2.3.4 Storm and sanitary sewers

The residential areas within the watershed are not serviced with storm sewers. Drainage is accomplished by overland flow, ditch flow, tile lines and culverts. Many of the streets and roads in the project area are not paved. All homes but a few around Lake Sarah in Greenfield are currently serviced by city sewer. However, in 1991, only 110 homes around the lake were serviced by sanitary sewer. The City of Independence extended sanitary sewer service to all the homes on the Independence side of Lake Sarah in 1994. The existing sewer line had the capacity to add the homes to it. In addition to the need for additional sewer hook-ups, there is a need to improve maintenance to individual on-site systems. Based upon a survey sent to 210 residents around the lake in 1991 (44 responses were received), the average age of on-site septic systems was 7.7 years with a range of 2 to 20 years. Some of the respondents stated that they have never had their septic system pumped. Some do not know where their system is located. Two respondents use septic system additives. Several use garbage disposals which add a substantial amount of waste to the system and require a septic tank capacity about 50% greater. Many use dishwashers. Dishwashers and washing machines add a lot of gray water to the system which may limit the system' s ability to treat sewage. At the time of the study, four homes on the lake still used outhouses as their sanitary sewage system. A summary of the study results is included in Appendix 4. Most of the soils around the lake are not suitable for standard on-site septic system drainfields. Approximately 1.2 miles of the 8.23 miles of shoreline can support standard type septic system drainfields. The remaining 85% of the shoreline has an ordinary high water table of 3 feet or less and would require mound systems. Some of the maintenance issues became less important with the extension of the sewer system to all homes. However, the systems must still be pumped and maintained. The survey represents what may be occurring throughout the watershed. This indicates the need for education of septic system maintenance.

2.3.5 Pesticide and fertilizer use estimates

Quantitative estimates of pesticide and fertilizer use were obtained through a survey of residents around the lake. Each resident was mailed a survey (Appendix 4) with questions about their use of fertilizers and pesticides as well as other questions. Two-hundred ten surveys were sent out, forty four were completed and returned (21%). The majority of the fertilizer is applied in the spring (20.5 applications). During the summer, only 8 applications of fertilizer occurred. In the fall, there was 14 applications of fertilizer. If these numbers were extended to all the residents around the lake, this would mean that there would be approximately 103 applications of fertilizer in the spring, 43 in the summer and 69 in the fall for a total of 215 applications of fertilizer to the land immediately around the lake each year. It should be noted that 52 percent of the respondents do not apply any fertilizers. No questions were asked regarding pesticide use. However, it is likely that some pesticide use is occurring since many brands of fertilizers also include herbicides (i.e. weed & feed).

It is commonly stated that phosphorus binds to the soil. However, in a study conducted by the Wisconsin Department of Natural Resources (Bannerman et. al. 1992) sheet flow runoff was collected from lawns during rain events. The mean total phosphorus (TP) concentration was 3470 μg/l and the mean dissolved phosphorus concentration was 2400 μg/l. This is a higher concentration than observed in any of the streams draining to Lake Sarah. Lawn fertilizers may provide a substantial, although unmeasured, TP load to the lake.

Estimates of quantity of fertilizer used were taken from a study of herbicide and fertilizer use in two suburban communities, St. Louis Park and Bloomington (Hennepin Conservation District 1992). Respondents answered multiple questions regarding their use of fertilizers and pesticides. Many homeowners do not know what fertilizer formulation they use. The majority (>80 %) have never had their soils tested to determine fertilizer need. Of the Lake Sarah homeowners, most are careful to keep fertilizers/herbicides away from the lake. However, there was a range of 3 feet to 400 feet distance from the shore (average 59.5 feet). Several homeowners applied fertilizers or herbicides to within five feet of the lake.

2.3.6 Regional runoff and precipitation

Normal precipitation for the period of May-September is 19-20 inches. Normal annual total precipitation is 29-30 inches (.74 - .76 m). Average annual lake evaporation for the region is 30-31 inches (.76 - .79 m) (U.S. Weather Bureau T.P. 37). Estimated annual runoff for the region is 5.9 inches (.15 meters - 50th percentile value). Estimates for high and low runoff years are 0.20 and 0.05 meters respectively (7.9 and 2 inches). The 25 year 24 hour rainfall in 4.75 inches.

2.3.7 Snow melt

Snow melt runoff values for Lake Sarah were found in USDA NEH4, Exhibit 21-1 (Zeug, 1986).

Table 10. Snowmelt Runoff

Frequency	Depth
500 year	8.5"
100 year	7.2"
50 year	6.5"
25 year	5.8"
10 year	4.7"

2.3.8 Rating curves

Stage discharge relationships were determined for the two monitored inlets and the outlet. The measured flow values were checked against the staff gauge readings and adjusted for drift as needed. For the few times when the flow meters were not functioning or data was lost, the rating curves were used to determine flow based upon staff gauge readings. Base flows were approximately 0.1-0.5 cfs at Loretto Creek. Base flow for Dance Hall Creek was 1-2cfs. At Sarah Creek (the outlet) base flows were approximately 0.2 cfs. Reverse flow conditions occurred early in the Spring. Lake storage area and volume at various elevations is presented in Table 11 (Zeug, 1986).

Table 11. Stage- Discharge (Zeug, 1986)

Stage	Q (cfs)	Storage
978.5	0	4380
978.6	8	4450
979.0	11	4750
979.5	16	5100
980.0	24	5470
980.5	42	5820
981.0	61	6160
981.5	82	6480
982.0	102	6800
982.5	122	7120
983.0	142	7400

2.3.9 Flow characteristics and hydrographs

Hydrographs for the two inflow sites and outlet are shown in Figures 12-14. Dance Hall Creek exhibited longer runoff events (approximately 11 days) in comparison to Loretto Creek which had an average event length of 7 days. This is expected since the watershed draining to Dance Hall Creek is substantially larger. The average flow for the monitoring period (March 10, 1991 - October 31, 1991) at Dance Hall Creek and Loretto Creek was 1.81 hm^3 and 1.02 hm^3 respectively. Outlet flow was at times restricted due to beaver activity. In early spring of 1991 flow was into the lake rather than out. Mean flow for the monitoring period at the outlet was 3.16 hm^3. Spring runoff accounted for a large percentage of the total runoff.

The outlet of Lake Sarah, Sarah Creek, flows westerly a distance of approximately 2 miles to where it empties into the Crow River near Rockford.

2.3.10 Aquifer assessment

Analysis of groundwater movement in the region was completed with the help of MPCA staff. Groundwater movement is generally from north to south. A limited amount of inflow of groundwater occurs around the shoreline of the lake. Evidence of groundwater inflow was noted in February 1992 as the ice was saturated in areas where groundwater was likely flowing into the lake. At three sites along the north shoreline of the lake, groundwater was pumped using a mini well. In other areas where groundwater could not be pumped up, a tight blue clay soil was found effectively sealing the lake bottom. The south side of the lake did not yield any groundwater through the mini well. Groundwater does not appear to be a significant part of the water budget for Lake Sarah.

2.3.11 Water quality

The water quality sampling results for the streams are presented in Table 12. Samples were collected at Dance Hall Creek, Loretto Creek and Sarah Creek (outlet). The results were used in the modeling to determine pollutant loading. High phosphorus concentrations were observed at both inflow sites (Figure 15). A maximum phosphorus concentration of 1202 µg/l TP was measured in Dance Hall Creek in March. Loretto Creek exhibited TP above 1000 µg/l in July and September. Total nitrogen and total suspended solids concentrations are shown in Figures 16 and 17.

Figure 12. Dance Hall Creek Hydrograph

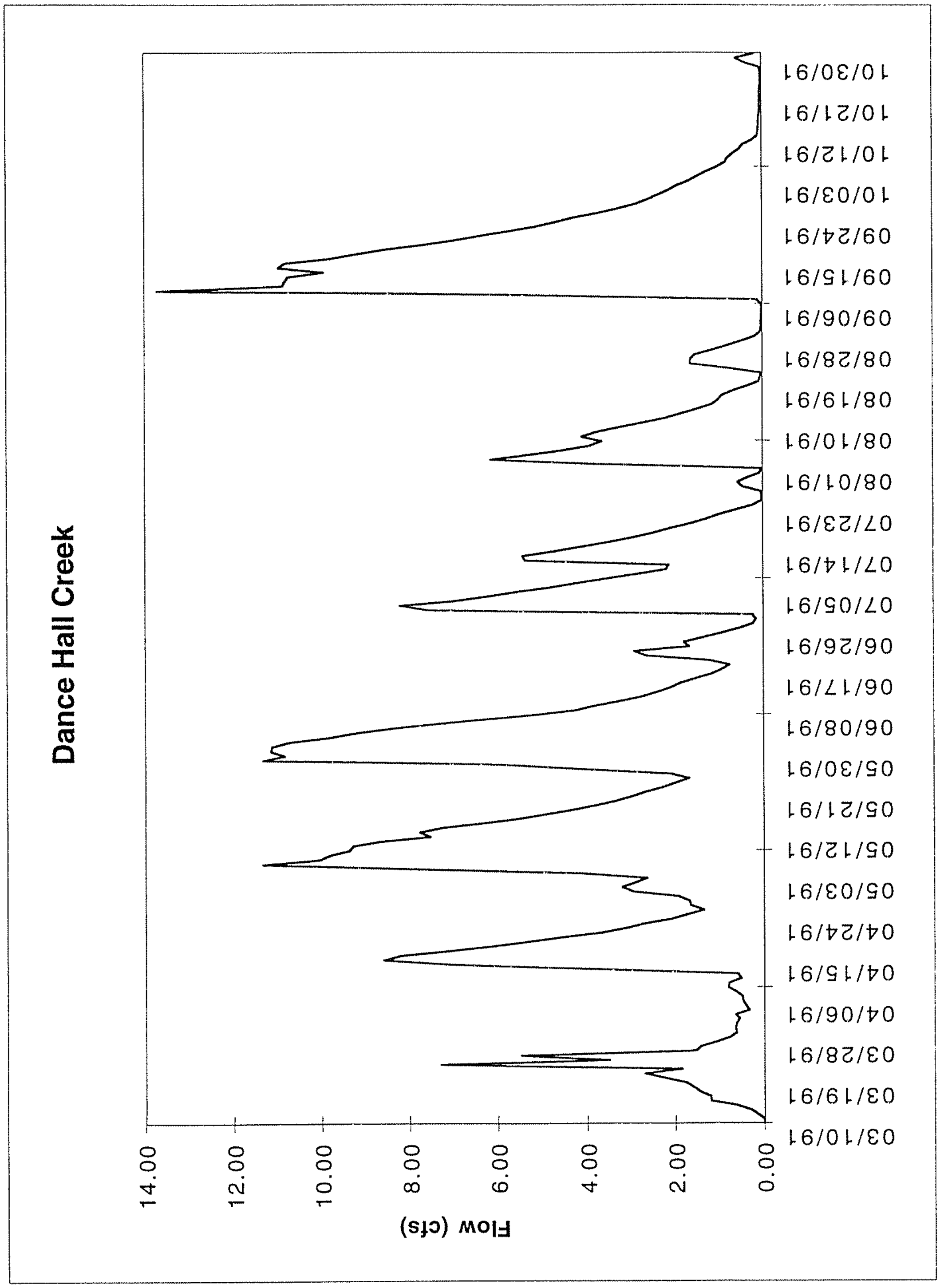


Figure 13. Loretto Creek Hydrograph

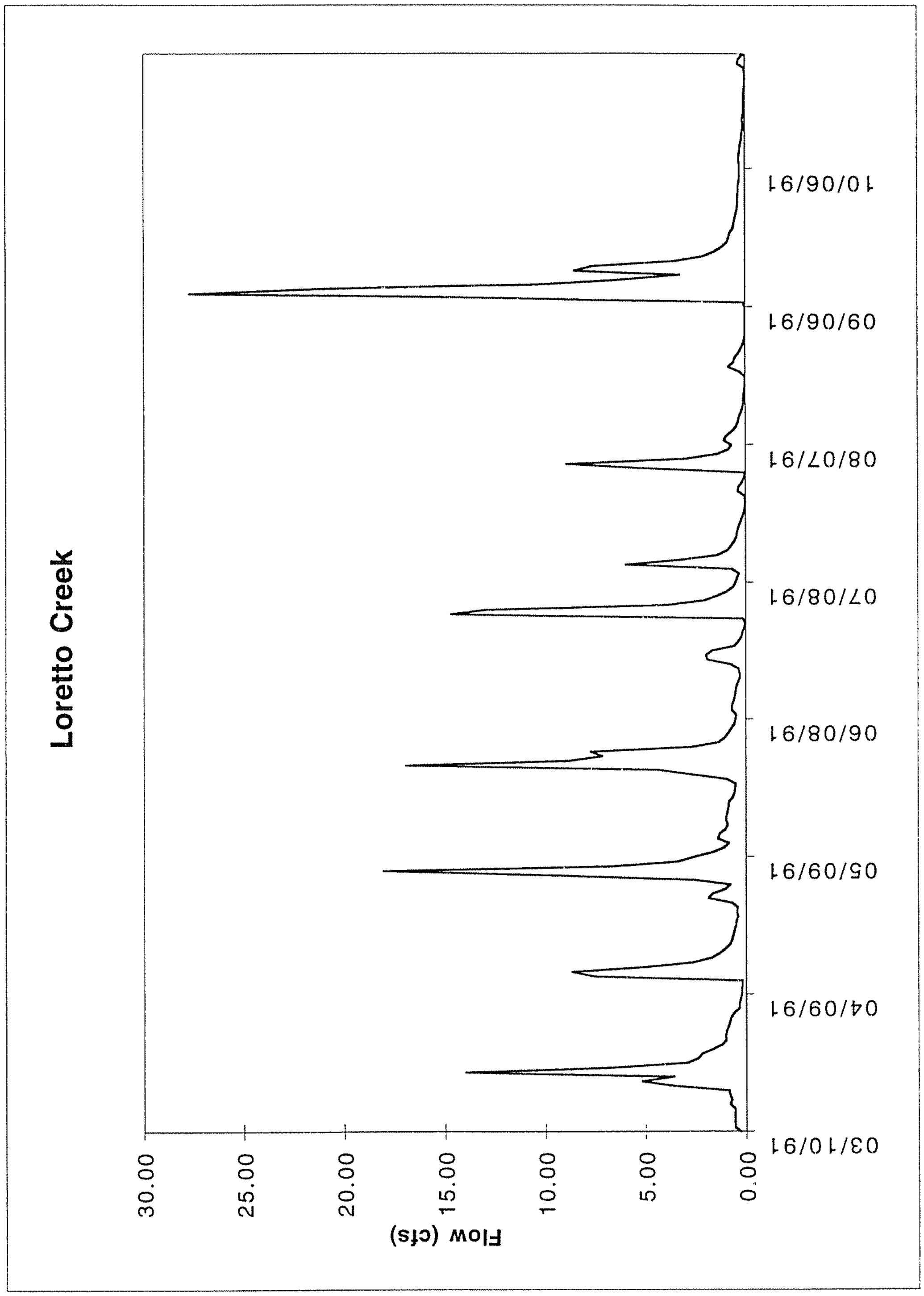


Figure 14. Sarah Creek Hydrograph

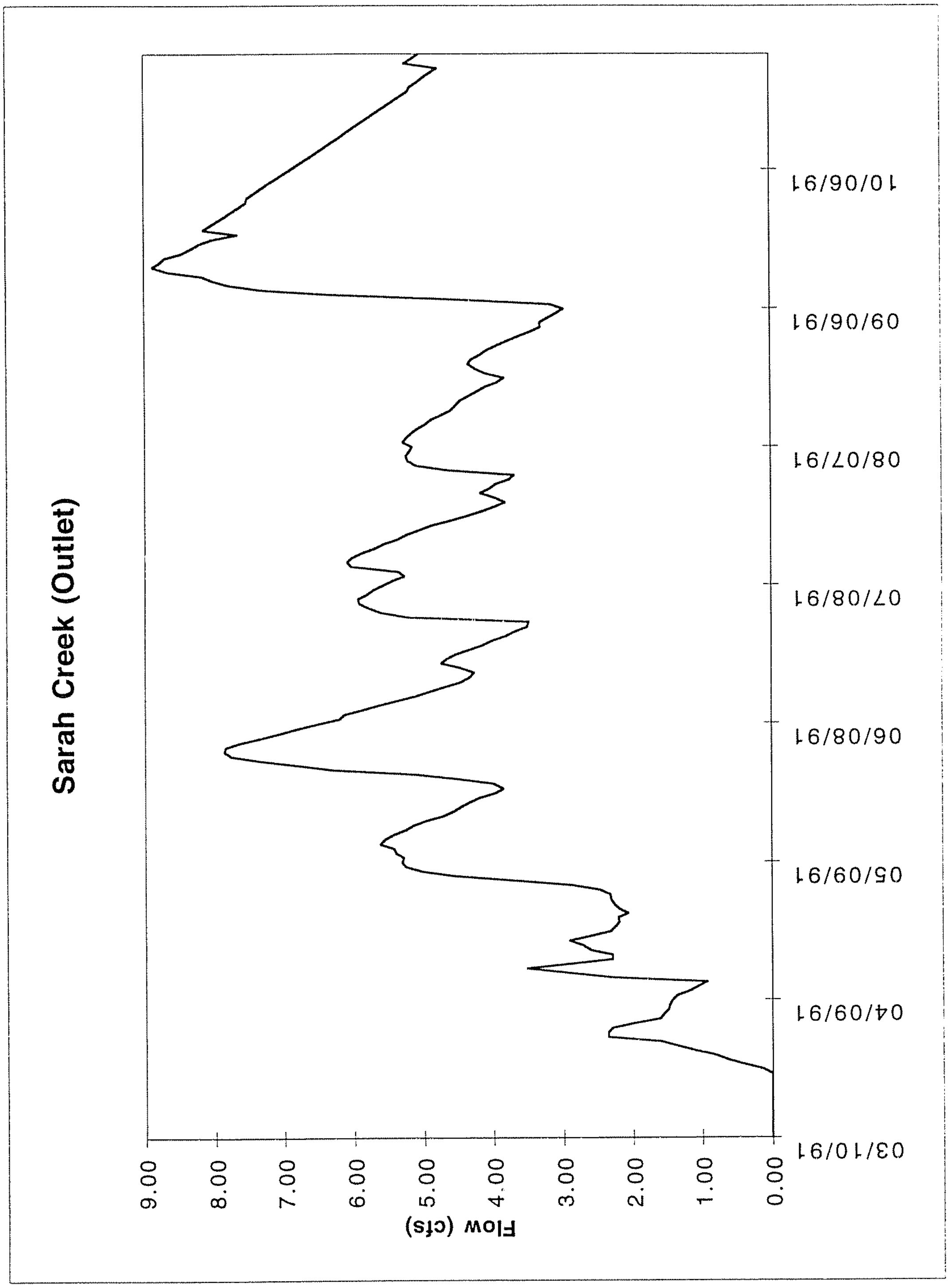


Table 12. Stream Sample Data

STATION ID

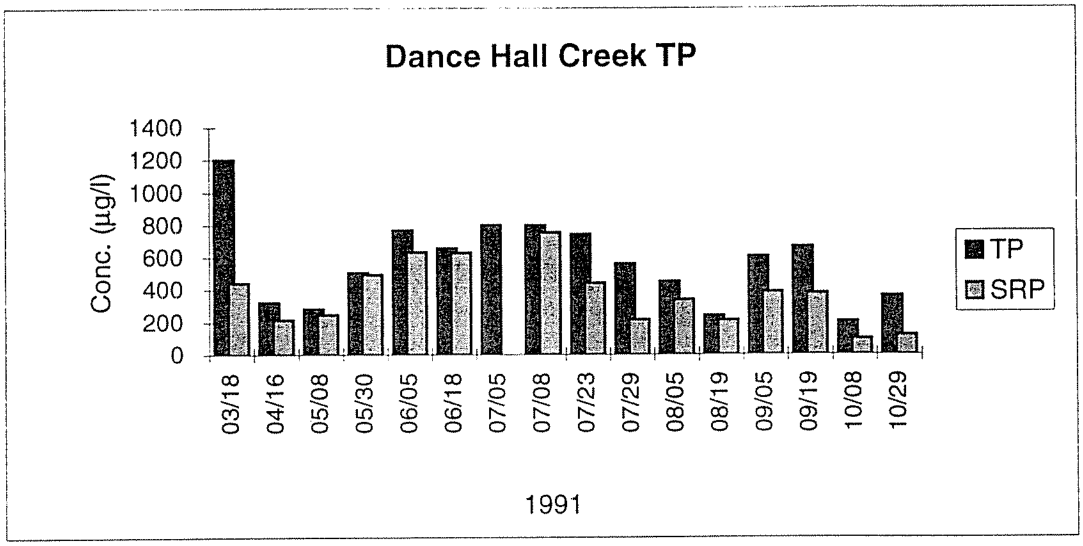
DANCE HALL CK

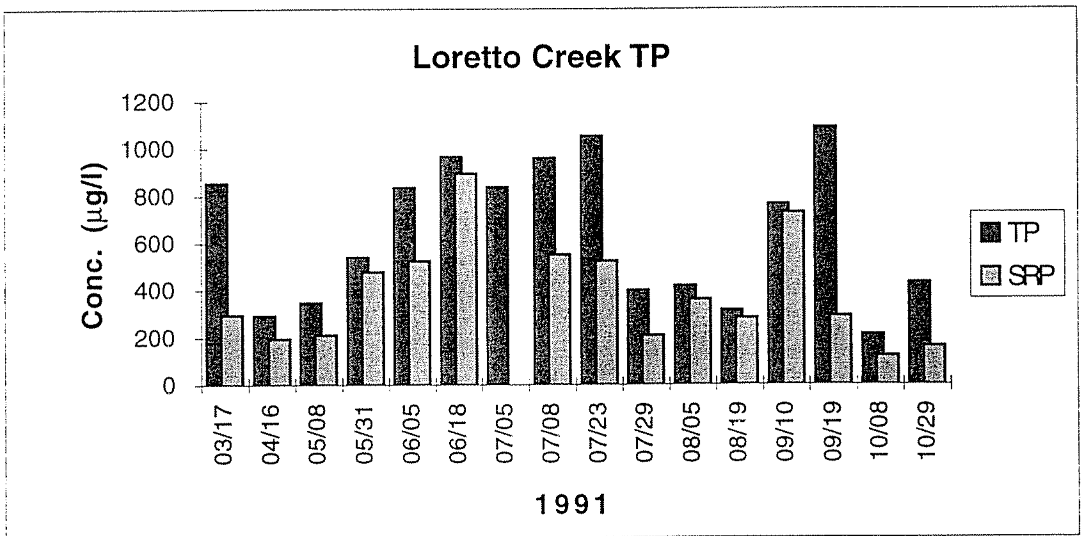
		FLOW	TP	SRP	TKN	TSS	TVSS	NH3	NO_2+NO_3	TN	ON	IN
	DATE	cfs	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l
STA1	03/18	0.69	1202	440	2248	2200	2000	228	1389	3637	2020	1617
STA1	04/16	5.6	321	216	1099	5000	3000	79	3629	4728	1020	3708
STA1	05/08	10.36	284	248	1072	3700	2400	136	2399	3471	936	2535
STA1	05/30	10.53	504	492	2023	43300	3300	1057	160	2183	966	1217
STA1	06/05	8.47	769	634	1639	5000	3900	115	178	1817	1524	293
STA1	06/18	1.06	657	629	2026	3200	1200	431	1150	3176	1595	1581
STA1	07/05	11.87	800		2135	37300	22400					
STA1	07/08	0.025	800	756	1063	6000	3200	433	1088	2151	630	1521
STA1	07/23	0.83	743	443	1217	10300	7400	440	460	1677	777	900
STA1	07/29	0.38	561	213	1014	3000	800	310	680	1694	704	990
STA1	08/05	4.63	448	340	1138	4300	3400	74	853	1991	1064	927
STA1	08/19	0.52	240	210	1827	16500	7800	75	638	2465	1752	713
STA1	09/05	0.14	605	384	5037	10600	9300	1162	524	5561	3875	1686
STA1	09/19	8.09	666	378	975	14400	8000	211	381	1356	764	592
STA1	10/08	0.78	203	97	9066	3000	3000	228	1163	10229	8838	1391
STA1	10/29	0.12	362	120	2969			357	415	3384	2612	772
MEAN		4.01	573	350	2284	11187	5407	334	944	3095	1817	1363
STD DEV.		4.44	264	211	2081	12645	5393	334	928	2334	2085	853
CONFIDENCE		2.18	129	103	1020	6196	2642	164	455	1144	1021	418
25TH %		0.49	352	212	1092	3450	2700	106	407	1786	774	836
50TH %		0.95	583	359	1733	5000	3300	228	659	2324	1042	1217
75TH%		8.19	750	455	2163	12500	7600	432	1153	3513	1819	1599

LORETTO CREEK		FLOW	TP	SRP	TKN	TSS	TVSS	NH3	NO_2+NO_3	TN	ON	IN
	DATE	cfs	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l
STA2	03/17	1.28	855	294	1203	2800	2400	206	858	2061	997	1064
STA2	04/16	0.5	291	194	1354	9000	6000	116	2791	4145	1238	2907
STA2	05/08	7.91	346	211	963	5000	2900	145	2244	3207	818	2389
STA2	05/31	9.02	540	476	1351	70600	2600	244	596	1947	1107	840
STA2	06/05	0.98	835	524	1140	3600	1100	152	186	1326	988	338
STA2	06/18	1.06	965	895	1947	10500	2600	197	1145	3092	1750	1342
STA2	07/05	7.16	836		2843	156000	96000			2843	2843	
STA2	07/08	0.005	961	550	1952	8000	6000	1171	1019	2971	781	2190
STA2	07/23	0.14	1054	525	629	10000	5500	200	830	1459	429	1030
STA2	07/29	0.33	399	206	611	2700	900	130	730	1341	481	860
STA2	08/05	1.41	418	360	809	2400	1600	35	680	1489	774	715
STA2	08/19	0.04	315	280	1242	15000	13800	67	676	1918	1175	743
STA2	09/10	24.37	764	728	2312	56500	15900	546	560	2872	1766	1106
STA2	09/19	1.3	1087	289	1144	6200	3200	386	398	1542	758	784
STA2	10/08	0.28	210	121	2029	1100	800	134	1501	3530	1895	1635
STA2	10/29	0.1	432	161	1409			246	272	1681	1163	518
MEAN		3.4928	644	363	1434	23960	10753	248	905	2339	1185	1231
STD DEV.		6.3338	303	237	625	41901	24009	279	736	892	617	738
CONFIDENCE		3.1035	148	116	306	20531	11764	137	361	437	302	362
25TH%		0.245	386	203	1096	3200	2000	127	520	1529	779	764
50TH%		1.02	652	292	1297	8000	2900	175	705	2004	1052	1030
75TH%		2.8475	882	524	1948	12750	6000	245	1051	3001	1366	1489

OUTLET		FLOW	TP	SRP	TKN	TSS	TVSS	NH3	NO_2+NO_3	TN	ON	IN
	DATE	cfs	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l
STA3	01/17	0	108	77	1129			253	49	1178	876	302
STA3	02/19	0	145	111								
STA3	03/19	0	223	27	719					719	719	
STA3	04/17	2.90	140	19	1280			300	1046	2326	980	1346
STA3	05/08	5.24	87	23	856	2600	2400	402	782	1638	454	1184
STA3	05/22	4.33	62	19	572	900	800	189	69	641	383	258
STA3	06/05	7.32	117	58	465	800	800	581	101	566		682
STA3	06/18	4.32	134	45		6500	6100					
STA3	07/08	5.56	128	38	725			106	1144	1869	619	1250
STA3	07/23	4.39	113	23		4200	3600	581	101	101		682
STA3	08/05	5.24	75	24	768	8700	8400	16	796	1564	752	812
STA3	08/19	4.20	42	12		5700	5500					
STA3	09/05	3.07	47	15	980	15500	1300	855	465	1445	125	1320
STA3	09/19	8.33	237	133	646	3800	1800	86	218	864	560	304
STA3	10/08	6.69	182	123		10900	6100					
MEAN		4.11	123	50	814	5960	3680	337	477	1174	608	814
STD DEV.		2.57	58	42	252	4650	2682	267	430	660	263	439
CONFIDENCE		1.26	29	20	124	2278	1314	131	211	324	129	215
25TH%		2.99	81	21	664	2900	1425	127	101	680	454	399
50TH%		4.33	117	27	747	4950	3000	277	342	1178	619	747
75TH%		5.40	143	68	949	8150	5950	536	793	1601	752	1234

Figure 15. Stream Total Phosphorus Concentrations





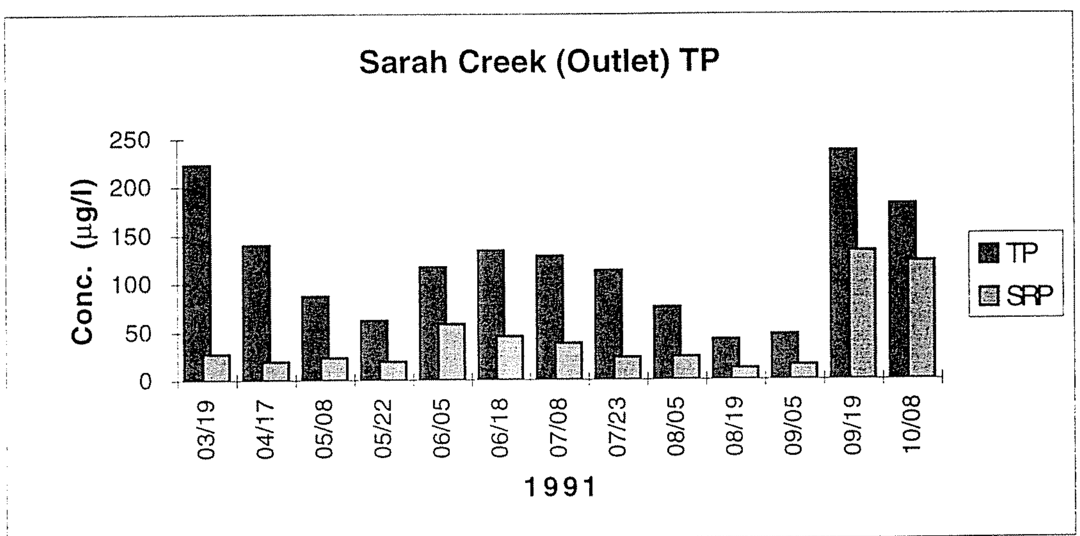
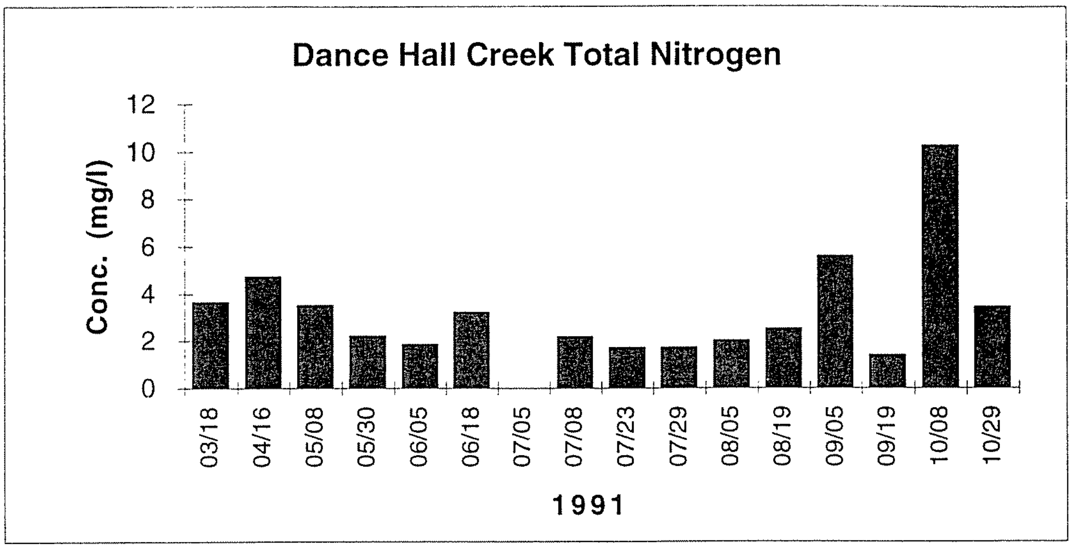
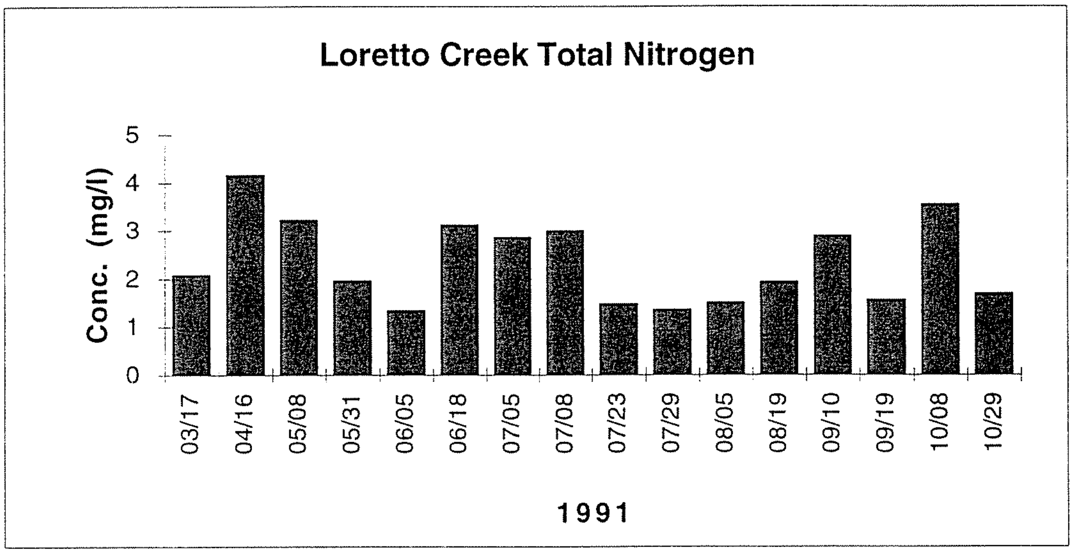


Figure 16. Stream Total Nitrogen Concentrations





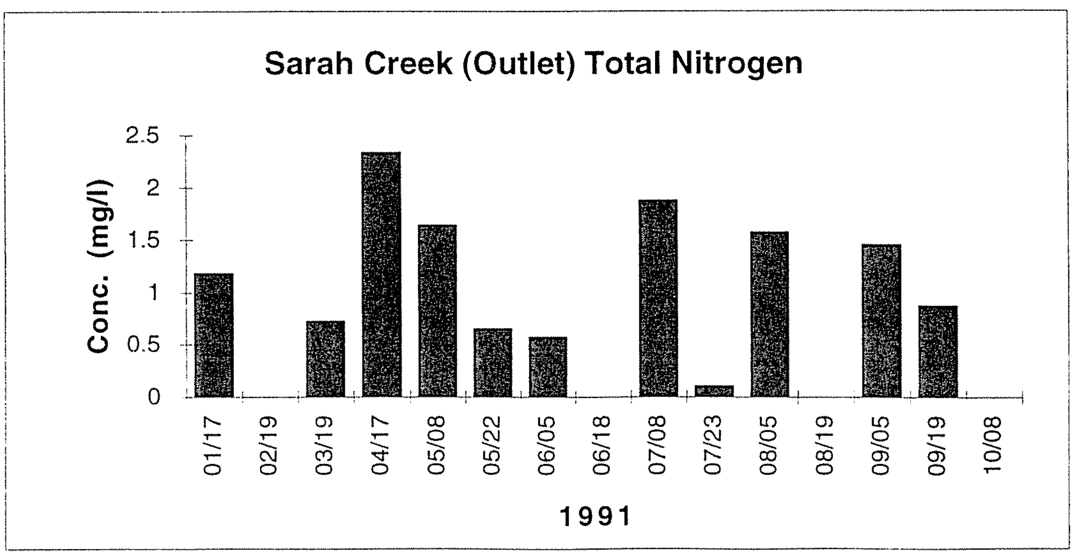
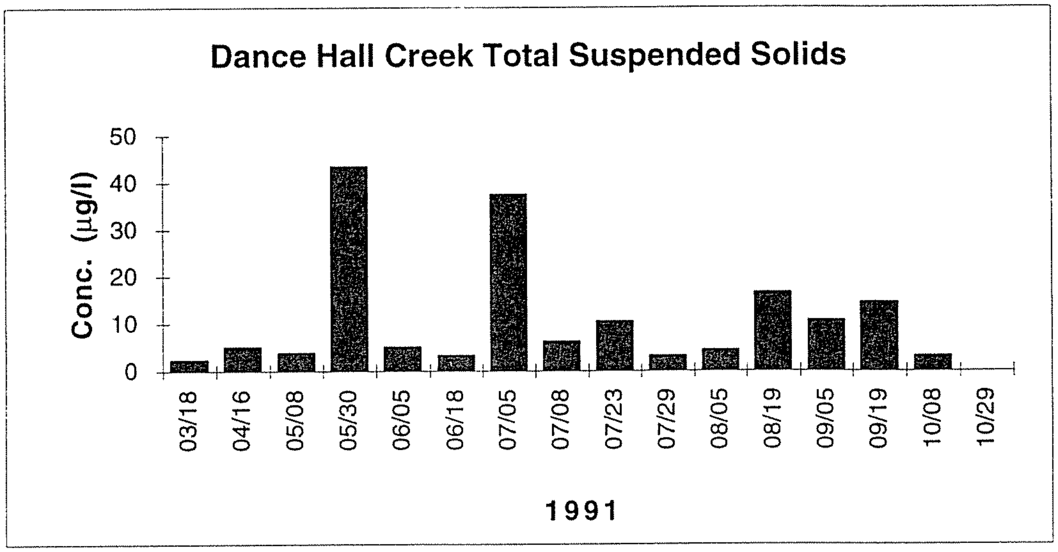
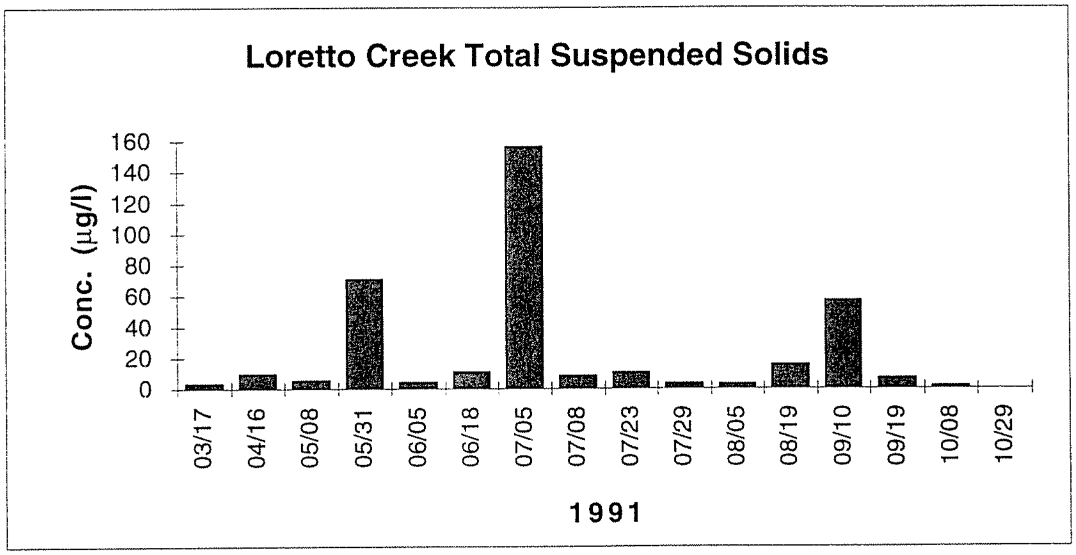
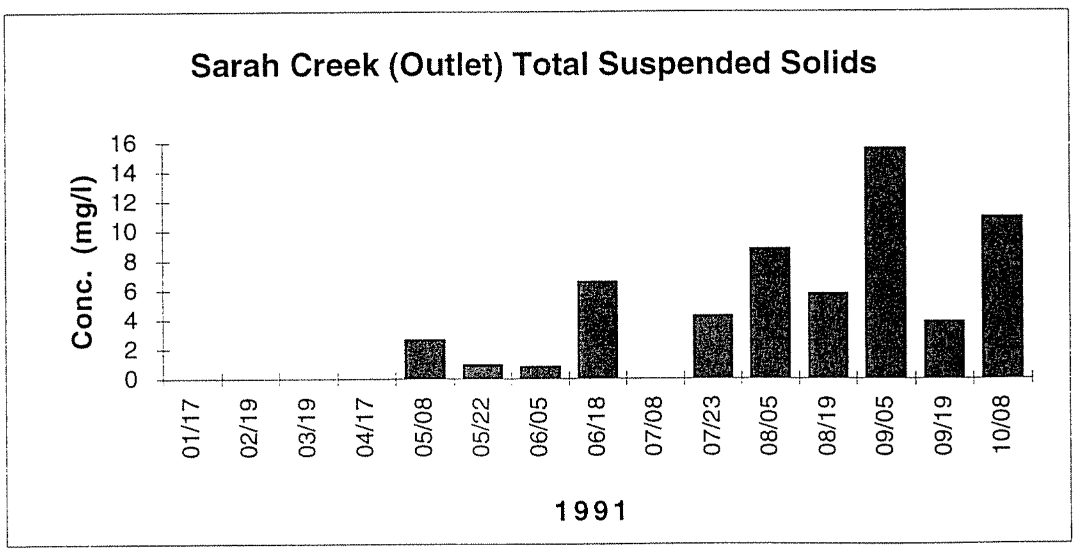


Figure 17. Stream Total Suspended Solids Concentrations







2.3.12 Water balance

A water balance was determined for Lake Sarah using the model BATHTUB (Walker, 1995). Mean flows were calculated using FLUX (Walker, 1995). Appendix 5 includes computer printouts of the model results. The water balance was adjusted to account for error which is believed to have occurred in the outlet flow measurements. Measured and estimated inflow was greater than measured outflow. Since the outlet channel was not well defined and beaver activity affected these measurements, the flow estimates may have been somewhat inaccurate. The outflow was adjusted to balance with the inflow. The water balance for Lake Sarah consists of 2 gauged inflow tributaries, un-gauged inflow, precipitation, evaporation and change in storage. The water level was high at the end of the monitoring. The water balance for the measured period March 10, 1991 - October 31, 1991 (0.646 year) was:

Table 13. Lake Sarah Water Balance

Source	Flow (hm^3) 3/10/91- 10/31/91
Tributary inflow (+)	3.74
Precipitation (+)	1.65
Point Source inflow (+)	0.01
Total Inflow	5.40
Gauged outflow (-)	3.16
Advective Outflow (-)	0.03
Total Outflow	8.59
Evaporation (-)	1.61
Storage Increase (-)	.60

BATHTUB was also used to calculate pollutant loadings by subwatershed. The majority of the phosphorus loading comes from the two major tributaries to Lake Sarah. Estimates of pollutant loading from these tributaries is based upon measured concentrations. Dance Hall Creek contributed 1714 kg of phosphorus during the monitoring period in 1991 (.646 year). Loretto Creek contributed 1251 kg (Figure 18). The un-gauged tributaries and direct input accounted for a total of 662 kg. Septic systems and groundwater contributed an estimate of 12.1 kg phosphorus. Precipitation accounted for 103 kg phosphorus loading. Internal loading was determined to be a significant source at 526 kg phosphorus. The phosphorus budget for the Lake Sarah watershed during the monitoring period was:

[Inputs - Δ Storage] - Outflow = Retention

[4268 - 75] - 384 = 3809 kg TP

The top three contributors of total phosphorus to Lake Sarah in 1991 were:

Dance Hall Creek	40.2%
Loretto Creek	29.3%
Internal Loading	12.3%

The total nitrogen budget for the monitoring period was:

[Inputs - Δ Storage] - Outflow = Retention

[10506 - 516] - 3469 = 6521 kg TN

Dance Hall Creek contributed 47% of the nitrogen loading (Figure 19).

Although the watershed area of Dance Hall Creek (10.76) is almost twice as large as Loretto Creek (5.92 km^2), it is not contributing twice as much phosphorus. Dance Hall Creek contributed only 23% more phosphorus than Loretto Creek. The mean (monitoring period) phosphorus concentration of Loretto Creek (644 μg/l) was higher compared to that of Dance Hall Creek (573μg/l) and therefore contributed a proportionately higher amount of the phosphorus load. This indicates implementation efforts may be more cost-effective on the Loretto Creek subwatershed depending upon the type of practice installed.

Tributary and direct loading accounted for 85% of the total phosphorus load. Internal loading was 12.3% of the total, and precipitation contributed 2.4% of the phosphorus load. Septic systems accounted for 0.3%.

Figure 18. Lake Sarah Total Phosphorus Loading 1991

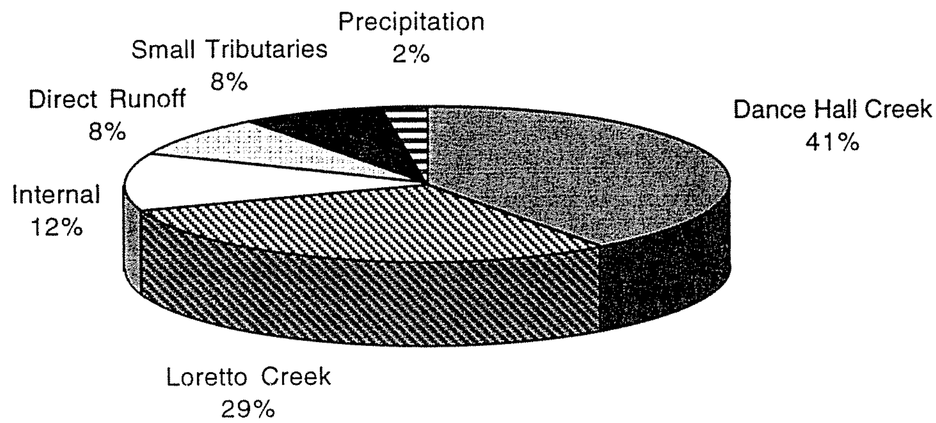
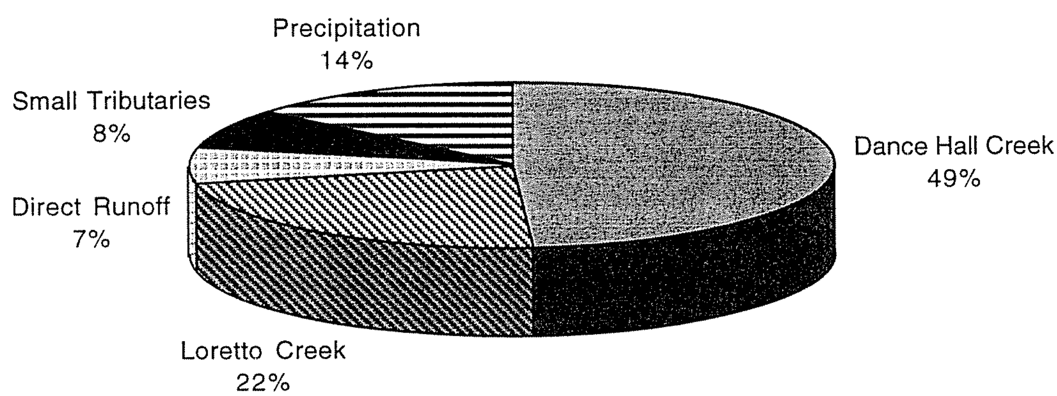


Figure 19. Lake Sarah Total Nitrogen Loading 1991



Lake Sarah retains approximately 89 percent of the phosphorus that enters the lake. The phosphorus settles to the bottom of the lake where it may become available to plants and algae at a later time. Lake Sarah is acting as a giant stormwater treatment pond for Sarah Creek. Internal loading is a significant source of phosphorus to Lake Sarah.

The phosphorus loading to Lake Sarah from the watershed is high. For a mixed agriculture land use, an estimate of 62 $kg/km^2/yr$ is expected (Prairie and Kalff, 1986) using the equation: log areal TP export = 1.880 - 0.063 log Area. TP export from the Lake Sarah watershed in 1991 was 294 $kg/km^2/yr$. In agricultural watersheds, the majority (85%) of the phosphorus is in particulate rather than dissolved form (Prairie and Kalff, 1986). This was not true for the two monitored creeks which had a majority in the dissolved form.

Data from the Lake Sarah monitoring can be compared to that of minimally impacted streams in the North Central Hardwood Forests ecoregion. The interquartile range for total phosphorus in minimally impacted streams is 70 - 170 µg/l (Fandrei et. al, 1988). This compares to a mean TP of 573 µg/l and 644 µg/l for Dance Hall and Loretto Creeks. Total phosphorus for these creeks falls between the 95th and 100 percentile measurements, indicating they are not minimally impacted.

The phosphorus loading to the lake is comprised of soluble and particulate phosphorus. The two creeks monitored in the study had a large percentage of soluble reactive phosphorus as part of the total phosphorus load. Soluble reactive phosphorus comprised 68% and 76% of the total phosphorus for Dance Hall Creek and Loretto Creek respectively. Soluble phosphorus is more difficult to treat (remove) than particulate.

Omernik (1977) found in watersheds where agriculture comprised greater than 50% of the land use, the mean total phosphorus concentration was 85 µg/l and the soluble phosphorus concentration was 37 µg/l or 43.5% of the total. Mean total nitrogen for the same category was 1820 µg/l and inorganic nitrogen was 945 µg/l. These figures may be compared to those from Dance Hall Creek and Loretto Creek, which drain watersheds that are primarily agricultural (60 - 70% agricultural land uses). The TP concentrations of Dance Hall and Loretto Creeks are substantially higher.

2.4 Pollutant Loading By Subwatershed

Figures 20 and 21 show land cover and subwatershed areas. A description of each subwatershed follows.

2.4.1 Subwatershed 1

Subwatershed 1 is a 1259 acre area with a primary land use of cropland. There are two feedlots within the subwatershed. Both feedlots are located adjacent to Loretto Creek. The pasture of one feedlot is located mainly in a wetland through which Loretto Creek flows. The cattle were not fenced off from the creek. The creek banks have eroded due to cattle trampling through the creek. Since the study was conducted, the area where the cattle entered the creek was sold for development. Several houses with large lot sizes are being constructed on this property. The majority of this subwatershed was monitored directly with the gauging station located at County Road 11. The monitoring station was located approximately 2/10 mile from the lake. The only commercial land use in the watershed is located in this subwatershed in the town of Loretto. Loretto also has the city park. The un-monitored part of the watershed was farmed close to the creek until 1994 when a cooperative effort between the landowner, U.S. Fish & Wildlife Service, Natural Resources Conservation Service and the Hennepin Conservation District resulted in 100 acres of planted prairie and restored wetlands, partially within the Lake Sarah watershed.

2.4.2 Subwatershed 2

Subwatershed 2 is an area 454 acres in size. No monitoring was conducted in this subwatershed. However, the DNR measured an instantaneous flow of 0.54 cfs from the main inlet during a fisheries survey. There are 2 additional inlets to the lake from small areas of the subwatershed. One is a culvert from a small pond to which a residential area drains. It has been reported that there are leaking septic systems draining to the pond. A grab sample from the culvert showed the presence of fecal coliform bacteria and a high phosphorus concentration. However, there is no documented proof that this was due to leaking septic systems. The second of these inlets drains through a culvert under Lake Sarah Heights drive and into a channel dredged for lake access. The main land use in this area is residential dwelling. The northern part is cropland.