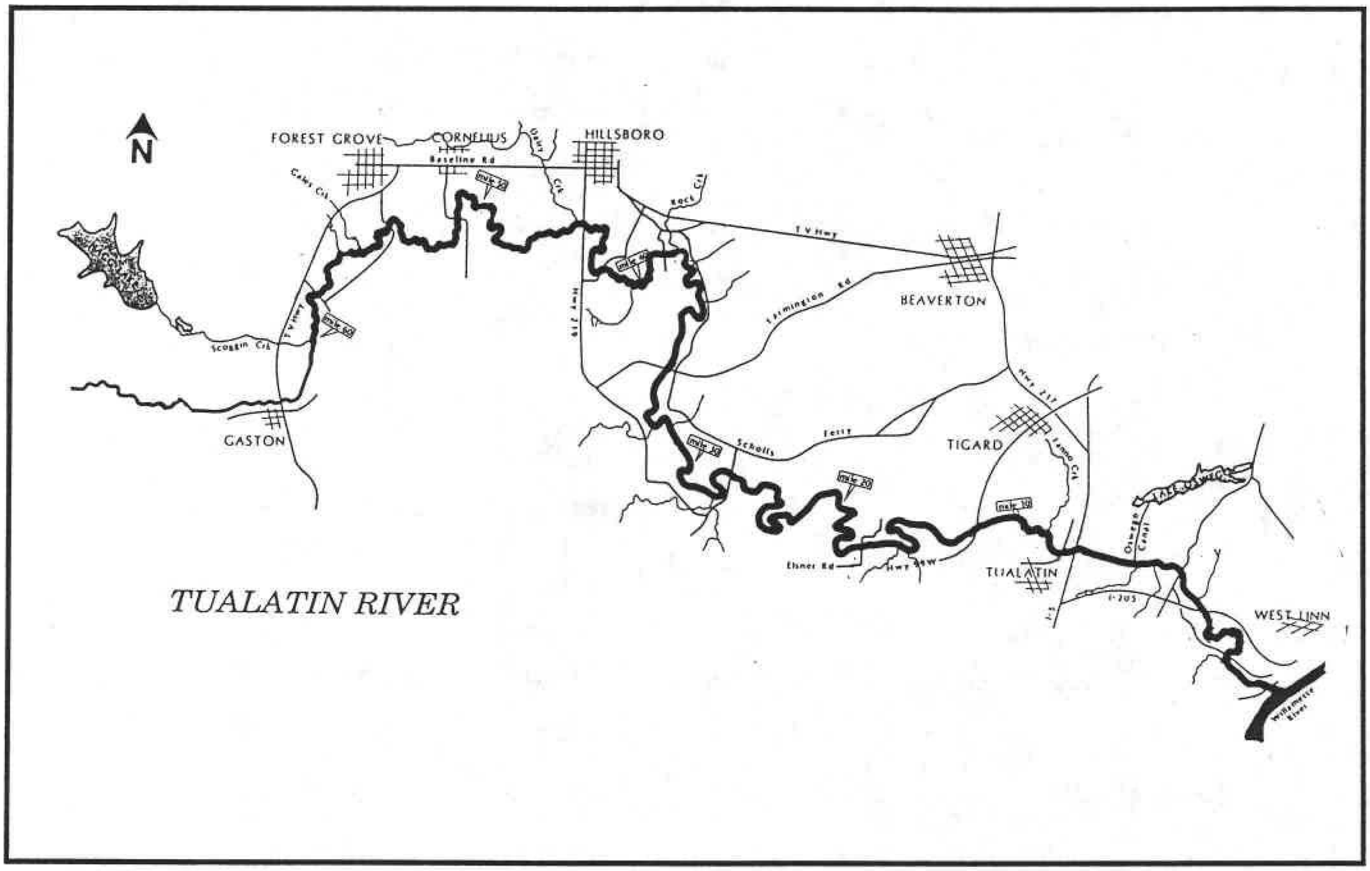
Mass Balance Analysis of Suspended Solids in the Tualatin River



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TUALATIN RIVER BASIN SPECIAL REPORTS

The Tualatin River Basin in Washington County, Oregon, is a complex area with highly developed agricultural, forestry, industrial, commercial, and residential activities. Population has grown in the past thirty years from fifty to over 270 thousand. Accompanying this population growth have been the associated increases in transportation, construction, and recreational activities. Major improvements have occurred in treatment of wastewater discharges form communities and industries in the area. A surface water runoff management plan is in operation. Agricultural and forestry operations have adopted practices designed to reduce water quality impacts. In spite of efforts to-date, the standards required to protect appropriate beneficial uses of water have not been met in the slow-moving river.

The Oregon Department of Environmental Quality awarded a grant in 1992 to the Oregon Water Resources Research Institute (OWRRI) at Oregon State University to review existing information on the Tualatin, organize that information so that it can be readily evaluated, develop a method to examine effectiveness, costs and benefits of alternative pollution abatement strategies, and allow for the evaluation of various scenarios proposed for water management in the Tualatin Basin. Faculty members from eight departments at Oregon State University and Portland State University are contributing to the project. Many local interest groups, industry, state and federal agencies are contributing to the understanding of water quality issues in the Basin. This OWRRI project is based on all these research, planning and management studies.

This publication is one in a series designed to make the results of this project available to interested persons and to promote useful discussions on issues and solutions. You are invited to share your insights and comments on these publications and on the process in which we are engaged. This will aid us in moving towards a better understanding of the complex relationships between people's needs, the natural environment in which they and their children will live, and the decisions that will be made on resource management.

MASS BALANCE ANALYSIS OF SUSPENDED SOLIDS IN THE TUALATIN RIVER

by
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ABSTRACT

The purpose of this study was to develop a mass-balance model for total suspended solids in the Tualatin River in order to better understand the clarity-turbidity problem in the river. Major sources and sinks of suspended solids in the river were identified, and seasonal effects were explored. The study also examined relationships between suspended solids and transparency, turbidity, chlorophyll a in an attempt to better understand processes occurring in the river and its watershed.

To perform the mass balance, the river was divided into twelve sections based on the monitoring stations of the Unified Sewerage Agency (USA) of Washington County, Oregon. Tributaries were treated as point sources flowing into one of these sections. The water quality and flow data of USA formed the basis of the mass balance, with additional flow data provided by the Oregon Water Resources Department, Tualatin Valley Irrigation District, and U. S. Geological Survey, and additional water quality data from Oregon Department of Environmental Quality.

Tributaries were found to be the major contributors of suspended solids loading in the Tualatin River. The major tributaries in this regard were Dairy Creek, Fanno Creek, Gales Creek, Rock Creek and Scoggins Creek. For the year 1992, the above five tributaries contributed 90% of the average suspended solids mass loading during the non-summer period and 79% during the summer season. Gales Creek is the major contributor to suspended solids mass loading during the non-summer season. Scoggins Creek, which receives the discharge of Hagg Lake is the major contributor of suspended solids to the river in the summer period (more than 50% of the combined loading of the five major tributary creeks, summer 1992). The

tributaries also accounted for 63% of the flow (including withdrawals) in the river during the summer of 1992 and for 84% during the 1992 non-summer season.

Changes in suspended solids loading in the Tualatin River were computed at stations above and below the entries of Scoggins, Gales, Rock and Dairy Creeks. Major increases were observed for these tributaries, emphasizing the finding that tributaries contribute suspended sediment to the river during the entire year and are major contributors during the non-summer season (except Scoggins, higher contributor during summer).

The seasonal variation of the suspended solids loading in the river differed by as much as a factor of ten, the loading being lower in summer when suspended solids concentrations averaged about 50% of non-summer values. Water clarity was found to be higher in summer, during which time chlorophyll a concentrations were also higher. Suspended solids concentration was inversely correlated with transparency (water clarity) and directly correlated with turbidity but found to be unrelated to chlorophyll a concentration, indicating the algae were not a primary constituent of the total solids.

Increased chlorophyll a concentrations were not found to relate to any one particular factor but were found to be related as a combination of air temperature, and total phosphorus concentrations. This indicates that the cause of algal blooms are due to a combination of factors especially nutrient levels, water temperature and the residence time of water in the quiescent pool area.

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INTRODUCTION

Background

The Tualatin River in Washington County, Oregon located on the west side of Portland, serves many beneficial uses including drinking water, irrigation, recreation and effluent disposal. Rapid development of the Washington county area in the last two decades has severely constrained water quality in the river.

Population increase, commercial and industrial development, and intensive agricultural and forestry activities in the last decade have contributed to the observed decline of water quality in the Tualatin River. One consequence of this has been the persistence of reduced water clarity throughout the year and frequent algal blooms in the lower reaches of the river during the summer months resulting from littoral eutrophication.

The Tualatin River has been identified as "Water Quality Limited" by the Oregon Departmental of Environmental Quality (DEQ). Current efforts to achieve water quality in the river have not proven adequate. Consequently, Total Maximum Daily Loads (TMDL) have been established for the river and its tributaries. Studies of the Tualatin River have identified phosphorus as the limiting nutrient for algal growth. Controlling phosphorus concentrations is thus the current approach for controlling algal growth in the lower reaches of the river and a limit of 0.07 mg/L of total phosphorus has been set for the river (Wolf, 1991).

Objectives

The aim of this study was to develop a steady-state mass balance model for suspended solids and to relate suspended solids concentration to turbidity, transparency and chlorophyll concentration to determine whether a causal relationship exists between these parameters. The following are the specific objectives:

1. To develop a suspended solids mass balance model for total suspended solids, for the Tualatin River main stem and the Dairy Creek tributaries;
2. To use the model to assess sources of suspended solids in the river;
3. To relate the sources and sinks of suspended solids to processes occurring in the river, including seasonal effects;
4. To examine the relationship between suspended solids concentration and water clarity (transparency), chlorophyll a concentration, and turbidity;
5. To examine the relationship between algal growth in the river (chlorophyll a concentration) and water clarity (transparency).

METHODS AND APPROACH

Approach

A model is defined as "An assembly of concepts in the form of one or more mathematical equations that approximate a natural system or phenomena", (McCutcheon, 1989). Models form an essential part in describing and predicting water quality in a stream or river basin. Water quality models are also necessary to understand the cause-effect relationships that are responsible for water quality which in turn leads to better water management.

The basic principle underlying water quality modelling is conservation of mass. This is done by performing a mass balance over a control volume for a specified period of time. Some of the materials for which balances are done are organic carbon, nitrogen, suspended sediment and phosphorus. In general this could be done for any material with known transformation kinetics. The balance is actually performed by accounting for all the material entering and leaving the control volume plus accounting for the losses or gains within the control section.

Model dimensions are based on the importance of variability of water quality parameters in the vertical, lateral and longitudinal directions. The zero-dimension model assumes the homogeneity of all major parameters in all directions. For this analysis of the Tualatin River, a one dimensional model describing longitudinal variation (disregards variation in the lateral and vertical directions) has been adopted.

Tualatin River Mass Balance

Model/Study Domain Description

The Tualatin River has its origin in the Oregon Coast Range and runs towards the

Willamette River on the east 40 miles away. It passes through approximately 86 miles of main channel and drains 711 square miles of land with varied topography (Carter, 1975). For the last 40 miles of its flow the river has a slow-moving almost lake-like character due to the small drop in elevation. The upper portion of the river flows through forested areas, the middle region through agricultural lands and the lower region through urban areas.

The model domain was chosen to extend from near the junction of the Willamette River, Weiss (RM[1] 0.2), to the monitoring station at Springhill Road (RM 71.5) near Dilly Road. This area includes the Dairy-McKay hydrologic unit which has been identified to be a significant contributor to the water quality problems in the Tualatin River. The Dairy-McKay basin comprises 256 square miles of the Tualatin basin with about half the land forested and the other half used for agricultural purposes.

There are fourteen major tributaries flowing into and one channel flowing out of the main stem of the river in the area of study, the contributions of which are treated as point sources. Other noteworthy hydrologic features in the study area are the presence of Hagg Lake and the Lake Oswego dam. Since the primary purpose of this model is to quantify processes along the different reaches and not to forecast, the establishment of exact boundaries for the model domain is not an important consideration.

Figure 3.1 is a schematic representation of the Tualatin River and gives details of the locations of the monitoring stations on the main stem with details of their distance from the mouth in river miles. Figure 3.2 is a representation of the tributaries feeding into the Tualatin River.

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[1] Rm = River Mile

Water is withdrawn from the Tualatin River for irrigation and municipal purposes and to feed Lake Oswego. The water rights for these purposes are given to the Tualatin Valley Irrigation District (TVID) and Oregon Water Resources Department (OWRD). The total water rights assigned to TVID amounts to 110 cfs and is 359 cfs for OWRD. Municipal water for the townships of Beaverton, Forest Grove and Hillsboro is withdrawn at river mile 56.3 as part of the water rights allotted to OWRD. The model assumes the water withdrawals for irrigation are spread over the entire summer period while municipal water withdrawals are spread over the entire year. Table 3.1 presents the actual figures for withdrawals and the locations of withdrawals.

Also present on the Tualatin River are four waste water treatment plants discharging into the river. The four plants are located at Durham (RM 9.5), Rock Creek (RM 38), Hillsboro (RM 44) and Forest Grove (RM 57). The plants located in Forest Grove and Hillsboro do not discharge during the summer months. The Durham plant and the Rock Creek plant have average summer discharges of 23 and 22 cfs, respectively.

Computational Network

For numerical description the river is broken into computational elements forming a network. The network scheme adopted is illustrated in Figure 3.3 which shows the cells/elements and the relative locations of the monitoring stations.

The river was sub-divided into elements based on the existing monitoring sites operated by the many different agencies. Each element is bounded by a monitoring station on either extremity. The elements vary in length from 1.8 to 10.6 miles. Since monitoring stations were

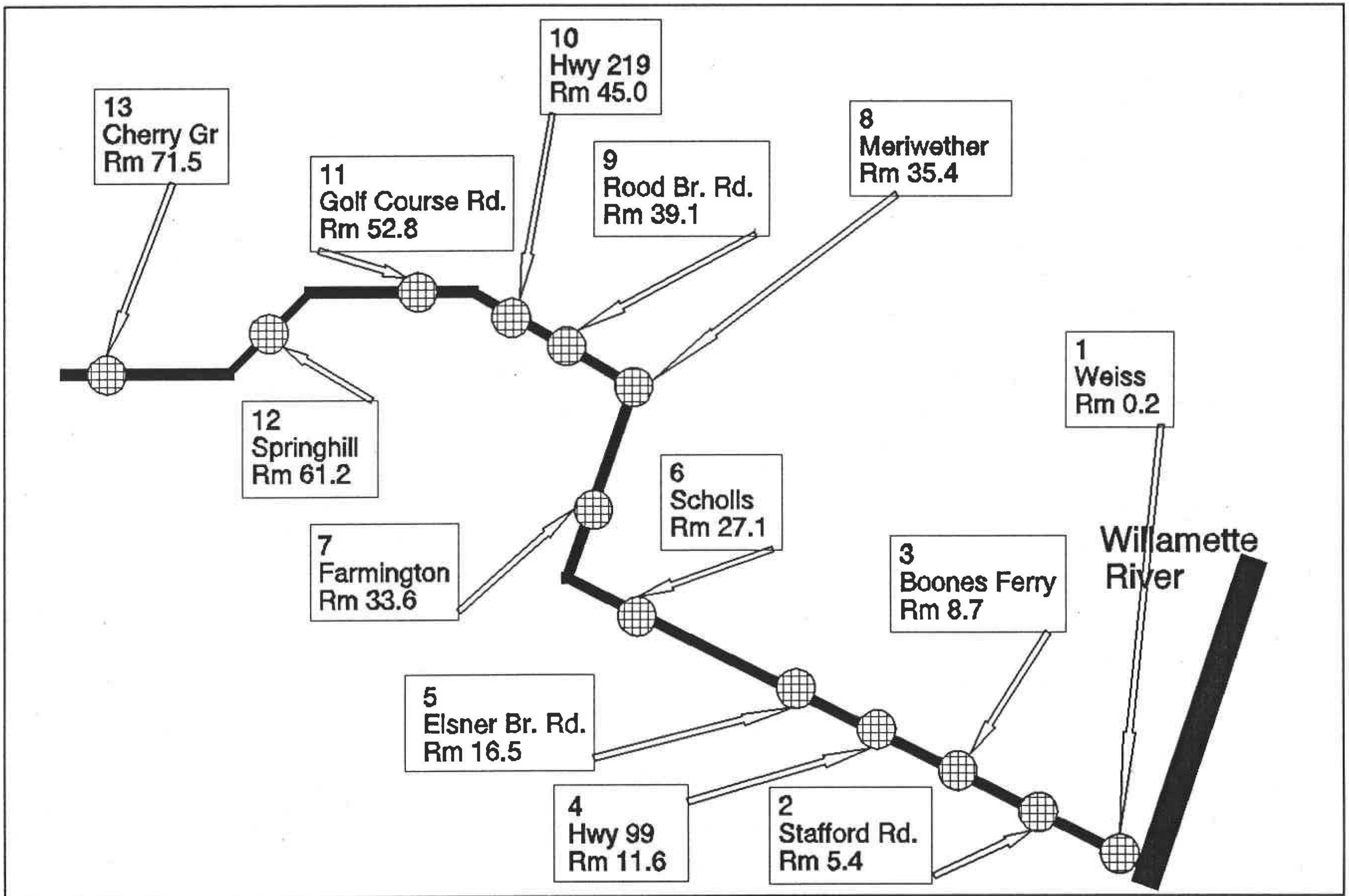

Figure 3.1 Schematic representation of the Tualatin River with locations of sampling stations

also present on the mouth of most tributaries, more accurate assessment of their contributions to the overall water quality was made possible.

Table 3.1 Withdrawal rights (cfs) for the Tualatin River

River Mile	TVID	OWRD	TOTAL
0.2		1.84	1.84
5.4		62.54	62.54
8.7		2.14	2.14
11.6	2.03	3.57	5.60
16.5	20.44	19.88	40.32
27.1	12.83	19.32	32.15
33.6	5.81	2.88	8.69
35.4	5.14	7.92	13.06
39.1	5.74	18.21	23.95
45.0	19.85	22.14	41.99
52.8	6.48	160.67	167.15
61.2			
71.5			
TOTAL	78.32	321.11	399.43

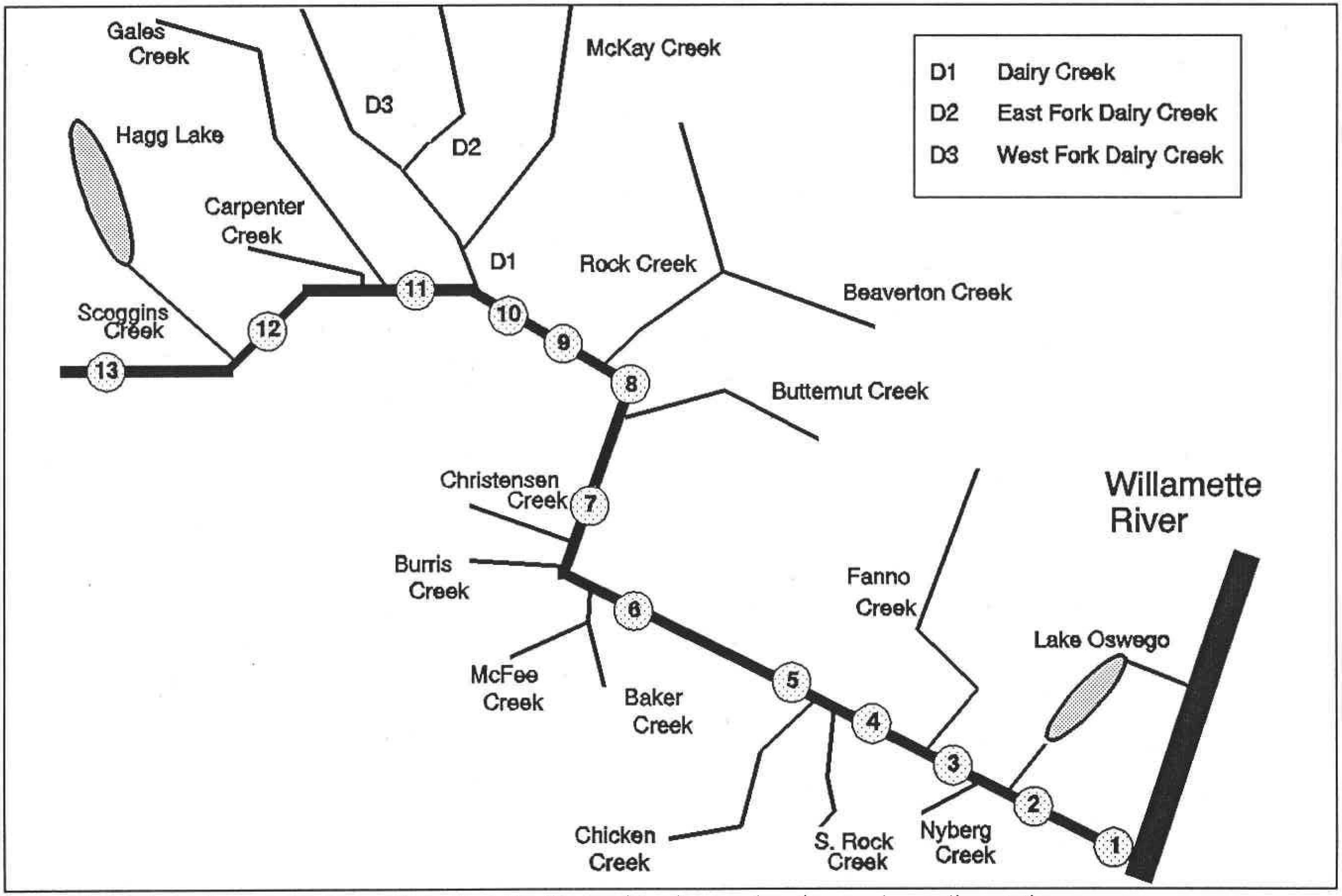

Figure 3.2 Schematic representation of the Tualatin River with tributary locations and sampling stations

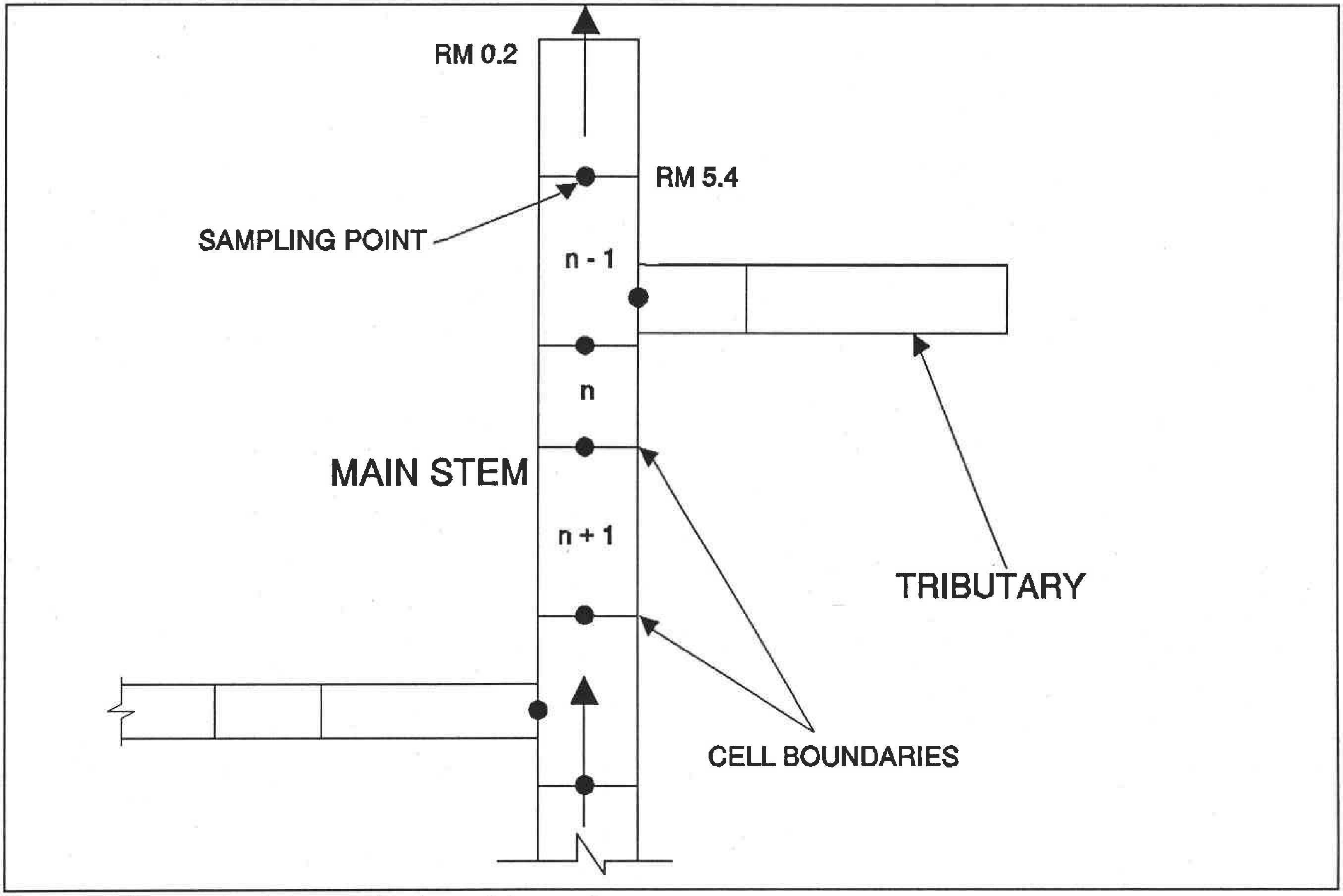

Figure 3.3 Computational elements for the model network

Data Sources/Types

The basic data required for a suspended solids mass balance are water flow and total suspended solids concentration. The product of flow and total suspended solids concentration, expressed as mass loading, can be modelled to estimate factors affecting water clarity or turbidity. Table 3.2 lists the sources and the types of data used subsequently in the mass balance model.

Several agencies are involved in monitoring the water quality in the Tualatin River basin; there thus exists redundant information for certain sites and none for some others. Among the data sources, the most comprehensive set was that maintained by the Unified Sewerage Agency (USA) of Washington County. This served as the primary data base for this study, to which the information from other sources were either added or compared to complement the analysis.

Table 3.2 Data sources, types and time period collected

Agency	Type	Dates
USA	TSS, Turbidity, Flow	1990-1992
USGS	Flow	1991-1992
TVID	Flow	1990-1992
OWRD	Flow	1991-1992
DEQ	Turbidity	1990-1993
OSU	TSS, Flow	1992

Model - Development

Models based on the principle of conservation of mass are used in groundwater, air and surface waters. The model used here is a simple steady-state Eulerian-reference-based simple model. A simple model is based on probabilistic or deterministic equations and is used for screening over extensive areas for the purpose of identifying and predicting trouble spots. Screening involves the use of readily available data and is also used to identify data needs for more intensive follow up studies. The choice for a simple model over a more complex model was based on the belief that:

1) Easier interpretation was possible than for a complex model; and

2) The amount of data needed to validate a more complex model would be greater and was not available.

The basic equation of the simple model can be written as:

$$\text{Accumulation}_i = \text{Sum of Inflows}_i - \text{Sum of Outflows}_i + \text{Sources}_i - \text{Sinks}_i. \qquad (1)$$

Where i specifies the ith reach (or element) to which the equation is applied and the source, sink, inflow, and outflow terms account for all changes of storage, inflows and outflow in that section. This equation is derived from the one-dimensional advective-dispersive mass transport equation.

Referring to figure 3.3. for cell n,

$$R_n = \Sigma\overline{(QT)}_{i,n} - \Sigma\overline{(QT)}_{o,n} + S_n \qquad (2)$$

In which

R_n = the average rate change at mass in cell n over the time period

$\Sigma(QT)_{i,n}$ = sum of average input fluxes (transport rates) into cell n over time period

$\Sigma(QT)_{o,n}$ = sum of average output fluxes (transport rates) from cell n over time period

S_n = the net sources and sinks within cell n (average rate) for time period

Assuming a steady state ($R_n = 0$), S_n can be calculated for each cell.

The numerical data at hand were split into two season-based classifications: summer and non-summer. The summer data were those collected during the months from June through October. The remaining data were considered non-summer. Consideration was given to classifying the data based on flow events (high flow and low flow) but it was found that the season-based classification is also a flow-based classification as most low flows occur during summer and the high flows occur during non-summer months. In addition, high-flow and low-flow events were not specifically sampled - hence use of the classification based on flow events would probably give inconclusive results.

The data sampling frequency for the different agencies ranged from daily to monthly and depended on the season of the year (summer vs. non summer). In order to obtain uniformity in the computations of the solids loading of the river, weighted averages were used. Mathematically the weighted average transport into out of in an element is represented as:

$$\overline{TQ}=\frac{\sum_i \frac{(T_iQ_i+T_{i+1}Q_{i+1})}{2}\Delta t}{\sum_i \Delta t_i} \tag{3}$$

Where

i is the date on which the sample was obtained

i+1 was the date the next sample was taken

Δt is the time in days between the two dates of sampling interval i

T is total suspended solids values (measured on dates i and i+1)

Q is flow values (measured on dates i and i+1)

TQ is the transport rate of suspended solids across a specified cross-section

This says that a time period is divided into i intervals each equal to Δt_i. T_i and Q_i are values at the beginning of time interval i. T_{i+1} and Q_{i+1} are values at the end of the time interval. TQ is the average transfer (flux) rate over the entire period $(\Sigma \Delta t_i)$.

The output from this equation applied to the thirteen sectors of the river resulted in two values for each year, a summer average and a non-summer average (if data were available year round). An upper limit of Δt_i equal to nine days was set for the averaging period. Some of the processes in a river affecting suspended solids loading, such as urban/agricultural runoff, are difficult to quantify directly and a mass loading balance can be helpful in their identification and quantification.

RESULTS

The results obtained from the mass balance model are presented in the form of summary tables and plots. Complete flow and suspended solids concentration data obtained from different sources for the various stations are presented in Appendix I.

The data from different agencies were pooled to provide the most comprehensive information of flow and total suspended solids concentration for all the monitoring stations in the period 1990-1992. The fully compiled data record was not entirely complete and there were time periods and locations for which no information was available, resulting in lack of representation, especially during the non-summer months. The gaps in data occurred mainly during the time period from November through April.

River Overview - Flow and Suspended Solids Variation

Figures 4.1 through 4.6 illustrate stream flows and suspended solids variations during the study period for three different locations along the river. The locations were chosen as to provide an overview of the river and are located at the upstream end (Cherry Grove, RM 71.5), near the mouth (Weiss, RM 0.2) and the middle (Meriwether, RM 35.4) of the river. Average flow for the upper segment of the river (above Farmington, RM 33.6) was around 200 cfs. The presence of Henry Hagg Lake on Scoggins Creek above river mile 62 affects the Tualatin main stem in terms of increased flow during summer and increased suspended solids mass loading during summer and non-summer seasons. Flow in the river before the inflow from Scoggins Creek averaged less than 40 cfs. Suspended solids on the upper portion of the river before inflow from Scoggins Creek (RM 61.2) averaged around 3 mg/L and about 10-12 mg/L after.

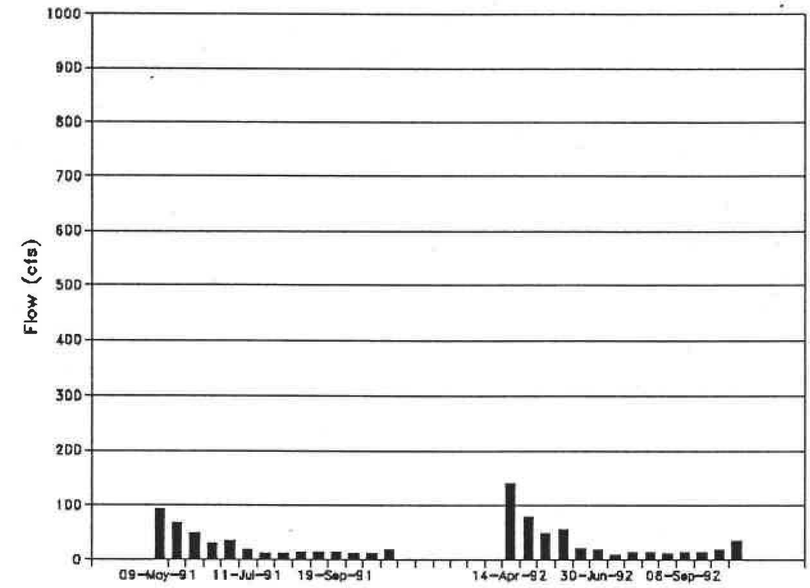

Figure 4.1 Tualatin River flow at Cherry Grove (RM 71.5), 5/9/91 - 10/20/92

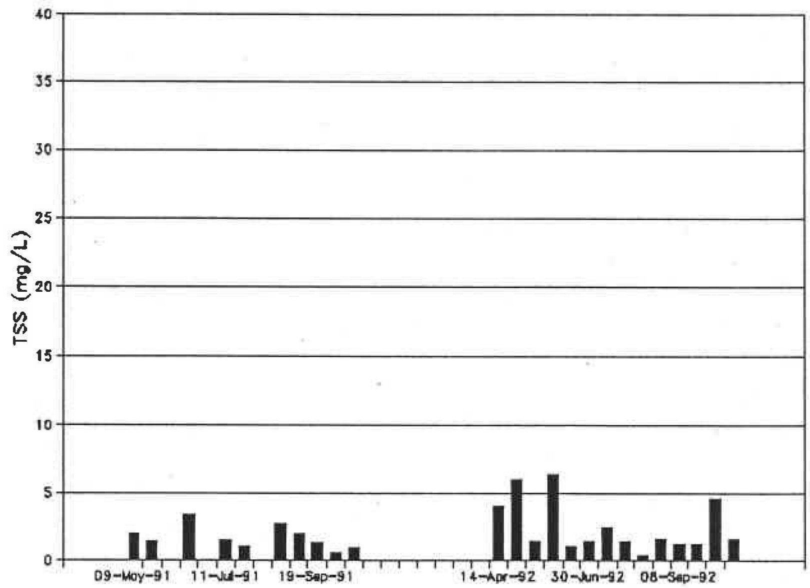

Figure 4.2 Suspended solids concentration at Cherry Grove (RM 71.5), 5/9/91 - 10/20/92

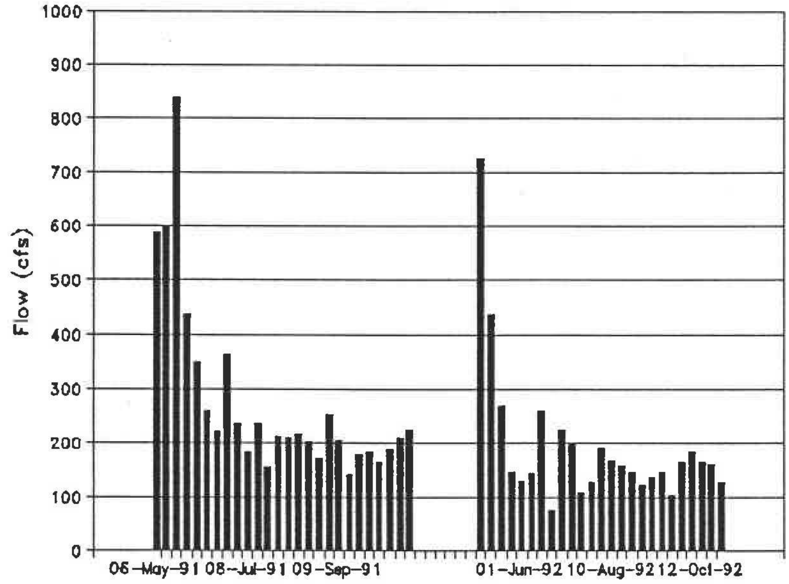

Figure 4.3 Tualatin River flow at Meriwether (RM 35.4), 5/6/91 - 10/27/92

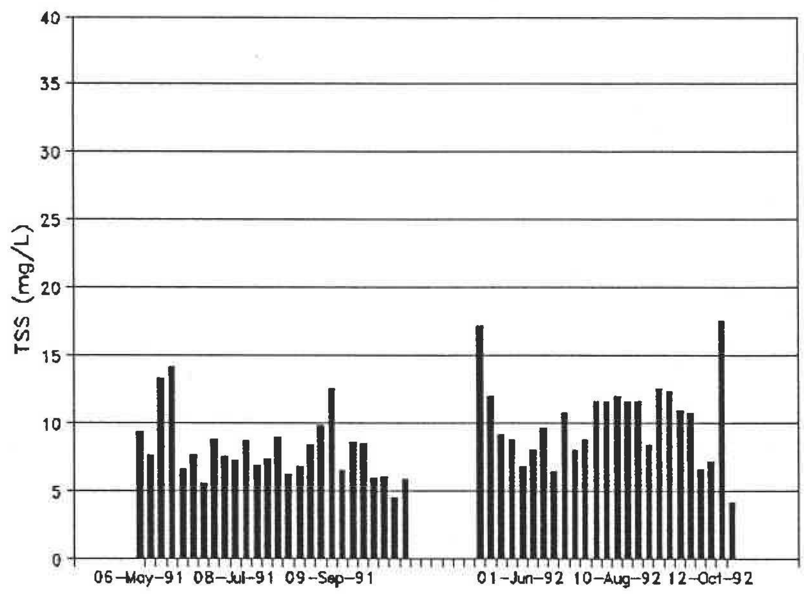

Figure 4.4 Suspended solids concentration at Meriwether (RM 35.4), 5/6/91 - 10/27/92

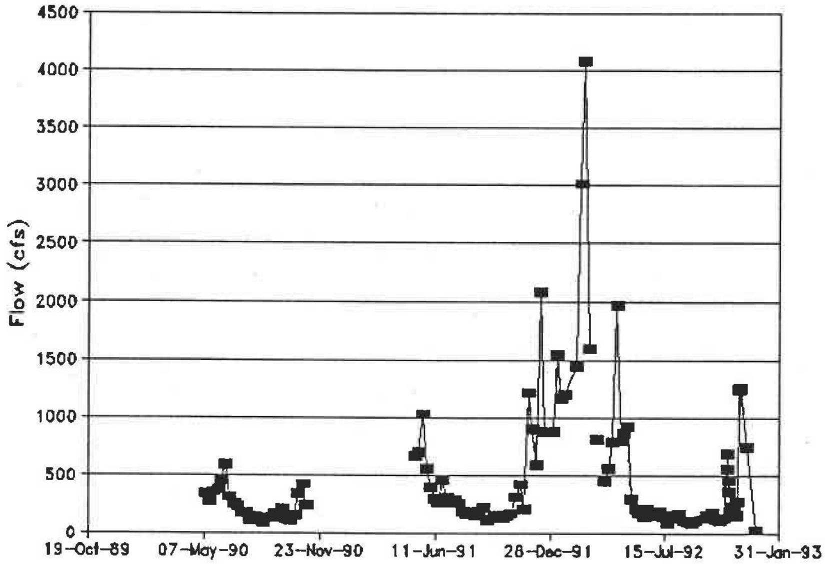

Figure 4.5 Tualatin River flow at Weiss (RM 0.2), 1/2/90 - 12/21/92

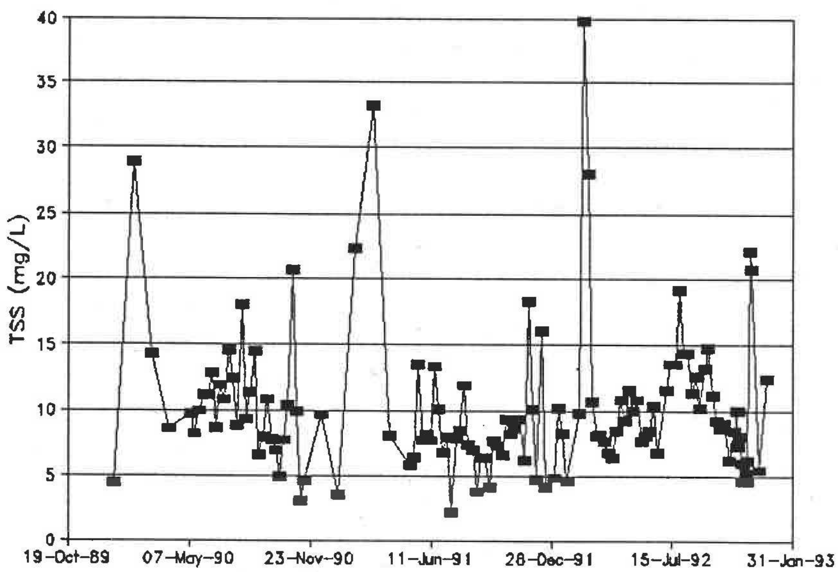

Figure 4.6 Suspended solids concentration at Weiss (RM 0.2), 1/2/90 - 12/21/92

At the lower end of the river at Weiss (RM 0.2) peak flow events during the non-summer season were as high as 4,000 cfs. Typical summer flows at Weiss (RM 0.2) averaged less than 300 cfs. Variation of suspended solids concentration at this site followed closely with change in flow. The peak occurrences of concentration (> 20 mg/L) were always during the non-summer period. The average suspended solids concentration for the summer was around 10 mg/L, and the flow average was around 150 cfs.

Flow Balance

A basic requirement for the mass balance approach is the availability of flow information. In order to verify that the flow data satisfied the laws of conservation, a flow balance was performed. The results are tabulated in Table 4.1, which is a compilation of the time averaged flow data obtained from the different agencies involved in Tualatin River management. The two data classifications for each year are represented as 'Summer (S)' and 'Non-Summer (NS)'. Non-summer extended from November 1st through May 31st of the next year, i.e, non-summer 1991 (NS 91) would represent data collected between November 1st 1990 and May 31st 1991. Summer 1991 (S 91) would represent data collected between June 1st and October 31st of 1991. The weighted average flow was calculated for each time period similar to that of the mass balance (Equation 3). The following equation was used:

$$\overline{Q}=\frac{\sum \frac{(Q_i+Q_{i-1})}{2}\Delta t}{\sum \Delta t_i} \qquad (4)$$

where the terms are defined in chapter 3.

The weighted average was required since all the agencies did not sample and monitor flow with

Table 4.1 Average flow (cfs) for main stem and tributary monitoring stations of Tualatin River (Main stream stations in bold)

			1990		1991		1992		1993
STATION #	**RIV. MILE**	**LOCATION**	**NS**	**S**	**NS**	**S**	**NS**	**S**	**NS**
1	00.2	**WEISS**	334	222	782	227	1098	135	410
2	05.4	**STAFFORD RD**	350	220	2052	222	1048	136	381
		LAKE OSWEGO CHANNEL				58	47	61	
14	00.2	NYBERG CK			1	1	1	1	
3	08.7	**BOONES FERRY RD**				235	1093	195	
15	01.2	FANNO CK	21	6	19	12	49	6	32
4	11.6	**HWY 99**							
21	00.5	S ROCK CK				1	1	1	
22	02.0 .	CHICKEN CK				3	27	2	
5	16.5	**ELSNER BR RD**					950		829
6	27.1	**SCHOLLS**							
23	00.1	BAKER CK				3	5	1	
24	01.0	McFEE CK				3	7	2	
25	00.5	BURRIS CK				1	3	1	
26	01.8	CHRISTENSEN CK				1	2	0	

			1990		1991		1992		1993
STATION #	**RIV. MILE**	**LOCATION**	**NS**	**S**	**NS**	**S**	**NS**	**S**	**NS**
7	33.6	**FARMINGTON**	2145	221	1590	204	1124	152	1093
27	0.2	BUTTERNUT CK			1	1	1		
8	35.4	**MERIWETHER**			649	221	373	155	
28	01.2	ROCK CK	33	14		14	117	11	67
9	39.1	**ROOD BR RD**	334	194	396	167	702	111	280
10	45.0	**HWY 219**				137	698	99	304
37	02.1	DAIRY CK	103	44	126	37	295	21	74
11	52.8	**GOLF COURSE RD**				111	354	89	196
41	01.5	GALES CK	50	20	76	25	178	14	100
42	01.1	CARPENTER CK							
12	61.2	**SPRINGHILL**	103	138	115	133	186	127	102
44	01.7	SCOGGINS CK			50	111	32	125	
13	71.5	**CHERRY GR**			81	21	64	21	

the same frequency. The primary means of obtaining flow information was through staff gauge readings and flow rating tables. For the stations in the lower Tualatin (Stations 2, 3, 4, 5 & 6) which are located in the impoundment area created when the Lake Oswego diversion dam was up, the flow data either were not available or were obtained using flow meters. For the stations at Boones Ferry Road (RM 8.7) and Stafford Road (RM 5.4), the flow information was estimated from the station located at West Linn as outlined below:

flow at Stafford = West Linn flow

flow at Boones Rd = West Linn flow + Oswego Canal outflow

The above substitutions were possible since there were no tributaries or diversions other than the Oswego Canal (RM 6.8) and there was assumed to be no significant change in flow between West Linn and Boones Ferry Road.

Flow values increased in the direction of river flow with added inputs from the tributaries, and summer flows were less than non-summer flows. A reversal of trend in flow pattern was observed at Scoggins Creek located below Hagg Lake; the summer flows were higher than the non-summer flows. Due to low water levels in the Tualatin River during summer, water is released from the lake into the river. This accounts for the reversed flow pattern. There are two instances (Stafford, RM 5.4, NS 91' & Meriwether, RM 35.4, NS 92') of flow values being lower than expected. For the case of Meriwether in the non-summer period of 1992, there is a 325 cfs drop in flow value in an otherwise increasing flow trend in the downstream direction. There are no withdrawals in the vicinity of this station which could account for this. This violates the mass balance as it contradicts with the laws of conservation. Possible reasons for this are data entry error or too few data points for that season leading to averaging errors.

Suspended Solids Mass Balance

The suspended solids mass balance used the averaged product of flow and suspended solids concentration, expressed as mass loading in kilograms per day. It was averaged for summer and non-summer periods. The resulting values are tabulated in Table 4.2. The blanks in the table were due to either missing flow data (mostly) or missing suspended solids concentration data.

Summer suspended solids loadings were typically lower than non-summer values, except on Scoggins Creek. Water released from Hagg Lake during summer months to the Tualatin River through Scoggins Creek causes this elevated suspended solids level. There was no appreciable increase in the suspended solids loading beyond the site at Meriwether (RM 35.4). Unfortunately, the limited availability of the data has made it impossible to perform a complete mass balance on all river segments (See Tables 4.1 and 4.2), even for a single year.

Table 4.2 Average suspended solids loading (kg/day) for main stem and tributary monitoring stations of Tualatin River

			1990		1991		1992		1993
STATION #	**RIV. MILE**	**LOCATION**	**NS**	**S**	**NS**	**S**	**NS**	**S**	**NS**
1	00.2	**WEISS**	7913	6296	18439	4312	44718	3628	12343
2	05.4	**STAFFORD RD**	7813	6078	128048	4497	46662	3181	24209
		LAKE.OSWEGO CHANNEL.							
14	00.2	NYBERG CK			52	42	32	32	
3	08.7	**BOONES FERRY RD**				4104	42411	5908	
15	01.2	FANNO CK	1836	320	391	2462[2]	6087	286	2892
4	11.6	**HWY 99**							
21	00.5	S ROCK CK				10	10	16	
22	02.0	CHICKEN CK				43	865	27	
5	16.5	**ELSNER BR RD**					44925		21279
6	27.1	**SCHOLLS**							
23	00.1	BAKER CK				25	52	18	
24	01.0	McFEE CK				55	155	34	
25	00.5	BURRIS CK				4	22	9	

[2] Increased loading due to storm event, June 1991

			1990		1991		1992		1993
STATION #	**RIV. MILE**	**LOCATION**	**NS**	**S**	**NS**	**S**	**NS**	**S**	**NS**
26	01.8	CHRISTENSEN CK				22	31	7	
7	33.6	**FARMINGTON**			13128				
27	0.2	BUTTERNUT CK			7	6	4	3	
8	35.4	**MERIWETHER**			17760	4247	11568	3846	
28	01.2	ROCK CK	2904	602		181	3428	230	1793
9	39.1	**ROOD BR RD**	9665	5694	9972	4019	43038	2843	13543
10	45.0	**HWY 219**				3386	39327	2530	14721
37	02.1	DAIRY CK	2501	1238	3578	744	7970	390	2215
11	52.8	**GOLF COURSE RD**				2392	20845	1950	7085
41	01.5	GALES CK	755	454	970	204	9812	146	5923
42	01.1	CARPENTER CK							
12	61.2	**SPRINGHILL**	2245	2730	2242	2222	11218	2379	1757
44	01.7	SCOGGINS CK			243	1260	112	1263	
13	71.5	**CHERRY GR**			346	57	676	145	

DISCUSSION

Flow Data Comparison

Flow Data from TVID and USA for the site at Golf Course Road (RM 52.8) were compared for consistency. In order to determine the statistical significance of the two sets of flow readings they were plotted against each other and a regression model was used to fit the data. Figure 5.1 is a linear regression plot of the flow data obtained from these two sources during September through December, 1992. The correlation coefficient (R^2) for the fitted line was 0.988, which indicates very good agreement between the data from the two sources. Human, instrumental and measurement errors probably all contribute to the small discrepancy present in the correlation between the readings of the two agencies.

Seasonal Effects

Figures 5.2 through 5.5 show the weighted average flow values along the main stem stations of the river from for the periods S 91, NS 92, S 92 and NS 93 (November-December 1992). This is the time period for which the most information (flow and suspended solids concentration) is available. Figures 5.6 through 5.9 present the suspended solids mass loading for the same period. These figures plot the averaged observed flow and suspended solids loading values at each station. Hence, the net effect of inflows and outflows are included.

The seasonal changes (Summer/Non-Summer) in the suspended solids loading varied by as much as a factor of ten, as can be seen from the figures (note the differences in vertical scales used because of this). The loading in the summer months was noticeably less than the loading during the rest of the year. As flow rates go down in the summer so does the loading rate,

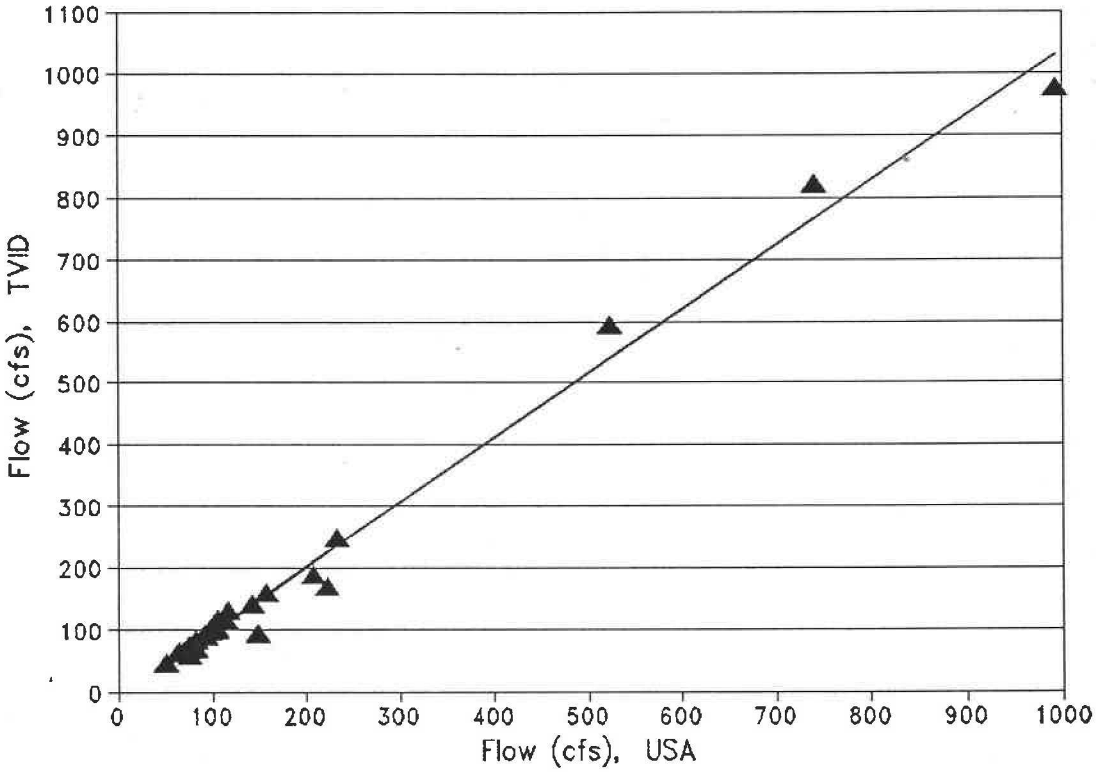

Figure 5.1 Comparison of USA & TVID data at Golf Course Road (RM 52.8)

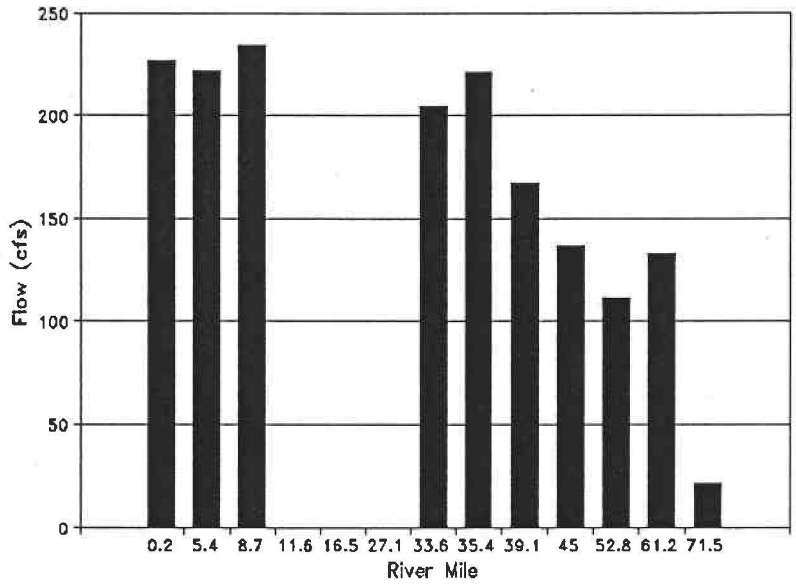

Figure 5.2 Average flow for June 91 - Oct. 91 (S 91)

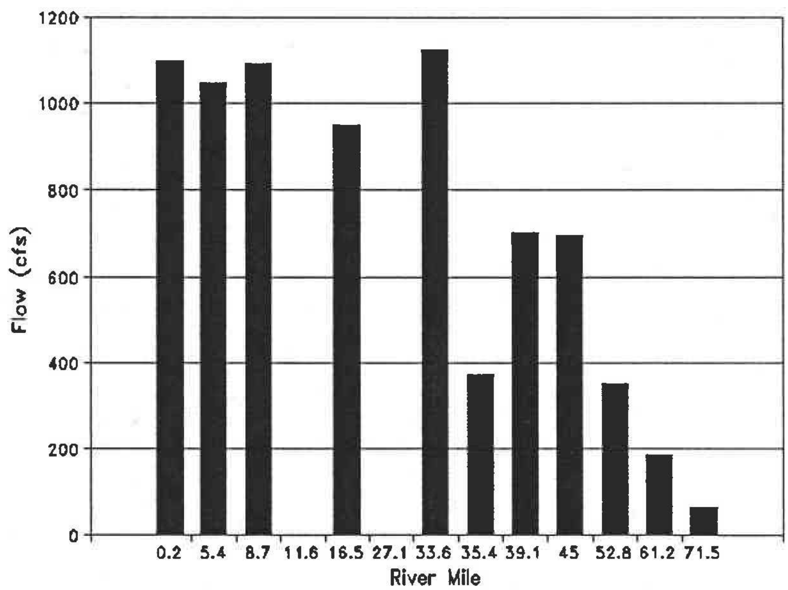

Figure 5.3 Average flow for Nov. 91 - May 92 (NS 92)

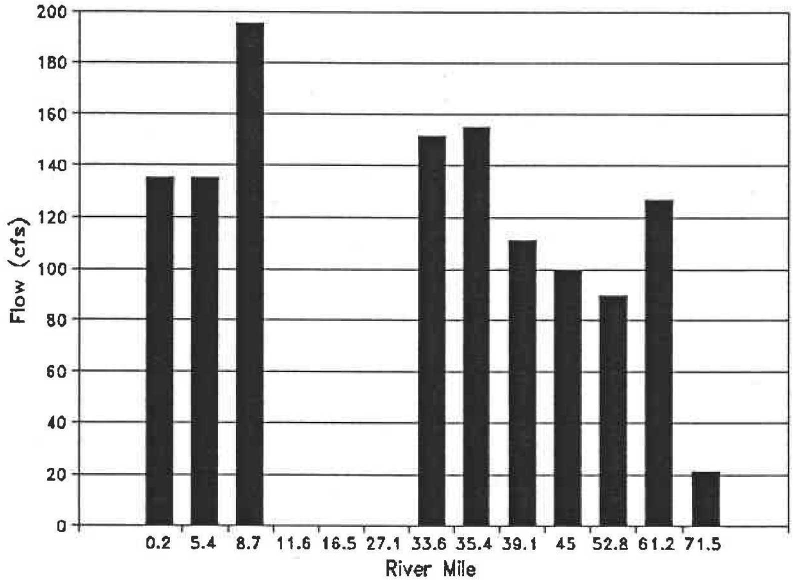

Figure 5.4 Average flow for June 92 - Oct. 92 (S 92)

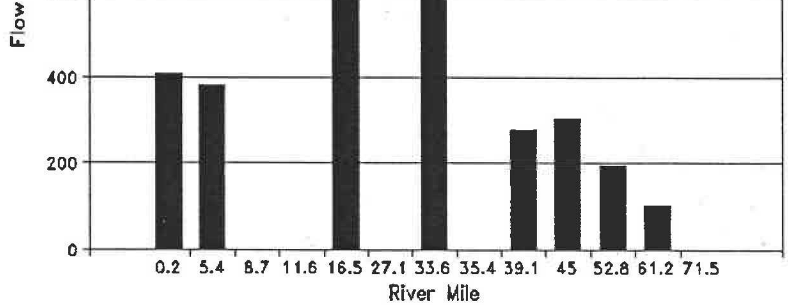

Figure 5.5 Average flow for Nov. 92 - Dec. 92 (NS 93)

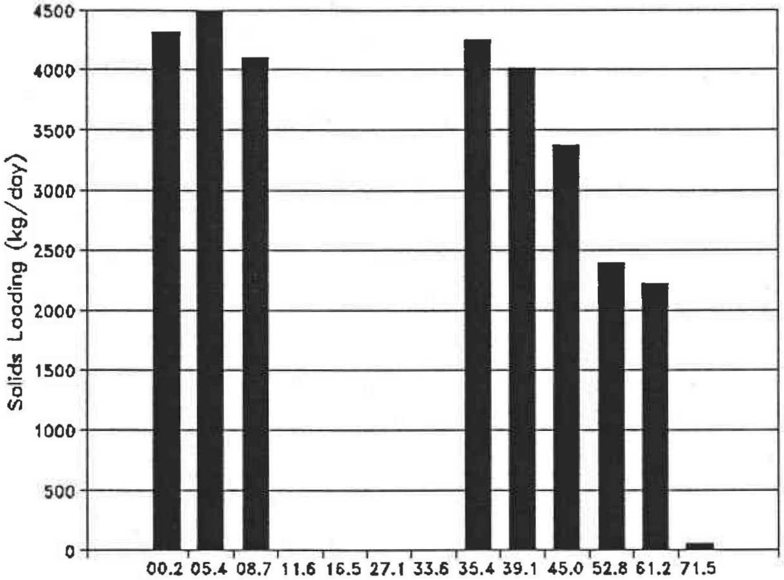

Figure 5.6 Average suspended solids mass loading for June 91 - Oct. 91 (S 91)

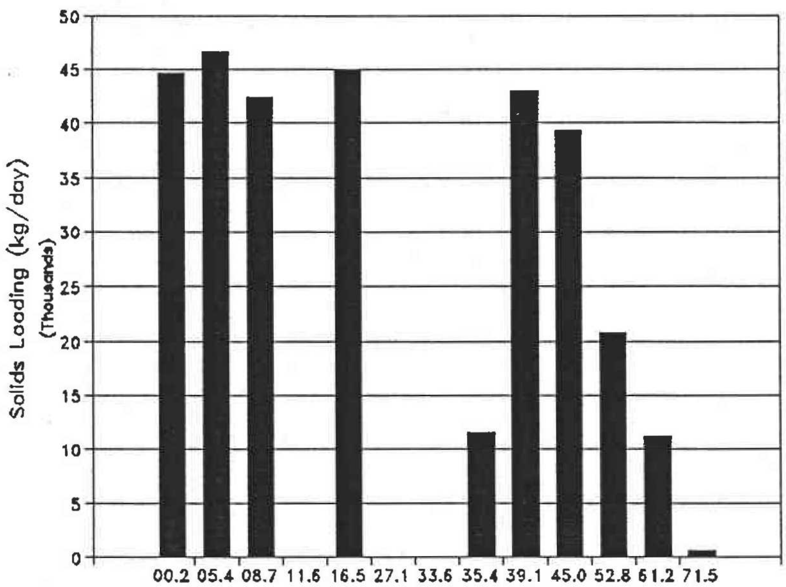

Figure 5.7 Average suspended solids mass loading for Nov. 91 - May 92 (NS 92)

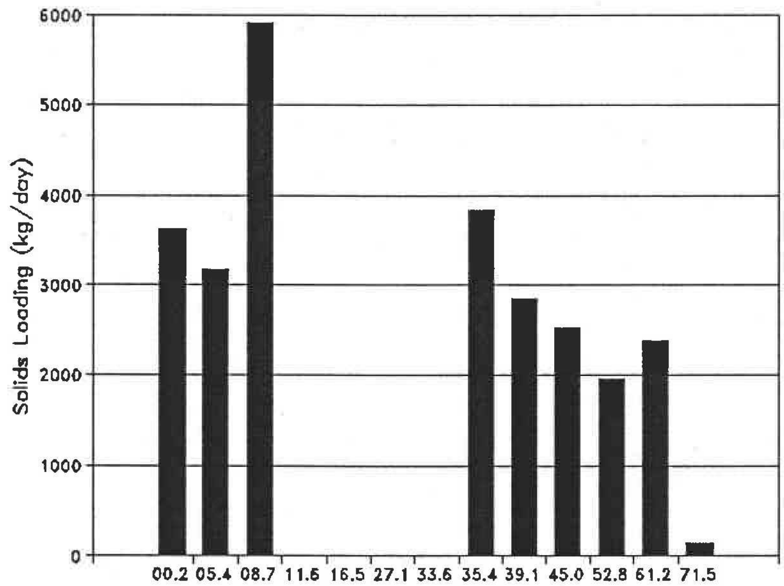

Figure 5.8 Average suspended solids mass loading for June 92 - Oct. 92 (S 92)

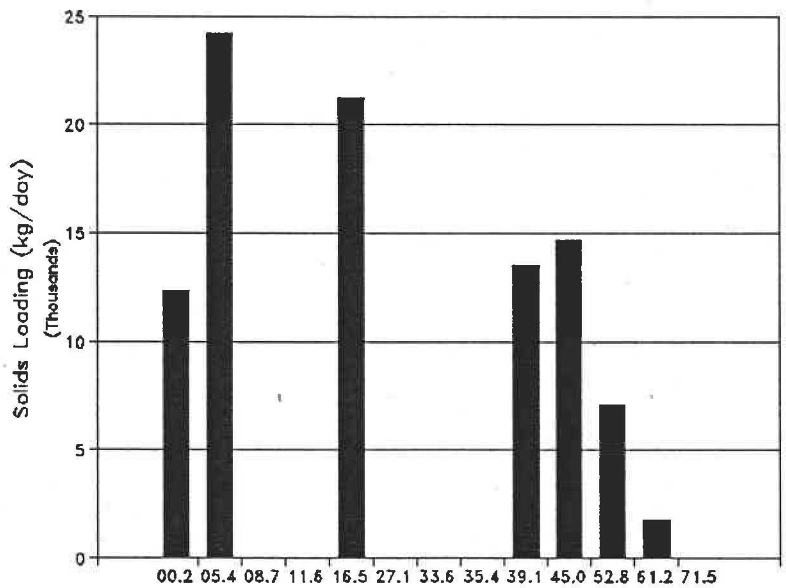

Figure 5.9 Average suspended solids mass loading for Nov. 92 - Dec. 92 (NS 93)

indicating that the suspended solids loading is related directly to flow. This is indicative of a source of solids also associated with the flow. The station at Weiss (RM 0.2) in the year 1992 is used as an example.

Table 5.1 Non-Summer/Summer ratio of parameters at Weiss (RM 0.2) for 1992

Parameter	Ratio NS 92/S 92	Change
Solids Loading	44500 kg/day / 3600 kg/day	12.4
Flow	1100 cfs / 135 cfs	8.1
Suspended Solids Concentration[3]	16.65 mg/L / 10.94 mg/L	1.5

Table 5.1 shows the calculated ratio of change from non-summer to summer for solids loading, flow, and suspended solids concentration. From Table 5.1 it can be inferred that the increase in loading during the non-summer months is not due to increases in flow alone but also due to an increase (50% increase from summer, in this case) in the suspended solids concentration. Since this station is located at the mouth of the river and therefore indicates the cumulative effects of the whole basin, surface runoff due to increased rainfall events during the non-summer portion of the year is a likely source of sediments. The increased flows and flow velocities undoubtedly caused scour of the river bottom and banks, which would also have increased the solids loading in the river.

Effect of River Location

Figures 5.2 through 5.9 show a general increase in suspended solids mass loading and flow

[3] Flow weighted average

in the downstream direction. The most notable increases in suspended solids mass loading occurred before the station at Meriwether (RM 35.4). This is due to the combined inflows from four major tributaries (Scoggins, Dairy, Gales and Rock Creeks) into the river above the station.

Suspended solids mass loading in the river generally did not change significantly beyond the station at Meriwether (RM 35.4). In spite of the limited flow information (little or no information is available for the sites between RM 8.7 and RM 35.4), it can be concluded that the major portion of the loading occurs above this station in the river. That is, the change in solids mass between the sites at Meriwether (RM 35.4) and Weiss (RM 0.2) is small (3%, flow, S 91). An increase in loading and flow is observed at the monitoring site at Boones Ferry Road (RM 8.7), but the Oswego Canal (RM 6.8), which feeds Lake Oswego and is a major withdrawal from the Tualatin River, causes lower flow and suspended solids loading level at the stations beyond the withdrawal channel. Averaging over fewer number of data points (as few as two data points in some cases), especially for the non-summer season, resulted in inconsistencies such as in Figure 5.9 at Stafford Road (RM 5.4), showing a high solids loading level. Flow data error is suspected at RM 35.4 in Figure 5.3 and is reflected in the corresponding mass loading in Figure 5.7.

Sources and sinks of suspended solids were identified for each section by comparing the average mass transport loading at the upstream and downstream stations of that section. The notable sources of suspended solids were the stations at Highway 219 (RM 45.0) and Springhill (RM 61.2), throughout the year. The station at Golf (RM 52.8) was a sink and Weiss (RM 0.2) was a sink only during the non-summer months. Since information at either end of the sections were required to identify sources and sinks only the above stations could be identified.

The expected general trend in flow is an increase in the downstream direction (except at points of major withdrawals) due to the additive effect of the tributary inflows. Figure 5.10 represents water withdrawals during the summer months by TVID and OWRD, Washington County, for irrigation and municipal purposes from the Tualatin River. The cumulative effect of these withdrawals has been incorporated in Figures 5.11 through 5.14. These figures are a theoretical representation of the mass balance for flow and suspended solids loading. Comparing

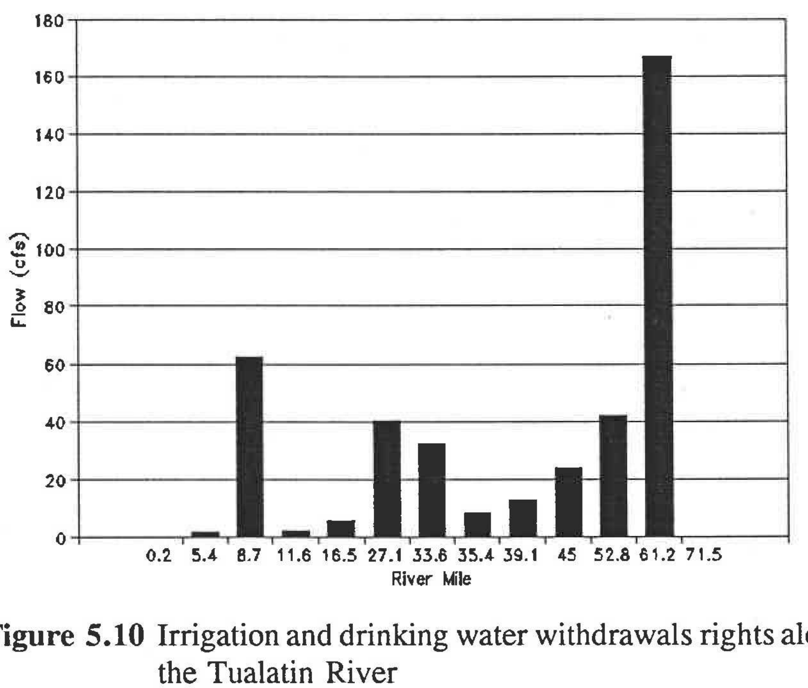

Figure 5.10 Irrigation and drinking water withdrawals rights along the Tualatin River

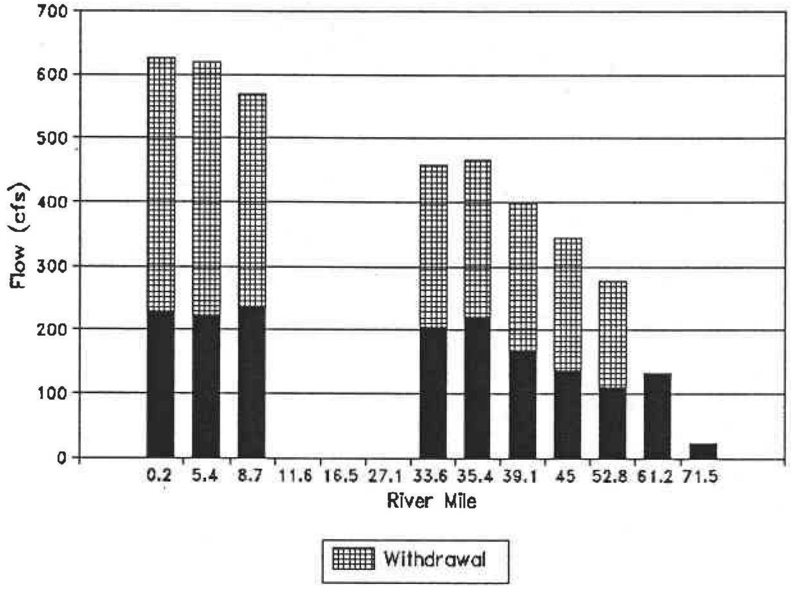

Figure 5.11 Average flow and cumulative withdrawal for June 91 - Oct. 91 (S 91)

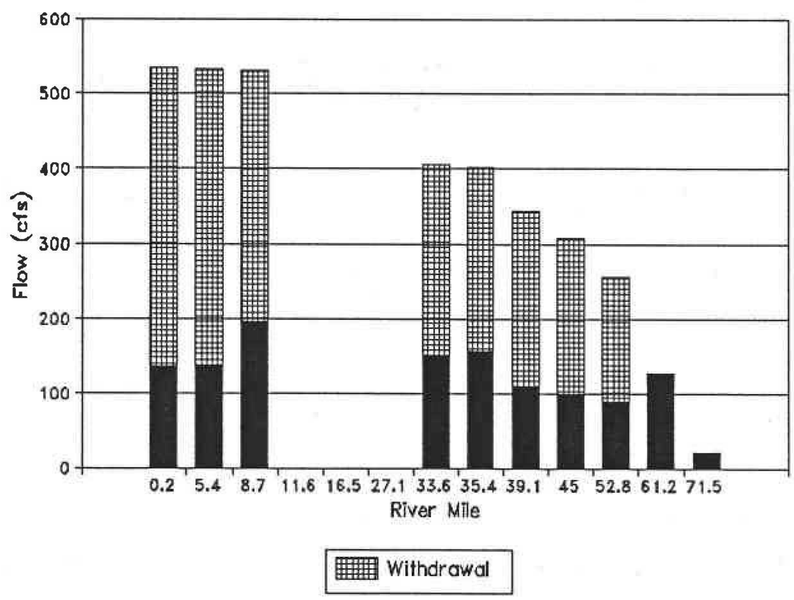

Figure 5.12 Average flow and cumulative withdrawal for June 92 - Oct. 92 (S 92)

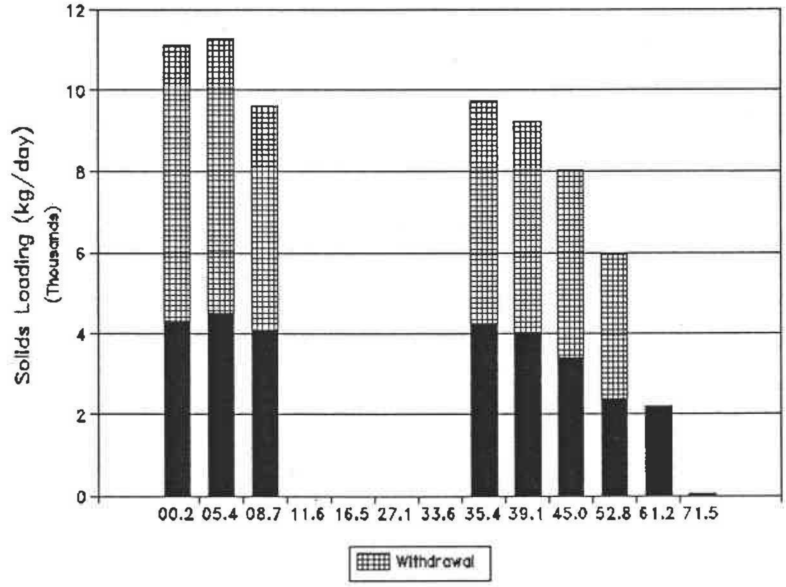

Figure 5.13 Average suspended solids loading including cumulative effects of withdrawal for June 91 - Oct. 91 (S 91)

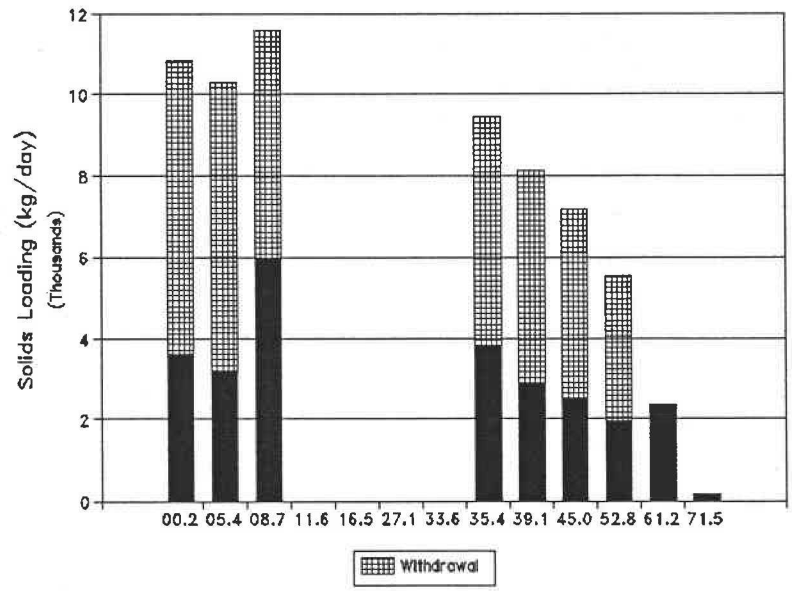

Figure 5.14 Average suspended solids loading including cumulative effects of withdrawal for June 92 - Oct. 92 (S 92)

similar figures with and without the effects of withdrawal (Figures 5.2 and 5.11 as well as 5.4 and 5.12) it is seen that there is an uniform increase in flow in the downstream direction with addition of the withdrawal effects. Similar observations can be made, comparing the mass loading figures (Figure 5.6 and 5.13 as well as 5.8 and 5.14). The inclusion of this information has helped identify that irrigation and municipal water withdrawal are significant sinks in the river. It has also shown that the mass balance satisfies the laws of conservation. Data are plotted only for summer (S 91 and S 92) since water is withdrawn for irrigation only during the summer season. Non-summer withdrawal at water treatment plants has little effect and is balanced by waste water addition.

Tributaries

Fifteen tributaries flow into the Tualatin River between the first (Weiss, RM 0.2) and the last (Cherry Grove, RM 71.5) monitoring stations on the main stem. Based on the magnitude of flow and mass loading (refer Table 5.2), the major tributaries are :

1. Scoggins Creek
2. Gales Creek
3. Dairy Creek
4. Rock Creek
5. Fanno Creek

For the year 1992 the above five tributaries contributed 90 % of the average suspended solids mass loading during the non-summer period and 79% during the summer season. Four of these five tributaries (Dairy, Gales, Rock and Scoggins Creek) are located above Meriwether (RM

Table 5.2 Flow (cfs) and suspended solids mass loading (kg/day) for the main tributaries of the Tualatin River

		FANNO CREEK		ROCK CREEK		DAIRY CREEK		GALES CREEK		SCOGGINS CK.	
		Flow	**Loading**	**Flow**	**Loading**	**Flow**	**Loading**	**Flow**	**Loading**	**Flow**	**Loading**
1990	**NS**	21	1836			103	2501	50	755		
	S	6	320			44	1238	20	454		
1991	**NS**	19	391			126	3578	76	970	50	243
	S	12	2462[4]	14	181	37	744	25	204	111	1260
1992	**NS**	49	6087	117	3428	295	7970	178	9812	32	112
	S	6	286	11	230	21	390	14	146	125	1263
1993	**NS**	32	2892	67	1793	74	2215	100	5923		

[4] Increased loading due to storm event, June 1991

35.4), which accounts for the major contribution to solids loading from this section of the river. The tributaries also accounted for 63 % of the flow (including withdrawals) in the river during the summer of 1992 and for 84 % during non-summer 1992.

Changes in suspended solids concentration in the Tualatin River were computed at stations above and below the entries of Scoggins, Gales, Rock, and Dairy Creeks. For Scoggins Creek in the year 1991 the change amounted to 350% during the non-summer period (NS 91) and 500% during summer (S 91). A 47% (S 91) increase in loading was observed in Scoggins Creek between the stations at Stimson Bridge (close to Hagg Lake) and Highway 47 (close to the Tualatin River junction). In the summer of 1992, concentration changes beyond the inflows from Gales and Dairy Creeks were 16% and 17%, respectively. In November and December of 1992 (NS 93) the change in concentration was 110% for Gales Creek and 34% for Dairy Creek. Rock Creek caused a 109 % increase in the suspended solids concentration during non-summer 1991. Due to lack of flow data for the station at Hwy 99 (RM 11.6), the change in mass loading could not be computed for Fanno Creek. Between the two seasons of the year Dairy, Gales, and Scoggins Creeks are the major contributors of suspended solids. Gales and Dairy Creek are the most significant contributors in the non-summer and Scoggins Creek during summer. These increases in suspended solids concentrations highlight the finding that tributaries contribute suspended sediment to the river during the entire year and are major contributors during the non-summer season (except Scoggins, higher contributor during summer).

Dairy Creek Tributaries

Of the tributaries flowing into the Tualatin River, Dairy Creek has been recognized as a

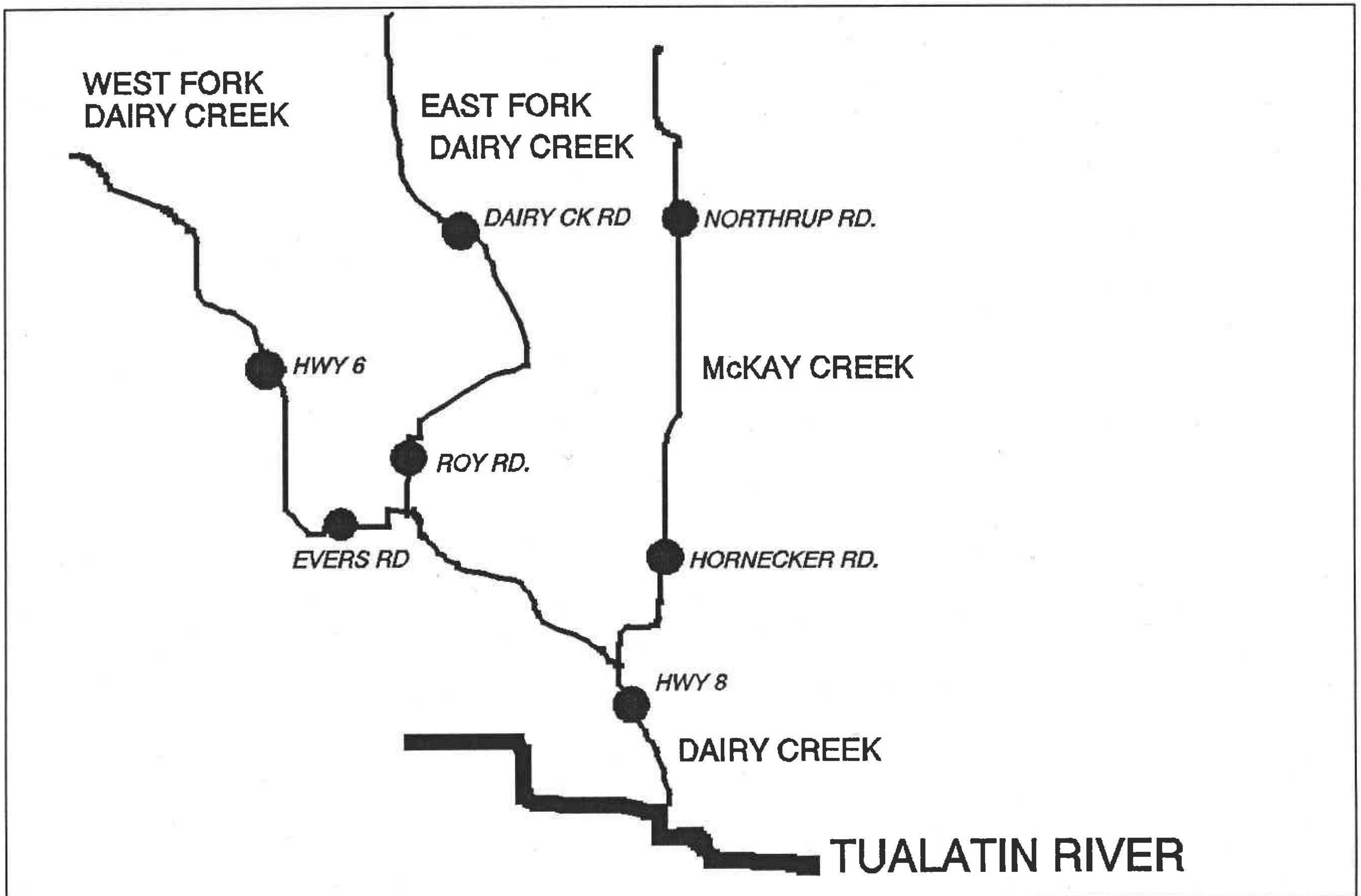

Figure 5.15 Schematic representation of the Dairy Creek and its tributaries

Table 5.3 Suspended solids mass loading (kg/day) for Dairy Creek tributaries

		1990	1991		1992
Tributary	**Site Name**	**S**	**NS**	**S**	**NS**
McKAY	NORTHRUP RD			36	140
McKAY	HORNECKER	57	225	89	196
E FK. DAIRY	DAIRY CK RD			240	372
E FK. DAIRY	ROY RD	439	807	338	1338
W FK. DAIRY	HWY 6			43	
W FK. DAIRY	EVERS RD			325	1511
DAIRY	HWY 8	1238	3578	744	7970

significant contributor to the water quality problem in the river (Wolf, 1991). Table 5.3 tabulates the loadings in the tributaries of Dairy Creek. Figure 5.15 is a schematic of Dairy Creek and its tributaries with the locations of the monitoring stations. The main tributaries of Dairy Creek are:

1. McKay Creek
2. East Fork Dairy Creek
3. West Fork Dairy Creek

The East Fork and the West Fork tributaries contribute the greatest suspended solids loading during the non-summer and summer seasons (Table 5.3) with higher loading during non-summer. During summer, the suspended solids loading at the station at Hwy 8 is almost equal to the sum of the loadings of the three tributaries. But during rest of year the loading at this station is more than twice that recorded for the tributaries. It follows from this that during the non-summer months more than 50% of the loading at Hwy 8 is contributed by the lower portion (beyond Roy Road and Evers Road) of Dairy Creek. Surface runoff during the summer months has been shown not be significant in these streams (Miner, 1992). Agriculture is the predominant land use in the lower Dairy Creek basin. It is possible that the location of many plant nurseries and the different agricultural practices in this area might contribute to suspended solids, transported by surface runoff to the river during the non-summer period of the year.

Transparency

Transparency is a measure of water clarity and is inversely related to suspended solids concentration. Figures 5.16 through 5.18 are plots of suspended solids concentration vs. transparency for the sites at Weiss (RM 0.2), Elsner Bridge Road (RM 16.5), and Rood Bridge Road (RM 39.1). A linear regression model was used to fit the data. Regression data for these sites (Table 5.4) indicate a weak correlation, partly due to fewer number of data points at higher suspended solids concentrations. The observed increase in transparency with decreasing

Table 5.4 Correlation coefficients for flow, and TSS vs. transparency

Figure Number	R^2*100
5.1	99.0
5.16	5.0
5.17	21.0
5.18	15.0

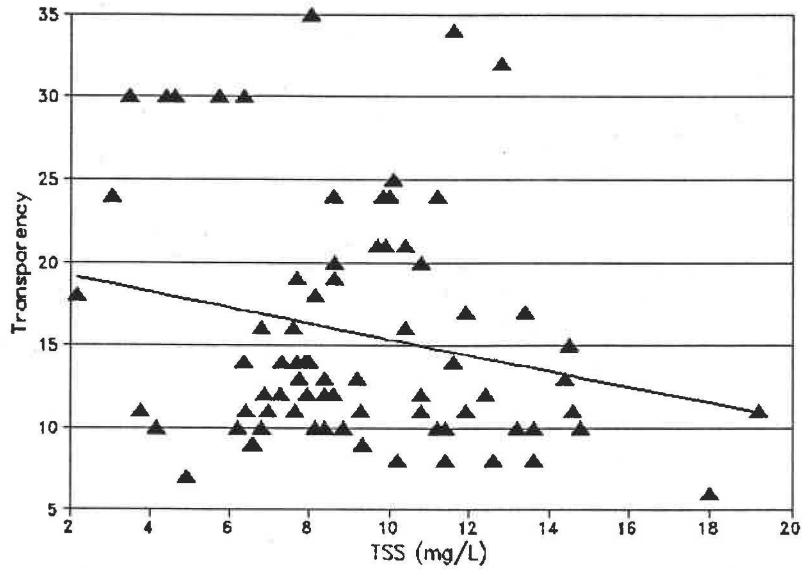

Figure 5.16 Solids-Transparency correlation at Weiss (RM 0.2)

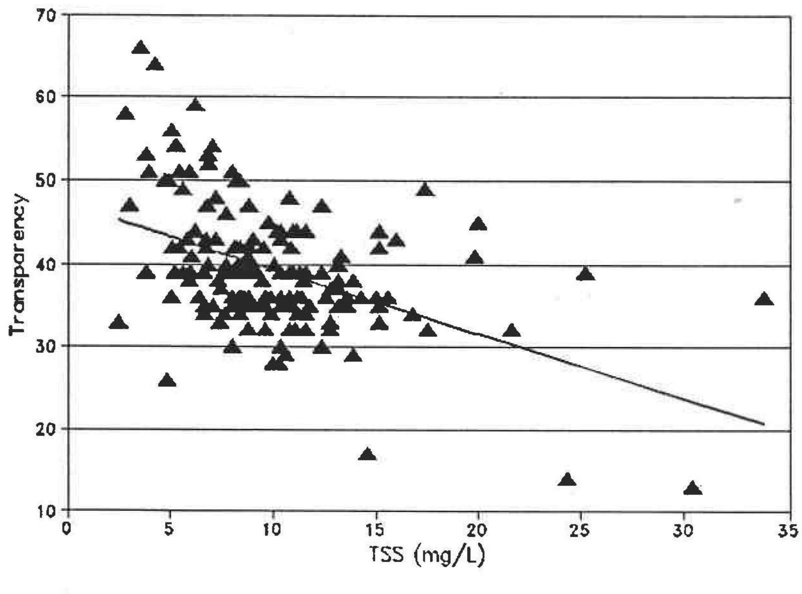

Figure 5.17 Solids-Transparency correlation at Elsner Bridge Road (RM 16.5)

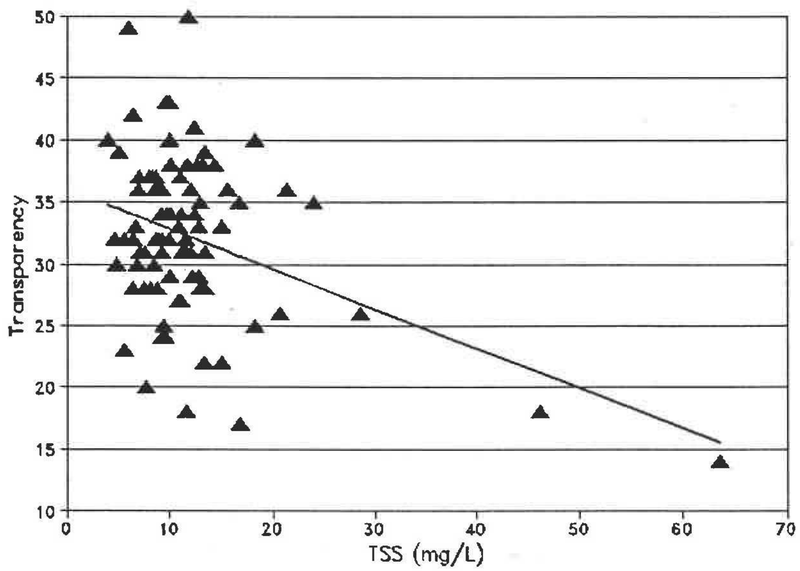

Figure 5.18 Solids-Transparency correlation at Rood Bridge Road (RM 39.1)

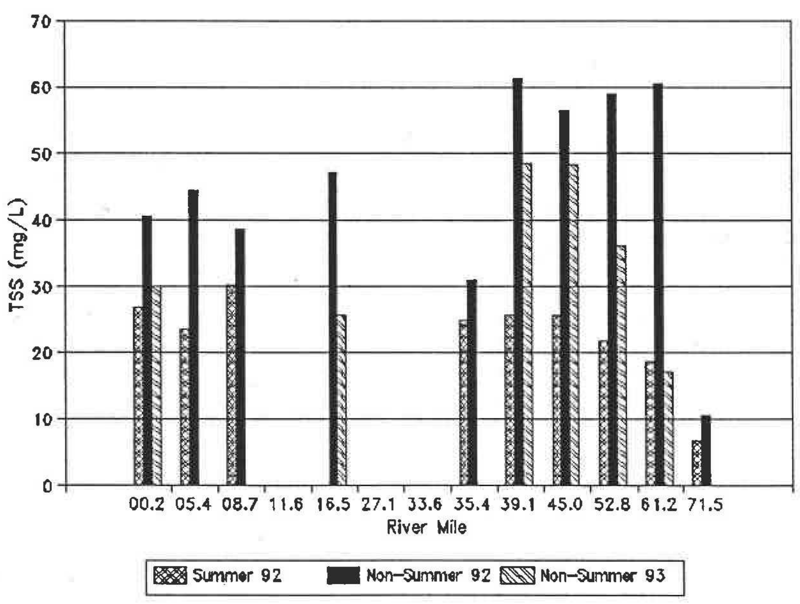

Figure 5.19 Flow weighted average suspended solids concentration for summer and non-summer 1992

suspended solids concentration implies that transparency is highest during the time when solids concentration is lowest. Figure 5.19 is a plot of flow-weighted average suspended solids concentration vs. river mile for the main stem stations during summer and non-summer of 1992. Non-summer data in Figure 5.19 indicates decreasing suspended solids concentration towards the lower end of the river. This indication of in-stream removal of suspended solids was not observed in the data for non-summer 1993. Since 1992 was a very low flow year, sedimentation due to low flow velocity could be the cause of this removal. The same phenomenon was not observed in 1993 due to higher flows. Average suspended solids concentrations in summer are typically lower than non-summer values by about 50 % (1992). Transparency is higher during summer, averaging (at Stafford, RM 5.4) 41 inches in summer and 36 inches in non-summer. As transparency indicates higher water clarity directly, sunlight penetration is to greater depths during the summer months. This aids photosynthesis in the euphotic zone, permitting a higher growth rate for algae during the summer season when other conditions (light intensity, temperature, residence time) are also favorable for algal growth.

Chlorophyll

Figures 5.20 and 5.21 are plots of temperature, chlorophyll a and suspended solids concentration for the sites at Scholls (RM 27.1) and Stafford (RM 5.4). The selected two stations are found in the upper and lower potions of the pool area in the Tualatin River where the problem of the summer algal blooms have been the most severe. The data spans the time period 1990 through 1992. Peak algal concentrations (Chlorophyll a) increase in the downstream direction and almost double between the station at Scholls (RM 27.1) and Stafford (RM 5.4). This indicates the algae problem is intensified in the lower pool area. Chlorophyll concentration

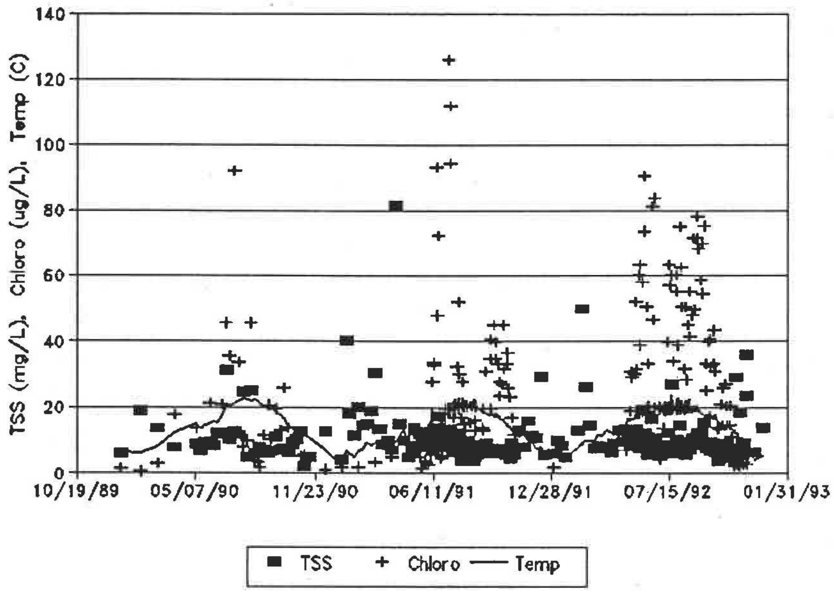

Figure 5.20 Suspended solids, chlorophyll concentrations and temperature at Stafford (RM 5.4), 1/2/90 - 12/21/92

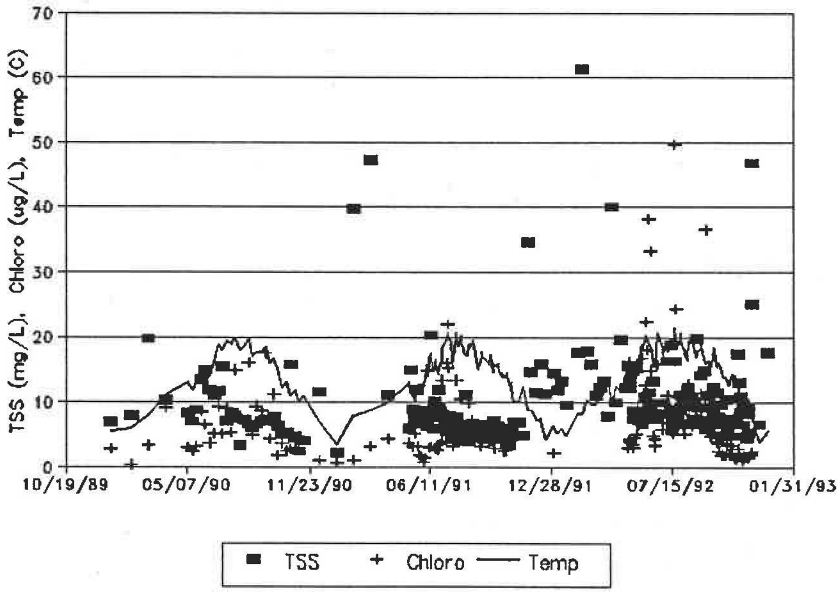

Figure 5.21 Suspended solids, chlorophyll concentration and temperature at Scholls (RM 27.1), 1/2/90 - 12/21/92

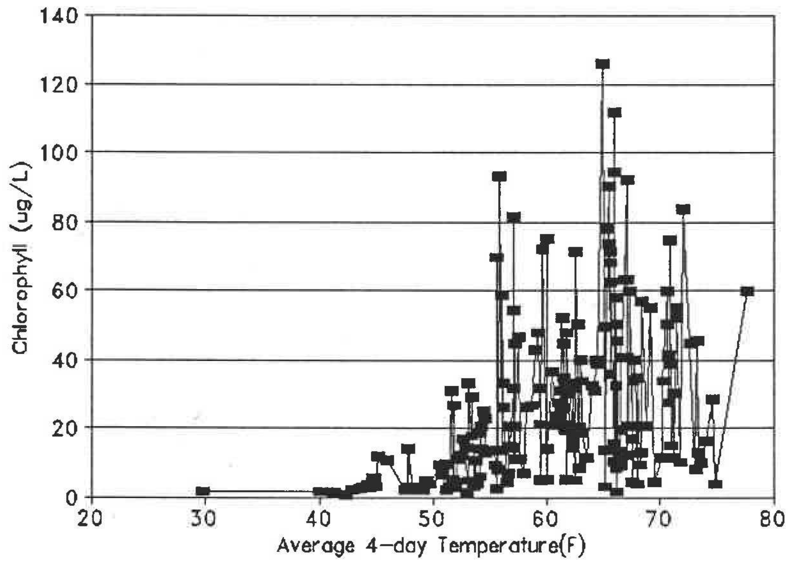

Figure 5.22 Chlorophyll concentration vs. antecedent air temperature at Stafford (RM 5.4)

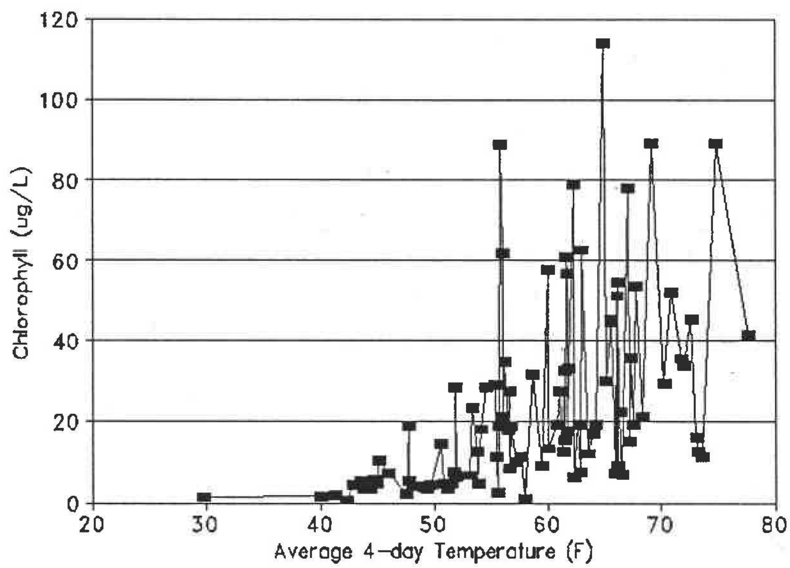

Figure 5.23 Chlorophyll concentration vs. antecedent air temperature at Weiss (RM 0.2)

appears to be related to water temperature, with high chlorophyll values occurring with water temperatures above 18° C. During the summer period, suspended solids concentration does not seem to be directly related to chlorophyll a concentration. Correlations between suspended solids and chlorophyll concentrations during summer were found to be statistically not significant. This may be due to a small fraction of the suspended solids matter being contributed by algal cells. Higher suspended solids concentrations during non-summer decreases water clarity, limiting the light available for the growth of algae. This along when other conditions (temperature, residence time) are also less favorable result in decreased chlorophyll a concentrations during non-summer.

Water temperature data were collected when water samples were collected providing no previous information. Consequently, it was decided to use air temperature data recorded daily and available from the state climate service. The four-day average antecedent air temperature served as an indicator of water temperature. Chlorophyll a concentrations were plotted against the average four-day antecedent air temperature in Figures 5.22 and 5.23. It was observed from these figures that although high chlorophyll events occurred at higher air temperatures, so did low chlorophyll events. This implies that occurrences of high chlorophyll were also influenced by factors other than air temperatures. For further investigation, at each of the four stations (Weiss RM 0.2, Stafford RM 5.4, Boones RM 8.7 and Elsner RM 16.5) on the lower Tualatin River, the high chlorophyll events were selected and the value of the other related parameter such as total and ortho phosphorus, suspended solids and air temperatures were queried.

The following characteristics were common to all the high chlorophyll events: minimum air temperature (four-day average) around 60°F, total and ortho phosphorus levels above 0.07 and

0.01 mg/L, and suspended solids 8-10 mg/L. For these conditions, the chlorophyll concentrations remained higher than 60 μg/L at Weiss (RM 0.2) and Stafford (RM 5.4) and above 50 μg/L at Boones (RM 8.7) and Elsner (RM 16.5). Decreased levels below the above mentioned values in any one factor (ortho and total phosphorus, air temperature, suspended solids) appear to be compensated by elevated levels in the others resulting in high chlorophyll concentrations.

The values of the different parameters stated previously are not a minimum number above which high chlorophyll concentrations occur but they are indicative of the multiple nature of the problem, caused by elevated levels of more than one parameter.

Turbidity

Turbidity is an indirect measure of suspended solids concentration. Turbidity data for four stations (Boones RM 8.7, Elsner RM 16.5, Scholls RM 27.1, and Rood RM 39.1) on the main stem were obtained from the Oregon Department of Environmental Quality (DEQ). The data spanned the period 1990-1993 and the sampling frequency was monthly. Figure 5.24 is a plot of the data against the date of sampling. It can seen from this figure that turbidity values are typically below 10 except during the period November through April which is the non-summer period of the year.

The turbidity data (DEQ) were combined with TSS and transparency data (USA) for the stations at Boones (RM 8.7), Elsner (RM 16.5), Scholls (RM 27.1) and Rood (RM 39.1). Linear regression was used to fit the data to ascertain the different relationships. Figures 5.25 through 5.28 present the variation of transparency, suspended solids and chlorophyll a concentrations with respect to turbidity for the four stations. The trends of all the three parameters (transparency, suspended solids and chlorophyll) remained the same in the four locations. Transparency and chlorophyll a decreased with increasing turbidity and suspended solids concentration varied directly with turbidity. This implies that chlorophyll and transparency are found to be higher during summer when the concentration of suspended solids is lower. The correlation coefficients for turbidity and transparency in these figures for the most part are above 0.64, which demonstrates good correlation (Table 5.5).

It can also be observed that there are changes in the slope of the fitted lines for transparency and suspended solids concentration between the stations above the pool area (Scholls, RM 27.1 and in the pool area (Stafford, RM 5.4, Boones, RM 8.7 and Elsner RM 16.5). A change in the nature of suspended solids from inorganic particles to algal cells could account for this difference in slopes. Correlation coefficients for chlorophyll a range below 0.3, indicating the weak relationship with suspended solids concentration.

Table 5.5 Correlation coefficients for turbidity vs. transparency, TSS, and chlorophyll

R^2*100	Transparency	TSS	Chlorophyll a
Figure 5.25	89.0	75.0	30.0
Figure 5.26	59.0	49.0	12.0
Figure 5.27	92.0	97.0	15.0
Figure 5.28	81	97	4

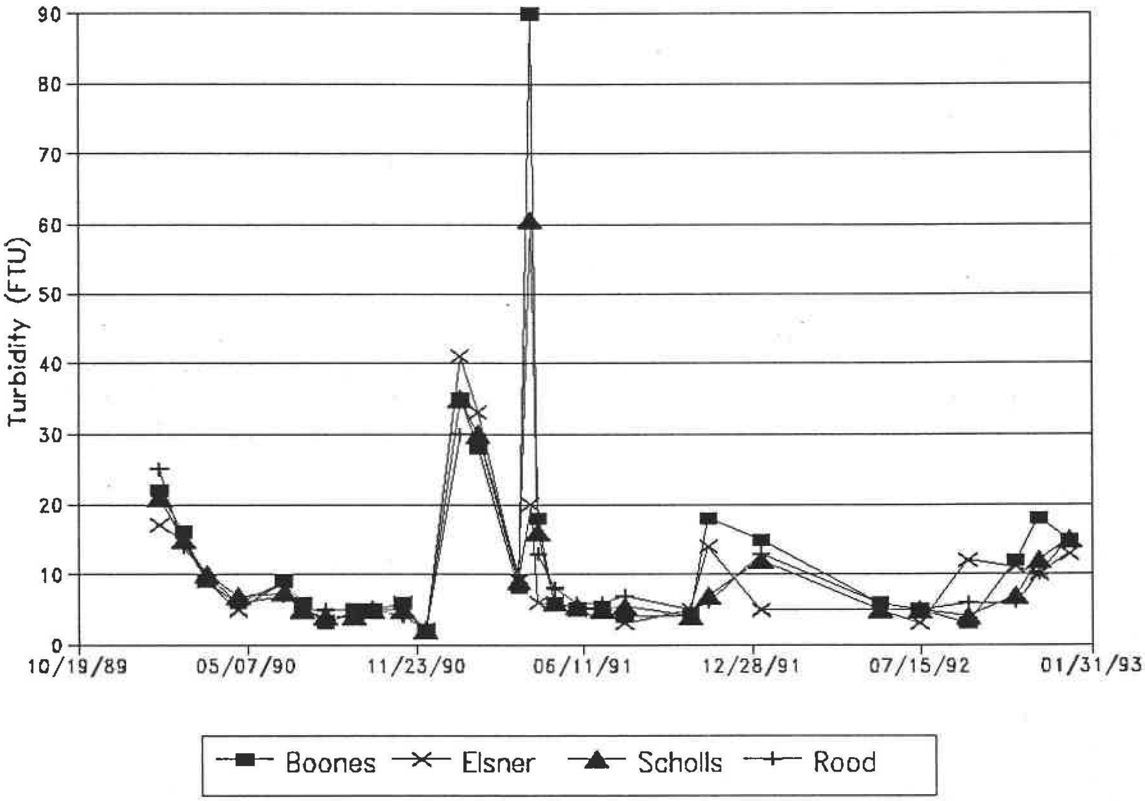

Figure 5.24 Turbidity on four stations of the Tualatin River, 1/23/90 - 1/5/93

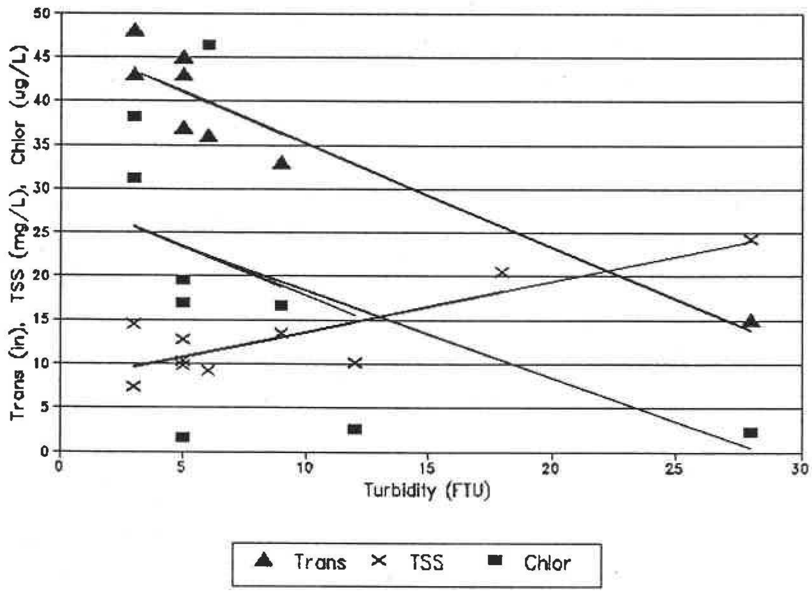

Figure 5.25 Turbidity correlation with transparency, suspended solids and chlorophyll a at Boones (RM 8.7)

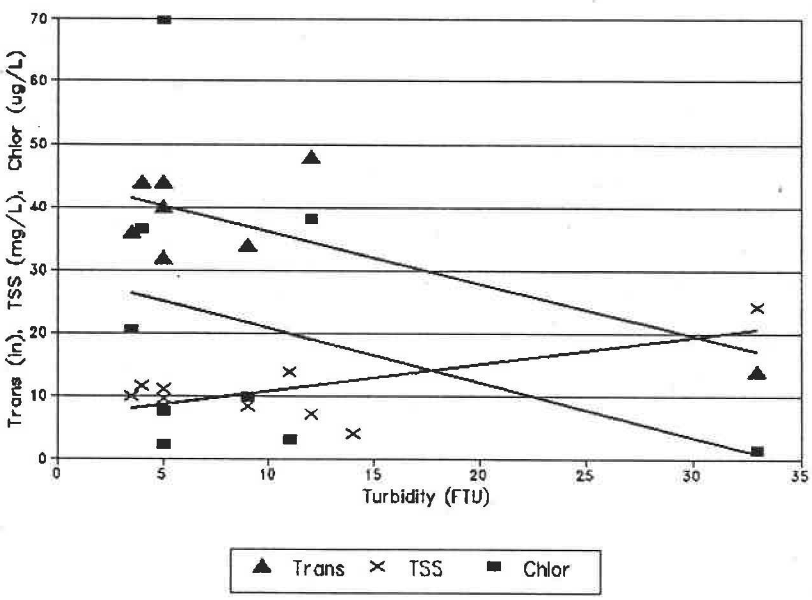

Figure 5.26 Turbidity correlation with transparency, suspended solids and chlorophyll a at Elsner (RM 16.5)

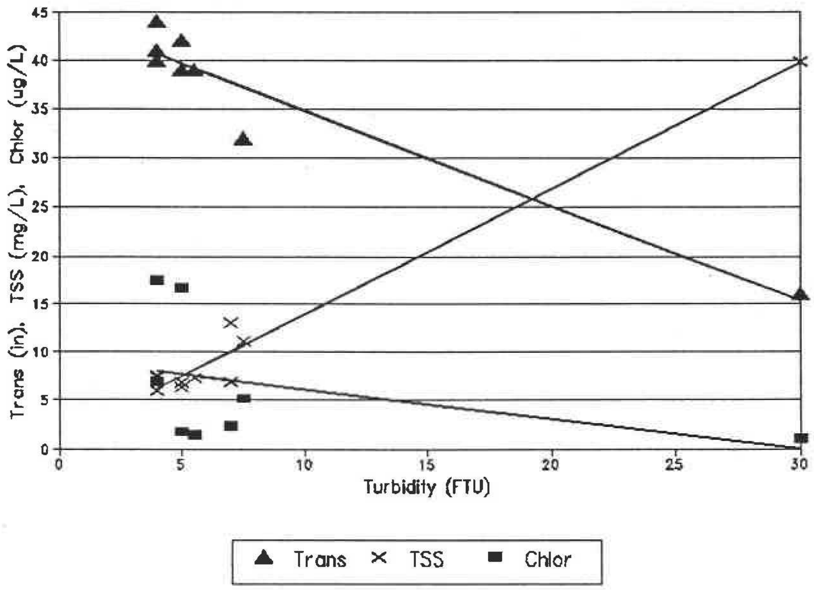

Figure 5.27 Turbidity correlation with transparency, suspended solids and chlorophyll a at Scholls (RM 27.1)

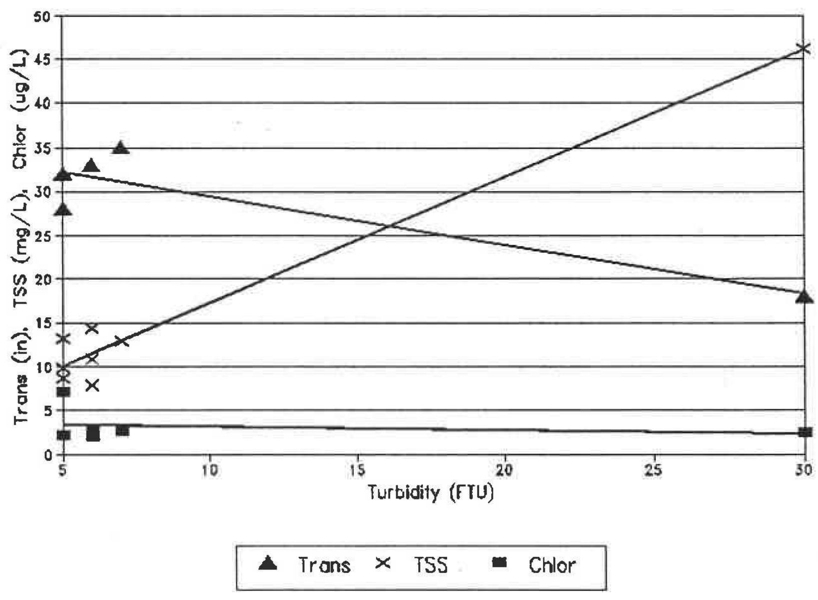

Figure 5.28 Turbidity correlation with transparency, suspended solids and chlorophyll a at Rood (RM 39.1)

SUMMARY AND CONCLUSIONS

A steady state mass balance model of suspended solids loading was developed for the main stem of the Tualatin River and for Dairy Creek tributary. The river was divided into twelve segments, or computational element. The fourteen monitored tributaries were treated as inflows and withdrawals were treated as outflows of the respective river segments. Suspended solids mass loading was computed as a flow-weighted average for two seasons of the year, summer and non-summer. Unfortunately, the limited availability of consistent data has made it impossible to complete a mass balance on all river segments, even for a single year.

Tributaries were found to be the major contributors of suspended solids loading in the Tualatin River. The major tributaries in this regard were Dairy Creek, Fanno Creek, Gales Creek, Rock Creek and Scoggins Creek. For the year 1992 the above five tributaries contributed 90% of the average suspended solids mass loading during the non-summer period and 79% during the summer season. Four of these five tributaries (Dairy, Gales, Rock and Scoggins Creek) are located above Meriwether (RM 35.4), which accounts for the major contribution to solids loading from this section of the river. Scoggins Creek, which receives the discharge of Hagg Lake is the major contributor of suspended solids to the river in the summer period (more than 50% of the combined loading of the five major tributary creeks, summer 1992). Major contributors in the non-summer season where Gales Creek and Dairy Creek. The tributaries also accounted for 63% of the flow (including withdrawals) in the river during the summer of 1992 and for 84% during non-summer 1992.

Changes in suspended solids concentration in the Tualatin River were computed at stations above and below the entries of Scoggins, Gales, Rock and Dairy Creeks. For Scoggins Creek in the year 1991 the change amounted to 350% during the non-summer period (NS 91) and 500% during summer (S91). A 47% (S 91) increase in loading was observed in Scoggins Creek between the stations at Stimson Bridge (close to Hagg Lake) and Highway 47 (close to the Tualatin River junction) in summer 1991. In the summer of 1992, concentration changes beyond the inflows from Gales and Dairy Creeks were 16% and 17%, respectively. In November and December of 1992 (NS 93) the change in concentration was 110% for Gales Creek and 34% for Dairy Creek. Rock Creek caused 109% increase in the suspended solids concentration during non-summer 1991. Due to lack of flow data for the station at Hwy 99 (RM 11.6), the change in mass loading was not be computed for Fanno Creek. These increases in suspended solids concentrations highlight the finding that tributaries contribute suspended sediment to the river during the entire year and Dairy and Gales Creeks are the major contributors during the non-summer season and Scoggins Creek during summer).

The seasonal variation of the suspended solids loading in the river differed by as much as a factor of ten, the loading being lower in summer when suspended solids concentrations averaged about 50% of non-summer values. Water clarity was found to be higher in summer, during which time chlorophyll a concentrations were also higher. Suspended solids concentration was inversely correlated with transparency (water clarity) and directly correlated with turbidity but found to be weakly related to chlorophyll a concentration, indicating that algae were not the primary cause of reduced water clarity.

Increased chlorophyll a concentrations were not found to relate to any one particular factor but were found to be related as a group to air temperature, and total phosphorus concentration levels. For four of the sites (Weiss RM 0.2, Stafford RM 5.4, Boones RM 8.7 and Elsner RM

16.5) in the pool the area the minimum values of air temperature, and total phosphorus causing high chlorophyll events were 60 F, and 0.07 mg/L. This indicates the cause of algal blooms are due to a combination of factors.

Based on the results of this study, the following specific conclusions were made:

1. Five major tributaries (Dairy Creek, Fanno Creek, Gales Creek, Rock Creek and Scoggins Creek) are the major sources of suspended solids loading in the Tualatin River, contributing 90% of the average suspended solids mass loading during the non-summer period (84% of flow) and 79% during the summer season (63% of flow).

2. Gales Creek and Dairy Creek are the major contributors to suspended solids mass loading during non-summer. Scoggins Creek, which receives discharge of Hagg Lake reservoir, is the major contributor of suspended solids to the river in the summer period (more than 50% of the combined loading of the five major tributary creeks, summer 1992).

3. Based on 1992 data for the Tualatin River, average suspended solids concentrations during summer were about 50% less than those in non-summer.

4. Non-summer data for 1992 seemed to indicate in-stream removal of suspended solids below river mile 35.4 but non-summer 1992 data indicated no change after river mile 35.4.

5. Withdrawals for irrigation, municipal water supply, and Oswego Canal were the major outflows of flow and suspended solids in the summer.

6. In the Dairy Creek basin, lower Dairy Creek (below Roy and Evers Road) contributed more than 50% of Dairy Creek suspended solids loading during the non-summer but very little during summer.

7. Summer data do not indicate a direct relationship between chlorophyll and suspended solids and temperature indicating that the relationship is of a more complex nature.

8. Data indicate a group relationship between antecedent air temperature, and total phosphorus concentrations to high chlorophyll concentrations, indicating that all these factors influence the occurrence of algae.

MONITORING PROGRAM ANALYSIS

Data Requirements

The present sampling schedules and methods of the different agencies are not well coordinated. A coordinated sampling program adopted by all the agencies would not only be economical but also beneficial in terms of better understanding the dynamics and mechanisms of the river processes. The adoption of a shared sampling program would reduce redundant sampling and thereby save manpower and other resources. Such a program would require its design involving all the agencies active in sampling and the adoption of certain common standards and guidelines. Among the other benefits of a shared sampling program are data collected with a standard frequency (leading to less averaging errors) and the use of quality control to ensure reduced data error.

Recommendations

The following are suggested guidelines for the development of a common sampling program:

Location	Sample all tributaries (eg. Carpenter Creek)
Season	Sample throughout the year (lesser frequency during non-summer but continuous)
Frequency	Higher frequency for storm events and for key stations if required
Coordination	No more than one agency sample the same site
Format	Information is made available by all agencies in a standard pre-specified format
Quality control	Develop methodology so as to control errors (eg. Meriwether)
Parameters	Necessary parameters eg. Volatile solids

Data handling	The creation of a database, accessible to the other agencies with an acceptable data format(s)

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APPENDIX I

Data used in this study are available in the electronic format on two floppy diskettes which maybe ordered from the Oregon Water Resources Research Institute. The data has been organized on the basis of stations located on the main stem of the river and on the tributaries. Files are located in two diskettes with volume labels "River" and "Tribs". The files have been named with a 'M' or a 'C' prefix followed by the name of the station. Files beginning with 'M' contain information relating to the mass balance. The 'C' files contain the chlorophyll and other information used in the study. DOS limitation on filenames is eight characters and hence where names were longer than eight characters they were truncated. All files are in the spreadsheet format and are Lotus/Quattro compatible.