VERDIGRIS BASIN TOTAL MAXIMUM DAILY LOAD

Waterbody / Assessment Unit (AU): Fall River Lake
Water Quality Impairment: Eutrophication bundled with Siltation and Dissolved Oxygen

1. INTRODUCTIONS AND PROBLEM IDENTIFICATION

Subbasin: Fall **HUC 8 (HUC 10):** 11070102 (01, 02)

Ecoregion: Flint Hills (28) **Counties:** Mostly Greenwood

Drainage Area: Approximately 550 square miles **(Figure 1)**

Conservation Pool: Surface Area = 2330 acres (3.64 square miles)
Watershed/Lake Ratio = 151:1
Maximum Depth = 7.0 meters; Mean Depth = 3.0 meters
Storage Volume = 19,245 acre-feet
Estimated Retention Time = ~0.06 years
Mean Annual Inflow = 330,600 acre-feet (1994-2008)
Mean Annual Discharge = 308,840 acre-feet (1994-2008)
Year Completed: 1949

Designated Uses: Primary Contact Recreation (A); Expected Aquatic Life Support; Domestic Water Supply; Food Procurement; Ground Water Recharge; Industrial Water Supply; Irrigation Use; Livestock Watering Use

303(d) Listings: 2002, 2004 & 2008 Verdigris River Basin Lakes

Impaired Use: All uses are impaired to a degree by eutrophication

Water Quality Standard: Nutrients – Narratives: The introduction of plant nutrients into streams, lakes, or wetlands from artificial sources shall be controlled to prevent the accelerated succession or replacement of aquatic biota or the production of undesirable quantities or kinds of aquatic life (K.A.R. 28-16-28e(c)(2)(A)).

The introduction of plant nutrients into surface waters designated for primary or secondary contact recreational use shall be controlled to prevent the development of objectionable concentrations of algae or algal by-products or nuisance growths of submersed, floating, or emergent aquatic vegetation (K.A.R. 28-16-28e(c)(7)(A).

Suspended Solids – Narrative: Suspended solids added to surface waters by artificial sources shall not interfere with the behavior, reproduction, physical habitat or other factors related to the survival and propagation of aquatic or semi-aquatic or terrestrial wildlife (K.A.R. 28-16-28e(c)(2)(B)).

Dissolved Oxygen: The concentration of Dissolved Oxygen in surface waters shall not be lowered by the influence of artificial sources of pollution. Dissolved Oxygen (DO): 5mg/L (K.A.R. 28-16-28e(d) Table 1g).

2. CURRENT WATER QUALITY CONDITION AND DESIRED ENDPOINT

Level of Eutrophication:

Overall Average (1989-2007): Trophic State Index = 51.2, Slightly Eutrophic
Chlorophyll *a* = 8.9 ug/l
Recent Condition (2001-2007): Trophic State Index = 52.3, Slightly Eutrophic
Chlorophyll *a* = 9.3 ug/l

The Trophic State Index (TSI) is derived from the chlorophyll *a* concentration (chl-a) as seen below. Trophic state assessments of potential algal productivity were made based on chlorophyll *a* concentrations, nutrient levels and values of the Carlson Trophic State Index (TSI). Generally, some degree of detrimental eutrophic condition is seen with chlorophyll *a* concentrations over 12 µg/l and hypereutrophy occurs at levels over 30 µg/l.

1. Oligotrophic	TSI: <40	chl a < 2.7 µg/l
2. Mesotrophic	TSI: 40-49.99	chl a < 7.2 µg/l
3. Slightly Eutrophic	TSI: 50-54.99	chl a < 12 µg/l
4. Fully Eutrophic	TSI: 55-59.99	chl a < 20 µg/l
5. Very Eutrophic	TSI: 60-63.99	chl a < 30 µg/l
6. Hypereutrophic	TSI: ≥ 64	chl a > 30 µg/l

Level of Dissolved Oxygen Deficiency: Low dissolved oxygen (DO) concentrations are consistently encountered at varying depths in the lake each year. Occasionally, the aerated portion of the lake is quite shallow, as in 2001 (Figure 2). DO profiles in 2004 and 2007 followed a more typical pattern with depths to 4 meters maintaining adequate DO. Turbidity diminishing light penetration and photosynthetic production of oxygen, as organic matter accumulates at the lower depths accounts for the depletion of oxygen with depth.

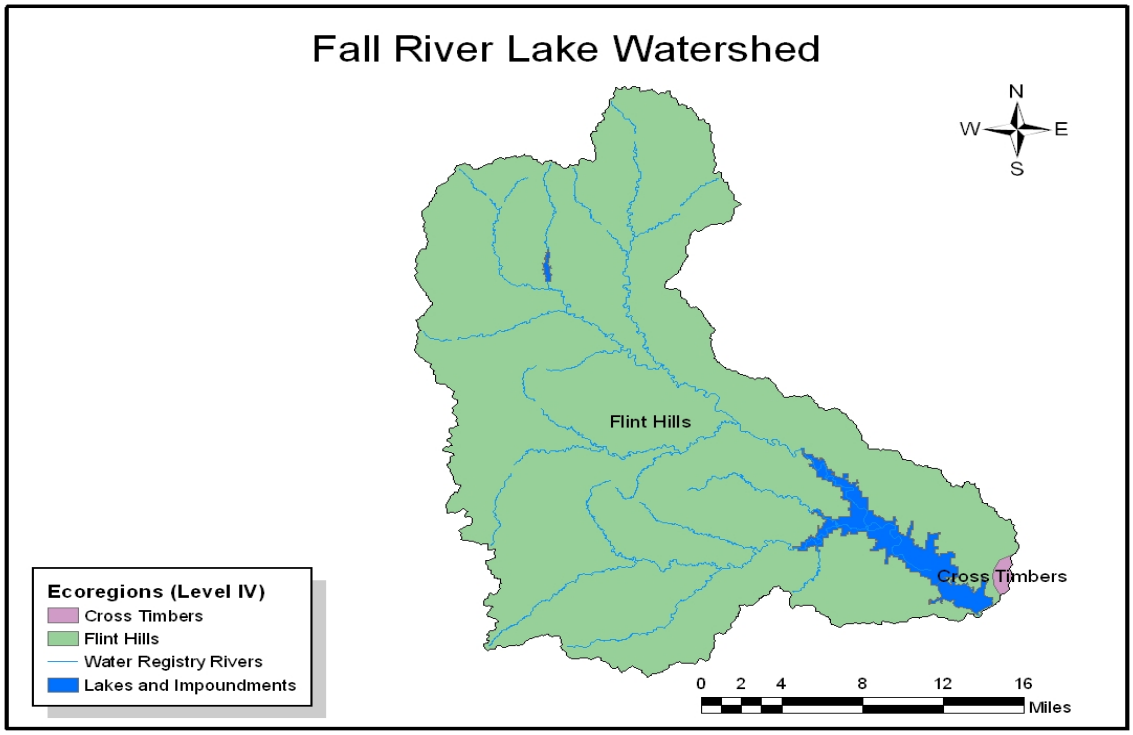

Figure 1. Fall River Lake and its Watershed

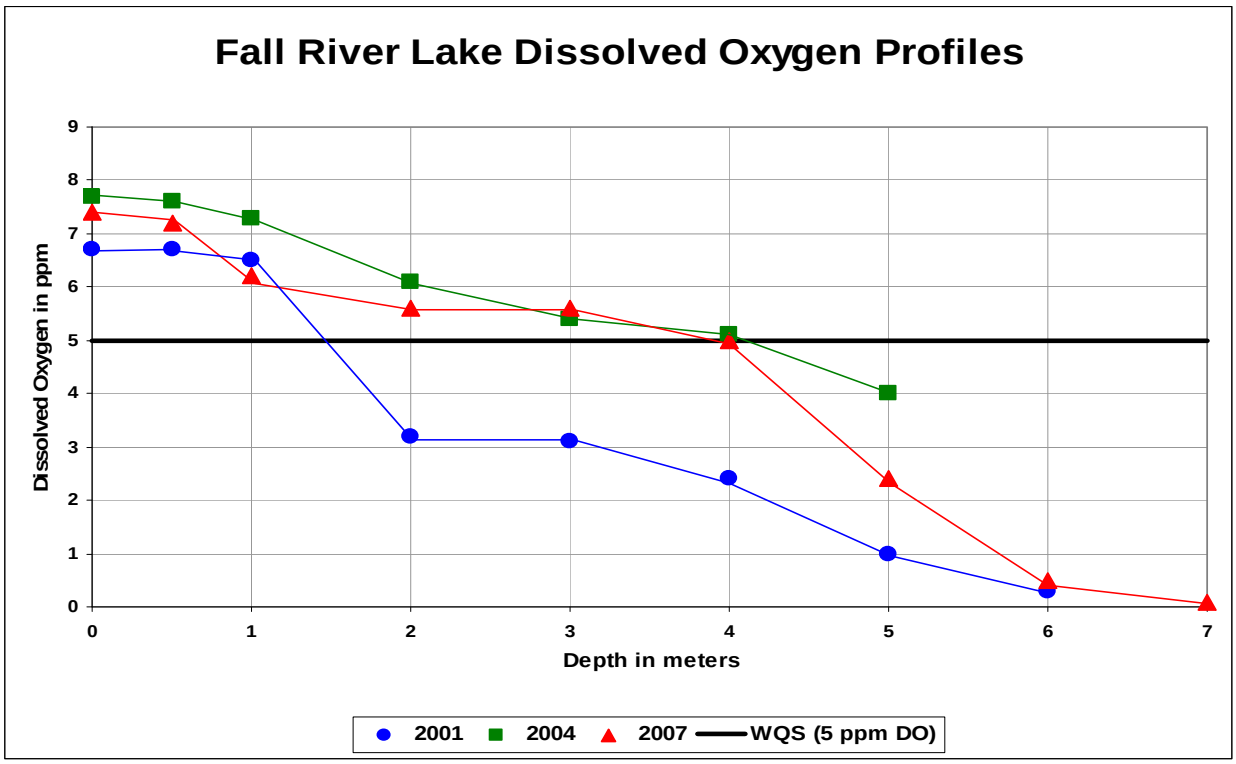

Figure 2. Fall River Lake Dissolved Oxygen Profiles

Level of Siltation Impairment: Fall River Lake has high inorganic turbidity and high levels of siltation. The lake is shallow and sediment is re-suspended easily due to wind, motorboat traffic, and moderate to high inflow events. In addition, siltation is aggravated during large runoff events, when releases from Fall River Lake are minimized to accommodate flood control along the Verdigris and Fall Rivers, which causes large silt deposits within the lake and the inflowing river channels. Subsequent runoff events of moderate duration then re-distribute the deposited sediment throughout the lake.

Lake Chemistry Monitoring Sites: KDHE Station LM023001 in Fall River Lake.
Period of Record Used: Eleven surveys conducted by KDHE in calendar years; 1975, 1978, 1981, 1986, 1989, 1992, 1995, 1998, 2001, 2004, and 2007.

Lake Inflow and Outflow Data: U.S. Army Corps of Engineers, Tulsa District Office
Period of Record Used: 1994-2008

Stream Chemistry Monitoring Sites (Period of Record Used):
Station 574 on Otter Creek, south of Climax (1990-2007)
Station 575 on Fall River, northeast of Climax (1990-2007)

Hydrologic Conditions: The Fall River flows into Fall River Lake after its confluence with Otter Creek. The watershed is dominated by the East and West Branches of Fall River, Otter Creek and Spring Creeks. Estimated flow conditions from these four stream segments are provided in **Table 1** (Perry, 2004).

Stream	Drainage Area	Mean Flow	Median Flow	10-yr Peak Flow
EB Fall R	73 sq.mi.	43 cfs	6.9 cfs	13,900 cfs
WB Fall R	98 sq.mi.	60 cfs	10.5 cfs	18,100 cfs
Spring Crk	85 sq.mi.	56 cfs	9.0 cfs	21,700 cfs
Otter Crk	153 sq.mi.	104 cfs	12.3 cfs	29,700 cfs

Table 1. **Fall River Lake Watershed – Major Streams and Associated Flows**

Comparing the mean flows to the medians, there is a large drop in flow magnitude, conversely, there is a three order of magnitude increase between average flows and peak flows. Baseflow separation of existing daily flow record at USGS gaging stations on Otter Creek and Fall River, indicate approximately 19% of the flows is baseflow. Thus, the watershed tends to be flashy during rainfall events but otherwise does not sustain flow during extended dry periods. Estimated long-term flow duration curves for the two main streams in the watershed are marked by truncated curves, indicating no flow periods occur on the streams **(Figure 3).** Peak flows do not occur until the upper decile flow (10%) is surpassed. The extended slope of the curves indicates the watershed drains steadily once rains cease with little support from baseflow. The majority of the watershed is underlain by the Pennsylvanian Wabaunsee Group of thick, water-tight shales. Thus, little ground water exists above the lake, except in the stream alluvium. Water use reported to the state for 2006 indicated only 20 acre-feet of ground water was used in all of Greenwood County. Surface water is used predominantly by municipalities and irrigators. The Corps estimates monthly lake inflows and outflows **(Figure 4).**

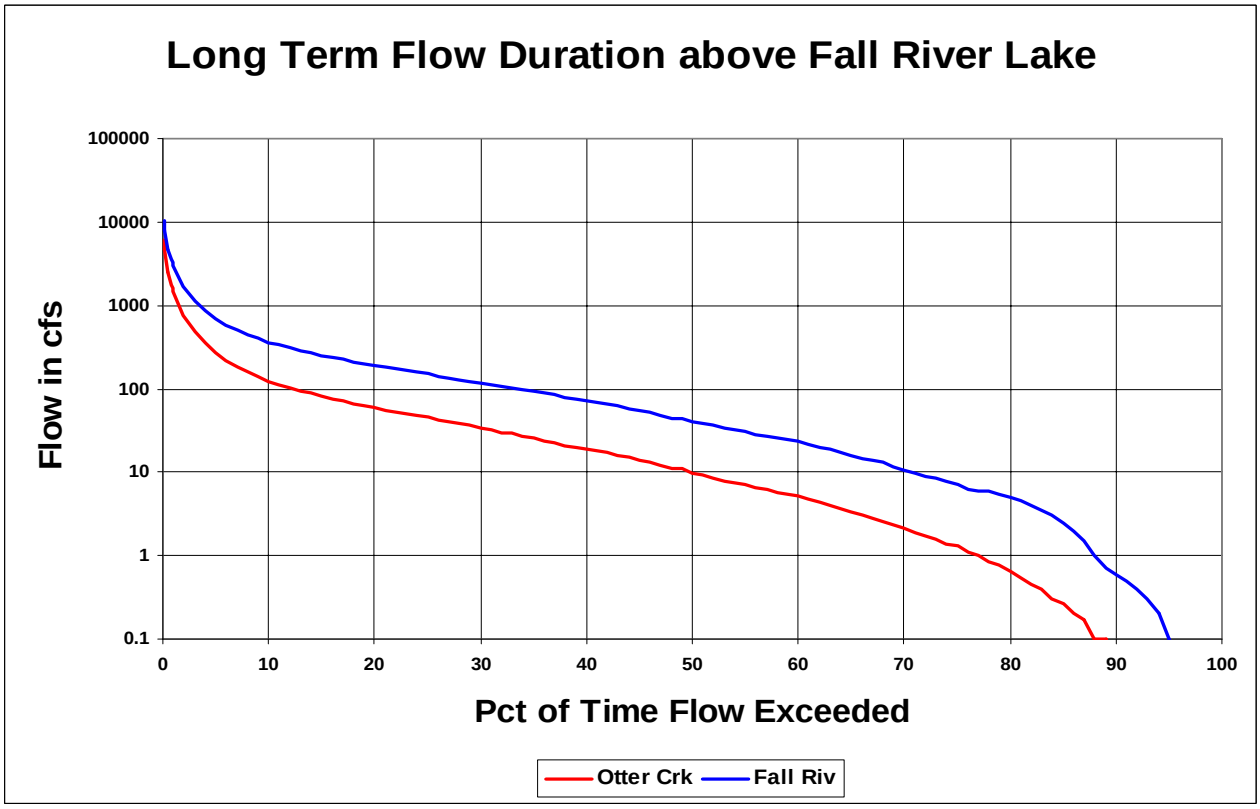

Figure 3. Estimated Long-Term Flow Duration Curves for Fall River & Otter Creek

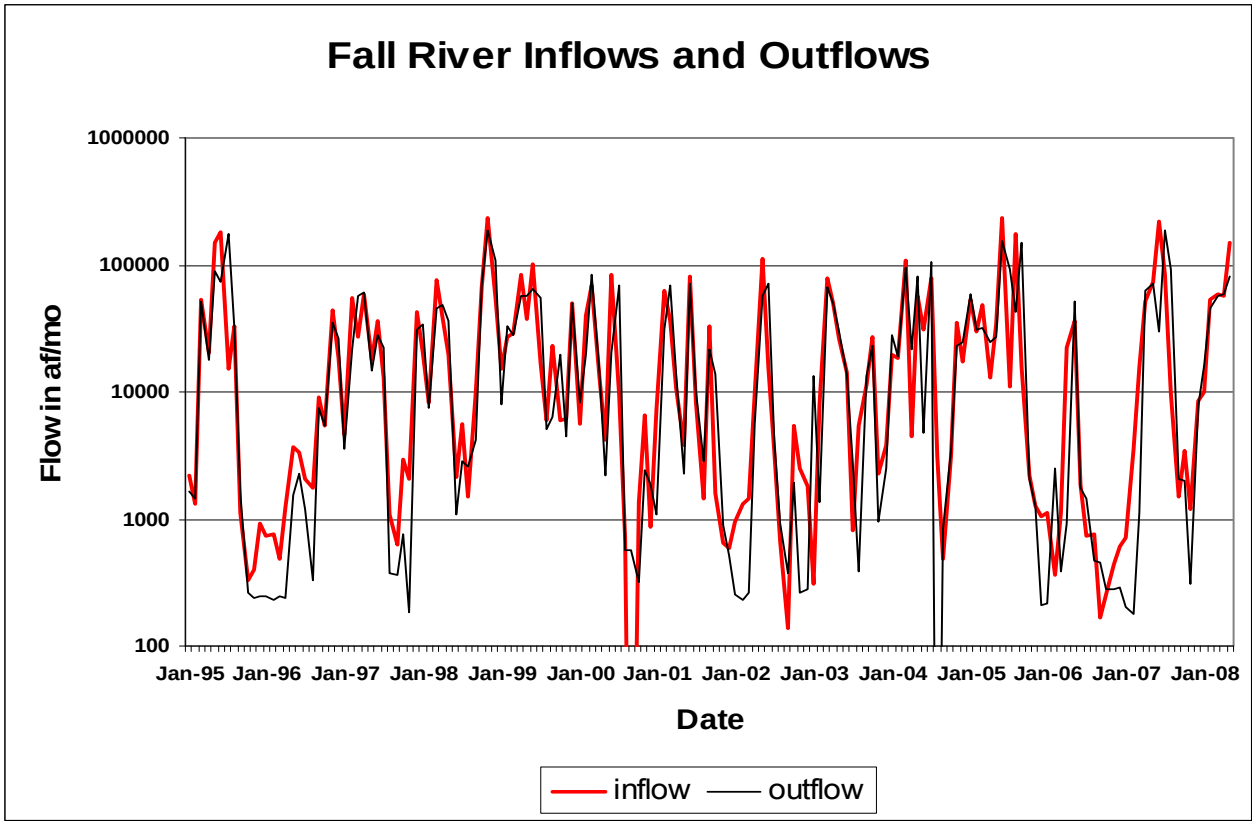

Figure 4. Tulsa District Estimates of Monthly Fall River Lake Inflow & Outflow

Monthly plots of water entering and leaving Fall River Lake nearly align on top of one another. The average inflow into Fall River Lake over 2004-2008 is 463 cfs, while the average outflow is 447 cfs. Residence time of water in the lake is about 21 days. Therefore, the water column of the lake is flushed out within each month. Otter Creek makes up about 25% of the flow entering the lake with the remainder distributed along Fall River and its branches.

The lake averages 36 inches of precipitation annually and 53 inches of evaporation. The net evaporative loss of water accounts for the difference between average inflow and outflow from the lake. The conservation storage is maintained at 948.5 feet MSL and current estimates of available storage are 19,245 acre-feet, a decrease of 25% from the original storage volume in 1949. The last bathymetric survey was completed in 1990 and a new survey is scheduled for 2010.

Fall River Watershed Joint District #21 exists above the lake and has constructed 28 impoundments throughout the Fall River watershed. Approximately 51% of the watershed is controlled by these watershed structures and there remains up to eight projects to be constructed, which would increase the controlled area to 55%. Another Watershed District exists along Otter Creek, but few structures have been completed in that watershed. There are also over 800 small farm ponds throughout the drainage. Over 50% of first and second order streams and 30% of third order streams have been "separated" from the lake watershed (Fall River WRAPS, 2004). .

Current Water Quality Condition: The chlorophyll *a* (chl-a) concentration average over 1978 – 2007 is 9 µg/L. Annual concentration averages exceeded 10 µg/L in the sampling years of: 1975, 1981, 1995 and 1998, with the maximum of 36 µg/L occurring in 1975. The more recent chlorophyll *a* concentration average for KDHE samples obtained from 1995-2007 is 10.6 µg/L. **Table 2** summarizes water quality characteristics of Fall River Lake during the 11 surveys taken since 1975. Low chlorophyll generally is the rule and is likely driven by the elevated levels of suspended solids and turbidity. Phosphorus levels are high enough to trigger algal production if light was not a limiting factor. Average TP concentrations are 54 µg/L, while water column TSS and turbidity levels average 21 mg/l and 23 NTU, respectively. Secchi depths have been quite low, typically 1-2 feet, again because of high turbidity levels. Dissolved oxygen falls below the 5 mg/lmg/l water quality criterion at varying depths, with almost the entire water column compliant at times, while at other times, only the top 2-3 meters have sufficient oxygen.

Table 3 displays the various Carlson Trophic State Index values based on chlorophyll, total phosphorus and Secchi depth over 1989 – 2007. Values generated by chlorophyll levels indicate slight eutrophic conditions, whereas concomitant TSI values from total phosphorus suggest the lake would be very eutrophic. The difference is from limited light penetration. The TSI values derived from Secchi depths indicate hypereutrophy, but must be discounted because the limited Secchi depth occurs through inorganic turbidity not algal biomass. Nonetheless, the turbid state of Fall River Lake maintains low algal

populations. Since surface sampling typically occurs at 0.5 meters depth, small Secchi depths indicate light is diminished considerably and dampens primary productivity.

Yr	Depth	Chl a	TP	TSS	Turb	Secchi	DO<5 mg/l
1975	8.8 m	36 µg/l	---	16 mg/l	15	-----	2.7 m
1978	8.8 m	10 µg/l	---	24 mg/l	15	-----	7.9 m
1981	8.2 m	12 µg/l	60 µg/l	20 mg/l	19	-----	4.9 m
1986	8.5 m	5.5 µg/l	45 µg/l	15 mg/l	16	-----	5.0 m
1989	9.0 m	4.5 µg/l	55 µg/l	37 mg/l	52	0.35 m	8.0 m
1992	-----	5 µg/l	50 µg/l	20 mg/l	30	-------	------
1995	7.0 m	12 µg/l	55 µg/l	18 mg/l	12	0.30 m	3.0 m
1998	7.5 m	13 µg/l	65 µg/l	16 mg/l	22	0.28 m	7.0 m
2001	6.0 m	8 µg/l	62 µg/l	29 mg/l	24	0.33 m	2.0 m
2004	5.0 m	10 µg/l	51 µg/l	18 mg/l	20	0.67 m	5.0 m
2007	7.0 m	10 µg/l	33 µg/l	14 mg/l	19	0.58 m	5.0 m

Table 2. Water Quality Characteristics of Fall River Lake, 1975 - 2007

Yr	Trophic State Index based on:			Trophic State by Chl a	Trophic State by Total P
	Chl a	Total P	Secchi Depth		
1989	45	62	75	Meso	Very Eutro
1992	46	63	------	Meso	Very Eutro
1995	54.9	63	77	Slightly Eutro	Very Eutro
1998	55.5	64	78	Fully Eutro	Hypereutro
2001	51	63.7	76	Slightly Eutro	Very Eutro
2004	53	60.8	66	Slightly Eutro	Very Eutro
2007	53	54.6	68	Slightly Eutro	Slightly Eutro

Table 3. Trophic State in Fall River Lake as Indicated by Chlorophyll, Phosphorus & Secchi Depth

As a reference, two lakes residing in the overall Fall River watershed have also been sampled. **Table 4** indicates the water quality characteristics of Otis Creek Lake, located upstream of Fall River Lake, and Severy City Lake, located downstream of Fall River Lake. Although only sampled twice, the values represent the ideal condition that implementing water quality practices could achieve in Fall River Lake.

Lake	Yrs	Chl a	Total P	Secchi
Otis Creek	1995, 2007	5 µg/l	< 20 µg/l	2.4 meters
Severy City	1989, 2007	5.8 µg/l	< 20 µg/l	1.5 – 1.76 meters

Table 4. Water Quality Values from Reference Lakes in Fall River Watershed

The last five surveys over 1995 – 2007 were done with the lake in or near the boundary elevation of the conservation pool and flood pool (948.5 ft). Although 1995 saw a seven-foot drop in elevation in the days preceding sampling, the next three surveys saw pool elevation changes of less than 0.40 feet. The survey in 2007 occurred after the lake had dropped about 0.9 feet in recent days. Large pool changes indicate imbalance between inflows and releases as floodwaters are detained then released. Such instability in the lake would likely reflect turbid conditions.

The ratio of total nitrogen and total phosphorus is a common ratio utilized to determine which of these nutrients is likely limiting plant growth in Kansas aquatic ecosystems. Typically, lakes that are nitrogen limited have a water column TN:TP ratio < 8 (mass); lakes that are co-limited by nitrogen and phosphorus have a TN:TP ratio between 9 and 21; and lakes that are P limited have a water column TN:TP ratio > 29 (Dzialowski et al., 2005). Fall River Lake has varied between being nitrogen limited in 1992, 2001, and 2004; and co-limited by nitrogen and phosphorus in 1995, 1998, and 2007. Since 1992, chlorophyll *a* concentrations averaged 12 µg/L when the lake was co-limited by nitrogen and phosphorus and 7.7 µg/L when the lake was deemed to be nitrogen limited.

Table 5 lists six metrics measuring the roles of light and nutrients in Fall River Lake. Non-algal turbidity (NAT) values < 0.4 m^{-1} indicates there are very low levels of suspended silt and/or clay. The values between 0.4 and 1.0 m^{-1} indicate inorganic turbidity assumes greater influence on water clarity but would not assume a significant limiting role until values exceed 1.0 m^{-1}.

The depth of the mixed layer in meters (Z) multiplied by the NAT value assesses light availability in the mixed layer. There is abundant light within the mixed layer of the lake and potentially a high response by algae to nutrient inputs when this value is < 3. Values greater than 6 would indicate the opposite.

The partitioning of light extinction between algae and non-algal turbidity is expressed as Chl-a*SD (Chlorophyll *a* * Secchi Depth). Inorganic turbidity is not responsible for light extinction in the water column and there is a strong algal response to changes in nutrient levels when this value is > 16. Values < 6 indicate that inorganic turbidity is primarily responsible for light extinction in the water column and there is a weak algal response to changes in nutrient levels.

Values of algal use of phosphorus supply (Chl-a/TP) that are greater than 0.4 indicate a strong algal response to changes in phosphorus levels, where values < 0.13 indicate a limited response by algae to phosphorus.

The light availability in the mixed layer for a given surface light is represented as Zmix/SD. Values < 3 indicate that light availability is high in the mixed zone and there is a high probability of strong algal responses to changes in nutrient levels.

Shading values less than 16 indicate that self-shading of algae does not significantly impede productivity. This metric is most applicable to lakes with maximum depths of less than 5 meters (Carney, 2004).

The above metrics conclude that Fall River Lake generally has high levels of inorganic turbidity (suspended silt/clay particles) that limits light availability in the mixed layer, and throughout the water column, and there is a muted algal response to changes in phosphorus levels. According to these metrics, Fall River Lake is limited by light and nitrogen in 2001 and 2004 and limited by light, nitrogen, and phosphorus (co-limited) in 1998 and 2007.

Year	TN/TP	Non-algal Turbidity	Light Availability in the Mixed Layer	Partioning of Light Extinction between Algae & Non-algal Turbidity	Algal Use of Phosphorus Supply	Light Availability in the Mixed Layer for a Given Surface Light	Shading in Water Column due to Algae and Inorganic Turbidity
		NAT	Zmix*NAT	Chl-a*SD	Chl-a/TP	Zmix/SD	Shading
1998	14.4	3.25	9.81	3.56	0.20	10.76	7.91
2001	2.5	2.83	7.97	2.64	0.12	8.54	6.46
2004	6.8	1.24	2.99	6.67	0.20	3.59	3.90
2007	25.6	1.47	4.43	5.89	.31	5.20	5.26

Table 5. Metrics for Determining Limiting Factors of Light, Nitrogen & Phosphorus

Another method for evaluating limiting factors is the TSI deviation metrics. **Figure 5** (Multivariate Deviation Graph) summarizes the current trophic conditions at Fall River Lake by comparing TSI values from chlorophyll, phosphorus and Secchi depths. Where TSI(Chl-a) is greater than TSI(TP), the situation indicates phosphorus is limiting chlorophyll *a*, whereas negative values indicate turbidity limits chlorophyll *a*. Where TSI(Chl-a)-TSI(SD) is plotted on the horizontal axis, if the Secchi depth (SD) trophic index is less than the chlorophyll *a* trophic index, than there is dominant zooplankton grazing. Transparency would be dominated by non-algal factors such as inorganic turbidity if the Secchi depth index were more than the chlorophyll *a* index.

For the years plotted in **Figure 5**, Fall River Lake is clearly limited by non-algal turbidity reducing available light. Although most visits were marked by surplus phosphorus and some influence by nitrogen, the most recent survey in 2007 began to show signs of phosphorus becoming co-limiting with nitrogen.

Table 6 compares median trophic conditions within Fall River Lake in relation to other federal lakes in the state. Median nitrogen and phosphorus in Fall River Lake is lower than overall Federal lakes in the state, but is higher than the trophic benchmarks for Flint Hills region and statewide lakes. Chlorophyll levels are within reach of statewide values,

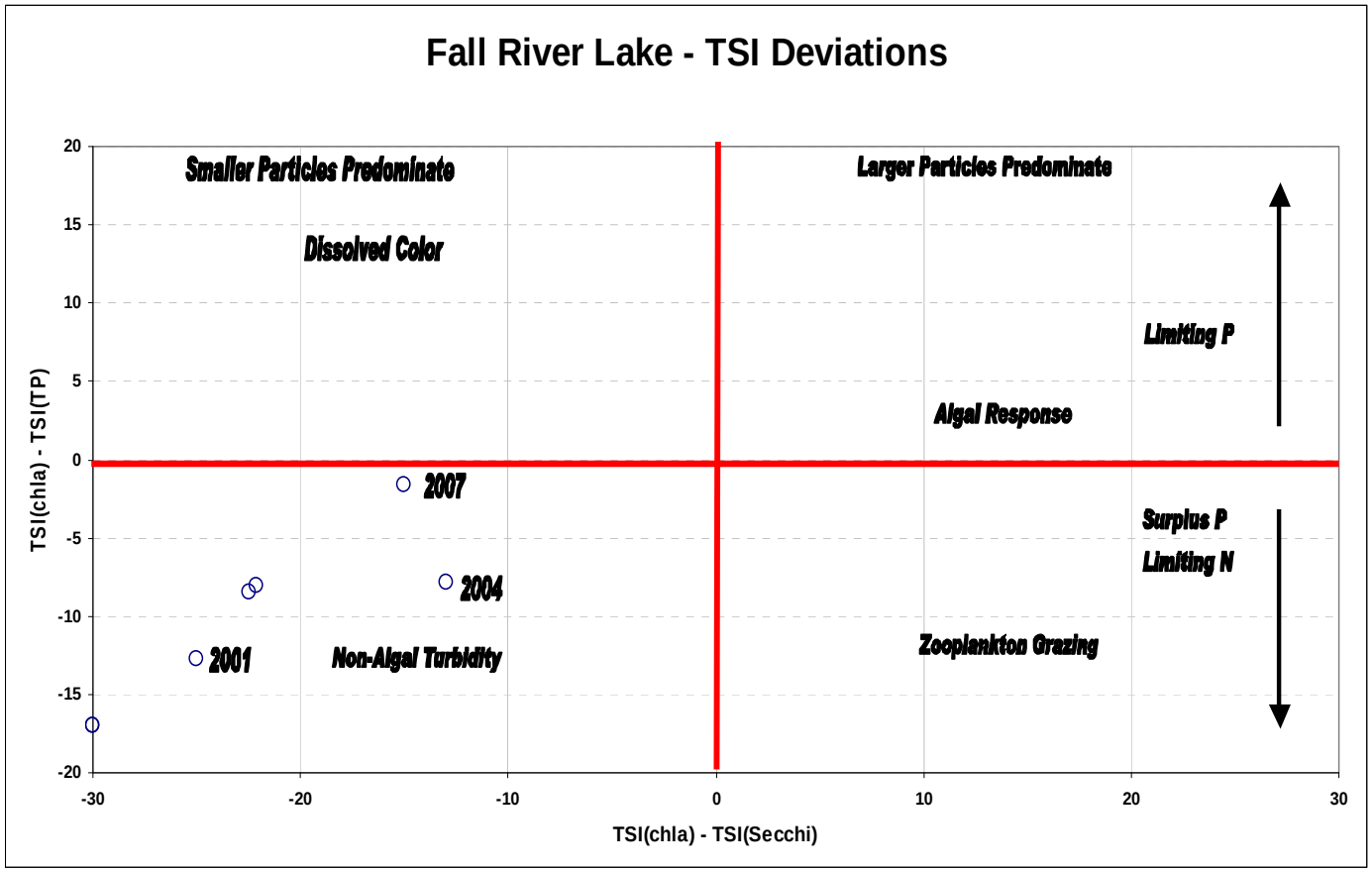

Figure 5. Multivariate TSI Evaluation for Fall River Lake

but that likely reflects the diminished availability of light because of pervasive turbidity in the lake. Even with light limitations, chlorophyll *a* concentration for Fall River Lake is higher than expectations for a Flint Hills lake. The conditions at Otis Creek and Severy City lakes reflect the expected conditions for the Flint Hills. The nutrient benchmarks were derived from 47-58 lakes and reservoirs, based on data collected between 1985 and 2002 (Dodds et al., 2006)

The median secchi depth reading for the lake is much less than the other benchmarks as well. Since the watershed lies within the Flint Hills ecoregion, the median trophic conditions for Fall River Lake suggest poor conditions relative to reference lakes within the Flint Hills.

Trophic Indicator	Fall River Lake	Federal Lakes	Flint Hills	Statewide Benchmark
Secchi Depth (cm)	33	95	112 – 149	129
TN (µg/L)	732	903	301	625
TP (µg/L)	55.0	76	19 – 23	23
Chlorophyll a (µg/L)	10	12	5 – 9	8

Table 6. **Median trophic indictor values of Fall River Lake (KDHE data 1995-2007) in comparison with other federal lakes and nutrient benchmarks in Kansas.**

The low Secchi Depths are related somewhat to the in-lake turbidity **(Figure 6)**. Based on the limited data, there is a threshold turbidity value of 21 NTU's, below which greater Secchi depths and light availability occurs. The relationship between in-lake turbidity and water column TSS concentrations is much less defined **(Figure 7)**. Turbidity hovers around 20 NTUs regardless of the TSS concentration for a majority of the samples. In comparing certain parameters, there appear to be some differences in magnitude under low (<21 NTUs) and high turbidity in the lake **(Figure 8)**. None of these differences are statistically significant, but they do suggest certain mechanisms are evident under the two conditions.

Chlorophyll a concentrations average 7.6 µg/l under high turbid conditions, but rise to an average of 12 µg/l once turbidity falls below 21 NTUs. Light limitation and availability is the logical explanation for the differences. Secchi depths decline on average from 0.52 meters to 0.32 meters once turbidity exceeds 21 NTUs, a logical association between transparency and turbidity. The lake depth where dissolved oxygen concentrations falls below 5 mg/l tends to be greater (5.7 meters) when turbidity gets high, although the depth when turbidity is relatively low averages 4.8 meters, which is not significant. The more turbid conditions might reflect more water column mixing induced by either wind over shallow areas or the influx of runoff into the lake. Finally, total phosphorus averages 49 µg/l under low turbidity and 61 µg/l at high turbidity. Given the relationship between suspended solids and attached phosphorus, this result would be expected.

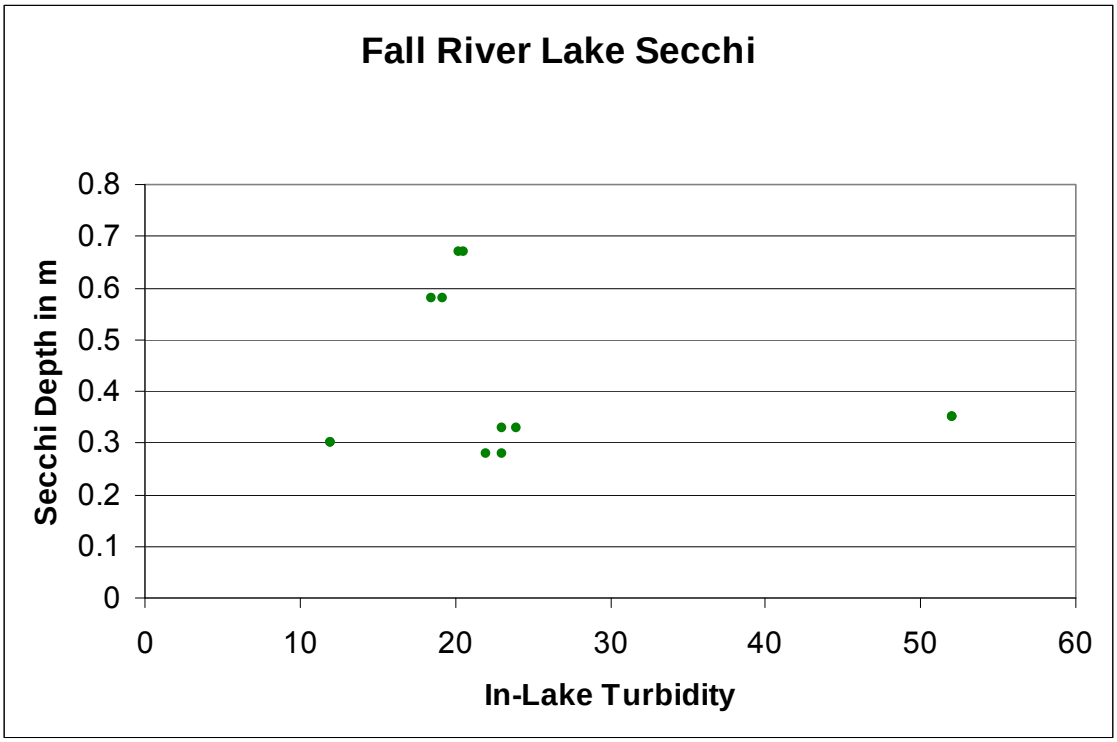

Figure 6. Relationship between Secchi Depth and Turbidity in Fall River Lake

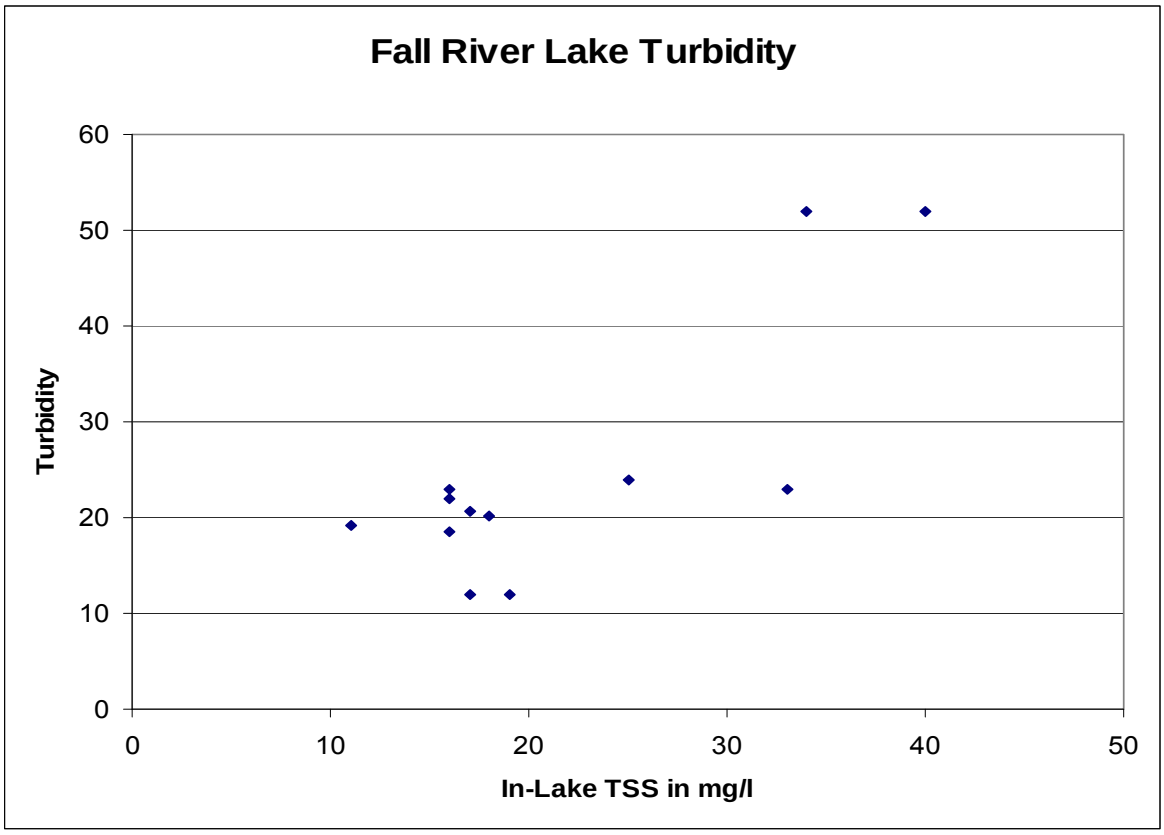

Figure 7. Relationship between Turbidity and TSS Concentrations in Fall River Lake

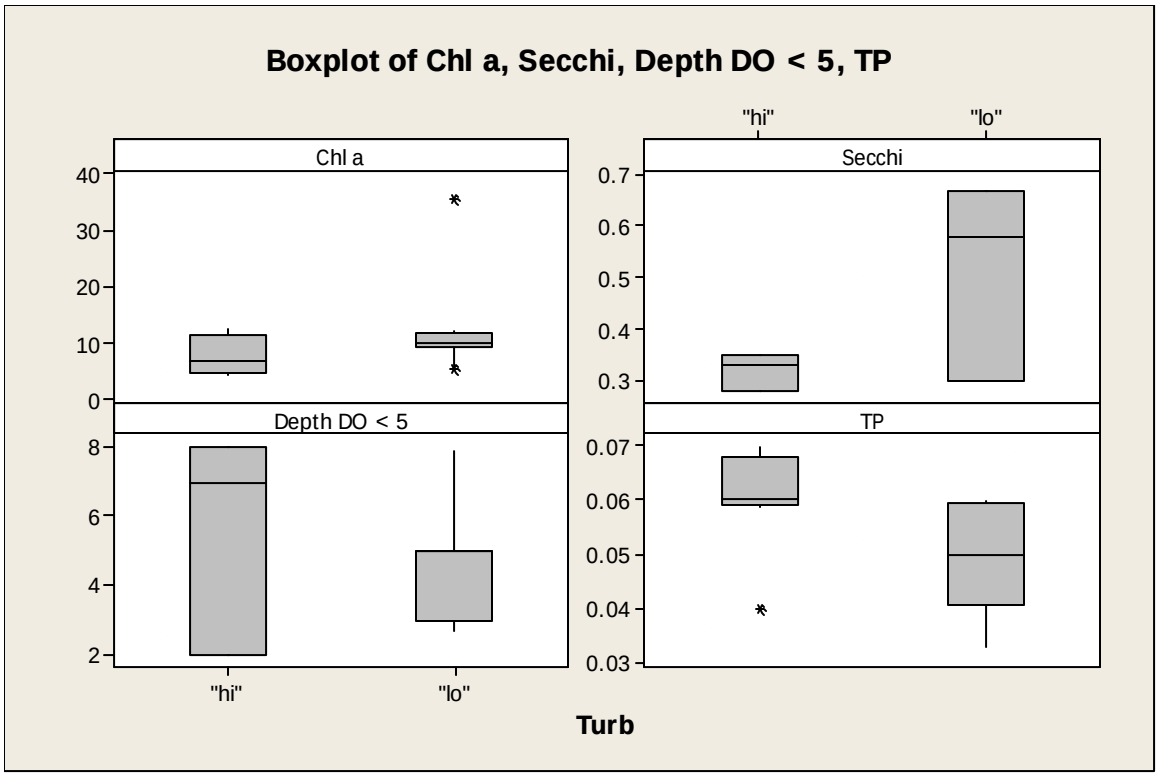

Figure 8. Comparison of Water Quality Parameters at Low and High Lake Turbidity in Fall River Lake

The USGS obtained three sediment cores from Fall River Lake in October 2006 to characterize historic sediment and nutrient loads accumulating in the lake since 1948 (Juracek, 2008). The cores indicated that sediments were over 99% silt and clay. Total nitrogen content in the cored sediments was constant, 2000 mg/kg, whereas total phosphorus showed a rising trend with early sediments having a content of 750 mg/kg and the most recent sediments having 910 mg/kg of phosphorus.

The USGS estimates average annual loading of sediment to be 162,000 tons and the annual load of phosphorus to be 267,000 pounds (121,400 kg/yr). The estimated yields from the Fall River watershed are 293 tons of sediment per square mile and 480 pounds (218 kg) of phosphorus per square mile. Given that the mean bulk density of the sediment cores was 40 pounds per cubic foot, the estimated volume of sediment coming into Fall River Lake is 185 acre-feet per year. This is comparable to the estimated loss of conservation pool storage over 1948-1990, when the last bathymetric survey was completed. Current estimated volume of the conservation pool is 19,300 acre-feet.

The cores were also examined for diatom composition. Since diatoms have a silicon frustule, their remnants are identifiable as to species. Certain species, in turn, have been associated with particular trophic states of the lakes where they reside. In the case of Fall River Lake, the diatom *Aulacoseira granulata* was clearly the predominant (~60%) species found in the sediments. This diatom has been widely found in other Kansas lake sediment cores and is implicated to be associated with eutrophic conditions. Remnants of the blue-green alga *Anabaena* were also found throughout the sediment cores, further evidence of historic eutrophy in the lake.

Algal Communities: As seen in **Table 7**, algal communities in Fall River Lake were initially dominated by green algae and diatoms based on total cell counts. Blue-green algae became prevalent in 1998 and have continued to grow in proportionate composition. Cell counts are somewhat lower than found in other Federal reservoirs, possibly because of the limitations imposed by turbid lake waters.

Sampling Date	Total Cell Count cells/mL	Percent Composition				Chl-*a*
		Green	Blue Green	Diatom	Other	
6/6/1989	500	38	0	50	12	4.5
8/10/1992	2800	44	0	53	2	5.0
7/31/1995	2710	72	0	23	5	12.0
6/22/1998	6363	14	30	48	8	13.0
7/23/2001	2930	41	34	25	0	8.0
8/9/2004	11529	9	75	14	2	10.0
9/4/2007	11592	1	93	4	2	10.1

Table 7. Algal Communities Observed in Fall River Lake

Stream Concentrations: KDHE has collected nutrient and TSS data on Fall River and Otter Creek since 1990. **Table 8** indicates the average concentrations overall and over normal-to-low (30-99 percent exceedance) flow conditions. Overall averages are skewed upward by the increased concentrations seen at high flows. Nitrogen is less susceptible to skewness than either phosphorus or total suspended solids, primarily because nitrogen tends to be chiefly in solution while phosphorus is largely particulate. **Figure 9** shows the relationship of nutrient concentrations on Otter Creek as a function of flow condition measured at the USGS gage on Otter Creek. Concentrations straddle the normal flow average line and increase markedly as high flow become prevalent. **Figure 10** shows similar patterns for Fall River. **Figures 11 and 12** present the relationship between total suspended solids and flow condition on both streams.

Stream	Total Nitrogen		Total Phosphorus		Total Suspended Solids	
Flow Condition	All Flows	30- 99% Flows	All Flows	30- 99% Flows	All Flows	30- 99% Flows
Otter Creek	512 µg/l	450 µg/l	83 µg/l	51 µg/l	54 mg/l	19 mg/l
Fall River	751 µg/l	692 µg/l	109 µg/l	63 µg/l	80 mg/l	29 mg/l

Table 8. Average Nutrient and TSS values for Otter Creek and Fall River (1990-2008)

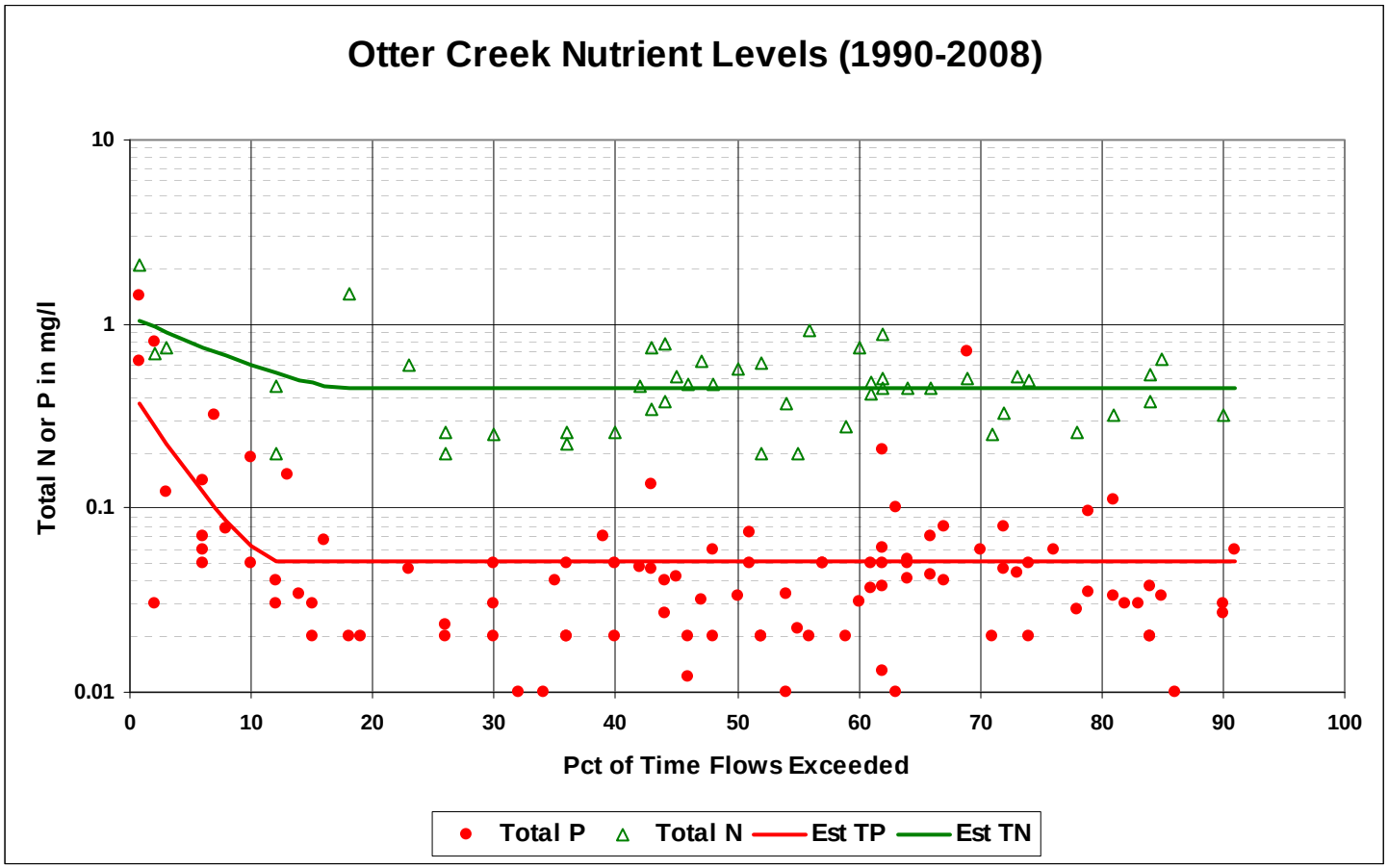

Figure 9. Otter Creek Historic Nutrient Concentrations

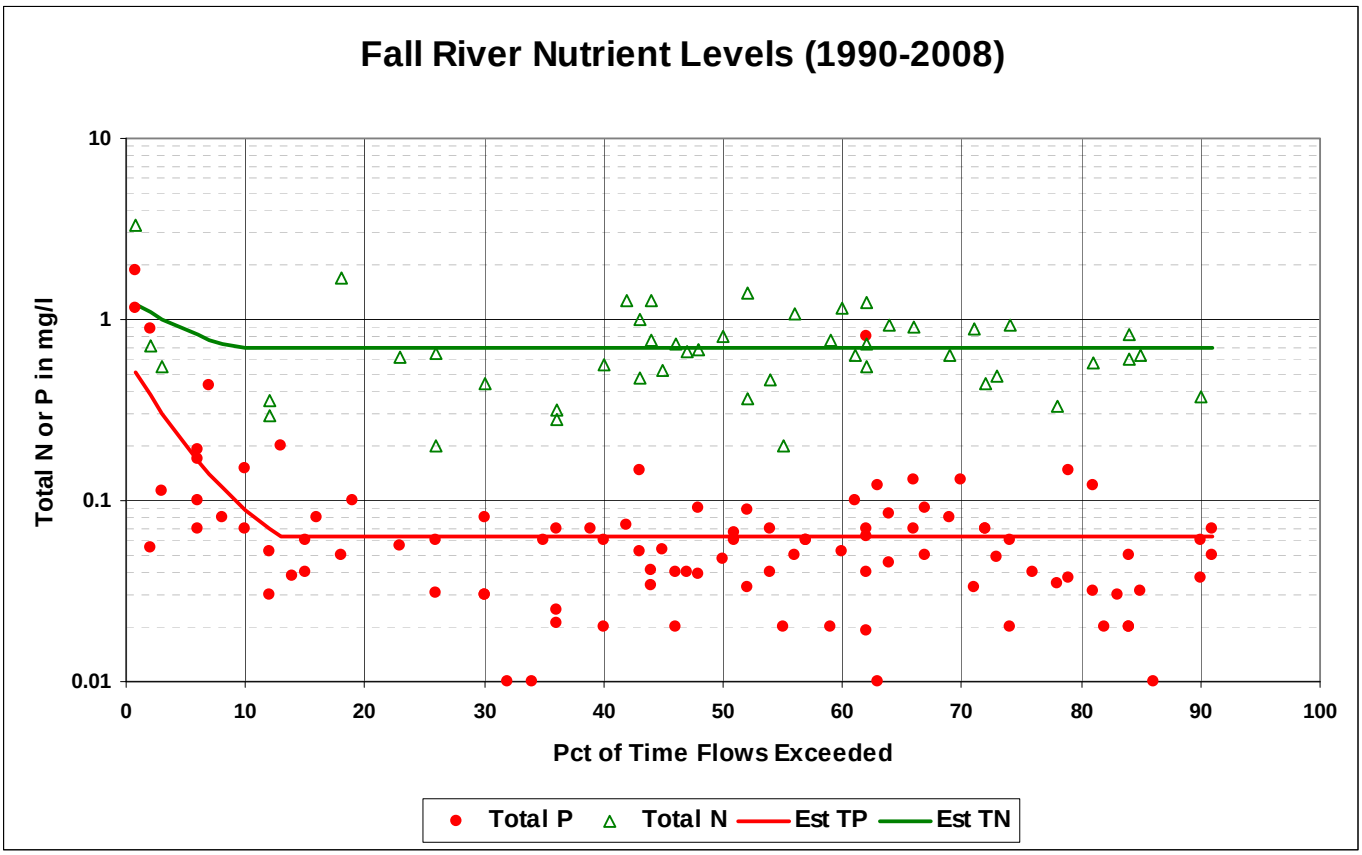

Figure 10. Fall River Historic Nutrient Concentrations

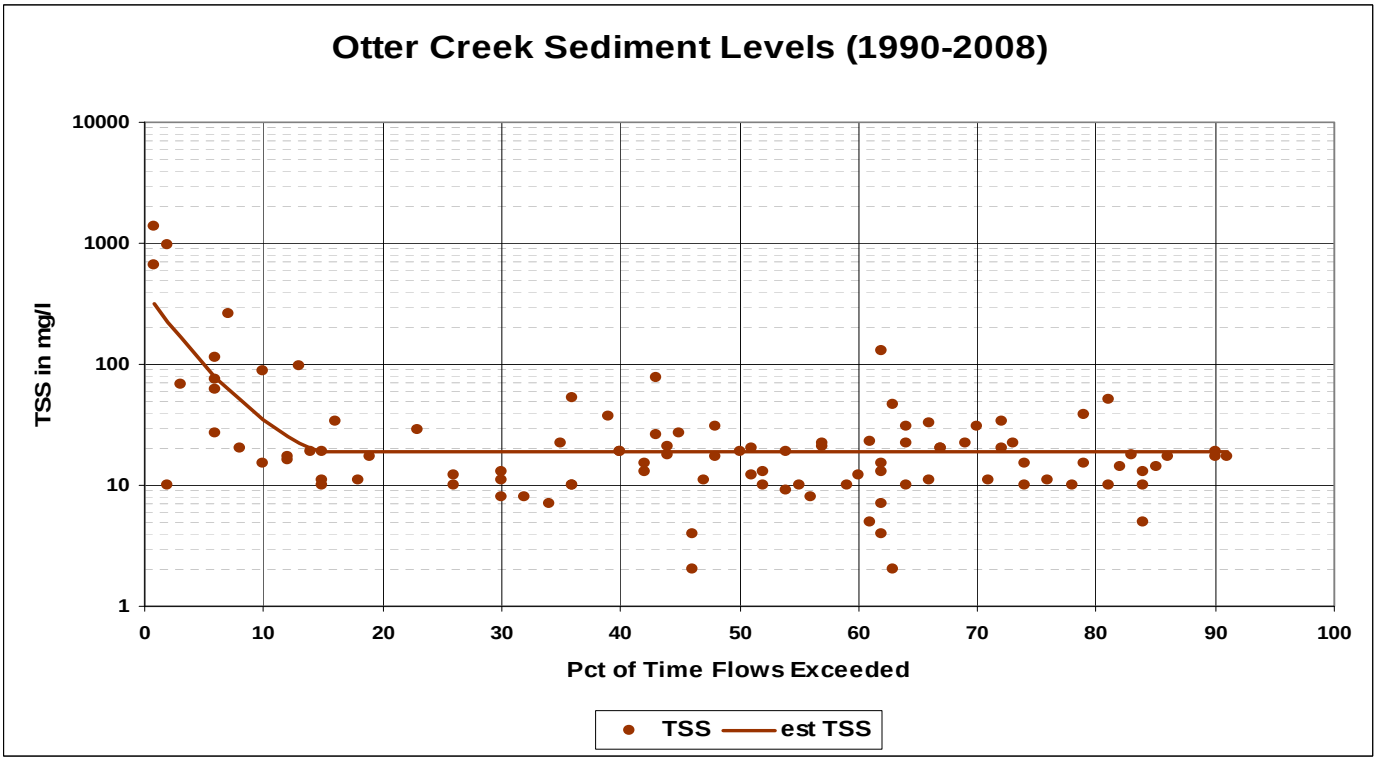

Figure 11. Otter Creek TSS Concentrations.

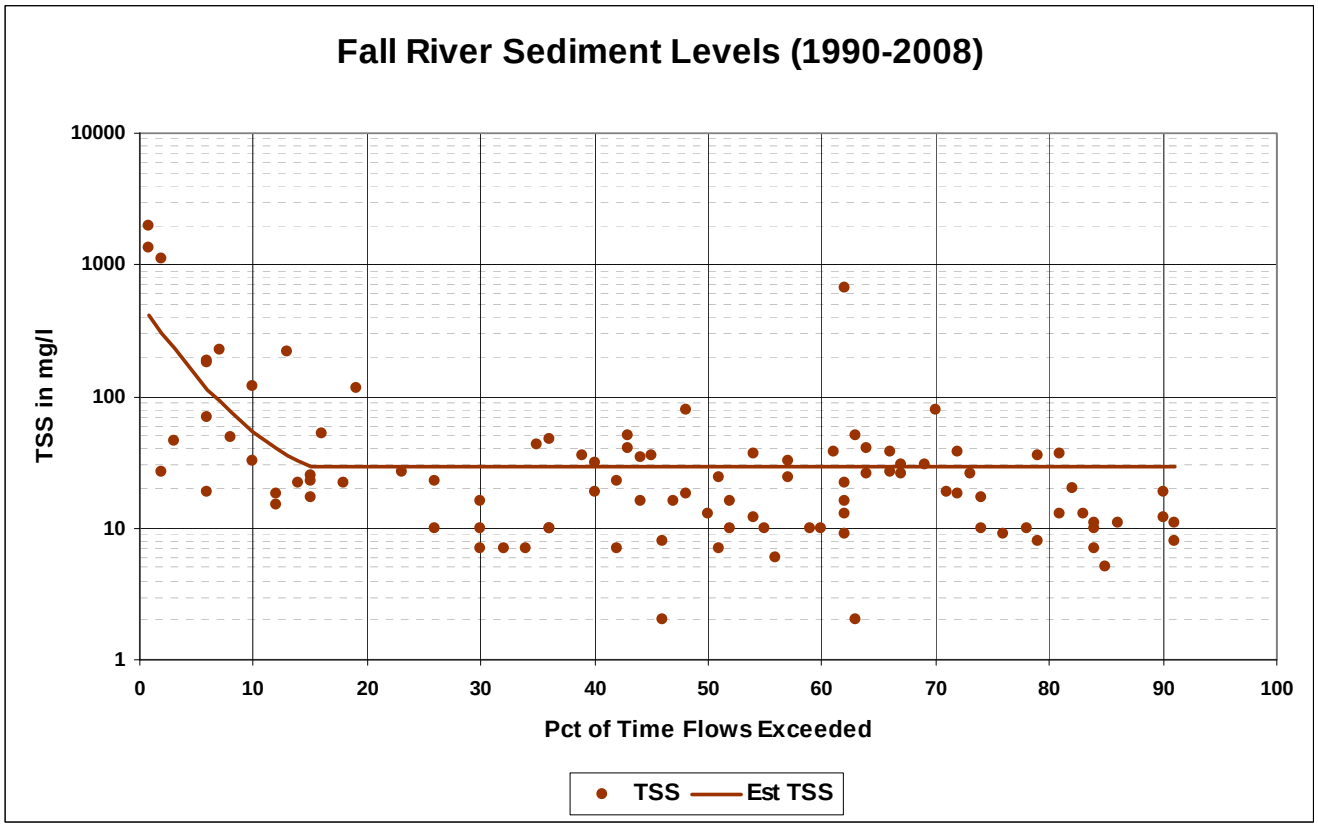

Figure 12. Fall River Historic TSS Concentrations

It is apparent that the majority of sediment and nutrient loads are occurring with large runoff when flows and concentrations are increasing at a rapid rate. Nutrient benchmarks for streams derived by KDHE – BEFS are generally 80 µg/l for phosphorus and 700 µg/l for nitrogen in Flint Hills streams. Using those benchmarks, the nitrogen concentrations on Otter Creek indicate relatively good conditions. Phosphorus levels slightly exceed the benchmark when all flows are considered, but are well below during normal to low flows.

On Fall River, nitrogen concentrations over all flow conditions is greater than the Flint Hills benchmark, and slightly below it when high flows are excluded. Similarly, phosphorus is well above the benchmark but is less than the suggested value at lower flows. This comparison suggests that under most flow conditions the streams in the watershed for Fall River Lake are fairly in line with what is considered good quality conditions, except during wet weather. Some nutrient and sediment management might be necessary in certain spots along the streams for normal flows, but more extensive watershed treatment would be necessary to reduce the nutrient and sediment loadings under runoff conditions.

There are some historic data collected by USGS on streams in the Fall River watershed **(Table 10).** Those data indicate that Fall River tends to have higher concentrations than Otter Creek. Spring Creek, a major tributary to Fall River above the confluence of the river with Otter Creek, had relatively low levels of nutrients. **Figure 13** displays the distribution of suspended sediment with flow along Fall River and Otter Creek.

Stream	Fall River	Otter Creek	Spring Creek
Time Period	1947 – 1976	1962 – 1970	1947 – 1980
Nitrate	1.50 mg/l	1.25 mg/l	0.70 mg/l
Phosphate	0.40 mg/l	NA	0.10 mg/l
Suspended Sediment	340 mg/l	245 mg/l	NA

Table 10. Historic USGS Water Quality Data from Streams in Fall River Watershed

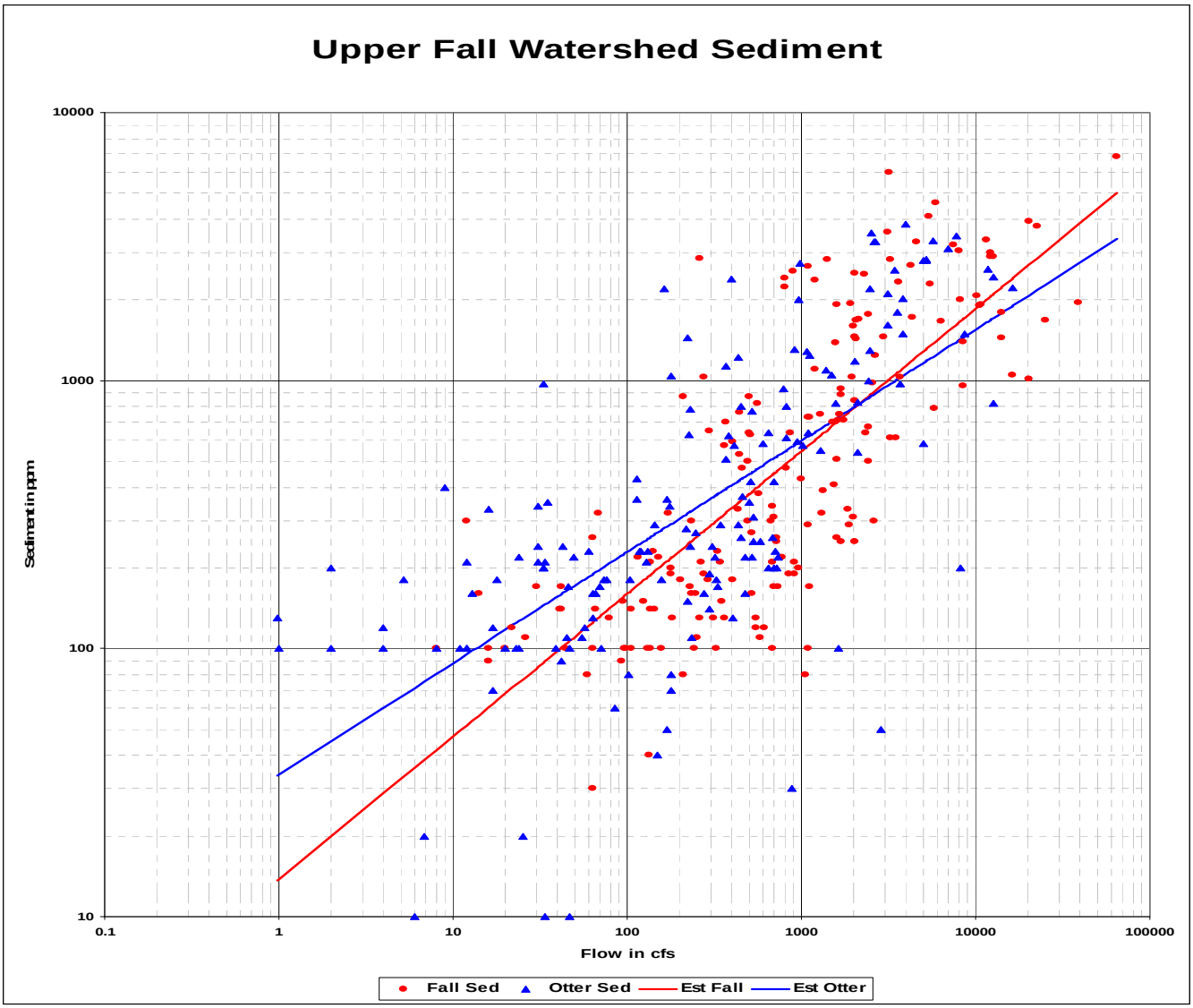

Figure 13. Historic Sediment and Flow on Otter Creek and Fall River

Although there is quite a bit of scatter among the data, there is a clear trend of increased concentrations with flow. The two streams are comparable at lower flows, but concentrations on Fall River overtake those of Otter Creek as flows surpass 1000 cfs.

Kansas State also collected data over 2003-2004 in the watershed (Barnes, 2005). **Table 11** displays average flow, TSS and phosphorus values for portions of the watershed, including subwatersheds that are controlled by watershed dams and those that are free flowing.

Three things are apparent from the dataset. First, the small order streams of the upper basin are relatively low in TSS and phosphorus. Second, streams controlled by watershed structures tend to have lower TSS and phosphorus values than uncontrolled streams, likely because of trapping of sediment behind the dams. Finally, the streams near their mouths pick up notable increases in flow, TSS and phosphorus. In fact, the highest values occur on the lowest reaches of Fall River.

Stream	**Controlled?**	**Flow**	**TSS**	**TP**
Ivanpah Creek	Yes	1.46 cfs	18 mg/l	21 µg/l
Ivanpah Creek	No	2.08 cfs	31 mg/l	21 µg/l
Upper West Branch	Yes	6.47 cfs	15 mg/l	19 µg/l
Upper West Branch	No	4.85 cfs	35 mg/l	22 µg/l
Upper East Branch	Yes	2.96 cfs	22 mg/l	20 µg/l
Upper East Branch	No	2.10 cfs	36 mg/l	27 µg/l
West Branch	Partially	101 cfs	29 mg/l	41 µg/l
East Branch	Partially	94 cfs	37 mg/l	34 µg/l
Trib above Eureka	No	0.97 cfs	30 mg/l	39 µg/l
Trib below Eureka	Yes	7.17 cfs	29 mg/l	55 µg/l
Fall River abv Eureka	Partially	195 cfs	43 mg/l	51 µg/l
Upper Spring Creek	Yes	6.74 cfs	18 mg/l	25 µg/l
Upper Spring Creek	No	2.26 cfs	32 mg/l	42 µg/l
Spring Creek	Partially	75 cfs	47 mg/l	41 µg/l
Fall River blw Eureka	Partially	269 cfs	60 mg/l	61 µg/l

Table 11. Kansas State Water Quality Data from the Fall River Watershed

Based on the greater flow volume and higher concentrations on Fall River, initial attempts to reduce loads should concentrate on the lower portion of that stream, followed by the lower reaches of Otter Creek. Because much of the upper watershed is controlled by structures, opportunities to abate loads are diminished above Eureka.

Desired Endpoints of Water Quality (Implied Load Capacity) in Fall River Lake in 2016:

In order to improve the trophic condition of Fall River Lake and maintain it at or below Slightly Eutrophic conditions, the short term endpoint will be to maintain summer chlorophyll *a* concentrations below 10 µg/L, nominally 9.5 µg/L with the reductions focused on nutrients (TN and TP) entering the lake. The chlorophyll *a* endpoint of 10 µg/L is the statewide goal for Federal Lakes and lakes serving as Public Water Supplies, which will also ensure long-term protection to fully support Primary Contact Recreation and aquatic life within the lake. As sediment loads are reduced, there is a high probability that water clarity in the lake will improve. Because existing phosphorus levels may trigger algal blooms once light limitations lessen, the long-term endpoint will be to maintain ambient phosphorus concentrations in the lake below 35 µg/l. The anticipated lower production of organic matter should help the lake maintain dissolved oxygen levels over 5 mg/l throughout the entire water column.

Regarding sediment and siltation, in order to improve the quality of the water column and the siltation impairment, the endpoint should also result in an increase in the average transparency of the lake to 0.70 meters, as measured by the Secchi disk depth within the main basin of the lake. To extend the utility and uses of the lake, the estimated loss of storage each year should be reduced from 188 acre-feet to 115 acre-feet annually.

3. SOURCE INVENTORY AND ASSESSMENT

Land Use: The predominant land cover in the watershed above Fall River Lake is 87% grasslands and pasture, covering the scenic Flint Hills. The remaining land use/cover composition is 6.7% forest, water and wetlands, 3.6% developed land (although most of that is open space) and barren ground and 2.8% croplands **(Table 12)**.

Table 13 indicates the relative land cover distribution of each of the three sub-watersheds monitored by the KDHE network. The upper main stem Fall River sub-watershed has the most area and the highest proportion of grasslands. Forested and wetlands grow in percentage for the Otter Creek and lower Fall River sub-watersheds. Cropland becomes more proportionately prevalent in the lower Fall River sub-watershed. Developed land is evenly distributed percentage-wise among the three sub-watersheds.

As seen in **Figure 14**, the majority of the forested land is riparian timber adjacent to the streams in the watershed. Similarly, the cultivated land used for crops lies in the flood plains of those streams. The city of Eureka is the major developed land center in the watershed. The balance of the uplands is grasslands, pasture and shrublands. Estimates from USGS indicate that the entire watershed would produce runoff with about 1.7 inches of rain in an hour and modestly dry conditions (Juracek, 2000). Rainfall intensities of 1.14 inches per hour and 0.57 inches per hour would cause 95.6% and 84.0% of the watershed to produce runoff under drier antecedent moisture conditions. The average soil permeability across the watershed is 0.4 inches per hour and most land slope is less than 5% **(Figures 15 & 16).** At very low rainfall, runoff is likely restricted to areas along the lower Fall River and Otter Creek (Juracek, 1999)

Land Cover	Otter Crk Subwatershed	Upper Fall River Subwatershed	Lower Fall River Subwatershed	Total Watershed
Developed & Barren	2920 acres	7798 acres	2015 acres	12733 acres (3.6%)
Forest, Water & Wetland	5513 acres	9341 acres	8989 acres	23853 acres (6.7%)
Grass, Shrub & Pasture	68030 acres	193841 acres	45762 acres	307633 acres (86.9%)
Cropland	2530 acres	5128 acres	2298 acres	9956 acres (2.8%)
Total Area	79003 acres	216108 acres	59064 acres	354175 acres
Percent of Watershed	22.4 %	61.0%	16.7%	100%

Table 12. Land Cover in Monitored Sub-watersheds of Fall River Lake

Land Cover %	Otter Creek	Upper Fall River	Lower Fall River
Developed & Barren	3.7%	3.6%	3.4%
Forest, Water & Wetland	7.0%	4.3%	15.2%
Grass, Shrub & Pasture	86.1%	89.7%	77.5%
Croplands	3.2%	2.4%	3.9%

Table 13. Relative Proportion of Land Cover in Each Sub-watershed

Livestock Waste Management Systems: There are seven permitted confined animal feedlot operations located throughout the watershed, which are all located adjacent to stream corridors **(Figure 17).** All of these permitted livestock facilities (two beef and one dairy) have waste management systems designed to minimize runoff entering their facility and detain runoff emanating from their operations. None of the facilities exceeds the 1000 animal unit threshold for Federal NPDES permitting. There are also one dairy and five beef operations that are certified not to have a significant potential to pollute the waters in the watershed. **Table 14** lists the animal feeding operations by type, number of animal units and relative location within the watershed. The distribution of HUC 12s above the lake may be seen in **Appendix A**.

However, the high proportion of grassland and pasture may support a large number of smaller animal feeding operations that are not registered and close to streams, particularly in over-wintering. According to the 2006-2007 Kansas Agricultural Farm Facts, there are 77,000 head of cattle in Greenwood County. In addition, Greenwood County ranks second in the state for pasture acreage. Thus, highly variable livestock populations may reside within the watershed from one year to the next.

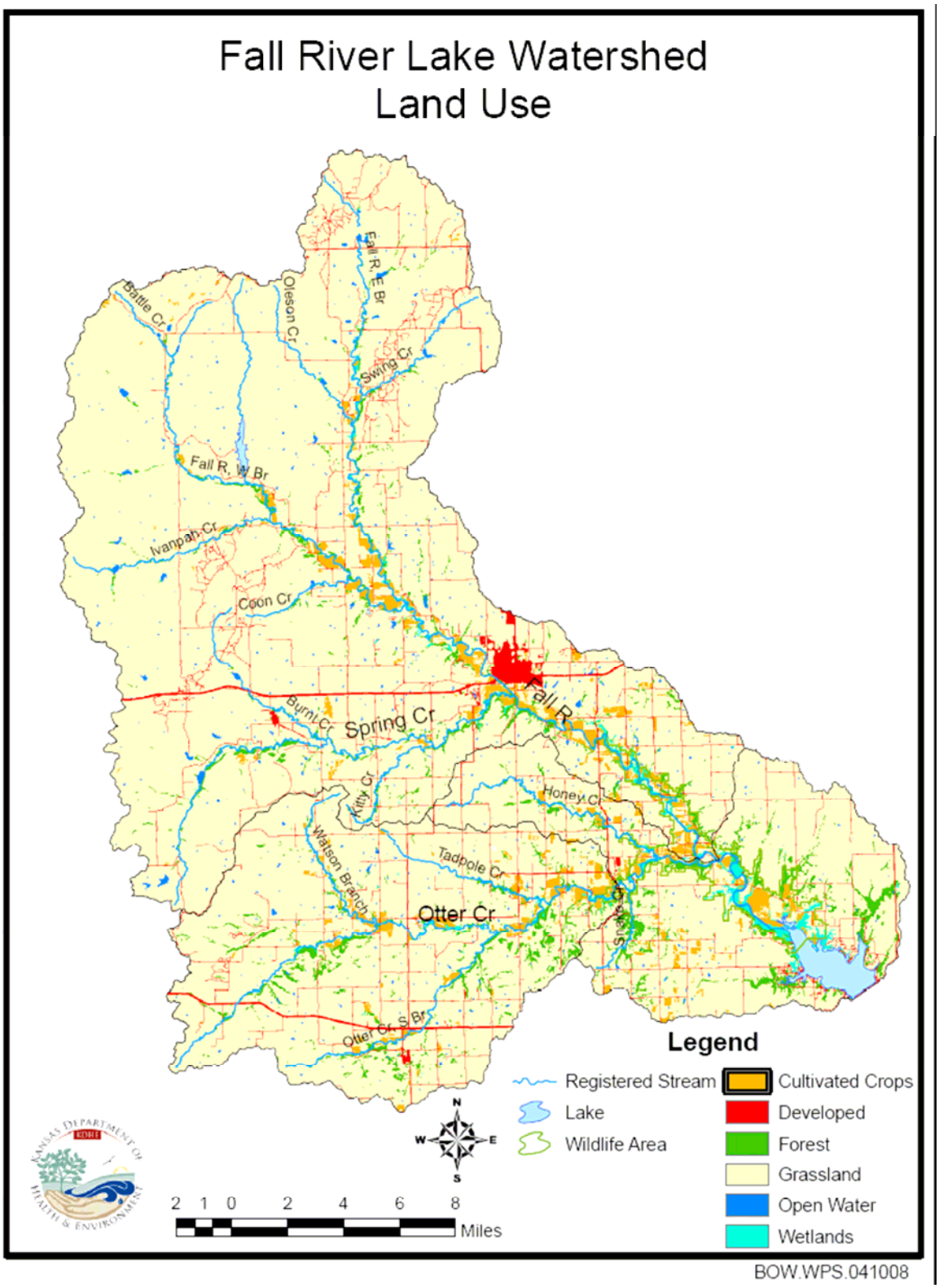

Figure 14. Land Use and Land Cover (2001) in the Fall River Watershed

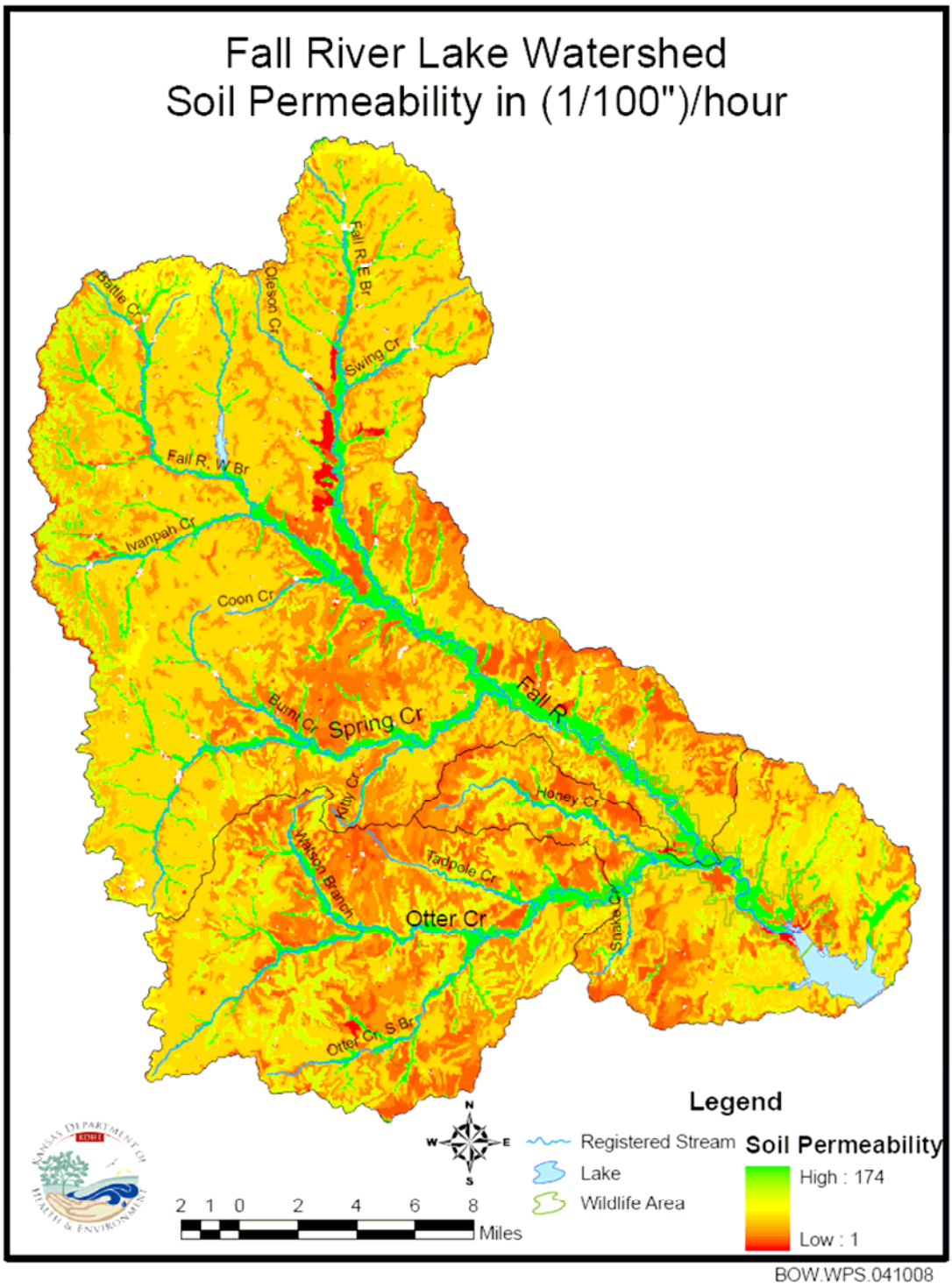

Figure 15. Soil Permeability in Fall River Lake Watershed

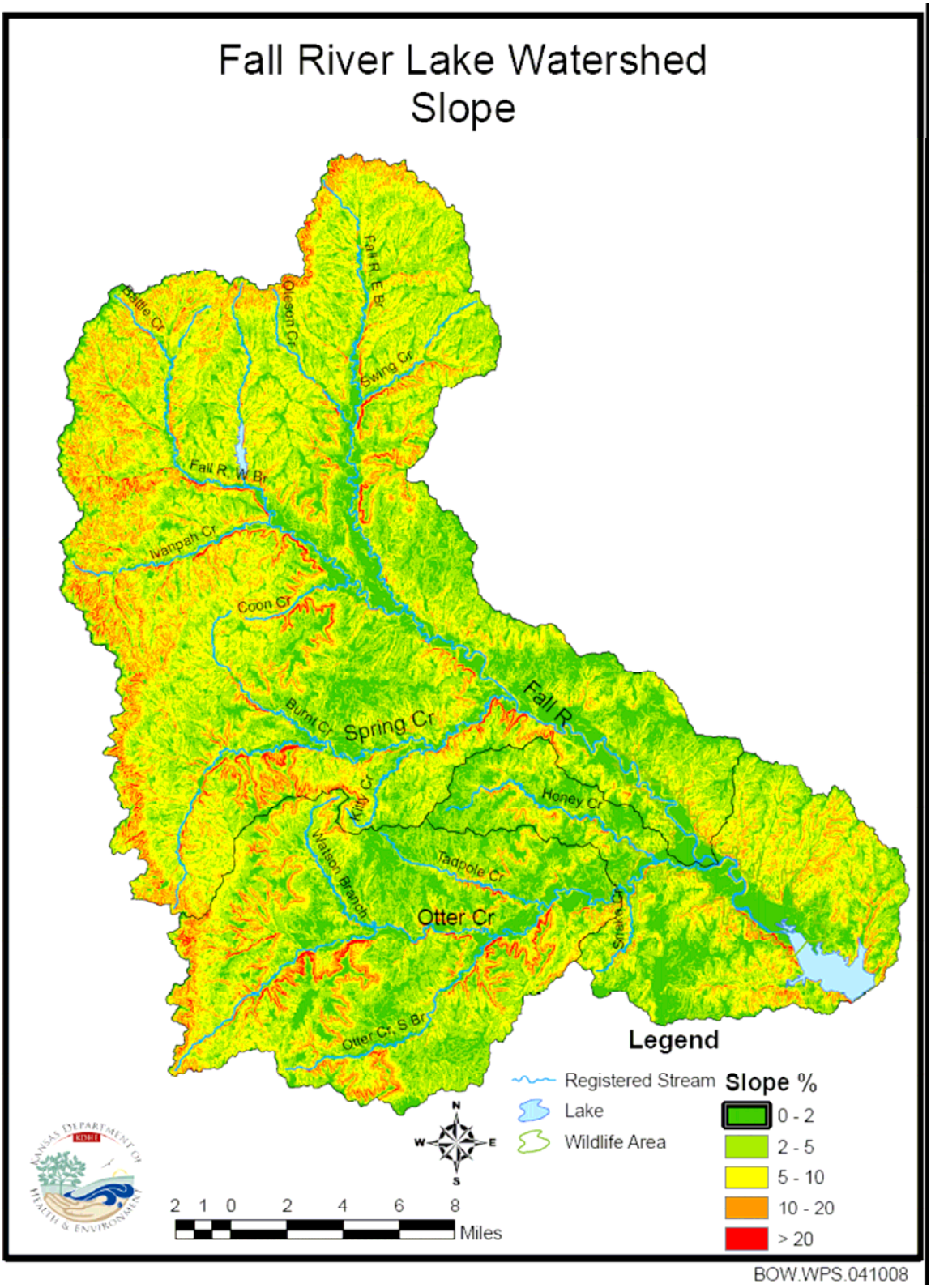

Figure 16. Land Slope in Fall River Lake Watershed

Permit or Cert #	Animal Type	Animal Units	HUC10/12	Permit/Certificate
A-VEGW-B001	Beef	950	0103	Permit
A-VEGW-BA06	Beef	280	0105	Certificate
A-VEGW-BA01	Beef	200	0106	Certificate
A-VEGW-B004	Beef	800	0107	Permit
A-VEGW-BA07	Beef	220	0201	Certificate
A-VEGW-BA05	Beef	250	0202	Certificate
A-VEGW-MA11	Dairy	28	0203	Certificate
A-VEGW-BA11	Beef	300	0203	Certificate
A-VEGW-M002	Dairy	75	0206	Permit

Table 14. Animal Feeding Operations in the Fall River Lake Watershed

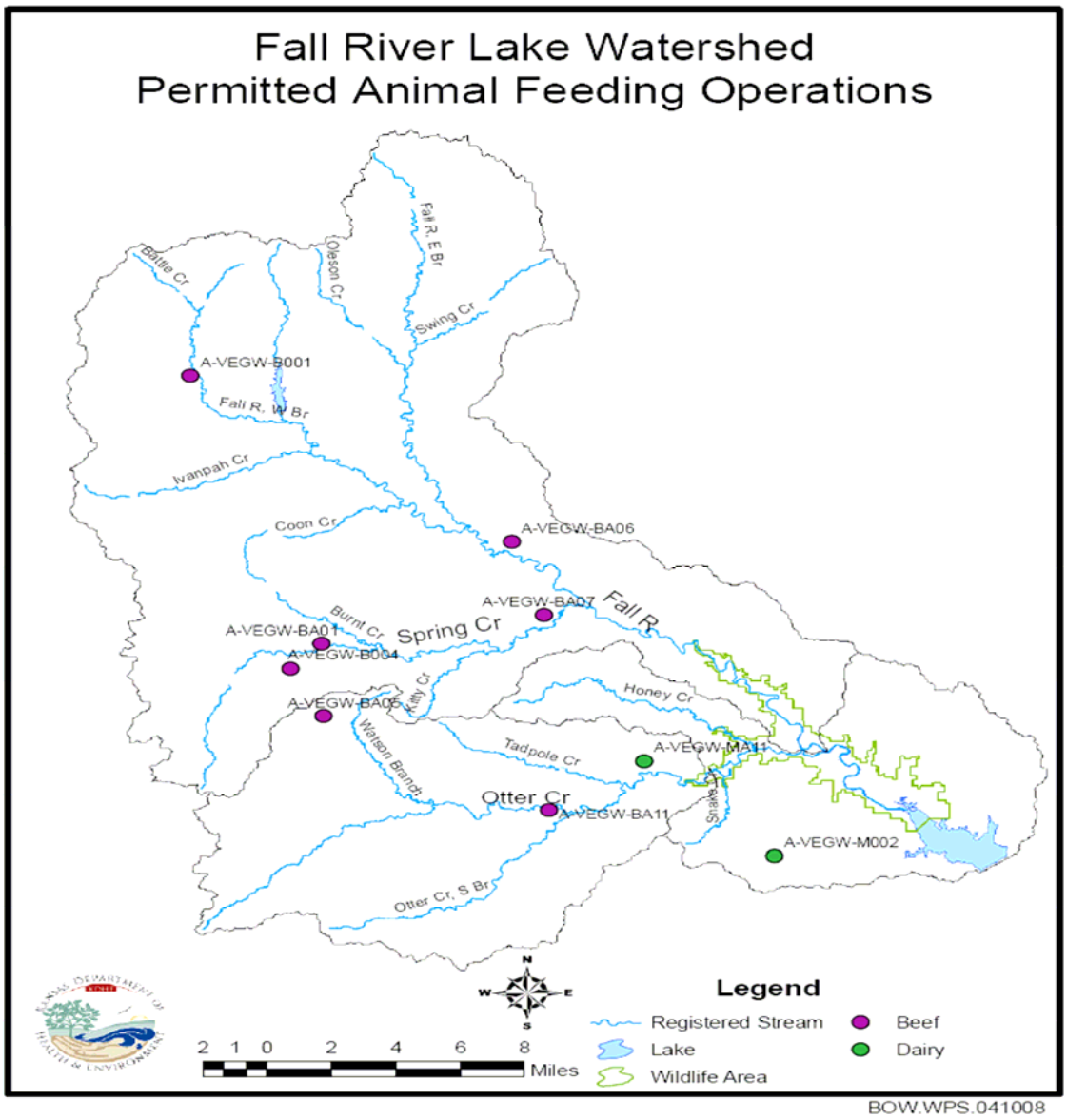

Figure 17. Animal Feeding Operations in Fall River Watershed.

NPDES There are five NPDES permitted facilities lying within the Fall River Lake watershed **(Figure 18; Table 15)**. Only one, the City of Eureka, discharges continuously to the watershed. Since it uses a lagoon system, Eureka's monitoring is limited to BOD, TSS, ammonia, pH and fecal coliform bacteria. Effluent BOD averages 19 mg/l for quarterly sampling since 2004, TSS averages 21 mg/l and ammonia averages 2.24 mg/l, although that falls to 1.08 mg/l once two wintertime samples are removed. Previous study by KDHE indicates average total phosphorus from well-operated lagoon systems should average 2 mg/l and total nitrogen should average 7 mg/l, values that are comparable to current goals under the Kansas Nutrient Reduction Strategy (annual averages of 1.5 mg/l TP and 8.0 mg/l TN). Population in Eureka was estimated to be 2607 in 2007, a 10% decrease from the 2000 population of 2914. The current capacity of the wastewater system appears to be adequate for current population levels. The only other incorporated town in the watershed is Climax, which has a population of 60 and no centralized wastewater system. The population of Greenwood County has declined about 8% since the 2000 census (7673 people).

The concrete and quarry operations have not discharged since 2004 and are designed to conserve on-site water for re-use and dust suppression. These facilities might only discharge during runoff/stormwater events. These facilities and the non-overflowing lagoon at the Family Camp would only discharge under extreme precipitation events, occurrences of limited frequency and duration. All non-discharging lagoon systems are prohibited from discharging to surface waters. Should water level in the lagoon approach two feet of the top of the lagoon dikes, the permittee notifies KDHE and steps may be taken to lower the water level. Discharges are allowed if there is no alternative and it is necessary to protect public safety or property and prevent damage to the facility.

Facility	**KS Permit #**	**NPDES #**	**Type**	**Design Flow**	**Permit Expires**
CMC-Eureka	I-VE16-PR01	KSG110079	Concrete Truck Washing	Likely None	9/30/2012
Harshman – Braden Quarry	I-VE08-PO02	KS0098892	Quarry Pit Dewatering	Likely None	12/31/2011
Martin-Marietta – Eureka Quarry	I-VE16-PO04	KS0095311	Quarry Pit Dewatering	Likely None	12/31/2010
Flint Hills Family Camp	C-VE16-NO01	None	2-Cell Non-Discharging Lagoon	Zero	5/31/2012
City of Eureka	M-VE16-OO02	KS0083178	4-Cell Lagoon System	0.282 MGD	9/20/2011

Table 15. NPDES Facilities in the Fall River Lake Watershed

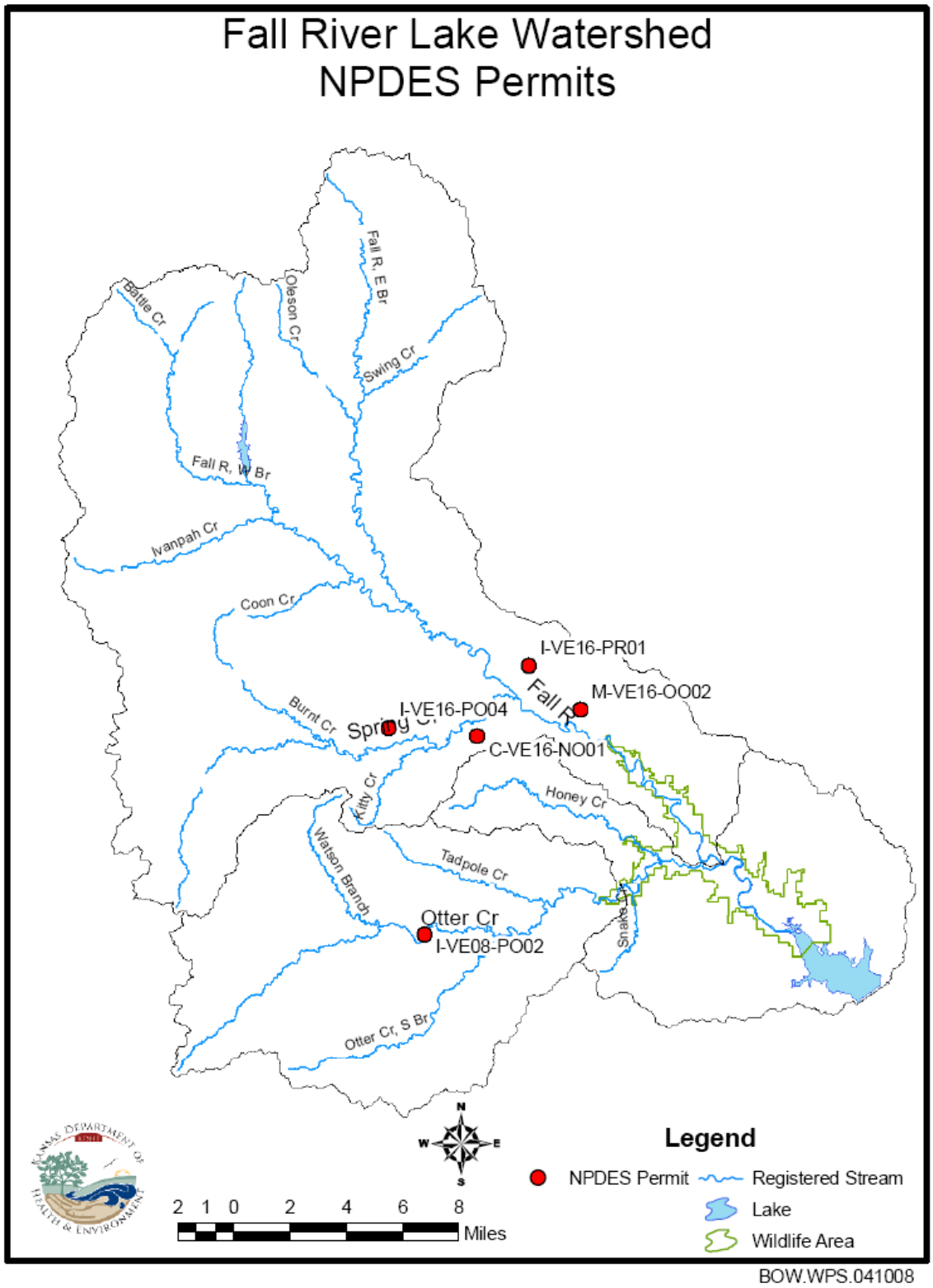

Figure 18. NPDES Facilities in the Fall River Lake Watershed

On-Site Waste Systems: Based on past census results, one-third of Greenwood County residents rely on septic systems. Most residents of the watershed living outside of Eureka are presumed to use on-site waste systems, although many of the soils in the county are ill-suited for septic fields or waste storage lagoons.

Stream Channel Stability: Geomorphic studies have indicated that over half of the first, second and third order streams in the Upper Fall River watershed have been lost through impoundment and inundation. Tributary channels tend to be slightly entrenched with moderate width to depth ratios and sinuosity and moderately low slopes (< 2%). Most channels are gravel. Studied stream channel segments controlled by watershed structures were shown to be stable and often aggrading as bankfull discharges were diminished by impoundment and the resulting flows lacked the power to move larger sediment out of the channel, pools and riffles. Generally, sediment supplies were low, either because of trapping by watershed structures or lack of source material in the Flint Hills ecoregion. There is an implication that diminished sediment supplies from the tributaries could induce main channel erosion along the Fall River as flowing water seeks an equilibrium with its transporting sediment load.

Watershed Soils: Much of the watershed has soils that support rangeland, have low permeabilities and moderate erodability. The exception lies in the channel and flood plains of the Fall River and its tributaries. Silt loam soils of the Reading-Ivan-Chase Association dominate the alluvial valleys and constitute the majority of cropland production in the watershed. Reading soils are relatively deep, susceptible to erosion, but are flooded infrequently. Chase soils are fairly thin on low terraces within the flood plain, have higher clay content and lower permeabilities. Ivan soils are within and along the channels and are frequently flooded. Because of their potential for fertilization for agricultural production and proximity to flows eroding and transporting sediment and nutrients down to the lake, these three soil types are likely primary sources of the loads entering the lake.

Contributing Runoff: The watershed of Fall River Lake has a mean soil permeability value of 0.4 inches/hour. Rainfall over one inch per hour will generate runoff from 96% of the watershed, as intensity exceeds the ability of the soils to infiltrate. At lower rainfall intensities ~0.5 inches per hour, 84% of the watershed contributes runoff (Juracek, 1999, 2000). However, at lower rainfalls, the portion of the watershed immediately above Fall River Lake chiefly contributes flow. In contrast to infiltration excess, saturation excess, where the water table rises to the land surface in response to percolating rainfall, is more likely to occur in the alluvial areas of the streams. Relatively shallow soils with low permeability over shale-dominated geology are likely to cause the high proportion of the watershed to generate runoff. Runoff is primarily generated as infiltration excess with rainfall intensities greater than soil permeability.

Background: Nutrients released from leaf decomposition and wastes derived from natural wildlife may be contributing to the nutrient load. Atmospheric deposition and seepage from geological formations (i.e., soil and bedrock) may also contribute to the nitrogen load. The suspension of sediment and nutrients within the lake may be

influenced by the wind and boating activities. Within Fall River Lake, there is not a strong, extended stratification in the lake with incumbent anoxic conditions. Deep depth concentrations in 2001, 2004 and 2007 for total phosphorus were 0.106, 0.04 and 0.069 mg/l, respectively. These values were greater than the concentrations taken just below the surface, and are likely particulate and organic-bound phosphorus, since ortho-phosphorus concentrations were below detection limits. Similarly, there was no difference in ammonia concentrations or any real difference in nitrate between samples taken near the top and those near the bottom. Therefore, potential nutrient sources feeding into internal loading to the lake were not prevalent. Hence, any internal loading of nutrients to the lake was considered implicitly through the use of net sedimentation rates in the BATHTUB simulation model.

4. ALLOCATION OF POLLUTANT REDUCTION RESPONSIBILITY

Fall River Lake is primarily limited by light availability, although during recent, low flow years, both nutrients become co-limiting. Since the years that were co-limited have higher chlorophyll *a* concentrations, both phosphorus and nitrogen allocations will be made under this TMDL. To address the siltation component of this TMDL, load allocations will be made for sediment loading by establishing loads for Total Suspended Solids (TSS) within the watershed.

BATHTUB is an empirical receiving water quality model that was developed by the U.S. Corps of Engineers (Walker, 1996), and has been widely used in the nation to address many TMDLs relating to issues associated with morphometrically complex lakes and reservoirs (Wang et al., 2005). The BATHTUB model was utilized for the eutrophication assessment of Fall River Lake. Fall River Lake was not segmented into sections for the BATHTUB model, because the lake is relatively small compared to its watershed, it does not have significant arms leading into the lake and it has a very short residence time for the water detained by its storage. Furthermore, calibrating data were available at the main body of the lake, but were lacking for any arm of the lake.

Water quality data from the main basin was averaged using the 1995-2007 data from KDHE. Model input data for the lake inflows were estimated as a weighted average of the 1990-2007 KDHE stream chemistry data from monitoring stations on the Fall River (SC575) and Otter Creek (SC574). Weighting was based on the proportions of drainage area and average flow attributed to Fall River above Otter Creek (75%) and Otter Creek (25%). **Table 16** indicates the various water quality values used to calibrate current lake conditions and for input for stream loading into the lake.

Atmospheric loads of TP and TN were the default values found in the model and compared similarly to those used in the Toronto eutrophication TMDL. Calibration was made first to hydrology, with calculated hydraulic residence time (0.07 yrs) falling within KDHE previous estimates of 0.06 – 0.12 yrs. Calculated in-lake nutrient and chlorophyll a concentrations were next calibrated to the values in Table 16, by adjusting sedimentation rates within the lake segment subroutine of BATHTUB [TP: 1.75; TN: 1.17; chl a: 1.14; Secchi: 0.70]. The resulting model-estimated values closely matched

the observed in-lake values. Second-order models were used to estimate phosphorus and nitrogen levels in the lake. Availability factors were not set, thus total P and N of inflow drove in-lake concentrations; ortho-P and inorganic N did not influence those results. Chlorophyll was estimated with a model that factored phosphorus, nitrogen, turbidity and flushing rate within the lake.

Load reductions to achieve the TMDL endpoints of 9.5 ug/l chlorophyll a was accomplished by reducing the inflow phosphorus and nitrogen concentrations until the endpoints were reached. Additional reductions in phosphorus loading were determined in order to reach the ultimate endpoint of an in-lake TP concentration of 35 ug/l. Reducing phosphorus alone requires a load reduction of 35% from current levels in order to maintain chlorophyll a concentrations below 10 ug/l. If nitrogen loading is also reduced by 9%, the necessary phosphorus loading reduction is only 16% to achieve the same result. A long-term phosphorus load reduction of 49% is necessary to reduce in-lake phosphorus levels to 35 ug/l and corresponding chlorophyll concentrations of 8.2 ug/l. BATHTUB calculates that the lake retains 44% of incoming phosphorus, but only 15% of the nitrogen load is retained. The linkage between phosphorus and sediment and the overriding sedimentation issue at Fall River Lake likely causes the disparity in retention.

Wasteload Allocations: Only the City of Eureka needs a wasteload allocation for nitrogen, phosphorus and total suspended solids because it is the only discharging NPDES facility in the watershed. All other operations either are designed as non-discharging or involve activities (quarrying) that is unlikely to discharge nutrients. Those facilities will have a zero wasteload allocation. Eureka operates a lagoon system with a design flow of 0.282 MGD (0.44 cfs). Nutrient levels from well-operated lagoon systems should average 2 mg/l TP and 7 mg/l TN. These expectations form the basis of the wasteload allocation for Eureka: 2.2 kg/d TP and 7.5 kg/d TN. The wasteload allocation for TSS is based on the existing permit limit (monthly average of 80 mg/l TSS) and equals 190 lbs/d.

Calibration and Input Values	Total P	Total N	Chl a	Secchi	Non-Algal Turbidity	Annual PPT	Annual ET	Drainage Area	Annual Inflow	Surface Area	Mean Depth
In-Lake Values	55 µg/l	600 µg/l	10.6 µg/l	0.45 m	1.35/m	0.91 m	1.35 m	1419 sq. kms	407.8 cu hm	9.43 sq kms	3 m
Fall River	109 µg/l	83 µg/l	NA	NA	NA	NA	NA	1064 sq. kms	305.9 cu hm	NA	NA
Otter Crk	83 µg/l	512 µg/l	NA	NA	NA	NA	NA	355 sq. kms	101.9 cu hm	NA	NA
Weighted Inflow	103 µg/l	690 µg/l	NA	NA	NA	NA	NA	1419 sq. kms	407.8 cu hm	NA	NA

Table 16. Input Values to BATHTUB Eutrophication Model for Fall River Lake

No changes are directed at Eureka during the short term implementation of this TMDL because model analysis indicates that elimination of the WLA would result in a 1.3% decrease in current in-lake TP, a 0.8 decrease in in-lake TN and a 1.0% decrease in chlorophyll a concentrations. The initial emphasis will be on reductions in load from non-point sources. Further reductions in loading from Eureka may be made during implementation of the ultimate endpoint of phosphorus reduction in Fall River Lake.

Load Allocations: Table 17 indicates the various loadings from the atmosphere, non-point sources and the City of Eureka into Fall River Lake. Model input and output for the various scenarios is presented in Appendix B. The resulting in-lake conditions from the scenarios are shown in **Table 18**. As seen in **Table 17**, the majority of the contributions are non-point in nature, associated with nutrient loadings from wildlife, riparian cropland and livestock waste. While moderate reductions would result in achieving the initialchlorophyll level goals in the lake, more substantial controls would be necessary to influence the nutrient levels found in the lake. Percent reductions were rounded upward to enhance the margin of safety. Daily expression of the loads is found in Appendix C.

The modest reductions necessary to induce algal productivity to decline to acceptable levels are created by the light limitations in the lake water column, because of the turbid nature of the lake. Low Secchi Disk depths reflect the low transparency of the lake, making light the dominant limiting factor. There is a strong relationship between phosphorus and sediment, thus controls reducing phosphorus will invoke some reduced sediment loading as well. The ultimate phosphorus reduction scenario reflects some reduction in turbidity and increased Secchi depths.

Sensitivity analysis of the BATHTUB modeling results indicates there are multiple tradeoff combinations for load reduction between phosphorus and nitrogen. Appendix D contains a graphical display of possible loading combinations. A net reduction in nitrogen appears to have more impact than a similar reduction in phosphorus. If nitrogen loading is reduced by 13% (inflow TN concentration = 600 µg/l), no reduction in phosphorus loading would be necessary to reach the 9.5 µg/l chlorophyll a endpoint. Additional reductions in nitrogen loading would make Fall River Lake robust against any future increases in phosphorus loading. However, because of soluble nature of nitrogen, allowing it to load the stream system via runoff, groundwater or the atmosphere, it is markedly easier to reduce phosphorus loading through runoff and sediment control. Therefore, the TMDL will work on achieving a 10% reduction in nitrogen loads, permitting a 16% reduction in phosphorus loads. Both allocations appear to be feasible.

Siltation: Sediment loading is predominantly from non-point sources, notably the croplands along the riparian areas of the streams in the Fall River watershed. **Table 19** shows surveyed and estimated volumes of conservation storage and storage lost to sedimentation since 1948. Overall annual storage loss has hovered around 0.6% per year; however, the incremental proportion of storage loss is growing as the remaining conservation storage dwindles. The goal of the TMDL is to hold the incremental storage loss percentage to the overall loss value over the period of 2010 – 2020. The Kansas Water Office and the Kansas Biological Survey will conduct a bathymetric survey of Fall

Scenario	Atmos P	Inflow P		Total P Load Capacity	Atmos N	Inflow N		Total N Load Capacity
		NPS LA	Eureka WLA			NPS LA	Eureka WLA	
Current Chl a = 10.6 µg/l	94 kg/yr	41208 kg/yr	795 kg/yr	42098 kg/yr	6601 kg/yr	278632 kg/yr	2750 kg/yr	287983 kg/yr
Reduce P to reach 9.5 µg/l chl a	94 kg/yr	26528 kg/yr	795 kg/yr	27417 kg/yr (-35%)	6601 kg/yr	278632 kg/yr	2750 kg/yr	287983 kg/yr
Reduce P <u>& N</u> to reach 9.5 µg/l chl a	94 kg/yr	34684 kg/yr (34611)	795 kg/yr	35573 kg/yr (-16%)	6601 kg/yr	252125 kg/yr (249850)	2750 kg/yr	261476 kg/yr (-9%)
	Adjusted Load Capacity =			**35500 kg/yr**	Adjusted Load Capacity =			**259200 kg/yr**
Reduce P to reach 35 µg/l TP in lake	94 kg/yr	20818 kg/yr (20160)	795 kg/yr	21707 kg/yr (-49%)	6601 kg/yr	254164 kg/yr	2750 kg/yr	263515 kg/yr
	Adjusted Load Capacity =			**21050 kg/yr**				

Table 17. Phosphorus and Nitrogen Loads to Achieve Endpoints in Fall River Lake

Scenario	TP	TN	Chl a	Secchi
Current	55 µg/l	600 µg/l	10.6 µg/l	0.4 meters
P Only	41 µg/l	600 µg/l	9.5 µg/l	0.4 meters
P & N	49 µg/l	552 µg/l	9.5 µg/l	0.4 meters
Ultimate P	35 µg/l	552 µg/l	8.2 µg/l	0.8 meters

Table 18. Corresponding Lake Water Quality to Loading Scenarios

River Lake in 2010 and that information can affirm the estimates made in **Table 19** and adjust the 2020 goal.

Juracek (2008) estimated the annual net sediment deposition into Fall River Lake to be 162,000 tons per year. Assuming from the phosphorus modeling that the lake traps half the sediment entering it, the corresponding load from the watershed is 324,000 tons per year. A 39% decrease in the incremental annual storage loss over 2010-2020 is necessary to achieve the storage goal. Therefore, directly applying that decrease to the estimated annual load yields a load capacity of 198,000 tons per year. The wasteload allocation for Eureka TSS is 35 tons per year, or less than 0.02% of the load capacity. A majority of the load is likely coming from bankfull discharges flowing over unprotected riparian cropland.

Year	Cons Storage	Change from 1948 Storage	Incremental Storage Change	Percent Change from 1948	Incremental Annual Change	Incremental Annual Percent Change	# of Years since 1948
1948	30,400 af	0	0	0	0	0	0
1990	22600 af	-7800 af	-7800 af	-25.7%	-186 af/yr	-0.61%	42
2006	19600 af	-10800 af	-3000 af	-35.5%	-188 af/yr	-0.83%	58
2010	~18850 af	-11550 af	-750 af	-38.0%	-188 af/yr	-0.96%	62
2020	17700 af	-12700 af	-1150 af	-41.8%	-115 af/yr	-0.60%	72

Table 19. Changes in Conservation Storage in Fall River Lake over 1948 - 2020

Table 20 shows there are weak relations between water column TSS concentrations, turbidity measurements, Secchi disk depths and the dissolved oxygen concentration at 5 meters depth. Juracek (2008) found that over 99 percent of the sediment deposited in Fall River Lake was fine silts and clays. If colloidal clays are loaded into the lake, they will diminish transparency with little mass distributed in the water. Dissolved oxygen at depth is influenced by the vertical movement of the water column (affected by wind), diminished oxygen production because photosynthesis is limited by light penetration, respiration of benthic biota, decomposition of allochthonous and autochthonous organic matter settling to the deep portions of the lake. The TMDL assumes that increased clarity in the lake will result from decreased sediment loads into the lake and the increased penetration of light will allow more oxygen to be produced through photosynthesis, while decomposition of organic matter will be lower because of less loading from the watershed and manageable primary production in the lake, reflecting lowered phosphorus levels.

In conclusion, for management purposes, the reductions for TP, TN and TSS will be rounded upward to 15%, (50% for ultimate TP TMDL), 10% and 40%, respectively, to achieve the initial endpoints of this TMDL. **Figure 20** compares the current loadings with future loadings after implementation of the TMDL. Actual reductions might be targeted toward the high flow (and load) regimes.

Margin of Safety: The margin of safety for nutrients is implicit since the necessary load reductions are keyed to achieving a chlorophyll a concentration of 9.5 ug/l, below the 10 ug/l endpoint demarcating adequate and problematic trophic conditions. Furthermore, the TMDL intends to direct implementation to continue to reduce in-lake phosphorus levels to mitigate against the threat of algal blooms re-emerging as lake clarity improves with reductions in sediment loading. Finally, the necessary load reductions are rounded down from the modeled results, creating some margin for water quality.

The margin of safety for siltation is also implicit and based on the assumption that with the tight linkage between phosphorus and sediment, the aggressive reduction in long-term phosphorus loading (~50%) will correspond to a reduction in sediment loading beyond that necessary to maintain the integrity of the conservation storage in Fall River Lake. Similarly, dissolved oxygen profiles should show improved levels at depth with the diminishment of organic material settling toward the lake bottom.

Year	TSS	Turbidity	Secchi Depth	DO @ 5 m
1989	37 mg/l	52 NTU	0.35 m	5.8 mg/l
1995	18 mg/l	12 NTU	0.30 m	0.6 mg/l
1998	16 mg/l	23 NTU	0.28 m	6.1 mg/l
2001	29 mg/l	24 NTU	0.33 m	1.0 mg/l
2004	18 mg/l	20 NTU	0.67 m	4.0 mg/l
2007	14 mg/l	19 NTU	0.58 m	2.4 mg/l

Table 20. Relationship between Suspended Solids, Transparency and DO at Depth in Fall River Lake

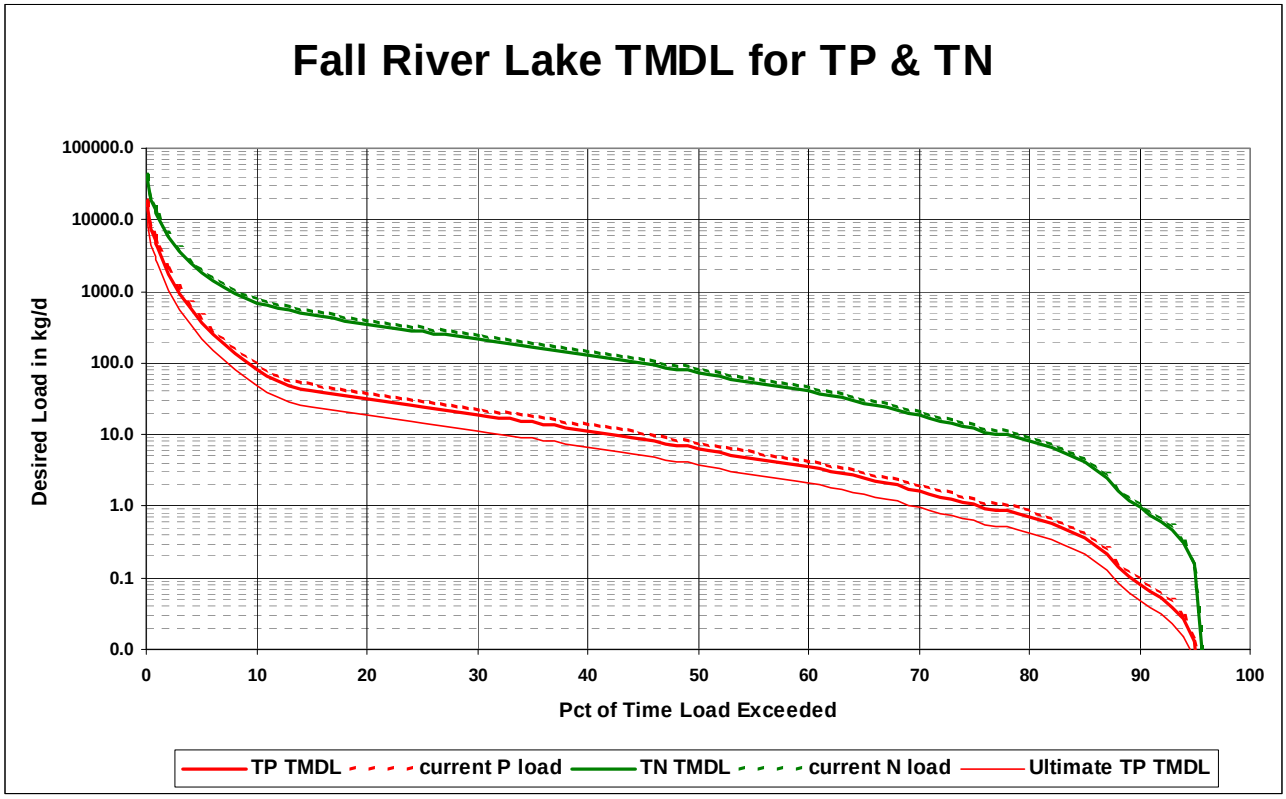

Figure 20. Current and TMDL Loadings of TP and TN into Fall River Lake

State Water Plan Implementation Priority: Since Fall River Lake is a Federal reservoir that serves as a public water supply source and regional recreation center, this TMDL will be a High Priority for implementation.

Unified Watershed Assessment Priority Ranking: The Fall River watershed (HUC8: 11070102) was found to be ranked 50th in priority, indicating a low priority for restoration work. This was chiefly because overall water quality in the watershed is good and there were issues with other resources in the watershed.

Priority HUC12s: Initial STEPL modeling indicates large rank variability among the 14 HUC12s lying above Fall River Lake. For the purposes of implementation, priority will consider proximity to the lake, hydrology and presence of cropland and erodable soils along the stream system. Therefore, priority for implementation will be placed in the subwatersheds immediately above the lake up to Eureka and the confluence of Spring Creek. The lower reaches of Fall River (HUC10/12s: 0108 and 0205) and Otter Creek (HUC10/12s: 0202, 0203 & 0204) will be the focus of implementation. HUC12s are identified in Appendix A.

5. IMPLEMENTATION

Desired Implementation Activities: There is a very good potential that agricultural best management practices will improve the condition of Fall River Lake. Some of the recommended agricultural practices are as follows:

1. Implement soil sampling to recommend appropriate fertilizer applications on cultivated croplands.
2. Maintain conservation tillage and contour farming to minimize cropland erosion.
3. Promote and adopt continuous no-till cultivation to increase the amount of water infiltration and minimize cropland soil erosion and nutrient transports.
4. Install grass buffer strips along streams and drainage channels in the watershed.
5. Reduce activities within riparian areas.
6. Implement nutrient management plans to manage manure land applications and runoff potential.
7. Adequately manage fertilizer utilization in the watershed and implement runoff control measures.
8. Utilize state-supported Fall River WRAPS process to coordinate load reduction of nutrients to the lake.

Implementation Program Guidance:

NPDES-KDHE

a. Evaluate nutrient loading from the City of Eureka.
b. Work with Eureka to reduce long-term nutrient loadings.

Watershed Management Program – KDHE

a. Support new and ongoing Section 319 implementation and demonstration activities conducted under WRAPS projects focused on Fall River Lake, including demonstration projects and outreach efforts dealing with erosion and sediment control and nutrient management.
b. Provide technical assistance on practices geared to establishment of vegetative buffer strips.
c. Provide technical assistance on nutrient management in the vicinity of streams.
d. Support Watershed Restoration and Protection Strategy (WRAPS) efforts for Fall River Lake.
e. Incorporate the provisions of this TMDL into WRAPS documents relating to Fall River Lake.

Water Resource Cost Share and Nonpoint Source Pollution Control Programs – SCC

a. Apply conservation farming practices and/or erosion control structures, including no-till, terraces and contours, sediment control basins, and constructed wetlands.
b. Provide sediment control practices to minimize erosion and sediment and nutrient transport.

Riparian Protection Program – SCC

a. Establish, protect or re-establish natural riparian systems, including vegetative filter strips and streambank vegetation.
b. Develop riparian restoration projects.
c. Promote wetland construction to assimilate nutrient loadings.

Buffer Initiative Program – SCC

a. Install grass buffer strips near streams.
b. Leverage Conservation Reserve Enhancement Program to hold riparian land out of production.

Extension Outreach and Technical Assistance – Kansas State University

a. Educate agricultural producers on sediment, nutrient, and pasture management.
b. Educate livestock producers on livestock waste management and manure applications and nutrient management planning.
c. Provide technical assistance on livestock waste management systems and nutrient management planning.
d. Provide technical assistance on buffer strip design and minimizing cropland runoff.
e. Encourage annual soil testing to determine capacity of field to hold nutrients.

f. Support outreach efforts by Fall River WRAPS projects and continue to educate residents, landowners, and watershed stakeholders about nonpoint source pollution.

Time Frame for Implementation: Initial implementation will proceed over the years from 2009-2016

Targeted Participants: Primary participant for implementation will be agricultural producers and stakeholders within the Fall River Lake watershed. A detailed assessment of sources conducted over 2009 should include local assessments by conservation district personnel and county extension agents to survey, locate, and assess the following within the lake drainage area:

1. Total row crop acreage and fertilizer application rates,
2. Cultivation alongside the lake and streams,
3. Livestock use of riparian areas,
4. Fields with manure applications.

Milestone for 2013: The year 2013 marks the midpoint of the eight-year implementation window for the watershed. At that point in time, sampled data from Fall River Lake will be reexamined to assess improved conditions in the lake. Should the impairment remain, adjustments may be made to source assessment, allocation, and implementation activities.

Delivery Agents: The primary delivery agents for program participation will be the Kansas Department of Health and Environment, the State Conservation Commission, the Natural Resources Conservation Service, the Kansas State University Extension Service, and the Fall River WRAPS SLT. Producer outreach and awareness will be delivered by the Kansas State Extension and/or coordinated through Fall River WRAPS Stakeholder Leadership Team. Implementation decisions and scheduling will be guided by planning documents prepared through Fall River WRAPS projects.

Reasonable Assurances:
Authorities: The following authorities may be used to direct activities in the watershed to reduce pollutants and to assure allocations of pollutant to point and nonpoint sources can be attained.

1. K.S.A. 65-164 and 165 empowers the Secretary of KDHE to regulate the discharge of sewage into the waters of the state.

2. K.S.A. 65-171d empowers the Secretary of KDHE to prevent water pollution and to protect the beneficial uses of the waters of the state through required treatment of sewage and established water quality standards and to require permits by persons having a potential to discharge pollutants into the waters of the state.

3. K.A.R. 28-16-69 to 71 implements water quality protection by KDHE through the establishment and administration of critical water quality management areas on a watershed basis.

4. K.S.A. 2-1915 empowers the State Conservation Commission to develop programs to assist the protection, conservation and management of soil and water resources in the state, including riparian areas.

5. K.S.A. 75-5657 empowers the State Conservation Commission to provide financial assistance for local project work plans developed to control nonpoint source pollution.

6. K.S.A. 82a-901, et. seq. empowers the Kansas Water Office to develop a state water plan directing the protection and maintenance of surface water quality for the waters of the state.

7. K.S.A. 82a-951 creates the State Water Plan Fund to finance the implementation of the *Kansas Water Plan*, including selected Watershed Restoration and Protection Strategies.
8. The *Kansas Water Plan* and the Verdigris Basin Plan provide the guidance to state agencies to coordinate programs intent on protecting water quality and to target those programs to geographic areas of the state for high priority in implementation.

9. K.S.A. 32-807 authorizes the Kansas Department of Wildlife and Parks to manage lake resources.

Funding: The State Water Plan Fund annually generates $16-18 million and is the primary funding mechanism for implementing water quality protection and pollutant reduction activities in the state through the *Kansas Water Plan*. The state water planning process, overseen by the Kansas Water Office, coordinates and directs programs and funding toward watershed and water resources of highest priority. Typically, the state allocates at least 50% of the fund to programs supporting water quality protection. Additionally, $2 million has been allocated between the State Water Plan Fund and EPA 319 funds to support implementation of Watershed Restoration and Protection Strategies. This watershed and its TMDL are among the highest in priority consideration, with implementation allotted up to $200,000 from the WRAPS funding.

Effectiveness: Nutrient and sediment control has been proven effective through conservation tillage, contour farming riparian restoration projects and use of grass waterways and buffer strips. In addition, the proper implementation of comprehensive livestock waste management plans has proven effective at reducing nutrient runoff associated with livestock facilities. The key to success will be widespread utilization of conservation farming and proper livestock waste management within the watershed cited in this TMDL.

6. MONITORING

KDHE will continue its 3-year sampling schedule in order to assess the trophic state of Fall River Lake. Based on the sampling results, the improved state of the lake will be evaluated in 2016. Should impairment status continue, the desired endpoints under this TMDL will be refined and more intensive sampling will be conducted over the period 2016-2018 to assess implementation progress.

7. FEEDBACK

Public Meeting: Public Meetings to discuss TMDLs in the Verdigris Basin have been held since 2002. An active Internet Web site was established at http://www.kdheks.gov/tmdl/index.htm to convey information to the public on the general establishment of TMDLs in the Verdigris Basin and these specific TMDLs.

Public Hearing: A Public Hearing on these Verdigris Basin TMDLs was be held in Neodesha on July 23, 2008. The record for this TMDL remains open until October 31, 2008 because of delays in its public release.

Basin Advisory Committee: The Verdigris Basin Advisory Committee met to discuss these TMDLs on September 25, 2007 in Eureka, February 27, 2008 in Independence, and July 23, 2008 in Neodesha.

Milestone Evaluation: In 2013, evaluation will be made as to implementation of management practices to minimize the nonpoint source runoff contributing to this impairment. Subsequent decisions will be made regarding the implementation approach, priority of allotting resources for implementation and the need for additional or follow up implementation in this watershed at the next TMDL cycle for this basin in 2013 with consultation from the Fall River WRAPS SLT.

Consideration for 303(d) Delisting: Fall River Lake will be evaluated for delisting under Section 303(d), based on the monitoring data over 2008-2015. Therefore, the decision for delisting will come about in the preparation of the 2016-303(d) list. Should modifications be made to the applicable water quality criteria during the implementation period, consideration for delisting, desired endpoints of this TMDL and implementation activities might be adjusted accordingly.

Incorporation into Continuing Planning Process, Water Quality Management Plan and the Kansas Water Planning Process: Under the current version of the Continuing Planning Process, the next anticipated revision would come in 2009, which will emphasize implementation of WRAPS activities. At that time, incorporation of this TMDL will be made into the WRAPS. Recommendations of this TMDL will be considered in the *Kansas Water Plan* implementation decisions under the State Water Planning Process for Fiscal Years 2009-2015.

Revised November 6, 2008

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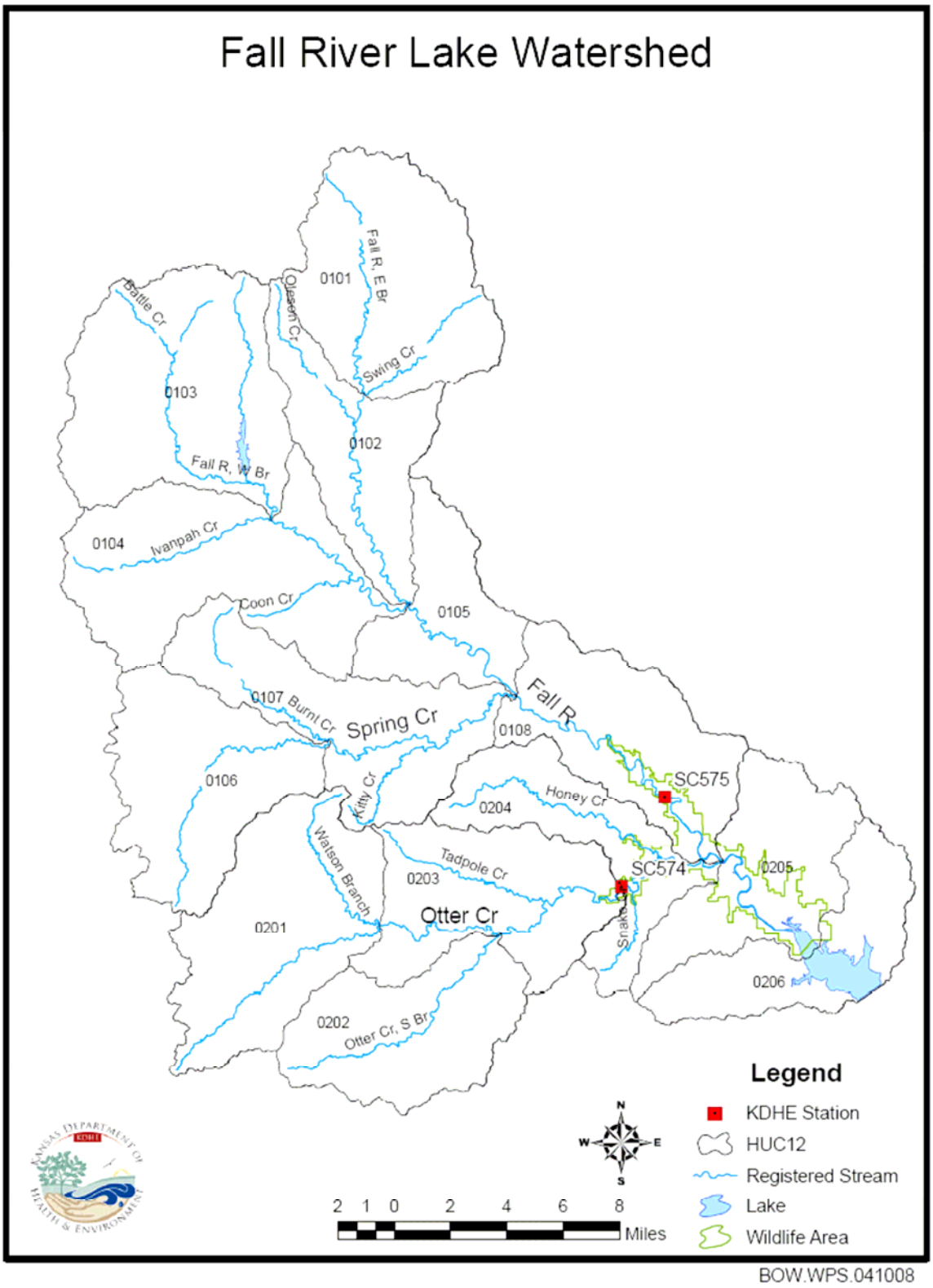
APPENDIX A. HUC 12s and Monitoring Stations in the Fall River Lake Watershed



Fall River Lake Watershed HUC12s

APPENDIX B - BATHTUB Model Input and Output

Fall River Reservoir Current Conditions
File: C:\BATHTUB\Fall River.btb
Description:

Global Variables	Mean	CV
Averaging Period (yrs)	1	0.0
Precipitation (m)	0.91	0.2
Evaporation (m)	1.35	0.3
Storage Increase (m)	0	0.0

Atmos. Loads (kg/km^2-yr)	Mean	CV
Conserv. Substance	0	0.00
Total P	10	0.10
Total N	700	0.10
Ortho P	10	0.10
Inorganic N	700	0.10

Model Options	Code	Description
Conservative Substance	0	NOT COMPUTED
Phosphorus Balance	1	2ND ORDER, AVAIL P
Nitrogen Balance	1	2ND ORDER, AVAIL N
Chlorophyll-a	1	P, N, LIGHT, T
Secchi Depth	1	VS. CHLA & TURBIDITY
Dispersion	1	FISCHER-NUMERIC
Phosphorus Calibration	1	DECAY RATES
Nitrogen Calibration	1	DECAY RATES
Error Analysis	1	MODEL & DATA
Availability Factors	0	IGNORE
Mass-Balance Tables	1	USE ESTIMATED CONCS
Output Destination	2	EXCEL WORKSHEET

Segment Morphometry

		Outflow		Area	Depth	Length	Mixed Depth (m)		Hypol Depth		Non-Algal Turb (m^{-1})		Internal Loads (mg/m2-day) Conserv.		Total P
Seg	Name	Segment	Group	km^2	m	km	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean
1	Main Pool	0	1	9.43	3	6.4	3	0.2	0	0	1.35	0.3	0	0	0

Segment Observed Water Quality

	Conserv		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)	
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	0	0	55	0.2	600	0.2	10.6	0.2	0.45	0.4	350	0.3	45	0.3	0	0

Segment Calibration Factors

	Dispersion Rate		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)	
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	1	0	1.75	0	1.17	0	1.14	0	0.7	0	1	0	1	0	1	0

Tributary Data

				Dr Area	Flow (hm^3/yr)		Conserv.		Total P (ppb)		Total N (ppb)		Ortho P (ppb)		Inorganic I
Trib	Trib Name	Segment	Type	km^2	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean
1	Trib 1	1	1	1419	407.8	1.6	0	0	103	2	690	2	20	0.5	500

Model Coefficients	Mean	CV
Dispersion Rate	1.000	0.70
Total Phosphorus	1.000	0.45
Total Nitrogen	1.000	0.55
Chl-a Model	1.000	0.26
Secchi Model	1.000	0.10
Organic N Model	1.000	0.12
TP-OP Model	1.000	0.15
HODv Model	1.000	0.15
MODv Model	1.000	0.22
Secchi/Chla Slope (m^2/mg)	0.025	0.00
Minimum Qs (m/yr)	0.100	0.00
Chl-a Flushing Term	1.000	0.00
Chl-a Temporal CV	0.620	0
Avail. Factor - Total P	0.330	0
Avail. Factor - Ortho P	1.930	0
Avail. Factor - Total N	0.590	0
Avail. Factor - Inorganic N	0.790	0

Initial Input for Current Condition

Fall River Reservoir Current Conditions
File: C:\BATHTUB\Fall River.btb

Predicted & Observed Values Ranked Against CE Model Development Dataset

Segment: 1 Main Pool

	Predicted Values--->			Observed Values--->		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	55.4	1.41	56.4%	55.0	0.20	56.1%
TOTAL N MG/M3	599.8	1.69	21.1%	600.0	0.20	21.1%
C.NUTRIENT MG/M3	31.0	1.59	43.1%	31.0	0.20	43.0%
CHL-A MG/M3	10.7	1.60	56.8%	10.6	0.20	56.3%
SECCHI M	0.4	0.36	11.4%	0.4	0.40	12.5%
ORGANIC N MG/M3	503.0	0.78	54.6%	350.0	0.30	27.6%
TP-ORTHO-P MG/M3	47.0	0.68	68.2%	45.0	0.30	66.5%
ANTILOG PC-1	382.7	2.21	63.3%	327.4	0.27	58.8%
ANTILOG PC-2	3.9	0.77	17.6%	3.8	0.31	15.7%
(N - 150) / P	8.1	2.61	13.9%	8.2	0.33	14.1%
INORGANIC N / P	11.5	13.46	16.9%	25.0	1.93	43.1%
TURBIDITY 1/M	1.4	0.30	81.7%	1.4	0.30	81.7%
ZMIX * TURBIDITY	4.1	0.36	62.7%	4.1	0.36	62.7%
ZMIX / SECCHI	6.9	0.40	74.0%	6.7	0.44	71.7%
CHL-A * SECCHI	4.6	1.38	13.3%	4.8	0.45	14.2%
CHL-A / TOTAL P	0.2	1.85	49.2%	0.2	0.28	48.9%
FREQ(CHL-a>10) %	42.1	2.38	56.8%	41.4	0.30	56.3%
FREQ(CHL-a>20) %	9.4	4.66	56.8%	9.1	0.59	56.3%
FREQ(CHL-a>30) %	2.4	6.20	56.8%	2.3	0.79	56.3%
FREQ(CHL-a>40) %	0.7	7.35	56.8%	0.7	0.94	56.3%
FREQ(CHL-a>50) %	0.3	8.27	56.8%	0.2	1.06	56.3%
FREQ(CHL-a>60) %	0.1	9.05	56.8%	0.1	1.16	56.3%
CARLSON TSI-P	62.0	0.32	56.4%	61.9	0.05	56.1%
CARLSON TSI-CHLA	53.9	0.29	56.8%	53.8	0.04	56.3%
CARLSON TSI-SEC	72.1	0.07	88.6%	71.5	0.08	87.5%

Calibration of Modeled Conditions to Observed Current Conditions

Fall River Reservoir Current Condition
File: C:\BATHTUB\Fall River.btb

Overall Water & Nutrient Balances

Overall Water Balance — **Averaging Period = 1.00 years**

Trb	Type	Seg	Name	Area km^2	Flow hm^3/yr	Variance (hm3/yr)^2	CV -	Runoff m/yr
1	1	1	Trib 1	1419.0	407.8	4.26E+05	1.60	0.29
PRECIPITATION				9.4	8.6	2.95E+00	0.20	0.91
TRIBUTARY INFLOW				1419.0	407.8	4.26E+05	1.60	0.29
***TOTAL INFLOW				1428.4	416.4	4.26E+05	1.57	0.29
ADVECTIVE OUTFLOW				1428.4	403.7	4.26E+05	1.62	0.28
***TOTAL OUTFLOW				1428.4	403.7	4.26E+05	1.62	0.28
***EVAPORATION					12.7	1.46E+01	0.30	

Overall Mass Balance Based Upon Component: TOTAL P — **Predicted Outflow & Reservoir Concentrations**

Trb	Type	Seg	Name	Load kg/yr	%Total	Load Variance (kg/yr)^2	%Total	CV	Conc mg/m^3	Export kg/km^2/yr
1	1	1	Trib 1	42003.4	99.8%	1.16E+10	100.0%	2.56	103.0	29.6
PRECIPITATION				94.3	0.2%	8.89E+01	0.0%	0.10	11.0	10.0
TRIBUTARY INFLOW				42003.4	99.8%	1.16E+10	100.0%	2.56	103.0	29.6
***TOTAL INFLOW				42097.7	100.0%	1.16E+10	100.0%	2.56	101.1	29.5
ADVECTIVE OUTFLOW				22372.4	53.1%	2.93E+09		2.42	55.4	15.7
***TOTAL OUTFLOW				22372.4	53.1%	2.93E+09		2.42	55.4	15.7
***RETENTION				19725.3	46.9%	3.41E+09		2.96		

Overflow Rate (m/yr)	42.8	Nutrient Resid. Time (yrs)	0.0372
Hydraulic Resid. Time (yrs)	0.0701	Turnover Ratio	26.8
Reservoir Conc (mg/m3)	55	Retention Coef.	0.469

Overall Mass Balance Based Upon Component: TOTAL N — **Predicted Outflow & Reservoir Concentrations**

Trb	Type	Seg	Name	Load kg/yr	%Total	Load Variance (kg/yr)^2	%Total	CV	Conc mg/m^3	Export kg/km^2/yr
1	1	1	Trib 1	281382.0	97.7%	5.19E+11	100.0%	2.56	690.0	198.3
PRECIPITATION				6601.0	2.3%	4.36E+05	0.0%	0.10	769.2	700.0
TRIBUTARY INFLOW				281382.0	97.7%	5.19E+11	100.0%	2.56	690.0	198.3
***TOTAL INFLOW				287983.0	100.0%	5.19E+11	100.0%	2.50	691.6	201.6
ADVECTIVE OUTFLOW				242112.4	84.1%	3.48E+11		2.44	599.8	169.5
***TOTAL OUTFLOW				242112.4	84.1%	3.48E+11		2.44	599.8	169.5
***RETENTION				45870.6	15.9%	2.52E+10		3.46		

Overflow Rate (m/yr)	42.8	Nutrient Resid. Time (yrs)	0.0589
Hydraulic Resid. Time (yrs)	0.0701	Turnover Ratio	17.0
Reservoir Conc (mg/m3)	600	Retention Coef.	0.159

Current Condition Loadings and Mass Balance

Fall River Reservoir P reduced only condition
File: C:\BATHTUB\Fall River P only.btb

Predicted & Observed Values Ranked Against CE Model Development Dataset

Segment: 1 Main Pool

	Predicted Values--->			Observed Values--->		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	41.1	1.46	43.2%	55.0	0.20	56.1%
TOTAL N MG/M3	599.8	1.69	21.1%	600.0	0.20	21.1%
C.NUTRIENT MG/M3	27.7	1.38	37.5%	31.0	0.20	43.0%
CHL-A MG/M3	9.5	1.44	50.8%	10.6	0.20	56.3%
SECCHI M	0.4	0.33	11.9%	0.4	0.40	12.5%
ORGANIC N MG/M3	476.1	0.67	50.3%	350.0	0.30	27.6%
TP-ORTHO-P MG/M3	44.9	0.59	66.4%	45.0	0.30	66.5%
ANTILOG PC-1	326.1	1.92	58.6%	327.4	0.27	58.8%
ANTILOG PC-2	3.7	0.73	15.1%	3.8	0.31	15.7%
(N - 150) / P	10.9	2.65	25.9%	8.2	0.33	14.1%
INORGANIC N / P	123.7	6.17	92.4%	25.0	1.93	43.1%
TURBIDITY 1/M	1.4	0.30	81.7%	1.4	0.30	81.7%
ZMIX * TURBIDITY	4.1	0.36	62.7%	4.1	0.36	62.7%
ZMIX / SECCHI	6.8	0.38	72.9%	6.7	0.44	71.7%
CHL-A * SECCHI	4.2	1.27	10.5%	4.8	0.45	14.2%
CHL-A / TOTAL P	0.2	1.53	60.5%	0.2	0.28	48.9%
FREQ(CHL-a>10) %	34.9	2.45	50.8%	41.4	0.30	56.3%
FREQ(CHL-a>20) %	6.6	4.56	50.8%	9.1	0.59	56.3%
FREQ(CHL-a>30) %	1.5	5.95	50.8%	2.3	0.79	56.3%
FREQ(CHL-a>40) %	0.4	6.99	50.8%	0.7	0.94	56.3%
FREQ(CHL-a>50) %	0.1	7.81	50.8%	0.2	1.06	56.3%
FREQ(CHL-a>60) %	0.1	8.50	50.8%	0.1	1.16	56.3%
CARLSON TSI-P	57.7	0.36	43.2%	61.9	0.05	56.1%
CARLSON TSI-CHLA	52.7	0.27	50.8%	53.8	0.04	56.3%
CARLSON TSI-SEC	71.8	0.07	88.1%	71.5	0.08	87.5%

Resulting Water Quality in Fall River Lake with Only Reduction to TP Loading

Fall River Reservoir P reduced only condition
File: C:\BATHTUB\Fall River P only.btb

Overall Water & Nutrient Balances

Overall Water Balance — **Averaging Period = 1.00 years**

Trb	Type	Seg	Name	Area km^2	Flow hm^3/yr	Variance (hm3/yr)^2	CV -	Runoff m/yr
1	1	1	Trib 1	1419.0	407.8	4.26E+05	1.60	0.29
PRECIPITATION				9.4	8.6	2.95E+00	0.20	0.91
TRIBUTARY INFLOW				1419.0	407.8	4.26E+05	1.60	0.29
***TOTAL INFLOW				1428.4	416.4	4.26E+05	1.57	0.29
ADVECTIVE OUTFLOW				1428.4	403.7	4.26E+05	1.62	0.28
***TOTAL OUTFLOW				1428.4	403.7	4.26E+05	1.62	0.28
***EVAPORATION					12.7	1.46E+01	0.30	

Overall Mass Balance Based Upon Component: TOTAL P — **Predicted Outflow & Reservoir Concentrations**

Trb	Type	Seg	Name	Load kg/yr	%Total	Load Variance (kg/yr)^2	%Total	CV	Conc mg/m^3	Export kg/km^2/yr
1	1	1	Trib 1	27322.6	99.7%	4.90E+09	100.0%	2.56	67.0	19.3
PRECIPITATION				94.3	0.3%	8.89E+01	0.0%	0.10	11.0	10.0
TRIBUTARY INFLOW				27322.6	99.7%	4.90E+09	100.0%	2.56	67.0	19.3
***TOTAL INFLOW				27416.9	100.0%	4.90E+09	100.0%	2.55	65.8	19.2
ADVECTIVE OUTFLOW				16581.5	60.5%	1.61E+09		2.42	41.1	11.6
***TOTAL OUTFLOW				16581.5	60.5%	1.61E+09		2.42	41.1	11.6
***RETENTION				10835.4	39.5%	1.10E+09		3.06		

Overflow Rate (m/yr)	42.8	Nutrient Resid. Time (yrs)	0.0424
Hydraulic Resid. Time (yrs)	0.0701	Turnover Ratio	23.6
Reservoir Conc (mg/m3)	41	Retention Coef.	0.395

Overall Mass Balance Based Upon Component: TOTAL N — **Predicted Outflow & Reservoir Concentrations**

Trb	Type	Seg	Name	Load kg/yr	%Total	Load Variance (kg/yr)^2	%Total	CV	Conc mg/m^3	Export kg/km^2/yr
1	1	1	Trib 1	281382.0	97.7%	5.19E+11	100.0%	2.56	690.0	198.3
PRECIPITATION				6601.0	2.3%	4.36E+05	0.0%	0.10	769.2	700.0
TRIBUTARY INFLOW				281382.0	97.7%	5.19E+11	100.0%	2.56	690.0	198.3
***TOTAL INFLOW				287983.0	100.0%	5.19E+11	100.0%	2.50	691.6	201.6
ADVECTIVE OUTFLOW				242112.4	84.1%	3.48E+11		2.44	599.8	169.5
***TOTAL OUTFLOW				242112.4	84.1%	3.48E+11		2.44	599.8	169.5
***RETENTION				45870.6	15.9%	2.52E+10		3.46		

Overflow Rate (m/yr)	42.8	Nutrient Resid. Time (yrs)	0.0589
Hydraulic Resid. Time (yrs)	0.0701	Turnover Ratio	17.0
Reservoir Conc (mg/m3)	600	Retention Coef.	0.159

Reduced TP Loadings and Mass Balance if Only TP Load Reductions are Implemented

Fall River Reservoir TMDL Conditions
File: C:\BATHTUB\Fall River.btb

Predicted & Observed Values Ranked Against CE Model Development Dataset

Segment: 1 Main Pool

	Predicted Values--->			Observed Values--->		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	49.4	1.43	51.3%	55.0	0.20	56.1%
TOTAL N MG/M3	551.7	1.70	17.6%	600.0	0.20	21.1%
C.NUTRIENT MG/M3	27.7	1.64	37.6%	31.0	0.20	43.0%
CHL-A MG/M3	9.5	1.71	50.8%	10.6	0.20	56.3%
SECCHI M	0.4	0.36	11.9%	0.4	0.40	12.5%
ORGANIC N MG/M3	476.2	0.79	50.4%	350.0	0.30	27.6%
TP-ORTHO-P MG/M3	44.9	0.68	66.4%	45.0	0.30	66.5%
ANTILOG PC-1	326.4	2.30	58.7%	327.4	0.27	58.8%
ANTILOG PC-2	3.7	0.84	15.1%	3.8	0.31	15.7%
(N - 150) / P	8.1	2.70	14.0%	8.2	0.33	14.1%
INORGANIC N / P	16.8	20.06	28.4%	25.0	1.93	43.1%
TURBIDITY 1/M	1.4	0.30	81.7%	1.4	0.30	81.7%
ZMIX * TURBIDITY	4.1	0.36	62.7%	4.1	0.36	62.7%
ZMIX / SECCHI	6.8	0.40	72.9%	6.7	0.44	71.7%
CHL-A * SECCHI	4.2	1.49	10.5%	4.8	0.45	14.2%
CHL-A / TOTAL P	0.2	1.94	49.1%	0.2	0.28	48.9%
FREQ(CHL-a>10) %	35.0	2.91	50.8%	41.4	0.30	56.3%
FREQ(CHL-a>20) %	6.6	5.45	50.8%	9.1	0.59	56.3%
FREQ(CHL-a>30) %	1.5	7.13	50.8%	2.3	0.79	56.3%
FREQ(CHL-a>40) %	0.4	8.39	50.8%	0.7	0.94	56.3%
FREQ(CHL-a>50) %	0.1	9.40	50.8%	0.2	1.06	56.3%
FREQ(CHL-a>60) %	0.1	10.24	50.8%	0.1	1.16	56.3%
CARLSON TSI-P	60.4	0.34	51.3%	61.9	0.05	56.1%
CARLSON TSI-CHLA	52.7	0.31	50.8%	53.8	0.04	56.3%
CARLSON TSI-SEC	71.8	0.07	88.1%	71.5	0.08	87.5%

Resulting Water Quality in Fall River Lake if TN and TP Loads are Reduced

Fall River Reservoir TMDL Conditions
File: C:\BATHTUB\Fall River.btb

Overall Water & Nutrient Balances

Overall Water Balance — **Averaging Period = 1.00 years**

Trb	Type	Seg	Name	Area km^2	Flow hm^3/yr	Variance (hm3/yr)^2	CV -	Runoff m/yr
1	1	1	Trib 1	1419.0	407.8	4.26E+05	1.60	0.29
PRECIPITATION				9.4	8.6	2.95E+00	0.20	0.91
TRIBUTARY INFLOW				1419.0	407.8	4.26E+05	1.60	0.29
***TOTAL INFLOW				1428.4	416.4	4.26E+05	1.57	0.29
ADVECTIVE OUTFLOW				1428.4	403.7	4.26E+05	1.62	0.28
***TOTAL OUTFLOW				1428.4	403.7	4.26E+05	1.62	0.28
***EVAPORATION					12.7	1.46E+01	0.30	

Overall Mass Balance Based Upon Component: TOTAL P — **Predicted Outflow & Reservoir Concentrations**

Trb	Type	Seg	Name	Load kg/yr	%Total	Load Variance (kg/yr)^2	%Total	CV	Conc mg/m^3	Export kg/km^2/yr
1	1	1	Trib 1	35478.6	99.7%	8.26E+09	100.0%	2.56	87.0	25.0
PRECIPITATION				94.3	0.3%	8.89E+01	0.0%	0.10	11.0	10.0
TRIBUTARY INFLOW				35478.6	99.7%	8.26E+09	100.0%	2.56	87.0	25.0
***TOTAL INFLOW				35572.9	100.0%	8.26E+09	100.0%	2.55	85.4	24.9
ADVECTIVE OUTFLOW				19925.8	56.0%	2.33E+09		2.42	49.4	13.9
***TOTAL OUTFLOW				19925.8	56.0%	2.33E+09		2.42	49.4	13.9
***RETENTION				15647.1	44.0%	2.20E+09		3.00		

Overflow Rate (m/yr)	42.8	Nutrient Resid. Time (yrs)	0.0393
Hydraulic Resid. Time (yrs)	0.0701	Turnover Ratio	25.5
Reservoir Conc (mg/m3)	49	Retention Coef.	0.440

Overall Mass Balance Based Upon Component: TOTAL N — **Predicted Outflow & Reservoir Concentrations**

Trb	Type	Seg	Name	Load kg/yr	%Total	Load Variance (kg/yr)^2	%Total	CV	Conc mg/m^3	Export kg/km^2/yr
1	1	1	Trib 1	254875.0	97.5%	4.26E+11	100.0%	2.56	625.0	179.6
PRECIPITATION				6601.0	2.5%	4.36E+05	0.0%	0.10	769.2	700.0
TRIBUTARY INFLOW				254875.0	97.5%	4.26E+11	100.0%	2.56	625.0	179.6
***TOTAL INFLOW				261476.0	100.0%	4.26E+11	100.0%	2.50	628.0	183.1
ADVECTIVE OUTFLOW				222675.0	85.2%	2.94E+11		2.43	551.7	155.9
***TOTAL OUTFLOW				222675.0	85.2%	2.94E+11		2.43	551.7	155.9
***RETENTION				38801.0	14.8%	1.83E+10		3.48		

Overflow Rate (m/yr)	42.8	Nutrient Resid. Time (yrs)	0.0597
Hydraulic Resid. Time (yrs)	0.0701	Turnover Ratio	16.8
Reservoir Conc (mg/m3)	552	Retention Coef.	0.148

Reduced TN and TP Loadings to Fall River Lake and Mass Balances

Fall River Reservoir Ultimate Conditions
File: C:\BATHTUB\Fall River.btb

Predicted & Observed Values Ranked Against CE Model Development Dataset

Segment: 1 Main Pool

	Predicted Values--->			Observed Values--->		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	34.7	1.50	36.0%	55.0	0.20	56.1%
TOTAL N MG/M3	551.7	1.70	17.6%	600.0	0.20	21.1%
C.NUTRIENT MG/M3	24.1	1.38	31.1%	31.0	0.20	43.0%
CHL-A MG/M3	8.2	1.50	43.2%	10.6	0.20	56.3%
SECCHI M	0.8	0.32	36.8%	0.4	0.40	12.5%
ORGANIC N MG/M3	446.2	0.64	45.3%	350.0	0.30	27.6%
TP-ORTHO-P MG/M3	42.5	0.57	64.3%	45.0	0.30	66.5%
ANTILOG PC-1	199.8	1.95	43.8%	327.4	0.27	58.8%
ANTILOG PC-2	5.3	0.77	35.6%	3.8	0.31	15.7%
(N - 150) / P	11.6	2.74	28.7%	8.2	0.33	14.1%
INORGANIC N / P	105.5	6.82	89.9%	25.0	1.93	43.1%
TURBIDITY 1/M	1.4	0.30	81.7%	1.4	0.30	81.7%
ZMIX * TURBIDITY	4.1	0.36	62.7%	4.1	0.36	62.7%
ZMIX / SECCHI	3.6	0.38	31.3%	6.7	0.44	71.7%
CHL-A * SECCHI	6.9	1.35	28.9%	4.8	0.45	14.2%
CHL-A / TOTAL P	0.2	1.52	61.8%	0.2	0.28	48.9%
FREQ(CHL-a>10) %	26.6	2.99	43.2%	41.4	0.30	56.3%
FREQ(CHL-a>20) %	4.1	5.28	43.2%	9.1	0.59	56.3%
FREQ(CHL-a>30) %	0.8	6.77	43.2%	2.3	0.79	56.3%
FREQ(CHL-a>40) %	0.2	7.87	43.2%	0.7	0.94	56.3%
FREQ(CHL-a>50) %	0.1	8.74	43.2%	0.2	1.06	56.3%
FREQ(CHL-a>60) %	0.0	9.47	43.2%	0.1	1.16	56.3%
CARLSON TSI-P	55.3	0.39	36.0%	61.9	0.05	56.1%
CARLSON TSI-CHLA	51.3	0.29	43.2%	53.8	0.04	56.3%
CARLSON TSI-SEC	62.6	0.08	63.2%	71.5	0.08	87.5%

Resulting Water Quality in Fall River Lake if TP Loads are Significantly Reduced in Future

Fall River Reservoir Ultimate Conditions
File: C:\BATHTUB\Fall River.btb

Overall Water & Nutrient Balances

Overall Water Balance — **Averaging Period = 1.00 years**

Trb	Type	Seg	Name	Area km^2	Flow hm^3/yr	Variance (hm3/yr)^2	CV -	Runoff m/yr
1	1	1	Trib 1	1419.0	407.8	4.26E+05	1.60	0.29
PRECIPITATION				9.4	8.6	2.95E+00	0.20	0.91
TRIBUTARY INFLOW				1419.0	407.8	4.26E+05	1.60	0.29
***TOTAL INFLOW				1428.4	416.4	4.26E+05	1.57	0.29
ADVECTIVE OUTFLOW				1428.4	403.7	4.26E+05	1.62	0.28
***TOTAL OUTFLOW				1428.4	403.7	4.26E+05	1.62	0.28
***EVAPORATION					12.7	1.46E+01	0.30	

Overall Mass Balance Based Upon Component: TOTAL P — **Predicted Outflow & Reservoir Concentrations**

Trb	Type	Seg	Name	Load kg/yr	%Total	Load Variance (kg/yr)^2	%Total	CV	Conc mg/m^3	Export kg/km^2/yr
1	1	1	Trib 1	21613.4	99.6%	3.06E+09	100.0%	2.56	53.0	15.2
PRECIPITATION				94.3	0.4%	8.89E+01	0.0%	0.10	11.0	10.0
TRIBUTARY INFLOW				21613.4	99.6%	3.06E+09	100.0%	2.56	53.0	15.2
***TOTAL INFLOW				21707.7	100.0%	3.06E+09	100.0%	2.55	52.1	15.2
ADVECTIVE OUTFLOW				13992.1	64.5%	1.15E+09		2.42	34.7	9.8
***TOTAL OUTFLOW				13992.1	64.5%	1.15E+09		2.42	34.7	9.8
***RETENTION				7715.6	35.5%	5.80E+08		3.12		

Overflow Rate (m/yr)	42.8	Nutrient Resid. Time (yrs)	0.0452
Hydraulic Resid. Time (yrs)	0.0701	Turnover Ratio	22.1
Reservoir Conc (mg/m3)	35	Retention Coef.	0.355

Overall Mass Balance Based Upon Component: TOTAL N — **Predicted Outflow & Reservoir Concentrations**

Trb	Type	Seg	Name	Load kg/yr	%Total	Load Variance (kg/yr)^2	%Total	CV	Conc mg/m^3	Export kg/km^2/yr
1	1	1	Trib 1	254875.0	97.5%	4.26E+11	100.0%	2.56	625.0	179.6
PRECIPITATION				6601.0	2.5%	4.36E+05	0.0%	0.10	769.2	700.0
TRIBUTARY INFLOW				254875.0	97.5%	4.26E+11	100.0%	2.56	625.0	179.6
***TOTAL INFLOW				261476.0	100.0%	4.26E+11	100.0%	2.50	628.0	183.1
ADVECTIVE OUTFLOW				222675.0	85.2%	2.94E+11		2.43	551.7	155.9
***TOTAL OUTFLOW				222675.0	85.2%	2.94E+11		2.43	551.7	155.9
***RETENTION				38801.0	14.8%	1.83E+10		3.48		

Overflow Rate (m/yr)	42.8	Nutrient Resid. Time (yrs)	0.0597
Hydraulic Resid. Time (yrs)	0.0701	Turnover Ratio	16.8
Reservoir Conc (mg/m3)	552	Retention Coef.	0.148

Ultimate Reduced TP Loadings and Mass Balances in Fall River Lake

Appendix C – Conversion to Daily Loads per EPA Region VII Recommendations

The TMDL has estimated annual average loads for TN and TP that if achieved should meet the water quality targets. A recent court decision often referred to as the "Anacostia decision" has dictated that TMDLs include a "daily" load (Friend of the Earth, Inc v. EPA, et al.).

Expressing this TMDL in daily time steps could be misleading to imply a daily response to a daily load. It is important to recognize that the growing season mean chlorophyll *a* is affected by many factors such as: internal lake nutrient loading, water residence time, wind action and the interaction between light penetration, nutrients, sediment load and algal response.

To translate long-term averages to maximum daily load values, EPA Region 7 has suggested the approach describe in the Technical Support Document for Water Quality Based Toxics Control (EPA/505/2-90-001)(TSD).

Maximum Daily Load (MDL) = (Long-Term Average Load) * $e^{[Z\sigma - 0.5\sigma^2]}$

where $\sigma^2 = \ln(CV^2 + 1)$

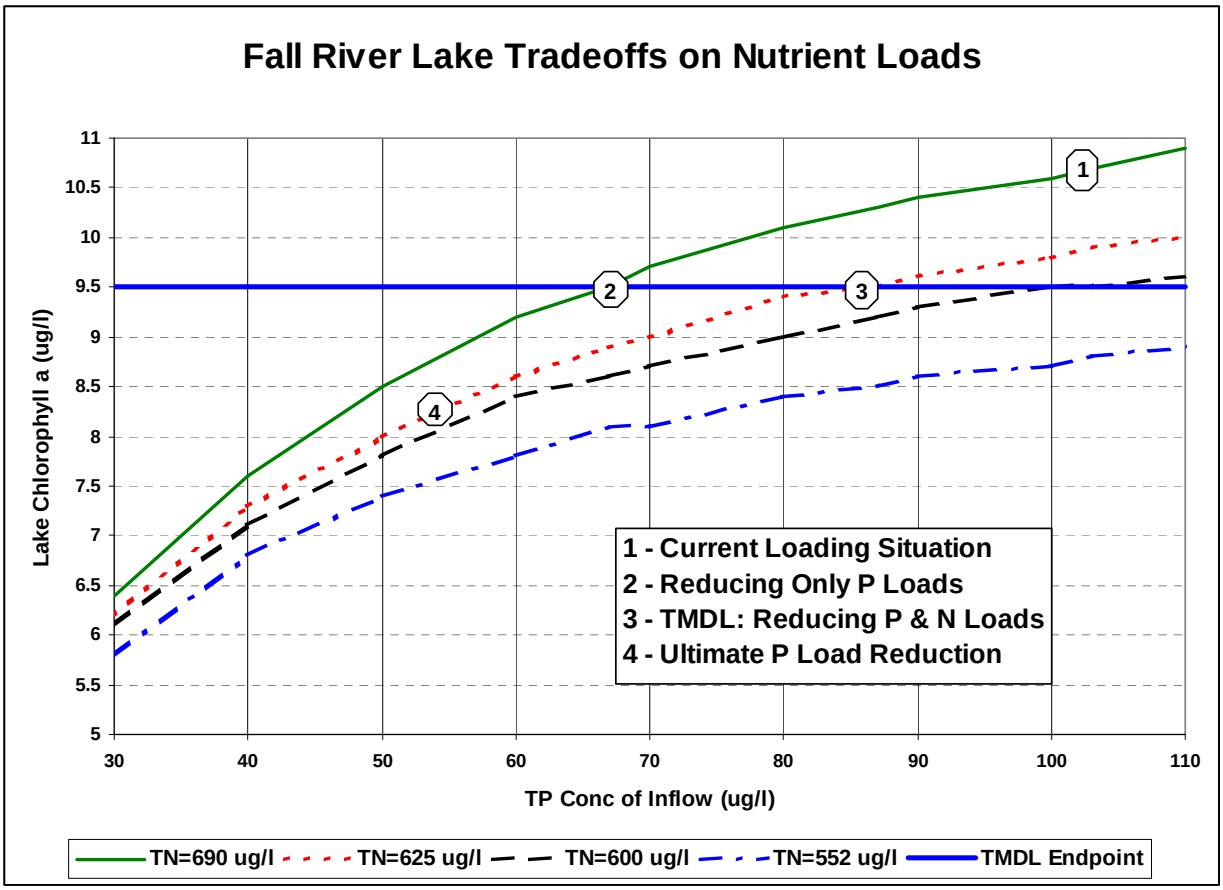
CV = Coefficient of variation = Standard Deviation / Mean

Z = 2.326 for 99th percentile probability basis

LTA= Long Term Average
LA= Load Allocation
MOS= Margin of Safety

Parameter	LTA kg/yr	CV	$e^{[Z\sigma - 0.5\sigma^2]}$	MDL kg/day	Atm LA kg/day	NonPoint LA kg/day	WLA kg/day
16% Less TP	35500	2.55	9.918	964.9	0.3	962.1	2.2
50% Less TP	21050	2.55	9.918	572.0	0.3	569.5	2.2
10% Less TN	259200	2.50	9.809	6965.7	18.1	6940.1	7.5
TSS*	198000*	0.50	2.6837	1455.8*	0.0	1455.7	0.1*

* - TSS in tons/year and tons/day.

CV for nutrients came from model output; CV for sediment follows past practice

Appendix D: Sensitivity Analysis of Nutrient Load Tradeoffs