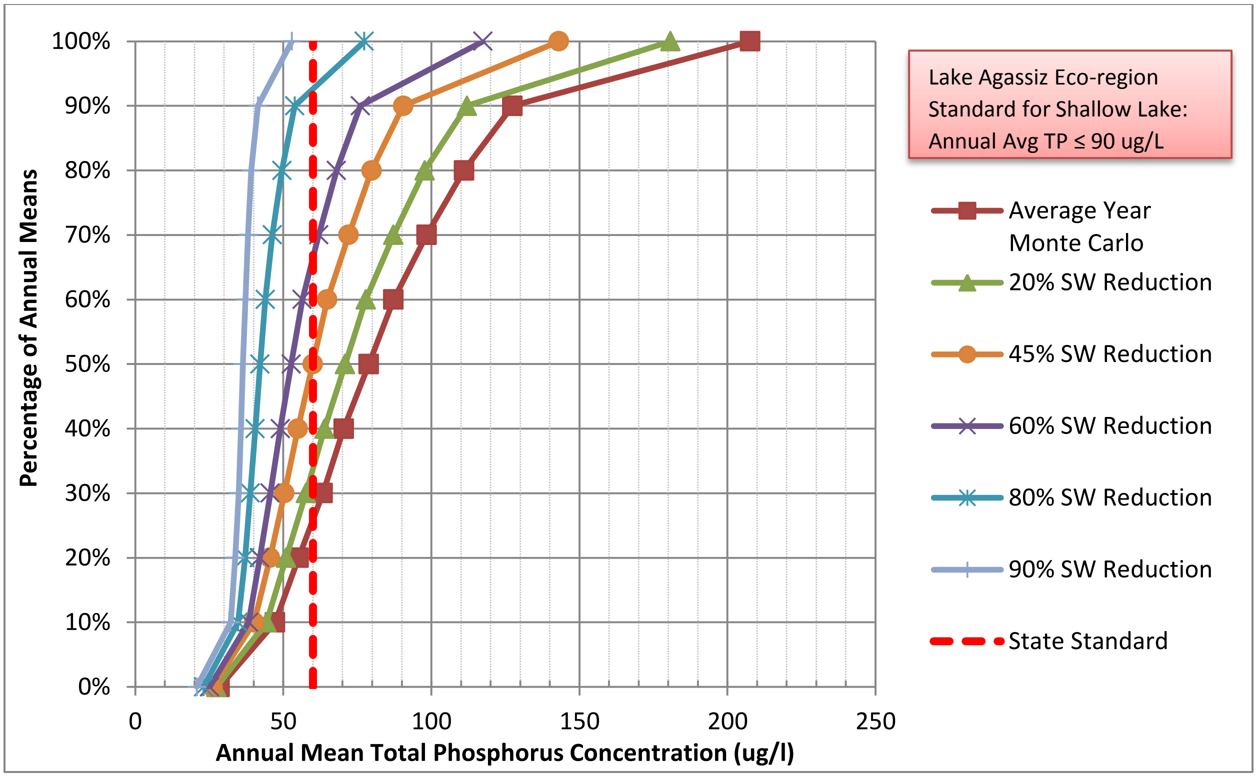

Figure A.17.2. West Labelle (Duck) Lake Frequency Distribution of Annual Mean TP Concentrations Resulting from Select Load Reduction Scenarios.

Table A.17.2. Data used to Produce the Annual Mean TP Concentrations (ug/L) Frequency Distribution (Figure A.17.2) for West Labelle (Duck) Lake.

Non-Exceedance Percentile	Average Year Monte Carlo	20% Reduction	45% Reduction	60% Reduction	80% Reduction	90% Reduction
Load	62.0 kg	49.6 kg	34.1 kg	24.8 kg	12.4 kg	6.2 kg
Mean	83.9	75.2	63.2	55.3	43.4	36.6
0%	28.5	27.4	26.1	25.1	23.1	20.8
10%	47.2	44.4	40.1	38.3	34.7	32.2
20%	55.2	51.0	45.5	42.0	37.1	33.8
30%	63.3	57.7	50.4	45.6	38.8	34.9
40%	70.4	63.9	54.9	49.0	40.5	35.6
50%	78.9	70.9	59.9	52.7	42.1	36.4
60%	87.2	77.8	64.8	56.4	43.9	37.2
70%	98.4	87.2	72.1	62.0	46.3	38.1
80%	111.0	97.8	79.8	67.9	49.5	39.2
90%	127.4	112.0	90.5	76.0	53.9	41.5
100%	207.7	180.7	143.1	117.4	77.4	52.9

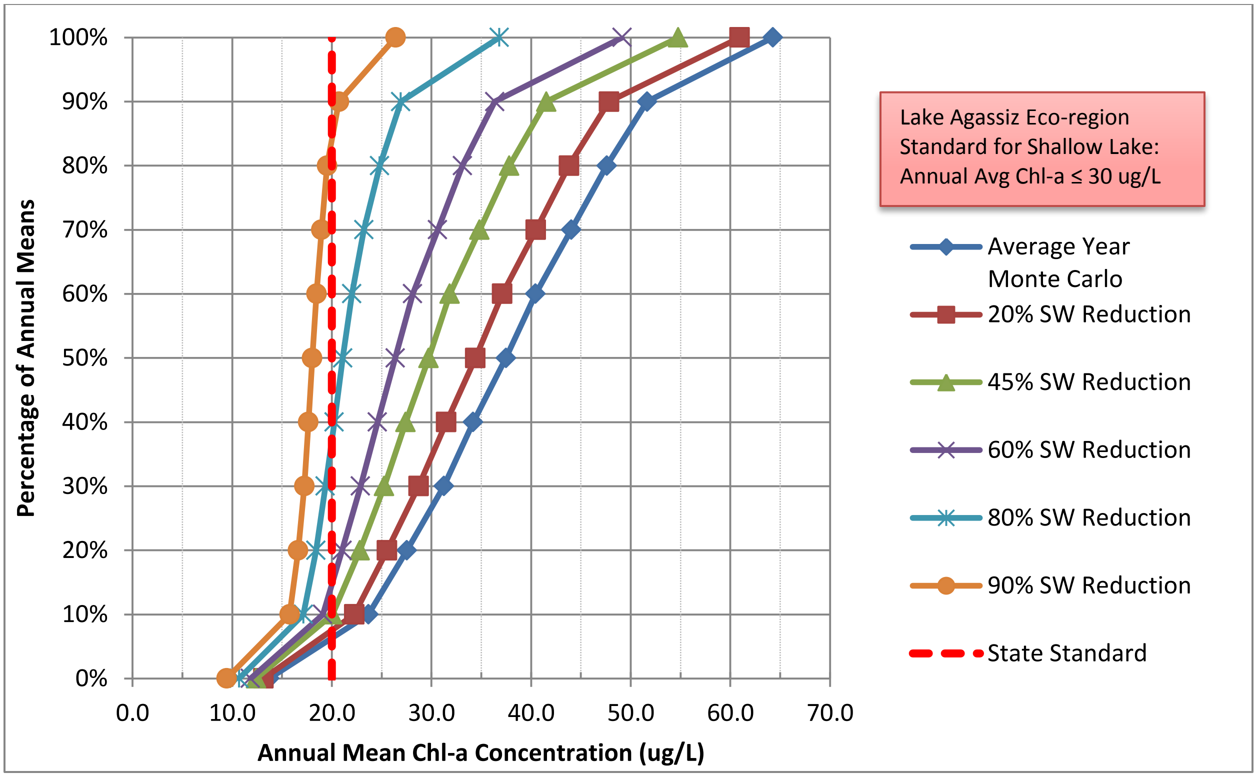

Figure A.17.3 West Labelle (Duck) Lake Frequency Distribution of Annual Mean Chl-*a* Concentrations Resulting from Select Load Reduction Scenarios.

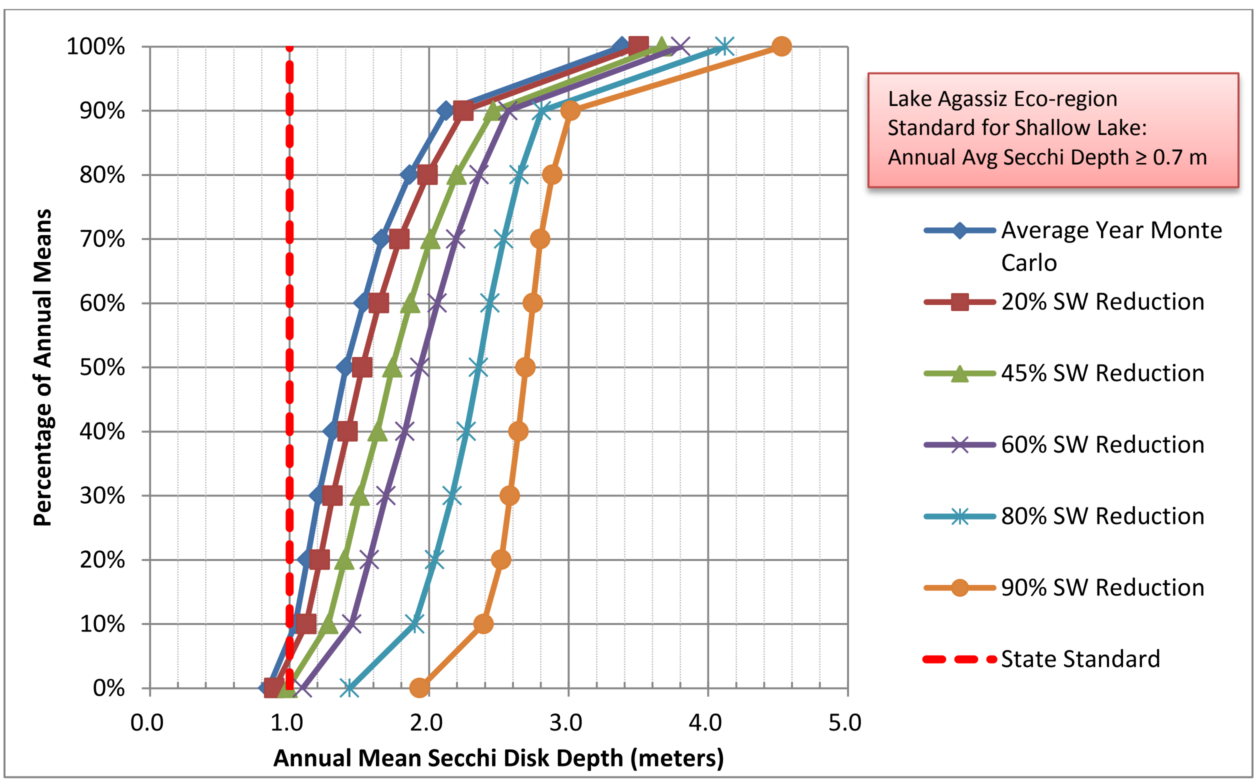

Figure A.17.4. West Labelle (Duck) Lake Frequency Distribution of Annual Mean Secchi Disk Depths Resulting from Select Load Reduction Scenarios.

A.18 Yort (Sand) Lake

Table A.18.1. Annual BRW SWAT outputs (1995-2009) for Yort (Sand) Lake.

Year	Precipitation (m/yr)	Evaporation (m/yr)	Contributing Drainage Inflow (hm^3/yr)	Contributing Drainage Area Load (kg/yr)	Tributary Flow (hm^3/yr)	Tributary Loading (kg/yr)
1995	0.661	0.859	0.080	18	1.40	120
1996	0.691	0.969	0.145	86	2.60	318
1997	0.911	1.010	0.301	125	6.32	912
1998	0.878	1.095	0.311	90	5.81	883
1999	0.774	1.061	0.189	71	3.32	365
2000	0.804	1.058	0.114	25	2.06	212
2001	0.762	1.026	0.270	73	4.96	780
2002	0.717	1.016	0.171	67	2.84	1,188
2003	0.537	1.158	0.067	5	0.24	113
2004	0.791	1.040	0.140	24	2.21	252
2005	0.909	1.085	0.240	117	4.19	964
2006	0.685	1.132	0.200	87	3.38	577
2007	0.691	1.030	0.214	49	3.57	494
2008	1.021	0.933	0.356	236	7.38	1,521
2009	0.802	0.979	0.333	120	6.66	1,009
Average	**0.776**	**1.030**	**0.21**	**79**	**3.80**	**647**

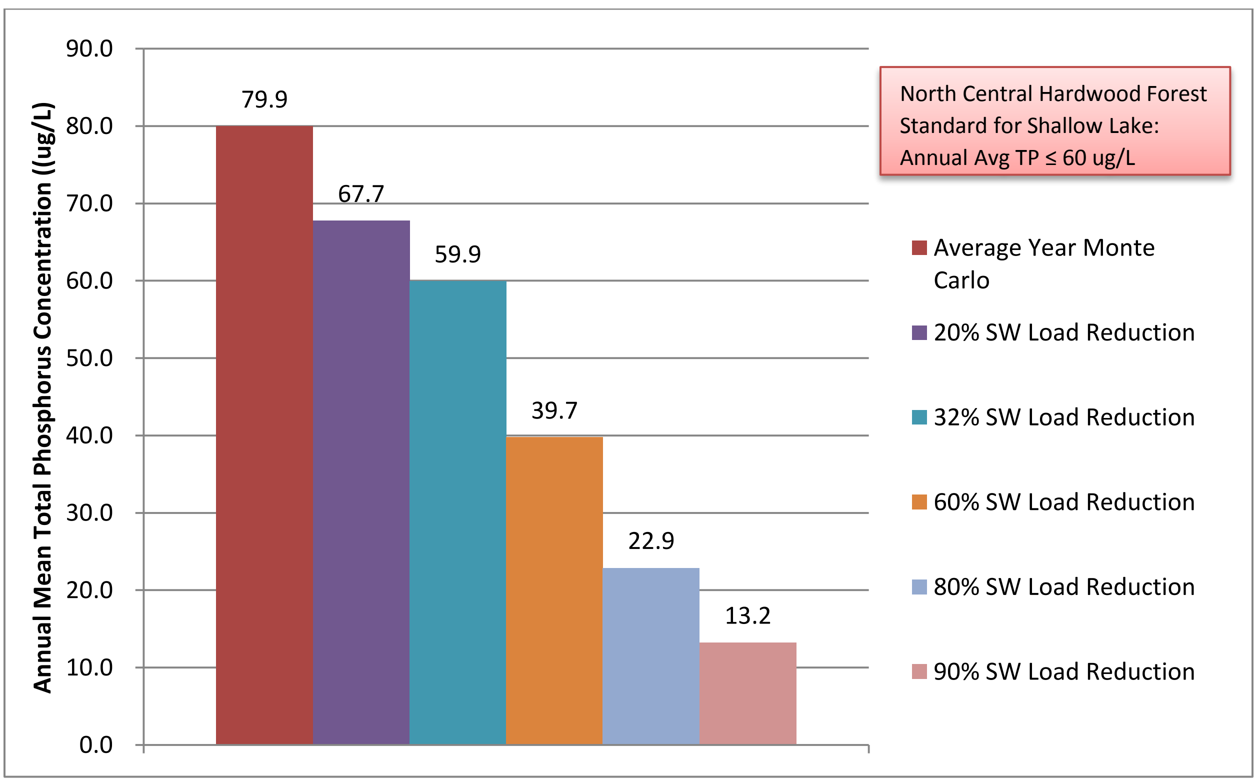

Figure A.18.1. Yort (Sand) Lake Annual Mean TP Concentrations under Select Load Reduction Scenarios.

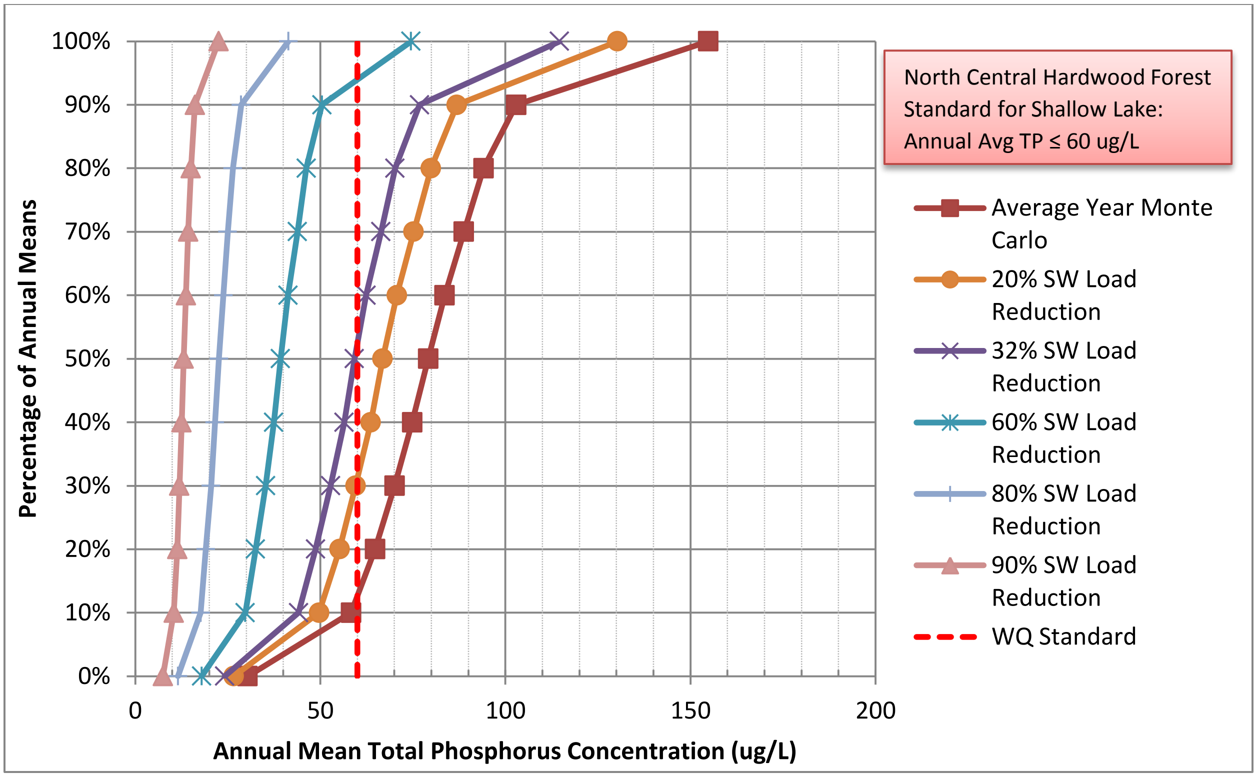

Figure A.18.2. Yort (Sand) Lake Frequency Distribution of Annual Mean TP Concentrations Resulting from Select Load Reduction Scenarios.

Table A.18.2. Data used to Produce the Annual Mean TP Concentrations (ug/L) Frequency Distribution (Figure A.18.2) for Yort (Sand) Lake.

Non-Exceedance Percentile	Average Year Monte Carlo	20% Reduction	32% Reduction	60% Reduction	80% Reduction	90% Reduction
Load	589.0 kg	471.2 kg	400.5 kg	235.6 kg	117.8 kg	58.9 kg
Mean	79.9	67.7	59.9	39.7	22.9	13.2
0%	30.3	26.6	24.2	18.0	11.5	7.5
10%	58.3	49.7	44.1	29.7	17.7	10.4
20%	64.8	55.2	48.7	32.5	19.1	11.4
30%	70.1	59.5	52.8	35.2	20.5	11.9
40%	74.8	63.6	56.4	37.4	21.5	12.5
50%	79.1	66.8	59.2	39.2	22.6	13.1
60%	83.6	70.7	62.4	41.3	23.8	13.7
70%	88.8	75.2	66.4	43.8	25.0	14.3
80%	94.1	79.9	70.2	46.2	26.4	15.0
90%	102.9	86.9	76.8	50.5	28.6	16.1
100%	154.8	130.3	114.6	74.5	41.4	22.5

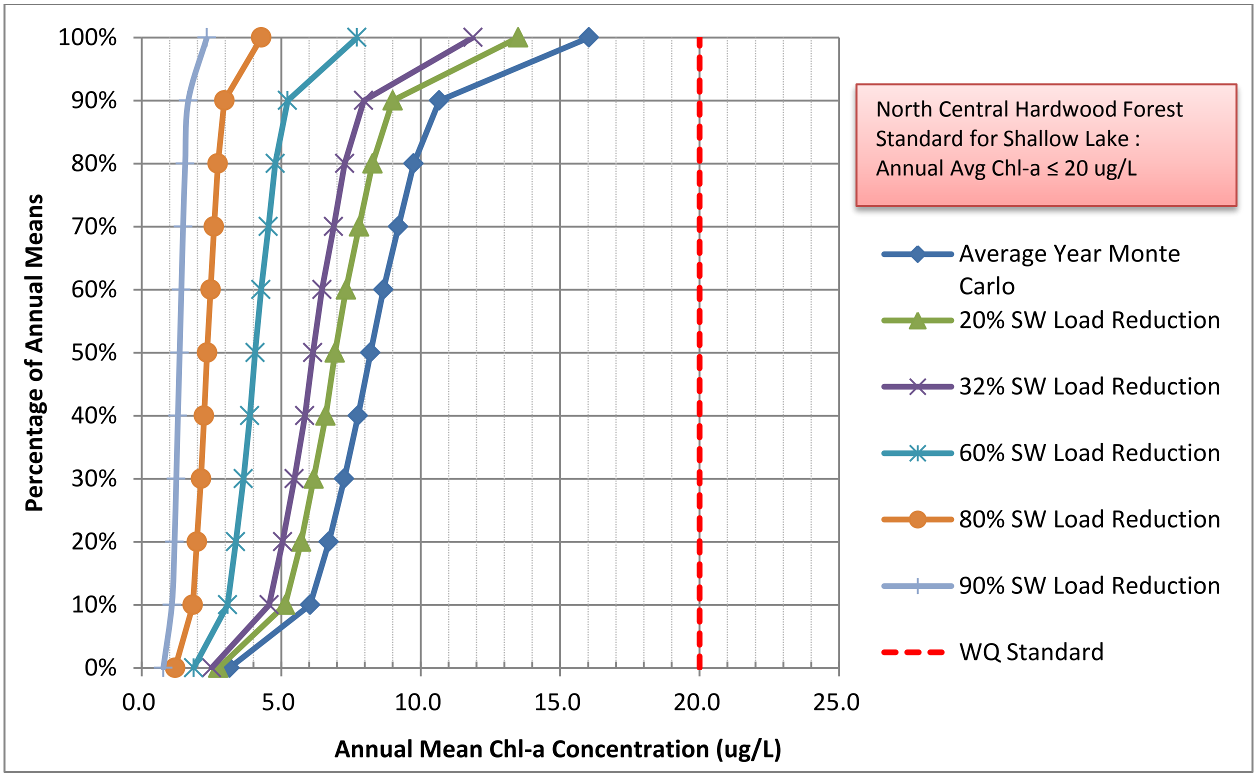

Figure A.18.3 Yort (Sand) Lake Frequency Distribution of Annual Mean Chl-*a* Concentrations Resulting from Select Load Reduction Scenarios.

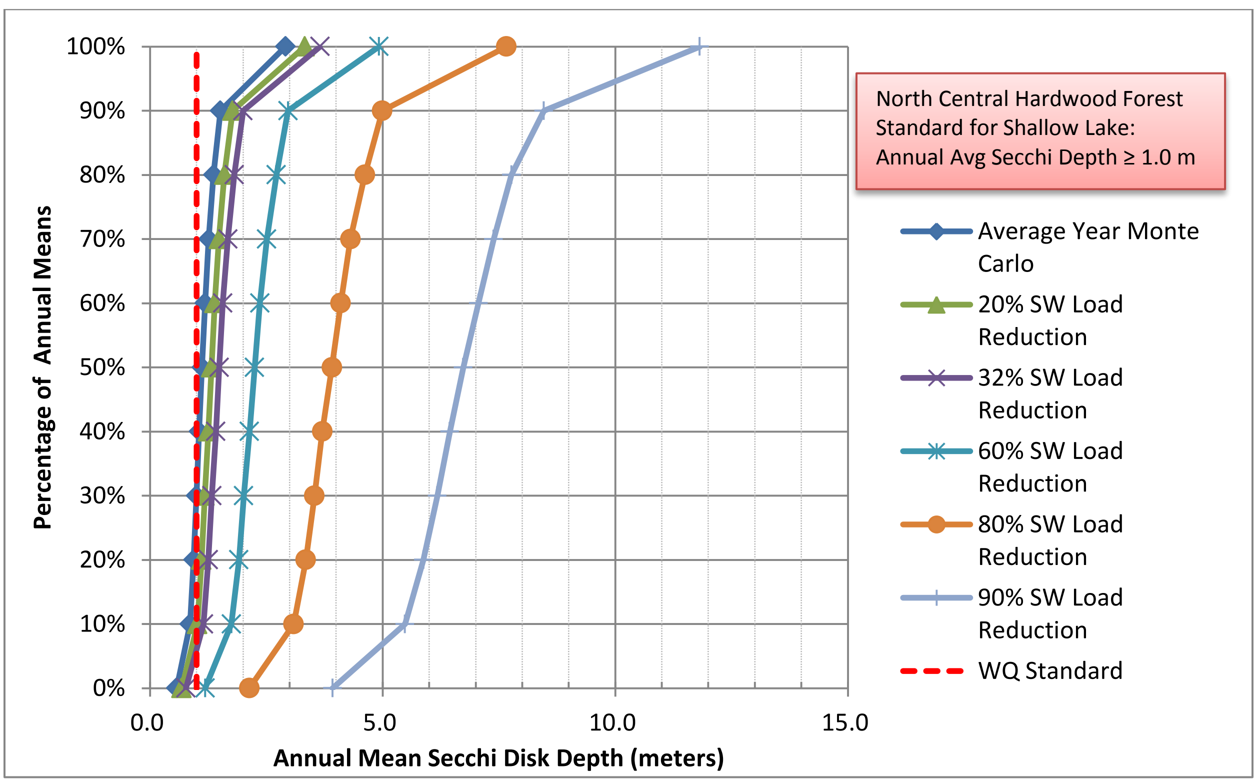

Figure A.18.4. Yort (Sand) Lake Frequency Distribution of Annual Mean Secchi Disk Depths Resulting from Select Load Reduction Scenarios.

The following figures are results from the Monte Carlo Simulation under load reduction scenarios for Yort (Sand) Lake where tributary flows are meeting the water quality standard of the upstream lakes (Talac Lake).

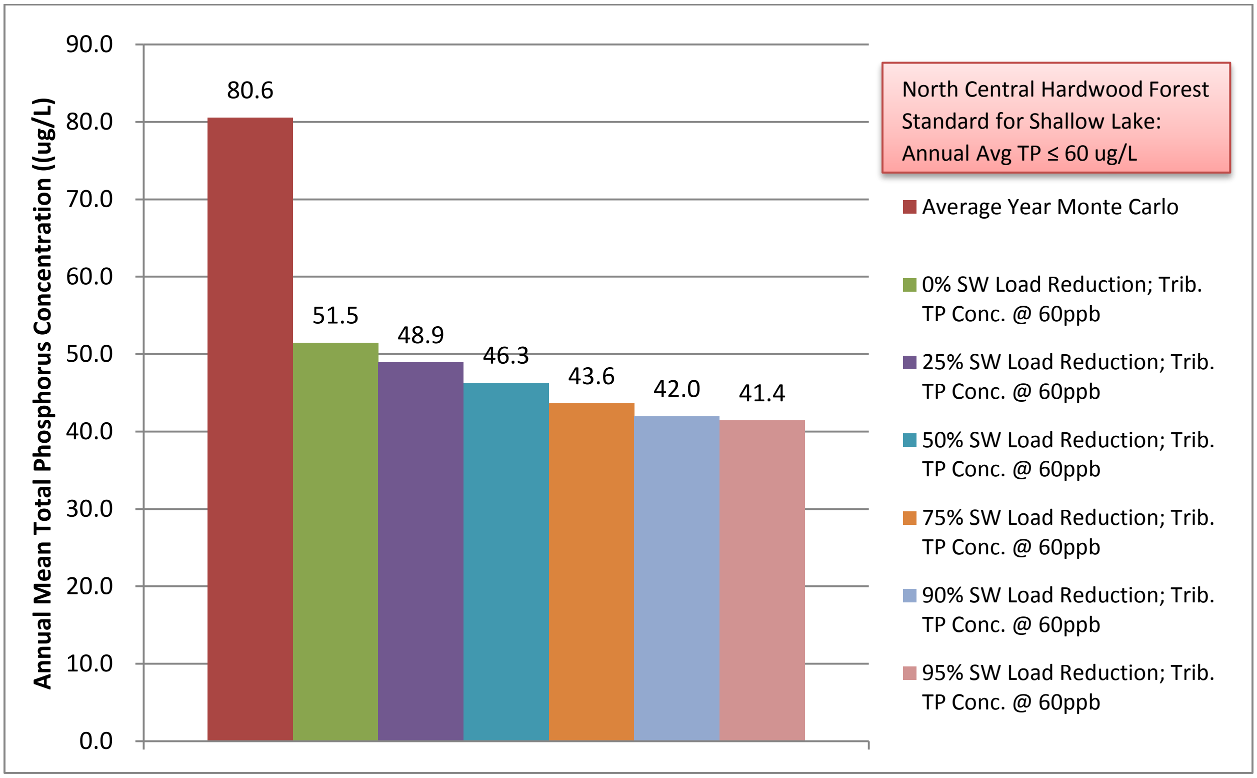

Figure A.18.5. Yort (Sand) Lake Annual Mean TP Concentrations under Select Load Reduction Scenarios where Tributary Inflows Meet Water Quality Standards (60 ug/L).

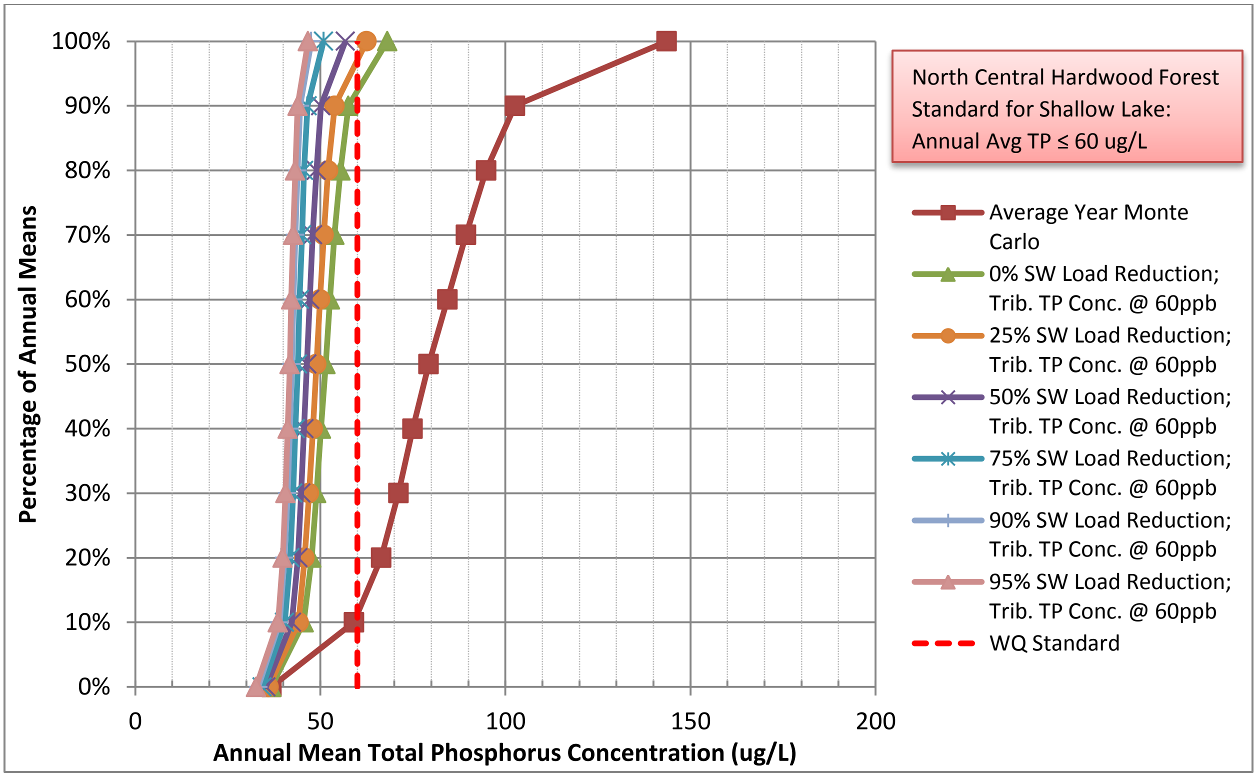

Figure A.18.6. Yort (Sand) Lake Frequency Distribution of Annual Mean TP Concentrations Resulting from Select Load Reduction Scenarios where Tributary Inflows Meet Water Quality Standards (60 ug/L).

Table A.18.3. Data used to Produce the Annual Mean TP Concentrations (ug/L) Frequency Distribution (Figure A.18.2) for Yort (Sand) Lake where Tributary Inflows Meet Water Quality Standards (60 ug/L).

Non-Exceedance Percentile	Average Year Monte Carlo	0% Reduction; Trib. TP Conc. @ 60ppb	25% Reduction; Trib. TP Conc. @ 60ppb	50% Reduction; Trib. TP Conc. @ 60ppb	75% Reduction; Trib. TP Conc. @ 60ppb	90% Reduction; Trib. TP Conc. @ 60ppb	95% Reduction; Trib. TP Conc. @ 60ppb
Load	614 kg	614 kg	460 kg	230 kg	58 kg	5.8 kg	0.3 kg
Mean	80.6	51.5	48.9	46.3	43.6	42.0	41.4
0%	36.8	36.8	36.1	35.3	34.3	33.3	32.6
10%	59.1	45.5	44.1	42.3	40.4	39.0	38.5
20%	66.4	47.6	45.7	43.9	41.8	40.3	39.9
30%	71.1	48.9	47.0	44.8	42.6	41.2	40.6
40%	75.0	50.2	48.0	45.6	43.3	41.8	41.2
50%	79.3	51.4	48.9	46.4	43.9	42.3	41.7
60%	84.3	52.6	49.9	47.2	44.4	42.7	42.2
70%	89.4	53.8	50.9	47.9	45.0	43.2	42.7
80%	94.8	55.5	52.1	49.0	45.6	43.8	43.2
90%	102.6	57.6	53.8	50.1	46.5	44.5	43.9
100%	143.5	68.1	62.5	56.8	50.9	47.6	46.7

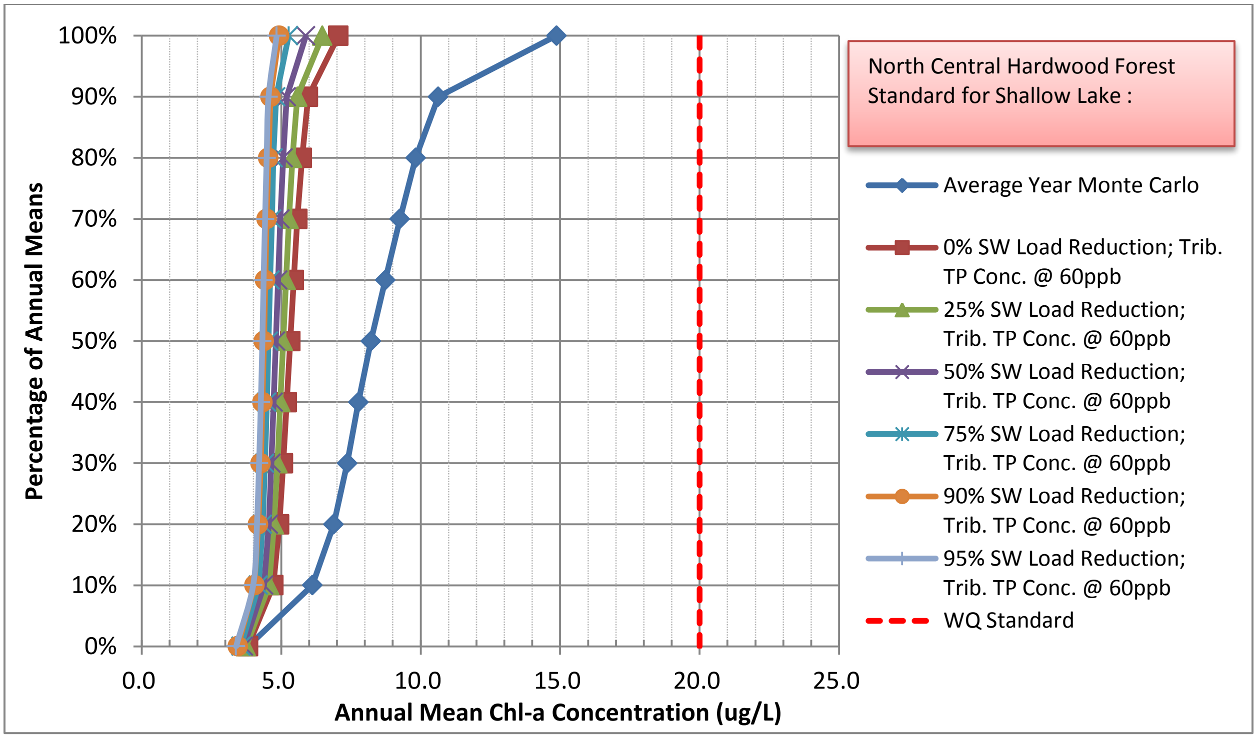

Figure A.18.7 Yort (Sand) Lake Frequency Distribution of Annual Mean Chl-*a* Concentrations Resulting from Select Load Reduction Scenarios where Tributary Inflows Meet Water Quality Standards (60 ug/L).

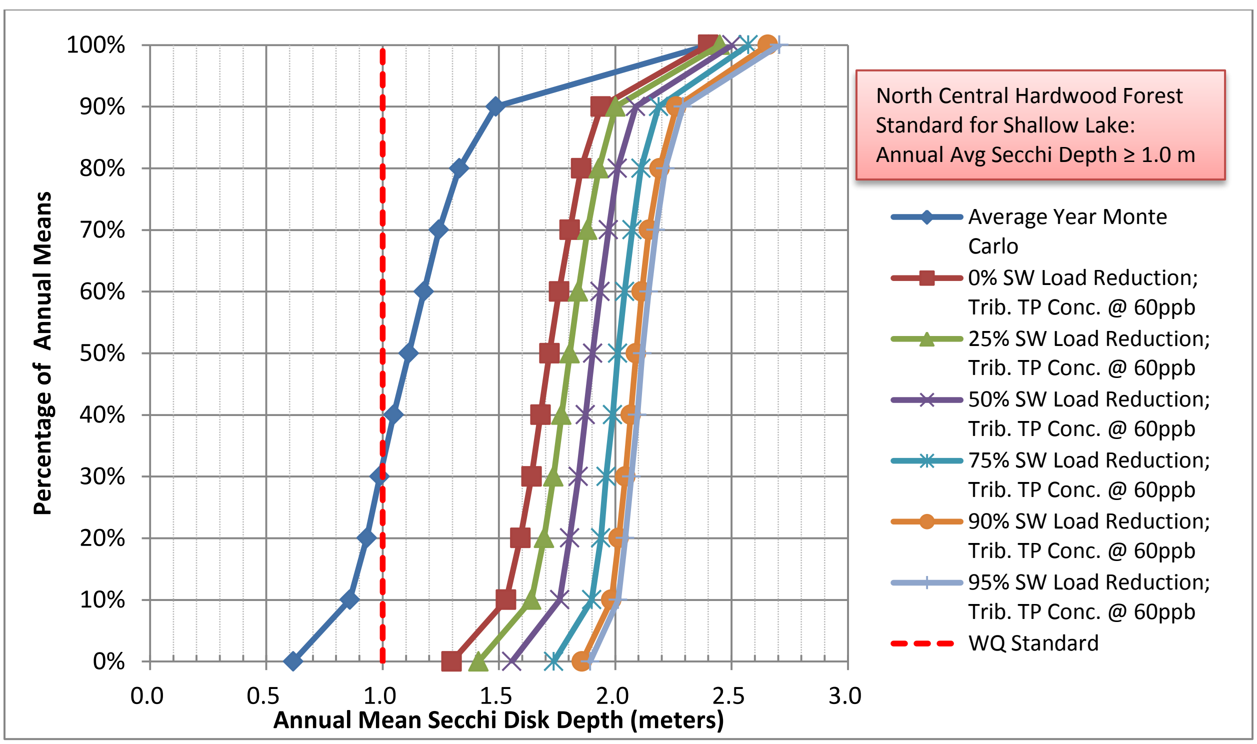

Figure A.18.8. Yort (Sand) Lake Frequency Distribution of Annual Mean Secchi Disk Depths Resulting from Select Load Reduction Scenarios where Tributary Inflows Meet Water Quality Standards (60 ug/L).

A.19 LA-Deep Lake

Table A.19.1. Annual BRW SWAT outputs (1995-2009) for LA-Deeep Lake.

Year	Precipitation (m/yr)	Evaporation (m/yr)	Contributing Drainage Inflow (hm^3/yr)	Contributing Drainage Area Load (kg/yr)	Tributary Flow (hm^3/yr)	Tributary Loading (kg/yr)
1995	0.661	0.737	0.191	166	0.0	0.0
1996	0.691	0.821	0.434	265	0.0	0.0
1997	0.911	0.854	0.978	425	0.0	0.0
1998	0.879	0.940	0.879	764	0.0	0.0
1999	0.775	0.925	0.612	236	0.0	0.0
2000	0.805	0.939	0.428	66	0.0	0.0
2001	0.762	0.916	0.770	641	0.0	0.0
2002	0.717	0.887	0.450	117	0.0	0.0
2003	0.537	1.007	0.237	16	0.0	0.0
2004	0.791	0.905	0.396	193	0.0	0.0
2005	0.910	0.944	0.704	196	0.0	0.0
2006	0.685	0.976	0.597	228	0.0	0.0
2007	0.692	0.884	0.615	389	0.0	0.0
2008	1.021	0.809	1.087	428	0.0	0.0
2009	0.802	0.840	1.003	624	0.0	0.0
Average	**0.776**	**0.892**	**0.63**	**317**	**0.0**	**0.0**

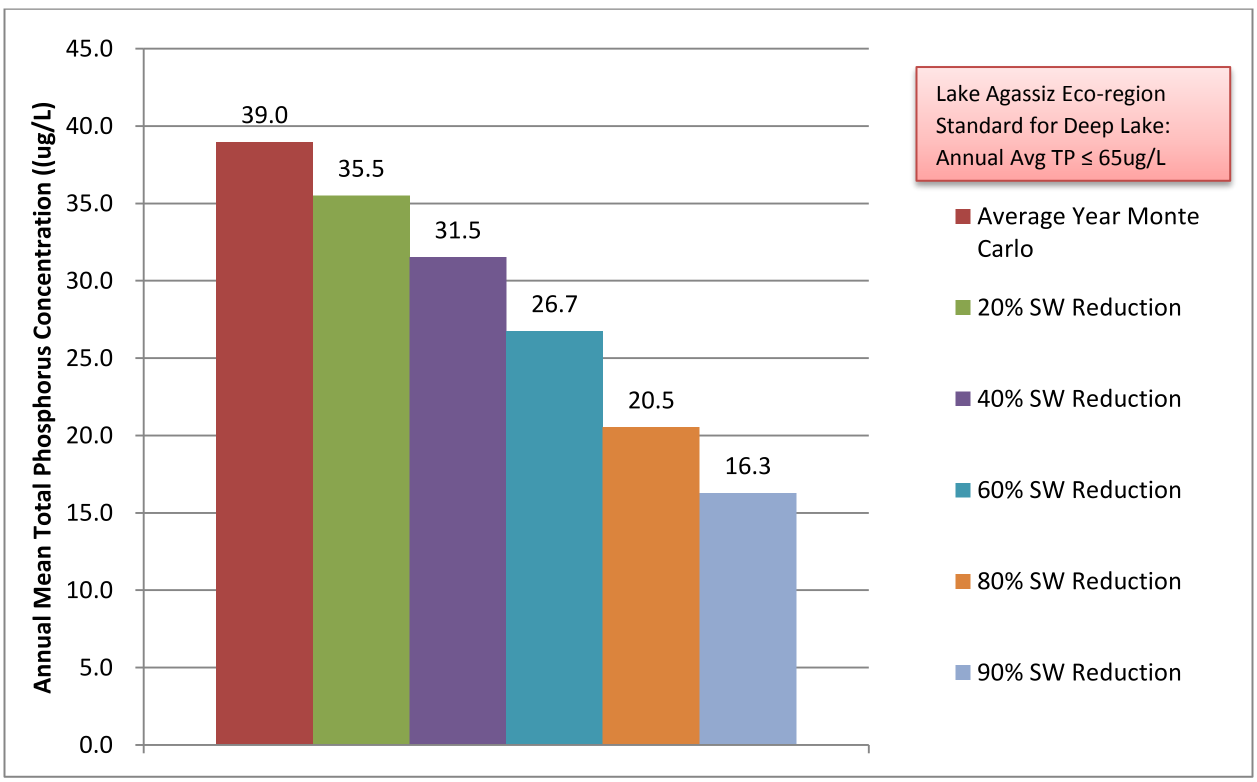

Figure A.19.1. LA-Deeep Lake Annual Mean TP Concentrations under Select Load Reduction Scenarios.

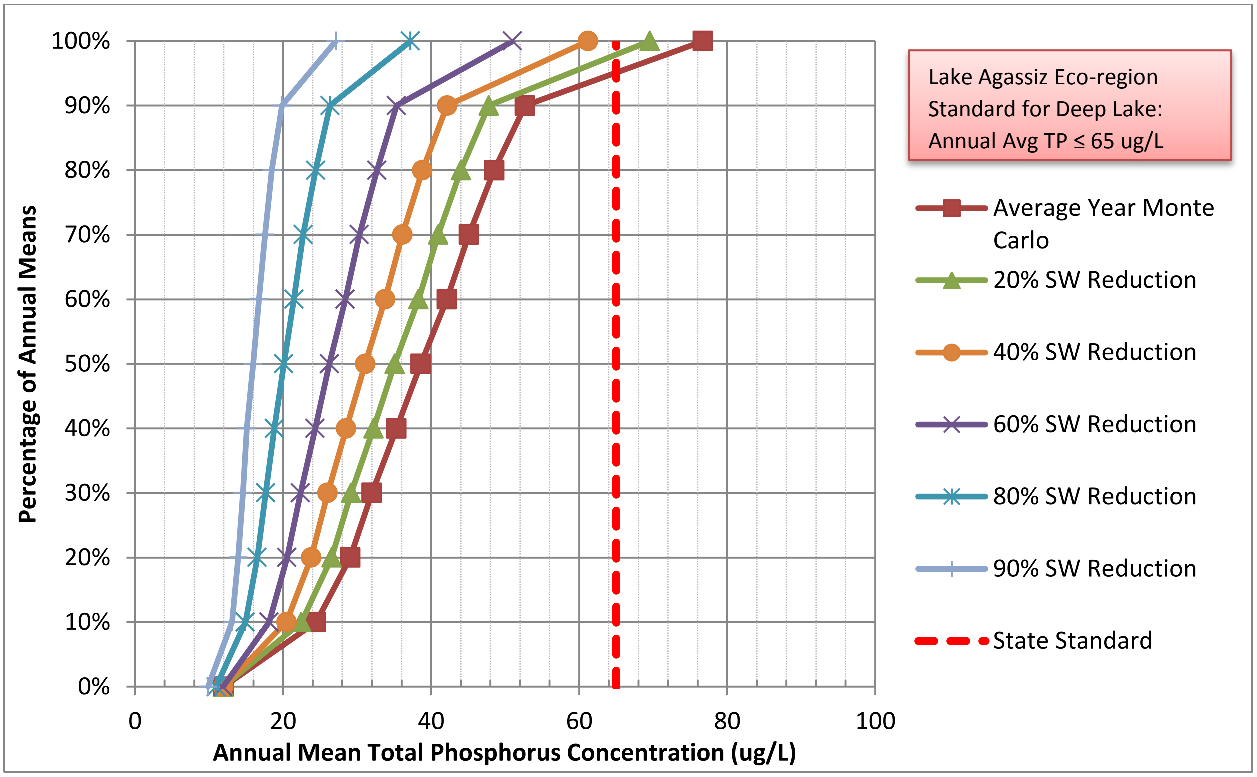

Figure A.19.2. LA-Deeep Lake Frequency Distribution of Annual Mean TP Concentrations Resulting from Select Load Reduction Scenarios.

Table A.19.2. Data used to Produce the Annual Mean TP Concentrations (ug/L) Frequency Distribution (Figure A.19.2) for LA-Deeep Lake.

Non-Exceedance Percentile	Average Year Monte Carlo	20% Reduction	40% Reduction	60% Reduction	80% Reduction	90% Reduction
Load	321.1 kg	256.9 kg	192.6 kg	128.4 kg	64.2 kg	32.1 kg
Mean	39.0	35.5	31.5	26.7	20.5	16.3
0%	12.0	11.9	11.9	11.9	11.0	9.9
10%	24.5	22.5	20.5	18.1	14.9	13.1
20%	29.1	26.6	23.8	20.5	16.5	13.9
30%	32.0	29.2	26.0	22.4	17.7	14.6
40%	35.3	32.2	28.5	24.3	18.8	15.1
50%	38.6	35.1	31.1	26.3	20.1	16.0
60%	42.1	38.3	33.8	28.4	21.5	16.7
70%	45.1	41.0	36.1	30.3	22.7	17.6
80%	48.5	44.0	38.8	32.7	24.4	18.5
90%	52.7	47.8	42.2	35.3	26.3	19.8
100%	76.7	69.5	61.2	51.0	37.2	27.1

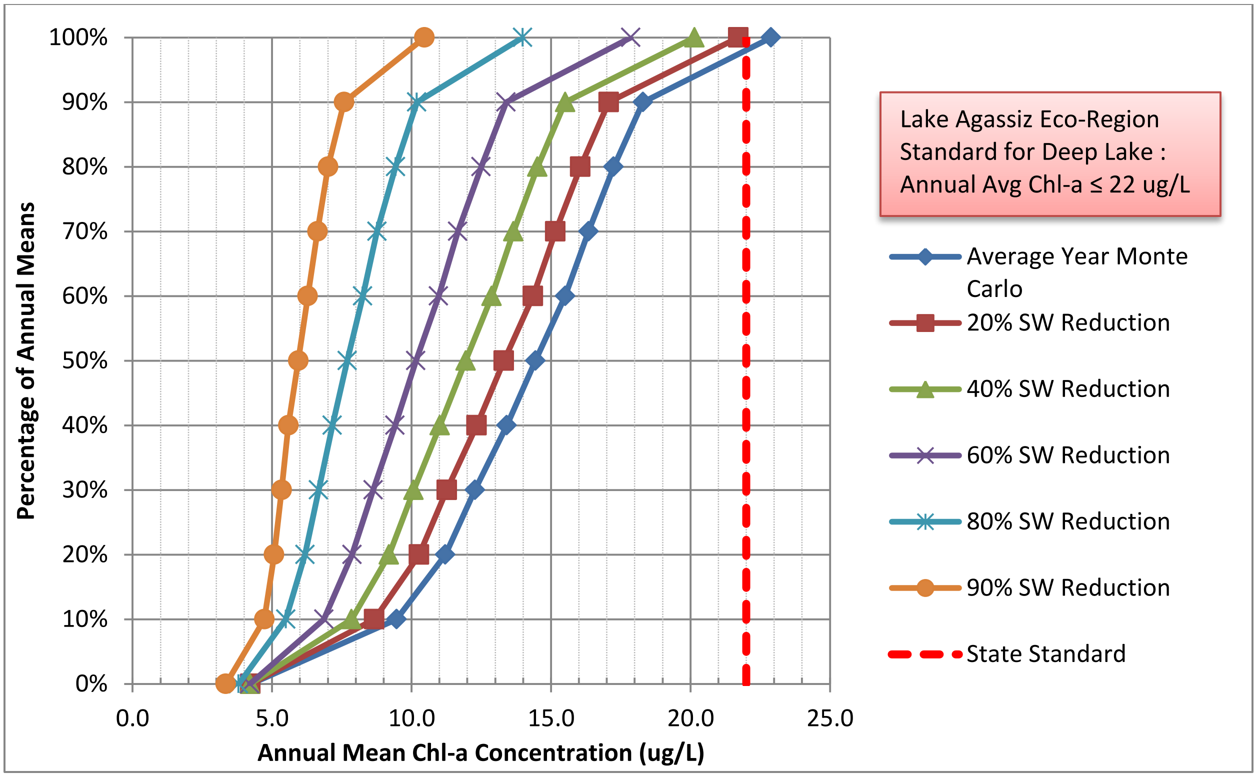

Figure A.19.3 LA-Deeep Lake Frequency Distribution of Annual Mean Chl-*a* Concentrations Resulting from Select Load Reduction Scenarios.

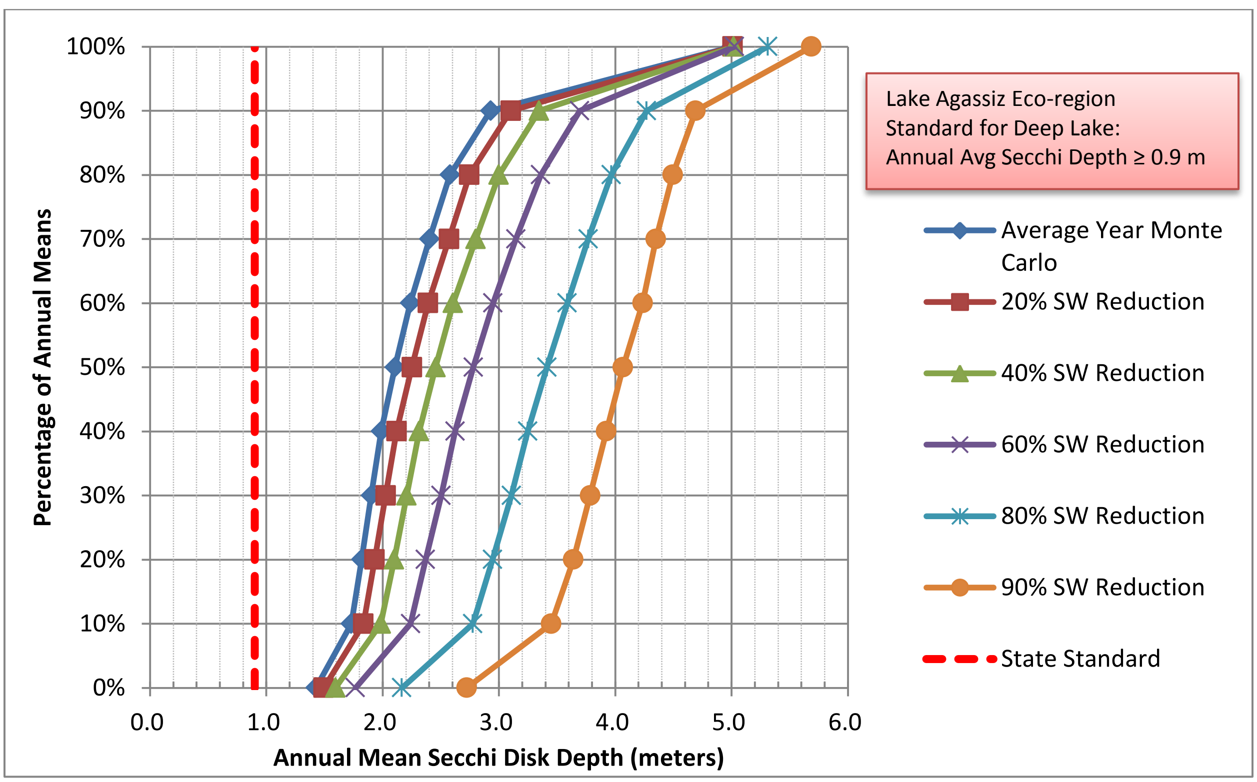

Figure A.19.4. LA-Deeep Lake Frequency Distribution of Annual Mean Secchi Disk Depths Resulting from Select Load Reduction Scenarios.

A.20 LA-Shallow Lake

Table A.20.1. Annual BRW SWAT outputs (1995-2009) for LA-Shallow Lake.

Year	Precipitation (m/yr)	Evaporation (m/yr)	Contributing Drainage Inflow (hm^3/yr)	Contributing Drainage Area Load (kg/yr)	Tributary Flow (hm^3/yr)	Tributary Loading (kg/yr)
1995	0.650	0.701	0.190	76	0.0	0.0
1996	0.657	0.775	0.344	418	0.0	0.0
1997	0.902	0.799	0.697	802	0.0	0.0
1998	0.877	0.891	0.683	505	0.0	0.0
1999	0.756	0.867	0.372	235	0.0	0.0
2000	0.789	0.887	0.217	113	0.0	0.0
2001	0.719	0.866	0.470	261	0.0	0.0
2002	0.695	0.843	0.292	241	0.0	0.0
2003	0.532	0.953	0.080	33	0.0	0.0
2004	0.798	0.857	0.260	165	0.0	0.0
2005	0.872	0.896	0.447	428	0.0	0.0
2006	0.656	0.927	0.346	417	0.0	0.0
2007	0.684	0.824	0.399	279	0.0	0.0
2008	0.975	0.757	0.701	766	0.0	0.0
2009	0.783	0.773	0.656	767	0.0	0.0
Average	**0.756**	**0.841**	**0.41**	**367**	**0.0**	**0.0**

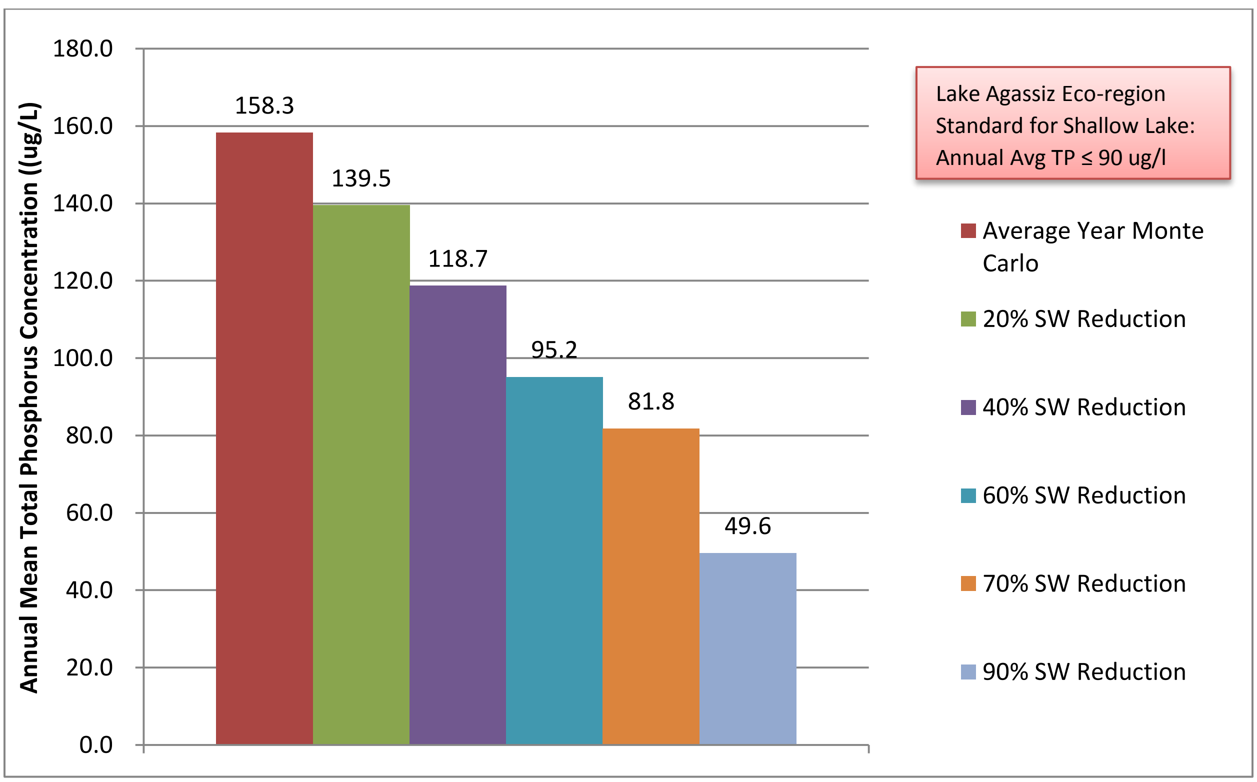

Figure A.20.1. LA-Shallow Lake Annual Mean TP Concentrations under Select Load Reduction Scenarios.

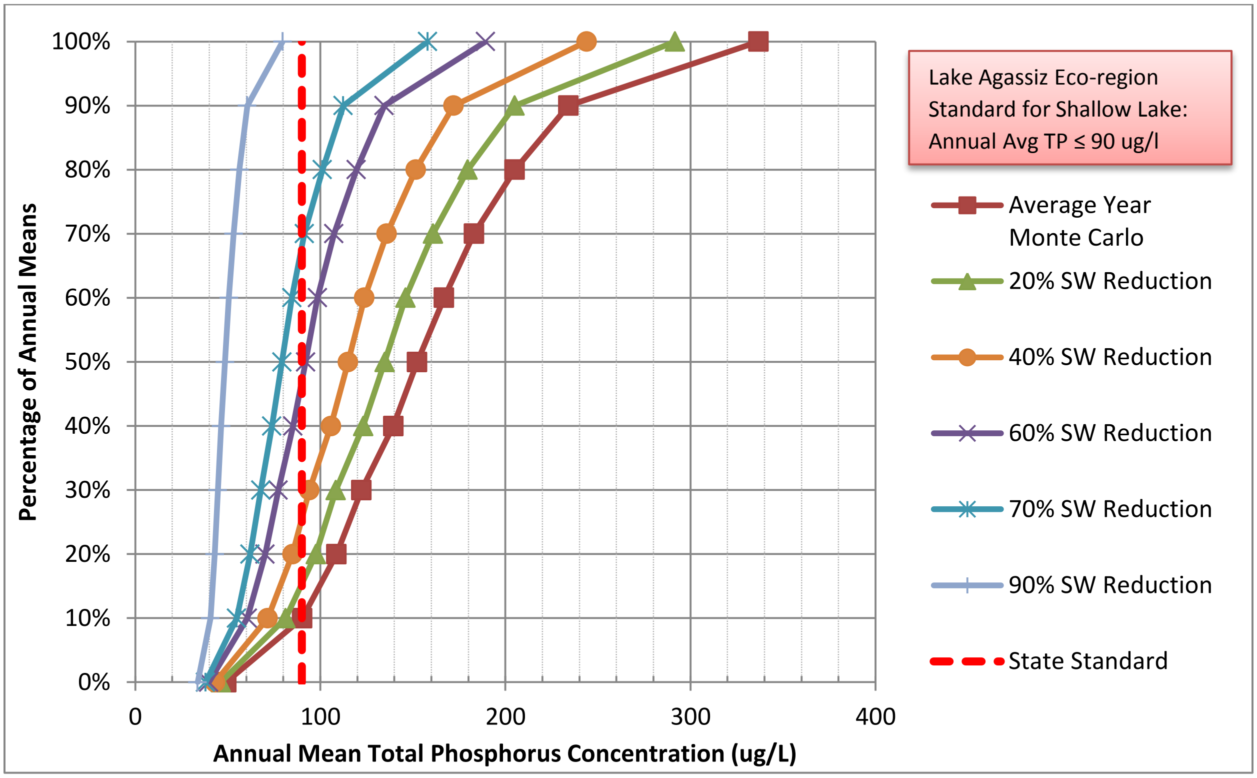

Figure A.20.2. LA-Shallow Lake Frequency Distribution of Annual Mean TP Concentrations Resulting from Select Load Reduction Scenarios.

Table A.20.2. Data used to Produce the Annual Mean TP Concentrations (ug/L) Frequency Distribution (Figure A.20.2) for LA-Shallow Lake.

Non-Exceedance Percentile	Average Year Monte Carlo	20% Reduction	40% Reduction	60% Reduction	70% Reduction	90% Reduction
Load	380.5 kg	304.4 kg	228.3 kg	152.2 kg	114.1 kg	38. kg
Mean	158.3	139.5	118.7	95.2	81.8	49.6
0%	49.2	46.3	43.1	39.8	38.0	33.7
10%	90.3	81.3	71.6	60.6	54.8	40.7
20%	108.8	97.6	85.0	70.2	62.1	42.9
30%	122.2	108.4	94.0	77.3	67.8	44.6
40%	139.4	123.2	105.7	85.2	73.8	46.5
50%	152.4	134.8	115.0	92.0	79.3	48.5
60%	166.8	146.0	123.8	98.4	84.6	50.6
70%	183.0	160.9	135.9	107.4	91.4	53.1
80%	205.0	179.6	151.6	119.5	101.1	56.2
90%	234.0	205.1	172.1	134.6	112.4	60.6
100%	336.8	291.6	243.9	189.3	157.9	79.6

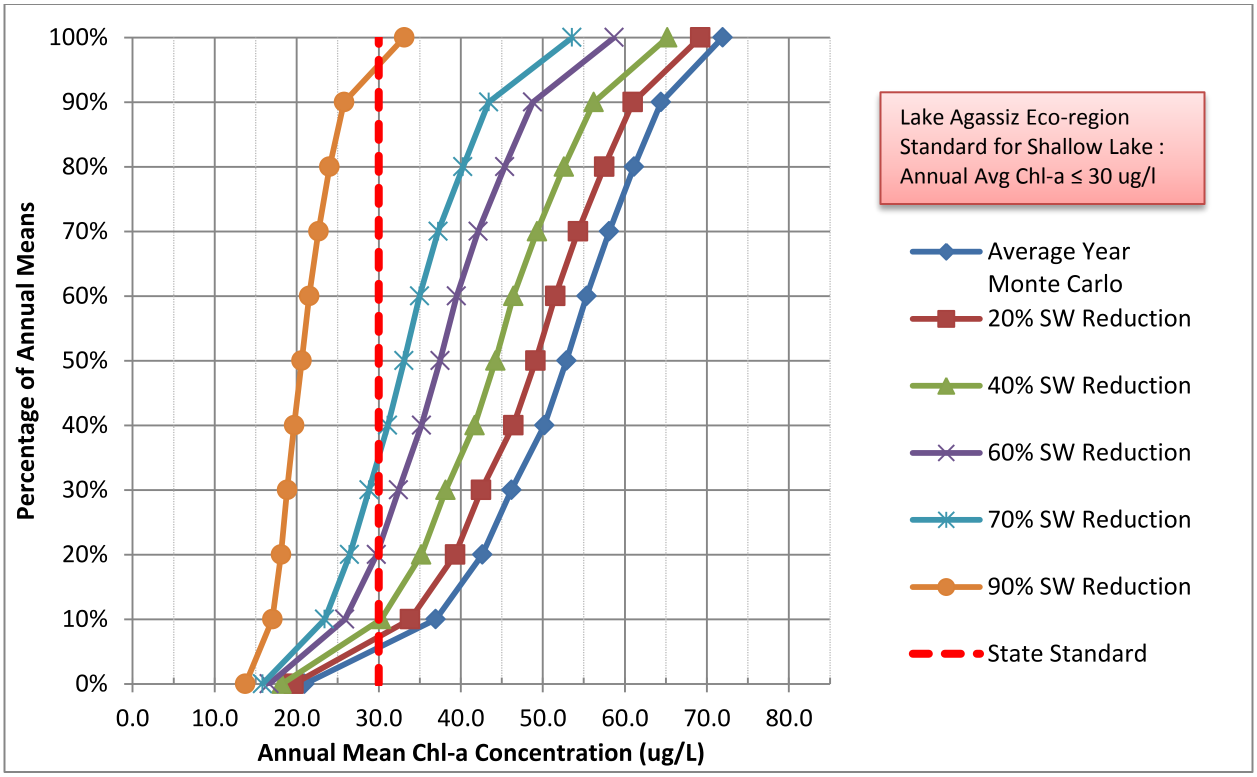

Figure A.20.3 LA-Shallow Lake Frequency Distribution of Annual Mean Chl-*a* Concentrations Resulting from Select Load Reduction Scenarios.

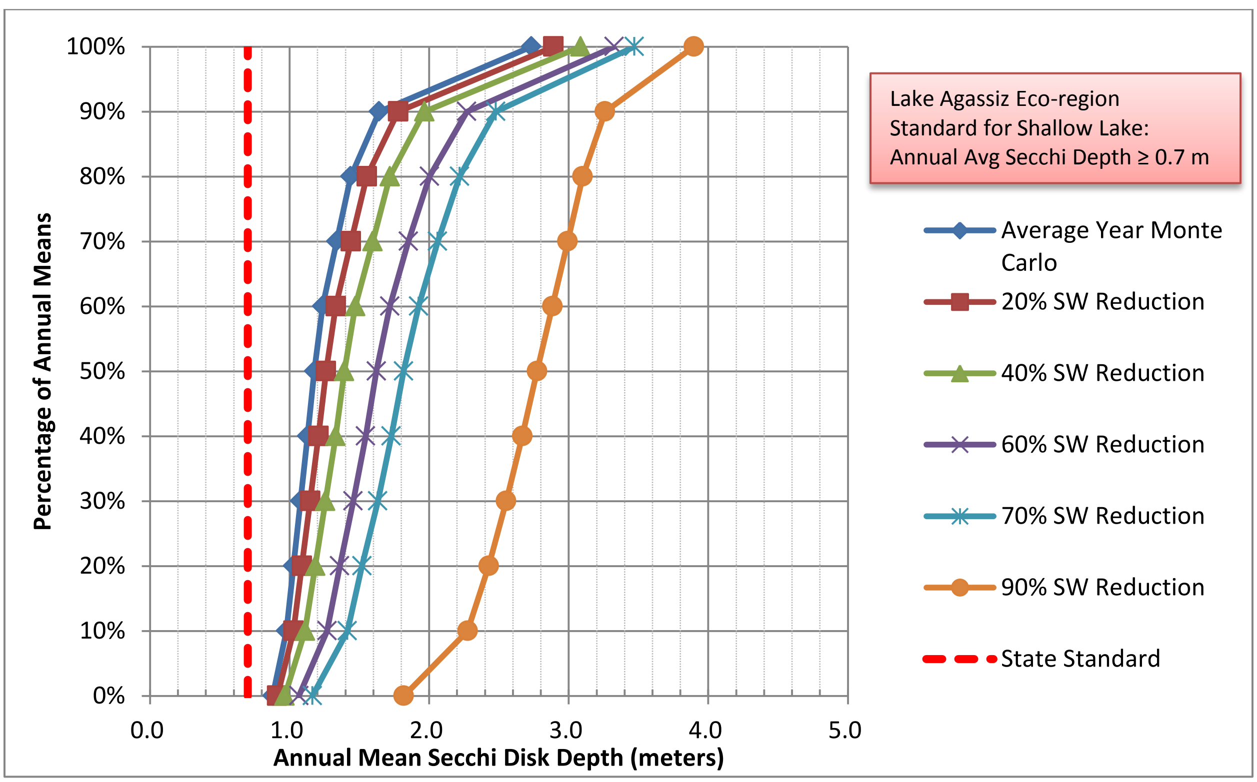

Figure A.20.4. LA-Shallow Lake Frequency Distribution of Annual Mean Secchi Disk Depths Resulting from Select Load Reduction Scenarios.

A.21 NCHF-Deep Lake

Table A.21.1. Annual BRW SWAT outputs (1995-2009) for NCHF-Deep Lake.

Year	Precipitation (m/yr)	Evaporation (m/yr)	Contributing Drainage Inflow (hm3/yr)	Contributing Drainage Area Load (kg/yr)	Tributary Flow (hm3/yr)	Tributary Loading (kg/yr)
1995	0.646	0.743	0.177	53	0.0	0.0
1996	0.637	0.830	0.319	196	0.0	0.0
1997	0.875	0.858	0.672	375	0.0	0.0
1998	0.885	0.943	0.675	258	0.0	0.0
1999	0.731	0.906	0.355	142	0.0	0.0
2000	0.776	0.913	0.230	67	0.0	0.0
2001	0.699	0.878	0.444	101	0.0	0.0
2002	0.656	0.868	0.317	170	0.0	0.0
2003	0.540	0.999	0.098	35	0.0	0.0
2004	0.801	0.891	0.289	194	0.0	0.0
2005	0.854	0.931	0.350	165	0.0	0.0
2006	0.625	0.967	0.348	161	0.0	0.0
2007	0.697	0.844	0.357	133	0.0	0.0
2008	0.927	0.770	0.550	267	0.0	0.0
2009	0.731	0.799	0.683	232	0.0	0.0
Average	**0.739**	**0.876**	**0.39**	**170**	**0.0**	**0.0**

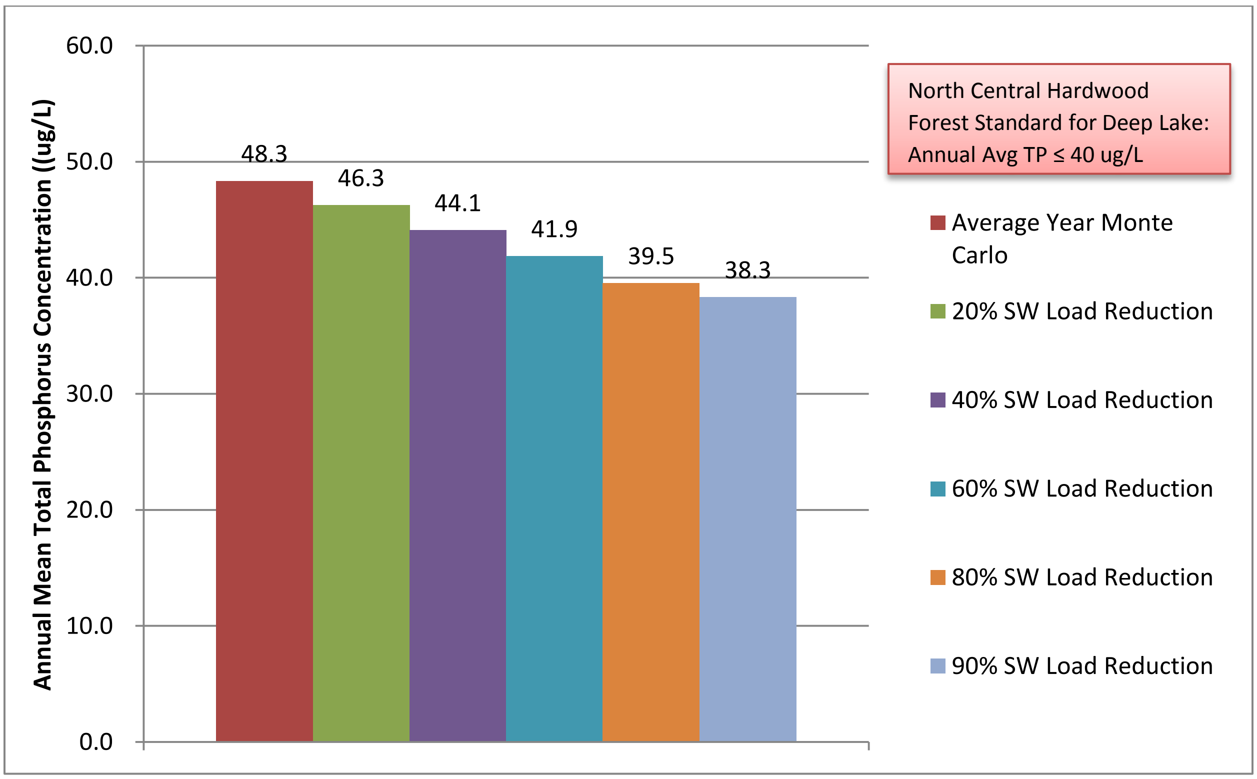

Figure A.21.1. NCHF-Deep Lake Annual Mean TP Concentrations under Select Load Reduction Scenarios.

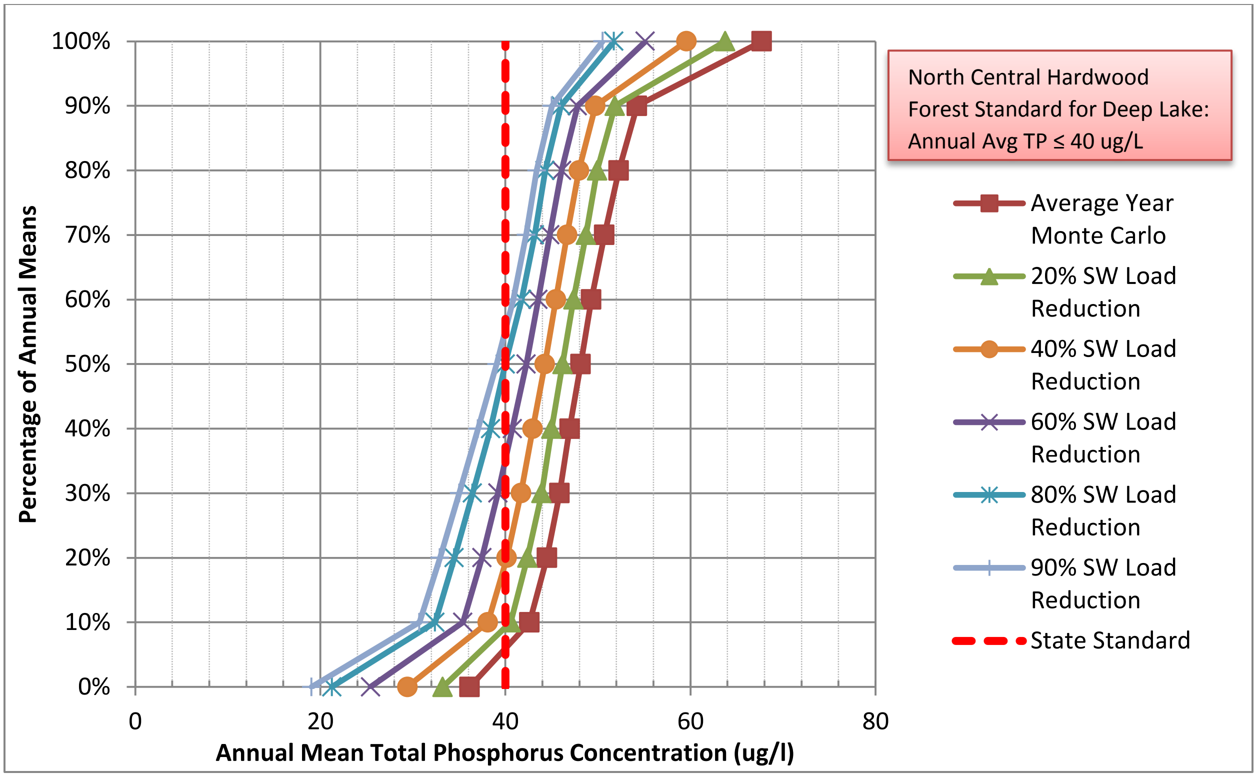

Figure A.21.2. NCHF-Deep Lake Frequency Distribution of Annual Mean TP Concentrations Resulting from Select Load Reduction Scenarios.

Table A.21.2. Data used to Produce the Annual Mean TP Concentrations (ug/L) Frequency Distribution (Figure A.21.2) for NCHF-Deep Lake.

Non-Exceedance Percentile	Average Year Monte Carlo	20% Reduction	40% Reduction	60% Reduction	80% Reduction	90% Reduction
Load	12.7 kg	10.2 kg	7.6 kg	5.1 kg	2.5 kg	1.3 kg
Mean	48.3	46.3	44.1	41.9	39.5	38.3
0%	36.1	33.2	29.4	25.4	21.2	19.1
10%	42.6	40.6	38.1	35.4	32.4	30.7
20%	44.5	42.4	40.2	37.5	34.5	32.9
30%	45.9	43.9	41.7	39.2	36.5	35.0
40%	47.0	45.0	43.0	40.8	38.4	37.0
50%	48.1	46.2	44.3	42.3	40.0	39.1
60%	49.3	47.4	45.5	43.5	41.8	40.8
70%	50.7	48.7	46.7	44.8	43.2	42.2
80%	52.3	49.9	47.9	46.1	44.3	43.4
90%	54.2	51.8	49.7	47.8	46.0	45.0
100%	67.7	63.7	59.6	55.1	51.7	50.5

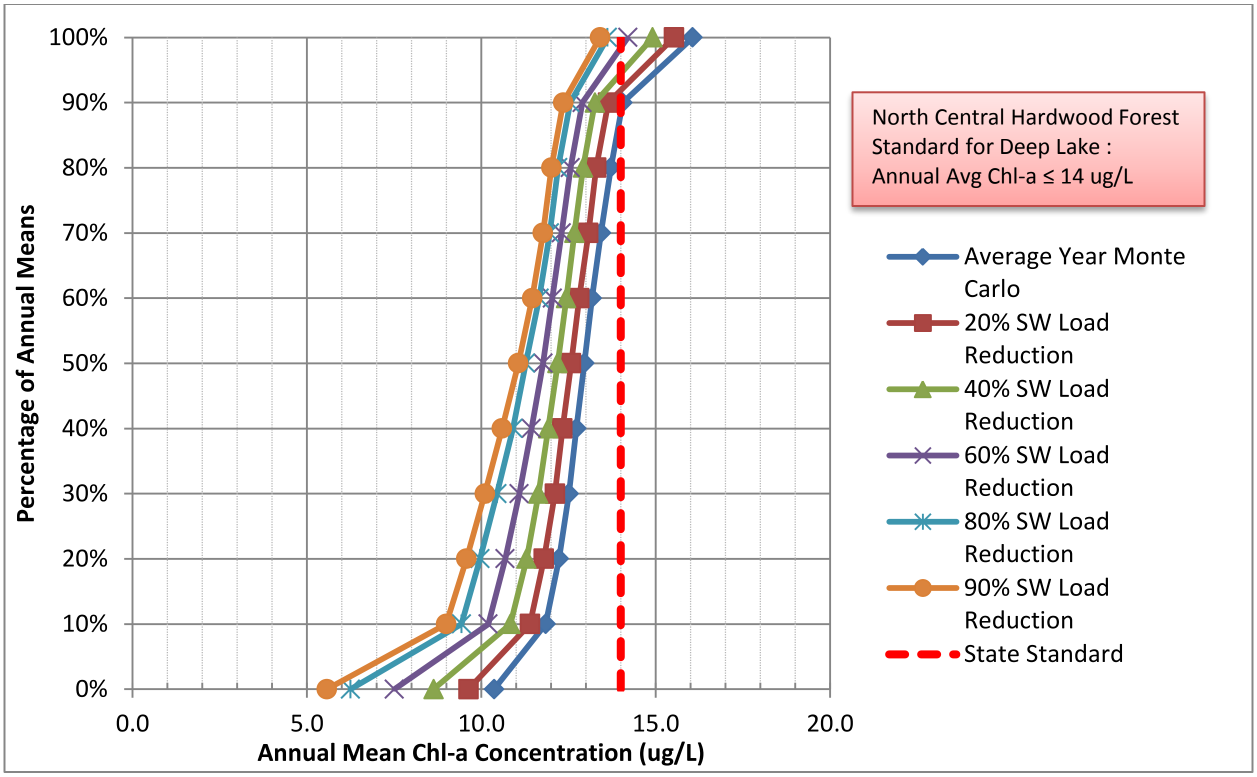

Figure A.21.3 NCHF-Deep Lake Frequency Distribution of Annual Mean Chl-*a* Concentrations Resulting from Select Load Reduction Scenarios.

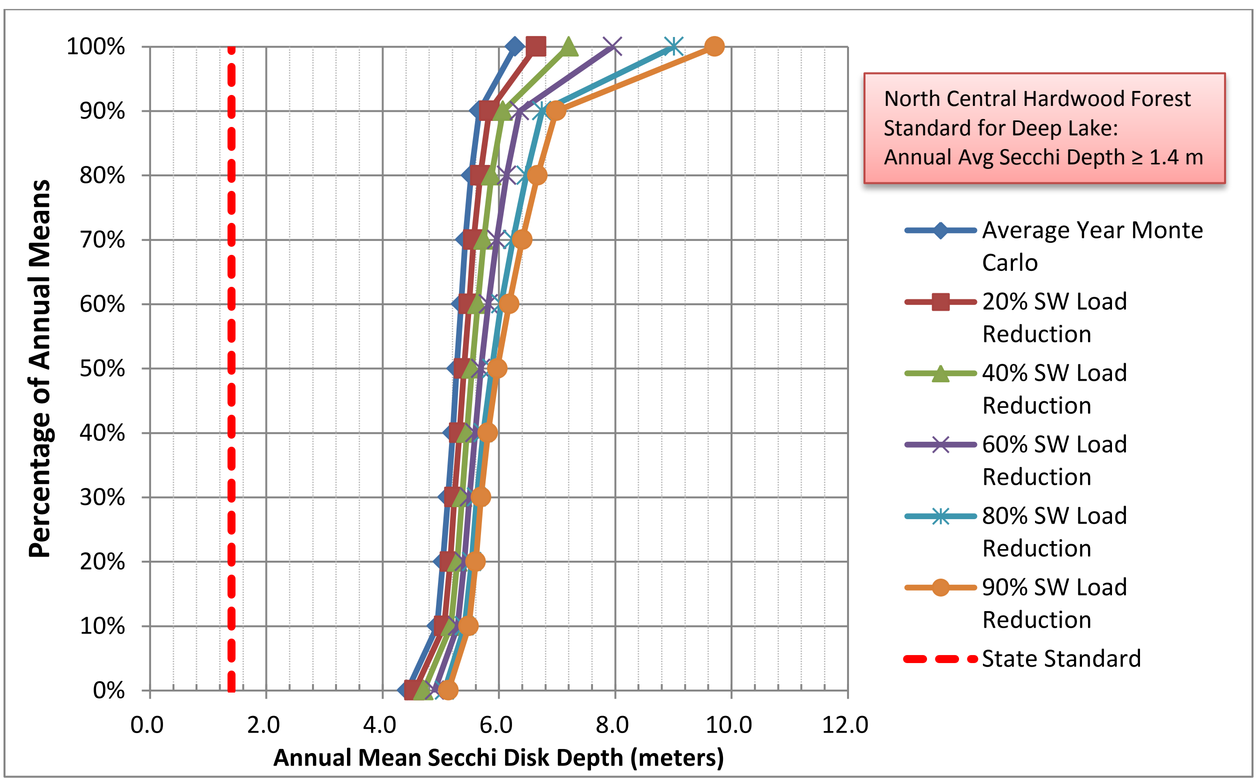

Figure A.21.4. NCHF-Deep Lake Frequency Distribution of Annual Mean Secchi Disk Depths Resulting from Select Load Reduction Scenarios.

A.22 NCHF-Shallow Lake

Table A.22.1. Annual BRW SWAT outputs (1995-2009) for NCHF-Shallow Lake.

Year	Precipitation (m/yr)	Evaporation (m/yr)	Contributing Drainage Inflow (hm^3/yr)	Contributing Drainage Area Load (kg/yr)	Tributary Flow (hm^3/yr)	Tributary Loading (kg/yr)
1995	0.646	0.743	0.177	53	0.0	0.0
1996	0.637	0.830	0.319	196	0.0	0.0
1997	0.875	0.858	0.672	375	0.0	0.0
1998	0.885	0.943	0.675	258	0.0	0.0
1999	0.731	0.906	0.355	142	0.0	0.0
2000	0.776	0.913	0.230	67	0.0	0.0
2001	0.699	0.878	0.444	101	0.0	0.0
2002	0.656	0.868	0.317	170	0.0	0.0
2003	0.540	0.999	0.098	35	0.0	0.0
2004	0.801	0.891	0.289	194	0.0	0.0
2005	0.854	0.931	0.350	165	0.0	0.0
2006	0.625	0.967	0.348	161	0.0	0.0
2007	0.697	0.844	0.357	133	0.0	0.0
2008	0.927	0.770	0.550	267	0.0	0.0
2009	0.731	0.799	0.683	232	0.0	0.0
Average	**0.739**	**0.876**	**0.39**	**170**	**0.0**	**0.0**

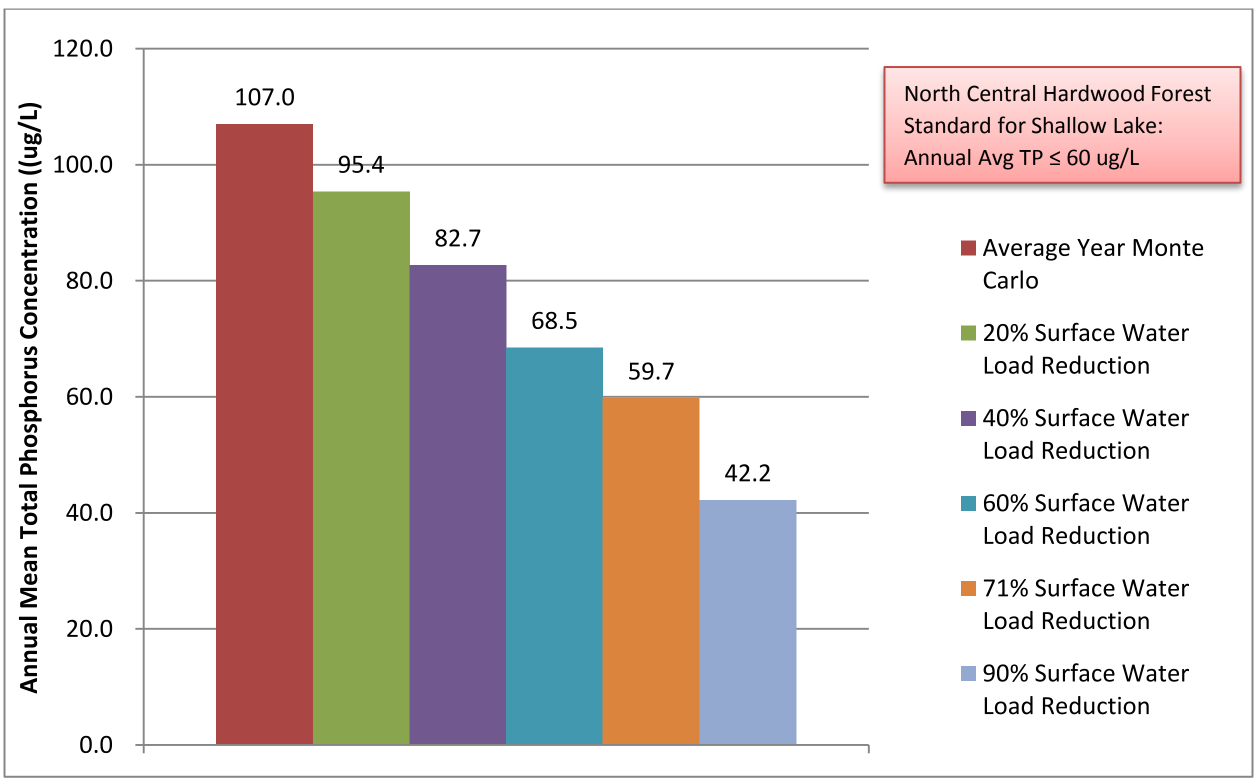

Figure A.22.1. NCHF-Shallow Lake Annual Mean TP Concentrations under Select Load Reduction Scenarios.

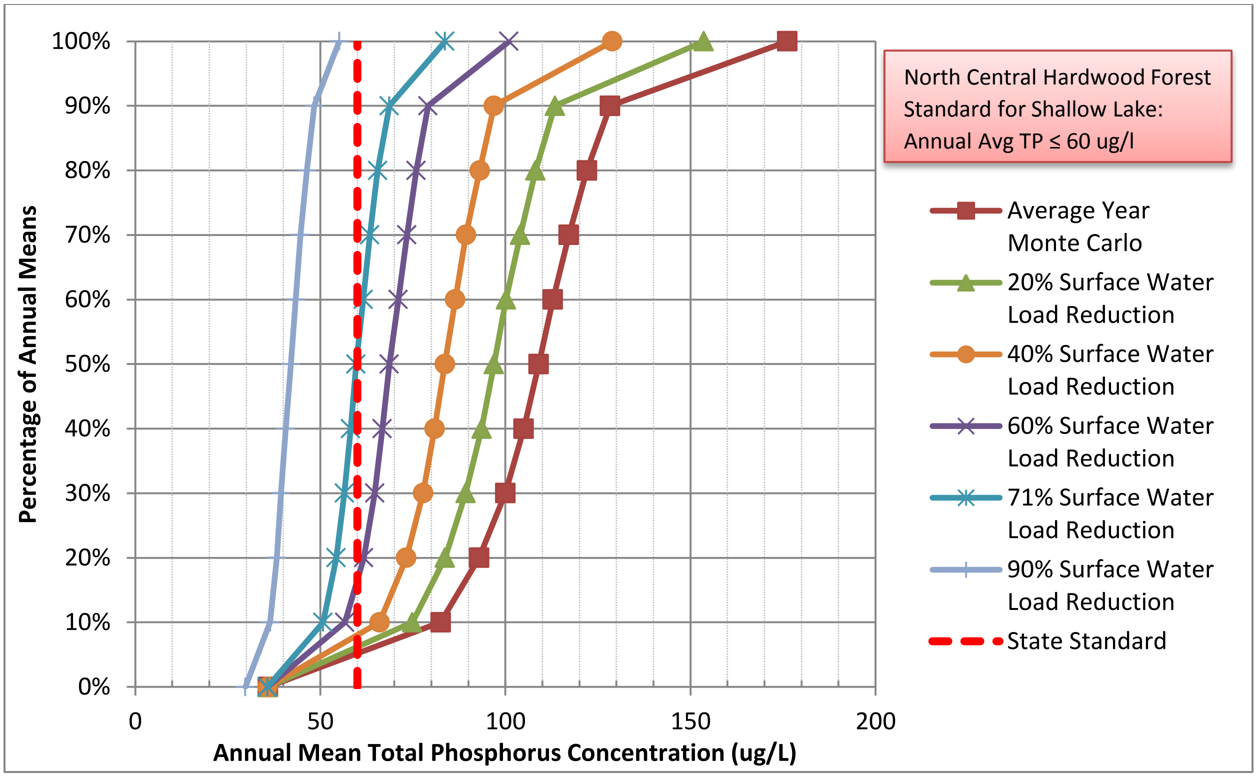

Figure A.22.2. NCHF-Shallow Lake Frequency Distribution of Annual Mean TP Concentrations Resulting from Select Load Reduction Scenarios.

Table A.22.2. Data used to Produce the Annual Mean TP Concentrations (ug/L) Frequency Distribution (Figure A.22.2) for NCHF-Shallow Lake.

Non-Exceedance Percentile	Average Year Monte Carlo	20% Reduction	40% Reduction	60% Reduction	71% Reduction	90% Reduction
Load	178.2 kg	142.6 kg	106.9 kg	71.3 kg	51.7 kg	17.8 kg
Mean	107.0	95.4	82.7	68.5	59.7	42.2
0%	35.8	35.8	35.8	35.7	35.7	29.7
10%	82.5	74.9	66.0	56.6	50.7	36.4
20%	92.9	83.7	73.2	61.7	54.3	38.2
30%	100.0	89.2	77.8	64.7	56.5	39.3
40%	105.0	93.6	80.9	66.7	58.2	40.7
50%	109.0	96.9	83.6	68.7	59.6	42.0
60%	112.8	100.2	86.4	71.1	61.6	43.4
70%	117.2	104.0	89.3	73.4	63.4	44.6
80%	122.0	108.1	93.1	75.9	65.5	46.4
90%	128.3	113.4	96.9	79.1	68.6	48.4
100%	176.2	153.6	128.9	101.0	83.7	55.1

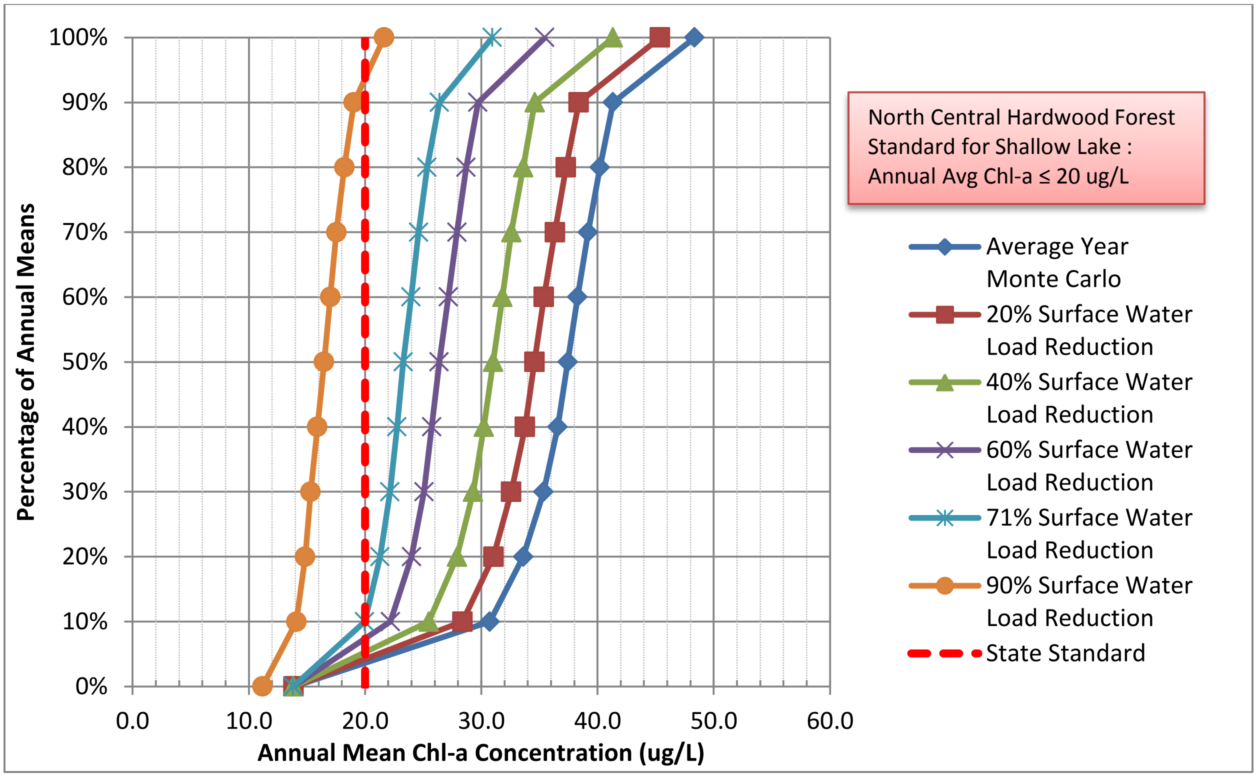

Figure A.22.3 NCHF-Shallow Lake Frequency Distribution of Annual Mean Chl-*a* Concentrations Resulting from Select Load Reduction Scenarios.

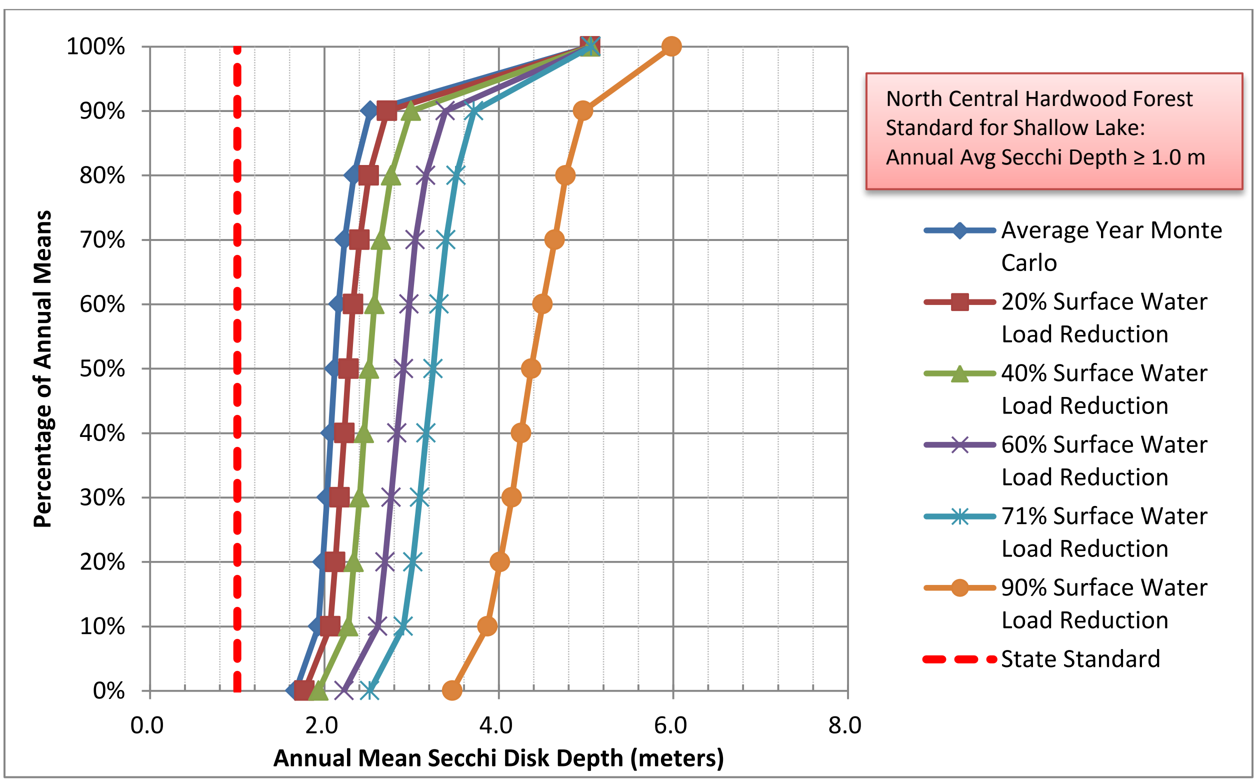

Figure A.22.4. NCHF-Shallow Lake Frequency Distribution of Annual Mean Secchi Disk Depths Resulting from Select Load Reduction Scenarios.

A.23 NLF-Shallow Lake

Table A.23.1. Annual BRW SWAT outputs (1995-2009) for NLF-Shallow Lake.

Year	Precipitation (m/yr)	Evaporation (m/yr)	Contributing Drainage Inflow (hm^3/yr)	Contributing Drainage Area Load (kg/yr)	Tributary Flow (hm^3/yr)	Tributary Loading (kg/yr)
1995	0.580	0.638	1.335	21.8	0.0	0.0
1996	0.558	0.699	1.252	19.8	0.0	0.0
1997	0.638	0.739	1.536	33.3	0.0	0.0
1998	0.752	0.809	1.607	31.5	0.0	0.0
1999	0.797	0.810	2.042	43.1	0.0	0.0
2000	0.695	0.839	1.501	23.3	0.0	0.0
2001	0.630	0.825	1.553	25.8	0.0	0.0
2002	0.585	0.787	1.273	16.7	0.0	0.0
2003	0.415	0.876	0.935	6.6	0.0	0.0
2004	0.811	0.783	1.544	49.3	0.0	0.0
2005	0.694	0.821	1.570	29.5	0.0	0.0
2006	0.586	0.841	1.490	31.5	0.0	0.0
2007	0.673	0.709	1.496	36.8	0.0	0.0
2008	0.730	0.621	1.768	58.6	0.0	0.0
2009	0.582	0.650	1.520	39.1	0.0	0.0
Average	**0.648**	**0.763**	**1.49**	**31.1**	**0.0**	**0.0**

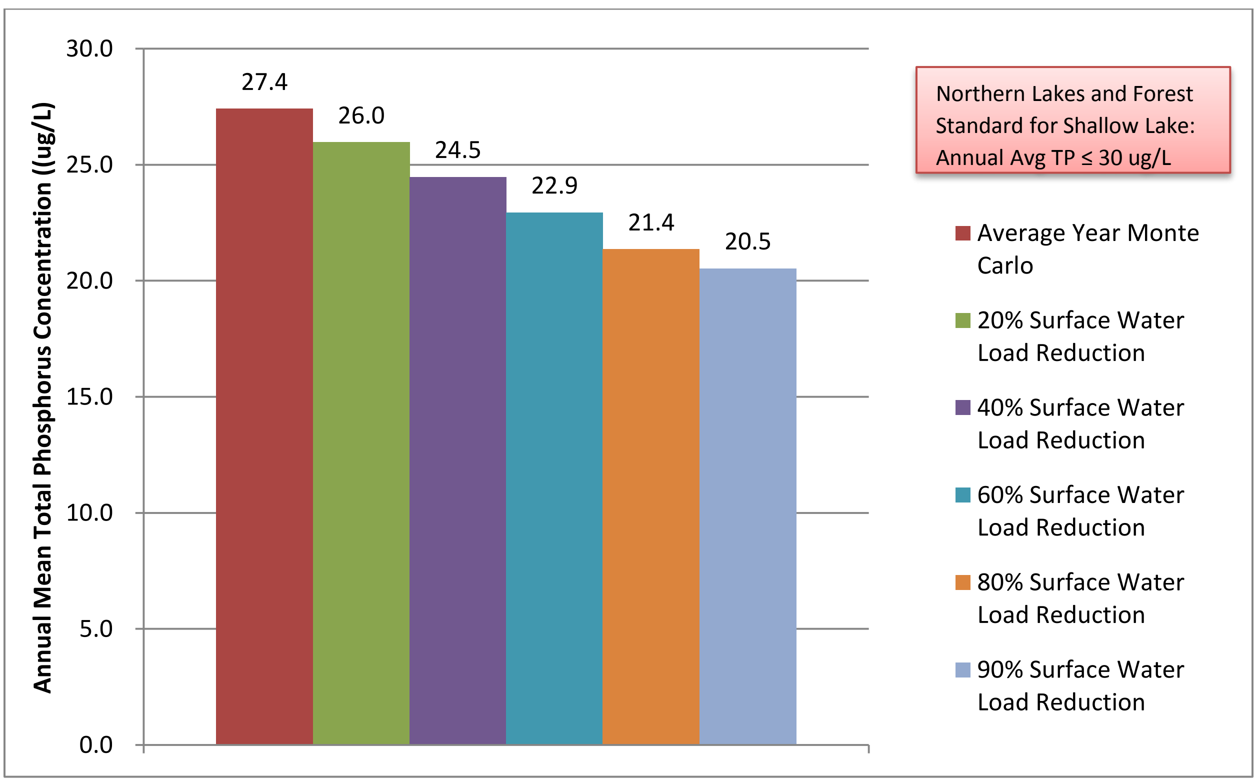

Figure A.23.1. NLF-Shallow Lake Annual Mean TP Concentrations under Select Load Reduction Scenarios.

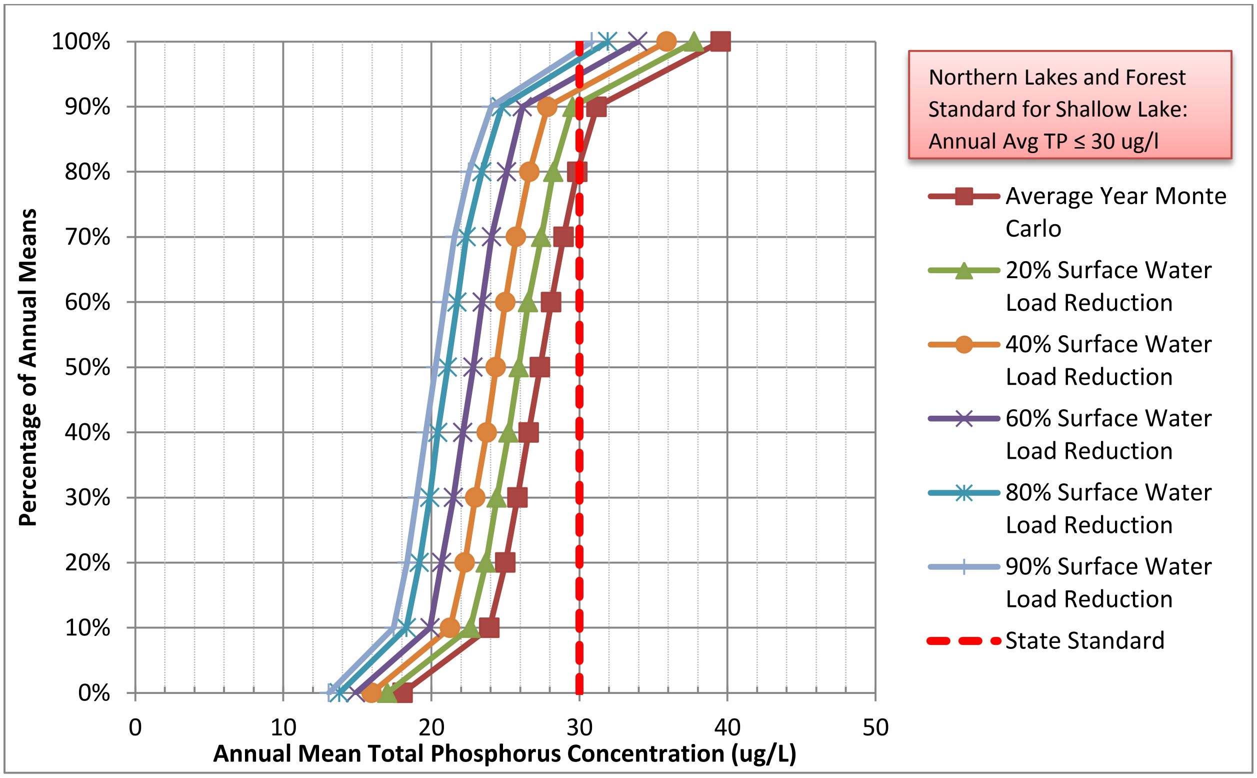

Figure A.23.2. NLF-Shallow Lake Frequency Distribution of Annual Mean TP Concentrations Resulting from Select Load Reduction Scenarios.

Table A.23.2. Data used to Produce the Annual Mean TP Concentrations (ug/L) Frequency Distribution (Figure A.23.2) for NLF-Shallow Lake.

Non-Exceedance Percentile	Average Year Monte Carlo	20% Reduction	40% Reduction	60% Reduction	80% Reduction	90% Reduction
Load	31.6 kg	25.3 kg	19. kg	12.7 kg	6.3 kg	3.2 kg
Mean	27.4	26.0	24.5	22.9	21.4	20.5
0%	18.1	17.0	16.0	14.9	13.8	13.1
10%	23.9	22.6	21.3	19.9	18.3	17.5
20%	25.0	23.7	22.3	20.7	19.2	18.4
30%	25.8	24.4	23.0	21.5	19.9	19.0
40%	26.6	25.2	23.7	22.1	20.4	19.6
50%	27.3	25.9	24.4	22.8	21.1	20.3
60%	28.1	26.5	25.0	23.4	21.7	20.9
70%	28.9	27.4	25.7	24.1	22.4	21.6
80%	29.9	28.2	26.6	25.1	23.4	22.5
90%	31.2	29.5	27.8	26.1	24.7	24.0
100%	39.5	37.8	35.9	34.0	31.9	30.8

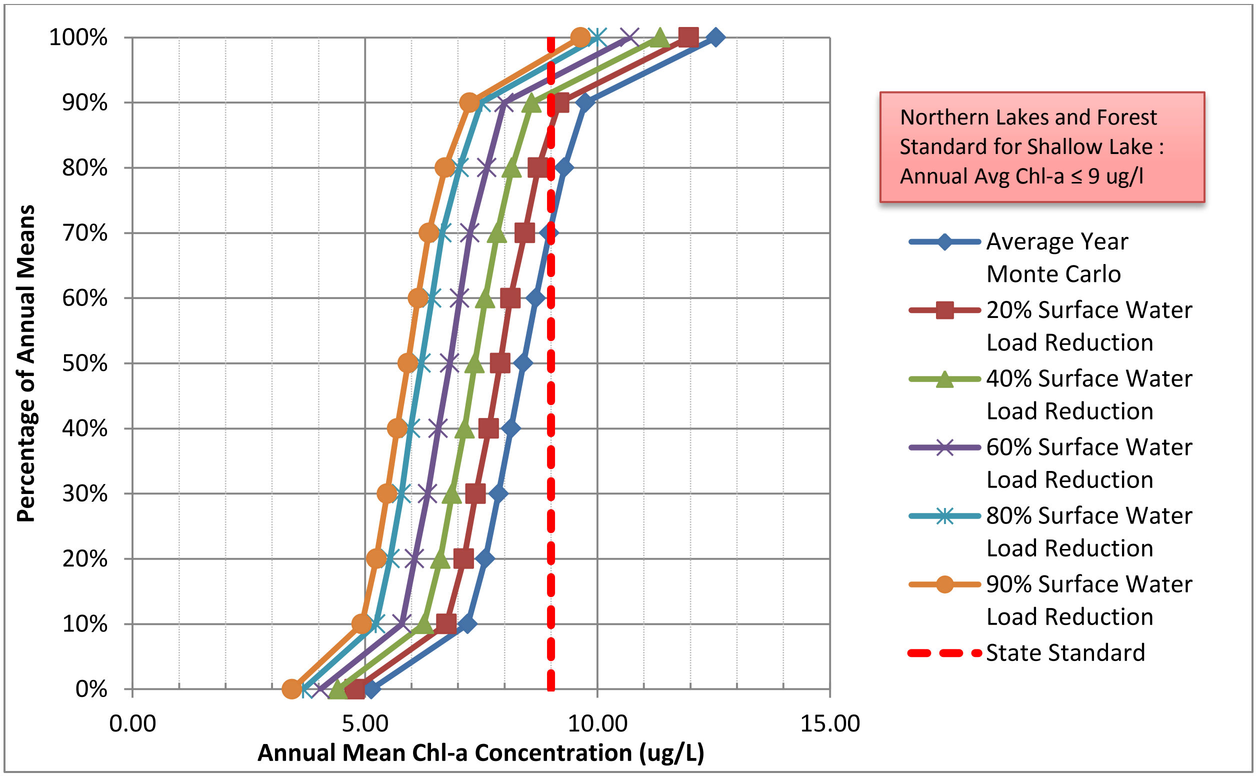

Figure A.23.3 NLF-Shallow Lake Frequency Distribution of Annual Mean Chl-*a* Concentrations Resulting from Select Load Reduction Scenarios.

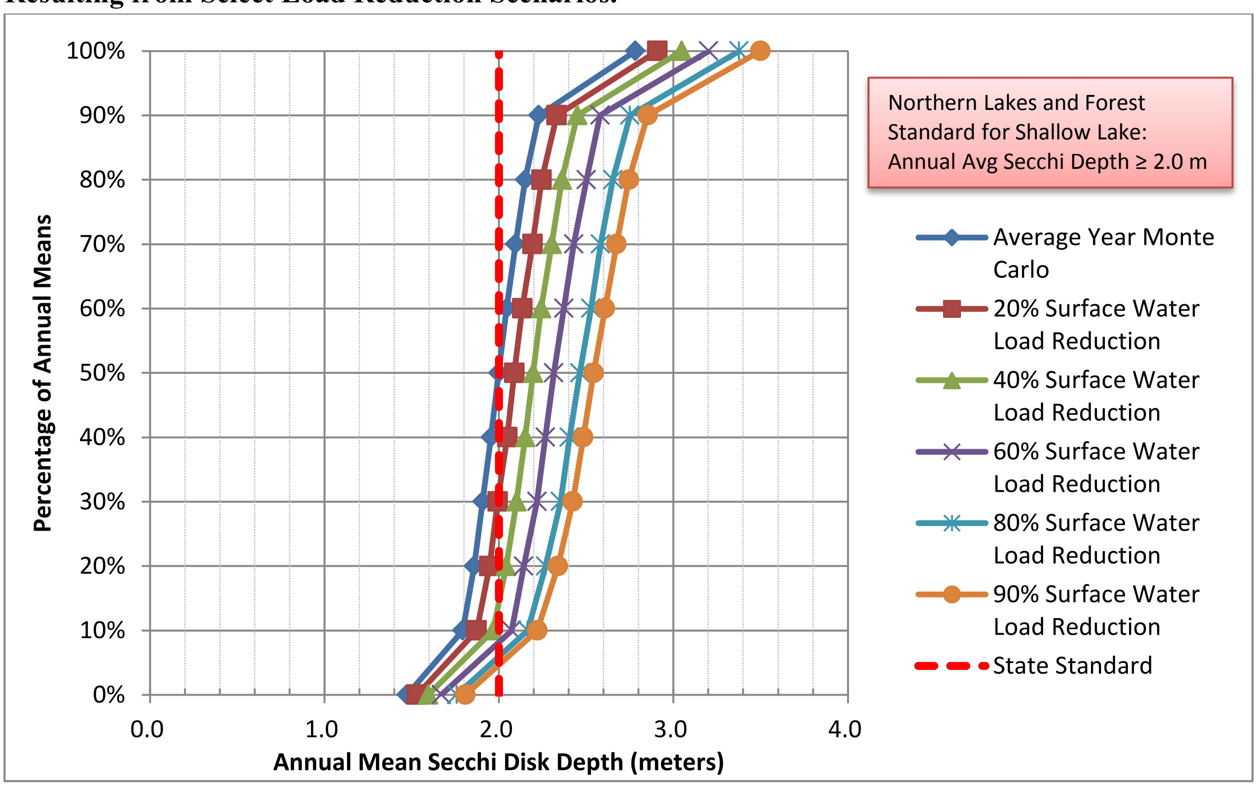

Figure A.23.4. NLF-Shallow Lake Frequency Distribution of Annual Mean Secchi Disk Depths Resulting from Select Load Reduction Scenarios.