Utah Department of Environmental Quality, Division of Water Quality

TMDL Section

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U.S. EPA, Region 8

Browne Lake

Waterbody ID	Upper Green-Flaming Gorge Reservoir Watershed: Browne Lake, HUC #14040106
Location	Daggett County, North Eastern Utah
Pollutants of Concern	Dissolved Oxygen and Total Phosphorus
Impaired Beneficial Uses	Class 2B (Recreation use and aesthetics); 3A (Cold water game fish and organisms in their food chain); 4 (Agriculture)
Loading Assessment	
Current Loading	108 Kg/yr total phosphorus
Loading Capacity	87 Kg/yr total phosphorus
Margin of Safety	Explicit MOS of 5% (4 Kg/yr), implicit MOS through conservative assumptions
Wasteload Allocation	No point sources, wasteload allocation set to zero
Load Allocation	83 Kg/yr total phosphorus
Load Reduction	25 Kg/yr total phosphorus
Defined Targets/Endpoints	1) Total phosphorus concentrations less than 0.025 mg/L (in-lake) and 0.05 mg/L (tributary inflow) 2) Trophic State Index Values less than 50 (mesotrophy) 3) Dissolved Oxygen concentrations greater than 4.0 mg/L (one day average for at least 50% of the water column) 4) Shift from blue-green algal dominance
Implementation Strategy	1) Maintain and improve upland range condition through application of best management practices 2) Maintain and improve riparian area function through application of best management practices 3) Reduce nonpoint source pollution from recreation by applying best available technologies
This document is identified as a TMDL for Browne Lake and is officially submitted under §303d of the CWA for USEPA approval.	

Acknowledgments

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1.0 Background

The EPA's *Water Quality Planning and Management Regulations* (40 CFR 130) require states to develop Total Maximum Daily Loads (TMDLs) for waters that are exceeding water quality standards. TMDLs will be completed for Browne Lake, which is listed on Utah's 2000 303(d) list of impaired waters for impairments from phosphorus and dissolved oxygen. This report presents total phosphorus and dissolved oxygen TMDLs for Browne Lake.

Browne Lake is located in the southern portion of the Upper Green-Flaming Gorge Reservoir watershed (HUC 14040106) in the Uinta Mountains of northeastern Utah (Figure 1-1). The lake has been placed on Utah's 2000 303(d) list for total phosphorus and dissolved oxygen impairments. Browne Lake has a priority ranking of low. Although Browne Lake has been listed as low priority for TMDL development on the State's 2000 Section 303(d) list, the availability of technical assistance from Tetra Tech and support from Ashley National Forest has allowed the Utah Division of Water Quality to proceed without disrupting the scheduled completion of TMDLs for high priority waterbodies. Table 1-1 presents the 2000 303(d) list information for Browne Lake.

Table 1-1. Listed waterbody characteristics

Waterbody Name	Waterbody Size (Acres)	Designated Uses[a]	Pollutant of Concern	Primary Source of Impairment
Browne Lake	54	2B, 3A, 4	Total Phosphorus, Dissolved Oxygen	Grazing, Recreation, Logging

[a] 2B = Recreational use and aesthetics: secondary contact recreation;
3A = Aquatic wildlife: cold water game fish and organisms in their food chain;
4 = Agriculture: including irrigation of crops and stock watering

Browne Lake is a small, mesotrophic artificial lake in the eastern High Uintas in Daggett County. It lies at the top of Carter Creek Gorge, one of the tributaries to Flaming Gorge, and is impounding Beaver Creek in a mid-elevation meadow (Lake Reports, 1993). Table 1-2 presents the characteristics of Browne Lake. The lake was originally created as a reservoir for irrigation use in the summer, but is now used solely for recreation. It is owned and maintained by the state of Utah to provide recreational fishing. The shoreline is owned by the Ashley National Forest and public access is unrestricted. A U.S. Forest Service campground, fishing, and a trail to Leidy Peak make this a popular recreation area. Utah Division of Wildlife Resources (DWR) stocks Browne Lake with rainbow and brook trout every year. The fish population of the lake also consists of three percent native Colorado River cutthroat trout (DWR 2002). Small boats may be launched from an unimproved dirt boat ramp. The campground has privies, drinking water, and picnic areas.

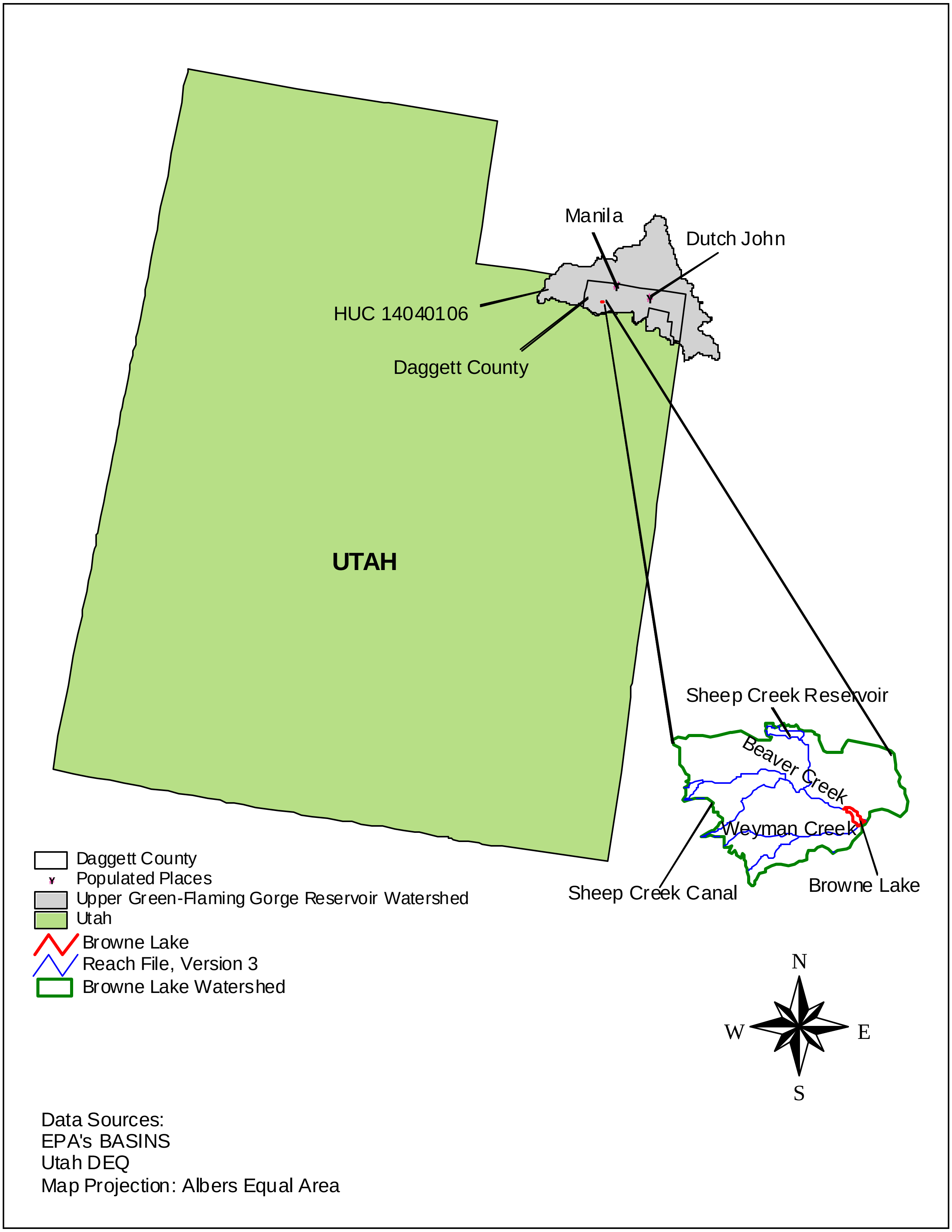

Figure 1-1. Location of the Browne Lake watershed

Table 1-2. Browne Lake characteristics

Lake Name	Surface Area (acres)	Volume (at capacity) (acre-feet)	Maximum Depth (Feet)	Mean Depth (Feet)	Length (Feet)	Width (Feet)	Shoreline Length (miles)
Browne Lake	54	642	25	12	3,000	800	1.0

Flow regulation at the lake's outlet flow structure is maintained by DWR. In the late 1990s DWR lowered the water level to repair the outflow structure and removed vegetation on the dike leading up to the spillway, but generally the lake is not drawn down. It has been stabilized since 1958 to be used as a fishery resource. The area around the lake is meadow with sage-grass vegetation and a few rock outcroppings, but coniferous forest covers most of the watershed. Much of the forest burned in a wildfire in 1985 and has been slow to grow back.

The high point of the watershed is 3,680 meters (12,074 ft) above sea level and results in an average slope to the lake of 9.6 percent (270 feet per mile). The Sheep Creek Canal diverts much of the runoff out of the Browne Lake watershed into Long Park Reservoir and Manila for agricultural use. The canal is at an approximate elevation of 9,100 feet and collects most of the watershed's runoff from above this elevation. The inflows to Browne Lake are Beaver Creek and Weyman Creek as well as some small intermittent streams. The upper portion of Beaver Creek, the primary tributary to Browne Lake, enters the Sheep Creek Canal and the lower portion flows into Browne Lake. Only a small fraction of the water is diverted back into the Beaver Creek drainage. Weyman Creek has also been diverted by the Sheep Creek Canal, but runoff into the lower reaches drains into the lake. Sheep Creek Lake is an upstream impoundment of Sheep Creek Canal water that flows into Beaver Creek. Sheep Creek Lake is also a man-made reservoir that is not drawn down for agricultural use. The outflow of Browne Lake is Carter Creek.

The primary activities in the watershed include grazing, logging, and recreational activities including camping, horseback riding, and fishing. Much of the watershed burned in a forest fire in 1985. The area was subsequently logged to salvage the burned timber. Some salvaging operations are still occurring. The fire may have caused some short-term increases in sediment production, but the damage to the watershed from the wildfire has diminished due to the regrowth of vegetation.

Current possible nonpoint sources of phosphorus to the lake include grazing, recreation, logging, and the burned area of the watershed. Grazing takes place throughout the watershed although livestock no longer have direct access to the lakeshore as of August 2002 (E. Richmond, pers. comm.). There are no point sources of pollution in the watershed. These sources of phosphorus are described in greater detail in Section 3.0.

2.0 Water Quality Standards

Utah's *Standards of Water Quality for Waters of the State* (Utah, 2001) present the applicable water quality criteria for the state of Utah. Table 1-2 presents Utah's lake water quality criteria for the designated uses of Browne Lake.

Table 2-1. Applicable Utah water quality criteria

Parameter	Secondary Contact Recreation (2B)	Cold Water Aquatic Life (3A)	Agriculture (4)
Dissolved Oxygen	–	Not to exceed 110% saturation	–
		30 day avg: 6.5 mg/L	
		7 day avg: 9.5mg/L when early life stages present, 5.0 mg/L when all life stages present	
		1 day avg: 8.0 mg/L when early life stages present, 4.0 mg/L when all life stages present	
Total Phosphorus*	0.025 mg/L*	0.025 mg/L*	–

*Total phosphorus is a pollution indicator that is considered along with other corroborating parameters in order to determine if impairment exists.

2.1 Utah's Listing Methodology

2.1.1 Dissolved Oxygen

In practice, Utah uses the one-day average dissolved oxygen criterion of 4.0 milligrams per liter (mg/L) to evaluate attainment of water quality standards. To determine the beneficial use support for aquatic life (3A) in listing lakes and reservoirs, Utah Division of Water Quality (DWQ) applies the following additional criteria:

- Initial support status
- Exceedance by percentage of the water column
- Support status
- Trophic status
- Blue-green algae
- Fish kills

An initial support status is determined for three conventional parameters (dissolved oxygen, temperature, and pH) according to national 303(d) criteria. The data for these three parameters are analyzed for the entire water column and a percent of the readings in exceedance of the state standard is determined in order to apply a support status for the waterbody. However, state water quality criteria account for the fact that anoxic or low dissolved oxygen conditions may exist in the bottom of reservoirs and therefore, exceedance of the state dissolved oxygen criteria in the lower 25 percent of the water column is allowed (UDEQ-DWQ 2000a).

Evaluation of dissolved oxygen profile data is specific to each sampling day and is not averaged over a seasonal or annual basis. When dissolved oxygen is greater than 4.0 mg/L for greater than 50 percent of the water column depth, a fully supporting status is assigned; partial support is assigned when 25-50 percent is greater than 4.0 mg/L, and non-support is assigned when less than 25 percent of the water column is greater than 4.0 mg/L. Unless a reservoir is classified as fully supporting its designated uses, it is eligible to be placed on the 303(d) list.

Data associated with Trophic State Index (TSI) rating, fish kills, winter anoxia, or blue-green algal dominance are used to support listing of the waterbody. A final determination to list the waterbody is made through an evaluation of the historical beneficial use support trends since 1989. It is necessary with such an evaluation to incorporate the hydrology and seasonality associated with lakes and reservoirs. In general, if a waterbody exhibits a beneficial use that is consistently partially supporting or not supporting, DWQ will place it on the 303(d) list. However, if a waterbody exhibits a mixture of partially and fully supporting conditions over a period of time, DWQ will not list the waterbody, but continue it's evaluation (UDEQ-DWQ 2000a).

2.1.2 Total Phosphorus

The entire water column of a lake on any one day is evaluated for comparison to the 0.025 mg/L total phosphorus pollution indicator. If the phosphorus criterion is exceeded in 10 percent or fewer of the measurements on a given day, the lake is assigned as fully supporting its designated uses. An exceedance of the phosphorus criterion in greater than 10 percent, but less than or equal to 25 percent, of the measurements is assigned a designation of partially supporting. When the criterion is exceeded in greater than 25 percent of phosphorus measurements in the water column a designation of non support is assigned.

In addition to the numeric pollution indicator for phosphorus, secondary pollution indicators including TSI values and ~~a~~ blue-green algal dominance are also evaluated before listing a waterbody for total phosphorus. If a waterbody exhibits a constant status of partial support or non support along with increased TSI values and blue-green algal dominance, it is placed on the 303(d) list.

2.2 TMDL Endpoints

TMDL endpoints represent water quality targets used in quantifying TMDLs and their individual components. Different TMDL endpoints are necessary for each impairment type (i.e., phosphorus and dissolved oxygen). Utah’s numeric water quality criteria for phosphorus and dissolved oxygen (identified in Section 2.0) were used to identify endpoints for TMDL development. Based on water quality observations in Browne Lake (see Section 3.3), summertime hypolimnion conditions were assumed to be the critical conditions in the watershed for both phosphorus and dissolved oxygen. The TMDL endpoints applied were the Cold Water Aquatic Life criteria for phosphorus and dissolved oxygen of 0.025 mg/L and 4.0 mg/L, respectively, established in Utah’s water quality standards. The 0.025 mg/L total phosphorus endpoint is applied to the entire water column. The 4.0 mg/L dissolved oxygen endpoint also applies to the entire water column, however, an exceedance of that criterion is allowed in the bottom 25 percent of the water column.

In addition, secondary endpoints of a shift in algal dominance away from blue-green algae and a TSI value between 40 and 50 have been adopted.

3.0 Data Inventory and Review

A wide range of data and information were reviewed for use in the development of phosphorus and dissolved oxygen TMDLs for Browne Lake. The categories of data used include physiographic data that describe the physical conditions of the watershed and environmental monitoring data that can be used to identify potential pollutant sources, their location, and their loading contribution. Table 3-1 presents the various data types and data sources reviewed in the watershed.

Table 3-1. Inventory of data and information used for the source assessment of the watershed

Data Category	Description	Data Source(s)
Watershed Physiographic Data	Land Use (MRLC), Forestry Activities Coverage	USGS & USEPA, Ashley National Forest
	Stream Reach Coverage	Reach File, Version 3
	Weather Information	Western Regional Climate Center, NCDC
	Digital Elevation Maps (DEM)	USGS
	Soils	STATSGO Soils Database
	Lake Characteristics	Utah DEQ
Environmental Monitoring Data	303(d) Listed Waters	Utah DEQ
	Water Quality Monitoring Data	STORET, Utah DEQ
	Streamflow data	STORET, Utah DEQ

3.1 Flow Data

Flow data from upstream of Browne Lake are necessary to characterize the inflow of water and estimate phosphorus loads to the lake. There is no current or recent continuous flow data available in the watershed to represent inflow to Browne Lake. There are 18 days of flow data available at the Beaver Creek (593794) water quality station directly above Browne Lake. The 18 flow observations were taken between August of 1980 and October of 2001. Table 3-2 presents the flow data from the Beaver Creek station. Figure 3-1 presents the water quality and flow stations evaluated in the TMDL development for Browne Lake.

Table 3-2. Flow data from Beaver Creek above Browne Lake (593794)

Date	Instantaneous Flow (cfs)
8/5/80	10.0
6/28/89	4.0
8/29/89	1.0
6/19/91	5.0
9/5/91	2.0
7/8/93	5.0
9/16/93	3.0
7/20/95	12.0

Date	Instantaneous Flow (cfs)
9/19/95	4.0
7/23/97	7.0
9/18/97	4.0
7/8/99	4.0
9/1/99	4.0
6/27/01	5.0
8/1/01	3.0
8/30/01	0.5
9/6/01	4.0
10/18/01	1.5

There were also 13 flow observations at the water quality station on Weyman Creek above Browne Lake (593793). The flow observations at the Weyman Creek station are presented in Table 3-3.

Table 3-3. Flow data from Weyman Creek above Browne Lake (593793)

Date	Instantaneous Flow (cfs)
8/5/80	5.0
6/28/89	1.7
8/29/89	1.5
6/19/91	2.5
9/5/91	3.5
7/8/93	3.5
9/16/93	0.5
7/20/95	4.0
9/19/95	2.0
7/23/97	1.5
7/8/99	6.0
9/1/99	3.0
9/6/2001	2.5

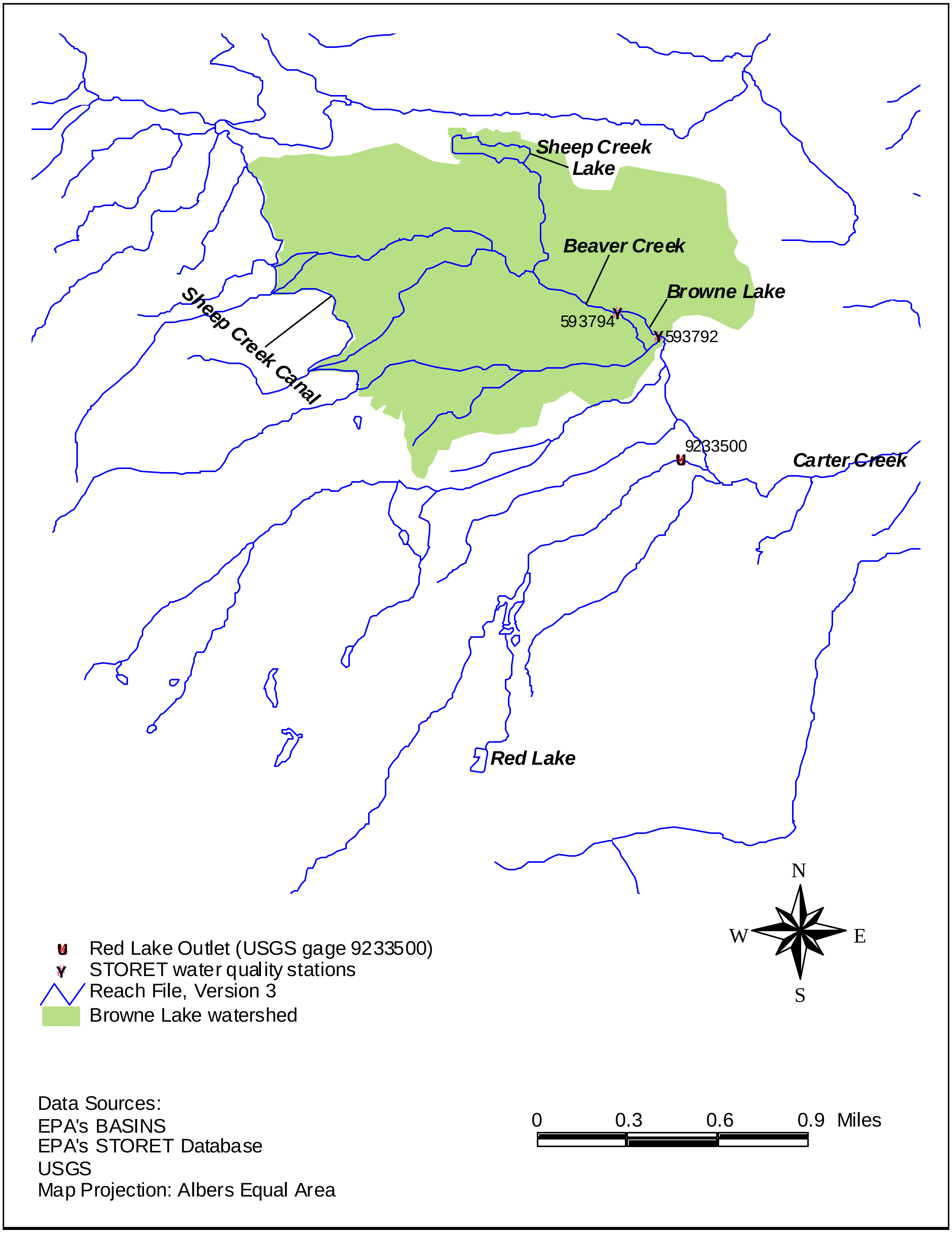

Figure 3-1. Water quality and flow monitoring stations evaluated in TMDL development for Browne Lake

Since no continuous flow data were available to represent inflow to Browne Lake and the hydrology of the watershed, the flow data at nearby USGS gage 09233500 (Red Lake Outlet near Manila, Utah) were analyzed. The Red Lake Outlet gage is located approximately 1 mile from Browne Lake and has a watershed area of 19 square miles. The watershed consists of mostly forested land uses, which is similar to the Browne Lake watershed. The location of the Red Lake Outlet gage is presented in Figure 3-1. The gage has flow data from October 1945 through September 1949. It is assumed that since the watershed is very rural that any land use activities in the Red Lake watershed area would be similar to those in the Browne Lake watershed. The watershed also has hydrologic properties similar to Browne Lake watershed including streamflow driven by spring snowmelt events. There are no other flow gages with recent continuous flow data near Browne Lake.

The daily flow observations from the Red Lake Outlet gage were used as input to the USGS hydrograph separation program HYSEP. HYSEP is a Fortran program that is capable of estimating the groundwater component of the streamflow at a particular stream gage (Sloto and Crouse 1996). Figure 3-2 presents the results of the hydrograph separation at the Red Lake Outlet gage. The results show that approximately 90-95 percent of the summer streamflow and 100 percent of the winter streamflow comes from groundwater. It is assumed that the Browne Lake watershed displays similar hydrologic properties.

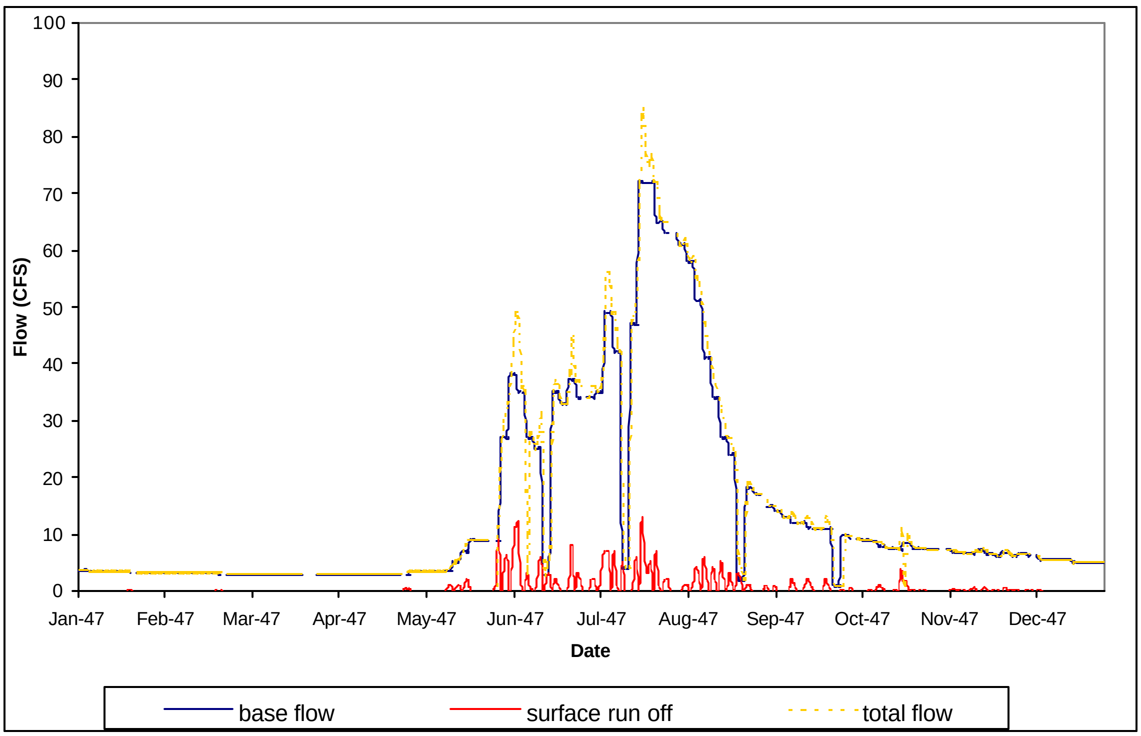

Figure 3-2. Hydrograph separation for the Red Lake Outlet flow data using HYSEP

A very small percentage of the precipitation in Utah becomes groundwater, but the few areas of recharge tend to be in mountainous areas of high elevation where the precipitation can easily enter the cracks and fractures of the mountain rocks (UWRL, accessed 2002). The Eastern High Uintas are a known area of groundwater recharge in Utah. The geologic nature of recharge areas provide easy access for contaminants to enter the groundwater (see Section 3-6).

3.2 Stream Water Quality Data

In-stream water quality data from EPA's STORET database were analyzed to characterize potential sources of phosphorus from the Browne Lake watershed to the lake. Table 3-4 presents a summary of available water quality data from Beaver Creek (593794), the major tributary to the lake. The location of the Beaver Creek water quality station is presented in Figure 3-1.

Table 3-4. Water quality data from Beaver Creek (Station 593794)

Date	Dissolved Oxygen (mg/L)	Total Phosphorus (mg/L)	Total Non-filterable Residue (mg/L)
8/5/80	8.1	0.020	8
6/18/81	6.6	0.020	5
6/28/89	N/A	0.005	N/A
8/29/89	N/A	0.005	N/A
6/19/91	10.0	0.010	8
9/5/91	9.3	0.042	15
7/8/93	9.8	0.018	5
9/16/93	8.9	0.016	5
7/20/95	9.6	0.010	9
9/19/95	9.0	0.010	5
7/23/97	7.4	N/A	5
9/18/97	9.9	N/A	4
7/8/99	8.7	0.055	N/A
9/1/99	9.3	Non-detect*	N/A
6/27/01	7.6	0.02	N/A
9/6/01	9.3	Non-detect*	N/A
10/17/01	N/A	Non-detect*	N/A
10/18/01	9.6	Non-detect*	N/A

* Detection limit is 0.02 mg/L

Table 3-5 presents a summary of the available water quality data from Weyman Creek, the other main tributary to Browne Lake.

Table 3-5. Water quality data at Weyman Creek above Browne Lake (Station 593793)

Date	Dissolved Oxygen (mg/L)	Total Phosphorus (mg/L)
8/5/80	8.5	0.02
6/18/81	6.4	0.02
6/28/89	N/A	Non-detect (0.005)
8/29/89	N/A	Non-detect (0.005)
6/19/91	10.2	Non-detect (0.01)
9/5/91	7.3	0.04
7/8/93	8.8	0.02
9/16/93	9.3	Non-detect (0.01)
7/20/95	10.0	0.02
9/19/95	9.2	0.02
7/23/97	7.5	N/A
9/18/97	10.0	N/A
7/8/99	8.5	0.025
9/1/99	9.2	Non-detect (0.02)
6/27/01	7.95	Non-detect (0.02)
9/6/01	8.64	Non-detect (0.02)

3.3 Browne Lake Dissolved Oxygen and Total Phosphorus Data

There is one water quality sampling station located in Browne Lake (Browne Lake 01 above Dam 593792) (Figure 3-1). EPA's STORET data as well as data from Utah DEQ at this station were pulled from 1980 through 2001. Station 593792 on Browne Lake has dissolved oxygen data for 13 days between August 1980 and July 1999. Total phosphorus data are available for 10 days between August 1980 and September 1995. Figures 3-3 and 3-4 present the dissolved oxygen and phosphorus data from Browne Lake, respectively. Data from June 2001 and September 2001 were also provided after the TMDL was completed. The exact depths for each of the samples is not readily available, however, it is known that the samples were taken at the surface, above the thermocline, below the thermocline, and at the bottom of the lake. These data are presented in Tables 3-6 and 3-7.

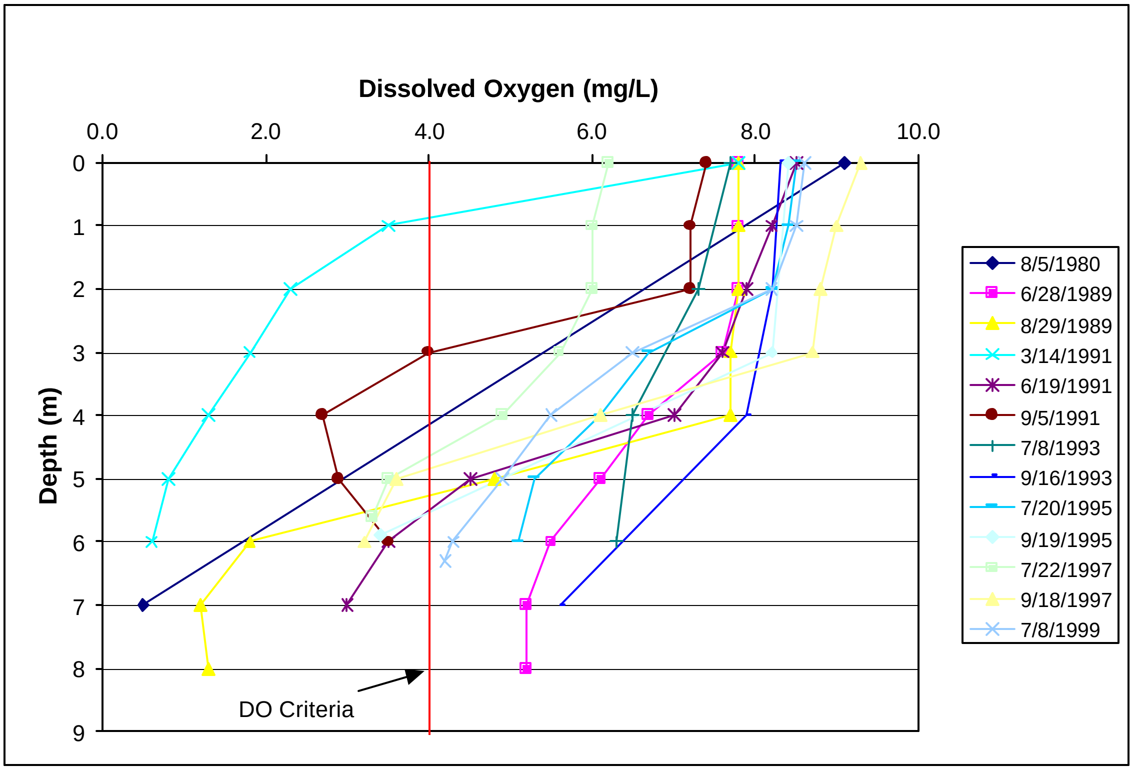

Figure 3-3. Dissolved Oxygen observations with depth in Browne Lake (Station 593792)

The maximum depth of the lake is approximately 8 meters. The dissolved oxygen criteria must be above 4.0 mg/L for at least 50 percent of the entire water column, however, anoxic conditions are allowed in the bottom 25 percent of the lake. The majority of sample days represent “fully supporting” conditions with dissolved oxygen concentrations above 4.0 mg/L in at least 50 percent of the water column. March 14, 1991 shows some very low dissolved oxygen observations, however, low winter dissolved oxygen concentrations are common in high mountain lakes and no fish kills have been reported to indicate that the low winter dissolved oxygen is a problem in the waterbody. All non-winter sampling efforts show that water quality in Browne Lake is meeting the dissolved oxygen criterion.

The June and September 2001 dissolved oxygen data are presented in Table 3-6.

Table 3-6. Dissolved oxygen data in Browne Lake (Station 593792) for June and September 2001

Date	Location of Sample	Dissolved Oxygen (mg/L)
6/27/01	Lake Surface	10.65
	Lake Bottom	4.58
9/6/01	Lake Surface	7.96
	Above the Thermocline	7.92
	Lake Bottom	0.51

Analysis of the most recent dissolved oxygen data (1993-2001) indicates attainment of the appropriate dissolved oxygen criterion. However, the total phosphorus TMDLs developed will prevent the possibility of future dissolved oxygen impairments due to the relationship between nutrients and dissolved oxygen (see Section 4.3).

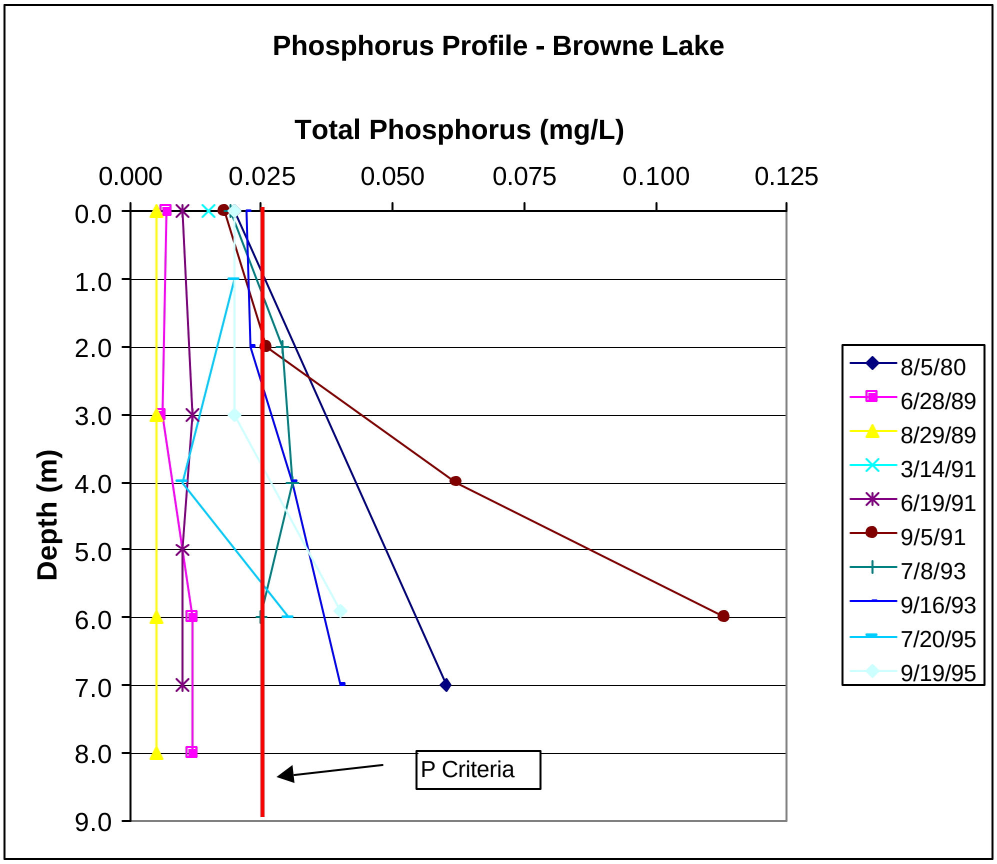

Figure 3-4. Total Phosphorus observations with depth in Browne Lake (Station 593792)

Of 12 days of total phosphorus samples in Browne Lake, six days have more than 25 percent of the samples exceeding the 0.025 mg/L phosphorus pollution indicator, indicating excess nutrient loading conditions. The phosphorus exceedances tend to be largest in the late summer months in the hypolimnion and may be related to the release of phosphorus from bottom sediments under anoxic conditions (see Section 4.1.4).

Table 3-7. Total phosphorus data in Browne Lake (Station 593792) for June and September 2001

Date	Location of Sample	Total Phosphorus (mg/L)
6/27/01	Lake Surface	0.023
	Above the Thermocline	0.025
	Below the Thermocline	0.028
	Lake Bottom	0.036
9/6/01	Lake Surface	Non-detect (0.02)
	Above the Thermocline	0.026

Date	Location of Sample	Total Phosphorus (mg/L)
	Below the Thermocline	0.023
	Lake Bottom	0.022

3.4 Additional Water Quality Data

Low dissolved oxygen can often be related to increased levels of nutrients as well as increased temperatures. All available water quality data in Browne Lake were analyzed to support the development of total phosphorus and dissolved oxygen TMDLs for the lake.

3.4.1 Limiting Nutrient

Phosphorus is the limiting nutrient for aquatic growth in most freshwater bodies. However, the ratio of the amount of nitrogen to the amount of phosphorus is often used to make the determination of the limiting nutrient (Thomann and Mueller 1987). If the nitrogen/phosphorus ratio is less than 10, nitrogen is limiting; if the nitrogen/phosphorus ration is greater than 10, phosphorus is the limiting nutrient. Based on the analysis of all available nitrogen and phosphorus data in the lake, phosphorus was determined to be the limiting nutrient. This result supports the lake's listing for total phosphorus.

Although past data indicate that Browne Lake is a phosphorus limited system, more recent data indicate that the lake may be becoming nitrogen limited (UDEQ_DWQ 1993). However, there are not sufficient data to support this. The TMDLs developed for total phosphorus in this study will also be protective of the waterbody if nitrogen is found to be the limiting nutrient because the sources responsible for contributing phosphorus to the waterbody are the same sources that contrbute nitrogen.

3.4.2 Temperature

All available temperature data were also analyzed as a potential cause for decreased dissolved oxygen levels, however all temperature data were found to be below the maximum temperature of 20°C required by Utah's water quality standards for cold water fisheries such as Browne Lake. Figure 3-5 presents the temperature data at water quality station 593792.

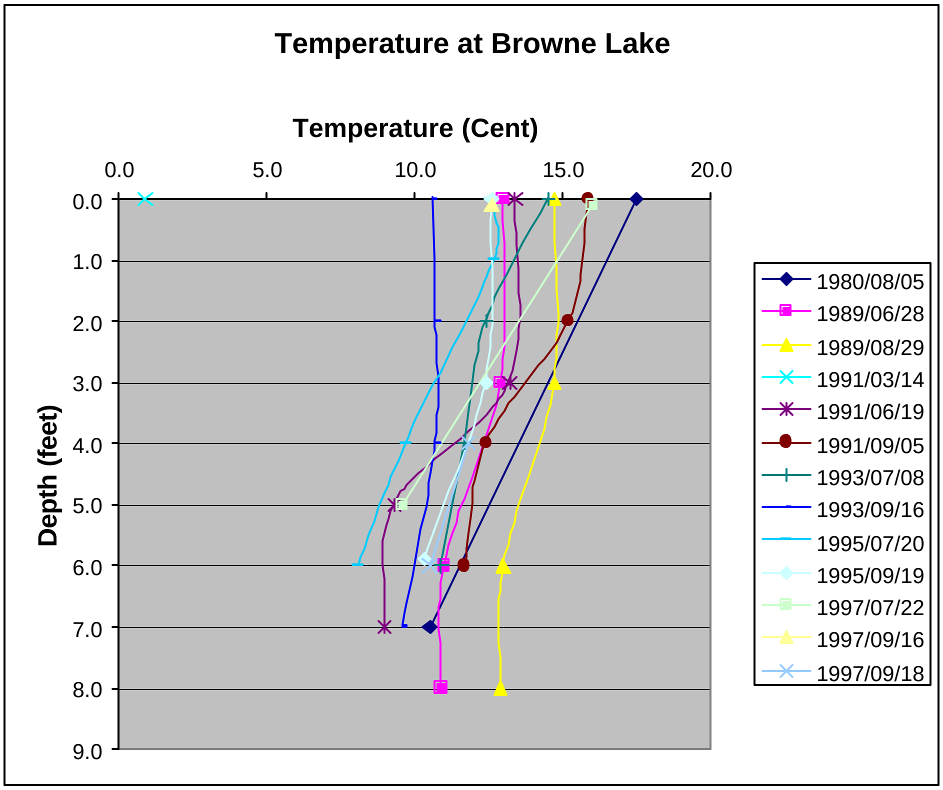

Figure 3-5. Temperature (°C) observations with depth in Browne Lake (Station 593792)

3.4.3 Dissolved Phosphorus

Of all the phosphorus compounds in lakes, phytoplankton can use only soluble phosphate (PO_4) for growth (Horne and Goldman 1994). There are no recent observations of PO_4 available. The only PO_4 data available are from one day in 1980 and one day in 1981. The 1980 data shows very high levels of PO_4 (0.02 mg/L and 0.06 mg/L). Due to the lack of available PO_4 data, dissolved phosphorus was also analyzed (see Figure 3-6).

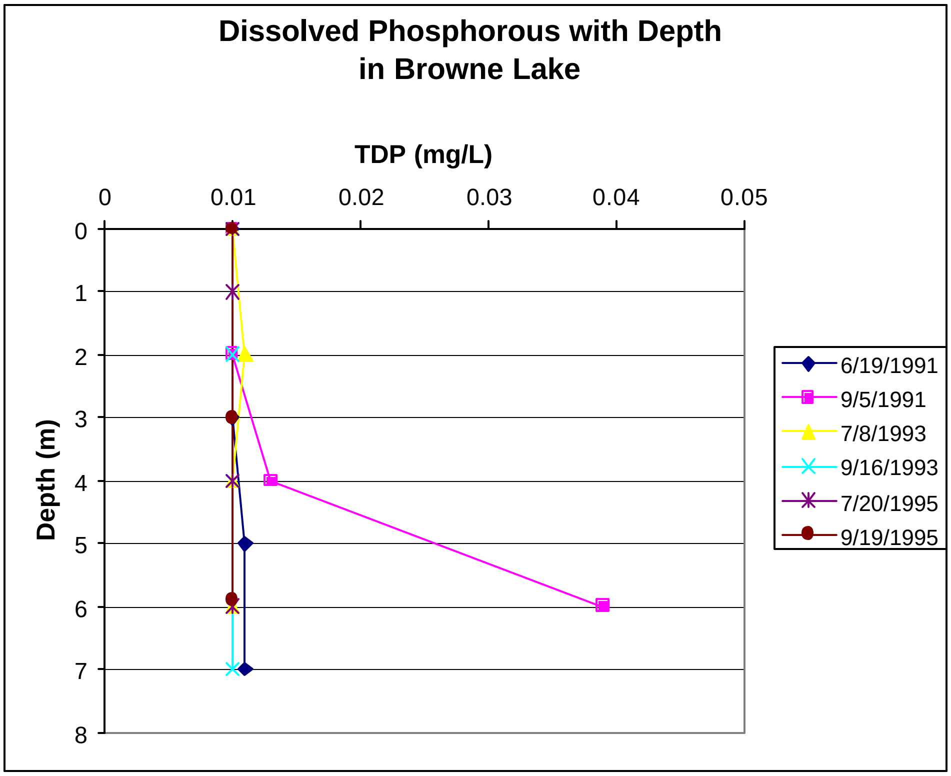

Figure 3-6. Dissolved phosphorus observations with depth in Browne Lake (Station 593792)

There are six days of recent dissolved phosphorus data available. The dissolved phosphorus concentrations are fairly low throughout the water column, however, September of 1991 shows a dramatic increase in dissolved phosphorus levels, which corresponds with an increase in total phosphorus on that same date. Overall, the dissolved phosphorus levels in the lake appear to be fairly low, however, there are a few days when the dissolved phosphorus observations are exceptionally high and the total phosphorus observations tend to be high as well on those days. It is believed that a reduction in total phosphorus will lead to a reduction in available dissolved phosphorus as well.

3.4.4 TSI Values

In addition to comparison of water quality observations to the total phosphorus pollution indicator of 0.025 mg/L, TSI values are also observed to support listing a waterbody for phosphorus. The concept of TSI values in a lake is based on the fact that changes in nutrient concentrations (measured by total phosphorus) cause changes in algal biomass (measured by Chlorophyll *a*), which in turn causes changes in lake clarity (measured by Secchi disk transparency) (US EPA 2002).

A common way to determine the trophic state of a lake is known as Carlson's Trophic State Index and was developed by Dr. Robert Carlson of Kent State University. The index is based on total phosphorus, Secchi depth, and Chlorophyll *a* and results in a range of TSI values. The range between 40 and 50 is usually associated with mesotrophic (moderate productivity) waterbodies. Index values greater than 50 are associated with eutrophic (highly productive) waterbodies and values less than 40 are associated with oligotrophic (low productivity) waterbodies. Table 3-8 presents the TSI values available for Browne Lake as an average of the TSI values for total phosphorus Chlorophyll *a*, and Secchi depth.

Table 3-8. TSI values for Browne Lake

Date	Phosphorus TSI Value	Secchi Depth TSI Value	Chlorophyll *a* TSI Value
7/8/93	46.6	54.2	29.7
9/16/93	48.7	58.6	41.4
7/20/95	47	58.6	41.7
9/19/95	47	52.4	51.9
7/22/97	N/A	44.7	40.7
9/16/97	N/A	45.7	49.0
7/7/99	37.4	58.6	47.7
9/1/99	49.4	51.5	57.3
6/27/01	49.4	N/A	41.7
9/6/01	37.4	50.8	14.8

According to the TSI values, Browne Lake appears to be a on the border between a mesotrophic and eutrophic lake with most TSI values between 40 and 50 and some over 50. The Secchi depth and Chlorophyll *a* TSI values are the highest, which indicates a highly productive algal community. The best way to control the algal growth is to control nutrient loading to the lake.

3.4.5 Blue-green Algae Dominance

High TSI values indicate high productivity among the algal community in Browne Lake. Recent algal data from Browne Lake indicate that in the past three sampling years blue-green algae have been ranked either one or two based on relative density. Table 3-9 presents the most abundant algal species in Browne Lake based on the most recent sampling events.

Table 3-9. Dominant algal species in Browne Lake

Date	Rank 1*	Rank 2*
September 18, 1997	Euglenophyta	Blue-green (Cyanophyta)
September 1, 1999	Blue-green (Cyanophyta)	Euglenophyta
September 16, 2001	Green (Chlorophyta)	Blue-green (Cyanophyta)

* Rank is based on relative density

Blue-green algae contain the highest chlorophyll content of any plant and can cause unsightly algal scums on eutrophic lakes and shade out more edible algae and macrophytes that are more important to the fishery (Horne and Goldman 1994). A blue-green algal bloom in a lake is often the first sign of eutrophication, however, blue green algae are often abundant when nutrient concentrations are low. Most blooms occur in the late summer or autumn, although spring blooms and year-round growths are known.

Spring blooms can often occur due to the influx of nutrients at spring thaw. When nitrate and ammonia are depleted, the N_2 fixing blue-greens can still continue to grow. Blue-green algae have the ability to change from the use of NH_4 to NO_3 and then to N_2 as each nitrogen source is depleted. Blue-green algae have the capability to transform nitrogen gas to ammonia by an enzyme. N_2 fixation is important in lakes because it can be a major source of new, usable nitrogen. This is most obvious when the supply of phosphorus and iron, as well as warm weather, are favorable. Under these conditions, N_2 fixation can accelerate eutrophication even when other nitrogen sources are very low. Under the anoxic conditions found in the hypolimnion of some lakes, photosynthetic N_2-fixing bacteria are important. N_2 gas is released from the sediments in the anoxic hypolimnion and any necessary phosphorus is supplied through zooplankton recycling and from the sediments.

3.5 Land Use/Cover Data

The land cover distribution in the Browne Lake watershed is important when determining nonpoint sources of phosphorus contributions. The predominant land cover in the Browne Lake watershed were identified based on Multi-Resolution Land Characteristic's (MRLC's) National Land Cover Data (NLCD) (USGS and USEPA 1990s) for the state of Utah.

The MRLC Consortium was founded in 1992 to acquire satellite-based remote sensor data for environmental monitoring programs. The Consortium was originally sponsored by the U.S. Geological Survey (USGS), U.S. Environmental Protection Agency (USEPA), the National Oceanographic and Atmospheric Administration (NOAA), and the U.S. Forest Service (USFS) (MRLC 2002). During the 1990s, the MRLC Consortium produced several mapping programs including the NLCD project directed by USGS and USEPA. NLCD is land cover data for the conterminous United States based on land cover classes including various forest types, urban land uses, surface water, wetlands, and agricultural lands among others.

In addition to the NLCD data, a GIS coverage of forest management activities was provided by the Ashley National Forest. The GIS coverage provided by the Ashley National Forest presented coverages of clearcut areas, selective cut areas, mortality salvage areas, and areas of wildfire for the period of 1970 through 1998. For modeling purposes, the selective cuts and mortality salvages were grouped as selective cuts.

The forestry coverage from the Ashley National Forest was superimposed over the MRLC land coverage. The appropriate MRLC land cover classes were then subtracted from the watershed and replaced by the forestry categories of those particular areas, resulting in nine different land cover classes throughout the watershed (Table 3-10). It is recognized that in the time since 1970 many of the land uses have changed due to plant succession. Although the land types in Table 3-10 are included as the current land types, the burned and managed forest land areas were often treated as shrubland throughout the course of this project to account for the change in plant communities over the years. The major land type in the Browne Lake watershed is wildfire, which was burned in the 1985 Weyman burn. The area burned in the fire is approximately 40 percent of the entire watershed. Additional major land classifications in the watershed include forest at 34 percent and shrubland at 12 percent. Figure 3-7 presents the land coverage of the watershed.

Table 3-10. Land cover distribution in the Browne Lake watershed

Land Use/Cover*	Area (acres)	Percent Coverage
Shrubland	902	12%
Grassland	44	0.6%
Deciduous Forest	504	7%
Coniferous Forest	1997	26%
Mixed Forest	96	1%
Wildfire	3002	40%
Selective Cut	494	7%
Clear Cut	452	6%
Water	99	1%
TOTAL	**7,590**	**100%**

*Note: Although the land cover types in Table 3-10 are included as the current land cover, it is recognized that since 1970 many of the land covers have changed due to plant succession. The burned and managed forest land areas were often given the same parameters as shrubland during the modeling phase of this TMDL project to account for the change in plant communities over the years.

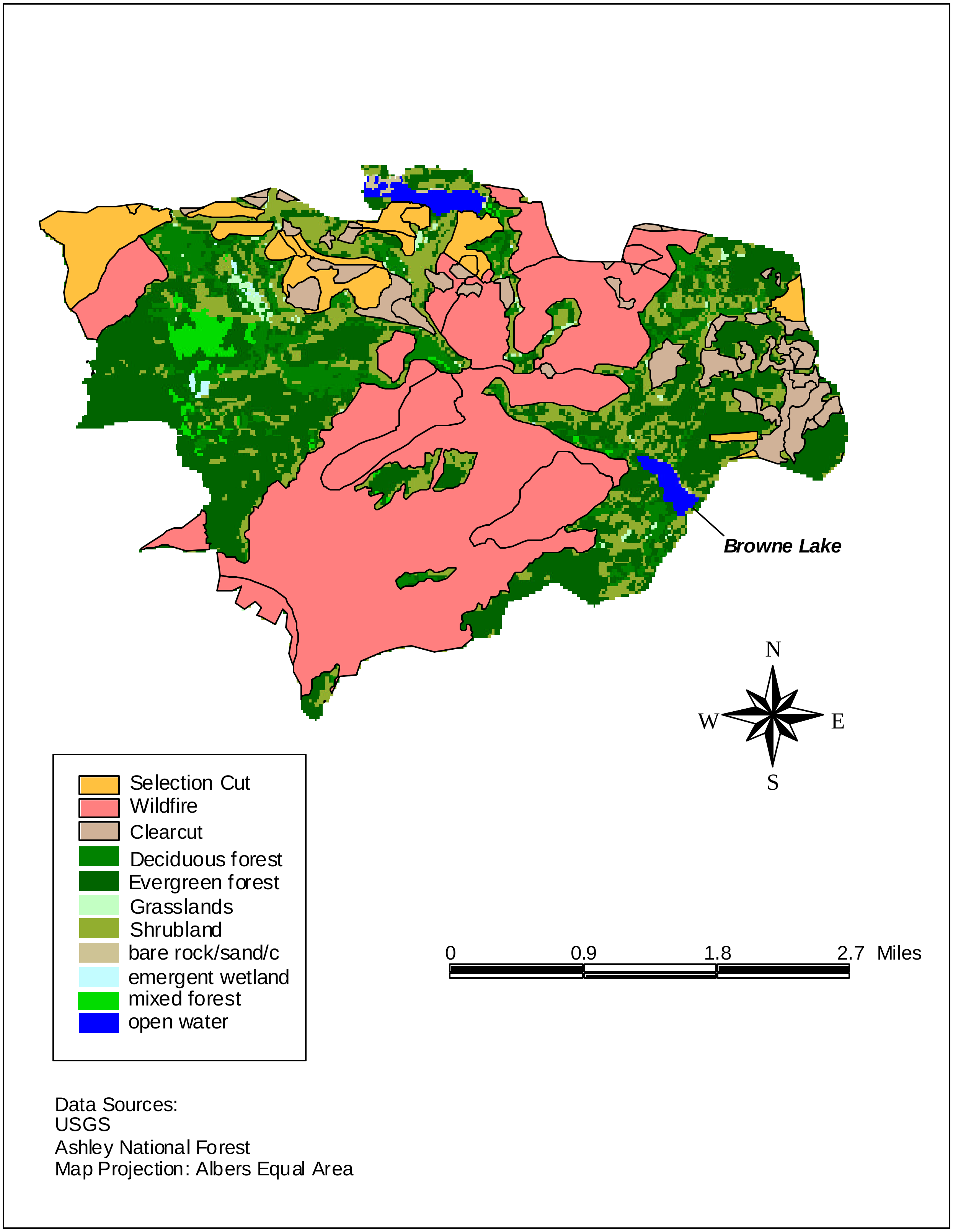

Figure 3-7. Land use coverage in the Browne Lake watershed

3.6 Geology and Soils

The majority of the Browne Lake watershed's geology is made up of the Pre-Cambrian Uinta Mountain Group with some smaller areas of Quaternary Alluvial deposits (along the stream and lake banks) and an even smaller area of Quaternary Glacial deposits. The older Pre-Cambrian geologic units are generally well consolidated and do not readily yield water except from faults and fractures. The parent rocks of the Pre-Cambrian areas are mostly quartzite with sandstone and shale beds. The Quaternary deposits are younger and generally are less consolidated than the older units and can form more permeable aquifers.

The soils in the watershed are mostly in soil hydrologic group B, which indicates moderate infiltration rates when the soil is thoroughly wetted. The soils in the watershed were formed mostly from alluvium mixed with sedimentary rocks and are well-drained.

3.7 Meteorological Data

In general, hourly precipitation data are recommended for nonpoint source modeling. Therefore, only weather stations with hourly recorded data were considered in developing a representative dataset. Long-term hourly precipitation data available from a NOAA weather station located near the watershed was considered.

Meteorological data were available at the NOAA weather station at Flaming Gorge, Utah (ID 422864). The data were obtained from the Western Regional Climate Center (WRCC) and included daily temperature, precipitation, snowfall, and snow cover observations for December 1957 through March 2000. The data set was missing data from August of 1995. The missing data were patched with precipitation and temperature data from Earthinfo data at the same weather station (422864). The station is located about 20 miles east of the Browne Lake watershed. Figure 3-8 presents the location of the Flaming Gorge weather station.

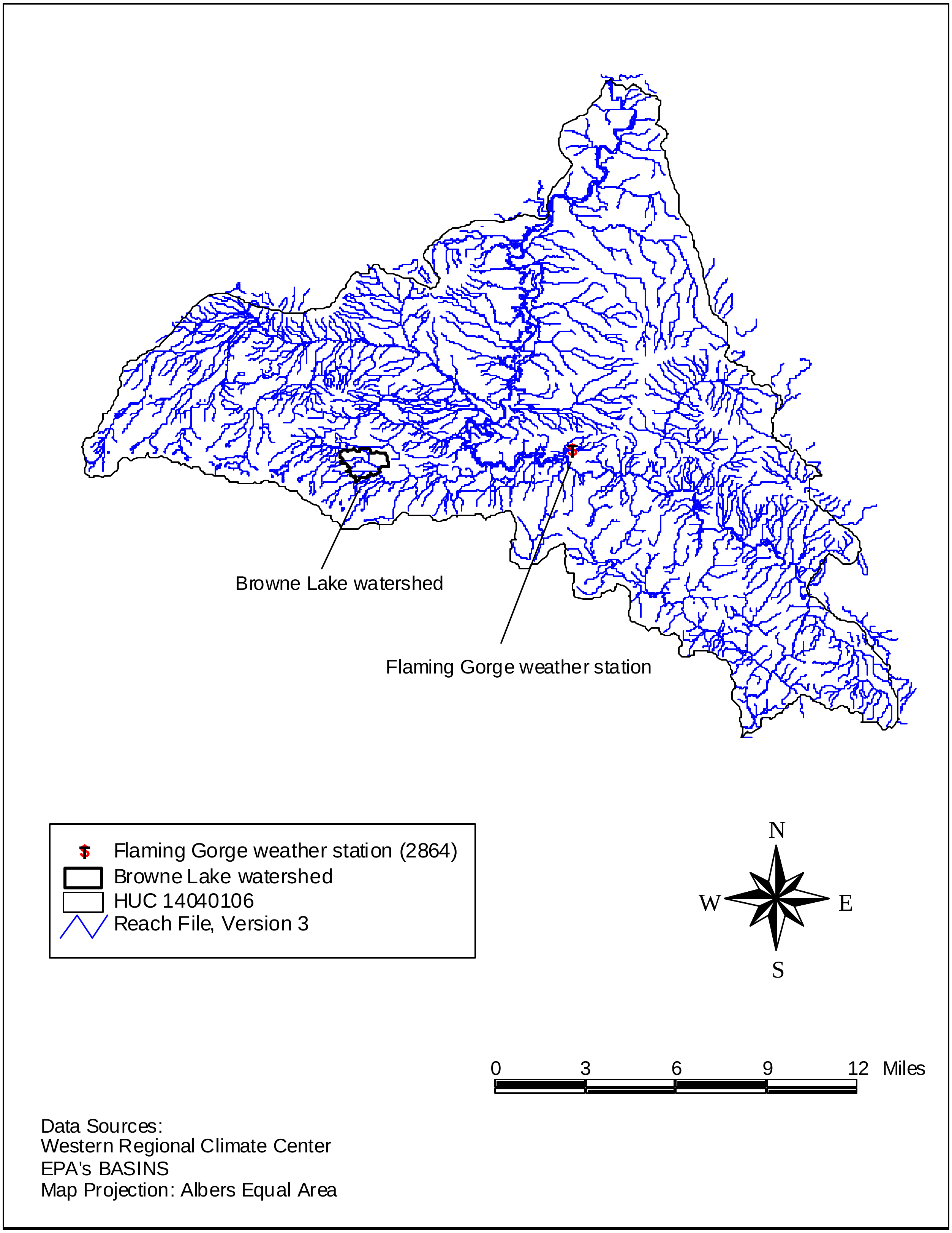

Figure 3-8. Location of the Flaming Gorge weather station

4.0 Source Assessment

A source assessment is an important part of defining the TMDL for any pollutant. The data and the sources have to be understood to be able to distinguish between point and nonpoint source impacts. Typically, the point source impacts can be quantified through permit limits and/or direct measurements at a certain location. A source assessment was performed on the Browne Lake watershed to determine the predominant sources of phosphorus loading to the system. Phosphorus and dissolved oxygen are often related, so it is assumed that the sources contributing to low dissolved oxygen levels in the lakes are the same sources that contribute to increased levels of phosphorus. See Section 4.3 for a discussion on the relationship between phosphorus and dissolved oxygen. Datasets used in assessing the pollutant sources in the watershed include livestock allotment information, county and state borders, watershed boundaries, land use coverages, stream networks and characteristics, National Pollutant Discharge Elimination System (NPDES) permitted locations, soil types and characteristics, and elevation maps. This section of the report identifies and examines the potential sources of phosphorus in the Browne Lake watershed. A wide range of data were used to identify potential sources and to characterize the relationship between point and nonpoint source discharges and responses at watershed and lake monitoring stations.

4.1 Assessment of Nonpoint Sources

Nonpoint sources represent contributions from diffuse, non-permitted sources. The predominant land covers in the Browne Lake watershed are forest, shubland, and the area recovering from the Weyman burn. Possible nonpoint sources of phosphorus impairment to Browne Lake include livestock grazing, recreation, forestry practices, internal loading, wildlife, and groundwater. The Browne Lake watershed is a rural watershed without any year-round homes. The various potential sources of phosphorus to the lake are discussed in more detail in the following sections.

4.1.1 Grazing Livestock

Grazing cattle and other agricultural animals deposit manure, and therefore, phosphorus on the land surface, where it is available for washoff and delivery to receiving waterbodies.

Numbers of grazing cattle in the watershed were provided by Ashley National Forest to evaluate the contribution of phosphorus from livestock. A portion of the Sheep Creek Park cattle allotment is in the Browne Lake watershed. The allotment has three units that are all partially within the Browne Lake watershed. The three units are called the Sheep Park unit (1,436 acres), the Half Moon unit (2,958 acres), and the Browne Beaver unit (4,153 acres) (Figure 4-1). The three units are grazed as follows:

- Sheep Park Unit—300 cattle grazed from July1 through July 25
- Half Moon Unit—300 cattle grazed from July 25 through August 21
- Browne Beaver Unit—300 cattle grazed from August 21 through September 20

The 300 cow/calf pairs are rotated among the three grazing areas for the time periods listed above. The cattle graze from July through September and are then moved to a lower elevation over the winter to be fed and supervised during calving. It was assumed that the cattle are grazing on shrubland and grassland in the watershed.

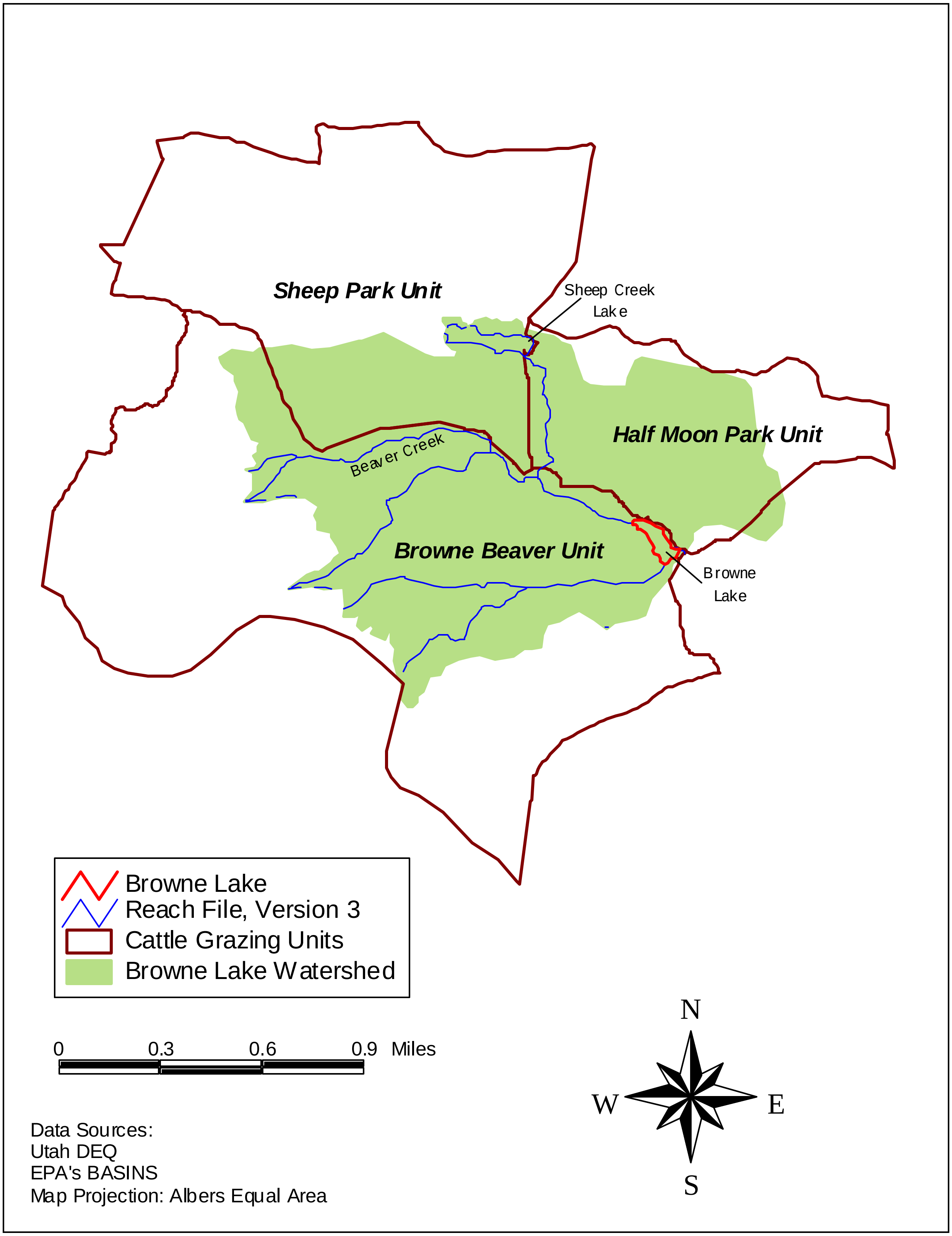

Figure 4-1. Locations of the cattle grazing units

4.1.2 Recreation

The Browne Lake watershed is a popular summer recreation area with no permanent residences. The Browne Campground situated along Weyman Creek consists of eight single family sites, 14 dispersed sites, and five wooden restroom buildings with vaults. There are 11 unplumbed summer cabins with outhouses at Half Moon Park. The cabins are available year round, but are primarily used from May 1st through October 31st. These sources are considered to be negligible because the vaulted toilets are pumped out and it is assumed little waste from the outhouses enters the lake. All eleven cabins in Half Moon Park are greater than 500 feet from the intermittent spring that runs through the park and into Browne Lake. This distance between the cabins and the waterway should provide an adequate area to filter any waste from the outhouses before it enters the lake.

4.1.3 Forestry

Silviculture can be a significant nonpoint source of sediment and phosphorus to waterbodies. Coverage of the managed forest area in the Browne Lake watershed was provided by Ashley National Forest. There was a major wildfire, referred to as the Weyman burn, that occurred in 1985 and burned approximately 5,500 acres in the Browne Lake watershed. The burned area was likely a major source of sediment as well as phosphorus to the lake at that time because of the lack of ground cover. Post fire treatment of timber consisted of piling and burning that occurred in the late 1980s and early 1990s in the Half Moon Park area. Fire wood gathering also occurred after the Weyman burn.

Beetle infestation occurred in the early 1980s causing a large die-off of Lodgepole pine within the watershed. Salvage from the beetle kill occurred in the early 1990s and continued into the late 1990s. The salvage occurred along Browne Lake Road, Hickerson Park Road, and near Ute Mountain. Some small-scale clearcutting and selective cuts are still carried out today. The forestry activities may have led to an increase of erosion in the watershed due to the land disturbance and lack of ground cover. The increased erosion may have resulted in an increase in sediment and any associated phosphorus to the lake.

4.1.4 Internal Loading

Normally, most total phosphorus loading to lakes comes from the tributaries, but the Browne Lake watershed is so rural that it does not have many significant sources of phosphorus. High watershed loads of nutrients are usually more representative of an agricultural watershed with large amounts of surface runoff and erosion. The Browne Lake watershed does not have land uses that produce large amounts of phosphorus except for areas of grazing and forestry.

Although there are no data available for Browne Lake or its watershed in the 1980s to evaluate the effects of the 1985 Weyman burn and intensive logging in the 1970s and 80s, it is likely that the fire as well as historical logging in the watershed had a significant effect on the nutrient and sediment loading to the lake. It is possible that greater amounts of sediment were contributed to the lake from the surrounding land uses after the fire and intensive logging activities. These sediments would have been high in nutrient content due to the lack of vegetation to utilize the nutrients in the soil and the soil would have been more easily eroded due to the lack of vegetation cover. Once delivered to the lake, sediments could have accumulated at the bottom of Browne Lake. The phosphorus in the bottom sediments might be contributing much of the phosphorus loading to the water column of the lake through internal loading.

High observed phosphorus concentrations indicate a large source of phosphorus to the lake might be from the lake-bottom sediment. The phosphorus concentrations in the upper layer of the lake never exceed the criterion, while all exceedances occur in the lower depths. This suggests a high level of release of phosphorus in the hypolimnion of Browne Lake. This internal sediment loading plus the loading from the watershed is probably causing the increased summer phosphorus levels. Nearby Spirit Lake does not show the same trend in increased phosphorus loads even though it currently has similar land uses and activities. This suggests that historical activities in Browne Lake watershed have played a crucial role in phosphorus contribution to the lake.

In shallow lakes or in the littoral zone, internal loading of phosphorus from the sediments is an important process (Horne and Goldman 1994). Lake sediments contain much higher concentrations of phosphorus than the overlying water (Wetzel 1983). Under anaerobic conditions the exchange of phosphorus at the sediment -water interface is strongly influenced by redox conditions. If the interface is oxygenated, phosphate ions are precipitated and do not pass freely to the lake water (Horne and Goldman 1994). Anoxic sediments can release phosphate as much as 1000 times faster than releases from oxygenated sediments.

4.1.5 Wildlife

Wildlife is an additional potential source of phosphorus loading to receiving waterbodies. Types of wildlife in the watershed were provided by Utah Department of Wildlife, DWR as GIS coverages. Population data for the wildlife species in the watershed were not readily available. Wildlife species in the Browne Lake watershed include black bear, cougar, elk, marten, moose, and mule deer. For modeling purposes it was assumed that phosphorus loads from wildlife are included in the natural background phosphorus loading to the watershed, which are represented by natural forested land areas (see Section 5.0).

4.1.6 Groundwater

A small percentage of precipitation in Utah actually soaks into the soils and becomes groundwater, however, most areas of groundwater recharge occur in places such as the Browne Lake watershed. Recharge generally occurs in mountainous places of higher elevation where the precipitation can enter the cracks and faults of the mountain rocks and the spaces between coarse particles of deposits that occur at the mountain bases (UWRL 2002). Because of the geologic nature of the recharge areas, they provide easy access for contaminants to enter the groundwater.

A 1970 hydrologic inventory of the Uintah Study Unit (10,890 mi^2 / 6,969,600 acres) by the Utah Water Research Laboratory estimated about 8 to 16 percent of the total tributary inflow in the Uintah Basin occurs as groundwater. This proportion varies from one area to another. About 35,000 acre-feet of groundwater originate on the south slope of the Uinta Mountains and 91,000 acre-feet on the north slope each year. The groundwater seeps into the streams through the alluvium and topsoil and may be used, and reused, as it drains to the Green River (UDEQ and UWRL 1970). However, the groundwater recharge in the Browne Lake watershed appears to be much greater than 8 to 16 percent. Analysis of the nearby Red Lake Outlet USGS gaging station (9233500) suggests that 95 percent of the streamflow in the Browne Lake area can be attributed to groundwater (see Section 3.1). The precipitation infiltrates the well-drained top soil layer of the watershed where it eventually hits the shallow bedrock layer of the mountain and flows as groundwater back into the stream channel and into the lake.

There are no groundwater phosphorus data available for the Browne Lake watershed area.

4.2 Assessment of Point Sources

There are no known point source discharges in the Browne Lake watershed.

4.3 Phosphorus and Dissolved Oxygen Relationship

Total phosphorus and low dissolved oxygen levels are specifically listed as impairments on the 2000 Section 303(d) List for Browne Lake. In general, high nitrogen and phosphorus levels can lead to increased productivity for algae and macrophytes, which can result in the depletion of oxygen in the water column through metabolic respiration.

Aquatic organisms are dependent upon an adequate concentration of dissolved oxygen. Less tolerant organisms generally cannot survive or are outcompeted by more tolerant organisms under low dissolved oxygen conditions. This process reduces diversity and alters community composition from a natural state.

High nutrient concentrations in Browne Lake have the potential to increase algal growth and community respiration, which leads to lower dissolved oxygen levels in the hypolimnion. A reduction in excess nutrient loading will subsequently decrease algal productivity in the water column resulting in an increase in dissolved oxygen concentration.

Typically in aquatic ecosystems the quantities of trace elements are plentiful; however, nitrogen and phosphorus may be in short supply. The nutrient that is in the shortest supply is called the limiting nutrient because its relative quantity affects the rate of production (growth) of aquatic biomass. If the nutrient load to a waterbody can be reduced, the available pool of nutrients that can be utilized by plants and other organisms will be reduced and, in general, the total biomass can subsequently be decreased as well (Novotny and Olem 1994). In most efforts to control eutrophication processes in waterbodies, emphasis is placed on the limiting nutrient.

Phosphorus is the limiting nutrient for aquatic growth in most freshwater bodies. In some cases, however, the determination of which nutrient is the most limiting is difficult. For this reason, the ratio of the amount of nitrogen to the amount of phosphorus is often used to make this determination (Thomann and Mueller 1987). If the nitrogen/phosphorus ratio is less than 10, nitrogen is limiting; if the nitrogen/phosphorus ration is greater than 10, phosphorus is the limiting nutrient. Phosphorus was determined to be the limiting nutrient in Browne Lake based on available water quality data. This result supports the Section 303(d) listing for total phosphorus, therefore, a phosphorus TMDL was developed for Browne Lake. Controlling the phosphorus loading to Browne Lake will limit plant growth and reduce eutrophication.

5.0 Technical Approach/Model Setup

5.1 Overall Technical Approach

The development of TMDLs for Browne Lake required the use of two models, one to model the contributing sources from the watershed and one to model the lake dynamics of Browne Lake. The Generalized Watershed Loading Function (GWLF) model (Haith and Shoemaker 1987, Haith et al. 1992) was chosen to estimate the stream flow and nutrient loading from the Browne Lake watershed because of its simple framework and proven effectiveness in the long term prediction of watershed loading. GWLF was chosen because there was no continuous flow data and a very limited number of water quality observations available to support a watershed model that needs extensive calibration. The model does not require a systematic calibration process. The model makes use of loading functions, which combine empirical export coefficients with temporal variation to produce loading estimates that are accurate in the long term and do not require extensive data for calculation. The GWLF model estimates total and dissolved nitrogen and phosphorus, sediment, and streamflow. The daily stream flow and phosphorus loadings produced by GWLF were used as input to the PHOSMOD lake model used to represent Browne Lake (see Section 5.3). The PHOSMOD lake model is a one-dimensional phosphorus loading model for lakes that divides the water column into two layers, an epilimnion and a hypolimnion. Phosphorus concentration is calculated in both layers over time using a mechanistic mass balance approach. The modeling effort is described in greater detail in the following sections.

5.2 Watershed Model

The streamflow and phosphorus loadings entering Browne Lake were determined using the GWLF model. The GWLF model, which was originally developed by Cornell University (Haith and Shoemaker 1987, Haith et al. 1992), provides the ability to simulate surface runoff, groundwater, and sediment and nutrient loadings from a watershed based on landscape conditions such as topography, land use/cover, and soil type. It is a continuous simulation model that uses daily time steps for weather data and water balance calculations. Monthly calculations are made for sediment and nutrient loads, based on the daily water balance accumulated to monthly values. All of the equations used by the model can be found in the original GWLF paper (Haith and Shoemaker 1987) and GWLF User's Manual (Haith et. al 1992).

For execution, the model requires three separate input files containing transport-, nutrient-, and weather-related data. The transport file (TRANSPRT.DAT) defines the physical parameters for each source area (e.g., area size, curve number) as well as global parameters (e.g., initial storage, sediment delivery ratio) that apply to all source areas. The nutrient file (NUTRIENT.DAT) specifies the various loading parameters for the different source areas identified (e.g., number of septic systems, runoff concentrations, groundwater concentrations). The weather file (WEATHER .DAT) contains daily average temperature and total precipitation values for each year simulated. The information used to create these three input files are described in sections 5.2.1 through 5.2.3.

5.2.1 Watershed Delineation

The contributing watershed area to Browne Lake was delineated as one large watershed rather than many smaller subwatersheds because of the relatively small size of the contributing area (7,616 acres). PHOSMOD requires daily streamflow and nutrient loads from the entire watershed as input, so modeling the area as one watershed suited the requirements of the lake model. As discussed in Section 1.0, the Sheep Creek Canal collects most of the runoff from the upper portions of the watershed and eventually drains into a lake outside of the Browne Lake watershed. The area above the canal is almost entirely natural forest, which is assumed not to be contributing large amounts of phosphorus and sediment to Browne Lake. Based on these facts, the Sheep Creek Canal was assumed to be the upper boundary of the watershed. The remaining boundaries of the watershed were determined based on DEM data and topographic maps of the area. Figure 5-1 presents the watershed boundaries used in modeling the Browne Lake watershed.

5.2.2 Streamflow Simulation

GWLF models streamflow based on the Soil Conservation Service Curve Number (SCS-CN) and daily weather (temperature and precipitation) data. A water balance is performed daily using supplied precipitation, snowmelt, initial unsaturated zone storage, maximum available zone storage, and evapotranspiration values. Evapotranspiration is determined using daily weather data and a vegetation cover factor dependent on land use type.

For subsurface flow, the model uses a water balance approach, not distinguishing subsurface flow contributions from different areas. Daily water balances are computed for an unsaturated zone as well as for a saturated subsurface zone, where infiltration is computed as the difference between precipitation and snowmelt minus surface runoff plus evapotranspiration.

Estimation of streamflow using GWLF requires the input of the following parameters:

- Recession coefficient—The rate of the hydrograph recession curve; estimated from historical streamflow data
- Seepage coefficient—the amount of water lost to deep seepage; default = 0
- Unsaturated storage—The initial amount of unsaturated soil; default = 10
- Saturated storage—The initial amount of soil that is saturated; default = 0
- Initial snowmelt—Snow cover in centimeters; default = 0
- Antecedent rainfall and snowmelt—rainfall and snowmelt for a given time period before the model simulation (usually 5 days)

Calculating the recession coefficient for a stream requires multiple days of time series flow observations along the receding leg of the hydrograph. There are only 18 days of flow data for Beaver Creek and 13 day of flow data fro Weyman Creek, therefore, there were not enough historical flow data from the tributaries to calculate a recession coefficient specifically for the Browne Lake watershed. However, a recession coefficient was calculated based on the Red Lake Outlet USGS gage (09233500) in a nearby watershed. The coefficient was calculated as 0.01. The typical range for recession coefficients is 0.01 to 0.2.

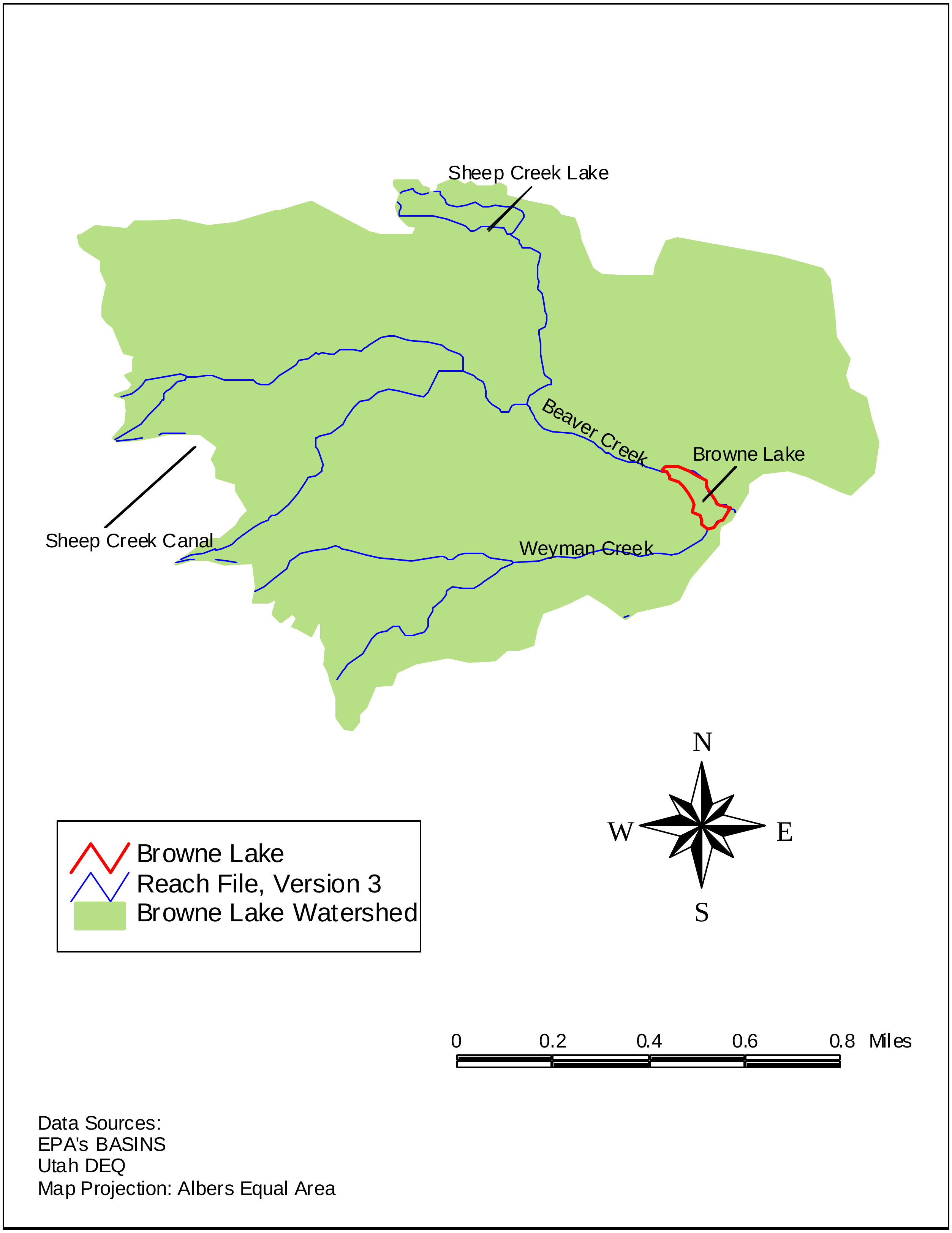

Figure 5-1. The Browne Lake watershed

The higher the recession coefficient value the faster the stream flow returns to normal flow after a storm event. A coefficient of 0.01 is a reasonable assumption for a rural watershed with good drainage, such as the Browne Lake watershed. The seepage coefficient was initially set at 0.001 assuming there is not deep seepage occurring since this is a mountainous watershed with shallow soils. Initial conditions were set for unsaturated storage, saturated storage, snow cover, antecedent rain and snowmelt for the five days prior to the simulation period. However, these data do not affect the model results for more than the first month or two of the simulation period.

5.2.3 Snowmelt and Precipitation

GWLF uses the average daily temperature to determine streamflow from snowmelt. Runoff occurs every time the temperature rises above freezing (0°C). Precipitation falls as rain when the temperatures are above the freezing point. Weather data to support the precipitation and snowmelt estimations were obtained from the Flaming Gorge weather station (2864). The data included daily temperature, precipitation, and snow cover from 1957 through 2000. There is a lag time between when the snow begins to melt and when the effect of that snowmelt is seen in the streamflow. The "Delay stream response to weather events" function in GWLF was used to delay the weather events by seven days to account for this lag time, since this is a snowmelt-driven stream system. The Browne Lake watershed is also 649 meters higher than the location of the Flaming Gorge weather station. The temperatures were adjusted to account for this change in elevation. The standard atmosphere lapse rate suggests that on average there is a difference of 6.5°C per 1000 feet (University of Oklahoma 2000).

5.2.4 Nonpoint Source Representation

In the GWLF model, the nonpoint source load calculated is affected by terrain conditions such as type of land use, land slope, and inherent soil erodibility. It is also affected by conservation practices used in the area, as well as by concentrations of nutrients in soil and groundwater. Various parameters are included in the model to account for these conditions and practices. Some of the more significant parameters used to estimate nonpoint source loading are summarized below:

Areal extent of different land use/cover categories: This establishes the areas/locations of the different land uses and is calculated from a GIS layer of land use/cover (see Section 3.3).

Curve number: This parameter determines the amount of precipitation that infiltrates into the ground or enters surface water as runoff. It is based on specified combinations of land use/cover and hydrologic soil type and is calculated using digital land use/cover and soils layers. To determine the soil curve number for each land use, a weighted average of the curve numbers for the soil types in each land use were used. Table 5-1 presents the curve numbers used for each land use in the Browne Lake watershed.

Table 5-1. Calculation of weighted average for soil runoff curve number

Land Use	Soil Types %		Soil Runoff Curve		Weighted Value
	C	B	C	B	
Deciduous forest	0.5%	99.5%	73	60	60
Coniferous forest	4.4%	95.6%	73	60	61
Mixed forest	0%	100%	73	60	60
Forest Fire	15.6%	84.4%	70	56	58
Selected Cut Forest	20.5%	79.5%	77	66	68
Clear Cut Forest	0%	100%	88	83	83
Shrubland	1.6%	98.4%	70	56	56
Grasslands	0.5%	99.5%	79	69	69
Open water	0%	100%	100	100	100

Universal Soil Loss Equation (USLE): The USLE is used in GWLF to estimate the sediment contribution from the various land uses in the watershed. The USLE is:

$$A=RKLSCP,$$

where A is soil loss in tons per acre per year. R is the rainfall and runoff factor in erosion index units. GWLF calculates the R factor, but the remaining values must be entered as input. K is the soil erodibility factor, which affects the amount of soil erosion taking place on a given unit of land. The LS factor signifies the steepness and length of slopes in an area and directly affects the amount of soil erosion. The C factor is related to the amount of vegetative cover in an area. Values range from 0 to 1.0, with larger values indicating greater potential for erosion. P is the support practice factor, which represents land use management or conservation practices used in the watershed. Values range from 0 to 1.0, with larger values indicating greater potential for erosion.

Soil erodibility factor (K) values were derived from the STATSGO soil layers and component databases. The K values for the top two soil layers for each map unit component were averaged and then multiplied by the percent composition to get a weighted average value for each soil unit id. The LS value was determined by land use type. The LS values for the forestry land uses were determined by extrapolating a value between agricultural and virgin forest. The C value for each land use was determined from the USLE guide book Predicting Rainfall Erosion Losses, A Guide to Conservation Planning (USDA 537). The C factors used in the GWLF modeling effort range from .0015 to .1 to represent the mostly forested watershed. There is no managed cropping in the watershed and so the management (P) value was assumed to be 1 for all land uses. The values for KLSCP used for modeling the Browne Lake watershed are presented in Table 5-2.

Table 5-2. USLE coefficients used in GWLF

Land Use	K	LS	C	P
Deciduous forest	.25	0.0	.0015	1
Coniferous forest	.25	0.0	.0015	1
Mixed forest	.25	0.0	.0015	1
Forest Fire	.25	20	.05	1
Selected Cut Forest	.25	20	.01	1
Clear Cut Forest	.25	50	.1	1
Shrubland	.25	50	.08	1
Grasslands	.25	100	.003	1
Open water	-	-	-	-

Sediment delivery ratio: This parameter specifies the percentage of eroded sediment delivered to surface water and is empirically based on watershed size. The sediment delivery ratio (SDR) was determined based on the watershed area from the linear function in the GWLF manual. The area of the Browne Lake watershed is 11.9 miles^2 and the SDR is 0.17197.

Unsaturated available water-holding capacity: This parameter relates to the amount of water that can be stored in the soil and affects runoff and infiltration. It is estimated using a digital soils layer and is adjusted during model calibrations.

Dissolved phosphorus in runoff: Similar to nitrogen, the value for this parameter varies according to land use/cover type, and reasonable values have been established in the literature. This rate, reported in milligrams per liter, can be readjusted based on local conditions such as forestry activities and grazing cattle areas. Table 5-3 presents the phosphorus concentrations assumed to be in the runoff from each specified land use.

Table 5-3. Nutrient concentrations in runoff

Land Use	Nutrient Concentrations		Description of Literature Value	Source
	N(mg/L)	P(mg/L)		
Deciduous forest	0.07	0.012	Background for forest	a
Coniferous forest	0.07	0.012	Background for forest	a
Mixed forest	0.07	0.012	Background for forest	a
Forest Fire	0.7	0.01	Rangeland	b
Selected Cut Forest	1.1	0.01	Silviculture	a
Clear Cut Forest	2.6	0.1	Fallow field	c
Shrubland	0.7	0.01	Rangeland	b
Grasslands	0.6	0.07	Grassland	a

[a] Novotny and Olem 1994
[b] Maidment et al. 1993
[c] Haith et al. 1992

Nutrient concentrations in runoff over manured areas: These concentrations are user-specified concentrations for nitrogen and phosphorus that are assumed to be representative of surface water runoff leaving areas on which manure has been applied. As with the runoff rates described above, these concentrations are based on values obtained from the literature. They also can be adjusted based on local conditions such as rates of manure application or farm animal populations. The cattle grazing section below describes the manure application phosphorus concentrations assumed for this TMDL.

Background nitrogen and phosphorus concentrations in groundwater: Subsurface concentrations of nutrients (primarily nitrogen) contribute to the nutrient loads in streams. There were no local groundwater phosphorus data to support the modeling effort, so groundwater phosphorus concentrations were specified based on values in the GWLF manual. The values for phosphorus were assumed to be approximately 0.015 mg/L for a watershed in the western US that is greater than 75 percent forest. Groundwater concentrations were adjusted for each land use based on the comparison of their associated runoff concentrations. The values for phosphorus concentrations in groundwater used in the Browne Lake watershed are presented in Table 5-4.

Table 5-4. Phosphorus concentrations in groundwater

Land Use	P mg/L
Deciduous forest	.01
Coniferous forest	.01
Mixed forest	.01
Forest Fire	.015
Selected Cut Forest	.013
Clear Cut Forest	.015
Shrubland	.015
Grasslands	.015

Background nitrogen and phosphorus concentrations in soil: Because soil erosion results in the transport of nutrient-laden sediment to nearby surface water bodies, reasonable estimates of background concentrations in soil must be provided. There were no local soil data to support the modeling effort so literature values were used. The percent sediment weight of phosphorus in the top 30 cm of soil was calculated from maps in the GWLF manual as 440 mg/kg.

More detailed information about these parameters and those outlined above can be obtained from the GWLF User's Manual (Haith et al. 1992).

Cattle Grazing

The shrubland and grassland land uses were assumed to be manured to account for the grazing of cattle in the watershed. There is no actual manure application on these land uses, but to represent the seasonal grazing of cattle in the watershed, the runoff concentrations for shrubland and grassland were assumed to be significantly less than the literature values representing areas where manure is applied as a fertilizer. Manure applied as a fertilizer is assumed to be applied in smaller, more concentrated areas and the grazing cattle are assumed to wander and contribute phosphorus to the landscape more diffusely. Initial phosphorus concentration values for pasture land uses from the GWLF manual were used. These values were lowered during calibration to represent the small numbers of cattle and their rotation among the three parcels of shrubland and grassland areas. Phosphorus concentrations of 0.01 mg/L and 0.07 mg/L are used to represent the runoff concentration from shrubland and grassland, respectively, during the non-grazing season (October through June). A phosphorus concentration of 0.1 mg/L replaces those values during the months of June through September to represent the increased phosphorus loads from grazing cattle during the summer months.

Land Use Contribution

GWLF is a lumped parameter watershed model, which means that in simulating surface loading, the model allows multiple land use/cover scenarios, but each area (e.g., land use) is assumed to be homogenous with respect to various attributes considered by the model. Additionally, the model does not spatially distribute the source areas, but aggregates the loads from each area into a watershed total. In other words, there is no spatial routing. To determine the phosphorus contribution to Browne Lake associated with each land use, transport and nutrient files were set up for each of the nine land uses in the watershed and run for each individual land use. By running each land use separately it could be determined how much phosphorus loading is attributed to each particular land use.

Erosion and sediment yield for each source area are estimated using monthly erosion calculations based on the USLE algorithm (with monthly rainfall-runoff coefficients). The sediment delivery ratio based on watershed size and a transport capacity based on average daily runoff was applied to the calculated erosion to determine sediment yield for each source area. Nutrient loads associated with watershed sediment loads were summed with the nutrient loads in the surface runoff to obtain the total phosphorus contribution from each land use.

Groundwater

To determine the nutrient contribution from groundwater to watershed streams, a dissolved phosphorus concentration for shallow groundwater was applied to the groundwater contribution from each of the watershed's land uses. The subsurface submodel considers only a single, lumped-parameter contributing area. To overcome this issue, each land use was modeled separately as described in the land use section above. The model was run for each of the nine different land uses to obtain groundwater phosphorus contributions from each specific land use.

5.2.5 Point Source Representation

There are no point source discharges present in the Browne Lake watershed, therefore there is no phosphorus contribution from point sources.

5.2.6 Comparison of Watershed Model Results with Observed Data

Hydrology Comparison

GWLF estimated overall streamflow in the Browne Lake watershed. The average climate conditions from April 1979 through March 1999 were used as the weather input for the Browne Lake watershed, and the model was run for the 20-year period using the most recent land use data from the mid-1990s. The modeled flow was compared to observed flow data in Beaver Creek for the time period of January 1989 through December 1995. Figure 5-2 presents the comparison of modeled streamflow to the flow observations available for Beaver Creek. Since the modeled streamflow represents the entire Browne Lake watershed, the flow is higher than the flow coming from the Beaver Creek drainage alone, which represents approximately 66 percent of the entire modeled watershed. Figure 5-2 presents the modeled flow for the entire watershed as well as 66 percent of that flow for comparison to the observed flow data from Beaver Creek.

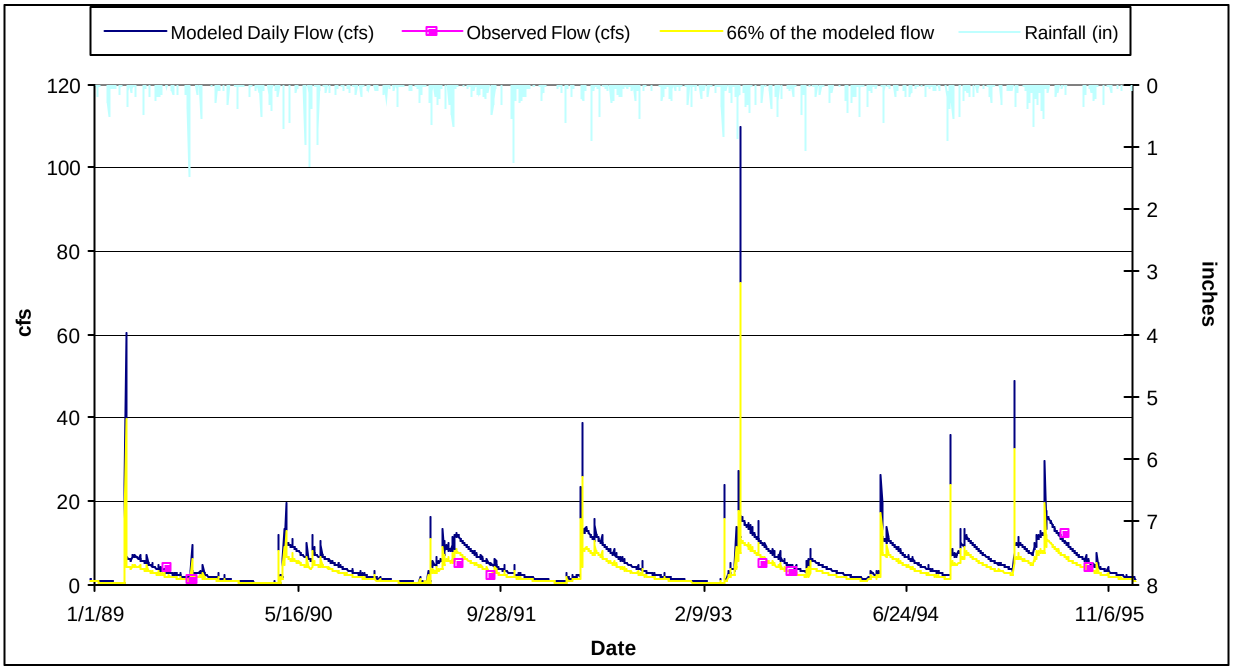

Figure 5-2. Modeled flow for the entire watershed and 66 percent of that flow compared to the observed flow data from Beaver Creek

Water Quality Comparison

Modeled phosphorus loadings from the Browne Lake watershed were compared to observed phosphorus loads in Beaver Creek from January 1989 through December 1995. The phosphorus observations at Beaver Creek were reported as a concentration, but the streamflow from the corresponding day was used to determine a phosphorus load in tons/day for comparison to the GWLF output. The pollutant loading predicted by the GWLF model for the Browne Lake watershed were within the ranges observed at the Beaver Creek water quality monitoring station. Figure 5-3 presents a comparison of the GWLF phosphorus loadings to the observed phosphorus loadings. As with the streamflow comparison, the modeled output represents the entire watershed, whereas the observed data only represent approximately 66 percent of the drainage to Browne Lake. The modeled output is shown in Figure 5-3 as well as 66 percent of the modeled phosphorus loading for comparison to the observed data in Beaver Creek.

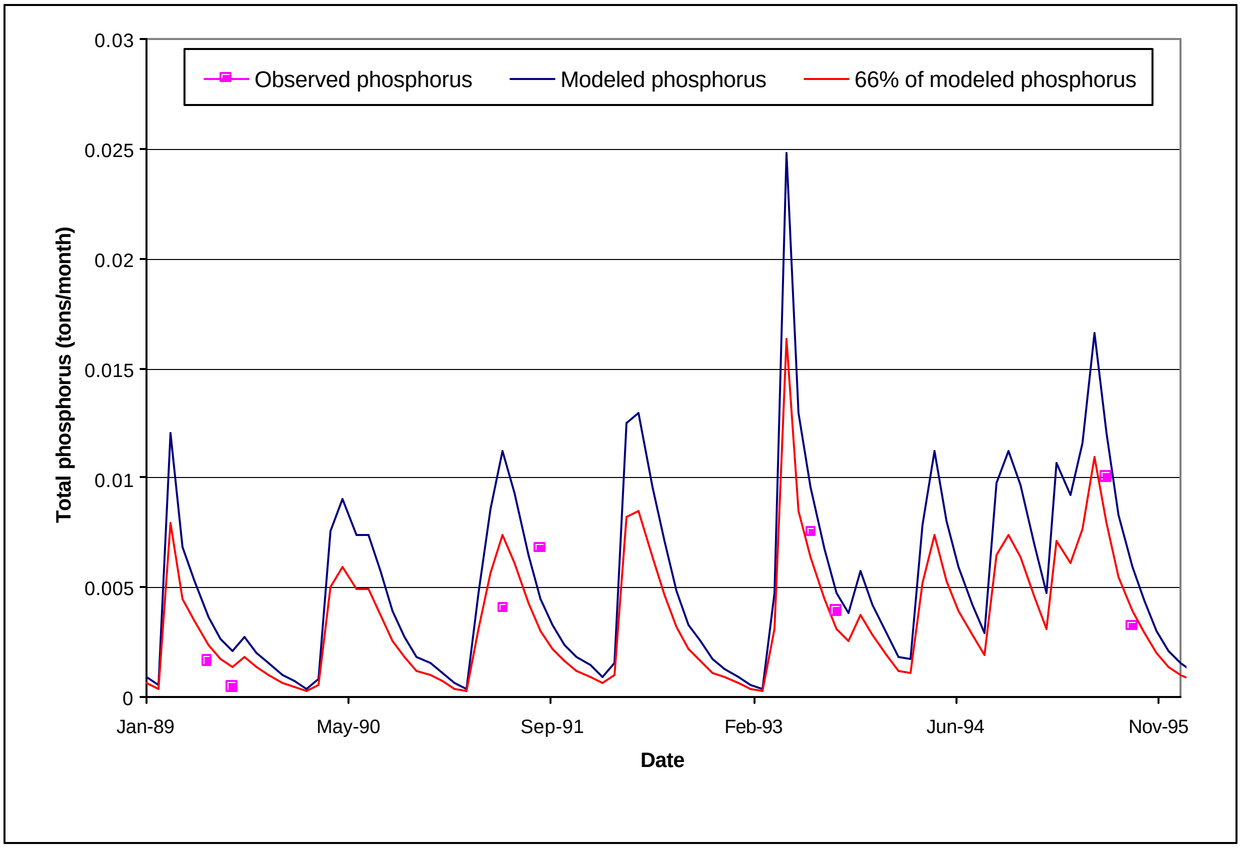

Figure 5-3. Modeled phosphorus loads from the entire Browne Lake watershed and 66 percent of the entire watershed compared to phosphorus observations in Beaver Creek

5.3 Lake Model

The PHOSMOD model was first developed by Chapra and Canale (1991) as a simplified methodology to quantify phosphorus- and sediment-water interaction in lakes. It was later modified to account for the two layers (the epilimnion and hypolimnion) in the water column of stratified lakes. It is based on a fundamental mass balance principle. The model is composed of two compartments: an epilimnion and a hypolimnion. Loading terms are calculated to account for inflow to the lake, outflow from the lake, settling from the epilimnion to the hypolimnion, settling from the hypolimnion to the sediment, resuspension from the sediment into the hypolimnion, and vertical eddy diffusion. Figure 5-4 provides a schematic cross section of the lake to assist in visualizing the transport of phosphorus in the modeled system.

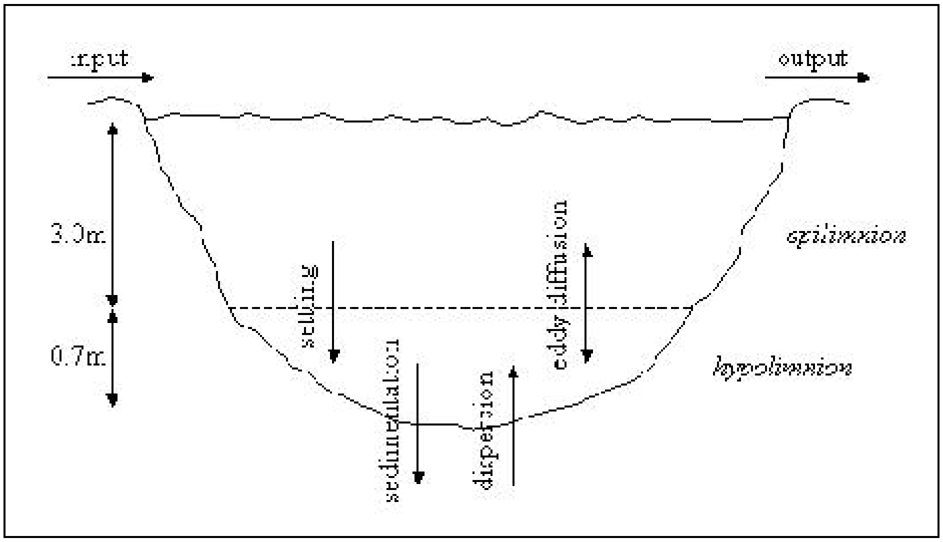

Figure 5-4. Schematic cross section of a lake. (Labels indicate type of phosphorus movement. Arrows indicate direction of movement. Hypolimnion and Epilimnion depths are for Browne Lake.)

The mass balance is established for total phosphorus and does not take into account chemical reactions in the water column. The equations for the mass balance in Figure 5-4. are listed below.

I. Phosphorus concentration in the Epilimnion:

$$V_1 \frac{dp_1}{dt} ? \; W ? \; Qp_1 ? \; vsA_2 p_1 ? \; D(p_2 ? \; p_1)A$$

input - output - settling + eddy diffusion

II. Phosphorus concentration in the Hypolimnion:

$$V_2 \frac{dp_2}{dt} ? \; v_s A_2 p_1 ? \; v_s A_2 p_2 ? \; v_r A_s p_s ? \; D(p_2 ? \; p_1)A$$

settling - sedimentation + dispersion - eddy diffusion

The result of the mass balance analysis is a set of differential equations that describe the concentrations of phosphorus in the two layers of the lake. A significant amount of stratification occurs in Browne Lake during the winter and summer months. During this period it is reasonable to assume that the mixing within the two layers is substantial but very little interaction occurs between the layers. The PHOSMOD model considers the following features of the lakes hydrology and phosphorus cycling.

- *Inflow*. The inflow term is taken from the output of the GWLF watershed loading model and accounts for all external phosphorus loads to the lake.
- *Outflow*. Accounts for all the phosphorus leaving the lake through surface water. This term is a function of the flow of water out of the lake and the concentration in the epilimnion.
- *Eddy-diffusion*. The eddy diffusion term accounts for all the phosphorus flow between the layers that results from differences in concentration. This term is a function of the concentration of phosphorus in the epilimnion and the hypolimnion and a vertical eddy diffusion coefficient.

- *Settling*. The settling term accounts for all the phosphorus that flows from the epilimnion into the hypolimnion as a result of gravity. This term is a function of the settling velocity of phosphorus.
- *Sedimentation*. The same process that causes settling from the epilimnion into the hypolimnion results in settling of phosphorus from the water column into the sediment. This term also is a function of the settling velocity.
- *Dispersion*. The water and sediment have a dynamic relationship in which phosphorus flows both ways across the water-sediment interface. The dispersion term is a function of the phosphorus concentration in the sediment and the phosphorus release rate.

Dissolved oxygen concentration in the hypolimnion is calculated by the model during the summer months when the lake is stratified. The hypolimnetic dissolved oxygen is calculated as a function of areal hypolimnetic oxygen demand (AHOD), which is determined from the phosphorus in the hypolimnion.

Chapra and Canale (1991) used the following relationship between AHOD ($gm/m^2/day$) and total phosphorus concentration in the lake: AHOD = $0.086\ p_2^{0.478}$, where p_2 is the concentration of phosphorus in the hypolimnion. The release rate of phosphorus from the sediment also depends on the hypolimnetic DO level and is at the maximum rate during the summer months when the hypolimnion is anoxic. During the rest of the year, when the DO in the hypolimnion is higher, the release rate is significantly smaller.

The parameters used in PHOSMOD for Browne lake are listed in Table 5-5.

Table 5-5. Lake parameters needed for PHOSMOD

Parameter	Value	Units
Volume of the Lake	792,000	m^3
Surface Area	218,528	m^2
Maximum depth	7.6	m
Average depth of epilimnion	3	m
Average depth of hypolimnion	0.7	m
Area of interfacial area between layers	126,516	m^2
Volume of the epilimnion	657,000	m^3
Volume of the hypolimnion	153,300	m^3

A table of the coefficients used in PHOSMOD for Browne lake are listed in Table 5-6. The coefficients used to calibrate PHOSMOD were drawn from a variety of sources. Some of the values were modified in order to account for the specifics of Browne Lake.

Table 5-6. Internal Loading Coefficients used in PHOSMOD.

Coefficient	Value	Units	Comments
Diffusion Coefficient	from 0.187 to 5.37	cm^2/sec	Adapted from Lung (1976) seasonally dependent
Settling Velocity	from 8 to 25	m/yr	seasonally dependent Vollenweider (1975)
Sediment Release Rate (Summer)	0.005	m/yr	Lung (1976) suggested value
Sediment Release Rate (Fall through Spring)	0.0005	m/yr	Lung (1976) suggested value

5.3.1 Calibration

The calibration of PHOSMOD was performed using average data from four separate years. Because there were not enough water quality data for any given year to perform a meaningful calibration, the data from 1990, 1991, 1993, 1995 were averaged and used to calibrate the model. The calibration process consisted of modifying the literature coefficients to produce a response in the model that is consistent with observed trends.

Because the majority of the water quality monitoring data was recorded during the summer months, the calibration process was conducted primarily for the summer months. The GWLF flow and load values are relatively small during the winter months due to the snow cover of the area. The majority of the flow and loading into the lake occurs during the early spring snowmelt and during summer storms. Calibration of a year round model for only the summer months was justified by the dominance of this one season in the hydrology of the watershed.

The calibration of the phosphorus component of the model produced an accurate prediction of the recorded data in the epilimnion (Figure 5-5). The hypolimnion baseline results were accurate but the model was unable to account for two unusually high peaks during August and September. These peaks both occurred in 1991 and represented a statistically significant deviation from the rest of the data set. Nevertheless, the model was able to accurately account for the peak in Hypolimnetic Phosphorus that occurs during the summer months.

The calibration of the dissolved oxygen component of the model produced accurate results in both the epilimnion and the hypolimnion (Figure 5-5). The epilimnion dissolved oxygen was assumed to remain constant throughout the year and this was substantiated by the recorded data. The dissolved oxygen in the hypolimnion demonstrated significantly lower levels during the summer months as a result of summer stratification. Model results in the spring are somewhere between the two recorded data for dissolved oxygen in the hypolimnion; this could be due to the annual variation in the onset of stratification, which is not directly presented in the model plots of average values.

The final calibration of PHOSMOD plotted with average water quality readings for each month during the summer can be found in Figure 5-5.

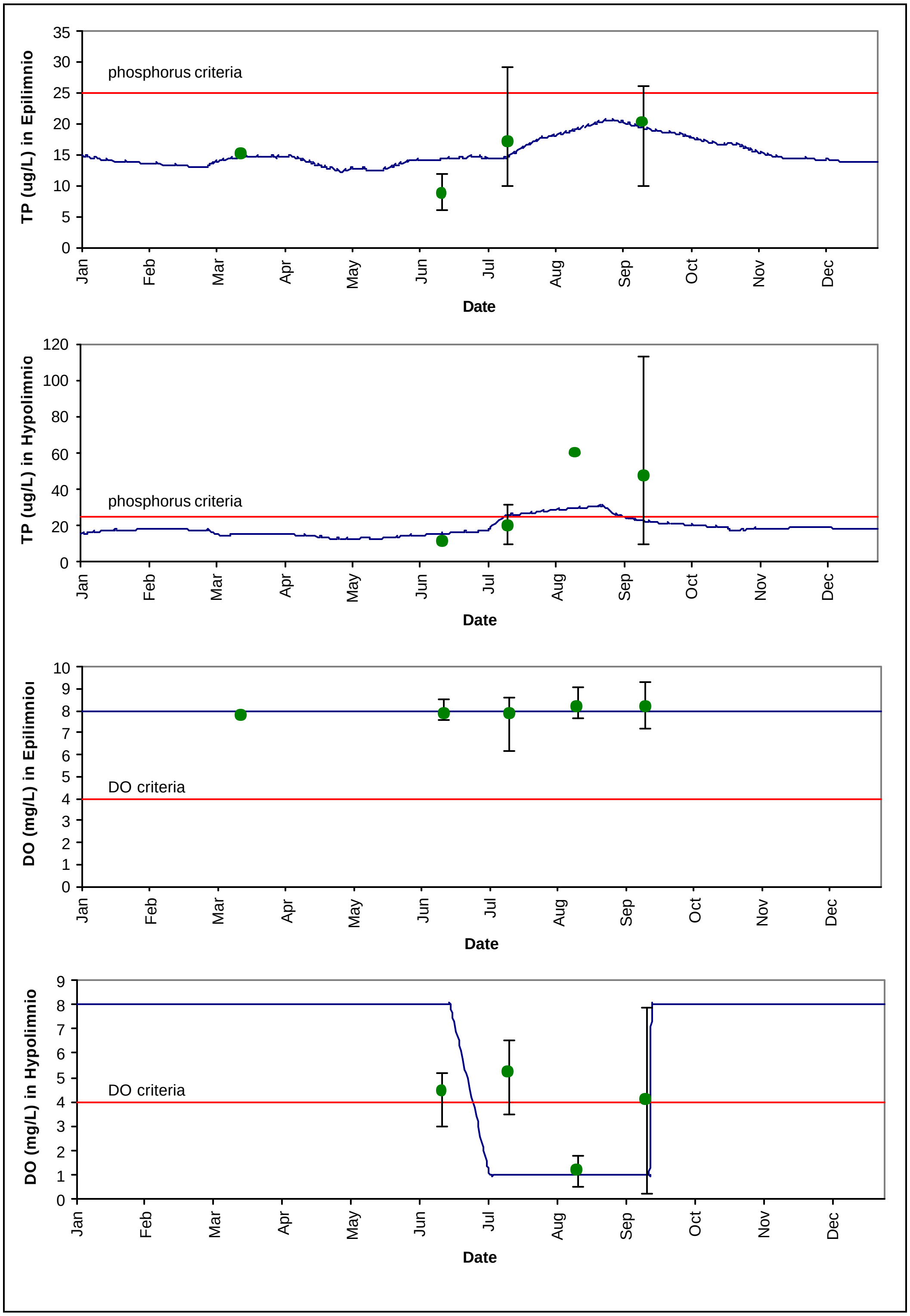

Figure 5-5 Model calibration using existing water quality data

5.4 Critical Conditions

Since low winter dissolved oxygen is a natural occurrence and increased phosphorus loads in the hypolimnion appear to be a summer problem during anoxic hypolimnetic conditions, the critical conditions for TMDL development were determined to be the summer months during low dissolved oxygen conditions in the hypolimnion.

5.5 Limitations and Assumptions

There are many limitations and assumptions necessary to consider in developing TMDLs for Browne Lake. Modeling of the watershed and the lake is limited by the lack of watershed and lake data. These are very few water quality and flow data in Beaver Creek and Weyman Creek. There are also no available outflow data for Browne Lake. It was assumed that the outflow was equal to the inflow. Lake data were only available every other year for 2 days. More data are necessary to more accurately represent nutrient and dissolved oxygen trends in the watershed and the lake. Because there are no monitoring data available to support assumptions on phosphorus concentrations in surface runoff, groundwater, and soils, these values were based on literature values and were justified through the watershed calibration process with the few data available. There were no stream or lake monitoring directly before or after the Weyman burn or before and after heavy logging activities to observe the impact of those events on the watershed and the lake. It was assumed that the phosphorus levels in the lake sediments are elevated due to an increase of sediment to the lake after the fire and logging. We are assuming a concentration of 250 mg/L in the lake sediments based on model calibration.

6.0 TMDLs

A TMDL is the total amount of a pollutant that can be assimilated by the receiving water while still achieving water quality standards. TMDLs can be expressed in terms of mass per time or by other appropriate measures. TMDLs are comprised of the sum of individual wasteload allocations (WLAs) for point sources and load allocations (LAs) for nonpoint sources and background levels. In addition, the TMDL must include a margin of safety (MOS), either implicitly or explicitly, that accounts for the uncertainty in the relationship between pollutant loads and the quality of the receiving waterbody. Conceptually, this definition is denoted by the equation:

TMDL = ▾ WLAs + ▾ LAs + MOS

The following sections present the phosphorus and dissolved oxygen TMDLs for Browne Lake.

Components of the TMDL for phosphorus are presented as kg/yr. No load is presented for dissolved oxygen. Summer dissolved oxygen concentrations in the lake are not currently below the criteria and it is assumed that the decrease in phosphorus loading will in turn assist in increasing the year-round dissolved oxygen concentrations. Therefore, the phosphorus load allocations are established to address both the phosphorus and the dissolved oxygen Section 303(d) listings for Browne Lake.

6.1 TMDLs and Allocations

The total phosphorus load allocations were developed by analyzing the existing contributions from the various land uses and reducing loads to result in attainment of the phosphorus target in the lake. Internal loading of phosphorus was also considered. Based on the examination of the existing model conditions represented in the model, significant phosphorus contributions to the lake are:

1. Loadings from Forestry
2. Loadings from cattle grazing
3. Internal loading from lake sediment

The average concentrations of phosphorus and dissolved oxygen in the model output were compared to the water quality criteria to determine the level of impairment under existing conditions. Figure 5-5 clearly demonstrates that the phosphorus level in the hypolimnion exceeds the criteria during the summer months.

The following general methodology was used when allocating to sources for the Browne Lake TMDL:

The Browne Lake TMDL was developed by reducing the loadings from the watershed and the sediment incrementally until the model results met the water quality criteria.

The watershed loading to the lake was reduced assuming that several landuses represent controllable sources. The loadings were allocated assuming that BMPs implemented on forestry, and grazing land uses would reduce the loads to the watershed. It was also assumed that the areas of the watershed that had experienced forest fires during the 1980s will contribute less loading as those areas become forested again.

The internal loading from the sediment was reduced based on the assumptions that the sediment in the lake is currently rich in phosphorus as a result of the 1985 forest fire and historical clear cutting in the watershed and the phosphorus in this sediment will gradually be buried by sediment with lower concentrations. The time required for this process to occur depends on the current concentration of phosphorus in the sediment and the effectiveness of the watershed load reductions.

When the model outputs met the applicable water quality criteria, loading reductions were calculated and TMDLs set for all contributors. The TMDLs are presented in Table 6-1.

Table 6-1. Phosphorus and dissolved oxygen TMDLs for Browne Lake

Source	Existing Load (Kg P/yr)	Percent Reduction	Load Allocation (Kg P/yr)	Wasteload Allocation (Kg P/yr)	5% Margin of Safety (Kg P/yr)	TMDL (Kg P/yr)
Watershed Loading	62.95	21%	50.0	0	2.6	52.63
Forest	*20.91*		*19.9*	*0*	*1.0*	*20.91*
Forest Fire	*26.73*		*19.2*	*0*	*1.0*	*20.17*
Silviculture	*6.77*		*4.9*	*0*	*0.3*	*5.11*
Grazing	*8.54*		*6.1*	*0*	*0.3*	*6.45*
Internal Loading (from the sediment)	45.06	37%	28.5	0	1.5	29.97

Figure 6-1 presents the modeled total phosphorus and dissolved oxygen concentrations in the epilimnion and hypolimnion based on TMDL conditions.

6.1.1 Wasteload Allocations (WLAs)

There are no point sources of phosphorus to the Browne Lake watershed, therefore, the WLA is zero.

6.1.2 Load Allocations (LAs)

A load allocation of 50 Kg/yr of total phosphorus was established as a gross allotment for all watershed loadings. The land uses were divided into four general categories, forest, forest fire/regrowth, silviculture, and grazing. The allocations were then divided based on the relative contribution of each source. The largest contribution came from burned forest land. The second largest net contributor was virgin forest because it covers the vast majority of the watershed, however, no reductions were required from forest because it was assumed to represent background conditions. Grazing and Silviculture were also considered to contribute phosphorus to the lake. Table 6-1 summarizes the load allocations broken down by land use.

A load allocation of 28.5 Kg/yr of phosphorus was established for contribution of phosphorus to the lake's water column from in-lake sediments.

6.1.3 Margin of Safety (MOS)

Section 303(d) of the Clean water Act and EPA's regulations at 40 CFR 130.7 require that "TMDLs shall be established at levels necessary to attain and maintain the applicable narrative and numerical water quality standards with season variations and a margin of safety which takes into account any lack of knowledge concerning the relationship between effluent limitations and water quality." The margin of safety can either be incorporated implicitly through conservative assumptions or explicitly as a separate component of the TMDL (USEPA 1991).

A margin of safety has been incorporated into the Browne Lake TMDL both implicitly and explicitly. The TMDL endpoint is based on the requirement that 50 percent of the water column meet the 4.0 mg/L dissolved oxygen criteria. Figure 6-1 shows that the dissolved oxygen concentrations will meet the criteria in greater than the 50 percent of the water column since the hypolimnetic area modeled in PHOSMOD is only a small percentage of the water column. The entire water column above that area will be meeting the dissolved oxygen criteria. A five percent explicit margin of safety has also been included within the TMDL to address the uncertainties associated with the modeling, due to the relative lack of tributary and lake sampling and flow data for calibration.

6.1.4 Seasonal Variation

A TMDL must consider seasonal variation in the derivation of the allocation. For the Browne Lake phosphorus and dissolved oxygen TMDLs, seasonal variation was considered in the formulation of the flow estimation. By using continuous flow simulation (estimating daily flow over a period of several years), seasonal hydrologic and source loading variability was inherently considered.

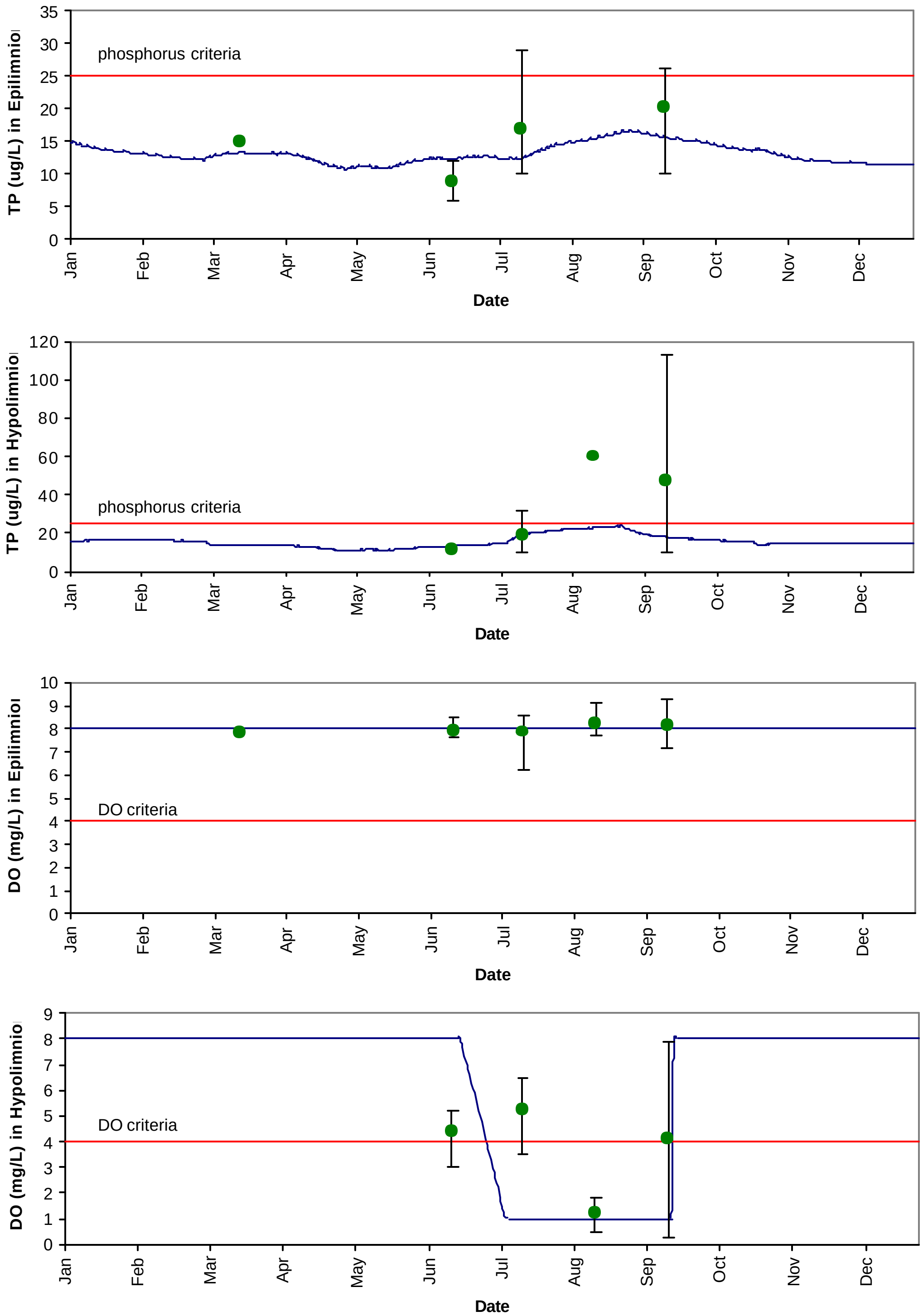

Figure 6-1. Model results for Browne Lake based on proposed TMDLs

7.0 Monitoring

Prior to any shift in management of the Browne Lake watershed, additional monitoring is necessary to determine any trends in the nutrient loading to the lake as well as trends in TSI values and algal dominance. It is necessary to determine nutrient loading trends in the lake because nutrient considerations will be incorporated into any future managements plans in the watershed.

Monitoring of Browne Lake will continue on the current schedule, which includes two sampling dates in the lake every other summer. Information that will be useful for future management of the Browne Lake watershed includes additional winter dissolved oxygen profiles in the lake and the sampling of all forms of nitrogen in order to determine whether the limiting nutrient is nitrogen or phosphorus. The collection of total phosphorus samples should also continue as well as the collection of dissolved phosphorus samples, since dissolved phosphorus is the form of phosphorus available to aquatic plants. Sampling will also continue in the lake's tributaries to determine if there are times when the tributaries represent large sources of nutrients to Browne Lake. It would also be useful to collect samples in the lake and in the contributing tributaries (Beaver Creek and Weyman Creek) during ice-off and spring runoff to determine if there is a large influx of nutrients and/or sediment to the lake during this period.

8.0 Reasonable Assurance

The largest source of sediment and nutrients to Browne Lake in recent history has been the Weyman burn in 1985. Protective measures were taken immediately by the Ashley National Forest to mitigate the effects of the fire, however, there were still effects that could not possibly be prevented. Over time, the nutrient-rich sediment at the bottom of Browne Lake will be covered with more recent sediment that does not have the high nutrient content associated with sediment deposited after the fire.

To assist in the assurance that unnecessarily high nutrient loads from the watershed will be introduced to the lake, the forest management practices established by the U.S. Forest Service will continue to be adhered to. The Forest Service's Soil and Water Conservation Practices Handbook (1998) outlines many management practices that either "directly or indirectly improve water quality, protect beneficial uses, reduce losses in soil erosion and productivity, and abate or mitigate management effects, while meeting other resource goals and objectives" (page 1, USFS 1998). Examples of management practices applied by the forest service to protect the watershed include:

- Revegetation of surface disturbed areas to protect soil productivity and water quality by minimizing soil erosion
- Soil moisture limitations for tractor operation and road traffic to minimize soil compaction, puddling, rutting, and gullying with resultant sediment production and loss of soil productivity
- Timber harvest unit design to ensure that timber activities will secure favorable conditions of water flow, maintain water quality and soil productivity, and reduce soil erosion and sedimentation.
- Protection of unstable areas
- Riparian area designation
- Erosion prevention and control measures during timber sale operations
- Revegetation and erosion prevention on areas disturbed by timber harvesting activities
- Stream channel protection to prevent sediment and other pollutants from entering streams

In addition to the above practices, vegetation management on National Forest System lands is conducted in the course of forest regeneration, brushland conversion to forests, utility transmission corridor maintenance, rangeland improvement, water yields improvement, and wildlife habitat improvements. Each project is evaluated through the NEPA process by an interdisciplinary team.

The watershed is also used for grazing cattle. Range resources in the watershed have provided summer forage for local livestock operators since pioneers first arrived in the area (Uinta National Forest 1999). Today, many of the permittees who graze livestock on the Forest rely on this forage to complete their overall livestock operations, and few permittees could maintain their operations without it. Improvements in permittee environmental awareness have resulted in their acceptance of and assistance in implementing the standards and guidelines developed in the Rangeland Ecosystem Amendment. Implementation of these standards and guidelines has had some impact in permittee operations by requiring them to be proactive in the management of their livestock. It has been noted that cattle often graze along Beaver Creek, however, Beaver Creek was recently surveyed and found to be in excellent condition.

Recent communication with Eileen Richmond, Flaming Gorge District Ranger, revealed that as of June 2002 fencing was constructed around a portion of the lake to restrict grazing cattle and rock barriers were established to exclude vehicular access to the lakeshore near the campground. Both of these actions will help considerably in the effort to reduce sediment and nutrient loads to Browne Lake.

Browne Lake appears to be slowly recovering from the Weyman Burn, however, extra consideration is needed to ensure that it fully recovers. The Forest Service is planning to implement additional management practices in the watershed in the near future that will assist in protecting the lake from potentially harmful nutrient and sediment loads. The possible management practices include moving the toilets at the campground farther away from Weyman Creek and Browne Lake to prevent the leakage of waste into the waterbodies and plans to improve the dirt road leading to the campground, which would likely decrease the contribution of sediment and associated nutrients to the lake as well.

9.0 Public Participation

Utah DEQ policy is that there must be full and meaningful public participation in the TMDL development process. As a result, it is the intent of the Utah DEQ to solicit public input by providing opportunities for public comment and review of the draft TMDLs. Initial comments by USEPA, Utah DEQ, the U.S. Forest Service, and Utah DWR were received and addressed. The Draft Browne Lake TMDL was made available to the public for a 30–day comment period from August 28, 2002 through September 26, 2002 . A public meeting was held on September 11, 2002 in Dutch John, Utah at the Forest Service conference center.

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