Utah Department of Environmental Quality
Division of Water Quality
TMDL Section

Strawberry Reservoir TMDL

EPA Approval Date: July 9, 2007

Waterbody ID	Strawberry Reservoir Watershed HUC # 14060004
Location	Wasatch County, Northern Utah
Pollutants of Concern	Dissolved Oxygen and Total Phosphorus
Impaired Beneficial Uses	Class 3A: Protected for cold water species and their food chain.
Current Load Loading Capacity (TMDL) Margin of Safety (MOS)	15,100 lbs/year of total phosphorus 15,100 lbs/year of total phosphorus Explicit Margin of Safety at 5% (755 lbs/year)
Wasteload Allocation Load Allocation	No Point Sources, 0 lbs/year of total phosphorus 14,345 lbs/year of total phosphorus
Defined Targets/Endpoints	1) 50 percent of the water column above 4 mg/L Dissolved Oxygen. 2) Average Trophic State Index between 40 and 50. 3) No fish kills. 4) Decrease the Dominance of Blue-Green Algae. 5) Total phosphorus concentrations less than 0.025 mg/L (in-lake) and 0.05 mg/L (tributary inflow)
Implementation Strategy	1) Maintain and improve existing watershed management practices 2) Maintain fishery management practices

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Chapter 1: Executive Summary

Strawberry Reservoir Water Quality Study and TMDL

1.1 Introduction

Strawberry Reservoir is located in Wasatch County, 23 miles east of Heber City on the Strawberry River. At full capacity, Strawberry Reservoir has a surface area of approximately 17,000 acres and an elevation of 7,600 ft above sea level. Strawberry Reservoir is considered to be Utah's premier trout fishery in terms of angler hours and number of fish produced. It is the destination for over 2 million visitors each year and is one of the most heavily used reservoirs in the state.

High total phosphorus and low dissolved oxygen concentrations in Strawberry Reservoir have exceeded the State's water quality standards for its aquatic wildlife beneficial use designation (Class 3A, Protected for cold water species and their food chain). This has resulted in the placement of Strawberry Reservoir on Utah's 2004 303(d) list of impaired waters as a high priority TMDL for total phosphorus and dissolved oxygen.

The purpose of this study is to determine if and to what extent Strawberry Reservoir's aquatic wildlife beneficial use is impaired. Various types and sources of data will be considered to make this assessment.

1.2 Sources of Data

Table 1-1 shows the sources of data utilized for this study. Where available, data were collected from 1990 through 2003. Chapter 2 contains a detailed explanation of the sources of data, data gaps, and statistical methods used in this study.

Table 1-1: Sources of Data

Type of Data	Source(s)
Chemical	Utah Department of Environmental Quality, Division of Water Quality
Flow	Utah Department of Environmental Quality, Division of Water Quality United States Bureau of Reclamation
Fishery	Utah Department of Natural Resources, Division of Wildlife Resources Utah State University

1.3 Reservoir Impairment Assessment

The 303(d) listed impairment to the cold water fishery in Strawberry Reservoir is based solely on the reservoir data compared to State standards. To determine whether Strawberry Reservoir is supporting its beneficial uses various analyses were completed. These are described and summarized below.

1.3.1 Limiting Nutrient

The overall median available Nitrogen to Phosphorus ratio was 3 that indicated that the reservoir is nitrogen limited. However, nutrient limitation may switch seasonally due to temperature dependent differences in nutrient recycling. In addition, the nuisance species of blue green algae or cyanobacteria, fix nitrogen from the atmosphere so that regardless of the limiting nutrient, phosphorus control is needed for reductions of this species.

1.3.2 Water Quality Criteria

In the deep waters of Strawberry Reservoir near the dam embankment, approximately 76 percent of the water column typically has DO concentrations less than 4.0 mg/l during the month of September. Using the State of Utah's criteria, impairment to the reservoir's fishery at that location exists because more than 50% of the water column is below 4.0 mg/l during part of the year. Other locations within the reservoir show more favorable conditions.

Evaluation of the available data for Strawberry Reservoir indicate that while some parts of the reservoir are non-supporting or partially supporting at certain times during the year, the cold water game fish population is no longer impaired due to water quality exceedances.

1.3.3 Morphoedaphic Index

The MEI estimates fishery production potential by utilizing the concentration of total dissolved solids and the mean depth of the water column. For Strawberry Reservoir, the calculated MEI falls between 5 and 6.5. This places the reservoir in the third quartile of 253 reservoirs assessed by the Army Corps of Engineers (USACE 1995). This indicates that, according to the MEI, Strawberry has above average fishery production potential.

1.3.4 Fish Population and Sustainability

A fish population and sustainability assessment was conducted based on Utah Division of Wildlife Resources (UDWR) surveys. From 1996 through 2003 game fish population trends show increasing population and age class robustness. Gill net surveys show a stable or increasing catch-rate for cutthroat and a decreasing catch-rate for rainbows. However, angler catch rates for rainbow are stable or increasing. Strawberry Reservoir currently sustains higher fishing pressure, greater catch rates, and larger average fish than ever before.

1.3.5 Correlating water quality conditions to fish populations

No apparent correlation could be identified between water quality exceedances and fish population trends in Strawberry Reservoir. A possible explanation for the lack of correlation between water quality and fish population trends may be that while water quality conditions are not ideal in some sections of the reservoir such conditions do not occur for a sufficient length of time to be detrimental to the local game fish populations.

1.3.6 Summary

Overall it has been concluded by these analyses that support of Strawberry Reservoir's cold water fishery beneficial use is due in part to stocking and fishery management by UDWR. Additional support for the fishery may be explained by the fact that conditions within the reservoir are not completely non-supporting or partially supporting at any one time and that no fish kills have been reported in recent years.

1.4 Water Quality Targets & Endpoints

A mass balance approach was used in the effort to identify the target loading rates for phosphorus and total suspended solids. These budgets were used to establish specific targets. Tools used in this analysis and a summary of findings is described below.

1.4.1 Vollenwieder Loading Plots

This plot shows that the two bay areas (East Portal Bay and Soldier Creek area) are bordering on mesotrophic to eutrophic conditions. The main body of the reservoir, however, shows low mesotrophic bordering on oligotrophic conditions.

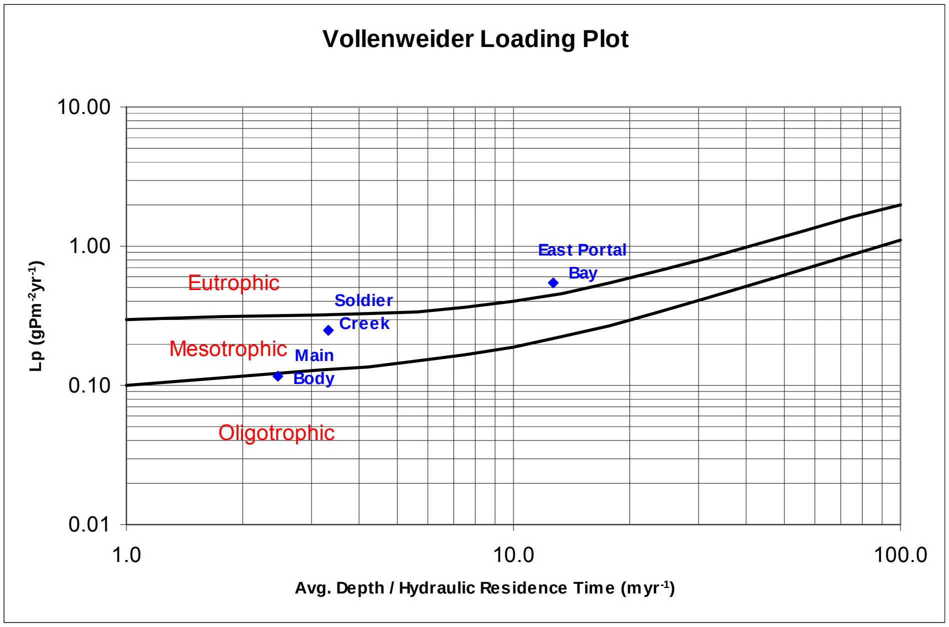


Figure 1-1: Vollenweider Loading (Trophic Status) plot for Strawberry Reservoir based on loadings from Normal Hydrology.

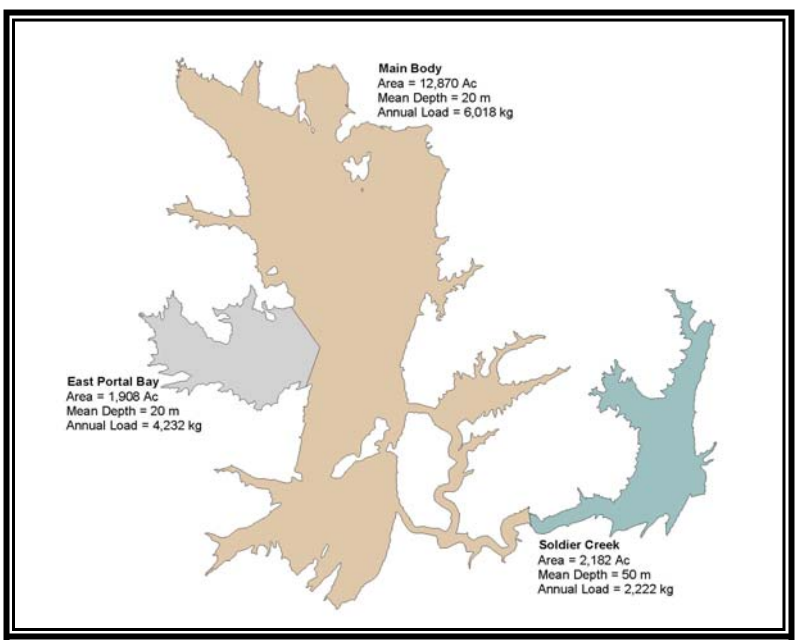


Figure 1-2: Vollenweider Loading (Trophic Status) plot for Strawberry Reservoir based on loadings from Normal Hydrology.

1.4.2 Trophic State Index (TSI) Analysis

The TSI has consistently been is the 40 to 50 range since 1996 which classifies the reservoir as a whole in the mesotrophic range. Also, TSI has slowly been decreasing since 1990, which indicates improvement over that time.

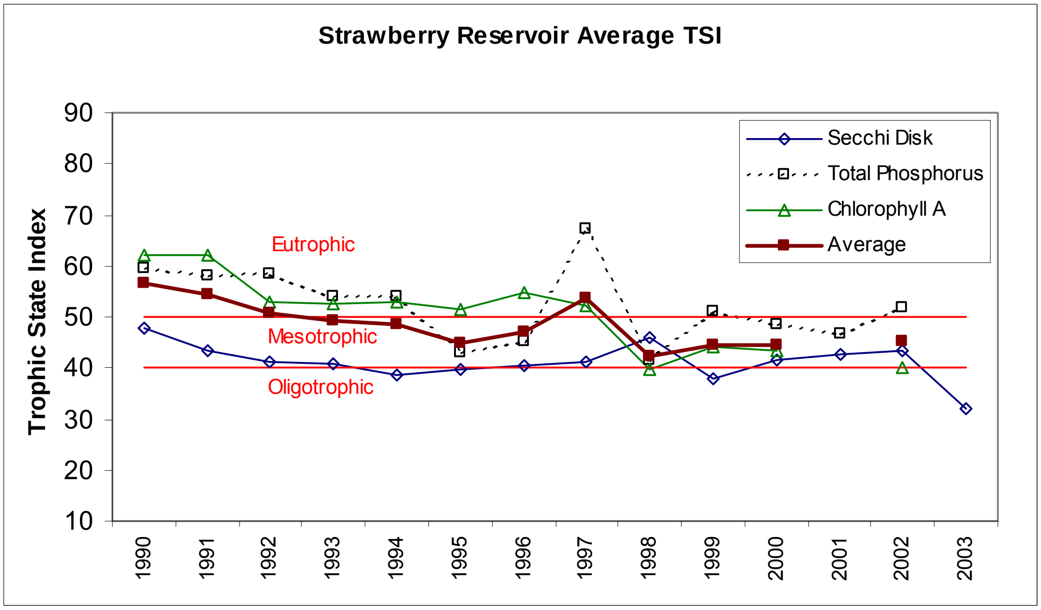


Figure 1-3: Strawberry Reservoir average Carlson Trophic State Index.

1.4.3 Phosphorus Reservoir Budget

Current average total phosphorus loading was estimated to be 6,800 kg (15,100 lbs) annually, based upon tributary inflows and internal loading from the bottom sediments.

1.4.4 Summary

In the Reservoir Impairment Assessment (Section 1.3) it was concluded that conditions within the reservoir, or within the water column at any specific site, are not completely non-supporting or partially supporting at any one time. Additionally, during recent years no fish kills have been reported in the reservoir. Adequate supporting habitat is available such that water quality conditions are not exerting a detrimental effect on fish populations.

The results of the analyses seem to indicate a fairly healthy reservoir that can be classified as a stable mesotrophic system. However, small bays and deep portions of the reservoir do experience less favorable conditions during some times of the year, particularly in the late summer.

The current condition and recent trends of the reservoir's health indicate drastic actions are not warranted, but instead, current and planned management efforts have and will continue to improve the quality and sustainability of Strawberry Reservoir's fishery.

Following this concept, the endpoints and targets that are recommended in this study are based on current loading and water quality levels. However, as is discussed in Chapter 5: *TMDL*, loading reductions will be necessary to accommodate for future growth and the margin of safety. Table 1-2 summarizes the recommended endpoints for Strawberry Reservoir.

Table 1-2 Summary of Recommended Targets / Endpoints

Parameter	Proposed Target
Dissolved Oxygen	>50% of the water column above 4 mg/L
Total Phosphorus Load to Reservoir	15,100 lbs/yr
Average TSI	40-50
Fish habitat Indicator	No Fish Kills
Blue-Green Algae	Decrease the Dominance of Blue-Green Algae

1.5 TMDL

The TMDL load allocation assigns loads to all sources including point, non-point and background sources. In addition, a margin of safety (MOS) is included to account for the uncertainty inherent in the analysis and ensure that beneficial uses are protected into the foreseeable future. The MOS is a required part of the TMDL development process (USEPA, 1991). For the Strawberry Reservoir TMDL, the MOS was included implicitly using conservative model assumptions to develop allocations and explicitly by allocating 5 percent of the loading capacity, or 755 lbs/yr.

Table 1-3 outlines the current loads, proposed reductions, and future loading allocation for each major source of phosphorus. These loads collectively equal 15,100 lbs per year of phosphorus. Details on the methods and calculations that were used to arrive at these loadings can be found in Significant Sources in the "Pollutant Loadings" section.

Table 1-3 Total Phosphorus TMDL Load Allocations (lbs / year)

Source	Current	Allocation	Reduction
Strawberry River	3,100	3,025	75
Indian Creek	400	400	0
Co-op Creek	900	880	20
Clyde Creek	300	295	5
Trout Creek	100	100	0
Chipman Creek	800	785	15
Mud Creek	300	300	0
Broad Hollow	200	200	0
Other Stream Inflows	1,700	1,700	0
Sheet Flow to Res.	2,300	2,300	0
The Ladders[1]	4,100	4,100	0
Release From Bottom Sediments	900	0	900
Future Sources		260	
Margin Of Safety		755	
TOTAL	**15,100**	**15,100**	**1,015**

[1]It is anticipated that future loads from The Ladders may average 5,500 lbs/yr due to changes in reservoir operations to accommodate full CUP deliveries .

The majority of the needed load reduction will come from the flushing of total phosphorus from bottom sediments out of the reservoir. Recent data show a net export of total phosphorus of approximately 4,000 lbs/year, well above the specified 900 lbs/year. Remaining load reductions were allocated proportionally among the tributary streams that have exceeded the 0.05 mg/L indicator value for total phosphorus, including Co-op Creek, Clyde Creek, Trail Hollow (tributary to Chipman Creek), and Strawberry River.

Even though water quality conditions currently exceed the State's indicator values and for total phosphorus and dissolved oxygen, the reservoir is currently believed to be supporting its Cold Water Fishery beneficial use (3A). It is expected that current and proposed management and operational practices will continue to improve conditions within the reservoir.

1.6 Recommendations

As Strawberry Reservoir has been determined to be a healthy system, we recommend that current and planned best management practices be continued to maintain the health of the watershed and reservoir. Specifically, the following practices have been recommended in the Strawberry Reservoir Watershed Restoration Report (2004) and should be continued:

Table 1-4: Recommended Stream & Watershed BMPs

BMP	Description	Desired Result
Road Maintenance	Regular and preventive road maintenance reduces erosion	Decreased loading of sediments and nutrients to streams.
Dispersed Recreation Management	Site rotation, hardening, limits, closure, etc. reduce erosion from sites	Decreased loading of sediments and nutrients to streams.
Grazing Management	Maintain sufficient vegetative cover to minimize hillslope erosion	Decreased loading of sediments and nutrients to streams.
Riparian Habitat	Decrease erosion through • Stream corridor protection • Vegetative Buffer Strips	Decreased loading of sediments and nutrients to streams. Decrease bank trampling. Improved buffering capacity of riparian vegetation.
Management of Beaver Dams	Appropriate management of beaver dams depending on fishery's goals and objectives.	Beaver dams allow for settling of solids and decreased stream velocities. The removal of beaver dams promotes improved fish spawning habitat.
Off-Channel Watering	Provide water sources away from streams and the reservoir for wildlife and livestock.	Decrease stream bank trampling, reduce animal waste and sediment load into streams.
Fishery Management and Stocking Practices	Management by UDWR to control various characteristics of the fishery.	Maintain the fishery
Watershed Groundcover	At least 70 percent of the watershed covered.	Groundcover helps prevent erosion. Decreased erosion reduces sediment and nutrient loads to streams.
Limit Herbicides and Fertilizers	Limit application to specific target plants species following manufacturer recommendations. Eliminate application along stream corridors.	Protect riparian vegetation.

2.1 Introduction

Waters in Utah that do not meet water quality standards for their assigned beneficial uses are the focus of the Clean Water Act's (CWA) Section 303 (d) list, which requires states to identify impaired waters, then develop and implement plans to improve them. The Total Daily Maximum Load (TMDL) process identifies pollution sources and the required methodology for addressing these waters.

The TMDL approach targets watersheds, addressing water quality in a site-specific way tailored to local conditions and objectives. It specifies the maximum pollution loadings where water quality goals are not being met and provides a framework for remedial action.

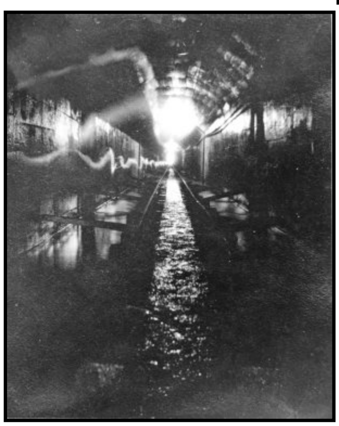
High total phosphorus and low dissolved oxygen concentrations in Strawberry Reservoir have exceeded the State's water quality standards for the beneficial use designation of aquatic wildlife, Class 3A (Protected for cold water species and their food chain). This has resulted in the placement of Strawberry Reservoir on Utah's 2004 303(d) list of impaired waters as a high priority TMDL for total phosphorus and dissolved oxygen.

The purpose of this study is to determine, through a scientifically based approach, if Strawberry Reservoir is impaired and, if so, to what extent. This determination will be based on an assessment of the cold-water fishery. Various types and sources of data will be considered to make this assessment.

2.2 Location and Description

2.2.1 Background

Strawberry Reservoir is located in Wasatch County, 23 miles east of Heber City on the Strawberry River. In addition to being considered Utah's premier trout fishery, it provides residents of Wasatch and Utah Counties with culinary and irrigation water, as well as being a popular destination for anglers and other outdoor enthusiasts. Much of the inflow to the reservoir comes from the Strawberry River, Co-op Creek, Indian Creek, and The Ladders (a trans-basin diversion from the upper Duchesne River watershed). There are several other minor inflows around the perimeter of the reservoir.



Strawberry Valley Project tunnel looking toward portal 1200' away

In December of 1905, the Department of the Interior authorized the Strawberry Project. This project included an earthen dam and a nearly 20,000-foot long, concrete-lined tunnel from the reservoir to the head of the Diamond Fork of the Spanish Fork River. The first irrigation water began to flow to Utah County in June of 1915 and eventually, nearly 300,000 acre-feet of water was delivered.

The project was completed on June 30, 1922, and the various water users assumed control and began gradual repayment of construction costs in 1926. The Strawberry Project proved highly beneficial to the economic growth of southern Utah County, as sugar beets, alfalfa, and truck farming increased their total acreage and seasonal yields. The project also provided employment for local workers in the Strawberry area, as well as incidental benefits such as electrical power, and improved roads.

Since completion of the Strawberry Reservoir Dam in 1913, the Strawberry Water Users Association, in conjunction with the US Forest Service, private landowners, and the Ute Indian Tribe of the Uintah and Ouray Reservation, has managed the land for recreational, watershed, and grazing purposes.

The construction of Soldier Creek Dam in 1974 increased the capacity of Strawberry Reservoir by more than 823,000 acre feet giving the reservoir a total capacity of 1,106,500 acre feet (Figure 2-1). Soldier Creek Dam is located approximately 8 miles downstream of the original dam site. It is a zoned earth-fill structure with a structural height of 272 feet. The upper and lower outlet works have a capacity of 1,350 and 1,480 cfs respectively.

Figure 2-1: Soldier Creek Dam on the Strawberry River.

Source: **http://www.usbr.gov/dataweb/dams/ut10135.htm**

The Strawberry watershed is approximately 136,000 acres in size, including the reservoir at full capacity (~17,000 acres surface area). Soils in the watershed area are loam textured with a high gravel and or cobble content, moderate to slow permeability, and variable productivity. Erosion hazard ranges from slight to severe.

Precipitation in the area ranges from 16 inches per year at the reservoir (elevation ~7612 ft) to 30 inches per year at the higher elevations. There are 132 miles of perennial streams and 235 miles of intermittent streams found within the watershed area.

Strawberry Reservoir is one of the principal water storage features of the Central Utah Project that delivers water to the Uinta Basin and the Wasatch Front. The Central Utah Project's Utah Lake Drainage Basin Water Delivery System (ULS) will, in the near future, deliver an average annual 101,900 acre-feet of water from Strawberry Reservoir to the Wasatch Front area for municipal and industrial (M&I) uses.

Reservoir And Valley Statistics*

Soldier Creek Dam

- **Dam type:** Zoned Earthfill
- **Volume:** 3,200,000 cubic yards
- **Maximum height:** 272 feet
- **Crest length:** 1,290 feet
- **Crest width:** 30 feet
- **Crest elevation:** 7,612 feet MSL
- **Height above stream bed:** 241 feet
- **Upper outlet works capacity:** 1,350 CFS
- **Lower outlet works capacity:** 1,480 CFS
- **Spillway type:** no spillway
- **Construction period:** 1970-1974
- **Filled to capacity:** 1998
- **Operated by:** Central Utah Water Conservancy District

Strawberry Reservoir

- **Reservoir capacity at top of active storage:** 1,106,500 acre-feet
- **Reservoir surface area at top of active storage:** 17,164 acres
- **Reservoir capacity at bottom of active storage:** 155,140 acre-feet
- **Reservoir surface area at bottom of active storage:** 6,770 acres
- **Depth at maximum pool:** 200 feet

* Source: www.wildlife.utah.gov/strawberry

2.2.2 Vegetation

Various types of vegetation are found within the watershed including sagebrush/grass, mountain brush, aspen, Douglas fir, lodge pole pine, white fir, spruce, fir, and forb communities. Aspen are the dominant species at higher elevations and sagebrush tends to dominate at lower elevations (Figure 2-2). Timber sales have been offered in the area. Vegetation is also managed using prescribed fire and mechanical treatments.

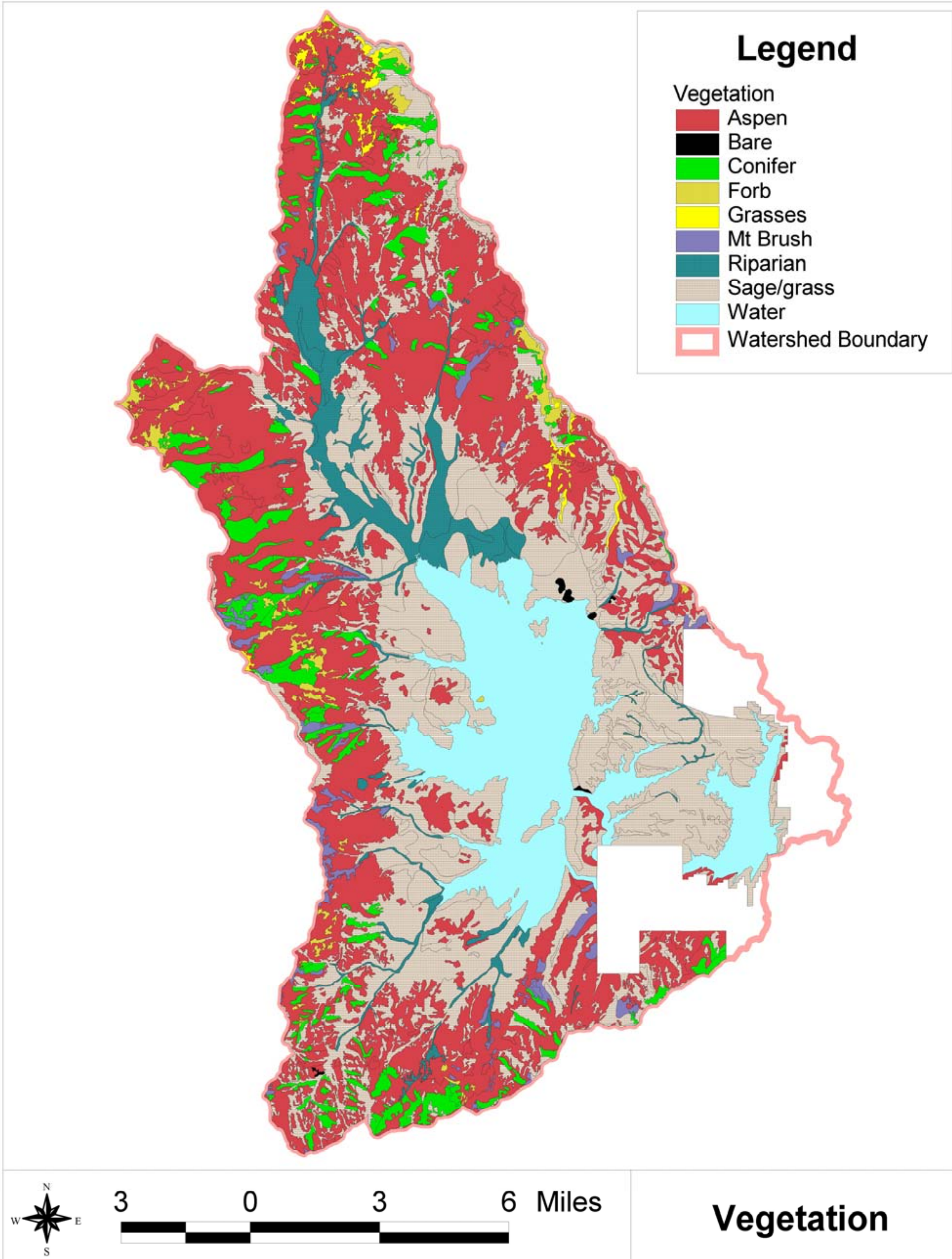


Figure 2-2: Vegetation of the Strawberry Reservoir watershed area.

2.2.3 Fishery & Wildlife

The Strawberry Reservoir watershed was historically inhabited by Colorado River cutthroat trout. Construction of the Strawberry Reservoir and the introduction of other non-native fish species have likely eliminated any genetically pure Colorado River cutthroat trout from the drainage area. Other native fish species include mottled sculpin, mountain sucker, and speckled dace. Introduced, non-game species include redside shiner, Utah chub and Utah sucker. The Utah Division of Wildlife Resources (UDWR) currently stocks Bonneville cutthroat trout, kokanee salmon and sterile rainbow trout. In 1988, 90 percent of the fish in Strawberry Reservoir consisted of non-game fish. In order to reestablish the fishery, the Utah Division of Wildlife Resources chemically treated the reservoir with rotenone during the summer of 1990. The rotenone killed more than 99% of chubs and suckers. At present, chubs make up about 15% of the weight of fish in the reservoir. At this level, competition with trout is not a problem (Wilson and Ward, unpublished data).

A new fisheries management approach was adopted by the UDWR after the 1990 chemical treatment to address new challenges and opportunities at Strawberry. This management plan was developed by the UDWR in consultation with other state and federal agencies and angler groups.

Sterile rainbow trout, Bear Lake cutthroat trout and kokanee salmon have been selected as the major species stocked for Strawberry because their presence will impede the increase of chubs and suckers. These species are not as severely impacted as rainbows are by competition, and should be able to maintain a good quality fishery in spite of large rough fish populations.

Northern goshawks, flammulated owls, sand hill cranes, and sage grouse nest in the region. The watershed also provides range for elk, mule deer, and moose.

2.2.4 Current Reservoir Elevations

Utah has experienced drought conditions statewide for the past several years. Decreased flow from major rivers in Utah has led to a decline in the water levels of many lakes and reservoirs, including Strawberry Reservoir (Figure 2-3). Drought conditions in Utah are common and normally last an average of about 4 years. The current drought is not unusual for its length but rather for its severity, as recent years will be recorded as the driest years on record for many parts of Utah.

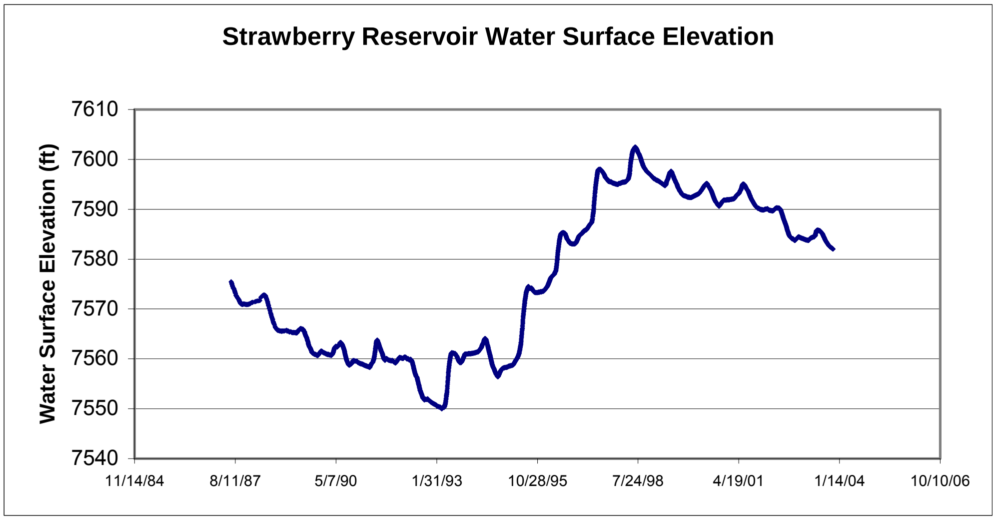


Figure 2-3: Historical changes in the water surface elevation of Strawberry Reservoir.

2.3 Thermal Stratification Cycle

The thermal stratification cycle of Strawberry Reservoir is similar to other lakes and reservoirs in Northern Utah. Increasing summer temperatures cause the reservoir to stratify into multiple layers of varying temperatures as the colder and denser water settles to the bottom of the reservoir. Stratification of Strawberry Reservoir is evident by the middle of July and continues through September. The surface temperatures during these months commonly exceed 20 °C while temperatures from mid-depth to the bottom rarely exceed 15 °C. Figure 2-4 shows the average monthly water temperature at various depths at selected reservoir locations. Temperature and dissolved oxygen profiles for all reservoir stations for June through August 2002 are presented in Appendix B. In addition to high water temperature at the surface during stratified periods, low dissolved oxygen conditions typically exist in the bottom portion of the water column.

In October, as air temperatures decrease and begin to cool the water on the surface, the reservoir mixes through a convection process, an event commonly known as turnover. The reservoir remains in a fully mixed state until surface temperatures approach freezing and a reverse stratification occurs. This state continues as long as the surface temperatures remain above 4 °C.

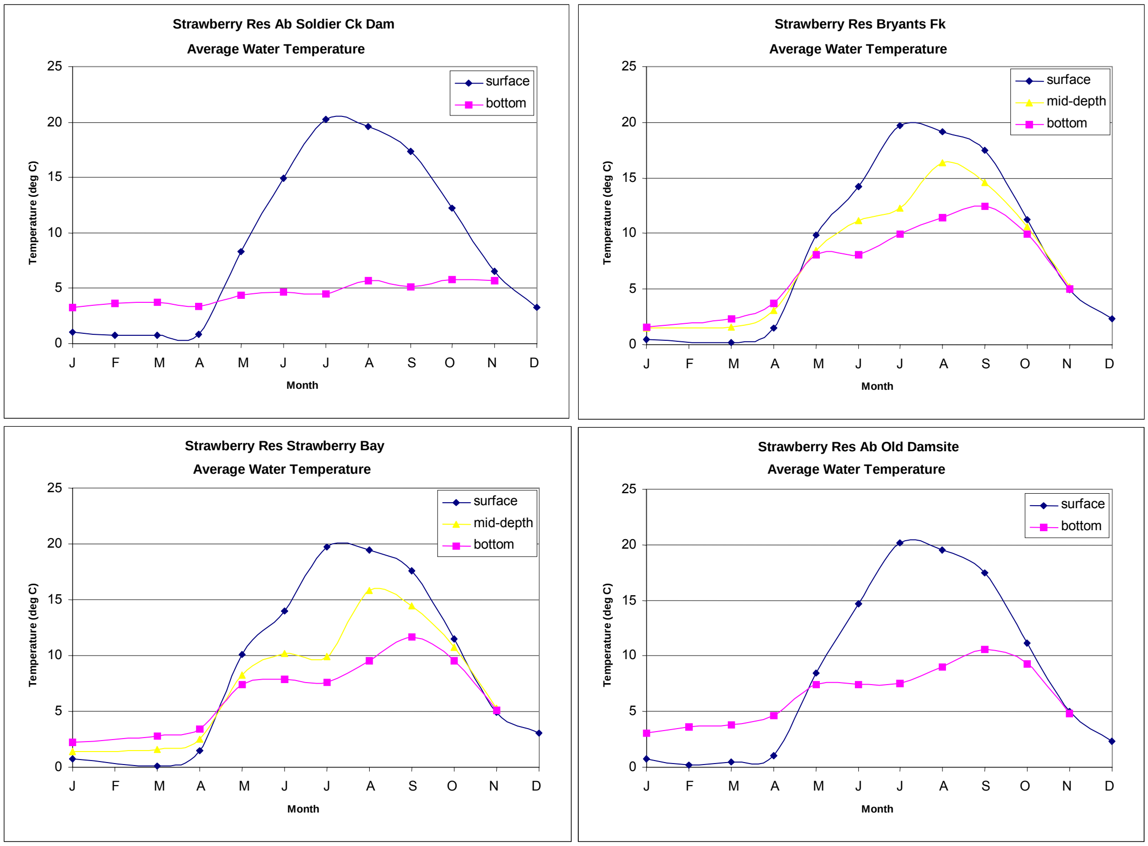


Figure 2-4: Average monthly water column temperatures at selected reservoir locations.

2.4 Previous Studies

2.4.1 USBOR Hydrology Study

In 1984 the Bureau of Reclamation (USBOR) completed a water quality study that included recommendations for improving and protecting water quality in Strawberry Reservoir and its tributaries. Recommendations are divided into two categories; reduction of sediment and phosphorus loads and protection from new sources of nutrients. A monitoring plan was also recommended. The report recommendations are summarized below:

- Improve the water quality by reducing eutrophication in the reservoir.
- Increase dissolved oxygen concentrations to a point where stratification does not lead to anaerobic conditions in the reservoir, thereby increasing the amount of usable fish habitat and eliminating or reducing fish kills.
- Reduce algae growth.
- Reduce sediment loads into the reservoir.
- Protect the reservoir from new sources and slugs of nutrients.
- Reduce turbidity in the streams.
- Reduce erosion and sediment loading to the streams.
- Sanitary facilities must be installed correctly and inspected to ensure that no sewage will escape.
- Eradicated trash fish should be cleaned up after any planned fish kills.

- Reduce ambient maximum stream temperatures.

Erosion was determined to be the direct cause of turbidity in the reservoir and the mechanism by which most of the external phosphorus loading was occurring. Grazing activities, road construction, off-road vehicle travel, and natural conditions were identified as contributing to soil erosion in the watershed.

A closely related problem was the deposition of animal waste directly into streams or bays, or onto adjacent denuded areas. A large percentage of this phosphorus is readily available for biological uptake within the reservoir.

Other sources of nutrient loading identified were bait fishing, fish cleaning, and inadequate sanitation facilities.

A target phosphorus reduction of 55 % was set for the original reservoir (about 5,000 kg per year) and 25 % for the enlarged reservoir (3,650 kg per year). These goals were to be achieved by eliminating imported water in Co-op Creek and stabilizing the area by re-establishing riparian vegetation. A 100-foot vegetative buffer strip along major stream channels was recommended to stop erosion and filter out sediments and nutrients from overland flow. In order to maintain the buffer strips, the report recommends eliminating grazing from the project lands.

The majority of the stream flow (75 percent), and a larger proportion of the phosphorus loading to the reservoir (90 to 95 percent of total phosphorus and 85 to 90 percent of the ortho-phosphate), occurred during the spring runoff period (April through June). An estimated 90 percent of the phosphorus load to Strawberry Reservoir is derived from streambank or hillside erosion. Ortho-phosphate loads did not increase in the same proportion as total phosphorus loads during spring runoff. Ortho-phosphate was only 15 to 20 percent of the total phosphate load. This indicates that total phosphorus loads were associated more with sediment loading than organic and animal waste loading, although the two cannot be clearly separated. Co-op Creek had by far the highest phosphorus loading, the next highest was Strawberry River. Mud Creek and Clyde Creek also appeared to have high nutrient loadings.

2.4.2 USFS Strawberry Watershed Restoration Report

The Strawberry Watershed Restoration Report (2004) discusses the management objectives for the portion of the Strawberry watershed that falls under the jurisdiction of the U.S Forest Service.

Bank erosion is a major sediment source for the valley. Annual bank erosion has been estimated at 14,500 tons per year, with an apparent migration rate of 0.44 feet per year (8 feet in 18 years). The largest source of sediment from bank erosion is the Strawberry River, which contributes 9,033 tons of sediment per year (63 % of total sediment derived from bank erosion) to the Strawberry Valley. Co-op Creek and Trail Hollow below Chipman Creek contribute 2,123 and 1,564 tons per year respectively. These three streams account for 88 % of the valley-wide bank erosion. Successful bank stabilization and intact beaver dams have helped lower erosion rates on Indian Creek above Streeper Creek. A general summary of the watershed is listed below:

- Almost every stream reach surveyed is incised to some extent.
- Channel adjustment following incision is the main driver of bank erosion.
- Riparian width has decreased substantially since the 1930's.
- Width-depth ratios (bankfull width to bankfull depth) vary widely from less than 5 to 40.
- Width-depth ratios on streams with healthy riparian vegetation would be between 10 and 20, and less than 10 for many streams.

The watershed erosion prediction project model (WEPP) was used to predict long-term sediment yields. The accuracy of the predicted sediment production is approximately ±50 %. Erosion events occur with only a handful of storm events during a 50-year cycle, with model output averaged over the 50-year period.

The results are based on soil erosion from current roads, dispersed campsites, aspen, and sagebrush stands. The results were confirmed visually in high sediment production areas. The results are presented in Table 2-1 and Figure 2-5. The thickness and color of the lines in Figure 2-5 correspond to the predicted loading rate to streams (tons/year).

Table 2-1: Predicted Sediment Delivery to Streams in Strawberry Watershed

Estimates of Sediment Reaching Streams from Selected Sources		
	Area (acres)	Sediment to Streams (tons/yr)
Strawberry Watershed Roads		
Closed Roads	12	109
High Clearance Vehicles Only Roads	267	2,404
Suitable for Passenger Cars Roads	147	1,327
Moderate Degree of User Comfort Roads	153	1,377
High Degree of User Comfort Roads	284	26
Trails	30	268
Unclassified Roads	300	2,704
Un-rated	41	366
Sub-Total	**1,234**	**8,581**
Dispersed Campsite (By Sub-Watershed)		
North Strawberry	0.92	0.28
South Strawberry	0.30	0.09
West Side	1.67	0.51
Indian	0.14	0.04
Trail Hollow	0.37	0.11
East Side	0.13	0.04
North Side	0.65	0.20
Co-op	0.24	0.07
Sub-Total	**4.42**	**1.34**
Grand Total	**1,238**	**8,582**

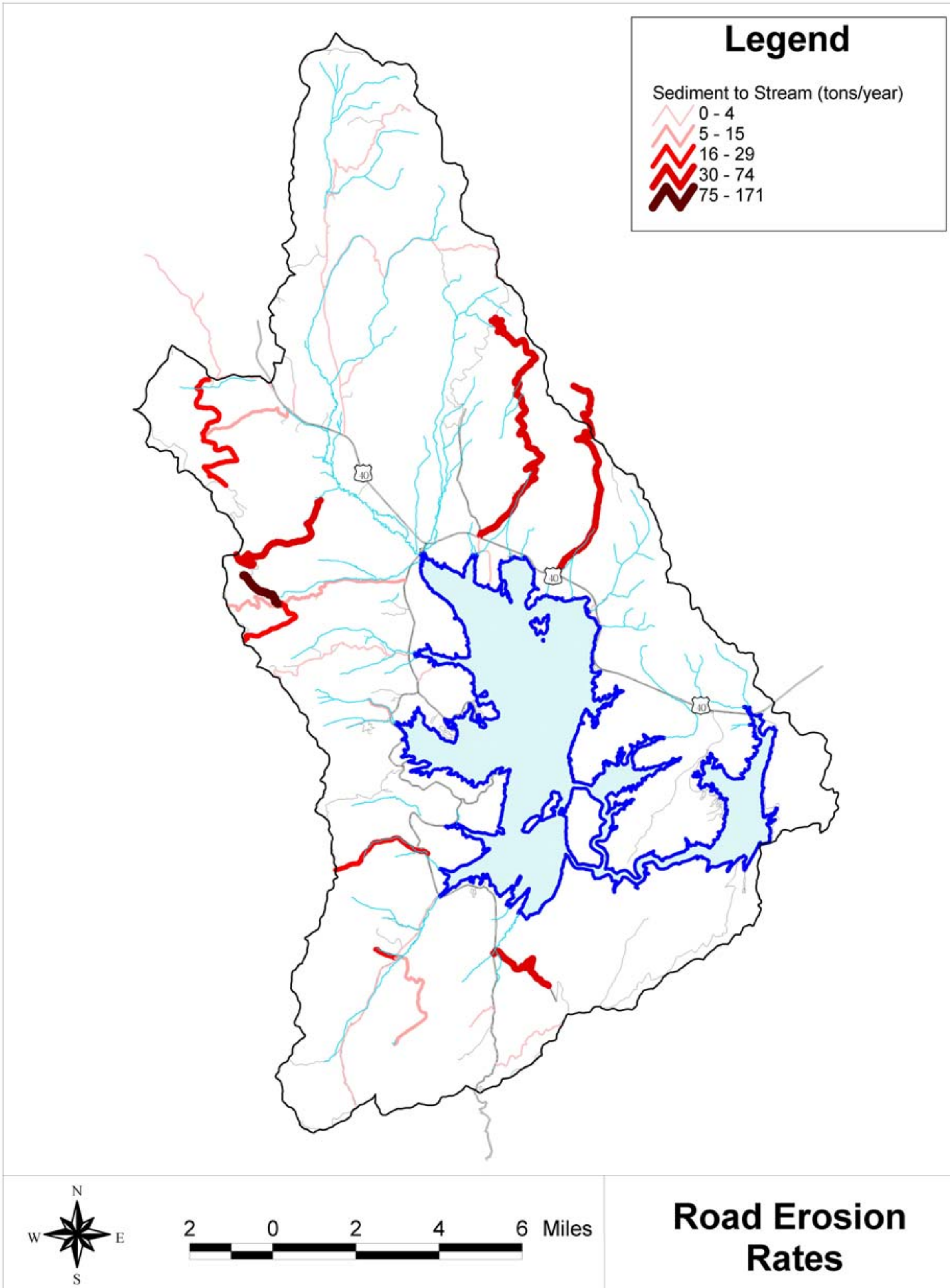


Figure 2-5: Predicted sediment load to streams (Strawberry Watershed Restoration Report, 2004)

2.4.3 Uinta National Forest Plan

The 2003 Forest Plan for the Uinta National Forest outlines the desired future conditions of the Strawberry Reservoir Management Area. The boundary for the management area is the topographic boundary for the Strawberry Reservoir watershed, along with the National Forest boundary on the east.

Desired future conditions are divided into seven categories: water and watershed, vegetation, recreation, heritage resources, range, lands and special uses, and transportation. The following is a synopsis of the identified desired future conditions for each category.

Water and watershed – Continue to implement standards and guidelines outlined for the Riparian Habitat Conservation Areas (RHCAs) and to improve watershed conditions within the management area.

Vegetation – Approximately 55,300 acres of this management area are comprised of forested vegetation. Those areas within the management prescription (40,960 acres) are managed to achieve multiple resource values while providing for multiple uses and timber production. While timber harvest may be used in areas outside of the management prescription, these areas are not managed to promote growth and yield – vegetation management in these areas is conducted for stewardship purposes only and may include commercial timber sales, prescribed fire, or other mechanical treatments.

An estimated 6,000 to 13,000 acres, split between the aspen and sagebrush types is treated to improve vegetation conditions and habitat diversity. Prescribed fire is primarily used in the upper elevation aspen stands while mechanical treatments are used in the lower sagebrush stands. The mechanical treatments are designed to improve sage grouse habitat and reduce fuels near private developments.

Recreation – A mix of recreational opportunities is provided throughout the area. The entire area is open to various forms of motorized and non-motorized recreation. Summer motorized recreation is limited to those roads and trails designated and appropriately signed for this use. Dispersed campsites along heavily used road corridors are hardened and signed to concentrate use and reduce the impacts to other resources. Campgrounds, boat launches, and other recreational facilities are managed to maintain current levels of use. Development of additional recreational facilities may be allowed. The non-motorized winter use trail system in the Daniels Summit/Dock Flat area is expanded. The Great Western Trail is managed to maintain its designation as a National Millennium Trail.

Heritage resources – An interpretation plan for the historic Strawberry military site is developed and implemented. Other heritage sites are also preserved, and heritage information is included in environmental education and interpretation programs. Historical information continues to play a role in ecological and interpretation programs. Historical information continues to play a role in ecological restoration efforts. The Northern Ute Indian Tribe is an active partner in both project planning and long-term management of the area.

Range – The portion of this management area known as the Strawberry Project lands continues to be closed to livestock grazing. Willows and other riparian vegetation once eliminated because of heavy grazing activity and herbicide use are showing consistent signs of rehabilitation. Livestock grazing activities continue on the other allotments within this management area.

Lands and special uses – The Bryant's Fork recreation residence tract is managed as a recreation special use development area. A utility corridor exists along U.S. Highway 40, which runs through the area. Vegetation management is limited to be consistent with installation and maintenance of the utility line and efforts employed to mitigate erosion and minimize visual quality impacts. Similar management strategies are employed on the mineral sites located within this area.

Transportation – The Indian Creek Road (#042) is reconstructed providing continuous passenger car road access from State Highway 6 to Strawberry Reservoir. Access to private land via the Devils Notch Road is maintained; this road is under jurisdiction of a public road authority from the Soldier Creek Dam to the Forest boundary.

2.4.4 USU Lake Bottom Sediment Study

This report evaluates and compares the availability of phosphorus in the lake bottom sediments of Strawberry Reservoir and several other water bodies within Utah including Scofield Reservoir, Flaming Gorge Reservoir and Panguitch Lake.

This study found that phosphorus release rates from Strawberry Reservoir bottom sediments are relatively low compared to the other waterbodies. Co-op Creek does, however, contribute a more significant source of available phosphorus than other inlets to the reservoir.

2.4.5 Strawberry Valley Non-point Source Watershed Plan (Mountainland Association of Governments)

In 1987, public attention was focused on the Strawberry Valley due to concerns about the management of project lands (56,970 acres of land surrounding the reservoir) and the apparent degradation of the trout fishery. That concern led to the placement of Strawberry Valley on the State's priority watershed ranking for non-point source control.

A number of Best Management Practices (BMP's) were recommended to improve water quality in the Strawberry Valley Watershed including:

- Provide a livestock grazing system compatible with primary forage plants, streambank protection, and fishery enhancement.
- Achieve total ground cover over 70 percent of the total watershed.
- Provide stability to streambanks by revegetation, instream structures, streambank contouring, off-stream watering, altered grazing system, and stream corridor protection.
- Provide vegetative buffer strips of willow and other riparian shrubs along streambanks.
- Control livestock access to streambanks.
- Restrict off-road vehicle use.
- Forage utilization will not exceed 30 or 50 percent of plant production on slopes greater or less than 30 percent respectively.
- Limit pesticide applications to specific target plant species using acceptable applications practices, and eliminated all application along stream corridors.
- Provide reseeding as warranted.
- Construct boundary fences and temporary fencing of project area streams
- Enhance habitat suitable for sustaining upland and aquatic wildlife.

A preliminary assessment of rehabilitation needs for Strawberry River, its tributaries, and Strawberry Reservoir tributaries was also completed.

Tributary restoration began in 1984 and has resulted in significant improvement and reduction of grazing impacts on Indian Creek. Grazing of livestock within the enlarged recreation boundary of Strawberry Reservoir has been reduced and habitat improvement projects have been completed or were under construction at the time the report was written. Almost all of the rehabilitation and stabilization projects, which had occurred by 1988, had been on land within the recreation management boundary and on National Forest lands.

2.4.6 Fishery Studies

Environmental Assessment of Plans to Restore the Strawberry Reservoir Fishery.

In 1986 the Utah Division of Wildlife Resources (UDWR) established a Federal Aid Project at Strawberry Reservoir through the Strawberry Interagency Fisheries Advisory Team (SIFAT) to restore the quality of the Strawberry Reservoir fishery and associated tributary streams and riparian corridors. Specific management objectives included:

- Maintain cutthroat trout as an integral component of the Strawberry Valley Fishery Complex
- Provide a minimum sustained output of 1.2 million hours of recreational angling yearly
- Achieve an average catch rate of 0.4 fish/hour
- Produce 10 million cutthroat trout young-of-the-year from Strawberry Valley Tributaries each year
- Rehabilitate and restore Strawberry Valley spawning tributaries
- Collect 6 million cutthroat trout eggs yearly from spawn taking operations for use elsewhere in the state
- Focus management of the Strawberry Valley fishery on three gamefish species:
    - Bear Lake strain of Bonneville cutthroat trout (*Oncorhynchus clarki utah*)
    - Kokanee salmon (Oncorhynchus nerka)
    - Sterilized rainbow trout (*Oncorhynchus mykiss*)

This species mix has the ability to effectively coexist and compete with prolific non-game fish species. Naturally sustainable gamefish populations are desirable as they act to reduce demand on hatchery production and allow fish populations to adapt to local conditions, creating a more robust and adaptable fishery.

The rehabilitation of Strawberry Valley streams and production of wild cutthroat trout are considered integral components of this plan, as was the 1990 rotenone treatment (Wilson and Spateholts, 1998).

UDNR Post-treatment summary report, July 1, 1991-June 30, 1997.

In 1997, the UDWR produced a summary report detailing the state of the fishery in Strawberry Reservoir following the 1990 rotenone treatment (Wilson and Spateholts, 1998). The report found that the fishery developed rapidly following treatment, recovering to pre-1985 levels, and the management goals for fishing pressure, catch rate, and fish size established by SIFAT were met or exceeded. Fishing at Strawberry Reservoir in 1997 was determined to be as good or better than it had ever been, and angler use was more than 50% greater than peak use during the 1970's. While selected tributaries to the reservoir were opened to catch and release fishing in 1996, angler impacts to the riparian areas were determined to be minimal.

Due to fluctuations in kokanee spawning runs, the number of eggs taken was low and the number of kokanee stocked fell short of the established 1 million fish goal. However, the quality of the eggs harvested was excellent. Successful natural recruitment for early-run kokanee salmon was found to be limited.

In 1997, Bear Lake cutthroat spawning was the largest observed since the 1990 treatment and extended well into many of the upper stream reaches. Naturally recruited cutthroat trout represented an equal or greater portion of the juvenile population than stocked fish and is expected to improve. However, the management objective for young of the year (YOY) cutthroat trout had not been achieved. The 1997 projection of cutthroat YOY (valley-wide) was 1 to 2 million, 10% to 20% of the established objective.

Non-game fish populations (primarily Utah chub (*Gila atraria*) and redside shiners (*Richardsonius balteatus*)) were found to be expanding in Strawberry Reservoir, comprising approximately 8% of the total fish biomass. It was projected that if non-game expansion were to continue at rates similar to those observed during the late 1970s and early 1980s gamefish populations and angler catch rates could be affected as early as 2002.

Management recommendations specific to this summary report include:

- Expansion of cutthroat stocking programs
- Development of strategies to improve survival of fall stocked fingerling cutthroat
- Immediate return of sterilized rainbow trout to the reservoir
- Continuation and potential supplementation of wild brood egg takes for kokanee
- Assessment of appropriate changes in fishing regulations to preserve and enhance the game fishery and predation on non-game species as a population control mechanism
- Evaluation of reservoir fluctuations on the survival and productivity of non-game fish with the potential development of a management strategy that will reduce non-game fish abundance in the reservoir
- Rehabilitation of tributary and riparian areas.

The tributary rehabilitation program was identified as a key component of fishery success. Concerns included high stream temperatures, limited cover, unstable banks, high proportion of fine sediments in spawning gravels and stream scouring. Specific improvements included removal of grazing impacts, revetments and willow plantings, and development of instream spawning complexes. The Strawberry River and associated drainages were of specific concern. The lower reaches of the Strawberry River were identified as containing poor spawning habitat. Production of YOY cutthroat trout in the Strawberry River drainage was estimated at 108,000, less than 3% of the 4.8 million projected for the drainage if fully restored.

Spawning and Recruitment of Strawberry Reservoir Salmonids, Annual Report for Fiscal Years 1994 and 1995 (Utah State University).

Spawning and recruitment viability of cutthroat trout and kokanee salmon in the Strawberry Reservoir drainage were examined by the Utah Cooperative Fisheries and Wildlife Unit, Department of Fisheries and Wildlife from Utah State University in both 1994 and 1995 (Knight *et al*., 1994; Orme *et al*., 1995).

In 1994, cutthroat spawning was assessed in Indian Creek, Trout Creek and Strawberry River. Spawning occurred to some degree throughout all three tributaries, but was predominantly concentrated in the downstream reach of Indian Creek and the two downstream reaches of Strawberry River. Indian Creek was observed to have the largest number of total cutthroat spawners (Orme *et al*., 1995), substantially greater than the numbers observed for Trout Creek and Strawberry River (388 and 362 respectively), although the relative size of male and female cutthroat spawners in each tributary was similar. Cutthroat egg to fry survival was estimated for Indian Creek at 21.2%, Trout Creek at 24.5% and Strawberry River at 12%. The percentage of cutthroat fry migrating to the reservoir in 1994 was 16% for Indian Creek and 32% for Trout Creek (Strawberry River out migration was unknown). A possible explanation given for the difference in out migration is that Indian Creek had more available rearing habitat than Trout Creek (Knight *et al*., 1994).

Kokanee spawning was predominantly concentrated in the two downstream reaches of Indian Creek and Trout Creek, but was limited to only the downstream reach of the Strawberry River, largely due to trap operations. Indian Creek was observed to have the largest peak number of kokanee spawners (5,357), substantially greater than the peak numbers observed for Trout Creek and Strawberry River (344 and 2,206 respectively). Relative size of male and female kokanee spawners in each tributary was similar, with the exception of females in Strawberry River, which were somewhat larger. Mean survival rate for kokanee eggs was estimated at 35% to 48% (30 days after peak spawning). Average fecundity and egg retention between the three tributaries was similar.

In 1995, cutthroat spawning was assessed in Indian Creek, Trout Creek and Strawberry River. The total number of spawning days available in 1995 was less than half of the spawning days available in 1994. In 1995, increased usage of higher stream reaches was observed, most likely a response to higher stream flows. Spawning occurred to some degree throughout all three tributaries, but was predominantly concentrated in the downstream reach of Indian Creek, and equally distributed in Trout Creek. Counts could not be made on Strawberry River due to high flows and turbid water. Indian Creek was observed to have the largest number of total cutthroat spawners (2,808), more than four times the number observed for Trout Creek (605). Cutthroat egg to fry survival was observed to increase from 1994 in all but Strawberry River: Indian Creek at 24%, Trout Creek at 46% and Strawberry River at 7%. The percentage of cutthroat fry migrating to the reservoir in 1995 was lower than that observed in 1994, 3% for Indian Creek and 12% for Trout Creek (Strawberry River out migration was unknown)(Orme *et al*., 1995).

In 1995, kokanee spawning was more abundant and more widely distributed than in 1994. Spawning occurred predominantly in the middle reach of Indian Creek, the two upstream reaches of Trout Creek, and was temporally distributed throughout the Strawberry River. Indian Creek was again observed to have the largest peak number of kokanee spawners (4,108), substantially greater than the peak numbers observed for Trout Creek and Strawberry River (2,404 and 538 respectively). In contrast to 1994, only one size class spawned in 1995 (age 3, 1992 brood stock) and females were smaller than observed in 1994. Mean survival rate for kokanee eggs was estimated at 49% to 57% (30 days after peak spawning).

Carrying Capacity of Strawberry Reservoir for Salmonids (Utah State University).

Studies completed by the Utah Cooperative Fisheries and Wildlife Unit, Department of Fisheries and Wildlife from Utah State University in 1995 and 1996 characterized the salmonid carrying capacity of Strawberry Reservoir (Beauchamp and Beauchamp, 1995; Ruzycki *et al*., 1996). Using model simulations and high growth rates observed in the fishery, these studies showed that the salmonid populations in the reservoir in the late 1990s were well below carrying capacity based on food availability.

If the Strawberry fishery is to be maintained, the report stressed that large populations of salmonids will be necessary to prevent Utah chub (*Gila atraria*) and Utah sucker (*Catostomus ardens*) from becoming dominant. The current managed population of Bonneville cutthroat trout (*Oncorhynchus clarki utah*), kokanee salmon (*Oncorhynchus nerka*), and sterilized rainbow trout (*Oncorhynchus mykiss*) should provide both competition for existing invertebrate forage species and predation on non-game species (Ruzycki *et al*., 1996). However, for competition and predation to work effectively in the managed fishery, the carrying capacity of the reservoir must be approached, as competition does not occur unless resources are limited.

Model simulations highlighted the importance of macroinvertebrate populations as a mainstay of stocked and natural fishery diets year-round. Macroinvertebrates were identified as especially critical during the winter season, and stressed the need for better understanding of the impacts of reservoir fluctuations on fish and invertebrate populations. The study also identified the critical nature of thermal and stratification dynamics on piscivory (Beauchamp and Beauchamp, 1995).

Water quality parameters were assessed as part of the 1996 study and differences between the Strawberry River and the Soldier Creek Basin were identified (Ruzycki *et al*., 1996). Temperature and dissolved oxygen profiles were examined for both basins and showed that stratification in the Soldier Creek Basin persisted longer than in the Strawberry River Basin, resulting in dissolved oxygen concentrations too low for salmonid use in the lower water column (below 20 meters). Blue green algae was also noted in the Soldier Creek Basin

The 1996 study (Ruzycki *et al*., 1996) was undertaken late in the year (October) and therefore may not have accurately sampled the adult kokanee population, the bulk of which had most probably migrated to tributary and near-shore spawning habitats. The study was also carried out during destratified conditions that may have allowed fish to elude sampling by inhabiting bottom or near-shore areas. While these difficulties may have resulted in an underestimation of total population, it was observed that cutthroat and kokanee dominated the fish assemblage in Strawberry Reservoir. The identified fish densities were relatively low (0.19 to 5.52 fish/1000 m^3) but were similar to measured densities in oligotrophic and mesotrophic lakes in central Idaho (0.79 to 5.78 fish/1000 m^3), suggesting that the habitat is capable of supporting significantly higher densities of fish.

Evaluation of the effects of reservoir fluctuations on non-game fish habitat and production in Strawberry Reservoir

In 2000 a study of reservoir fluctuations as a management tool for reducing non-game fish populations in Strawberry Reservoir was completed by Utah State University. Research focused on the Utah chub (*Gila atraria*), the most abundant species in the reservoir prior to the 1990 rotenone treatment. Information on the timing, distribution and duration of Utah chub life stages and stage-specific habitat was collected and reviewed with regards to depth, slope, fetch, shoreline morphology and vegetative or rocky cover (Kuehn, 2000). Both water-level fluctuation and the associated augmentation of submerged terrestrial and/or aquatic plants was investigated, as reservoir drawdowns during critical life stages may act to disrupt spawning, reduce critical habitat or increase egg/larval mortality.

While spawning and larval stages of the Utah chub have little overlap with salmonid species, and water level fluctuations may limit the production of this species in some areas of the reservoir, large areas of appropriate habitat were shown to remain available over all modeled water elevations and high density areas were not shown to be fragmented as water levels changed. Therefore, since adequate unfragmented habitat remained available over a broad range of water elevations, this study determined that water level manipulations could not significantly disrupt Utah chub reproduction (Kuehn, 2000).

Aquatic Program Accomplishments 2003 – 2004.

A summary of aquatic program accomplishments for Strawberry Reservoir was completed by the Utah Department of Natural Resources, Division of Wildlife Resources in March of 2004 (Department of Natural Resources, Division of Wildlife Resources, 2004).

The report concluded that total non-game fish catch rates remained about the same from spring 2002 to spring 2003 with some increase in Utah chub populations. Fall catch rates however declined dramatically from fall 2002 to fall 2003, with large decreases in both Utah chub (25%) and redside shiner (75%) catches, presumably the result of increased predation by large cutthroat trout. Current growth rates of cutthroat are equal to or in excess of those previously recorded and competition from non-game fish is not limiting growth.

Overall incidence of predation has increased over the last three years. During 2001 and 2002 the Utah chub population has also increased, providing a more readily available food source. Additionally, age-specific cutthroat growth has increased in each year class since 1998, a result of plentiful food supplies. Sampling in the fall of 2003 showed that nearly 28% of cutthroat sampled were feeding on Utah chubs and redside shiners. Larger cutthroat adults were even more likely to be piscivorous. Over 47% of cutthroat over 18 inches in length and over 64% of cutthroat over 20 inches in length with food in their stomachs were found to be feeding on chubs and shiners. New regulations were implemented in 2003 to protect and enhance the population of larger cutthroat trout in Strawberry Reservoir to more effectively prey on non-game fish.

Populations of adult cutthroat increased dramatically in 2002 and 2003, and are expected to increase in 2004, with high survival rates of the age 3+ to age 5+ cohorts contributing to the greater numbers of adult fish observed. Average survival rates from 1995 through 2003 were 43%, 33% and 18% respectively. New regulations do not appear to be resulting in negative population impacts in smaller cutthroat sizes, with an 85% survival rate observed for age 3+ cutthroat from 2002 to 2003. The age structure of the adult population has improved with the larger fish (greater than 20 inches in length) representing 15% of the adult population in 2003.

Kokanee spawning in 2003 was much improved over 2001 and 2002. Moderate to good runs were observed in Indian Creek, Trout Creek and Strawberry River. A large percentage of spawning fish came from natural reproduction (47% on Indian Creek and 72% on the Strawberry River). Egg takes in 2003 met the goal for Strawberry Reservoir production at just over 1.1 million eggs (the initial quota of 1.6 million eggs was revised downward to 1.2 million to meet the approved stocking rate of 400,000 kokanee).

Based on opportunistic creel census data, catch rates in July through September of 2003 averaged 0.24 fish/hour, 0.44 fish/hour, and 0.42 fish/hour. The overall average was 0.37 fish/hour, very close to the defined management goal of 0.4 fish/hour. However, the creel census data covers only a part of the season and therefore may not be representative of the overall yearlong catch rate. Catch rates observed in 2001 were 1.0 fish/hour in the winter and 0.5 fish/hour year round.

Overall opinion surveys of fishing quality taken in 2003 at Strawberry Reservoir show that over 50% of users rate the fishery as good or excellent.

2.5 Land Use

Originally, the Strawberry Valley contained 56,970 acres of land under the ownership of the United States Government. The Strawberry Water Users Association (SWUA) was given land management responsibilities under contract, and managed the land for grazing and watershed purposes. In 1982, the United States Government withdrew over 25,990 acres of project lands for the Central Utah Water Project. Approximately 8,765 of the withdrawn acreage is now covered by the enlarged reservoir, and the other 17,225 acres were turned over to the U.S. Forest Service to be managed as multiple use lands within the recreation boundary of Strawberry Reservoir. The Forest Service also manages the remaining 30,980 acres of Project Lands with an emphasis on wildlife and recreation. All land under the management of the U.S. Forest Service is managed as public lands for multiple uses (Figure 2-6). Dispersed recreational activities tend to occur near the larger tributaries. The areas designated as "Undeveloped" are closed to grazing.

Currently the area is used for a variety of recreational activities. Hunting and fishing are major attractions. Wildlife viewing, hiking, walking, mountain biking, horseback riding, camping, nature studies, boating, picnicking, OHV use, cross-country skiing, snowshoeing, snowmobiling, sailing, and water skiing are also popular activities in the watershed.

Many important archaeological and historical sites are located in the watershed boundaries. Until as recently as 150 years ago American Indians frequented the area. Dominguez and Escalante passed through with their Ute guides in 1776. Historical military sites can also be found in the valley.

Portions of the watershed are open to grazing. Oil, gas, and coal developments, although currently limited, are the major mineral resources of the area.

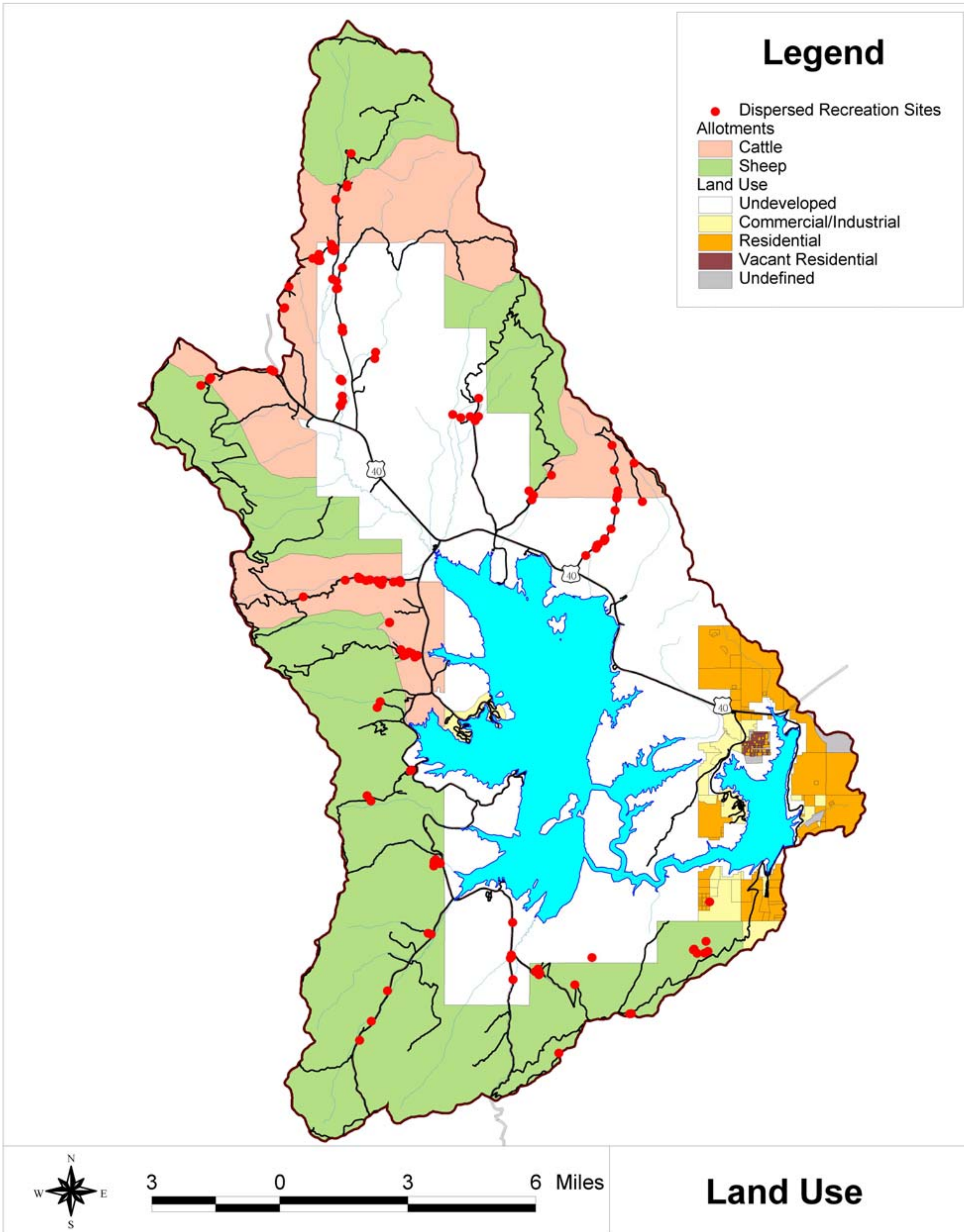


Figure 2-6: Land use in the Strawberry Reservoir watershed.

3.1 Introduction

Data for water quality, flow and fisheries were obtained from various sources that are identified further in this chapter. These data were screened and evaluated to determine their validity and applicability to this study

The first step in the data validation process was to gather the available data that would be used to assess the impairment of the water body, aid in the identification of potential pollution sources, and provide the basis for recommendations.

In addition to gathering water quality data, flow data for the inflows and outflows of the reservoir were obtained. Flow data are necessary for determining pollutant loads as well as for establishing the water budget for the reservoir.

Fisheries data from the Utah Department of Natural Resources, Division of Wildlife Resources was used to assess fishery health.

The water quality data used in this analysis were obtained from the State of Utah, Division of Water Quality (DWQ). Flow data were obtained from DWQ, US Bureau of Reclamation, and Central Utah Water Conservancy District (CUWCD).

3.2 Data Sources

3.2.1 Water Quality Data

The Utah Division of Water Quality monitors water quality in the Strawberry Reservoir Watershed in order to ensure compliance with it's designated beneficial uses. Samples are analyzed at the State of Utah Public Health Laboratory and the results are reported through the United States Environmental Protection Agency's (EPA) STORET database. Both reservoir and stream water quality data, from 1990 to 2003, were obtained for this report at the STORET monitoring locations listed in Table 3-1. Their locations within the watershed are shown in Figure 3-1.

Stream water quality data are available for a significant number of stations during the early-to-mid 1990s, including the Syar and Strawberry Tunnel outlets. During this time period, sampling occurred regularly between May and September. Sampling events were less frequent during 1998 and 1999 on the inflows to Strawberry Reservoir, and few stream stations have been sampled recently (post 2000). Table 3-2 shows the time periods where water quality data are available for the various stations.

Sampling in the reservoir was fairly consistent over the time period considered here. For each year there are at least two times where water quality samples were obtained. Reservoir sampling typically occurs during the months of May through September.

Several of the stations presented in Table 3-1 were not sampled with enough regularity to be useful in this study. A decision was made to exclude stations which were only sampled once or twice, or which were only sampled in the early 1990s. Table 3-3 shows these stations that were excluded.

Table 3-1: Water Quality Monitoring Sites

	Station	Description	Type
Stream Stations	493630	Strawberry R Bl Soldier Ck Dam	Outflow
	493647	Strawberry Aquaduct Ab Strawberry Reservoir	Inflow
	493650	Birch Ck Ab Strawberry River	Inflow
	493651	Trout Ck Ab Strawberry Res At Us40 Xing	Inflow
	493652	Streeper Creek Ab Indian Creek Road	Inflow
	493653	Co-Op Creek Above Cnfl/ Strawberry River	Inflow
	493654	Strawberry R Ab Strawberry Res	Inflow
	493655	Indian Creek Ab Mouth Of Streeper Creek	Inflow
	493656	Co-Op Creek @ Narrows 1 1/4 Mi Bl Usfs Bndy	Inflow
	493658	Trail Hollow Creek Ab Cnfl / Chipman Creek	Inflow
	493660	Mud Ck Ab Strawberry Res	Inflow
	493661	Indian Ck Ab Westside Rd Ab Strawberry Res	Inflow
	493662	Clyde Creek Below Westside Road	Inflow
	493663	Clyde Creek Ab Old National Forest Boundary	Inflow
	493665	Strawberry River At Westside Road	Inflow
	493668	Strawberry River Ab Daniels Diversion	Inflow
	493669	Willow Ck Ab Cnfl/ Strawberry River	Inflow
	493670	Wide Hollow Ck Ab Cnfl / Strawberry R	Inflow
	493671	Strawberry R At Us 40 Xing	Inflow
	493688	Current Ck Res Tunnel Ab Strawberry Res	Inflow
	499570	Syar Tunnel Outlet At Sixth Water	Outflow
	499578	Sixth Water @ Strawberry Tunnel Outlet	Outflow
Reservoir Stations	493632	Strawberry Res Ab Soldier Ck Dam T-14	Lake
	493633	Strawberry Res Narrows T-12	Lake
	493642	Strawberry Res Bryants Fk T-2	Lake
	493643	Strawberry Res Strawberry Bay T-5	Lake
	493645	Strawberry Res Ab Old Damsite T-8	Lake
	493648	Strawberry Res 3/4 Up Strawberry Bay	Lake
	593676	Strawberry Res Indian Ck Bay T-10	Lake

Table 3-2: Water Quality Data Availability By Station

	Station	Description	Type
Stream Stations	493630	Strawberry R Bl Soldier Ck Dam	Outflow
Stream Stations	493647	Strawberry Aquaduct Ab Strawberry Reservoir	Inflow
Stream Stations	493650	Birch Ck Ab Strawberry River	Inflow
Stream Stations	493651	Trout Ck Ab Strawberry Res At Us40 Xing	Inflow
Stream Stations	493652	Streeper Creek Ab Indian Creek Road	Inflow
Stream Stations	493653	Co-Op Creek Above Cnfl/ Strawberry River	Inflow
Stream Stations	493654	Strawberry R Ab Strawberry Res	Inflow
Stream Stations	493655	Indian Creek Ab Mouth Of Streeper Creek	Inflow
Stream Stations	493656	Co-Op Creek @ Narrows 1 1/4 Mi Bl Usfs Bndy	Inflow
Stream Stations	493658	Trail Hollow Creek Ab Cnfl / Chipman Creek	Inflow
Stream Stations	493660	Mud Ck Ab Strawberry Res	Inflow
Stream Stations	493661	Indian Ck Ab Westside Rd Ab Strawberry Res	Inflow
Stream Stations	493662	Clyde Creek Below Westside Road	Inflow
Stream Stations	493663	Clyde Creek Ab Old National Forest Boundary	Inflow
Stream Stations	493665	Strawberry River At Westside Road	Inflow
Stream Stations	493668	Strawberry River Ab Daniels Diversion	Inflow
Stream Stations	493669	Willow Ck Ab Cnfl/ Strawberry River	Inflow
Stream Stations	493670	Wide Hollow Ck Ab Cnfl / Strawberry R	Inflow
Stream Stations	493671	Strawberry R At Us 40 Xing	Inflow
Stream Stations	493688	Current Ck Res Tunnel Ab Strawberry Res	Inflow
Stream Stations	499570	Syar Tunnel Outlet At Sixth Water	Outflow
Stream Stations	499578	Sixth Water @ Strawberry Tunnel Outlet	Outflow
Reservoir Stations	493632	Strawberry Res Ab Soldier Ck Dam T-14	Lake
Reservoir Stations	493633	Strawberry Res Narrows T-12	Lake
Reservoir Stations	493642	Strawberry Res Bryants Fk T-2	Lake
Reservoir Stations	493643	Strawberry Res Strawberry Bay T-5	Lake
Reservoir Stations	493645	Strawberry Res Ab Old Damsite T-8	Lake
Reservoir Stations	493648	Strawberry Res 3/4 Up Strawberry Bay	Lake
Reservoir Stations	593676	Strawberry Res Indian Ck Bay T-10	Lake

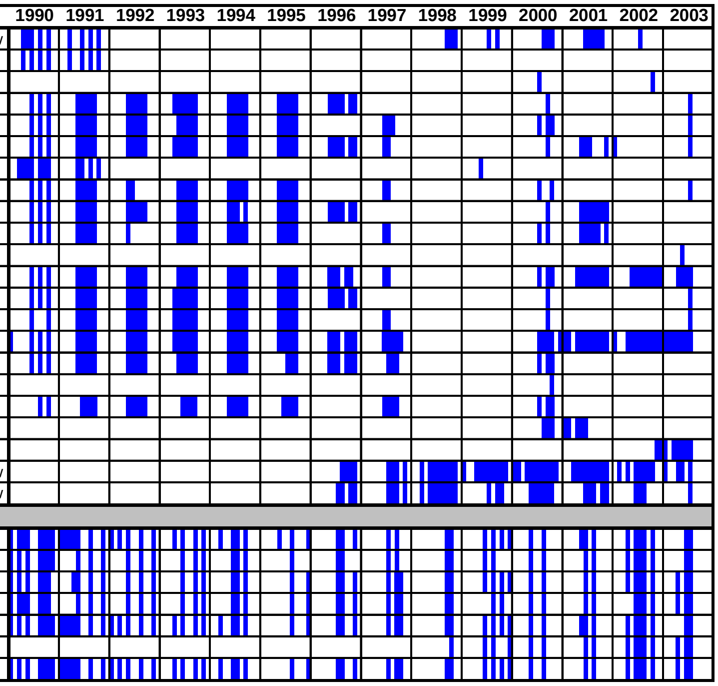


Table 3-3: Water Quality Sampling Stations Excluded From This Analysis

STORET	Description	Type
493650	Birch Ck Ab Strawberry River	Inflow
493654	Strawberry R Ab Strawberry Res	Inflow
493660	Mud Ck Ab Strawberry Res	Inflow
493669	Willow Ck Ab Cnfl/ Strawberry River	Inflow
493671	Strawberry R At Us 40 Xing	Inflow

Two stations (493647 and 493688), located at the inflow of The Ladders, had extremely limited data. However, as this is a significant inflow to Strawberry Reservoir, the data reported at these two stations were combined and labeled as station "100” for this study.

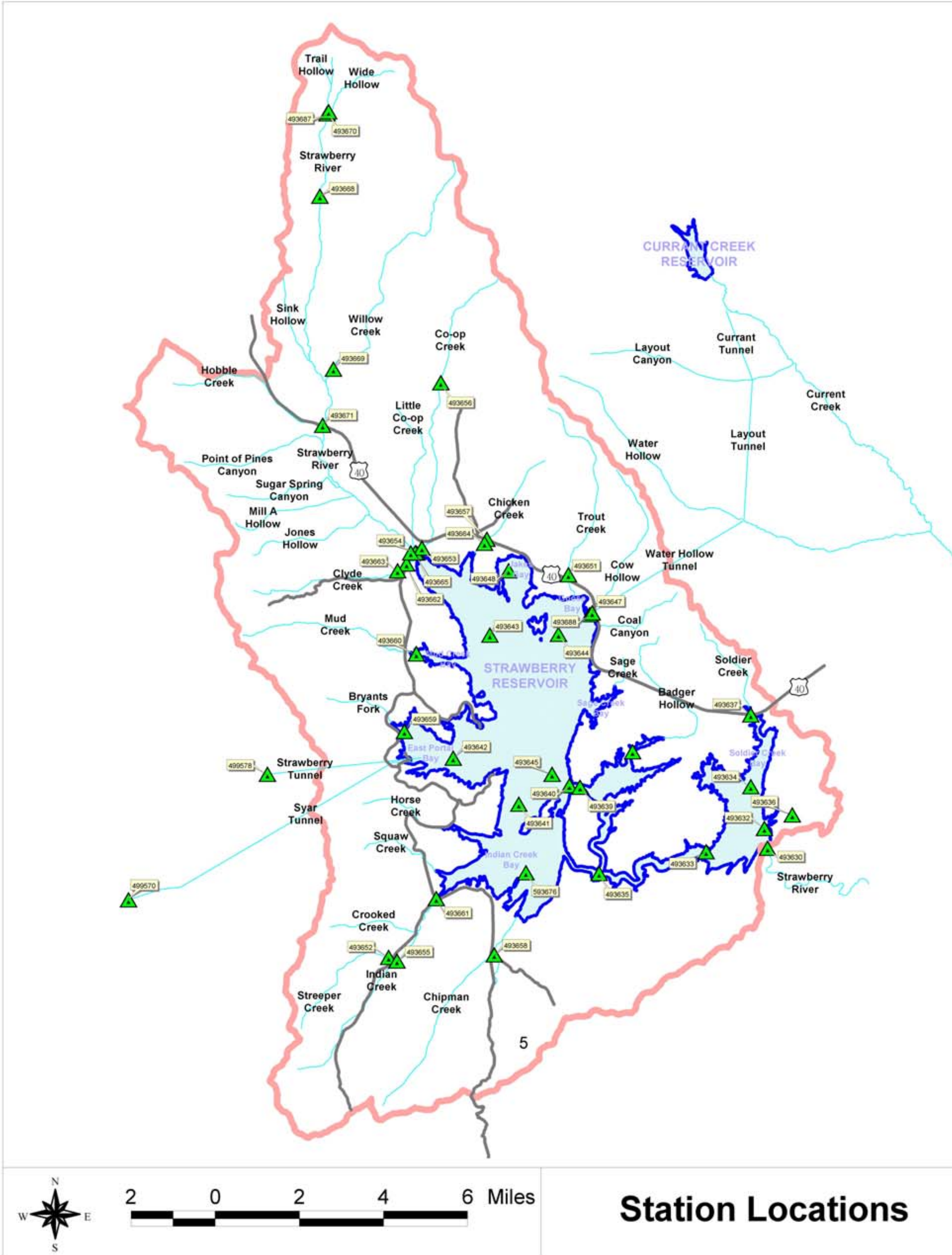


Figure 3-1: Reservoir and stream STORET stations within the watershed boundary.

In addition to stream sampling data, DWQ provided reservoir vertical profile data for the years 1997, and 1999-2003. This profile data includes measurements for both temperature and dissolved oxygen. Profile locations coincide with reservoir STORET sites.

3.2.2 Flow Data

No single, continuous record of flow data exists for the Strawberry watershed. It was therefore necessary to use flow data from multiple sources in order to complete this analysis. Specifically, data were obtained from three sources; the United States Bureau of Reclamation, the United States EPA STORET database, and the Central Utah Water Conservancy District.

In 1984 the Bureau of Reclamation performed a flow study on the Strawberry Reservoir watershed, including all significant inflows to the reservoir. Flow measurements continued for several years after the report was published, providing a nearly complete record of data from 1980 to 1991. This record includes inflows from Strawberry River, Co-op Creek, Indian Creek, and others representing over 80% of the total inflow to Strawberry Reservoir.

Additionally, stream flows were estimated during each water quality sampling event. The methods used to estimate flow have varying degrees of accuracy and are considered to be approximations of actual stream flow. These estimates, recorded in the STORET database, are valuable because they are recorded every time water quality samples are taken.

The Central Utah Water Conservancy District (CUWCD) provided daily flow data for The Ladders, the Syar and Strawberry Tunnel outlets, and release water from the dam, from 1986 to 2003. CUWCD also provided the daily fluctuations in reservoir water surface elevation.

3.2.3 Fishery Data

The Utah Division of Wildlife Resources (UDWR) monitors fish populations and species dynamics in Strawberry Reservoir and the associated drainage area in order to track long and short-term trends and progress toward established goals. Fish population, stocking and spawning data from both reservoir and tributary studies from 1991 through 2003 were obtained from UDWR and Utah State University studies (contracted by UDWR) for this report as listed in Table 3-4.

Referenced studies include Baldwin *et al.*, 1997; Beauchamp and Beauchamp, 1995; Knight *et al.*, 1994; Orme *et al.*, 1995; Ruzycki *et al.*, 1996; UDNR-UDWR, 2004a; UDNR-UDWR, 2004b; and Wilson and Spateholts, 1998.

Relative population information and stocking inventories are available for the Bear Lake strain of Bonneville cutthroat trout (*Oncorhynchus clarki utah*), kokanee salmon (*Oncorhynchus nerka*), and sterilized rainbow trout (*Oncorhynchus mykiss*) from 1991 through 2003. Additional age structure information (relative population of different age classes) is available for the Bear Lake strain of Bonneville cutthroat trout from 1993 through 2003; as are age class survival assessments from 1996 through 2003. Piscivorous (diet) information is also available for this species from 1991 through 2003.

Comparative spawning success data are available for the Bear Lake strain of Bonneville cutthroat trout and kokanee salmon for three tributaries (Indian Creek, Trout Creek and Strawberry River) to Strawberry Reservoir from 1994, 1995 and 1997.

Relative population information is available for the Utah chub (*Gila atraria*), Utah sucker (*Catostomus ardens*) and redside shiners (*Richardsonius balteatus*) from 1991 through 2003.

Table 3-4: Fishery Data Available for Strawberry Reservoir and Tributary Streams

Year	Bear River Cutthroat Trout	Kokanee Salmon	Rainbow Trout	Non-game Fish	Tributary Information	Reservoir Information	Study Author/source
1990	Stocking inventory	Stocking inventory	Stocking inventory				UDNR-UDWR, 2004b
1991	Population inventory Stocking inventory	Population inventory Stocking inventory	Population inventory Stocking inventory	Population inventory		Available	Wilson and Spateholts, 1998 UDNR-UDWR, 2004b
1992	Population inventory Stocking inventory Age structure	Population inventory Stocking inventory	Population inventory Stocking inventory	Population inventory		Available	Wilson and Spateholts, 1998 UDNR-UDWR, 2004b
1993	Population inventory Stocking inventory Age structure	Population inventory Stocking inventory	Population inventory Stocking inventory	Population inventory	Available	Available	Wilson and Spateholts, 1998 UDNR-UDWR, 2004b
1994	Population inventory Stocking inventory Age structure Spawning success	Population inventory Stocking inventory Spawning success	Population inventory Stocking inventory	Population inventory	Available	Available	Baldwin *et al.*, 1997 Beauchamp and Beauchamp, 1995 Ruzycki *et al.*, 1996 Knight *et al.*, 1994 Wilson and Spateholts, 1998 UDNR-UDWR, 2004b
1995	Population inventory Stocking inventory Age structure Survival (age class) Spawning success	Population inventory Stocking inventory Spawning success	Population inventory Stocking inventory	Population inventory	Available	Available	Baldwin *et al.*, 1997 Beauchamp and Beauchamp, 1995 Ruzycki *et al.*, 1996 Orme *et al.*, 1995 Wilson and Spateholts, 1998 UDNR-UDWR, 2004b
1996	Population inventory Stocking inventory Age structure Survival (age class)	Population inventory Stocking inventory	Population inventory Stocking inventory	Population inventory	Available	Available	Ruzycki *et al.*, 1996 Baldwin *et al.*, 1997 Wilson and Spateholts, 1998 UDNR-UDWR, 2004b
1997	Population inventory Stocking inventory Age structure Survival (age class) Spawning success	Population inventory Stocking inventory Spawning success	Population inventory Stocking inventory	Population inventory	Available	Available	Baldwin *et al.*, 1997 Baldwin, C.M., 1998 Wilson and Spateholts, 1998 UDNR-UDWR, 2004b
1998	Population inventory Stocking inventory Age structure Survival (age class)	Population inventory Stocking inventory	Population inventory Stocking inventory	Population inventory	Available	Available	UDNR-UDWR, 2004b

Year	Bear River Cutthroat Trout	Kokanee Salmon	Rainbow Trout	Non-game Fish	Tributary Information	Reservoir Information	Study Author/source
1999	Population inventory Stocking inventory Age structure Survival (age class)	Population inventory Stocking inventory	Population inventory Stocking inventory	Population inventory	Available	Available	UDNR-UDWR, 2004b
2000	Population inventory Stocking inventory Age structure Survival (age class)	Population inventory Stocking inventory	Population inventory Stocking inventory	Population inventory	Available	Available	Wilson and Ward, 2003 UDNR-UDWR, 2004b
2001	Population inventory Stocking inventory Age structure Diet information Survival (age class)	Population inventory Stocking inventory	Population inventory Stocking inventory	Population inventory	Available	Available	Wilson and Ward, 2003 UDNR-UDWR, 2004b
2002	Population inventory Stocking inventory Age structure Diet information Survival (age class)	Population inventory Stocking inventory	Population inventory Stocking inventory	Population inventory	Available	Available	Wilson and Ward, 2003 UDNR-UDWR, 2004b
2003	Population inventory Stocking inventory Age structure Diet information Survival (age class)	Population inventory Stocking inventory	Population inventory Stocking inventory	Population inventory	Available	Available	Wilson and Ward, 2003 UDNR-UDWR, 2004a UDNR-UDWR, 2004b

3.3 Methods

3.3.1 Data Validation Methods

Treatment of Non-Detect Values

When the concentration of a given constituent in a water sample is below the laboratory's ability to measure it, an assumption must be made to assign a numerical value. After consulting with DWQ, the assumption was made to represent all non-detect samples as half of the detection limit. For example, the detection limit for ammonia, as reported by DWQ, is 0.05 mg/L. The numerical value substituted for non-detect ammonia samples is half the detection limit or 0.025 mg/L.

The detection limit for total and dissolved phosphorus is given as 0.01 mg/L prior to 2000 and 0.02 mg/L afterwards. At the request of the Division of Water Quality, we have used 0.02 mg/L as the detection limit for total and dissolved total phosphorus for the entire dataset. Half of this value, or 0.01 mg/L was used, therefore, to represent non-detect samples for phosphorus.

Identification of Outliers

The data obtained for this project were analyzed in order to determine the approximate statistical parameters of the water quality measurements. For stream data, the average value and standard deviation for each constituent were calculated for each station. For reservoir data, the average value and standard deviation for each constituent were calculated for each station at the surface, at mid-depth, and at the bottom. Individual data points with values greater than three standard deviations from its respective mean value were removed from the dataset and classified as outliers. A total of 159 data points (1% of the total number of points) exceeded this criteria and, consequently, were removed from further analysis (presented in Appendix C).

3.3.2 Methods for Assessing Reservoir Impairments

Water Column Analysis

The Division of Water Quality has developed a procedure to determine whether a reservoir is supporting its beneficial use designation that takes into account water quality measurements at locations within the reservoir. Water temperature, dissolved oxygen, and pH are considered to determine how much of the water column (from the surface down to the bottom of the reservoir) is supporting the beneficial use designation. The number of samples per year which support and those which do not support the beneficial use are also considered to determine the support status of a water body.

Morphoedaphic Index (MEI)

The morphoedaphic index (MEI) is an empirical relationship that has been applied widely to predict lake and reservoir productivity (e.g., Oglesby 1982, Ryder 1982, Jenkins 1982). It has been used by aquatic resource managers to assess the biological productive potential of lakes and reservoirs. It is defined as the ratio of the total dissolved solids concentration in mg/L to the mean depth of the lake or reservoir in meters. Larger numerical values of this index are related to higher productivity on the presumption that higher dissolved solids correlate with higher nutrient levels and a smaller depth relates to a larger capacity to process energy and materials. The index correlates well with fish productivity, however the correlation with phytoplankton production is weak.

Water Quality Criteria Based Determination

The State of Utah water quality standards specific to the support of the cold water game fishery requires dissolved oxygen concentrations of no less than 6.5 mg/L as a 30-day average; no less than 9.5 mg/L for early life stages and no less than 5.0 mg/L for all life stages as a 7-day average; and no less than 8.0 mg/L for early life stages and no less than 4.0 mg/L for all life stages as a 1-day average (RS317-2-14, Table 2.14.2).

As fish and most other aquatic life species are mobile and can relocate to areas of suitable habitat in the event of a localized criteria exceedance, the State has further defined the support status of game fish populations relative to the percentage of the total water column experiencing depressed dissolved oxygen concentrations. Where less than 25 percent of the water column depth exhibits dissolved oxygen concentrations of 4.0 mg/L or greater, a non-support status has been defined; where 25 to 50 percent of the water column depth exhibits dissolved oxygen concentrations of 4.0 mg/L or greater, a partial-support status has been defined, and where greater than 50 percent of the water column depth exhibits dissolved oxygen concentrations of 4.0 mg/L or greater, a full-support status has been defined (Table 3-5).

Table 3-5: Beneficial Use Support Status Definition

% of the water column meeting the dissolved oxygen criteria	Minimum dissolved oxygen concentration	Support status
25% or less	4.0 mg/L	Non-Support
25% to 50%	4.0 mg/L	Partial Support
50% or greater	4.0 mg/L	Full Support

In addition, water quality standards specific to the support of cold water game fisheries requires water temperatures of no greater than 20 ^{o}C (RS317-2-14, Table 2.14.2).

The body of data available for this assessment from the US EPA STORET database included primarily grab-sample dissolved oxygen and temperature data collected at monthly or lesser frequency (rather than continuous or daily monitoring) in 1997 and 1999 through 2003. Therefore, construction of accurate, representative 30-day or 7-day averages was not possible. The identified criteria of no less than 4.0 mg/L dissolved oxygen as a 1-day average was selected as the best fit for evaluation of the available data, and the assumption was made that grab sample concentrations were representative of daily average dissolved oxygen concentrations. As the majority of data were collected between late morning and early afternoon time periods, this assumption is somewhat conservative in nature as maximum dissolved oxygen depletion due to photosynthetic processes commonly occurs in the early morning hours and is not well characterized by the sampling process. However, this assessment does result in a broad analysis of the areas where dissolved oxygen and temperature exceedances result in a concern for cold water game fish support.

Correlations of Water Quality Conditions to Fish Populations

A comparison of exceedances of water quality criteria and the available fish population data was completed to characterize the extent to which water quality criteria violations and non-supporting and partially supporting conditions (as based on percent of water column in violation of the numeric standards) may be influencing cold water game fish populations.

3.3.3 Methods for Hydrologic Analysis

Since the calculation for pollutant loadings into the reservoir is heavily influenced by stream flows, it is extremely important that the water budget be accurate so that the resulting loads are reasonable. Flow monitoring within the Strawberry watershed has been relatively infrequent given the size, usage, and importance of the reservoir. This lack of data posed a significant challenge.

Attempts to determine mean monthly flows for Strawberry's significant inflows were unsuccessful due to extremely limited data. The primary source of flow data for the inflows was the flow estimate recorded in the STORET database.

The best source of flow data for the inflows to the reservoir was a study that the US Bureau of Reclamation (USBR) conducted from 1982 to 1991. While data from this time period was outside of the time period of this study (1990-2003), it was the only time in recent history when the significant inflows have been continuously monitored. Records from this study provided daily flow values for the Strawberry River, Co-op Creek and Indian Creek

As expected, peak flows in the tributaries to the reservoir occur during the Spring runoff period (typically April and May). The flows from these stations were successfully correlated with precipitation data from the same period to determine a relationship between inflow volume and precipitation. Due to insufficient weather data within the Strawberry Reservoir watershed, the precipitation data from the Heber City weather station was used which is located outside of the watershed. However, the Heber station is similar in terms of total precipitation received and other topographic and climatological parameters. The correlation developed here serves as the basis for our estimate of the natural inflows into the reservoir under hydrologically "Normal" conditions. The flows in The Ladders and in the outflows from the reservoir were measured directly by CUWCD and did not need to be estimated.

3.3.4 Methods for Endpoint / Target Analysis

Carlson's Trophic State Index

The Trophic State Index (TSI) is determined by considering three factors: Secchi depth, Chlorophyll *a* concentration, and total phosphorus concentration. Carlson (1977) developed separate equations for each of these factors. If all of these data are available, three values are obtained for the TSI. Values above 50 denote a eutrophic system. Values below 40 indicate an oligotrophic system, and values between 40 and 50 denote a mesotrophic system. When a significant discrepancy exists between the three values obtained, judgment is required to determine which of the above-mentioned results is most reliable and applicable to the reservoir being considered.

Vollenweider Loading Plots

Vollenweider developed a method based on empirical data to determine the health of a reservoir. His method results in a plot that delineates zones for oligotrophic, mesotrophic, and eutrophic systems. These plots are based on the total phosphorus concentration, hydraulic residence time, and mean reservoir depth. Two key observations form the basis for the way the data is plotted. First, Vollenweider observed that deeper lakes are less likely to be eutrophic. Second, he observed that lakes with a shorter hydraulic residence time were also less likely to be eutrophic. For incompletely mixed systems lakes can be divided into a system of interconnected well-mixed systems. This can be done horizontally or vertically. For example, Chapra (1979) used two mass balance calculations to characterize a lake with a major embayment. In a similar manner, O. Melia (1972) and others have vertically divided the water column of thermally stratified lakes into surface and bottom layers. Since Strawberry reservoir exhibits variable water quality conditions for different areas of the reservoir it was broken into three (3) distinct systems as shown in Figure 3-18.

Reservoir Phosphorus Budget

A phosphorus mass balance was performed to determine the amount of phosphorus deposited in or exported from Strawberry Reservoir since the inputs and outputs have been monitored as well as in-lake concentrations. The mass balance equation shown below was used for this analysis.

Eq 3-1

$$V\,dp/dt = W - Qp - k_s V p$$

Eq 3-2

$$p = W/(Q+k_s V)$$

p = Reservoir Total Phosphorus concentration (mg/m^3)
W = Total Phosphorus Load Input (mg/yr)
Q = Flow (m^3/yr) (average = 360 cfs or $3.2x10^8$ m^3/yr)
V = Reservoir Volume (m^3) (average = $1.59x10^8$ m^3)
k_s = 1^{st} order settling constant (yr^{-1})

3.4 Water Quality Standards & Criteria

The Utah Department of Environmental Quality (DEQ) establishes water quality standards for Utah streams and reservoirs. Designated beneficial uses determine the applicable water quality criteria. The classifications of Strawberry Reservoir per Utah Administrative Code R317-2 Standards of Quality for Waters of the State are in Table 3-6.

Table 3-6: Strawberry Reservoir Beneficial Use Designations

Beneficial Use Designation	Description
1C	Protected for domestic purposes with prior treatment processes as required by Utah Department of Health.
2B	Protected for secondary contact recreation such as boating, wading and similar uses.
3A	Protected for cold water species of game fish and other cold water aquatic life, including the necessary aquatic organisms in the food chain.
4	Protected for agricultural uses including stock watering and irrigation of crops.

In addition to these classifications the Strawberry River is considered "High Quality" by the state of Utah. This designation prohibits new point source discharges and requires that existing water quality be maintained. The anti-degradation policy is also applicable to the streams and water bodies in the Strawberry Reservoir watershed area.

Water quality standards for the designated beneficial uses previously mentioned for total phosphorus, dissolved oxygen, and temperature are presented in Table 3-7.

Table 3-7: Water Quality Standards and Indicator Values

Constituent	Class 1C	Class 2B	Class 3A	Class 4
Total Phosphorus (mg/L)**	-	0.05 for Streams* 0.025 for Lakes*	0.05 for Streams* 0.025 for Lakes*	-
Dissolved Oxygen (mg/L)**	-	-	6.5	-
Water Temperature (Deg. C)	-	-	20	-

*Pollution Indicator Value **Key Impairment Parameters

3.5 Reservoir Impairment Assessment

3.5.1 Impairment Assessment Overview

The State of Utah has determined that Strawberry Reservoir is not supporting its Cold-Water Fishery (3A) beneficial use designation. For the 303(d) listing the State of Utah conducts a cursory analysis to determine whether a body of water supports its beneficial uses or not. The State of Utah relies upon the TMDL process to conduct a detailed analysis to determine if the water body is actually impaired.

The 303(d) listed impairment to the cold water fishery in Strawberry Reservoir is based solely on the reservoir data compared to State standards. To determine whether Strawberry Reservoir is supporting its beneficial uses various analyses were completed. These are described and summarized below. Details of each analysis are included on the following pages.

Determining the limiting nutrient of the reservoir - The overall median available Nitrogen to Phosphorus ratio was 3 which indicated that the reservoir is nitrogen limited. However, nutrient limitation may switch seasonally due to temperature dependent differences in nutrient recycling. In addition, blue green algae fix nitrogen from the atmosphere so that phosphorus control is needed for reductions of this nuisance species.

Assessing the amount of dissolved oxygen in the water column - In the deep waters of Strawberry Reservoir near the dam embankment, approximately 76 percent of the water column typically has DO concentrations less than 4.0 mg/l during the month of September. Using the State of Utah's criteria, impairment to the reservoir fishery exists because more than 50% of the column is below 4.0 mg/l during at least part of the year.

Calculating the Morphoedaphic Index for the reservoir to determine fishery production potential - The calculated MEI falls between 5 and 6.5. This places the reservoir in the third quartile of 253 reservoirs assessed by the Army Corps of Engineers (USACE 1995). This indicates that, according to the MEI, Strawberry has above average fishery production potential.

Identifying the available fisheries habitat based on water quality criteria – Evaluation of the available data for Strawberry Reservoir indicate that while some parts of the reservoir are non-supporting or partially supporting at certain times during the year, the cold water game fish population is not impaired due to water quality exceedances.

Analyzing the fish population and sustainability status as based on Utah Division of Wildlife Resources (UDWR) surveys - From 1996 through 2003 game fish population trends show increasing population and age class robustness. Gill net surveys show an increasing catch-rate for cutthroat and a stable or decreasing catch-rate for rainbows, not the overall decreasing trend that would be expected from impairment.

Correlating water quality conditions to fish populations - No apparent correlation could be identified between water quality exceedances and fish population trends in Strawberry Reservoir. A possible explanation for the lack of correlation between water quality and fish population trends may be that while water quality conditions are not ideal in some sections of the reservoir such conditions do not occur for a sufficient length of time and over a large enough area to be fatal to the local game fish populations.

Overall it has been concluded by these analyses that support and growth of the cold water game fishery is due in part to stocking and fishery management by UDWR. Additional support for the fishery may be explained by the fact that conditions within the reservoir are not completely non-supporting or partially supporting at any one time. Additionally, during recent years no fish kills have been reported in the reservoir indicating adequate habitat is available.

3.5.2 Limiting Nutrient

Liebig formulated the so-called "law of the minimum" in the 1800s, which states that only one factor limits the growth of a population at any particular time, although the identity of that factor can shift over time and space. Nitrogen availability sometimes limits primary production. In other places, however, phosphorus is the limiting nutrient, particularly in freshwater ecosystems, in which case controlling phosphorus inputs is an appropriate management goal.

Strawberry Reservoir has been characterized by the State of Utah (Judd, 1997) as being nitrogen limited with respect to algae growth. This means that the available nitrogen concentrations in the surface waters of the reservoir are small relative to the total phosphorus concentrations with respect to phytoplankton demand. Nitrogen limitation favors the dominance of blue-green algae (cyanobacteria) since those organisms are able to draw and fix nitrogen from the atmosphere and surrounding water. Other types of algae do not possess this ability, and are dependent solely on the nutrients available in the surrounding water. Hence, in nitrogen limited systems, once other available forms of nitrogen are no longer available, blue-green algae dominate since they can survive in this condition when other species of algae cannot.

Balanced growth, in which there are approximately consistent concentrations of available nitrogen and phosphorus for algae, exists when the available Nitrogen to Phosphorus ratio is about 7. The water quality database was examined to determine this ratio annually from 1990 through 2003 and overall for the in-reservoir water quality stations. The data were matched according to date/time and station, and the available N (ammonia + nitrite + nitrate) was divided by total phosphorus to yield the Nitrogen to Phosphorus ratio (Figure 3-2). A time series and box-whisker plot of the ratio are shown in Figure 3-3. The overall median available Nitrogen to Phosphorus ratio for all stations combined was 3 (1.5 – 4.38, 25th - 75th percentiles) supporting the UDEQ assessment that the reservoir is nitrogen limited. Even though, on average Strawberry Reservoir is considered to be nitrogen limited, long-term shifts and seasonal variations in conditions within the watershed may result in the system being phosphorus limited at times.

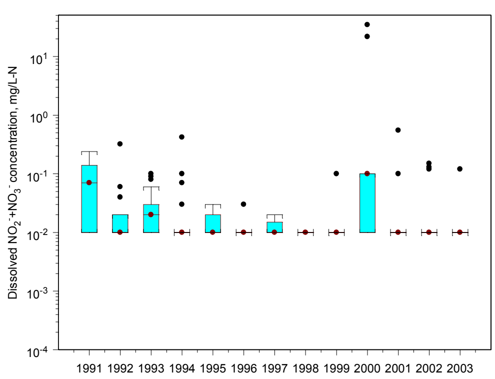


Figure 3-2: Box plots of ammonia and dissolved NO2- + NO3--N, Strawberry Reservoir - all sampling sites near water surface

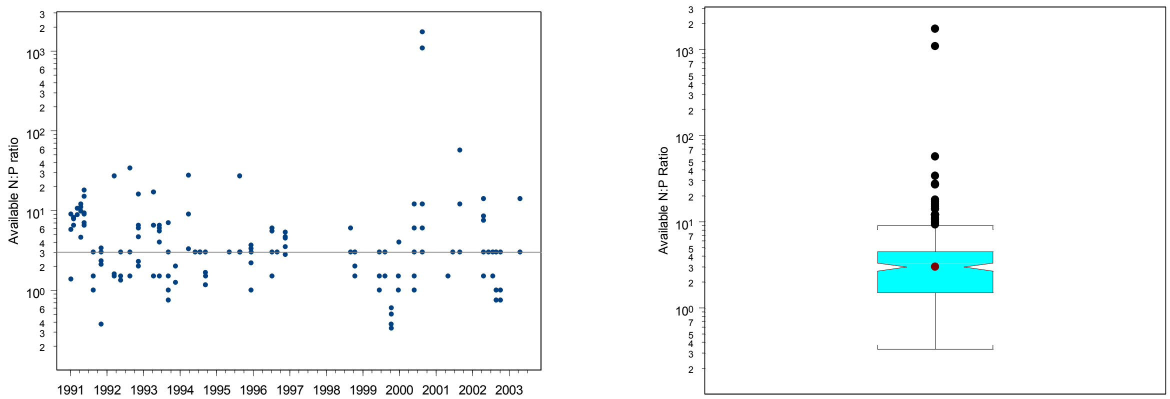


Figure 3-3: Time series and box plot of available Nitrogen to Phosphorus ratio, Strawberry Reservoir, all stations, surface samples, 1990-2003 - matched data

3.5.3 Dissolved Oxygen in Water Column

Concentrations of dissolved oxygen in the reservoir are directly related to the stratification cycle. As the reservoir becomes stratified and mixing between layers ceases, dissolved oxygen concentrations are depleted due to natural biological and chemical processes. Eventually, in the deeper portions of the reservoir, oxygen levels may become completely depleted, or anoxic. At this point only anaerobic chemical and biological processes continue. Changes in water chemistry and redox potential, resulting from anoxic conditions, may release phosphorus from lake sediments. In the deep waters of Strawberry Reservoir near the dam embankment, approximately 76% of the water column has had DO concentrations less than 4.0 mg/l (threshold value used by the State to assess beneficial use support) during the month of September. The State has determined impairment to the reservoir fishery exists because more than 50% of the column is below 4.0 mg/l during at least part of the year.

Figure 3-4 shows the average monthly percent of the water column measured to be below 4 mg/L and the corresponding depth in meters. These averages are based on the profile data obtained from DWQ. Data are only available for the months of May through October. High dissolved oxygen concentrations in the spring are followed by more depleted conditions from July to August before improving once again late in the fall due to turnover. Temperature and dissolved oxygen profiles for June through August 2002 at each reservoir sampling stations are presented in Appendix B.

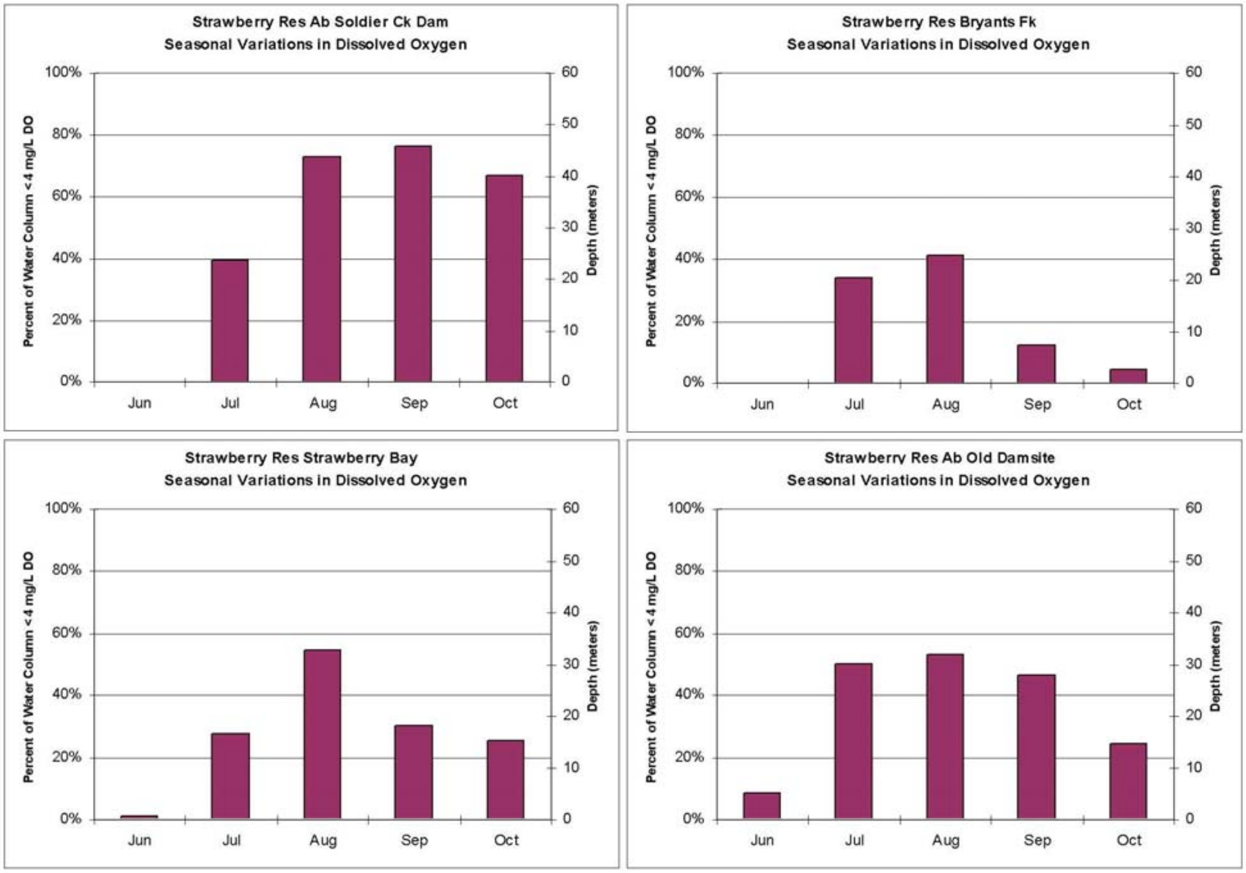
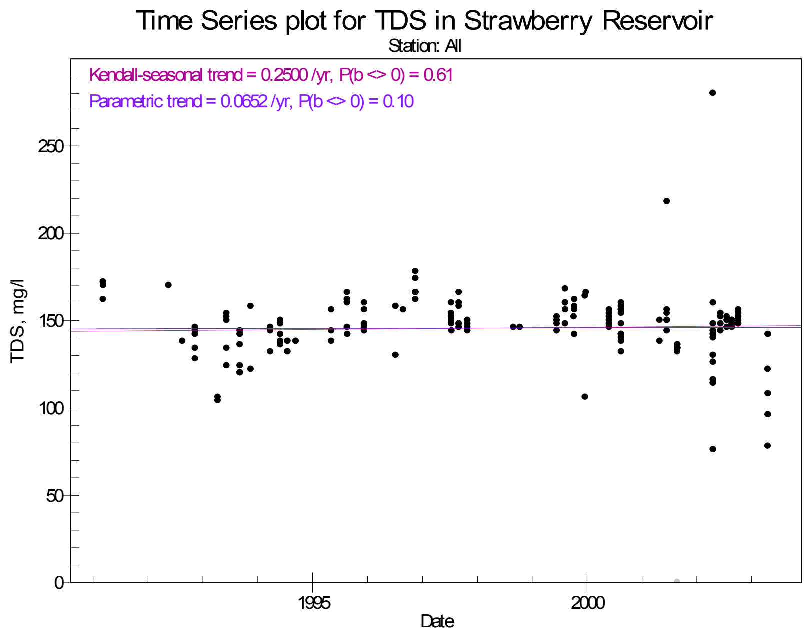


Figure 3-4: Average Monthly Percent of Water Column below 4 mg/L DO

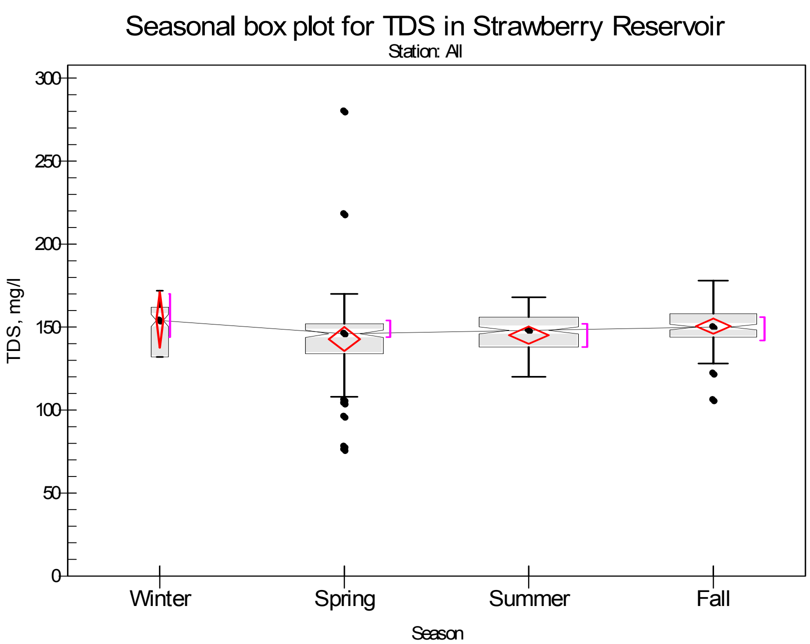
3.5.4 Morphoedaphic Index (MEI)

The terms in the MEI are variable in most systems, including Strawberry Reservoir. Dissolved solids concentrations vary with time. The values range from 100 to 180 and are season and site specific as shown in Figure 3-5(a). A box plot showing the seasonal variation in TDS is shown in Figure 3-5(b). We see that, overall, TDS appears to be somewhat higher in the winter, lower in the spring, and intermediate in the summer and fall, however these differences are not statistically significant.

Additionally, there is no significant long term trend in the overall TDS concentration (Figure 3-5(a)). The significance of this lack of a trend was determined by calculating the confidence interval for the slope for a parametric trend (least squares) and a non-parametric trend corrected for seasonality (Seasonal Kendall Slope, Gilbert (1987). The raw results are shown in Appendix A, and summarized in Table 3-8. The trends are consistently non-significant except at Station 693643 (Figure 3-1, near the north end of the reservoir), for which a slight trend is seen.



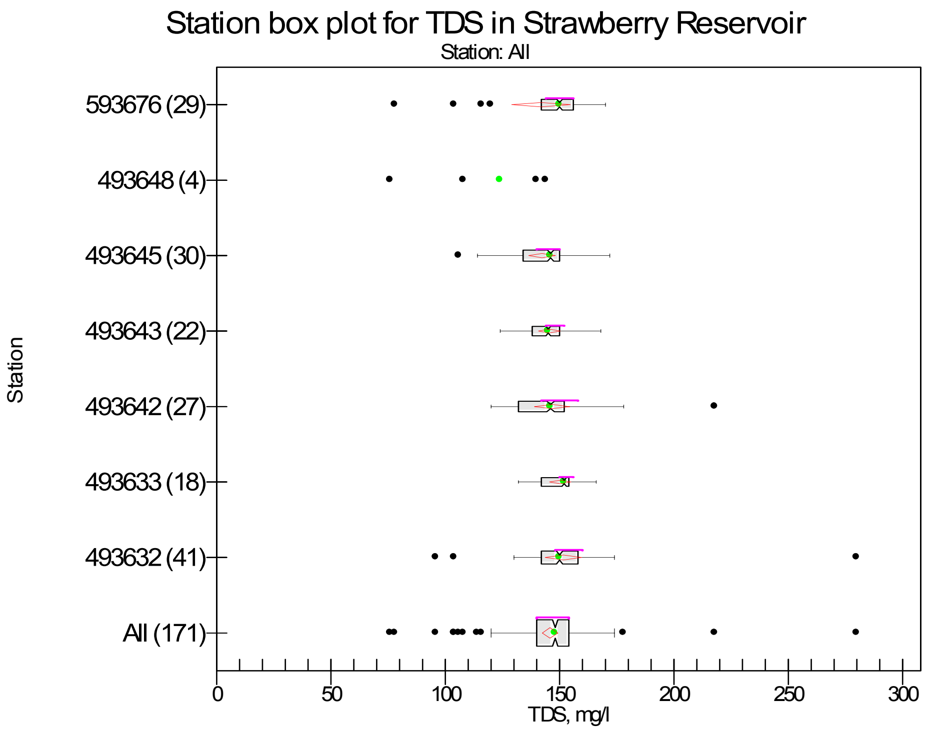
(a)

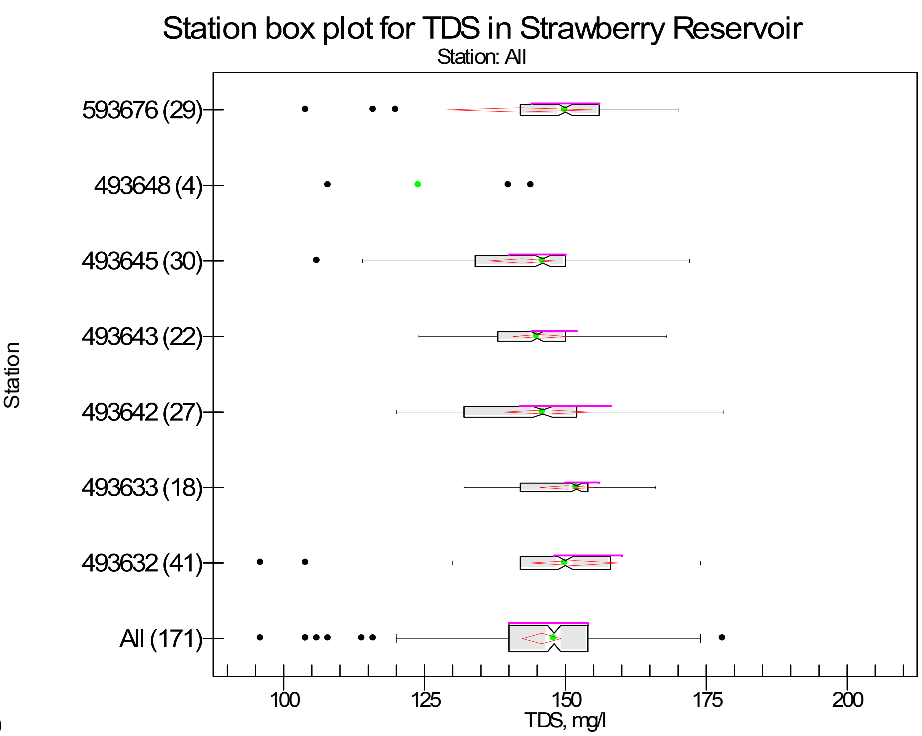


(b)

Figure 3-5 Time series (a) and Seasonal box plot (b) of TDS data in Strawberry Reservoir (diamonds = 95%CI on mean, bracket=most compact 50% of data) – all stations (significant with 96% confidence).

Also, the differences between stations does not appear to be important as shown in Figure 3-6.





(b)

Figure 3-6 Comparison of TDS data by Station for Strawberry Reservoir, 1991-2003, (a) is all data, (b) is same data on expanded horizontal scale (values in parentheses are the numbers of observations at each station)

Since there is no long term trend, only the seasonal variations would potentially cause the MEI to vary, and that would be due primarily to lake level fluctuations. The average lake elevation data for the period from 1999 – 2003 were used to calculate mean depths and varied over a range of 3-5 ft. The mean depths required by the MEI index were determined to be 25.1 ± 0.26 m (mean plus or minus 1 standard deviation). Thus, the mean depth over this four year period was 25 m.

Table 3-8: Trend analysis for total dissolved solids in Strawberry Reservoir, 1990-2003, all stations and using reservoir average depth in MEI calculation

All Stations, TDS, 1991 - 2003, Depth code: All, nObs = 171, Slope in mg/L-yr

Source	# Obs	Slope mg/L-yr	95% Confidence Interval	P(b <> 0)
Parametric (LS) trend	171	0.065	-0.929 < b < 1.060	P(b<>0) = 10.4
Kendall seasonal trend	171	0.250	-0.400 < b < 0.857	P(b<>0) = 60.9
Winter	6	8.667	0.000 < b < 0.000	
Spring	61	0.000	1.370 < b < 0.750	
Summer	66	0.472	-0.667 < b < 1.400	
Fall	38	1.000	0.000 < b < 2.200	

From the data shown in Figure 3-5, the TDS is 146 ± 11 ≈ 150 (mean plus or minus 1 standard deviation). Using a first order error analysis (assuming no correlation between mean depth and TDS, Berthouex and Brown 2002) the MEI = 5.82 ± 0.44 (mean plus or minus 1 standard deviation), or with 95% certainty, the MEI falls within about 5 and 6.5. Additional MEI analysis, by station, can be found in Appendix A.

In 1995 the US Army Corps of Engineers published a study where fishery production of 253 reservoirs were ranked and categorized. The MEI values for these reservoirs were also categorized. Their results are shown in Table 3-9 and Table 3-10.

Table 3-9: Standing Crop of Sportfish Categories (USACE 1995)

Category	Standing Crop of Sportfish
1	<51 pounds per acre
2	21 to 77 pounds per acre
3	78 to 116 pounds per acre
4	117 to 351 pounds

Table 3-10: MEI Value Categories (USACE 1995)

Category	MEI
1	0.20 to 1.85
2	1.86 to 3.49
3	3.50 to 8.90
4	8.91 to 33.92

Since the MEI values for Strawberry Reservoir lie between approximately 5.0 and 6.5, we concluded that the reservoir is in the third quartile of the MEI, when compared to 253 other reservoirs. We assume that the third quartile of MEI generally corresponds to the third quartile of Standing Crop, and conclude that Strawberry Reservoir has above average fishery production potential.

3.5.5 Fisheries Habitat and Water Quality Criteria – Based Determination

The identified impairment of the cold-water fishery on the 303(d) list is based solely on the reservoir data compared to numerical State standards. An investigation of the status of the fishery was conducted to determine the validity of the fishery impairment. The average water column data during the critical months of stratification (May - October) were analyzed at each of the reservoir STORET stations.

Preferred fish species inhabiting the Strawberry Reservoir watershed thrive in cool, clear, well-oxygenated water. Dissolved oxygen (DO) concentrations below 4.0 mg/L or water temperatures greater than 20 °C may adversely affect the fish habitat. By determining the DO and temperature the habitable fraction of a particular water column can be approximated on a seasonal basis. Figure 3-8 shows the average monthly water column conditions at selected reservoir sites. For each month, the water column composition is shown. The yellow portion of each column represents the percent of the water column that is potentially suitable habitat. The water column is divided into the following three zones:

- High Temperature Zone
- Anoxic Zone
- Ideal Fish Habitat Zone

Anoxic conditions were observed at all reservoir sites from July to October to different extents. During these months, concentrations of DO ranged from 80 % anoxic (July, Strawberry Reservoir Narrows) to 0 % anoxic (July, Strawberry Reservoir ¾ up Strawberry Bay).

In addition to anoxic conditions, which are a result of the depth of the reservoir and the effects of stratification, the low dissolved oxygen conditions near Soldier Creek dam are likely made worse by the chemical oxygen demand of sulfur springs in the area and incomplete mixing during spring and fall turnover. Figure 3-7 is a historical topographic map which shows conditions before the expansion of Strawberry Reservoir. The sulfurous "Stinking Springs" are located in the area that is currently inundated.

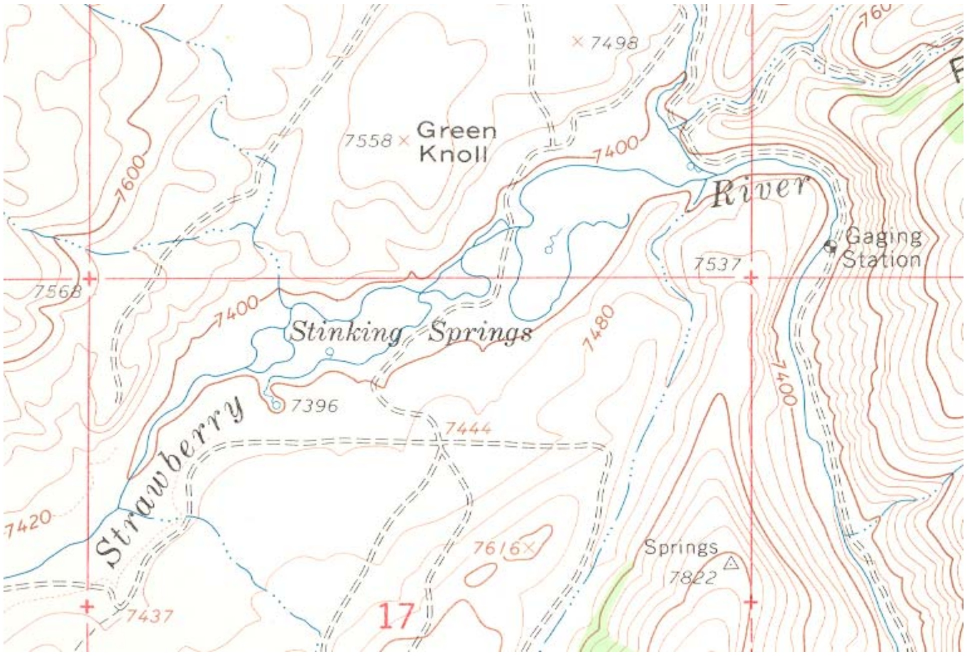


Figure 3-7: Historical Topographic Map Near Soldier Creek Dam Location

Temperature potentially impacts fish habitat during the month of July and occasionally in August, though to a lesser extent than DO. Site locations near the dam showed a greater tendency to be anoxic than sites further up the reservoir. This is due to the fact that locations near the dam are deeper than at any other part of the reservoir, which results in increased anoxia in the late summer months.

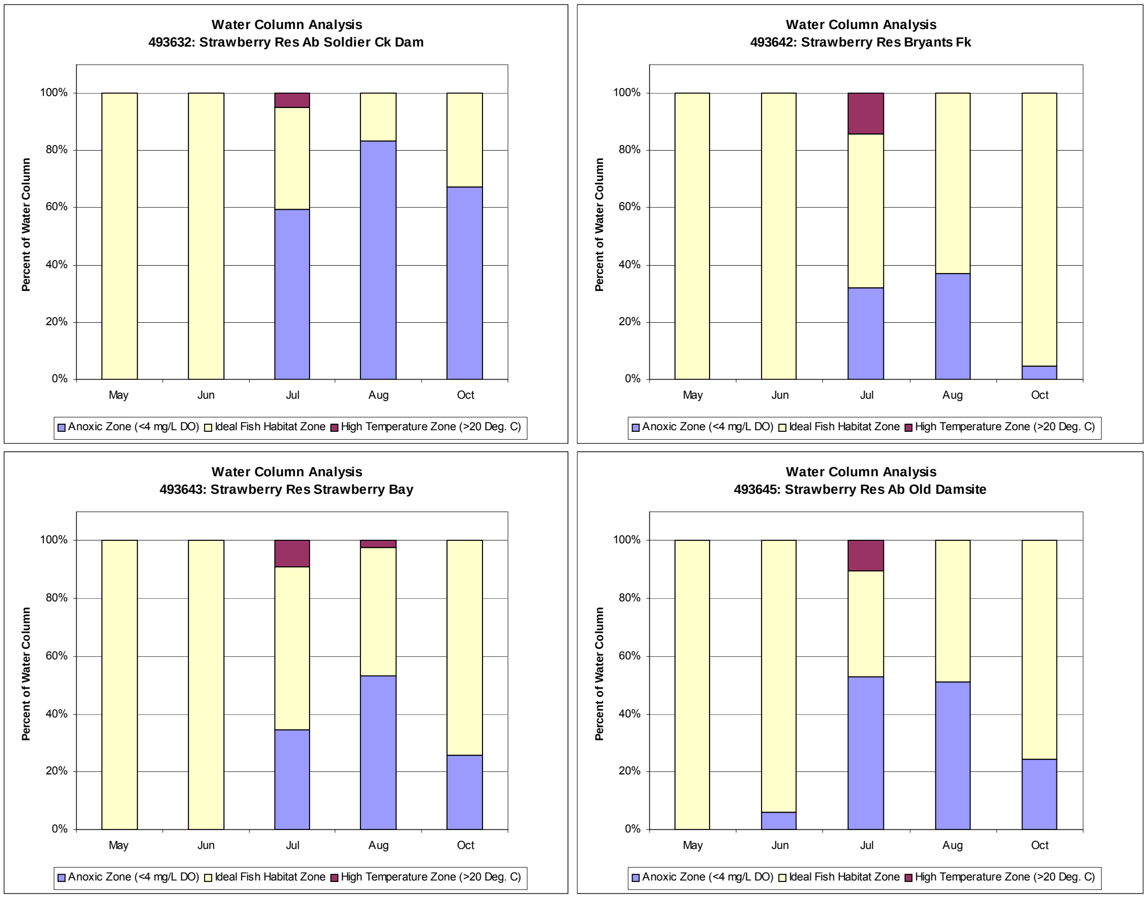


Figure 3-8: Available fish habitat as a function of temperature and DO.

Water column data collected from seven stations within the reservoir during the critical summer time period (May through September/October) were analyzed for Strawberry Reservoir above Soldier Creek Dam (site #493632), at the Narrows (site #493633), in Bryants Fork Bay (site #493642), in Strawberry Bay (site #493643), above the old dam site (site #493645), in Upper Strawberry Bay (site #493648) and in Indian Creek Bay (site #593676). The location of these sites is shown in Figure 3-1.

Dissolved oxygen and temperature exceedances, and viable fish habitat volume as a percentage of the total water column is presented in **Figure 3-9** through Figure 3-15. Data from 1997 and 1999 through 2003 is displayed in these figures together with the calculated average percentage of the water column experiencing criteria exceedances as based on the existing data set.

Exceedances of dissolved oxygen and temperature criteria were observed to occur only rarely and in a relatively small percentage of the water column within the reservoir during the early summer months of May and June, and the early fall (October), but were common throughout the reservoir in July and August.

Exceedances of the 4.0 mg/L DO criteria in greater than 50 percent of the water column volume (defined as partial support) occurred routinely in July and August at the monitoring sites in Strawberry Reservoir above Soldier Creek Dam (site #493632), at the Narrows (site #493633), in Strawberry Bay (site #493643), and above the old dam site (site #493645) as shown in **Figure 3-9** to Figure 3-15.

Exceedances of the 4.0 mg/L criteria in greater than 75 percent of the water column volume (defined as non-supporting) occurred routinely in August at the monitoring sites in Strawberry Reservoir above Soldier Creek Dam (site #493632) and at the Narrows (site #493633), as shown in **Figure 3-9** and Figure 3-10.

The magnitude and temporal extent of criteria exceedances show an increase in recent years (2002 and 2003). Temperature exceedances, rare in the limited data collected for 1997 and 1999 through 2001, occur almost routinely in 2002 and 2003. This may be an artifact of the more extensive data collection in later years, but is more likely a result of the extreme drought conditions occurring in Utah and the resulting lower stream flows, reservoir levels, and elevated air temperatures.

Support status determinations are presented in Table 3-11 based upon the available data set for each in-reservoir station (presented in **Figure 3-9** to Figure 3-15).

Two stations, Strawberry Reservoir at Bryant's Fork Bay (site #493642), and at Upper Strawberry Bay (site #493648), showed full support throughout the critical season (May through October).

All in-reservoir monitoring sites showed full support of the designated cold water game fishery (greater than 50% of the water column at dissolved oxygen concentrations greater than 4.0 mg/L) during the months of May and June.

Conditions resulting in partial support of the cold water game fishery (25% to 50% of the water column at dissolved oxygen concentrations of 4.0 mg/L or greater) were identified at five in-reservoir stations during the later part of the summer season. Strawberry Reservoir above Soldier Creek Dam (site # 493632), above the old dam site (site # 493645), and at Indian Creek Bay (site # 593676), showed partial support in July. The Strawberry Reservoir Narrows (site # 493633), and Strawberry Reservoir at Strawberry Bay (site # 493643), and above the old dam site (site # 493645), showed partial support in August. Strawberry Reservoir above the old dam site (site # 493632) also showed partial support in October.

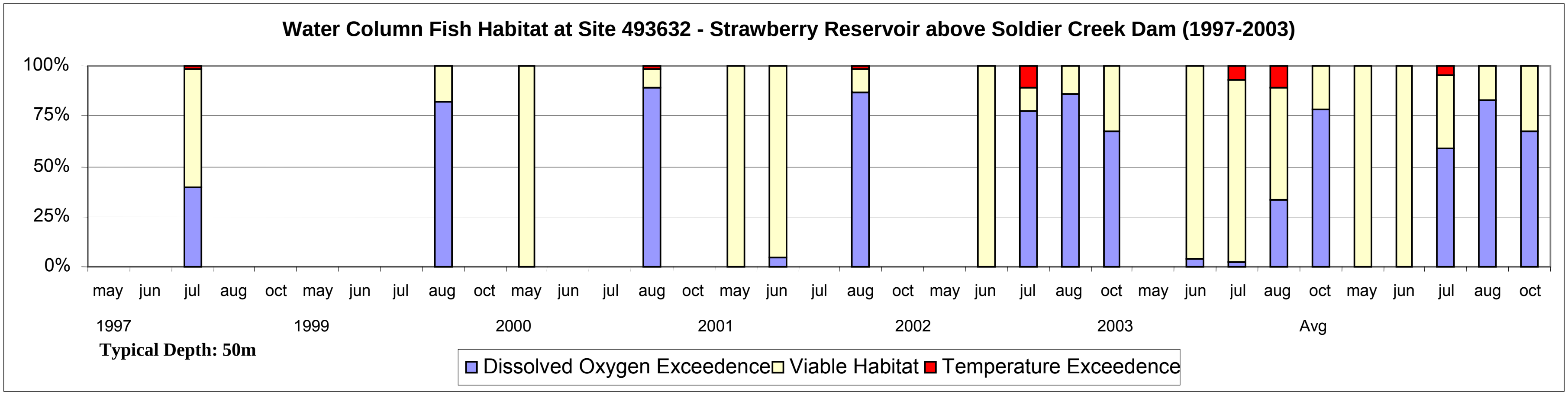


Figure 3-9: Available water column fish habitat and criteria exceedances for site # 493632, Strawberry Reservoir above Soldier Creek Dam for 1997, 1999 and 2000 through 2003.

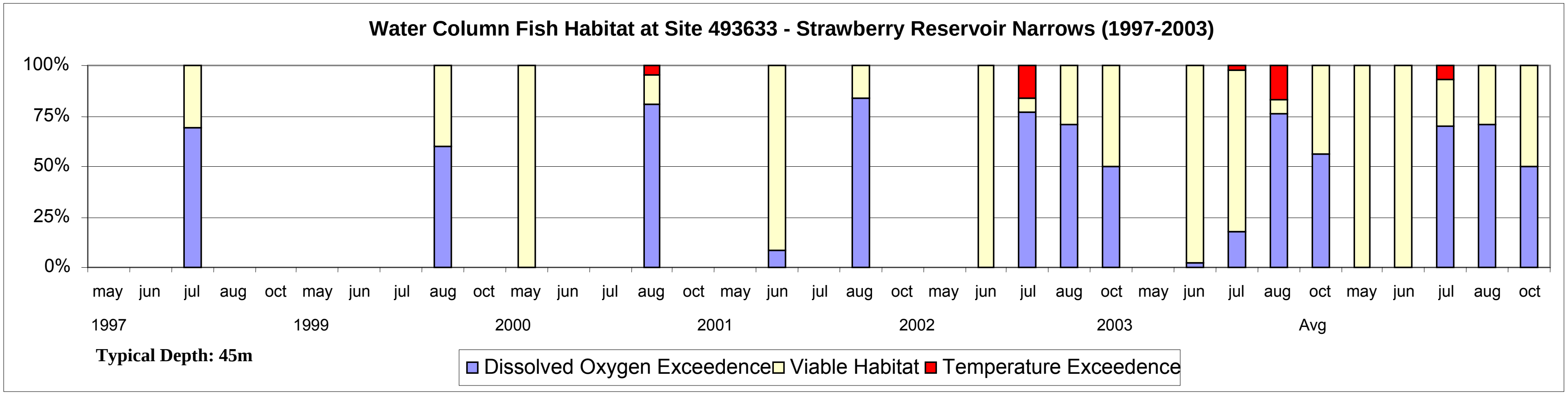


Figure 3-10: Available water column fish habitat and criteria exceedances for site # 493633, Strawberry Reservoir Narrows for 1997, 1999 and 2000 through 2003.

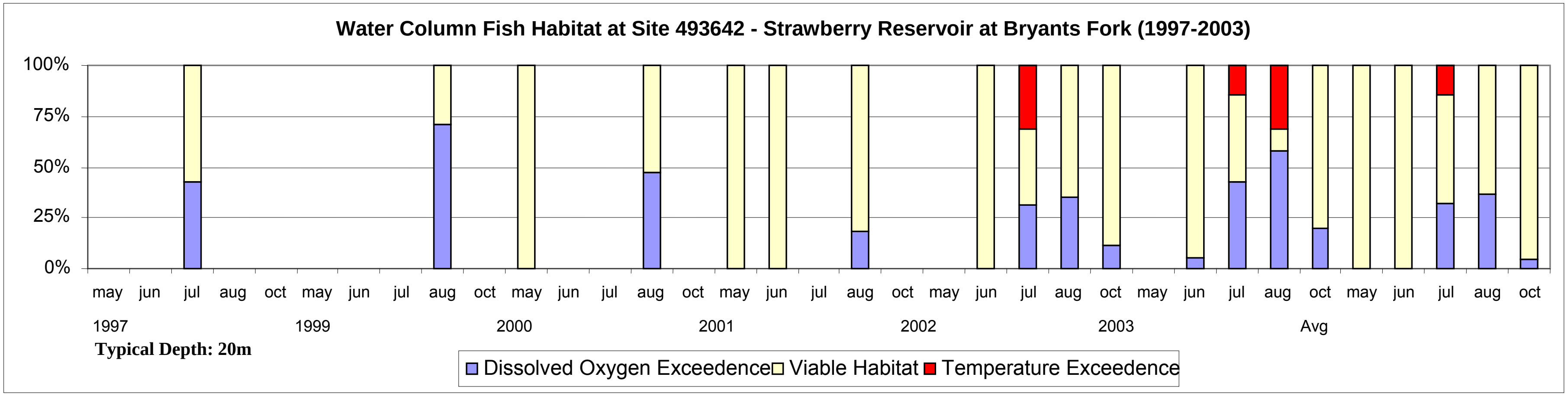


Figure 3-11: Available water column fish habitat and criteria exceedances for site # 493642, Strawberry Reservoir at Bryants Fork Bay for 1997, 1999 and 2000 through 2003.

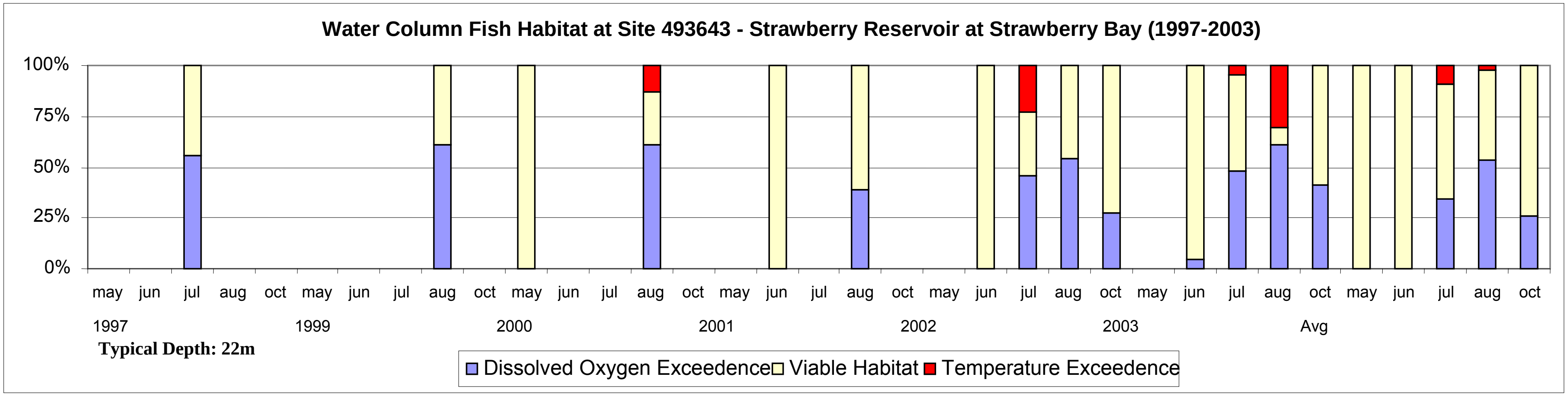


Figure 3-12: Available water column fish habitat and criteria exceedances for site # 493643, Strawberry Reservoir at Strawberry Bay for 1997, 1999 and 2000 through 2003.

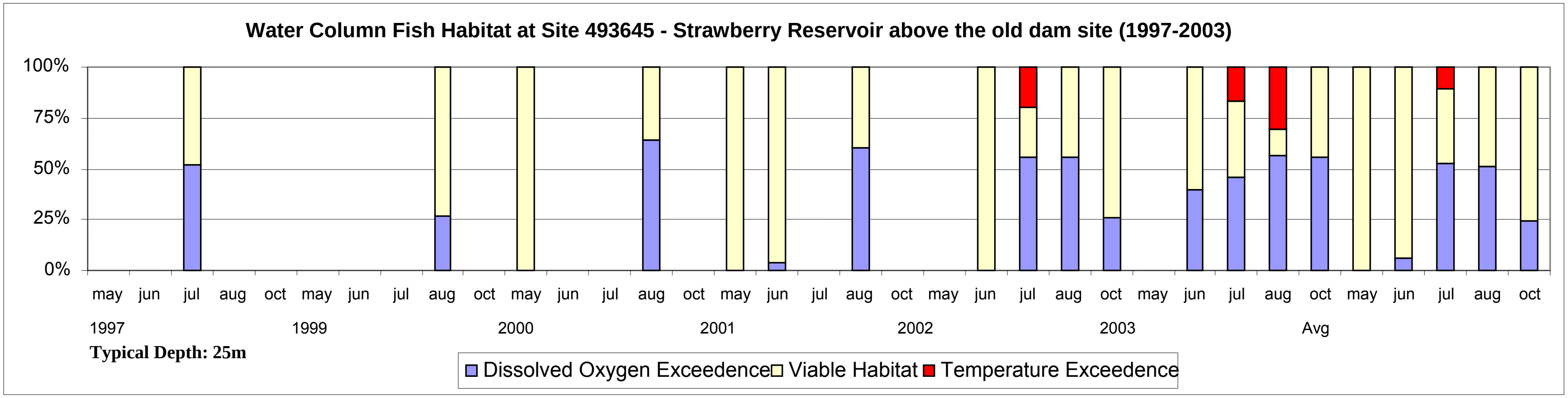


Figure 3-13: Available water column fish habitat and criteria exceedances for site # 493645, Strawberry Reservoir above the old dam site for 1997, 1999 and 2000 through 2003.

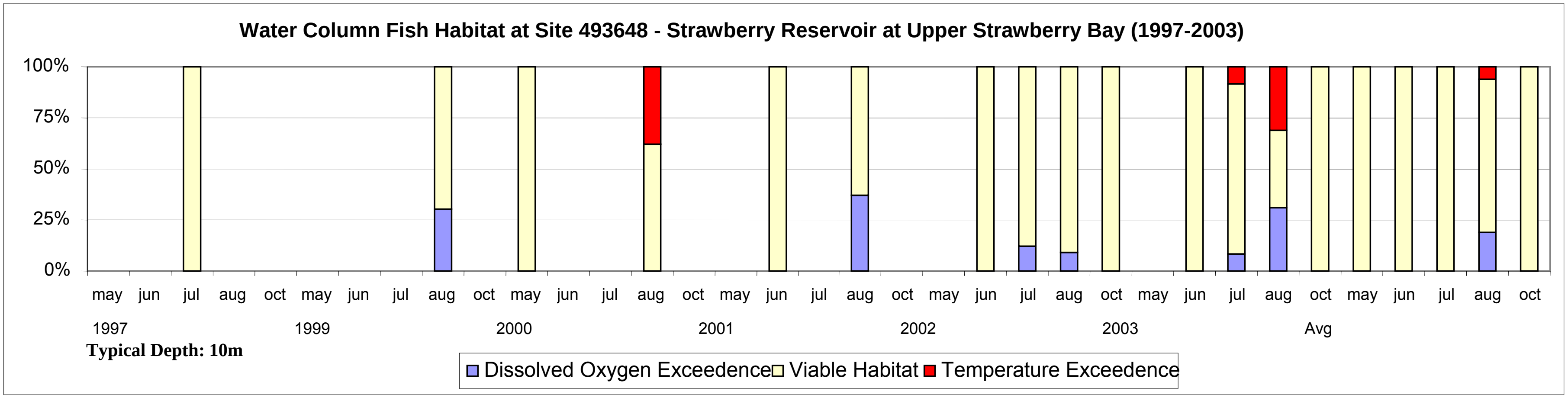


Figure 3-14: Available water column fish habitat and criteria exceedances for site # 493648, Strawberry Reservoir at Upper Strawberry Bay for 1997, 1999 and 2000 through 2003.

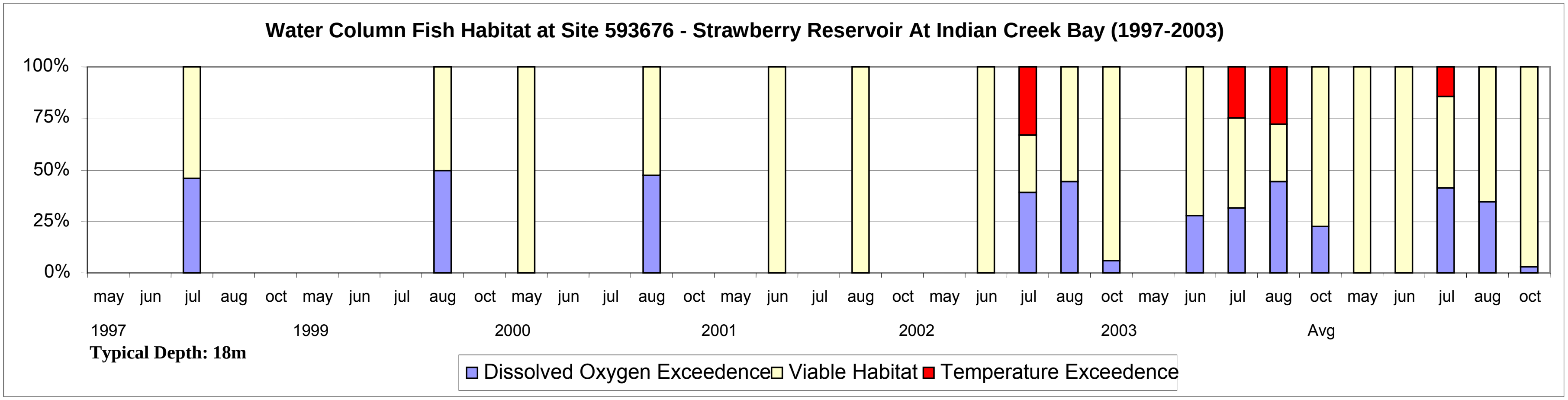


Figure 3-15: Available water column fish habitat and criteria exceedances for site # 593676, Strawberry Reservoir at Indian Creek Bay for 1997, 1999 and 2000 through 2003.

Table 3-11: Designated Beneficial Use Support Status for Cold Water Game Fish as Based on Water Column Dissolved Oxygen and Temperature Conditions

STORET	Month	Support Status	Responsible Parameter
Strawberry Reservoir above Soldier Creek Dam, Site #493632	May	Full	
	June	Full	
	July	**Partial**	DO, Temp
	August	**Non**	DO
	October	**Partial**	DO
Strawberry Reservoir Narrows, Site #493633	May	Full	
	June	Full	
	July	**Non**	DO, Temp
	August	**Partial**	DO
	October	Full	
Strawberry Reservoir at Bryants Fork Bay, Site #493642	May	Full	
	June	Full	
	July	Full	
	August	Full	
	October	Full	
Strawberry Reservoir at Strawberry Bay, Site #493643	May	Full	
	June	Full	
	July	Full	
	August	**Partial**	DO, Temp
	October	Full	
Strawberry Reservoir above the old dam site, Site #493645	May	Full	
	June	Full	
	July	**Partial**	DO, Temp
	August	**Partial**	DO
	October	Full	
Strawberry Reservoir at Upper Strawberry Bay, Site #493648	May	Full	
	June	Full	
	July	Full	
	August	Full	
	October	Full	

STORET	Month	Support Status	Responsible Parameter
Strawberry Reservoir at Indian Creek Bay, Site #593676	May	Full	
	June	Full	
	July	**Partial**	DO, Temp
	August	Full	
	October	Full	

Two stations frequently exhibit non-supporting conditions relative to dissolved oxygen during the critical summer months (493632 – Near Soldier Creek Dam & 493633 – At Narrows). Partial support is also encountered at other locations within the reservoir from time to time.

Although it indicates a measured water quality concern, a site-specific designation of non-support or partial support as based on numeric dissolved oxygen and temperature criteria is not necessarily an indication that the fishery as a whole is compromised. As there are some portions of the reservoir that exhibit fully supporting conditions throughout the critical season (Strawberry Reservoir at Bryant's Fork Bay, site #493642, and at Upper Strawberry Bay, site #493648), cold water game fish and associated species can move within the reservoir from those areas where water quality conditions are limited to areas that offer more viable habitat.

Refugia are available to cold water aquatic life throughout the reservoir. Although available data show water column dissolved oxygen and temperatures that exceed criteria at specific monitoring stations, criteria are being met concurrently at other stations within the reservoir. Refugia are present in the form of cold water tributaries, and may also include springs or other ground water inflows where localized water temperatures are cooler than those observed for the system as a whole. Therefore, the cold water game fishery is supported due to the joint use of both reservoir and tributary systems.

3.5.6 Fishery Population – Based Support Status Determination

To better characterize the support status of the cold water game fishery in Strawberry Reservoir, a population trend/age class survival assessment was undertaken using available fish population and species data (Baldwin *et al.* 1997, Beauchamp and Beauchamp 1995, Knight *et al*. 1994, Orme *et al.* 1995, UDWR 2004a-b, Ruzycki *et al.* 1996, Wilson and Spateholts 1998 and Wilson and Ward 2004).

Sport fish management in Strawberry Reservoir is influenced by water quality issues, habitat degradation in the tributary streams, fluctuations in angler success, and infestations of competitive non-game fish, mostly Utah chub, and Utah sucker (UDWR 2004 a-b, and UDWR 1987). Strawberry Reservoir has a long history of fishery management, using both stocking and chemical control techniques over the last 60 years. The reservoir was chemically treated in 1961 and 1990 to remove competitive non-game fish species. These treatments have proven successful in reestablishing a strong trout fishery within the reservoir.

UDWR has identified stocking as a crucial component in the management of the Strawberry Reservoir fishery, stating that without stocking, natural reproduction in the system would not be able to support the intense fishing pressure that Strawberry Reservoir receives each year (UDWR 2004a). Three game fish species are currently stocked in Strawberry including the Bear Lake strain of Bonneville cutthroat trout (approximately 1.6 million fish in 2004), sterilized rainbow trout (approximately 800,000 fish in 2004), and kokanee salmon (approximately 400,000 fish in 2004). Between three and five million fish are stocked in the reservoir and tributaries annually, all from state operated fish hatcheries (UDWR 2004 b-c).

The current game fish assemblage in Strawberry Reservoir is designed and maintained to preclude major non-game fish re-infestations. It was determined that Bear Lake cutthroat would be better able to survive in competition with the non-game fish species. Kokanee salmon were also determined to do well as competitors for food resources, and they inhabit a different niche than most of the non-game fish.

Special regulations have been used to enhance the sport fishery at Strawberry Reservoir. Between 1996 and 2002, the UDWR imposed a four fish aggregate limit, with only one trout (rainbow or cutthroat) allowed over 18" in length. During 2003, a slot limit was implemented which established a limit of no more than two cutthroat trout under 15 inches, no more than one cutthroat trout over 22 inches, and the mandatory release of all cutthroat trout from 15 to 22 inches in length. These changes are designed to increase the number of large cutthroat trout that prey on non-game fish species.

With current stocking rates and the recent changes in creel limits intended to increase the population of adult cutthroat and improve their age structure, cutthroat populations have increased (2002 to 2003) and are projected to continue to increase in 2004 through 2006 as shown in Figure 3-16. The age structure of the cutthroat population has changed to include older fish (five- and six-year-olds), which is critical to limiting Utah chub population growth in the reservoir (UDNR 2004a-c). Adjusted catch rates for cutthroat trout are estimated at 0.53 per hour (Spring 2003) and 0.51 per hour (Fall 2003) (UDWR 2004a).

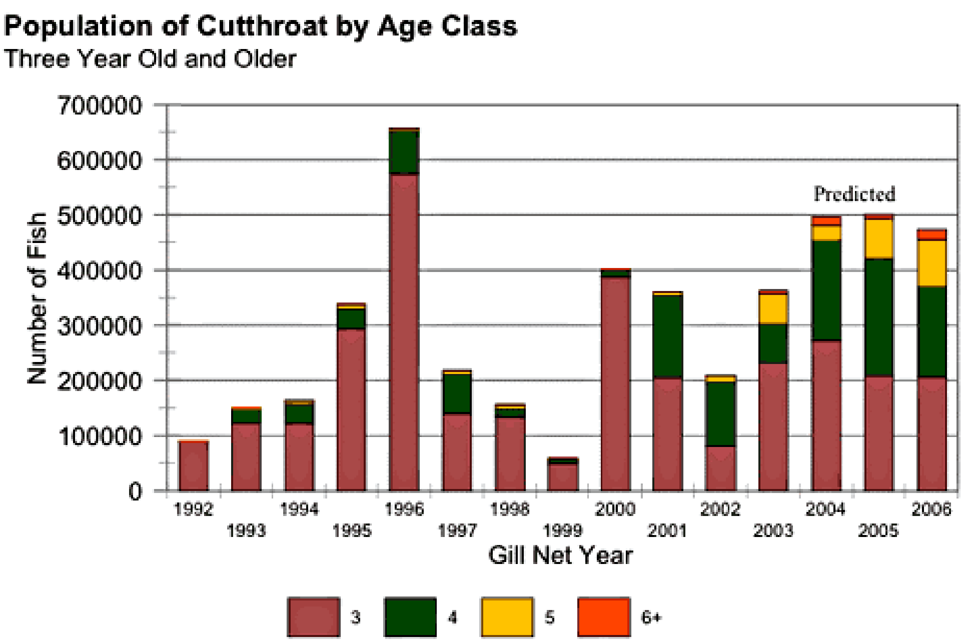


Figure 3-16: Population and age class trends in cutthroat trout three years old and older in Strawberry Reservoir from 1992 through 2003, with projected numbers for 2004 through 2006. (Provided by Utah Division of Wildlife Resources, 2004.)

Cutthroat survival rates were calculated by UDWR by age class. Survival rates for 1-2 year old, and 2-3 year old cutthroat were 43 percent. Survival rates for 3-4 year old cutthroat averaged 33 percent. Survival rates for 4-5 year old fish were projected at 18 percent prior to the new regulations and at 47 percent following the new regulations. All these rates are indicative of healthy, viable populations of cutthroat trout (personal communication, UDWR, Strawberry Reservoir Field Office, 21 April 2004).

In addition to overall population trends, relative age class numbers and average size have increased since the fall of 2002. Cutthroat trout over 20 inches long have increased in number by more than 150 percent, and the adult population of cutthroat trout has increased by 45 percent over this same time period (UDWR 2004c). Specific to these increases, predation on non-game fish by cutthroats has also increased (17 percent in 2002, to over 20 percent in 2003), leading to a correlated decrease in Utah chubs as based on fall gillnetting from 2002 to 2003 (UDWR 2004c). Studies of diet composition of cutthroat trout in Strawberry Reservoir observed that 28 percent of all cutthroat, 47 percent of cutthroat over 18 inches, and 64 percent of the cutthroat over 20 inches were feeding on chubs and shiners, an indication that the imposed creel limits on cutthroat are having a desirable effect on non-game fish (UDWR 2004a-c).

Additionally, UDWR biologists estimate that natural reproduction in the streams in the watershed has been responsible for producing as much as 60 percent of the adult cutthroat trout population in Strawberry Reservoir (UDWR 2004c). These findings indicate that conditions supportive of spawning and rearing are occurring within the watershed, and are acting in support of the cold water game fishery in the reservoir.

Rainbow trout numbers were observed to improve slightly from 2002 to 2003, but are still relatively low in UDWR gill net samples (UDWR 2004a). However, angler creel surveys conducted in 2003 show that catch rates are similar to those identified in 1996 and 2001 with many 2 to 5 pound rainbows reported caught in 2003. Adjusted gill-net catch rates for rainbow trout are estimated at 0.03 per hour (spring 2003) and 0.07 per hour (fall 2003) (UDWR 2004a).

Kokanee populations are difficult to track in the reservoir, as they are not sampled well by gill netting because of their open water schooling behavior (most of the trend gill nets are set near shore). Total populations have exhibited wide variability overall with 1999 and 2000 representing the two best kokanee runs on record, 2003 representing a moderate to good run and 2001 and 2002 representing some of the poorest runs recorded. However, natural reproduction appears to be well supported with some 72 percent of the 2003 spawning run in Strawberry River attributed to natural reproduction from spawning activity in 2000 (UDWR 2004a).

Utah chub numbers have generally increased from 1998 to 2002, with a substantial decrease (28%) observed between the fall of 2002 and the fall of 2003. The catch of one and two year old chubs during this same period decreased by 61 percent and 37 percent respectively, a 9 percent reduction in total adjusted biomass (chubs) from 2003 to 2004. Reductions in chub numbers and biomass can be attributed in large part to the imposition of the slot limit during 2003.

Evaluation of the available data for Strawberry Reservoir indicate that while some parts of the reservoir are non-supporting or partially supporting fish habitat at certain times during the year, the cold water game fish population is not impaired due to water quality exceedances.

Support and growth of the cold water game fishery is due in part to stocking and intensive fishery management by UDWR. Additional support for the fishery may be explained by the fact that conditions within the reservoir, or within the water column at any specific site are not completely non-supporting or partially supporting at any one time. In all situations where monitoring data were available, some portion of the reservoir maintained fully supporting conditions throughout the year. These areas of supporting conditions and the inflowing tributary systems may be utilized by cold water game fish populations as refugia during those months when water quality exceedances were the most pronounced in the lower portions of the reservoir.

In addition to the direct population assessment, the fishery is also identified as meeting or making substantial progress toward the realization of defined management goals.

3.5.7 Correlations of Water Quality Conditions to Fish Populations

The assessment of available water quality data within the reservoir showed exceedances of water quality criteria and non-supporting and partially supporting habitat conditions during the summer months of 2002 and 2003 (Figure 3-9 to Figure 3-15). A comparison of these occurrences and the available fish population data was completed to characterize the extent to which water quality criteria violations and non-supporting and partially supporting conditions (as based on percent of water column in violation of the numeric standards) may be influencing cold water game fish populations.

Available gillnetting surveys (UDWR 2004a) contain catch data from spring and fall catches, bracketing the water quality monitoring season (May through October). Overall fish population trends identified by UDWR included data from 1991 though 2003, a time period that correlates well with the time period of available water quality data collection (1997, 1999-2003).

Water quality data in 2002 and 2003 showed increasing numbers of criteria violations and decreasing levels of support. There was also an observed increase in the magnitude of water quality exceedances of dissolved oxygen and temperature observed in the later summer months (July and August) for most in-reservoir monitoring sites.

From 1996 through 2003 game fish population trends show increasing population and age class robustness for cutthroat trout. Adjusted catch rates for cutthroat and rainbow trout based on traditional trend gill netting in Strawberry Reservoir in 2003 are estimated at 0.53 and 0.03 per hour (spring 2003) and 0.51 and 0.07 per hour (fall 2003) respectively (UDWR 2004a) showing a stable catch-rate for cutthroat and an increasing catch-rate for rainbows, not the decreasing trend that would be expected from impairment due to poor water quality.

Given these apparently divergent conditions, no apparent correlation could be identified between water quality exceedances and fish population trends in Strawberry Reservoir.

Additionally, during recent years (identified as those in which the most substantial level of water quality criteria exceedance occurred) no fish kills have been reported in the reservoir (personal communication, UDWR, Strawberry Reservoir Field Office, 21 April 2004), indicating that while water quality conditions may not be ideal, adequate supporting habitat is available such that water quality conditions are not exerting a detrimental effect on fish populations sufficient to impair fish survival and population maintenance.

A possible explanation for the lack of correlation between water quality exceedances and fish population trends may be that while water quality conditions are not ideal in some sections of the reservoir, especially in the lower depths of the reservoir during the later summer months, such conditions do not occur for a sufficient length of time as to impair the local game fish populations. Given time, water quality conditions in these areas are observed to improve later in the year, providing appropriate habitat to local populations.

Cold water game fishery management objectives developed for Strawberry Reservoir by UDWR in consultation with other state and federal agencies and angler groups specific to fishery support within the reservoir include:

- Maintenance of cutthroat trout as an integral component of the Strawberry Valley Fishery Complex
- A minimum sustained output of 1.2 million hours of recreational angling yearly
- An average catch rate of 0.4 fish (12 inches long)/hour
- Production of 10 million cutthroat trout young-of-the-year from Strawberry Valley Tributaries each year
- Rehabilitation and restoration of Strawberry Valley spawning tributaries

Currently, fishery surveys indicate that Strawberry Reservoir supports over 1.4 million hours of angling pressure, and an average catch rate greater than 0.5 fish per hour (UDWR 2004a-c). It is estimated that natural cutthroat reproduction in the watershed contributes to as much as 60 percent of the adult cutthroat trout population in Strawberry Reservoir (UDWR 2004c). These first two conditions meet and exceed the cold water game fishery management objectives developed for Strawberry Reservoir by UDWR specific to fishery support within the reservoir. The natural cutthroat reproduction currently occurring is an indicator of substantial progress toward the realization of identified management goals.

Rehabilitation and restoration of tributary habitat is ongoing within the watershed. Due to implementation of best management practices and other habitat rehabilitation projects, conditions in a number of tributary streams have improved dramatically over the last ten years (UDWR 2004b-c). Streams within the watershed have the potential to produce millions of young-of-the-year cutthroat trout and kokanee salmon to supplement stocking programs, provided habitats are rehabilitated and adequately protected (UDWR 2004a-b). Current and future implementation will act to improve both spawning habitat and cold water refugia within the watershed.

3.6 Hydrologic Analysis

As discussed in the "Methodology" section, data from the Bureau of Reclamation's flow study formed the basis for determining flows from the natural inflows into the Strawberry Reservoir. Strawberry River, Co-op Creek, and Indian Creek were monitored as a part of this study. The period covered in the flow monitoring was from 1982 through 1991, but not all the streams were monitored for the entire period. Precipitation from the following weather stations in Table 3-12 were evaluated with the purpose of correlating annual flows in Strawberry's tributaries with annual precipitation recorded at each of the weather stations.

Table 3-12: Weather Stations near Strawberry Reservoir

Name/Location	Dates of Operation
DANIELS-STRAWBERRY	1978 – 1995
EAST PORTAL	1948 – 1955
SOLDIER CREEK	1968 –1973
STRAWBERRY DANIELS SUMM	1948 –1948
STRAWBERRY DIVIDE	1978 –1995
STRAWBERRY RESERVOIR EA	1905 –1977
STRAWBERRY HIWAY STN	1954, 1962 –1967, 1983 –1984

Due to the limited availability of data at the above stations, a surrogate station was sought which would be hydrologically similar to the conditions within the Strawberry watershed, but that would provide a longer period of record and would allow for the determination of "Normal" flow values.

A statistically significant correlation was found between annual flow (of the surface stream) and annual precipitation (at Heber) as shown in Figure 3-17.

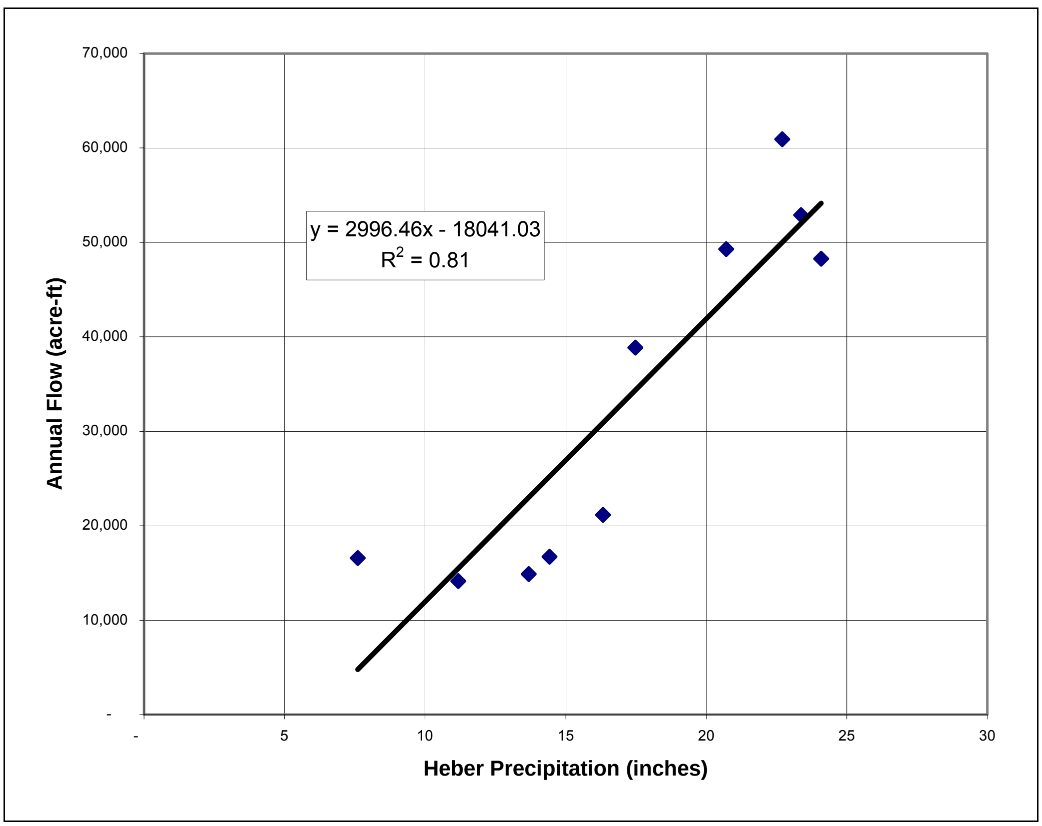


Figure 3-17: Flow of Strawberry River vs. Precipitation Correlation

In order to verify the methodology, annual flows were estimated for the most recent time period, the Water Years 2000 to 2003. The resulting water balance was within 10,000 acre-feet per year, or 9 percent, which is considered excellent. The seasonal distributions of the annual flow (annual hydrograph) for tributaries other than Strawberry River, Indian Creek and Co-Op creek were determined by averaging the annual flow patterns of the these three principal tributaries, with the exception of The Ladders. Estimates for the significant surface inflows to the reservoir are shown in Table 3-13. Additional detailed hydrologic analysis can be found in Appendix E.

Table 3-13: Monthly Tributary Inflows in acre-ft (Normal Hydrology)

Inflow	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Strawberry River	820	810	1,190	6,440	11,600	5,140	1,020	610	590	790	760	800	30,570
Indian Creek	180	180	270	1,350	3,220	1,710	480	230	210	200	160	200	8,390
Co-op Creek	110	110	170	720	2,530	1,550	520	230	190	140	90	140	6,500
Clyde Creek	80	70	110	550	1,320	700	190	90	80	80	70	80	3,420
Trout Creek	50	50	70	370	890	470	130	60	60	60	50	60	2,320
Chipman Creek	140	140	210	1,040	2,480	1,320	370	180	160	150	130	160	6,480
Mud Creek	60	50	80	410	970	510	140	70	60	60	50	60	2,520
Broad Hollow	40	40	60	310	740	390	110	50	50	50	40	50	1,930
Other Stream Inflows	320	320	480	2,380	5,680	3,010	840	400	360	350	290	360	14,790
Sheet Flow to Res.	460	460	680	3,400	8,120	4,310	1,200	580	520	510	410	510	21,160
The Ladders	2,430	1,680	5,120	5,990	19,150	17,360	8,920	3,610	2,820	5,040	4,270	2,330	78,720
Total	4,700	3,900	8,400	23,000	56,700	36,500	13,900	6,100	5,100	7,400	6,300	4,800	176,800

3.7 Water Quality Target Analysis / Endpoints

3.7.1 Target Analysis Overview

A mass balance approach was used to identify the target loading rates for phosphorus and total suspended solids. Tools used in this analysis and a summary of findings is described below. Detailed analysis is described in the following pages.

Vollenwieder Loading Plots - This plot shows that the two bay areas (East Portal Bay and Soldier Creek area) are bordering on mesotrophic to eutrophic conditions. The main body of the reservoir, however, shows low mesotrophic bordering on oligotrophic conditions.

Trophic State Index (TSI) Analysis – The TSI has consistently been in the 40 to 50 range since 1996 which classifies the reservoir as a whole in the mesotrophic range. Also TSI has slowly been decreasing since 1990 that indicates improvement over that time.

Phosphorus Reservoir Budgets - Current average total phosphorus loading was estimated to be 6,800 kg (15,100 lbs) annually.

Earlier in the Reservoir Impairment Section it was concluded that conditions within the reservoir, or within the water column at any specific site, are not completely non-supporting or partially supporting at any one time. Additionally, during recent years no fish kills have been reported in the reservoir. Adequate supporting habitat is available such that water quality conditions are not exerting a detrimental effect on fish populations.

The results of the analyses seem to indicate a fairly healthy reservoir that can be classified as a stable mesotrophic system. However, small bays and fringe areas do experience less favorable conditions during some times of the year.

The current condition and recent trends of the reservoir's health indicate drastic changes are not warranted, but instead, current and planned management efforts have and will continue to be effective in improving the quality and sustainability of Strawberry Reservoir's fishery.

Following this concept, the endpoints and targets that are recommended in this study are based on current loading and water quality levels. However, as is discussed in the TMDL, loading reductions will be necessary to accommodate for the margin of safety and future growth. Table 3-14 summarizes the recommended endpoints for Strawberry Reservoir.

Table 3-14 Summary of Recommended Targets / Endpoints

Parameter	Proposed Target
Dissolved Oxygen	>50% of the water column above 4 mg/L
Total Phosphorus Load to Reservoir	15,100 lbs/yr
Average TSI	40-50
Fish habitat Indicator	No Fish Kills
Blue-Green Algae	Decrease the Dominance of Blue-Green Algae

3.7.2 Vollenweider Loading

Vollenweider (1976) identified a method of determining trophic status based on areal phosphorus loading, average depth, and reservoir hydraulic residence time. As shown in Figure 3-19, the areal phosphorus loading in units of grams/meter^2/year is plotted on the vertical axis and the average depth/ hydraulic residence time is plotted on the horizontal axis of a log-log plot. The two plotted curves show the approximate boundaries between eutrophic, mesotrophic, and oligotrophic conditions as observed by Vollenweider.

Data for individual stations are shown in

Table 3-15. These data show that, although the mean values for total phosphorus are consistent (0.036 – 0.072), the variability is large (coefficients of variation from 0.6 to 1.3). Because of these variations, the reservoir was separated into three (3) areas (East Portal Bay, Main Body, and Soldier Creek) shown in Figure 3-18. Average total phosphorus concentrations for the Soldier Creek sites (493632 and 493633) is .066 mg/l while the average for the Main Body of the reservoir is .06 mg/l, and the East Portal Bay is .052 mg/l. Separate Vollenweider Indices for each area were calculated and are shown in Figure 3-19.

Figure 3-19 shows that both the East Portal Bay and the Soldier Creek area are generally in high mesotrophic to low eutrophic range. This would be typical for bays where little flushing flows of good quality water occur. The main body of the reservoir shows very favorable conditions straddling the oligotrophic and mesotrophic line.

Table 3-15: Summary Statistics for Total Phosphorus by Station - Strawberry Reservoir

Statistic	All	493632	493633	493642	493643	493645	493648	593676
# Obs	880	190	145	107	103	184	25	126
Minimum	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Maximum	0.740	0.380	0.400	0.330	0.740	0.380	0.090	0.410
Mean	0.064	0.070	0.061	0.052	0.066	0.072	0.036	0.063
Std.Dev.	0.063	0.061	0.057	0.047	0.085	0.067	0.023	0.060
Coef. Var	0.977	0.862	0.937	0.897	1.301	0.925	0.644	0.958
Skew	7.4	6.8	6.7	7.3	7.9	6.8	8.9	6.7
Kurtosis	43.	26.	29.	34.	58.	28.	27.	30.

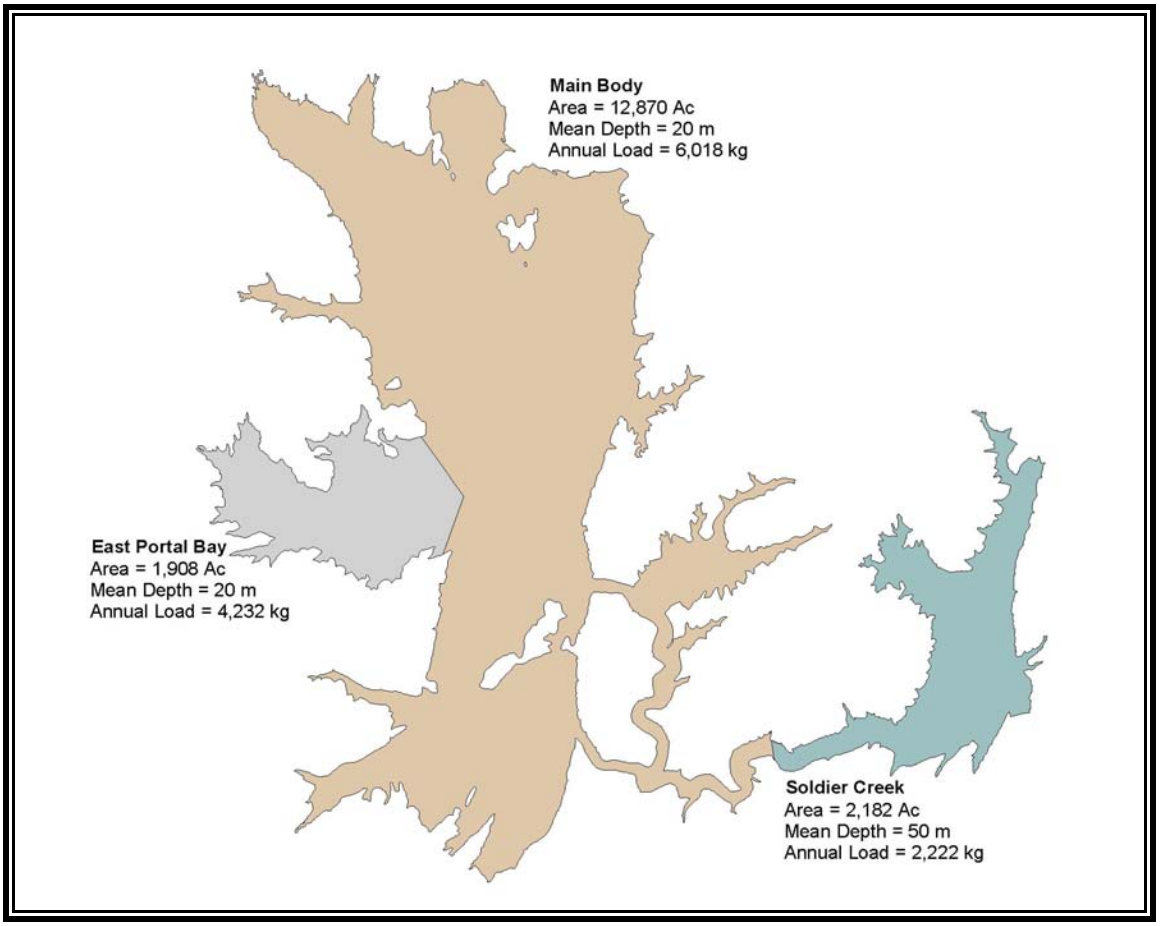


Figure 3-18 Three Systems for Vollenweider Calculations. Reservoir segmented into East Portal Bay, Main Body, and Soldier Creek areas.

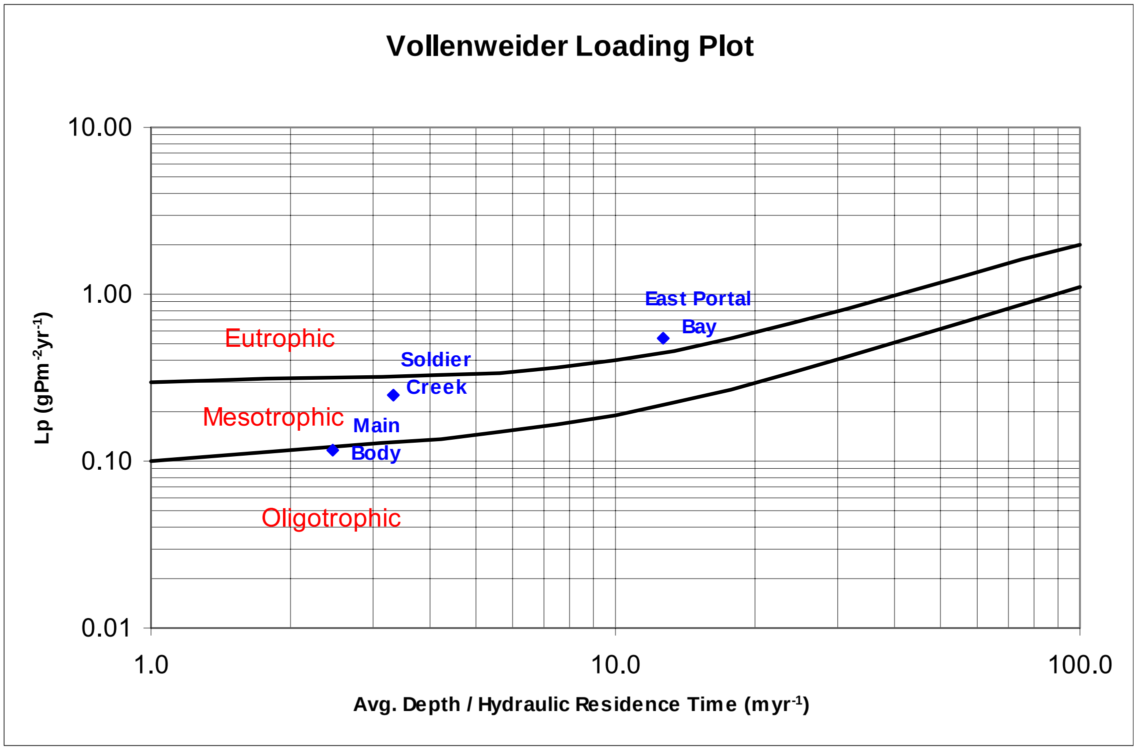


Figure 3-19: Vollenweider Loading (Trophic Status) plot for Strawberry Reservoir based on loadings from Normal Hydrology.

3.7.3 Carlson Trophic State Index (TSI)

Concentrations of dissolved oxygen are influenced by the trophic state of the reservoir. The trophic state of Strawberry Reservoir has been evaluated using the Trophic State Index (TSI) equations proposed by Carlson (1977). The average TSI is calculated using total phosphorus concentration, chlorophyll *a* concentration, and Secchi depths throughout the months of May to September. The following equations are used:

TSI = 60 - 14.41 ln [Secchi disk (meters)] **Equation 1**

TSI = 9.81 ln [Chlorophyll *a* (µg/L)] + 30. **Equation 2**

TSI = 14.42 ln [Total phosphorus (µg/L)] + 4.15 **Equation 3**

Figure 3-20 shows the calculated TSI values for Strawberry Reservoir and indicates a slight improvement in the reservoir since 1990. Improvements in the water quality of Strawberry Reservoir can be attributed to better management practices in the surrounding watershed as well as the importation of pristine water through the Strawberry aqueduct. The reservoir's trophic state appears to be mesotrophic or borderline oligotrophic (Appendix A).

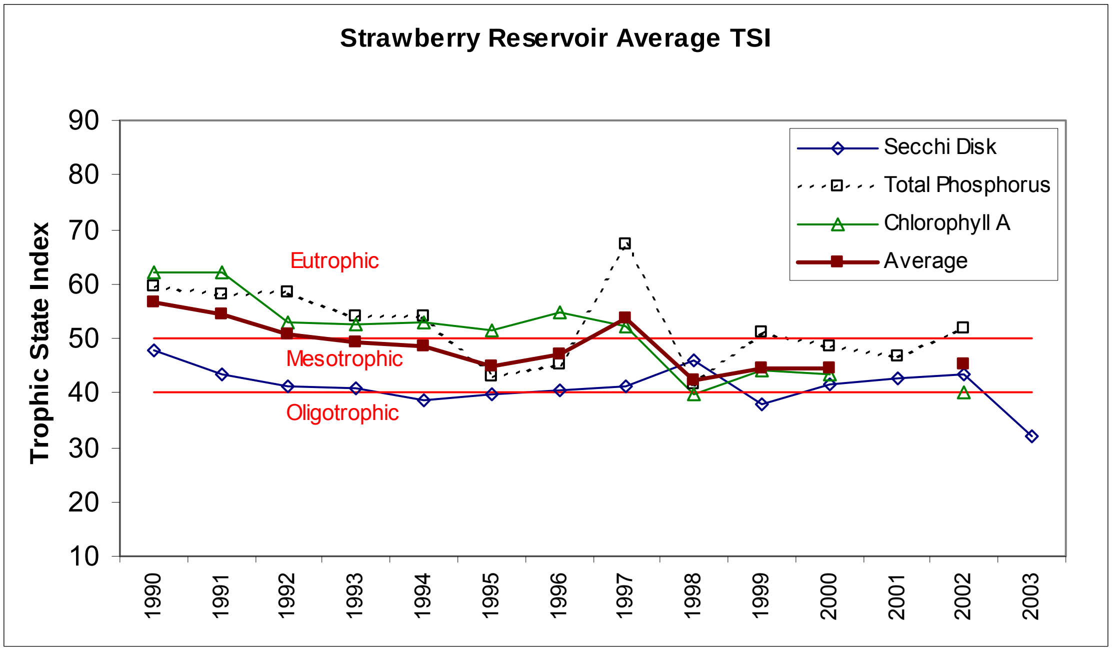


Figure 3-20: Strawberry Reservoir average Carlson Trophic State Index.

3.7.4 Phosphorus & Total Suspended Solids Budget

This section will focus on loading estimates for total phosphorus in Strawberry Reservoir. Load estimates for dissolved total phosphorus are excluded due to the relatively small amount of available data. The monthly and annual total phosphorus loadings under normal hydrologic conditions, including stream inflows and release from bottom sediments are shown in Table 3-16. Current average total phosphorus loading indicates an average annual phosphorus load of approximately 15,100 lbs. Under normal hydrologic conditions, we see a net export of approximately 4,000 lb per year from the reservoir.

Table 3-16: Total phosphorus budget – based on Normal hydrology phosphorus concentration and reservoir operations data

	IN			OUT				Net TP Export
	Streams & The Ladders		Release From Sediments	Tunnels		Soldier Ck. Dam		
	Avg. Flow (cfs)	Avg. Load (lb)	Avg. Load (lb)	Avg. Flow (cfs)	Avg. Load (lb)	Avg. Flow (cfs)	Avg. Load (lb)	Avg. Load (lb)
Jan	76	290	121	55	621	22	252	463
Feb	71	247	121	40	269	25	170	71
Mar	137	444	121	23	150	27	174	-240
Apr	386	1,969	-20	17	91	36	195	-1,662
May	922	5,181	-20	113	1,244	91	1,008	-2,910
Jun	613	3,238	121	373	2,051	36	329	-979
Jul	226	962	121	357	3,284	36	309	2,511
Aug	99	463	121	321	4,457	33	395	4,269
Sep	86	289	121	153	1,733	30	514	1,836
Oct	121	439	-20	22	185	23	234	-1
Nov	106	395	-20	45	438	22	215	278
Dec	77	284	121	46	487	22	234	316
Total		**14,200**	**889**		**15,011**		**4,029**	**3,951**

4.1 Introduction

This chapter will identify and describe point and non-point pollution sources into Strawberry Reservoir. This provides a basis for subsequent action to quantify the problem, identify responsible parties, develop and assess options to reduce pollution, and implement appropriate management plans. In the case of Strawberry Valley, four types of information were compiled and analyzed to complete this task:

- Identifying existing local conditions
- Calculating loadings for each subwatershed and for in-lake sources
- Identifying and locating non-point sources of pollution
- Identifying possible future sources

4.2 Existing Local Conditions

The local conditions of the watershed affect the amount of phosphorus that is put into the system. This section briefly describes land use patterns and ownership, as well as the hydrologic regime of the area.

4.2.1 Land Use Patterns and Ownership

In 1861, President James Buchanan set apart much of the Strawberry Valley as the permanent reservation for the Ute Indian Tribe. However, as a result of the Strawberry Reclamation project, the U.S. Government withdrew most of that land from the Indian Reservation in 1905 for the reservoir site. The land has since been under the ownership of the U.S. Department of the Interior. A small segment of the Uintah and Ouray Ute Indian Reservation remains near the south end of the watershed. About one percent of the land area is privately owned (Table 4-1 and Figure 4-1).

Table 4-1: Land Ownership in the Strawberry Watershed.

Owner	Area (Acres)
U.S. Forest Service / U.S. Bureau of Reclamation	109,100
State of Utah Wildlife Reserves	400
Private Land	7,000
Native American Reservation	2,700
Total	**119,200**

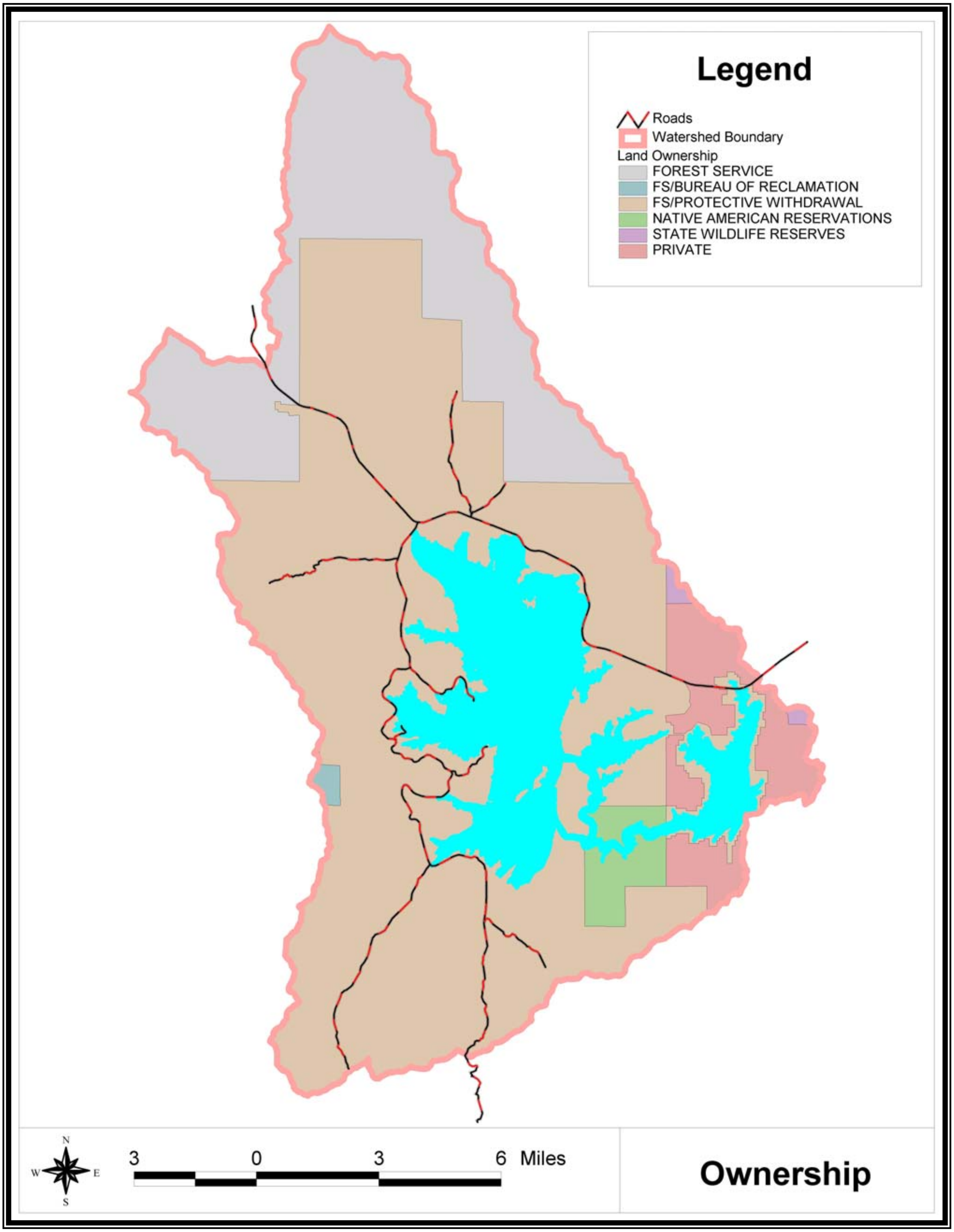


Figure 4-1: Land ownership in the Strawberry Reservoir watershed.

4.2.2 Hydrology

The Strawberry Valley has a long history of water development. The Strawberry Valley Project was one of the earliest federal reclamation developments, in which water is diverted from the Uintah Basin to the Wasatch Front (Utah and Salt Lake Valleys). Construction began in 1906 and water was first delivered for use in 1915. Water was collected in the 270,000 acre-feet of active storage capacity in Strawberry Reservoir, which was formed by a dam on the Strawberry River. Additional water was brought to the reservoir from Indian and Currant creeks through feeder canals. The Soldier Creek Dam, completed in 1973, increased the capacity of the Strawberry Reservoir from 273,000 to 1,106,500 acre-feet.

The first inter-basin diversion was developed in the spring of 1882 when water was diverted from the upper tributaries of the Strawberry River to Daniels Canyon in Wasatch County through three small canals. Not enough water was available to increase this diversion by gravity flow, so a 1,000-foot tunnel was excavated through the mountain. This allowed additional water to be diverted from the Strawberry River drainage to Daniels Canyon.

The Strawberry Tunnel, which is 3.7 miles long, extends from Strawberry Reservoir to Sixth Water Creek to the west. Sixth Water Creek is tributary to Diamond Fork, which flows into the Spanish Fork River. Historically, 61,500 acre-feet annually have been delivered through the Strawberry Tunnel to the Spanish Fork River and used for irrigation in the southern portion of Utah Valley. When the Bonneville Unit of the Central Utah Project is in full operation, annual exports from Strawberry Reservoir will increase to 163,400 acre-feet.

The Strawberry Collection System, completed in the late 1980s, diverts part of the flows of Rock Creek and eight other tributaries of the Duchesne River and conveys the diverted flows through the 36.8 mile-long Strawberry Aqueduct to the enlarged Strawberry Reservoir. Upper Stillwater and Currant Creek reservoirs serve as regulating reservoirs. The terminus of the aqueduct at Strawberry Reservoir is known as “The Ladders.”

The typical hydrologic values for the Strawberry watershed are shown in Table 4-2. Estimates for the significant surface inflows to the reservoir are shown in Table 4-3. Additional detailed hydrologic analysis can be found in Appendix E.

Table 4-2: Strawberry Reservoir Watershed Hydrology

Characteristic	Value
Drainage Area	170 sq mi
Peak Inflow	108,440 cfs
Inflow Volume	47,320 acre-ft
Precipitation	16 – 30+ inches

Table 4-3 Monthly Tributary Inflows in acre-ft (Normal Hydrology)

Inflow	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Strawberry River	820	810	1,190	6,440	11,600	5,140	1,020	610	590	790	760	800	30,570
Indian Creek	180	180	270	1,350	3,220	1,710	480	230	210	200	160	200	8,390
Co-op Creek	110	110	170	720	2,530	1,550	520	230	190	140	90	140	6,500
Clyde Creek	80	70	110	550	1,320	700	190	90	80	80	70	80	3,420
Trout Creek	50	50	70	370	890	470	130	60	60	60	50	60	2,320
Chipman Creek	140	140	210	1,040	2,480	1,320	370	180	160	150	130	160	6,480
Mud Creek	60	50	80	410	970	510	140	70	60	60	50	60	2,520
Broad Hollow	40	40	60	310	740	390	110	50	50	50	40	50	1,930
Other Stream Inflows	320	320	480	2,380	5,680	3,010	840	400	360	350	290	360	14,790
Sheet Flow to Res.	460	460	680	3,400	8,120	4,310	1,200	580	520	510	410	510	21,160
The Ladders	2,430	1,680	5,120	5,990	19,150	17,360	8,920	3,610	2,820	5,040	4,270	2,330	78,720
Total	4,700	3,900	8,400	23,000	56,700	36,500	13,900	6,100	5,100	7,400	6,300	4,800	176,800

4.3 Pollutant Loadings

4.3.1 Loading From Stream Inflows

One of the principal objectives of the TMDL process is to quantify the amount, or loading, of pollutants that enter the water body. The stream load represents the total mass of the pollutant that passes a given point in the stream during the time period considered. The loading into a reservoir represents the total of the loads from all of the inflows into the reservoir. For Strawberry Reservoir, total phosphorus (TP) and total suspended solids (TSS) loads into the reservoir were estimated. This section describes the methodology used to determine these loads.

The load in a stream may be calculated by combining the flow (typically in cubic feet per second) with the concentration of the constituent (typically in mg/L) multiplied by a conversion factor. Due to the limited data in the Strawberry Reservoir Watershed, we determined that the most appropriate method for calculating loads would be to determine average monthly loads for each stream based on average monthly concentrations and average monthly stream flows.

In order to improve the statistical reliability of our analysis, monthly average concentrations were calculated for months having five or more data points. This approach prevents months with few data points from being used in the analysis. Because of this restriction, average monthly concentrations based on STORET data could only be determined at five locations; Strawberry River (493665), Indian Creek (493661), Co-op Creek (493653), Clyde Creek (493662), and Trout Creek (493651). Also, sufficient data were only available for these stations from May to September.

Because the calculation of the load is highly sensitive to stream flow, seasonal flow patterns and precipitation determine, to a large extent, loading trends. Therefore it is critical to evaluate concentrations during those months when the flow and precipitation are at their peak, typically April through June. Because fewer than five samples were taken in April at these STORET stations, a relationship was established between concentrations measured in May and the few measurements that occurred in April (Figure 4-2 and Figure 4-3). These relationships were then used to predict April concentrations of TP and TSS, based on May concentrations.

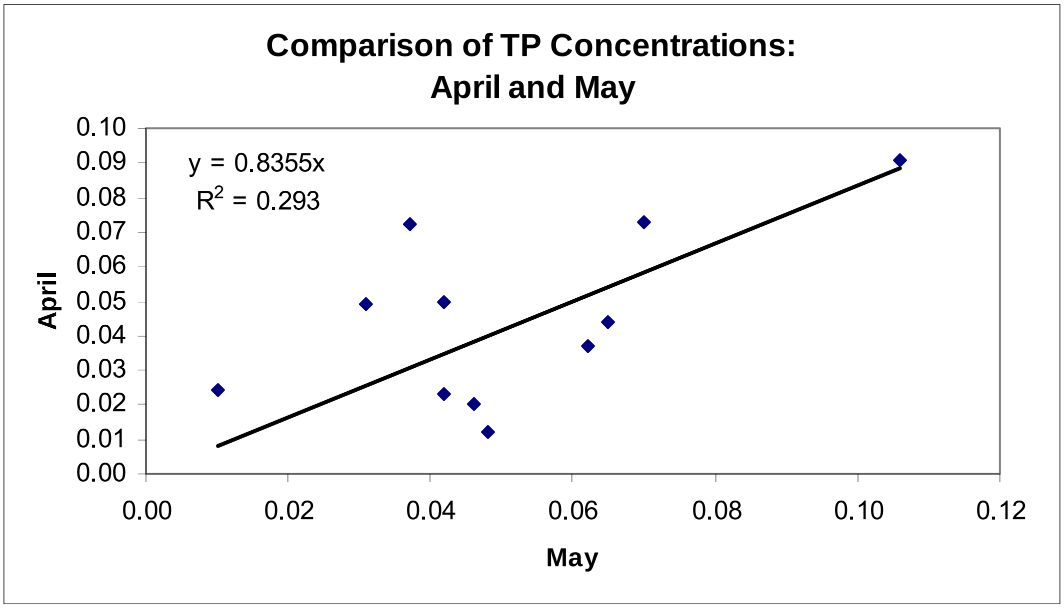


Figure 4-2: Relationship between TP concentrations in April and May.

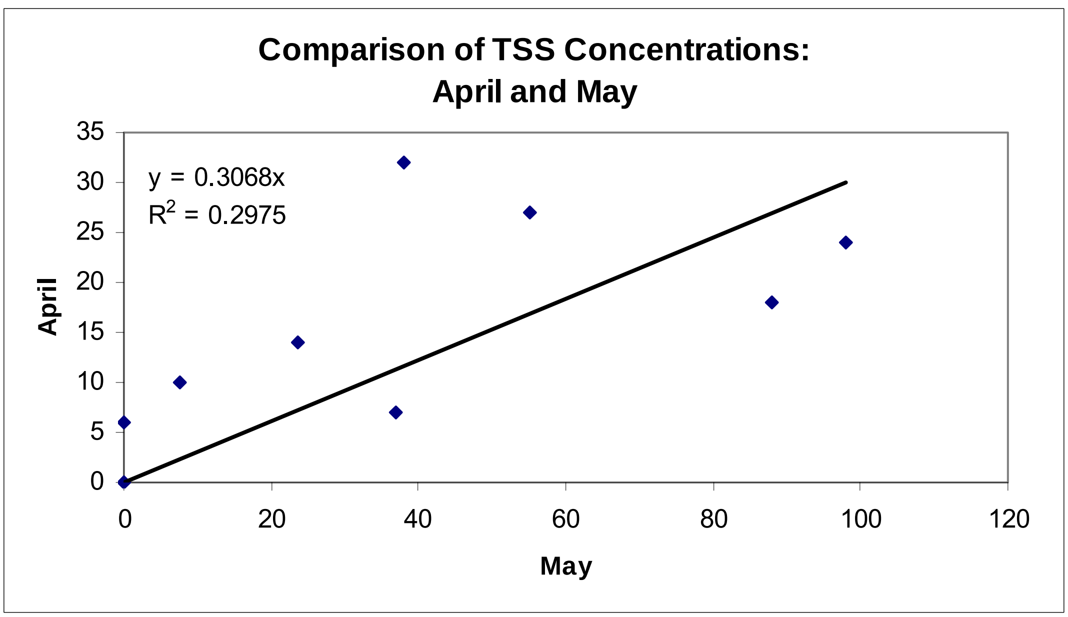


Figure 4-3: Relationship between TSS concentrations in April and May.

Much of the load from the watershed can be attributed to the cumulative effects of various smaller streams and sheet flow into the reservoir. Water quality and flow measurements at these locations are rare or non-existent. In order to determine the impact from these sources, a correlation was established between watershed area and loading from April through September at those five STORET locations where sufficient data were present (Figure 4-4 and Figure 4-5).

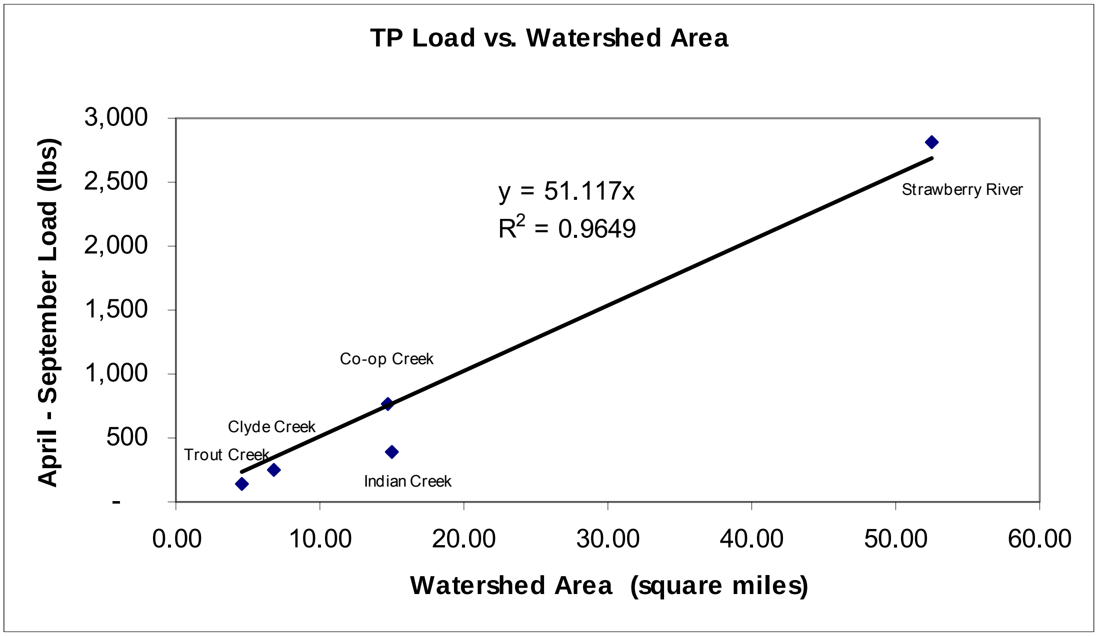


Figure 4-4 Correlation between Total Phosphorus Loading and Watershed Area

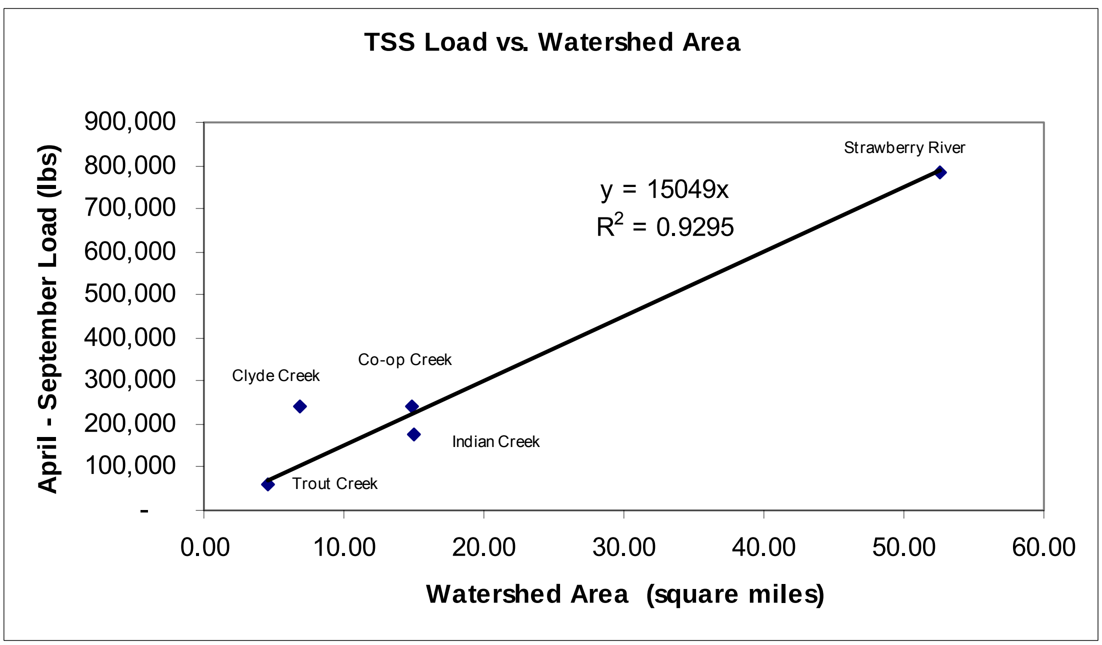


Figure 4-5 Correlation between Total Suspended Solids Loading and Watershed Area

The relationships established between load and watershed area were then used to estimate the six-month load (April – September) for those sub-watersheds where data did not exist.

Flow and runoff during the winter months, from October to March, are assumed to be minimal, and therefore account for only a small fraction of the total annual load. For the purposes of this analysis October to March loads were assumed to be 10 percent of the April to September loads.

Flow in The Ladders originates through a trans-basin diversion; therefore it is not affected by conditions within the Strawberry Reservoir watershed. Flows into the Reservoir from The Ladders represent approximately 45 percent of the total surface water inflows. Water quality in The Ladders is favorable based on the limited amount of data. Data were available from May to September. Total Phosphorus concentrations during this time period averaged 0.02 mg/L. It was assumed that concentrations during the months where data were unavailable would be equal to this average concentration. Flow in The Ladders is expected to change in the future as the Central Utah Project (CUP) transitions into providing increased project deliveries through Strawberry Reservoir. CUP water enters through The Ladders and exits the reservoir through the Syar Tunnel.

The results of the loading analysis for surface waters are shown in Table 4-4 and Figure 4-6.

Table 4-4 Stream Pollutant Loading Results and Normal Flow Calculations

TP — Average Monthly Concentration (mg/L)

Inflow	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	*6 Month Load (lbs)*		*Annual Load (lbs)**
Strawberry River (493665)				**0.034**	**0.041**	**0.059**	**0.018**	**0.022**	**0.011**				2,800	2,811	3,100
Indian Creek (493661)				**0.020**	**0.024**	**0.016**	**0.012**	**0.014**	**0.013**				400	394	400
Co-op Creek (493653)				**0.040**	**0.048**	**0.062**	**0.041**	**0.026**	**0.037**				800	765	900
Clyde Creek (493662)				**0.033**	**0.040**	**0.020**	**0.035**	**0.013**	**0.012**				300	255	300
Trout Creek (493651)				**0.023**	**0.027**	**0.030**	**0.018**	**0.016**	**0.011**				100	139	100
Chipman Creek													**700**	**653**	800
Mud Creek													**300**	**256**	300
Broad Hollow													**200**	**195**	200
Other Stream Inflows													**1,500**	**1,481**	1,700
Sheet Flow to Res.													**2,100**	**2,122**	2,300
The Ladders	0.02	0.02	0.02	**0.018**	**0.017**	**0.016**	**0.023**	**0.031**	**0.021**	0.02	0.02	0.02			4,100
Outflow												Total In	9,200		14,200
Release from Dam													-		
Combined Tunnels													-		
												Total Out	-		

TSS — Average Monthly Concentration (mg/L)

Inflow	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	*6 Month Load (tons)*	*Annual Load (tons)**
Strawberry River (493665)				**5**	**16.8**	**10.4**	**2.1**	**2.9**	**3.6**				390	430
Indian Creek (493661)				**4**	**14.1**	**6.2**	**3.7**	**0.8**	**2.2**				90	100
Co-op Creek (493653)				**6**	**20.6**	**19.4**	**1.3**	**0.7**	**3.1**				120	130
Clyde Creek (493662)				**14**	**46.7**	**25.1**	**2.8**	**7.5**	**1.2**				120	130
Trout Creek (493651)				**5**	**14.9**	**14.8**	**4.3**	**3.3**	**3.6**				30	30
Chipman Creek													**100**	110
Mud Creek													**40**	40
Broad Hollow													**30**	30
Other Stream Inflows													**220**	240
Sheet Flow to Res.													**310**	340
The Ladders				**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**				-	-

Flow — Average Monthly Flow (cfs) - Based on Normal Precip and Inflow

Inflow	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	*Annual Total (acft)*
Strawberry River (493665)	13.3	14.5	19.4	108.3	188.6	86.4	16.6	9.9	9.8	12.8	12.8	13.0	30,620
Indian Creek (493661)	3.0	3.3	4.4	22.7	52.4	28.7	7.7	3.7	3.5	3.3	2.7	3.3	8,405
Co-op Creek (493653)	1.8	2.0	2.7	12.1	41.1	26.1	8.5	3.7	3.3	2.3	1.5	2.3	6,522
Clyde Creek (493662)	1.2	1.3	1.8	9.3	21.4	11.7	3.2	1.5	1.4	1.3	1.1	1.3	3,440
Trout Creek (493651)	0.8	0.9	1.2	6.3	14.5	7.9	2.1	1.0	1.0	0.9	0.8	0.9	2,327
Chipman Creek	2.3	2.5	3.4	17.5	40.3	22.1	6.0	2.9	2.7	2.5	2.1	2.5	6,475
Mud Creek	0.9	1.0	1.3	6.8	15.8	8.6	2.3	1.1	1.0	1.0	0.8	1.0	2,529
Broad Hollow	0.7	0.8	1.0	5.2	12.0	6.6	1.8	0.9	0.8	0.7	0.6	0.8	1,922
Other Stream Inflows	5.3	5.8	7.8	40.0	92.3	50.6	13.6	6.6	6.1	5.8	4.8	5.8	14,821
Sheet Flow to Res.	7.5	8.3	11.1	57.2	132.0	72.4	19.5	9.4	8.7	8.2	6.9	8.3	21,195
The Ladders[1]	39.5	30.2	83.3	100.7	311.5	291.7	145.1	58.7	47.5	81.9	71.8	37.9	78,874

Notes

Blue bolded text indicates average monthly concentrations based on five or more samples.

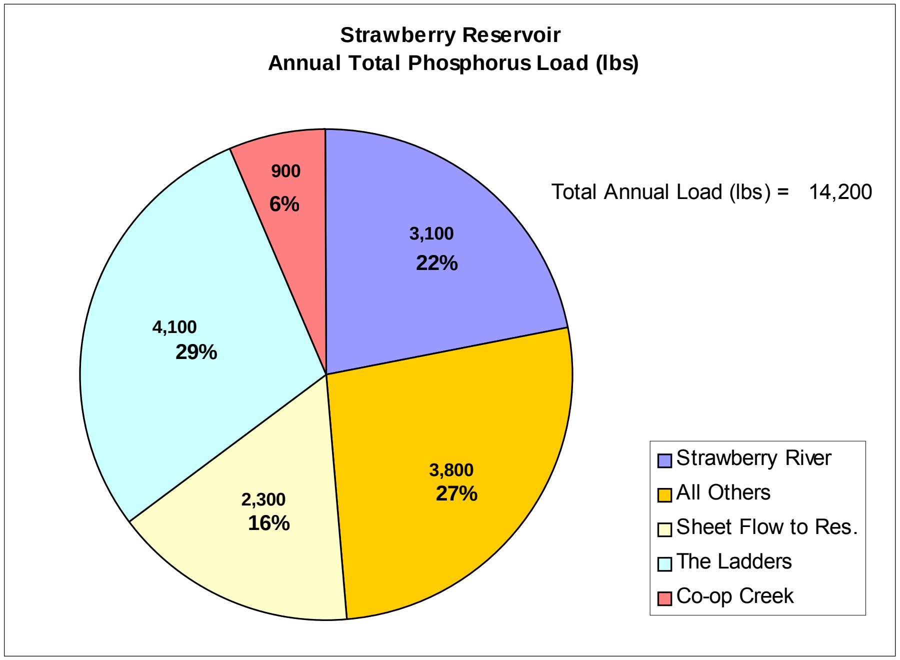
Violet bolded text based on available data from stations 493647 & 493688.

Red bolded text indicates concentration based on April to May correlation (TP_{April} = 84% of TP_{May}, TSS_{April} = 31% of TSS_{May}).

Orange bolded text values were calculated using a load (lbs) - area (square miles) relationship (TP_{Load} = 51*Area, TSS_{Load} = 15049*Area).

*October to March load assumed to be 10 % of the April to September load.

[1]These values represent operations under non-full-demand conditions. When operations require "The Ladders" (officially named Open Channel No. 2) to be operated under full-demand conditions, the average annual inflow will be 105,500 acre-feet (Supplement to the 1988 Definite Plan Report for the Bonneville Unit, Water Supply Appendix, Volumen 3, p. 2-3).



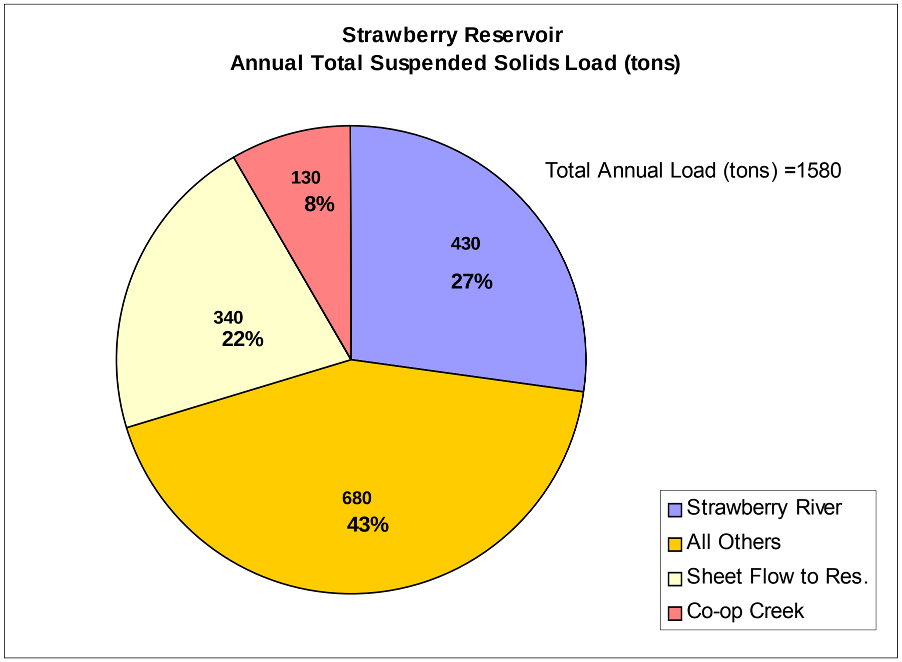


Figure 4-6 Surface Water Pollutant Loading Results

4.3.2 Loading From In-Lake Sources

There are several potential mechanisms by which phosphorus can enter the water column from sources within Strawberry Reservoir. These include:

- Human recreational sources
- Stocking of fish
- Bank erosion from wave action
- Bottom sediment-water interactions

The following sections describe these sources and mechanisms in more detail and provide, where appropriate, an approximation of the magnitude of the loading from each source to the reservoir.

Human Recreational Sources

Human recreational sources include direct deposition of human waste or other phosphorus containing waste into the reservoir. Strawberry Reservoir is very important recreationally to the State of Utah. Recreational uses include fishing, water skiing, swimming, and other direct contact activities. In general, restroom facilities and trash receptacles are available at all of the major recreation areas and so it is anticipated that little human waste is deposited within the reservoir. In addition, the climate of the reservoir limits the amount and types of recreation that occur. Ice covers the reservoir during several months of the year, making the reservoir inaccessible to boats. Ice fishing is popular during the winter, but much of the lake is inaccessible except to those with snowmobiles. Water temperatures during all but the warmest summer months make swimming and water skiing unattractive to most visitors. Given the above information, it is assumed that human recreational sources are not significant in Strawberry Reservoir.

Stocking of Fish

Although Strawberry Reservoir is stocked with game fish, this is not considered a significant source of phosphorus to the reservoir. There is relatively little phosphorus content in the biomass of the fish that are stocked to the reservoir. In addition, many anglers keep the adult fish that they catch, effectively removing many times the phosphorus content of a single stocked fish. The net effect of fish stocking/harvesting is likely negligible.

Bank Erosion

Bank erosion occurs as wind and boats cause enough wave action to detach sediment from the banks of the reservoir and entrain it in the water column. This mechanism requires that there is phosphorus associated with the soil that is detached and that there is enough wave energy to cause detachment to occur. When bank erosion does occur, the detached sediment is typically entrained in the water column within approximately 1-2 meters of the bank, after which it generally settles out and becomes part of the lake sediments. Although bank erosion can be a source of total phosphorus, it is typically not a source of bio-available phosphorus.

It is assumed that bank erosion by itself is not a significant source of phosphorus loading to Strawberry Reservoir. The mechanism by which loading occurs is limited to those times when there is open water (no ice cover) and sufficient wave activity to cause erosion, and the area affected by this source is limited to a relatively short distance from the banks to where the sediment settles out of the water column. Once the sediment settles from the water column, however, it becomes part of the lake sediments, which is addressed in the following section.

Bottom Sediment-Water Interactions

Bottom sediments have long been acknowledged as a potential source of phosphorus to the overlying waters of lakes and reservoirs (Chapra, 1997). This is particularly true in lakes and reservoirs in which anaerobic conditions occur in the hypolimnion (the deepest portion of the water column). Under anaerobic hypolimnetic conditions, phosphorus in the sediments can be converted into soluble forms that are bio-available. The soluble phosphorus can then be re-entrained in the overlying water column. When mixing of the hypolimnion and epilimnion occurs, during spring and fall turnover, the solublized phosphorus can be carried into the photic zone where it is available for algal uptake.

The process by which the sediments interact with the overlying water column is controlled by several factors, including:

- The length and severity of the anoxic conditions in the hypolimnion
- The chemical characteristics and phosphorus content of the sediments
- The surface area of sediment exposed to anoxic conditions and the overlying water column

The following sections provide a description of the conditions in Strawberry Reservoir related to these factors.

Hypolimnetic Anoxia

Strawberry Reservoir does exhibit periods of anoxia in the hypolimnion throughout much of the reservoir during the summer months, as exhibited by profile data collected by the Division of Water Quality. At many locations, oxygen concentrations approach 0 mg/L by mid to late July and can remain depleted until October when the fall turnover typically occurs.

Sediment/Water Flux Estimation

The approach taken to estimate phosphorus loading from bottom sediments included the review of existing information concerning in-lake phosphorus sources for Strawberry Reservoir, gathering spatial information for Strawberry Reservoir related to in-lake loadings, and calculating (where possible) or estimating annual loads. The primary source of information concerning phosphorus flux from sediments in Strawberry Reservoir is a study conducted by Messer et al. (1985) in which phosphorus release rates were directly measured in sediment cores sampled in the summer and fall of 1983 from several locations in the lake (Figure 4-7). Details of that work are included in Messer et al. (1985) and are not repeated here. The net result of that work was a set of sediment release rates under aerobic and anaerobic conditions, and under conditions enhanced by the addition of organic matter. Messer et al. (1985) concluded that the phosphorus release rates were small relative to other reservoirs in central Utah and that the phosphorus cycling is controlled by the presence of iron and manganese in the sediments and water column.

The results from their study are found in Table 4-5 and Table 4-6. In Table 4-5, phosphorus release rates ranging from -0.16 mg/m^2-day to +1.1 mg/m^2-day are reported. When placed under aerobic conditions, the summer 1983 samples indicated that phosphorus was removed from the water column by the sediments at sites 3, 4, 5, 6, 9, 10, and 11, which is common under iron-limited conditions (Stumm and Morgan, 1996). When the summer 1983 samples at sites 1, 2, 7, 8, and 12 were placed under aerobic conditions, the sediments released phosphorus. Phosphorus was released from the fall 1983 sediment samples in amounts ranging from 0.01 to 0.25 mg/m^2-day under both aerobic and anaerobic conditions, with little difference between the two conditions. Table 4-6 shows an even more mixed result, with removal of phosphorus related to both aerobic and anaerobic conditions at site 8, anaerobic conditions at sites 2 and 11, and none under aerobic conditions. Uncertainty in these estimates is about 40% of the mean value[1] (standard error of the mean divided by the mean).

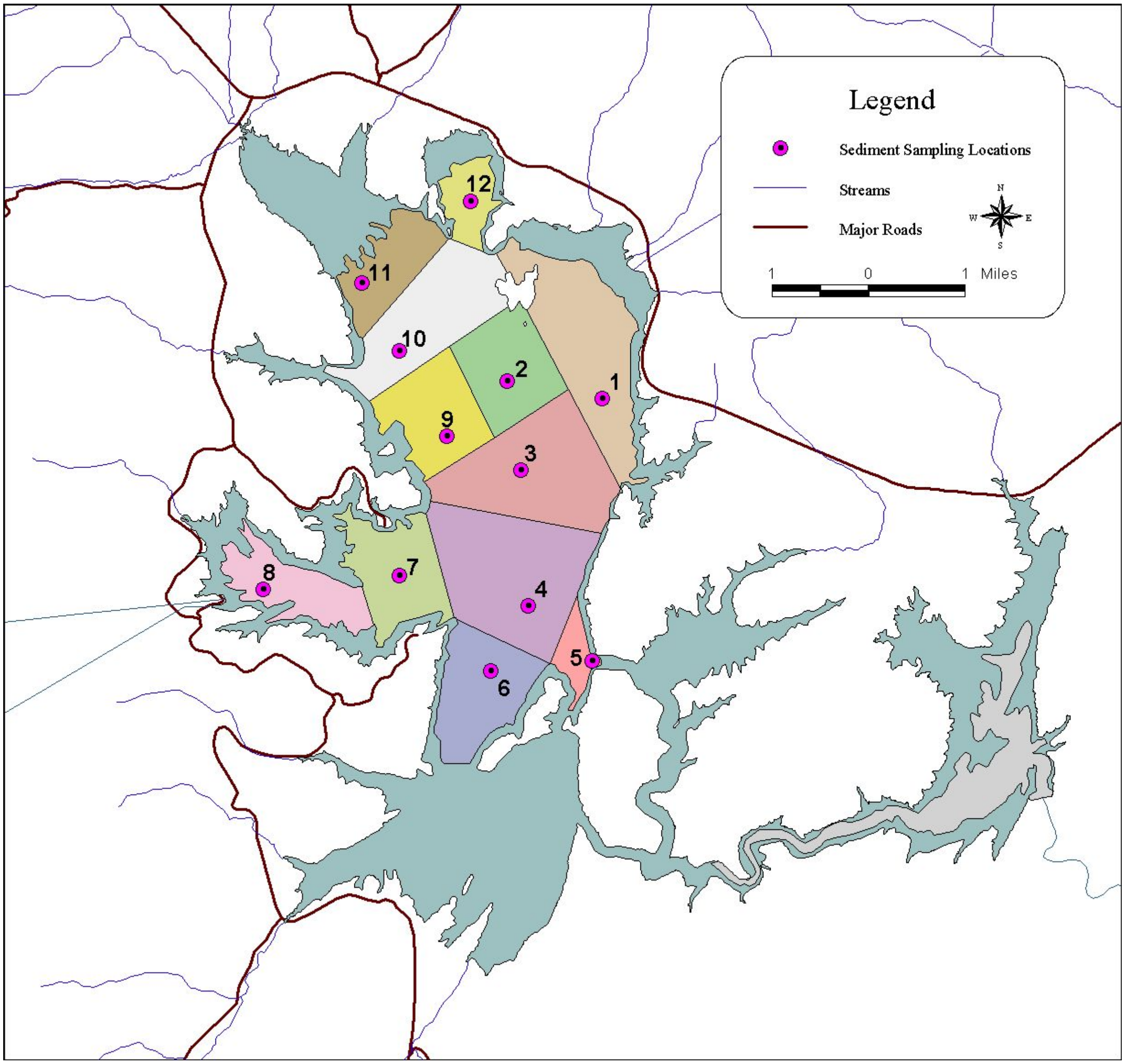


Figure 4-7. Locator map for Sediment Sampling Sites from Messer et al. (1985).

[1] The uncertainty estimate is based on statistical analysis of replicated results in Strawberry Reservoir, and in Flaming Gorge, Deer Creek, and Scofield reservoirs, in which more replicate results are available (Messer et al. 1985).

Table 4-5 Phosphorus release rates for Strawberry Reservoir sediment samples summer and fall, 1983 (Messer et al., 1985).

Site	Treatment	24-day phosphorus-Release Rate mg/m^2-day	
		Summer 1983	Fall 1983
Strawberry Bay (Sites 10 and 11)	Aerobic	-0.01	0.17
	Anaerobic	1.1	0.18
North Bay (Sites 1, 2, and 12)	Aerobic	N/D[a]	0.01
	Anaerobic	N/D	N/D
Center (Sites 3, 4, and 9)	Aerobic	-0.16	N/D
	Anaerobic	0.56	0.25
Indian Creek Bay (Sites 5 and 6)[b]	Aerobic	-0.16	0.07
	Anaerobic	0	0.02
East Portal Bay (Sites 7 and 8)	Aerobic	0.04	0.01
	Anaerobic	0.05	0.02

[a]No data for this site/treatment.

Table 4-6 Enhanced phosphorus release via addition of organic carbon – October 1983.

Site[2]	Treatment	24-day phosphorus-Release Rate mg/m^2-day
2	Anaerobic	-0.9
	+BOD	0.3
6	Aerobic	0.1
	Anaerobic	0
	+BOD	0.2
8	Aerobic	-0.3
	Anaerobic	-0.1
	+BOD	0.6
11	Aerobic	0.1
	Anaerobic	-0.6
	+BOD	1.1
12	Anaerobic	0
	+BOD	0.2

[2] See **Figure 4-7** for site locations

In all cases, the phosphorus fluxes measured in Strawberry Reservoir sediment samples are an order of magnitude lower than those seen in other Utah reservoirs under anaerobic conditions and about one third of those under aerobic conditions. However, even though these flux values are low, they may still prove to be significant to the overall phosphorus budget because of the large surface area of the sediments in Strawberry Reservoir.

The flux estimates from the Messer study were used to estimate the total loading from the sediments to the overlying water column in Strawberry reservoir. In order to estimate the overall loading from these fluxes it was first necessary to estimate the surface area of the sediments represented by the sampling sites in Table 4-5 and Table 4-6. In the absence of detailed bathymetric data for Strawberry Reservoir, the zones of influence surrounding each sediment sampling location using a GIS coverage of the surface area of the reservoir under the assumption that the surface area of the exposed sediments is approximately equal to the surface area of the reservoir. The polygon representing the surface of the reservoir was divided into several smaller polygons using a simple, visual approximation, with each smaller polygon being an approximation of the area represented by each of the Messer sampling locations.

Since the Messer study was done prior to the enlargement of the reservoir, the area inundated by the enlarged reservoir was delineated by digitizing the original extents of the reservoir prior to its enlargement from a USGS topographic map and then intersecting this area with the existing reservoir area. The results of this process are shown in Figure 4-7**.**

Each of the polygons within the reservoir has an associated Messer sampling location within it, except those areas of the reservoir that did not exist or were not sampled at the time of the Messer study.

The surface areas calculated using the above procedure for each site number are shown in Table 4-7 and Table 4-8. The areas labeled -1 and New are those portions of the reservoir inundated after the reconstruction of the Soldier Creek dam in 1970-1974 with the subsequent complete filling of the enlarged reservoir in the late 1980s. No flux measurements were made in these portions of the reservoir. Consequently, these areas were lumped with adjacent sites for calculation purposes.

The phosphorus fluxes from the sediments are shown in Table 4-8 and were found simply by multiplying the measured fluxes by the representative sediment surface areas. This table shows that under aerobic conditions there would be a net phosphorus removal using the information from the summer 1983 sample and the October 1983 sample, and large net phosphorus release under anaerobic conditions. As stated above, phosphorus was released from the sediment samples taken at all sites with about 20% more release under anaerobic conditions.

Table 4-7 Representative sediment surface areas corresponding to data of Messer et al (1985)

Site	Area (m^2)	Site	Area (m^2)
-1	3,414,366	7	2,465,886
1	4,212,733	8	1,986,660
2	2,421,321	9	2,375,545
3	4,260,024	10	3,424,101
4	4,792,537	11	1,825,750
5	620,311	12	1,004,931
6	2,616,865	New	32,853,070

Table 4-8 Total phosphorus fluxes in Strawberry Reservoir under different conditions, kg/year.

Sample time	Mean phosphorus Release kg/yr	Lower 95% CL kg/yr	Upper 95% CL kg/yr
Summer 1983			
Aerobic	-2830	-1262	-6348
Anaerobic	7325	3266	16430
Fall 1983			
Aerobic	1474	657	3306
Anaerobic	2424	1081	5437
October 1983			
Aerobic	1039	463	2329
Anaerobic	-7760	-3460	-17407
Net			
Aerobic	-106	-47	-237
Anaerobic	663	296	1487

Strawberry Reservoir stratifies annually. It was estimated from the temperature data that the reservoir is stratified for approximately ten months out of the year, with two months of mixed conditions associated with the spring and fall turnover periods. We assumed that during turnover, the oxygen from the water surface is mixed rapidly and that after the turnover period, approximately one month is required to revert to anaerobic conditions at the sediment-water interface. With two turnover events/year it is estimated that the lake sediments are aerobic for 4 of 12 months (1/3 of the year) and anaerobic for 8 of 12 months (2/3 of the year). Using these fractions, an overall annual flux from the sediment is 410 (180 – 910)[3] kg/yr or about 900 (400 – 2,000) lb/yr.

These net sediment fluxes calculated are quite low and represent the large differences in the different tests of Messer et al. (1985). For example, under anaerobic conditions, the mean fluxes range from a net **input** to the reservoir of 4,528 kg/yr in the summer, to a net **removal** of phosphorus of 7,760 kg/yr in October of the same year. As such, the estimates provided above should be regarded as rough approximations only.

4.4 Current and Future Sources of Pollution

There are currently no point sources within the Strawberry watershed. Initial efforts to identify and describe non-point source pollution were based on information prepared by the USFS and NRCS through the agencies' various reports and studies. Site visits were completed to review the findings and to assess the health of the watershed. The watershed's hydrologic regime was then reviewed to characterize how pollutants were transported through the drainage basin, eventually reaching the reservoir and then being dispersed through outflows to other areas.

The watershed as a whole is currently in a healthy, stable condition. However, with future pressures such as increased recreational activities, oil and gas exploration, and modified water diversions the area is still vulnerable. It is imperative that management programs and restoration plans continue to be implemented to address future concerns.

4.4.1 Soil Erosion

A number of human-related activities have the potential to adversely affect the ecological health of the watershed. Without proper management, timber harvest, livestock grazing, and recreational activities can increase erosion and levels of bacteria and nutrients in runoff. Loss of riparian vegetation can also facilitate the delivery of sediment and nutrients to rivers, streams, and ultimately the reservoir.

In the Strawberry Reservoir watershed, excess soil erosion resulting in increased sedimentation is a major concern. Excess sediment in streams can cover gravels needed for fish spawning and can smother the eggs. Since the effects of human-related activities in the watershed are cumulative, proper planning and monitoring of these activities is important to the watershed's ecological health.

The desired future condition (DFC) is a description of the land or resource as it is anticipated to look if Forest objectives are achieved. In accordance with the 2003 Uinta National Forest Plan, the DFC for the management of geology and soils in the Strawberry watershed is as follows:

> Most soils have at least minimal protective ground cover, soil organic matter, and large woody material. Soils have adequate physical properties for vegetative growth and soil-hydrologic function. Physical, chemical, and biological processes in most soils function similarly to soils that have not been disturbed. Degradation of soil quality and loss of soil productivity is prevented. Soil hydrologic function and productivity in riparian areas is protected, preserving the ability to serve as a filter for good water quality and regulation of nutrient cycling. Soil productivity, quality, and function are restored where adversely impaired and contributing to an overall decline in watershed conditions.

[3] Range in parenthesis is the 95% confidence interval for the estimated loading

Of particular concern with regards to soil erosion are the gray shale sub-soils of Strawberry River and Co-op Creek canyon that contain high concentrations of phosphorus (Figure 4-8). Runoff from this area often contains phosphorus-rich sediment.

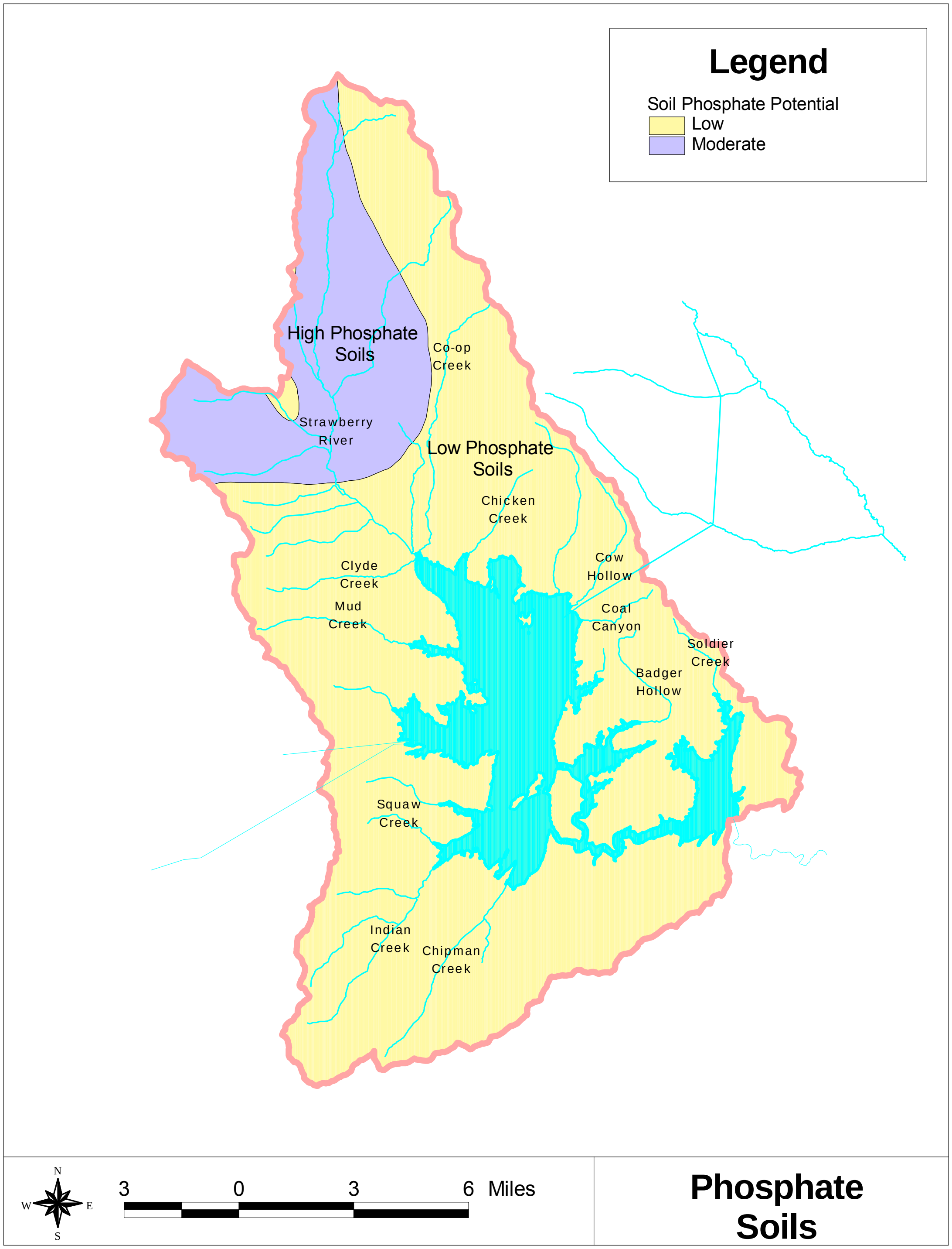


Figure 4-8: Soils containing high concentrations of phosphorus.

4.4.2 Septic Tanks

In rural areas, septic tanks are an economical alternative to a centralized sewer system. When installed and maintained properly septic tanks can effectively treat household wastewater. However, malfunctioning septic systems have the potential to contaminate surface and groundwater resources.

A number of cabins and campgrounds within the watershed have septic systems (Figure 4-9). Regions with high septic tank density are more likely to have elevated concentrations of nutrient and pathogenic contaminants.

4.4.3 Land Use

Private Property

The majority of privately owned land and Ute Tribal land is located near the Soldier Creek Arm of Strawberry Reservoir. This area also includes the following public facilities: Soldier Creek Campground and Boat Ramp, Aspen Grove Campground and the day use facilities at Soldier Bay and Rocky Point. Located within this area are five summer home developments with a total of 376 lots.

The future of private development in the Strawberry Reservoir Watershed is best summarized by the *Wasatch County General Plan, November 26, 2001:*

"It is anticipated that the popularity of the Strawberry Planning Area as a place for summer homes will continue as recreational activities are expanded into a broader range of outdoor activities in addition to fishing."

The County as a whole has been one of the fastest growing counties in the State of Utah with an average annual rate of population change of 2.81% as estimated by the Governor's office of Planning and Budget (2003). According to the County's General Plan, the percentage of non-primary residents is approximately 43% of the total residences in the County. This means that for every primary residence built in the County there is a corresponding secondary residence built. For purposes of this analysis it will be assumed that the rate of private development in the Strawberry Reservoir Watershed will be equal to the rate of population change for the County, or 2.81% per year.

Assuming a 10-year planning period this rate of change would create a 30% increase in pollutant loads from privately developed areas. The current estimated loading from developed areas is approximately 850 lbs of Total Phosphorus and 125 tons of Total Suspended Solids. This would equate to future sources of 260 lbs of TP and 38 tons of TSS.

Public Lands

Of the approximately 136,000 acres of land within the Strawberry Watershed nearly 126,000 acres (93%) are public lands. U.S. Forest Service property comprises 125,630 acres of the public lands. The Uinta National Forest has recently completed its *Uinta National Forest 2003 Land and Resource Management Plan*, as well as the Uinta National Forest Strawberry Watershed Restoration Report, April 2004. These reports were used as a basis to identify current and future land uses on public lands. Additionally, the plan and report make recommendations for restoration techniques to improve land uses; stream channel, riparian and aquatic habitat resources; and wildlife resources.

Recreation

Strawberry Valley receives over 2 million visitors per year. Developed recreational facilities include campground operation and concessionaire services for Forest Service developed recreation sites, Marina operations at four sites on Strawberry Reservoir, and lodge and restaurant facilities with 21 rooms at Strawberry Bay. Dispersed recreational activities primarily include fishing, boating, camping, ATV and motorcycle riding, snowmobiling, and hiking. These types of uses have been heavy in the past, and are rapidly expanding. Generally, if visitation increases there could be a corresponding increase in non-point source pollution. Therefore it is important that the Recreation Management Standards and Guidelines identified by the USFS be fully implemented to control any potential impact to the watershed from increased dispersed recreational activities.

The area has excellent developed recreational facilities funded by the Bureau of Reclamation as part of the mitigation for Soldier Creek Dam and later the enlarged Strawberry Reservoir. These developed sites attract a high number of users. Several services in the area are provided by special use permits, including three marinas, a lodge, outfitter and guide services and snowmobile rentals. Summer motorized recreation is limited to roads and trails designated as appropriate for this use. Dispersed campsites along heavily used road corridors have been hardened and signed to concentrate use and reduce the impacts to other resources. Campgrounds, boat launches, and other recreational facilities are managed to maintain current levels of use.

Hydrologic Modifications

The Restoration Report (USFS 2004) reviewed the history of management of the Strawberry Reservoir watershed and determined that historical water diversions, elimination of riparian species through herbicide spraying, trapping of beaver, and removal of beaver dams have all caused detrimental impacts to the hydrology of Strawberry Valley's rivers and streams. The system is recovering through the implementation of extensive management programs since the early 1980's. However, much work remains in maintaining and expanding effective restoration measures throughout the watershed. The Standards and guidelines for Riparian Habitat Conservation Areas (RHCAs) and aquatic habitat management continue to improve watershed conditions within the Uinta National Forest. Additional improvement is expected through implementation of the programs outlined in the 2004 Strawberry Watershed Restoration Report.

Timber

Approximately 55,300 acres of land within the Strawberry watershed are comprised of forested vegetation. The majority of those areas is within the 5.2 management prescription, Forest Vegetation - Vegetation Management, and are managed to maintain or restore vegetation to achieve multiple resource values. Areas harvested for timber are not managed to promote growth and yield, but harvesting is conducted for stewardship purposes along with prescribed fire and other mechanical treatment management techniques. There are limited timber sales to local sawmills of less than 250,000 board feet per year. No additional pollutant loads to streams are expected to occur from timber harvesting with implementation of best management practices.

Grazing

Livestock grazing occurs within allotments in the Strawberry Reservoir watershed (Figure 2-6). The land is managed by the US Forest Service, which leases out the land for grazing activities. It is expected that animal waste makes up a part of the phosphorus loading to the reservoir, although the portion of phosphorus loading attributable to grazing activities could not be determined from the available data. Livestock and wildlife generally have direct access to the tributaries of the reservoir for watering although riparian fencing and off-site water developments are becoming more prevalent. Overall, improved awareness of water quality concerns relative to grazing management practices are having a positive effect on the watershed.

Roads

U.S. Highway 40 passes through the watershed and is used by visitors as the primary access to Strawberry Reservoir. The watershed is accessible by 207 miles of classified roads. Approximately 40 miles of inventoried trails are also used to access the Forest. The Roads Analysis for the Uinta National Forest provides information for all roads within the forest boundaries, including all roads within the Strawberry Reservoir watershed. Results of the analysis show that 35 miles of road analyzed for the Strawberry watershed are rated as high risk for contributing sediment. These included

- Trout Creek road
- Devils Notch road
- Mill B road
- Squaw Creek road
- Clyde Creek road
- Chipman road
- Clyde Creek timber sale road

These roads correlate with higher levels of stream sedimentation as determined by the USFS sedimentation analysis. The Forest Plan provides unique standards and guidelines for managing forest roads and motorized trails. To minimize soil erosion, it will be imperative to implement these standards and guidelines that will in turn eliminate increased pollutant loads from future construction and maintenance of the roadways.

Oil and Gas Development

There is a proposed lease within the Strawberry Reservoir watershed for oil and gas exploration, development, and production with a decision date of July 2006 following a yearlong scoping period. As no decision has been made on whether to approve the lease this discussion will focus on the regulatory requirements and recommendations for permitting as it pertains to maintaining and improving water quality within Strawberry Reservoir. Strawberry Reservoir is classified as High Quality Waters – Category 1 in which new point source discharges of wastewater, treated or otherwise, are prohibited in such segments after the effective date of designation. In addition, due to the vital importance of Strawberry Reservoir as a premier fishery as well as one of the primary sources of municipal water for the Wasatch Front we recommend that all oil and gas developments and other permitted activities associated with it, be required to obtain individual permits to ensure that water quality is protected.

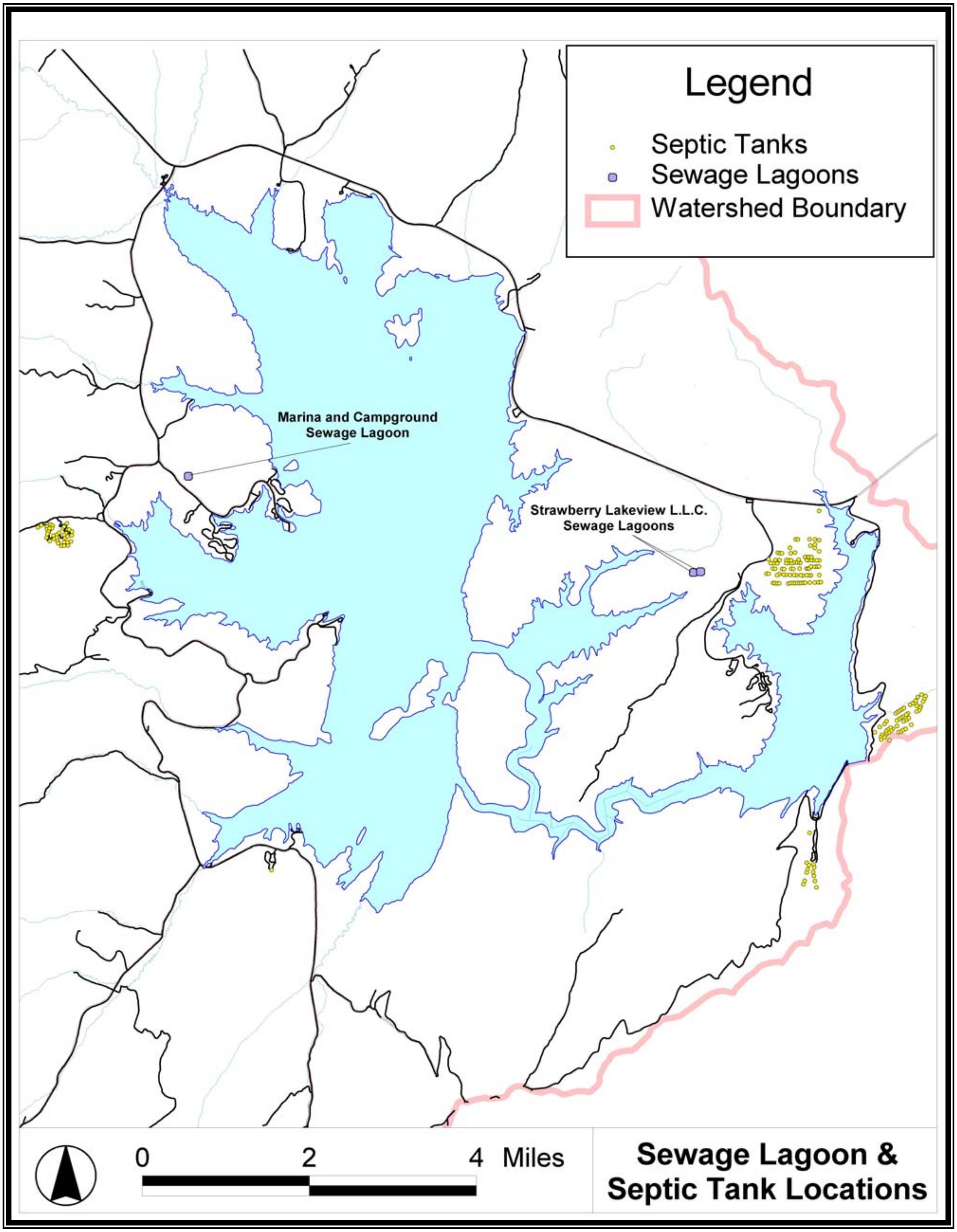


Figure 4-9 Septic Tank and Sewage Lagoon Locations

5.1 Introduction

The Total Maximum Daily Load (TMDL) process is an analytical method included within the Clean Water Act to determine the maximum amount of contaminants that a water body can contain and still support all of its beneficial uses. This chapter discusses in detail the TMDL that is being established for Strawberry Reservoir to address the water quality problems that have been explained in the Technical Analysis section. This chapter reviews how water quality endpoints would be achieved and maintained through actual load reductions from the sources.

5.2 Endpoints

Endpoints have been determined from the analysis described in the Technical Analysis section, and are shown in Table 5-1. Current data indicate that, for the most part, these endpoints have been achieved. The four endpoints identified are meant to maintain and control the overall health of the reservoir and the fishery.

Table 5-1 Summary of Recommended Targets / Endpoints

Parameter	Proposed Target
Dissolved Oxygen	>50% of the water column above 4 mg/L
Total Phosphorus Load to Reservoir	15,100 lbs/yr
Average TSI	40-50
Fish habitat Indicator	No Fish Kills
Blue-Green Algae	Decrease the Dominance of Blue-Green Algae

5.3 Dissolved Oxygen – Phosphorus Linkage

One of the essential components of developing a TMDL is to establish a link between predicted nutrient loads and the numeric indicators that have been chosen to measure the attainment of uses. Once this link has been established, it is possible to determine the total capacity of the water body to assimilate nutrient loadings while still supporting its designated uses. Allowable loads can then be allocated among the various pollutant sources.

The link can be established by using one or more analytical tools. Ideally, the link is based on a long-term set of monitoring data that allows an association to be developed between certain water body responses to flow and loading conditions. More often, however, the link must be established by using a combination of monitoring data, statistical and analytical tools (including simulation models), and best professional judgment.

In an effort to identify the target loading rates, total phosphorus and total suspended solids budgets were prepared using a mass balance approach. These budgets were used to establish specific targets, and then specific criteria were extrapolated. Tools used in this analysis and a summary of findings are described below, detailed analysis is described in Section 3.7 - Water Quality Target Analysis / Endpoints section.

Vollenwieder Loading Plots show that the two bay areas (East Portal Bay and Soldier Creek area) are bordering on mesotrophic to eutrophic conditions. The main body of the reservoir, however, shows a healthy system of low mesotrophic bordering on oligotrophic.

Trophic State Index (TSI) Analysis consistently placed the reservoir in the 40 to 50 range since 1996 which classifies the reservoir, as a whole, in the mesotrophic range. Also TSI has slowly been decreasing since 1990 that indicates improvement over that time (See Figure 5-1). The results of the analyses seem to indicate a fairly healthy reservoir that can be classified as stable.

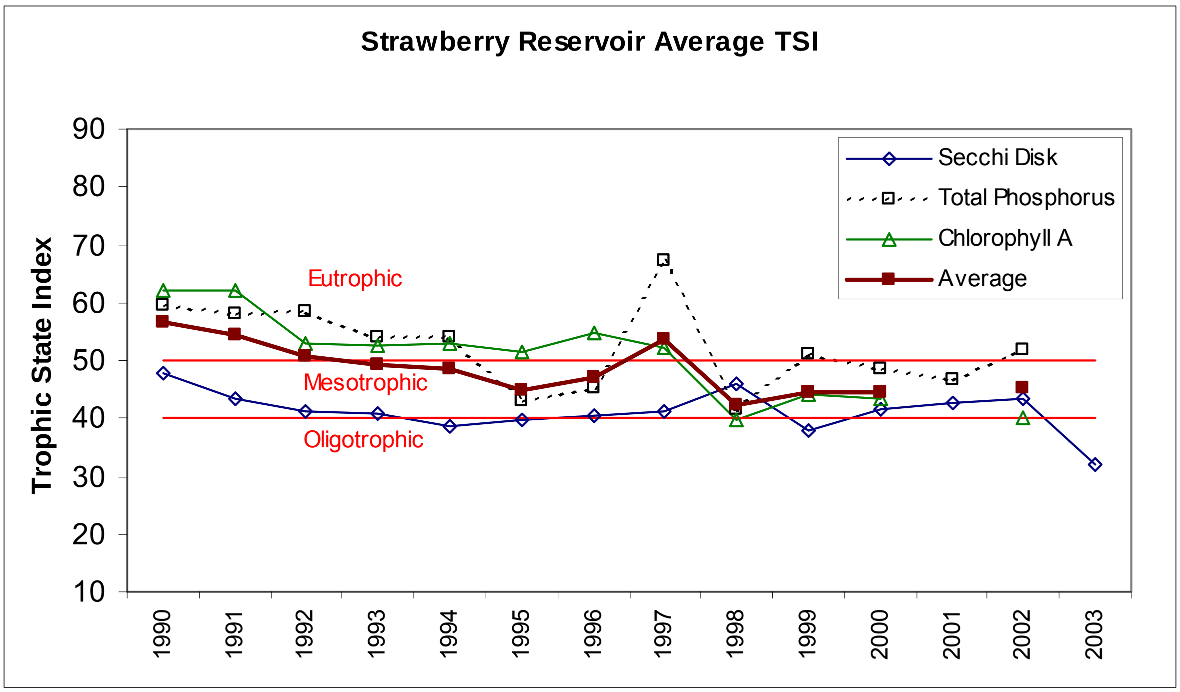


Figure 5-1 Strawberry Reservoir Trophic State Index

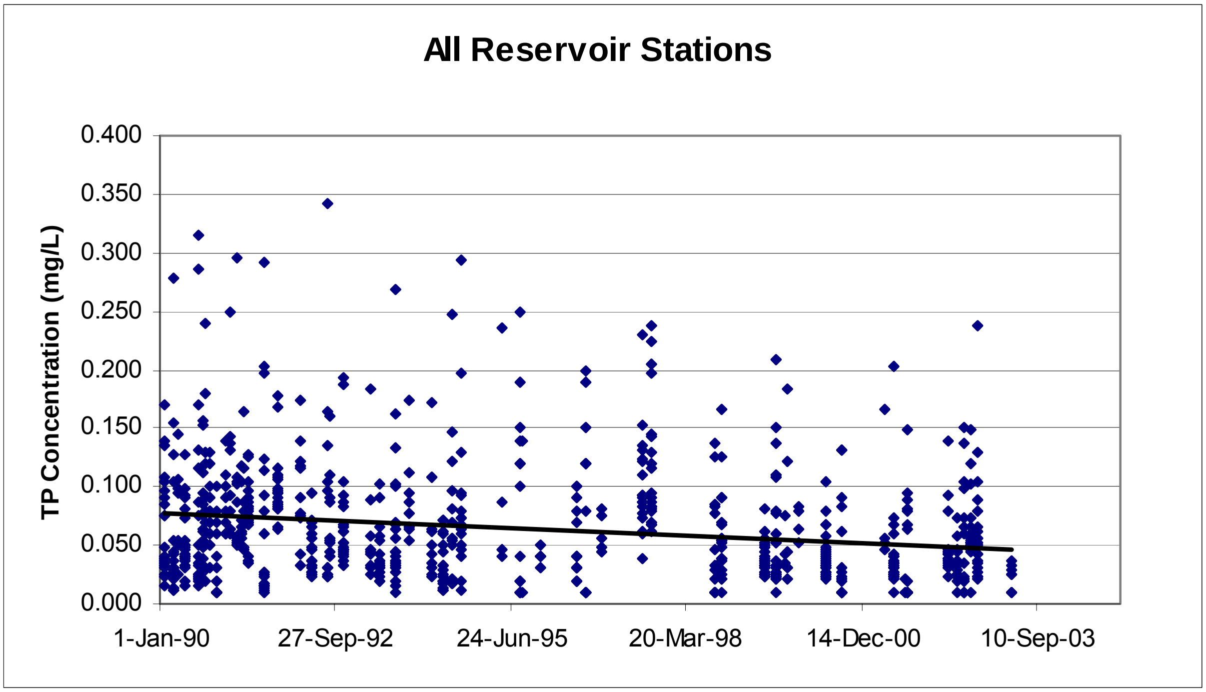


Figure 5-2 In-Lake Total Phosphorus Trends for Strawberry Reservoir

Figure 5-2 shows the total phosphorus trend in Strawberry Reservoir since 1990. Overall the concentrations are declining. Similar plots for each station within the reservoir are shown in Appendix F – In-Lake Total Phosphorus Trends. For the period from 1990 to 2003, both the average total phosphorus concentrations, as well as the TSI have been steadily decreasing. This would imply a correlation between Total Phosphorus and general health of the reservoir.

The current condition and recent trends of the reservoir's health indicate drastic actions are not warranted, but instead, current and planned management efforts have and will continue to improve the quality and sustainability of Strawberry Reservoir's fishery.

5.4 Load Allocations

The TMDL load allocation assigns loads to all sources including point, non-point and background sources. In addition, a margin of safety (MOS) is included to account for the uncertainty inherent in the analysis and ensure that beneficial uses are protected into the foreseeable future. The MOS is a required part of the TMDL development process. There are two basic methods for incorporating the MOS (USEPA, 1991). Implicit methods incorporate the MOS using conservative model assumptions to develop allocations. Explicit methods specify a portion of the total TMDL as the MOS, allocating the remainder to sources. For the Strawberry Reservoir TMDL, the MOS was included implicitly through conservative assumptions and explicitly by allocating 5 percent of the loading capacity, or 755 lbs/yr to the MOS.

The current watershed loading collectively equals 15,100 lbs per year of total phosphorus. Load reductions are allocated to the entire watershed to support the watershed-scale improvement projects that are planned in the near future.

Table 5-2 Total Phosphorus TMDL Load Allocations (lbs / year)

Source	Current	Allocation	Reduction
Strawberry River	3,100	3,025	75
Indian Creek	400	400	0
Co-op Creek	900	880	20
Clyde Creek	300	295	5
Trout Creek	100	100	0
Chipman Creek	800	785	15
Mud Creek	300	300	0
Broad Hollow	200	200	0
Other Stream Inflows	1,700	1,700	0
Sheet Flow to Res.	2,300	2,300	0
The Ladders[1]	4,100	4,100	0
Release From Bottom Sediments	900	0	900
Future Sources		260	
Margin Of Safety		755	
TOTAL	**15,100**	**15,100**	**1,015**

[1]It is anticipated that future loads from The Ladders may average 5,500 lbs/yr due to changes in reservoir operations to accommodate full CUP deliveries .

The majority of the needed load reduction will come from the flushing of total phosphorus from bottom sediments out of the reservoir. Recent data show a net export of total phosphorus of approximately 4,000 lbs/year, well above the needed 900 lbs/year. Remaining load reductions were allocated proportionally among the tributary streams that have exceeded the 0.05 mg/L indicator value for total phosphorus, including Co-op Creek, Clyde Creek, Trail Hollow (tributary to Chipman Creek), and Strawberry River.

Even though water quality conditions currently exceed the State's indicator values and for total phosphorus and dissolved oxygen, the reservoir is currently believed to be supporting its Cold Water Fishery beneficial use (3A). It is expected that current and proposed management and operational practices will continue to improve conditions within the water column.

5.5 Public Participation

Public participation for this TMDL was accomplished through a series of open meetings with the Friends of Strawberry Valley Committee (FOSV). FOSV is comprised of private individuals and agency personnel who represent key interests within the watershed. Their mission is to promote ecosystem health through balanced integration of multiple use interests, and provide input and support to Strawberry Valley Management Agencies. The presentations to the committee are provided in Appendix D. Some of the members of FOSV include:

- Fishermen and Anglers
- The Strawberry Water Users
- Wasatch County
- The U.S. Forest Service
- Utah Division of Wildlife Resources
- U.S. Bureau of Reclamation

- Central Utah Water Conservancy District
- Allotment Permitees

Public comment on the TMDLs was solicited with a notice published in the Salt Lake Tribune on TBA. The comment period was opened on TBA and closed on TBA. Formal comments and responses are included in Appendix ?.

In addition, the TMDL and dates for public comment were posted on the Division of Water Quality's website at (www.deq.state.ut.us/EQWQ/TMDL/TMDL_WEB.HTM).

6.1 Introduction

The purpose of this section is to provide methods and management practices that will reduce phosphorus loading into the reservoir thereby reducing algal growth and improving dissolved oxygen concentrations within the reservoir. Load reductions into the reservoir are primarily accomplished through watershed management practices that decrease the amount of phosphorus entering the reservoir directly or through its tributaries. Reservoir treatment techniques and operational management strategies may also be able to improve the quality of the water in Strawberry Reservoir.

6.1.1 Stream & Watershed BMPs

The Strawberry Reservoir watershed has been the subject of several previous studies aimed at improving water quality through the implementation of Best Management Practices (BMPs). The recommendations within the 2004 Forest Service Watershed Restoration Plan and the 1988 Mountainland Association of Governments Strawberry Valley Non-Point Source Watershed Plan are summarized in Table 6-1. It should be recognized that some of the projects listed below may result in short term negative effects but will ultimately result in long term benefits to water quality.

Table 6-1: Stream & Watershed BMPs

BMP	Description	Desired Result
Road Maintenance	Regular and preventive road maintenance reduces erosion	Decreased loading of sediments and nutrients to streams.
Dispersed Recreation Management	Site rotation, hardening, limits, closure, etc. reduce erosion from sites	Decreased loading of sediments and nutrients to streams.
Grazing Management	Maintain sufficient vegetative cover to minimize hillslope erosion	Decreased loading of sediments and nutrients to streams.
Streambank Stabilization	Decrease erosion through • Revegetation • Instream structures • Streambank contouring • Altered grazing system • Stream corridor protection • Vegetative Buffer Strips	Decreased loading of sediments and nutrients to streams. Decrease bank trampling. Improved buffering capacity of riparian vegetation.
Management of Beaver Dams	Appropriate management of beaver dams depending on goals and objectives.	Beaver dams may have both positive and negative effects based on their location and the conditions within the stream. Beaver dams allow for improved settling of solids and decreased stream velocities. The removal of beaver dams promotes improved fish spawning habitat.

BMP	Description	Desired Result
Off-Channel Watering	Provide water sources away from streams and the reservoir for wildlife and livestock.	Decrease stream bank trampling, reduce animal waste and sediment load into streams.
Fishery Management and Stocking Practices	Management by UDWR to control various characteristics of the fishery.	Maintain the fishery
Watershed Groundcover	At least 70 percent of the watershed covered.	Groundcover helps prevent erosion. Decreased erosion reduces sediment and nutrient loads to streams.
Limit Herbicides and Fertilizers	Limit application to specific target plants species following manufacturer recommendations. Eliminate application along stream corridors.	Decrease nutrients introduced into the watershed through fertilizers protect riparian vegetation.

6.1.2 In-Reservoir BMPs

The following management practices have been identified as having potential for reducing the amount of phosphorus released from the sediments in Strawberry reservoir. As the total loading from in-lake sources makes up only approximately 6 % of the total loading into Strawberry Reservoir, it is unlikely that any of the following options are economically viable if the cost per unit loading removed were to be considered. It is likely that removal of external loads which make up the remaining 94 % of the total loading to the reservoir would be much more cost effective, and is a necessary step prior to implementing some of the reservoir treatments discussed below.

Phosphorus Inactivation

In some cases, phosphorus release from the sediments can be controlled through the addition of aluminum salts to the water column resulting in an aluminum hydroxide floc that settles to the sediment surface forming a barrier to further release, even if anoxia persists (Cooke et al., 1993). This method has been used in many lakes and has proven to be effective in many cases. In every case, however, the successful inactivation of phosphorus release from the sediments must be preceded by the reduction or elimination of external phosphorus loads.

Pros: Addition of aluminum salts can result in both precipitation and removal of phosphorus in the water column and in the inactivation of phosphorus release from enriched sediments. This dual removal mechanism can significantly speed recovery of a treated water body after external loading has been controlled.

Cons: Aluminum can be toxic to fish and other aquatic life, particularly under acidified conditions. There have been relatively few studies of the effects of alum treatment on lake biota. Benthic invertebrate density and species richness can decline after treatment, but this is not always the case. Costs are high, especially with a potential treatment area as large as Strawberry Reservoir. This method has been shown to be ineffective if external phosphorus loads are not reduced or eliminated.

Potential for Use in Strawberry Reservoir: Reductions in water column phosphorus concentration of approximately 50 % have been observed, and two orders of magnitude reductions in phosphorus release rates from sediments have also been observed. However, observed reductions are lake and dose specific. Although chemical conditions in Strawberry Reservoir are conducive for phosphorus entrainment, it is unlikely that sufficient funds or an operation large enough to treat the affected area of the reservoir could be put in place.

Hypolimnetic Withdrawal

Hypolimnetic withdrawal involves the preferential removal of nutrient enriched waters in the hypolimnion through siphoning, pumping, or selective discharge from a control structure (dam). According to Cooke et al. (1993), this has been shown to be effective at accelerating phosphorus export, reducing surface phosphorus concentrations, and improving hypolimnetic oxygen content.

Pros: Reduced phosphorus concentrations in the hypolimnion, increased dissolved oxygen in the hypolimnion, and reduction in the rate of phosphorus release from sediments have all been observed in lakes where hypolimnetic withdrawal has been implemented. Reductions in epilimnetic phosphorus concentrations have also been observed.

Cons: Discharge of hypolimnetic anoxic water may contain high concentrations of phosphorus, ammonia, hydrogen sulfide, and metals and may cause a water quality problem downstream. Mixing of hypolimnetic water with epilimnetic water may minimize adverse downstream effects.

Potential for Use in Strawberry Reservoir: Withdrawals from Strawberry Reservoir are already primarily from the hypolimnion, and so further export of phosphorus from the reservoir via this mechanism is unlikely.

Artificial Circulation

This technique is used to prevent or eliminate thermal stratification through the mixing action of a rising column of air bubbles or through some other mechanical means. It has been shown to improve dissolved oxygen concentrations, and it can also decrease light penetration that limits algal growth in situations where nutrients are uncontrollable and can neutralize the factors favoring dominance by blue-green algae (Cooke et al., 1993).

Pros: Artificial circulation can mix the entire lake, increasing temperature and dissolved oxygen in the hypolimnion and prevent stratification. This method can reduce internal loading of phosphorus if the primary mechanism controlling solubility of phosphorus in sediments is iron redox chemistry.

Cons: In some instances, circulation can increase nutrient availability in the photic zone and may actually increase algal biomass. In many applied cases, circulation was inadequate to cause complete mixing, and limited results were observed (Cooke et al., 1993).

Potential for Use in Strawberry Reservoir: In general, water bodies treated with this mechanism are orders of magnitude smaller than Strawberry Reservoir, and in many cases the devices used to create the circulation were inadequate to cause complete mixing. This option is likely not feasible for all of Strawberry Reservoir due to the size of the reservoir. However, circulation may be feasible in isolated portions of the reservoir that exhibit seasonal water quality problems, for example in the Soldier Creek dam area. It is unlikely that a cost effective system designed to destratify the entire reservoir could be put in place. In addition, this is not a permanent solution.

Sediment Removal

Sediment removal achieves a reduction in internal phosphorus loading through the complete removal of the enriched sediment layer. It has a significant advantage over nutrient inactivation in that the source is actually removed rather than just covered over. Limitations to dredging of sediments include relatively high costs and the requirement of an adequate disposal site for the removed sediments. Elimination of external loading of phosphorus is required for sediment removal to be a viable long term treatment.

Pros: Completely removes phosphorus rich sediments.

Cons: Large volumes of sediments must be removed and disposed of in an appropriate disposal site. Dredging can cause the re-suspension of sediment and subsequent release of nutrients, and the destruction of benthic organisms. Costs associated with dredging and storage and disposal of removed sediments can be high. Sediment removal should also be regarded as a temporary solution unless external loading is also reduced.

Potential for Use in Strawberry Reservoir: Theoretically, a nearly 100 percent reduction in internal loading could be realized if all of the affected sediments were removed from Strawberry Reservoir. However, costs associated with the dredging operation and associated treatment and storage facility for removed sediments would likely be prohibitively expensive. In addition, public perception of this option would likely be negative.

Hypolimnetic Aeration

Hypolimnetic aeration has been shown to be effective at increasing dissolved oxygen in the hypolimnion (and therefore limiting anoxic conditions under which phosphorus would be released from the sediments) without de-stratifying the lake or reservoir (Cooke et al., 1993). This is generally accomplished with an air lift device, which brings cold hypolimnetic water to the surface where gases are exchanged, followed by its return to deep water.

Pros: Increases the oxygen content of the hypolimnion without de-stratifying the water column or warming the hypolimnion, and thus increases the oxygen content at the sediment water interface reducing the potential for phosphorus release from the sediments.

Cons: Aerobic sediments do not always preclude phosphorus release, which is the case where phosphorus release is not controlled by iron redox chemistry. This method is not a permanent solution. Hypolimnetic phosphorus concentrations have been observed to return to preaeration levels relatively rapidly after aeration is discontinued. The largest lakes treated are orders of magnitude smaller than Strawberry Reservoir, and this option is not considered feasible.

Potential for Use in Strawberry Reservoir: Reductions in hypolimnetic phosphorus concentrations of between 30 and 60 % have been observed in some lakes treated with hypolimnetic aeration. However, this option is not considered viable because it is not permanent and is likely not feasible due to the large area that must be treated.

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