Appendix E: GWLF/Bathtub Modeling for Lake Helena

E.1.0 GWLF Modeling Assumptions

The GWLF model was chosen to simulate loads from rural and urban land uses in the watershed. Values for the input parameters were assigned based on available monitoring data or on default parameters suggested in the GWLF User's Manual (Haith et al., 1992). This section summarizes the bases for the hydrologic, erosion, sedimentation, and nutrient modeling assumptions.

E.1.1 Hydrologic Input

Hydrologic parameters for the GWLF model were obtained from a variety of sources. The Lake Helena watershed was divided into four subwatersheds – Prickly Pear Creek, Silver Creek, Tenmile Creek, and Lake Helena Overland. These subwatersheds were delineated using available stream and topographic information, and are shown in Figure E-1. Land use and land cover was determined using MRLC data and aerial photography, and the data are summarized in Appendix A. The MRLC data, collected in the early 1990s, was modified for this analysis to reflect increasing development in the Lake Helena watershed. Low-density residential land was increased by 17 percent and assumed that development occurred primarily on pasture, hay, and grassland.

Information about irrigation systems and irrigated land was obtained from the Helena Valley Irrigation district. This information was input into the model to account for flow withdrawals and irrigation returns. Appendix A further summarizes the irrigation characteristics of the Lake Helena watershed.

Curve numbers for each land use were based on the STATSGO soils database and recommended values in the GWLF User's Manual. Table E-1 lists the SCS curve numbers for the land uses in the Lake Helena Watershed. Initial estimates of soil capacity, river recession, evapotranspiration, daylight hours, and rainfall erosivity were also based on the GWLF User's Manual with some minor modifications made during model calibration.

Table E-1. SCS Curve Numbers for Land Uses in the Lake Helena Watershed

Land Use	Curve Number
Bare Rock	98
Transitional	60
Deciduous Forest	55
Evergreen Forest	60
Shrubland	48
Grassland	69
Woody Wetland	98
Herbaceous Wetland	98
Recent Clear-cut	70
Clear-cut Regrowth	65
Dirt Roads	82
Water	100
Pasture/Hay	58
Small Grains	75
Fallow	86
Row Crops	78
Low Density Residential	65
Comm/Ind/Trans	90
Urban Grasses	69

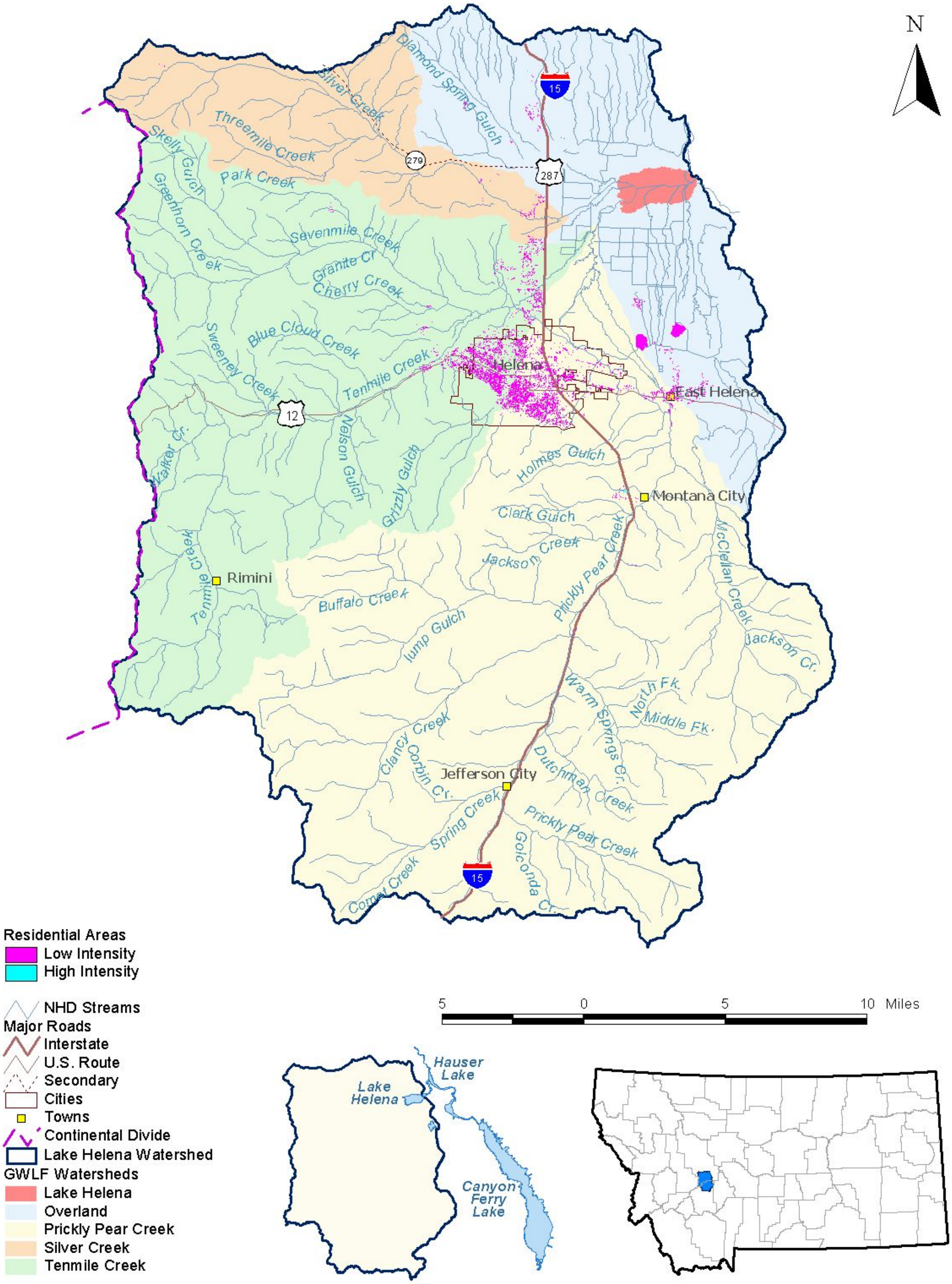

Figure E-1. Modeling subwatersheds in the Lake Helena TPA.

E.1.2 USLE Parameters

The USLE was set up based on general watershed assumptions applied to the entire watershed. The soil erodibility factor is 0.2, the slope length is 30 meters, the slope is 20 percent for the upland areas, 2 percent for the valley surrounding Lake Helena, and the practice factor for each land use is 1. Cover factors for each land use are based on GWLF default values and are summarized in Table E-2. The cover factor for dirt roads is based on the Watershed Characterization System estimates developed by Tetra Tech (2000).

The USLE equation estimates erosion. Delivered sediment is estimated by applying a sediment delivery ratio specific to each subbasin. The sediment delivery ratios for each subbasin are area-based as suggested in Haith et al. (1992).

Table E-2. Cover Factors by Land Use in the Lake Helena Watershed

Land Use	Cover Factor
Bare Rock	0.0001
Transitional	0.02
Deciduous Forest	0.003
Evergreen Forest	0.003
Shrubland	0.006
Grassland	0.01
Woody Wetland	0.003
Herbaceous Wetland	0.003
Recent Clear-cut	0.09
Clear-cut Regrowth	0.04
Dirt Roads	0.75
Water	0
Pasture/Hay	0.004
Small grains	0.03
Fallow	0.3
Row Crops	0.3
Low density residential	0.0065
Comm/Ind/Trans	0.01
Urban grasses	0.013

E.1.3 Soil Nutrient Concentrations

Soil nutrient concentrations are based on spatial distributions provided in the GWLF manual. The soil nitrogen concentration is 3,000 mg/kg based on Figure B-3 of the GWLF manual, which shows a median soil nitrogen content of 0.15 percent and suggests an enrichment ratio of 2. The soil phosphorus concentration is 440 mg/kg based on Figure B-4 in the GWLF manual which shows a soil P_2O_5 content of 0.05 percent (low end of range) and suggests an enrichment ratio of 2.

E.1.4 Groundwater Nutrient Concentrations

Groundwater nutrient concentrations were set to 0.07 mg-N/L and 0.012 mg-P/L based on baseflow measurements reported in the GWLF manual for forested watersheds.

E.1.5 Septic System Loading Data

The GWLF model requires an estimate of population served by septic systems to generate septic system loading rates. Daily per capita loading rates and plant uptake rates were set to GWLF default values and are summarized in Table E-3.

Table E-3. Septic System Loading Rates and Plant Uptake Rates

Parameter	Nitrogen	Phosphorus
Loading Rate (g/capita/d)	12	1.5
Plant Uptake Rate (g/d)	1.6	0.4

E.1.6 Point Sources

Three point sources in the Lake Helena Watershed contribute significant nutrient loading to the system; each discharges to the Prickly Pear Creek watershed. The GWLF model accounts for point source loads on a monthly basis (kg/mo). Average monthly loads were calculated from reported discharges from January 2000 to December 2002. Average loadings from each point source are presented in Table E-4 to Table E-6. The City of Helena WWTP loads are presented pre- and post-plant upgrades, which occurred in June 2001. It should be noted that the post-upgrade TP loads are in question because the loads increased following expansion. A possible lab or reporting error is being investigated. It should also be noted that the City of East Helena WWTP was upgraded in November/December 2003. The new system consists of a small, completely mixed aerated lagoon with a separate aerobic digestion cell for solids. Disinfection is with UV instead of the old chlorination system, and the new system has lined cells which do not seep to groundwater.

From April thru October, the majority of effluent from the City of Helena WWTP is used by a private landowner for irrigation of alfalfa fields (Clark, 2004). To model nutrient uptake, we assume that 95 percent of effluent is land applied during this time. Total phosphorus uptake is assumed 90 percent (reported ranges from 80 to 99 percent (USEPA, 2002a)). Ammonia and organic nitrogen are assumed taken up completely by plants. Nitrate/nitrite present in the effluent is assumed to pass through the system. According to the City of Helena WWTP DMRs, the average nitrate concentration prior to June 2001 was 0.18 mg-N/L; after the plant upgrades, the average nitrate concentration was 5.42 mg-N/L. The increase in nitrate concentrations is attributed to the upgraded ammonia removal process at the facility that results in more nitrogen in the effluent. Though plant upgrades have reduced the total nitrogen load by 70 percent, nitrogen loads passing through the irrigated fields are higher after the upgrades because more of the load is in the nitrate form.

Effluent that is not land applied travels approximately one mile through an open conduit before reaching Prickly Pear Creek (Ingman, 2004). Flow through the conduit is minimal from April through October. Nutrient uptake in the conduit is assumed negligible during the remaining months due to reduced biological activity under low-temperature conditions.

Table E-4. Average Monthly Nutrient Loads from the Evergreen Nursing Home (MT0023566)

Month	Average Total Nitrogen Load (kg/mo)	Average Total Phosphorus Load (kg/mo)
January	5.8	1.2
February	9.3	1.4
March	4.3	1.6
April	11.4	4.0
May	11.0	1.0
June	9.1	4.0
July	4.8	5.4
August	3.1	3.0
September	9.2	3.5
October	10.4	3.0
November	3.8	2.1
December	10.8	3.5

Table E-5. Average Monthly Nutrient Loads from the City of Helena, East WWTP (MT0022560)

Month	Average Total Nitrogen Load (kg/mo)	Average Total Phosphorus Load (kg/mo)
January	159.7	27.1
February	162.3	24.4
March	184.1	27.2
April	209.6	31.5
May	179.6	35.2
June	380.6	61.0
July	339.3	56.6
August	322.0	68.4
September	328.9	54.8
October	250.2	36.7
November	187.1	27.1
December	168.1	25.0

Table E-6. Average Monthly Nutrient Loads from the City of Helena WWTP Before and After Summer 2001 Plant Upgrades (MT0022641)

Month	Average Total Nitrogen Load Before Upgrades (kg/mo)	Average Total Phosphorus Load Before Upgrades (kg/mo)	Average Total Nitrogen Load After Upgrades (kg/mo)	Average Total Phosphorus Load After Upgrades (kg/mo)
January	12,859	1,625	2,501	1,758
February	11,767	1,698	3,053	8,166
March	12,088	1,721	4,773	2,864
April	10,945	1,697	3,307	7,027
May	8,205	801	3,438	8,312
June	7,012	1,102	3,312	1,313
July	9,803	719	2,894	4,129
August	8,605	1,467	3,657	941
September	8,940	543	2,512	1,725
October	9,341	1,636	2,833	1,607
November	12,859	1,562	2,962	696
December	12,934	1,401	1,711	2,224

E.1.7 Runoff Concentrations

Dissolved nutrient concentrations in runoff from each land use were set to GWLF default values and are summarized in Table E-7. Best professional judgment was used to estimate runoff concentrations from dirt roads.

Table E-7. Nutrient Runoff Concentrations for Rural Land Uses in the Lake Helena Watershed

Land Use	Nitrogen (mg/L)	Phosphorus (mg/L)
Bare Rock	0.09	0.009
Transitional	1.00	0.100
Deciduous Forest	0.07	0.012
Evergreen Forest	0.07	0.012
Shrubland	0.50	0.100
Grassland	3.00	0.250
Woody Wetland	0.07	0.012
Herbaceous Wetland	0.07	0.012
Recent Clear-cut	0.18	0.015
Clear-cut Regrowth	0.10	0.014
Dirt Roads	0.50	0.080
Water	0.07	0.012
Pasture/Hay	2.80	0.150
Small Grains	1.80	0.300
Fallow	2.60	0.100
Row Crops	2.90	0.260

E.1.8 Developed Land Buildup Rates

GWLF simulates nutrient loads from developed land uses through a buildup/washoff formulation. Buildup rates for nitrogen and phosphorus are based on weighted averages of pervious and impervious default values suggested in the GWLF manual (Table E-8).

Table E-8. Buildup Washoff Rates for Urban Land Uses in the Lake Helena Watershed

Land Use	Nitrogen (kg/ha-d)	Phosphorus (kg/ha-d)
Low Density Residential	0.020	0.0020
Comm/Ind/Trans	0.050	0.0050
Urban Grasses	0.012	0.0016

E.1.9 Forest Industry Land Uses

According to the “Water Quality Restoration Plan and Total Maximum Daily Loads (TMDLs) for the Lake Helena Watershed Planning Area” (USEPA, 2004), 93 percent of forest in the Lake Helena Watershed is timberland. In order to account for the impacts of silviculture, Tetra Tech apportioned 93 percent of the forestland identified in the MRLC database as timberland. Assuming a 90-yr harvesting cycle (Stuart, 2004), 1.11 percent of this timberland is assumed recently cut and assigned the land use “recent clear cut.” To estimate the area of “clear-cut regrowth,” we assumed a 5-yr regrowth period to re-establish 100 percent ground cover. The curve numbers, cover factors, and nutrient runoff concentrations of these silvicultural land uses vary from typical forestland as described in Tables E-1, E-2, and E-7. The area of dirt roads associated with timberland operations was based on best professional judgment. Two percent of the total forest area is allocated to dirt roads.

E.1.10 Grassland Under “Natural” Conditions

Under “Natural” conditions, grassland areas are assumed to have lower animal densities compared to grassland under existing conditions, which is often used for organized grazing. Under natural conditions, soil compaction is expected to be lower and vegetative cover higher. To account for these differences, grassland in the “Natural” scenario is assigned a curve number of 61 and a cover factor of 0.003.

E.1.11 GWLF Modeling Scenarios

Two sets of GWLF input files were generated to represent the Lake Helena modeling scenarios. The "Existing" scenario models current conditions by assigning current land uses (including urban development, agriculture, and silviculture), point sources, and septic system loads to the watershed. The number of total septic systems in the watershed varies by year based on the number of domestic wells. Information on the number of septic systems in was not available at the time of this report. The average household size is assumed 2.5 people per household. The "Natural" scenario models the watershed in its pre-disturbed condition: septic systems and point sources are removed from the loading and all urban, agricultural, and silvicultural land uses are converted to undisturbed forest. Table E-9 and Table E-10 summarize the inputs for the two modeling scenarios.

Table E-9. Land Use Areas for the Lake Helena Modeling Scenarios

Land Use	Existing (ac)	Natural (ac)
Bare Rock	385.6	385.6
Water	810.8	810.8
Transitional	789.0	-
Deciduous Forest	1,267.2	1,380.4
Evergreen Forest	148,346.7	216,452.0
Mixed Forest	18.2	18.2
Shrubland	37,412.7	37,412.7
Grassland	134,320.8	134,757.7
Pasture/Hay	13,504.5	-
Small Grains	21,404.4	-
Woody Wetland	626.7	626.7
Herbaceous Wetlands	126.8	126.8
Recent Clear-cut	1,684.1	-
Clear-cut Regrowth	8,420.5	-
Dirt Roads	3,259.6	-
Fallow	3,833.3	-
Row Crop	3,505.5	-
Low Density Residential	3,602.2	-
Commercial/Industrial/Transportation	7,064.2	-
Urban/Recreational Grasses	1,587.9	-

Table E-10. Population Served by Septic Systems in the Lake Helena Watershed Under Existing Conditions

Year	Normally Functioning	Short-Circuited[a]
1993	17,698	1,332
1994	17,964	1,352
1995	18,230	1,372
1996	18,496	1,392
1997	18,762	1,412
1998	19,028	1,432
1999	19,294	1,452
2000	19,560	1,472
2001	19,826	1,492
2002	20,092	1,512
2003	20,358	1,532

[a] Assumed 7 percent of onsite systems are short-circuiting based on national average (USEPA, 2002b).

E.2.0 GWLF Modeling Results

The GWLF model was used to simulate total nitrogen and total phosphorus loads to Lake Helena for the years 1993 through 2003. Figure E-2 and E-3 show the simulated nutrient loading to the lake in metric tons per year. There is a large increase in nutrient loading from “Natural” to “Existing” conditions, though a portion of the nitrogen increase has been offset by recent upgrades at the City of Helena WWTP. City of Helena nutrient loads are displayed in the figures to show the impacts of plant upgrades that occurred in 2001. There is some question to the validity of the total phosphorus loading estimates which are based on reported concentrations and flow rates in the City of Helena WWTP DMRs and the EPA point source query database. However, without additional data, we cannot justifiably alter the loading estimates.

Note that these estimates do not include loads from the Helena Valley Irrigation District, which are discussed in Section E.3.0.

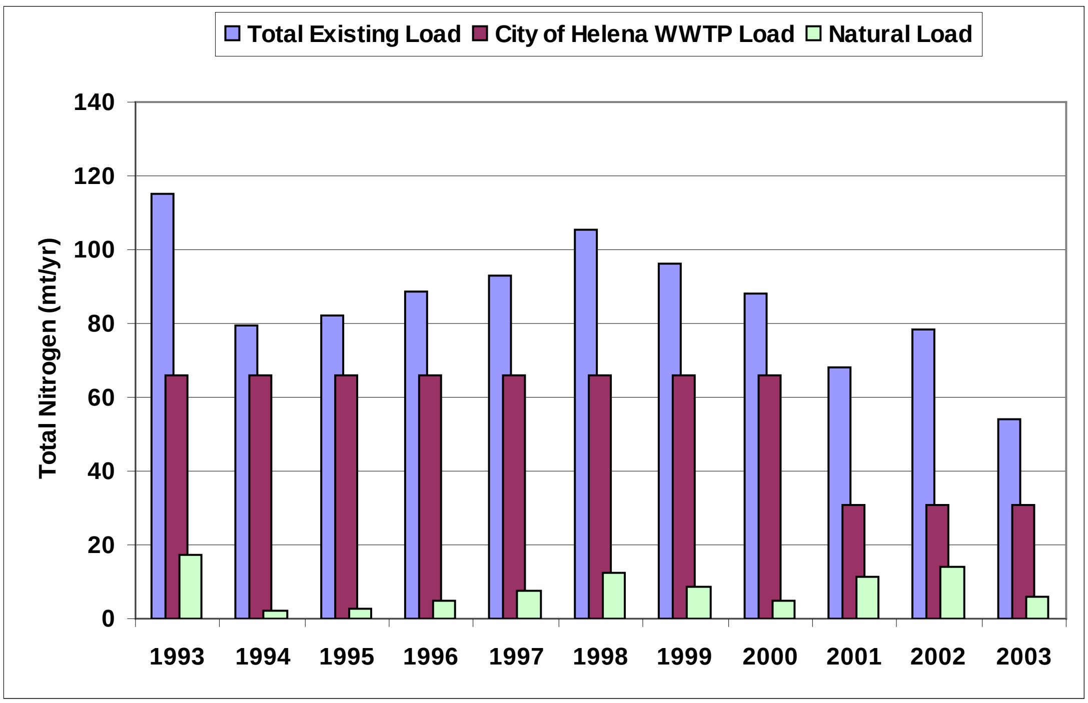

Figure E-2. Total Nitrogen Loads from the Lake Helena Watershed

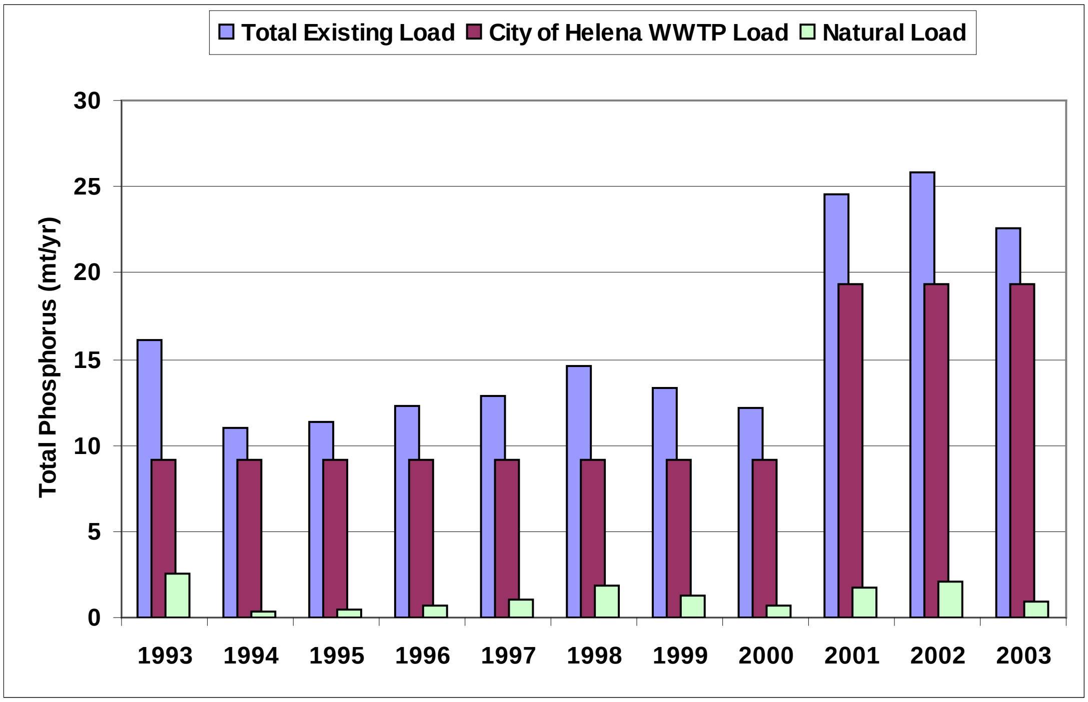

Figure E-3. Total Phosphorus Loads from the Lake Helena

E.3.0 BATHTUB Model Setup

The ACOE BATHTUB model (Walker, 1987) was set up to simulate nutrient response in Lake Helena for the years 1993 through 2003. Nutrient loads and streamflows were simulated with the Generalized Watershed Loading Function (GWLF) model based on land use/land cover data and local meteorological data. Lake morphometry data were provided by Montana DEQ (Supple, 2004).

E.3.1 Lake Morphology

The BATHTUB model requires basic lake morphometric data (Table E-11) to assess residence time, net flow rate, and potential euphotic depth. Morphometric data are based on data provided by Montana DEQ. Because the lake is fairly uniform and no ponding occurs along the downstream reaches of the tributaries, segmentation is not required.

Table E-11. Lake Helena Morphology

Lake Volume (10^6 m^3)	13.45
Average Depth (m)	1.6
Surface area (km^2)	8.41

E.3.2 Atmospheric Deposition to Lake Helena

Atmospheric deposition can contribute a significant proportion of nitrogen loads directly to a lake surface, particularly when the ratio of watershed area to lake surface area is low. The Lake Helena watershed to lake area ratio is relatively high (192) so atmospheric deposition is not likely a major source of nutrient loading.

Total wet and dry nitrogen deposition rates to the lake surface (1.5 kg/ha) were based on CASTNET monitoring at Glacier National Park (GLR468) for 1997. Phosphorus deposition rates (primarily from wind blown dust) are generalized estimates (0.1 kg/ha).

E.3.3 Loads from the Helena Valley Irrigation System

The Helena Valley Irrigation District provides approximately 350 cfs of water pumped from the Missouri River to the Lake Helena Watershed from mid-April through September each year. A water balance based on weir measurements of canal and drain flows, crop water use, and evaporation from the open conduits was used to apportion flows to Lake Helena into groundwater recharge and drain overflow fractions. The results are presented in Table E-12 for a typical water year (2003).

Nutrient loads were estimated by applying appropriate concentrations to each source of flow from the irrigation district. Groundwater-recharge nutrient concentrations were based on suggested GWLF values for primarily agricultural watersheds: 0.71 mg-N/L and 0.104 mg-P/L. The nutrient concentrations in overflow drains were estimated by averaging values observed in three overflow drains during the summer of 2004 (0.71 mg-N/L and 0.037 mg-P/L). Resulting loads are 52 metric tons of total nitrogen per year and 6.6 metric tons of total phosphorus per year.

Table E-12. Water Balance for the Helena Valley Irrigation District

Month	Groundwater Recharge (cfs)	Drain Overflow (cfs)	Evaporation (cfs)	Total Flow to Lake Helena (cfs)
April	25.0	56.0	0.25	80.75
May	36.5	39.5	0.39	75.61
June	178.0	41.0	0.45	218.55
July	200.3	29.7	0.63	229.37
August	210.9	51.1	0.53	261.47
September	129.7	34.3	0.31	163.69

E.3.4 Inorganic Nutrient Fractions

BATHTUB requires an estimate of inorganic nutrient fractions for all loads to the lake. The inorganic nutrient fractions for the watershed loads were approximated from the ratios of dissolved nutrient load to total nutrient load predicted by GWLF for each year. Atmospheric and groundwater recharge loads from the irrigation system were assumed 100 percent inorganic; loads in the irrigation system drains were assumed 25 percent inorganic due to algal synthesis. Table E-13 summarizes the inorganic fractions of nutrient loads to Lake Helena for each modeling year.

Table E-13. Inorganic Nutrient Fractions to Lake Helena

Year	Fraction Inorganic Nitrogen	Fraction Inorganic Phosphorus
1993	0.71	0.73
1994	0.90	0.94
1995	0.88	0.92
1996	0.84	0.88
1997	0.82	0.85
1998	0.76	0.78
1999	0.80	0.83
2000	0.85	0.88
2001	0.70	0.86
2002	0.68	0.84
2003	0.79	0.92

E.3.5 Light Penetration in Lake Helena

The BATHTUB model requires average Secchi depth to determine the nonalgal turbidity in the lake. Secchi depth data were collected in Lake Helena during the summer of 2003 and ranged from 0.15 m to 1.07 m. Because data are only available for 2003, the average value of 0.41 m will be applied to all modeling years.

E.3.6 BATHTUB Lake Response Modeling

BATHTUB model output for the “Existing” scenario was first compared to conditions observed in Lake Helena in 2002 and 2003, which are represented by DEQ data collected on 8/9/2002 and Land &Water data collected on 6/26/2003 and 8/29/2003. The BATHTUB model offers the user several choices for nutrient sedimentation models, which determine the predicted in-lake concentrations from loading rates and residence time. Predicted phosphorus concentrations are in agreement with epilimnetic observations with the sedimentation factor set to 1.5 (mid-range for phosphorus (Walker, 1987)). Predicted nitrogen concentrations approach observed values with a sedimentation factor of 1 (no adjustment). It is not possible, however, to accurately estimate these factors with the available data.

Due to time constraints, sedimentation models are not described in this preliminary memo. Detailed information can be found in Walker (1987). Simulated nutrient concentrations were compared to observed values for the summer of 2002 and 2003 and are presented in 0.

Table E-14. Simulated Nutrient Concentrations Based on Four Sedimentation Models

Model Number	Model Description	Total Nitrogen (µg/L)		Total Phosphorus (µg/L)	
		2002	2003	2002	2003
1	Second Order, Available Nutrient	1,230	1,140	185	185
2	Second Order, Decay Rate	1,250	1,120	180	180
3	Second Order, Fixed	1,060	930	110	100
4	Canfied & Bachmann (1981)	1,040	910	110	100
---	Observed	1,480	820	155	226

The BATHTUB model uses simulated nutrient concentrations to predict growing season average chlorophyll *a* concentration in the euphotic zone. Again, the user has several options for simulation. This memo presents the results of modeling option 1, which accounts for nutrients, light availability, and flushing rate. Modeling option 1 was simulated for each nutrient model described in Table E-15. Simulated chlorophyll *a* concentrations are shown in Table E-15. The first four predictions are based on nutrient concentrations simulated by the four nutrient simulation models. A prediction was also simulated with observed nutrient concentrations. In 2002, predicted chlorophyll *a* concentrations were generally 60 percent below the observed mean (89 µg/L). In 2003, predicted chlorophyll *a* concentrations were typically 130 percent higher than the observed mean (15 µg/L).

Table E-15. Simulated Chlorophyll *a* Concentrations in Lake Helena Based on Various Nutrient Simulation Models and Observed Water Quality

Nutrient Simulation Model	Chlorophyll *a* (µg/L)	
	2002	2003
1	43	41
2	44	40
3	33	29
4	32	28
Observed Nutrient Concentrations	48	29
Average Observed Chlorophyll *a* Concentration	89	15

Nutrient model 1 was chosen to simulate nutrient concentrations in the lake because of its general applicability. Table E-16 reports the predicted chlorophyll *a* concentrations in Lake Helena for 1993 through 2003. Chlorophyll *a* concentrations are predicted to range from 40.9 to 47.8 µg/L with an average value of 45.2 µg/L. There is little variation in the model predictions from year to year. This is likely due to the steady inputs from point sources, septic systems, and the irrigation system, which result in near-constant concentrations of total nitrogen and total phosphorus in the lake.

Table E-16. Chlorophyll *a* Concentrations Predicted by the BATHTUB Model for Lake Helena

Year	Chlorophyll *a* (µg/L)
1993	47.8
1994	45.6
1995	45.8
1996	46.1
1997	46.5
1998	47.3
1999	46.8
2000	46.2
2001	42.5
2002	43.5
2003	40.9

E.4.0 BATHTUB Modeling Scenarios

The BATHTUB model was used to simulate lake response to the two land use scenarios modeled for Lake Helena. Watershed nutrient loads simulated by GWLF and loads estimated from the irrigation system were used to drive the eutrophication model. The contributions to the additional nutrient loads (year 2003 loads relative to natural conditions) are summarized in Figure E-4 and E-5.

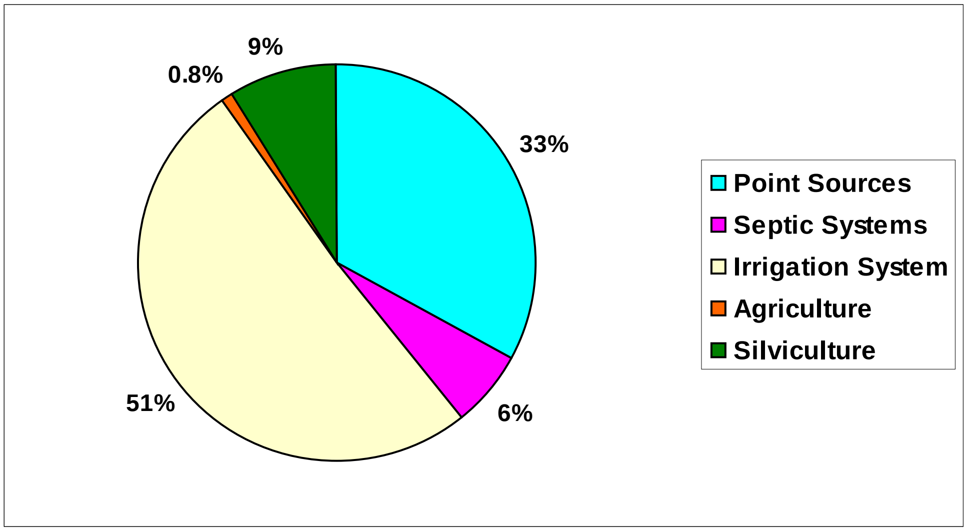

Figure E-4. Sources of Additional Total Nitrogen Loading (Year 2003) in the Lake Helena Watershed Compared to Natural Conditions

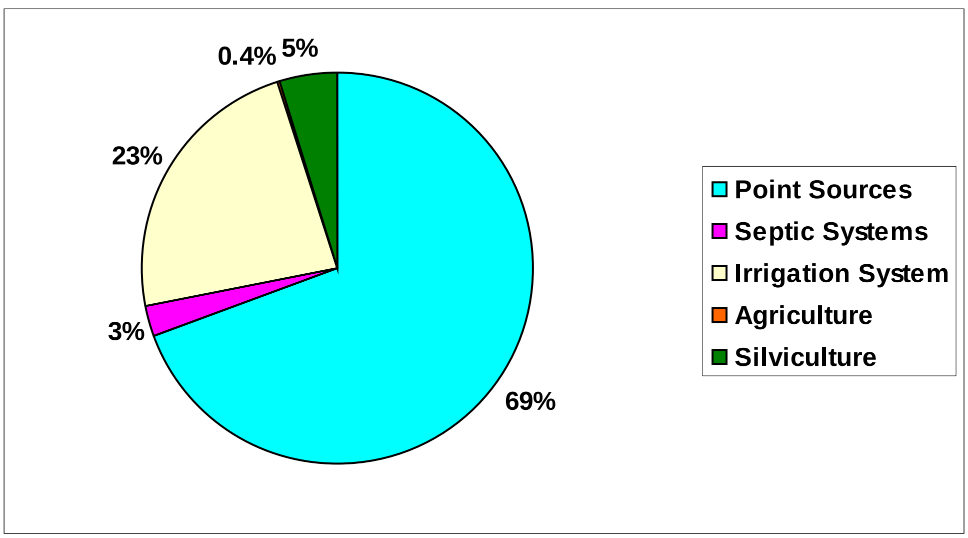

Figure E-5. Sources of Additional Total Phosphorus Loading (Year 2003) in the Lake Helena Watershed Compared to Natural Conditions

Nutrient sedimentation model 1 is used to simulate nitrogen and phosphorus concentrations from input loads. Chlorophyll *a* model 1, which accounts for nutrients, light availability, and flushing rate, is used to estimate chlorophyll *a* concentrations.

Predicted levels of eutrophication under two land use scenarios were compared. The "Existing" scenario accounts for current land use, point sources, septic systems, and the Helena Valley Irrigation System. The "Natural" scenario converts all land uses to an undisturbed state and removes the point sources, septic systems, and irrigation system from the loading. The simulated residence time in Lake Helena increases under natural conditions because additional flows from the irrigation system are not flushing through the system each summer. Figure E-6 compares the predicted chlorophyll *a* concentrations under each scenario. Under natural conditions, the mean predicted chlorophyll *a* concentration across all years is 9.3 µg/L; under existing conditions, the mean predicted concentration is 45.2 µg/L.

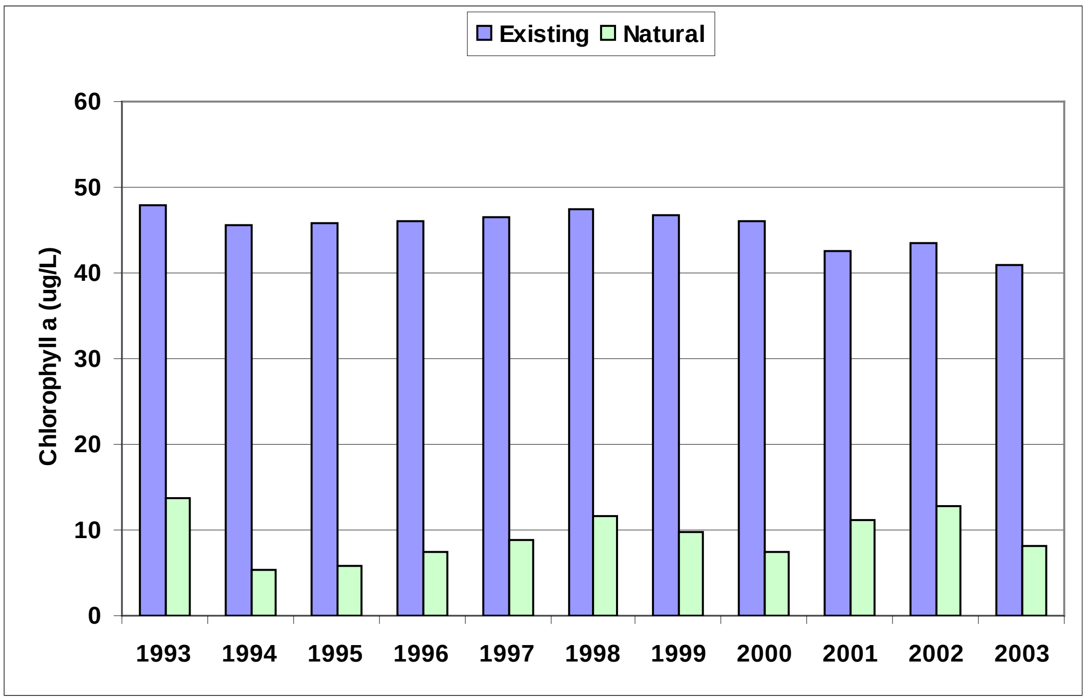

Figure E-6. Chlorophyll *a* Concentrations Simulated for Two Modeling Scenarios

E.5.0 Conclusions

It is difficult to calibrate the GWLF/BATHTUB model for the Lake Helena Watershed with the available data (one sampling date in 2002 and two dates in 2003). In addition, applying constant monthly loads from the Helena Valley Irrigation System, point sources, and septic systems may oversimplify the loading from these sources, which may explain the relatively constant chlorophyll *a* predictions for the lake across all modeling years. However, the BATHTUB model does predict an average chlorophyll *a* concentration of 45 µg/L, which is also the average of all samples collected in both 2002 and 2003 (45 µg/L). Thus, the model may be accurately depicting general eutrophication of the lake, rather than day-to-day variation detected by limited sampling data.

Results of the GWLF/BATHTUB model for this watershed under natural conditions are probably more reliable than for existing conditions because 1) transport parameters for undisturbed land uses are well established, and 2) the constant-input assumptions concerning the irrigation system, point sources, and septic systems do not apply. Under the natural scenario, chlorophyll *a* is predicted to range from 5.2 µg/L to 13.7 µg/L with a mean of 9.3 µg/L. It is not likely, therefore, that Lake Helena will ever achieve the current water quality target of 2.2 µg/L. The target is based on trophic state indices observed in shallow, reference lakes in Ecoregion II. Lake Helena has a relatively high ratio of watershed area to lake area. Even under natural conditions, total loading from upland areas would be expected to cause mild eutrophication in a lake this size.

E.6.0 References

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