WRIA 13 ASSESSMENT

CHAPTER 5 – SURFACE WATER

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5.1 WHY IS STREAMFLOW INFORMATION IMPORTANT TO WRIA 13 WATERSHED PLANNING?

Information on streamflow conditions will be vital for WRIA 13 Plan development and for future management of water resources. Information from multiple available sources is compiled in this section. Certain types of information or analysis are available on some streams but not others. Key information in this chapter includes:

- ***Basic watershed and stream conditions***: WRIA 13 is comprised of multiple independent stream basins. Their distinct characteristics need to be recognized as a foundation for water resource management.
- ***Low flow***: It is during low flow conditions that the groundwater "continuity" issue becomes acute. Typical and extreme low flows are a key limiting factor for salmon and other aquatic species. And direct or indirect withdrawals during this critical period are of paramount concern for habitat protection. For the Deschutes and Woodland Creek, we have more detailed "seepage study" information on low-flow conditions.
- ***High flow***: Our streams are all highly responsive to rainfall events. Variation in flow is a natural condition. But high flows can be altered in intensity and duration by changes in land use.
- ***Baseflow and runoff***: DOE analysis is available for Deschutes and Woodland Creek dividing streamflow into "runoff" and "baseflow" components throughout the year. This contributes to our understanding of the fundamental nature of these two streams.
- ***"Minimum Flows":*** The 1980 WRIA 13 Instream Resource Protection rules adopted by DOE are very significant to water resource management. Understanding what the 1980 WAC is (and is not) is important for Watershed Plan development – as changes in these rules could be recommended in the Plan.

Information is presented separately for the three principal drainage basins within WRIA 13: Budd/Deschutes, Henderson Inlet and East Eld Inlet.

5.2 BUDD/DESCHUTES BASIN

The Budd/Deschutes basin originates in the Deschutes watershed in the Bald Hills along the Thurston County/Lewis County boundary. The Deschutes watershed runs northwesterly to Capitol Lake. The Deschutes has several tributaries, including a handful of lakes. Several smaller streams discharge directly into Capitol Lake and Budd Inlet.

The Deschutes watershed encompasses about 162 square miles – by far the dominant share of the Budd/Deschutes Basin. About 10 square miles is added in the Percival Creek drainage to Capitol Lake. The narrow watershed area surrounding Budd Inlet encompasses about 18 square miles, including several small streams discharging directly to Budd Inlet.

5.2.1 DESCHUTES RIVER

Summary of Upper and Lower Basin Characteristics

Topography and geology

For the assessment, the Deschutes basin is divided into Upper and Lower segments reflecting distinct watershed and streamflow conditions. These are summarized on the following table.

The Upper Deschutes, the river flows out of the Bald Hills. Highest elevation is 1,340 feet. Average slope (average feet gain in elevation per stream mile) is 50 feet/mile (compared to only 9 feet/mile in the lower river.) The Bald Hills region has relatively steep slopes, generally shallow soils over bedrock and a extensive network of tributary streams totaling over 108 stream miles. Most of the upper watershed was not glaciated.

The Lower Deschutes flows through the Puget Lowland region. The Puget Lowland – unlike the Bald Hills – was subject to repeated glaciation, resulting in gently rolling topography and sediments reflecting the repeated advance and retreat of glaciers. Few streams are present in this portion of the watershed: Only 25 total miles of tributaries enter the lower 25 miles of mainstem Deschutes River.

Depth and composition of the glacial sediments reflect the region's geologic history. In the Lake Lawrence area, only one aquifer (water-bearing strata of sediment) is present. Near Tumwater, at least three more or less distinct aquifers are present in roughly 500 feet of glacial sediment, separated by tighter layers of material that typically restricts groundwater flow (aquitard.)

Streamflow Data Summary

A pair of long-established USGS gaging stations demarcate the Upper and Lower basins: the Rainier gaging station at Vail Loop Road and the E Street Bridge station near Tumwater.

The character of the watershed is reflected in the distinct streamflow conditions at these two stations. Key distinctions include:

- Low flows at Rainier are typically less than one-half the low streamflow at Tumwater, reflecting the shallow steep soils of the upper watershed versus the deeper water-bearing sediments in the lower watershed.

- Runoff is more pronounced in the steeper upper watershed. Much of the precipitation in the lower watershed soaks into the ground rather than flowing directly to streams. To illustrate this: DOE calculated that 70% of median flow at E Street is “baseflow” (versus runoff) while baseflow comprises 60% of median flow at Rainier.

Table 1: Summary watershed and streamflow characteristics

	Upper Deschutes	Lower Deschutes
USGS station location	Near Rainier (Vail Loop Rd)	E Street Bridge (Tumwater)
Area	90 square miles	72 square miles (162 sq. mi. total)
Elevation (maximum)	1,340 feet	950 feet
Mainstem stream length	25 miles	25 miles (50 miles total)
Tributaries	108 miles	25 miles (133 miles total)
Slope (average feet gain per stream mile)	50 feet/mile in upper river	9 feet/mile in lower river (24 feet/mile over entire length)
Years of record	40 years (1950-2001 not continuous)	26 years (1946-2001 not continuous)
Average total annual discharge	189,200 ac ft/year[1]	293,900 ac ft/year
Mean streamflow	261 cu ft second	406 cu ft second
Mean baseflow	160 cfs (60% of streamflow)	283 cfs (70% of streamflow)
Peak instantaneous flow	9,600 cfs (1/9/90)	10,700 cfs (2/9/96)
Peak daily flow	6,000 cfs (same)	8,150 cfs (same)
Median 7-day low flow	29 cfs	84 cfs
Minimum 7-day low flow	20 cfs (October 1994)	53 cfs (September 1995)
Lowest flow recorded	16 cfs (9/7/63)	51 cfs (9/22/95)
Flows exceeded by percentage of time:		
10% of the time, flow >	614 cfs	880 cfs
50% of the time, flow >	130 cfs	248 cfs
90% of the time, flow >	34 cfs	95 cfs

[1] Water Resources Data, Washington: Water Year 2001, Water Data Report WA-01-1, USGS. Source for average total annual discharge, average streamflow, peak and low flows.

Mean Flow: "Baseflow" and "Runoff" Components

Mean monthly "baseflow" and "runoff" at the Rainier and Tumwater USGS stations is illustrated below.[2] Note that the mean "runoff" component in winter is nearly equal at both Rainier and Tumwater stations – about 300 cfs. In winter, the steeper upper watershed contributes a significant fraction of flow to the stream. Summer flows, in contrast, are nearly all baseflow. Reflecting groundwater "gain" as the river flows north, summer mean streamflow nearly doubles between Rainier and Tumwater (roughly 50 cfs vs. 100 cfs.)

Figure 2 - Rainier Station, Deschutes River: Monthly Mean Baseflow & Surface Runoff

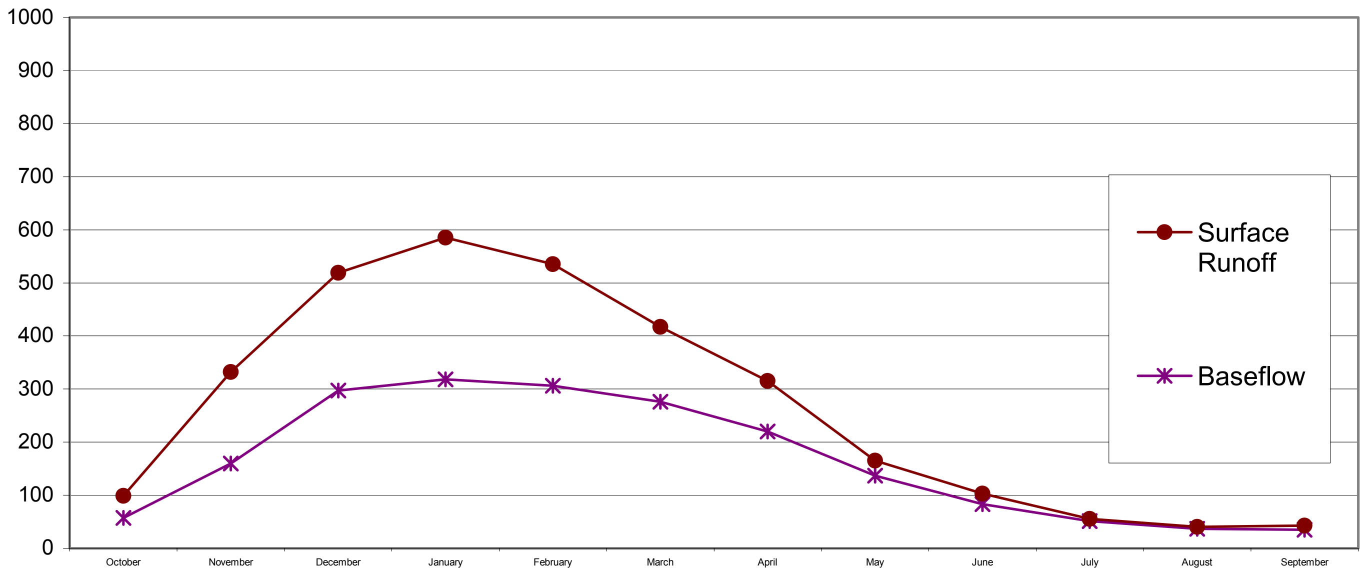
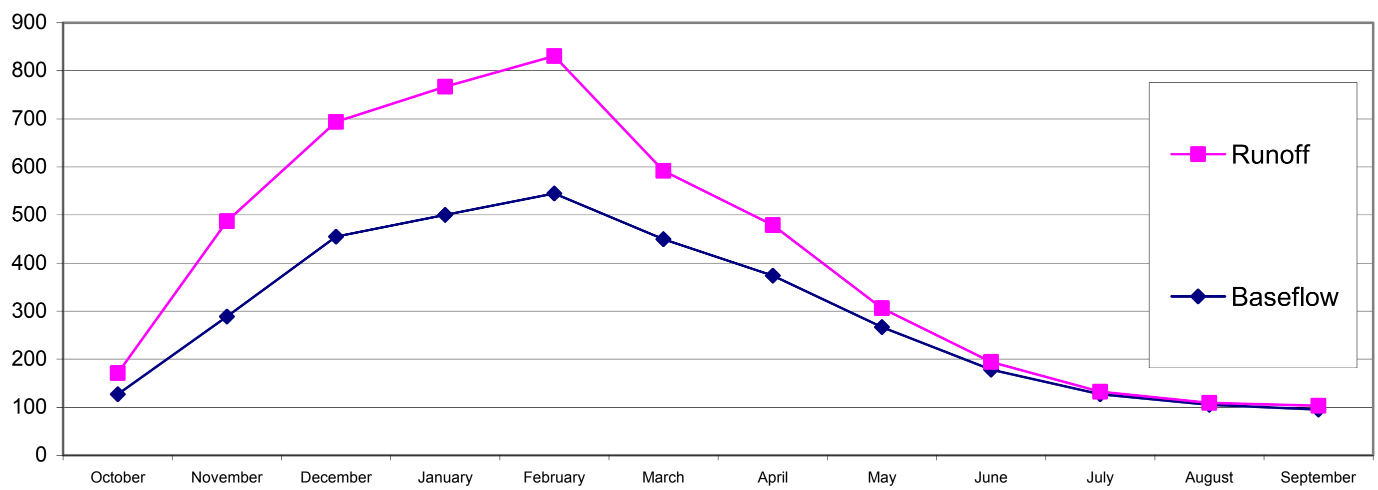


Figure 3 - Tumwater Station, Deschutes River: Monthly Mean Baseflow & Runoff



[2] Estimated Baseflow Characteristics of Selected Washington Rivers and Streams, Water Supply Bulletin No. 60, October 1999, Sinclair and Pitz, WA DOE. Streamflow is divided into "baseflow" (a broad definition of groundwater including shallow and deeper groundwater flow) and "runoff".

Low Flow

Significant data exists regarding low flow conditions in the Deschutes.

Table 2 – Deschutes Low Flow

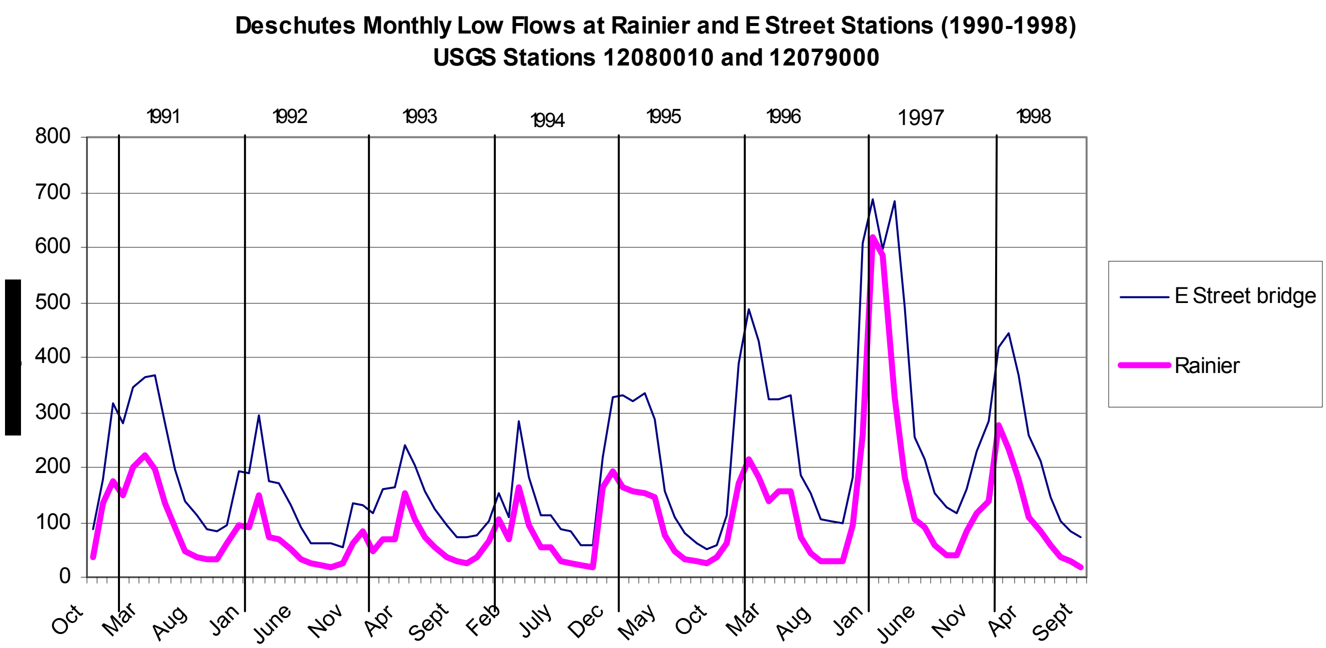
Basic low flow data for the upper and lower Deschutes from USGS.

	Upper Deschutes	**Lower Deschutes**
USGS station location	Near Rainier (Vail Loop Rd)	E Street Bridge (Tumwater)
Median 7-day low flow	29 cfs	84 cfs
Minimum 7-day low flow	20 cfs (October 1994)	53 cfs (September 1995)
Lowest flow recorded	16 cfs (9/7/63)	51 cfs (9/22/95)

Monthly low daily flows

Monthly low flows at the two USGS stations are illustrated below. The more robust groundwater supply for the lower river is evident. Also, the "flashy" nature of Deschutes flows is illustrated by winter typical monthly low flows around 200 cfs at Rainier and around 300 cfs at Tumwater. In contrast, mean monthly winter flow is 400 - 600 cfs at Rainier and 600 - 800 cfs at Tumwater.

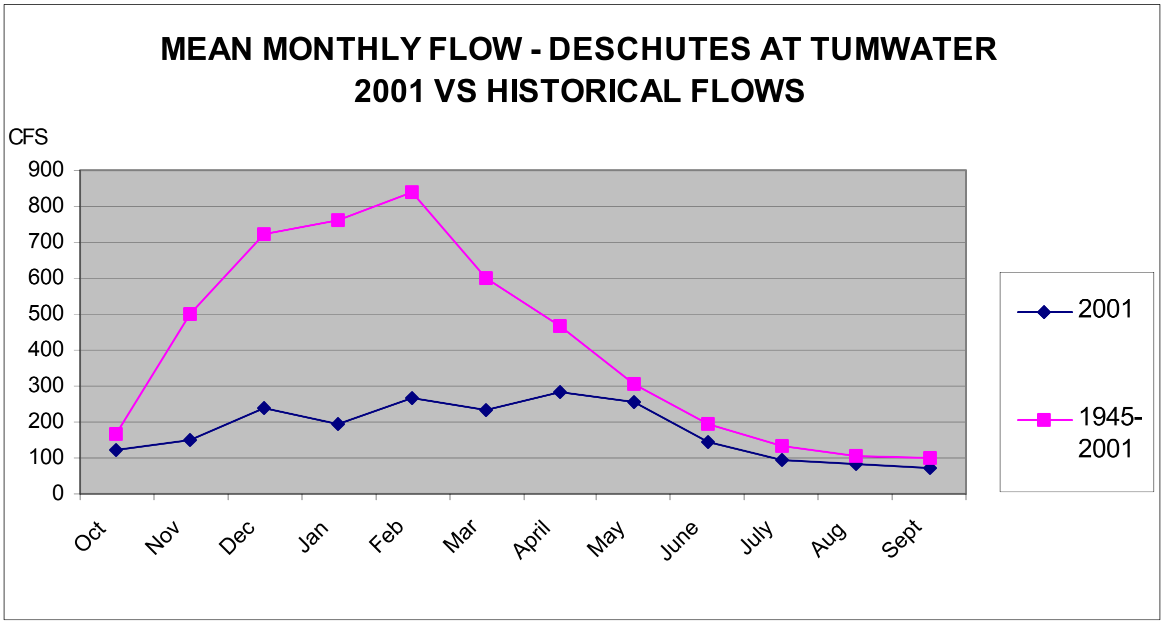
Figure 4

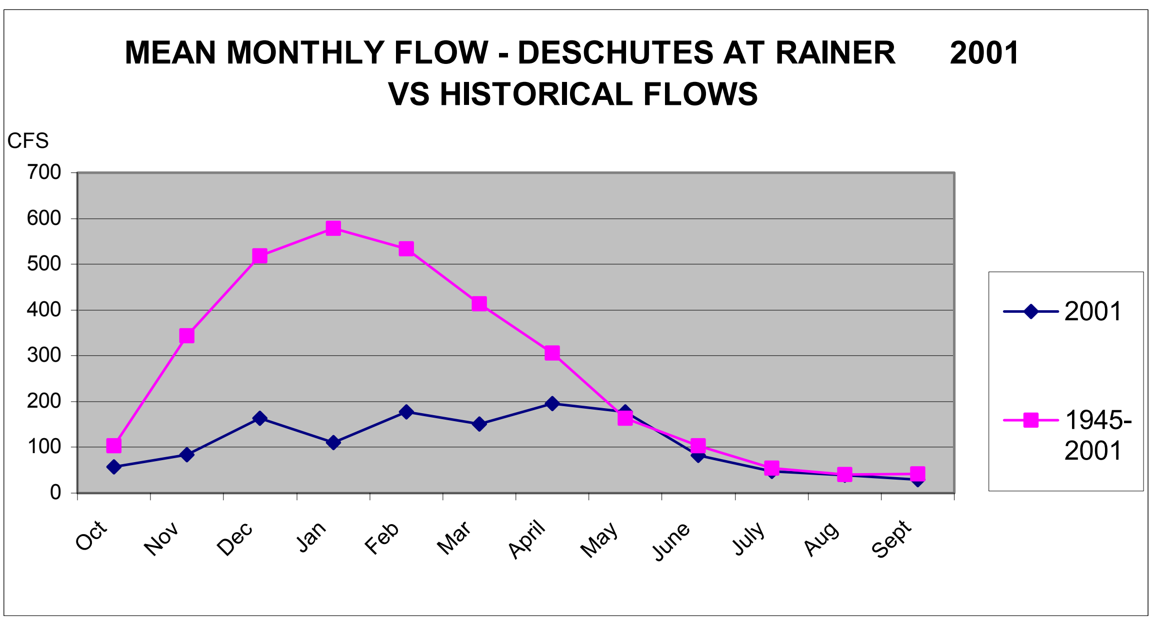


October 2000 – September 2001 Water Year

The 2001 water year was extraordinarily dry compared to the period of record. Rainfall at Olympia Airport was 33 inches, compared to 1955-2001 average annual rainfall of 50 inches. The low precipitation was reflected in very low streamflow during the winter months, as illustrate on the following graph.

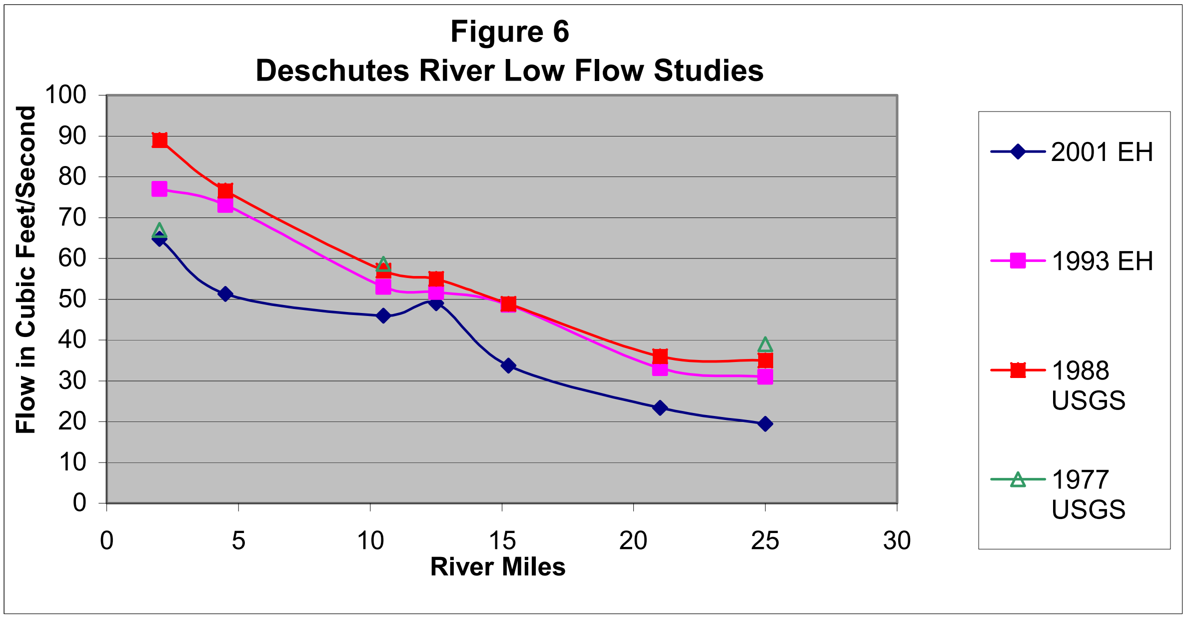
Figure 5: Mean Monthly Flows – 2001 vs. Historical Flows





Seepage Studies

Low flow studies – also called "seepage" studies – measure flow at several locations within one or two days to determine "gaining" and "losing" reaches of a stream. Surface water tributaries are subtracted from data to determine groundwater influence of the stream. Seepage studies of the Deschutes are illustrated below.



The earliest seepage data is from measurements taken by USGS at several road crossings in 1977. Seven mainstem stations and seven tributaries were measured by USGS in 1988 as part of the Thurston County groundwater study and model. [3] In 1993, these sites were again measured during low-flow conditions as part of a detailed field data collection project.[4]

A comprehensive groundwater inflow study was conducted during the extraordinary low flow conditions during summer of 2001. This study was funded by Watershed Planning Grant funds as a "phase 2 level 2" study.[5] Water temperature was used to identify areas of colder groundwater inflow. A piezometer – a pipe with holes around the bottom – was driven into the riverbed to identify whether the reach was losing water to groundwater.

[3] Conceptual Model and Numerical Simulation of the GW Flow System in the Unconsolidated Sediments of Thurston County, 1999, USGS (Water-Resources Investigations Report 99-4165). In seepage studies conducted in 1988, data was collected from 14 stations along the Deschutes (Vail Road to mouth)

[4] Cramer, Darin for Thurston County Deschutes Reach Scale Analysis, data collected at 11 sites on 9/21/93 (unpublished)

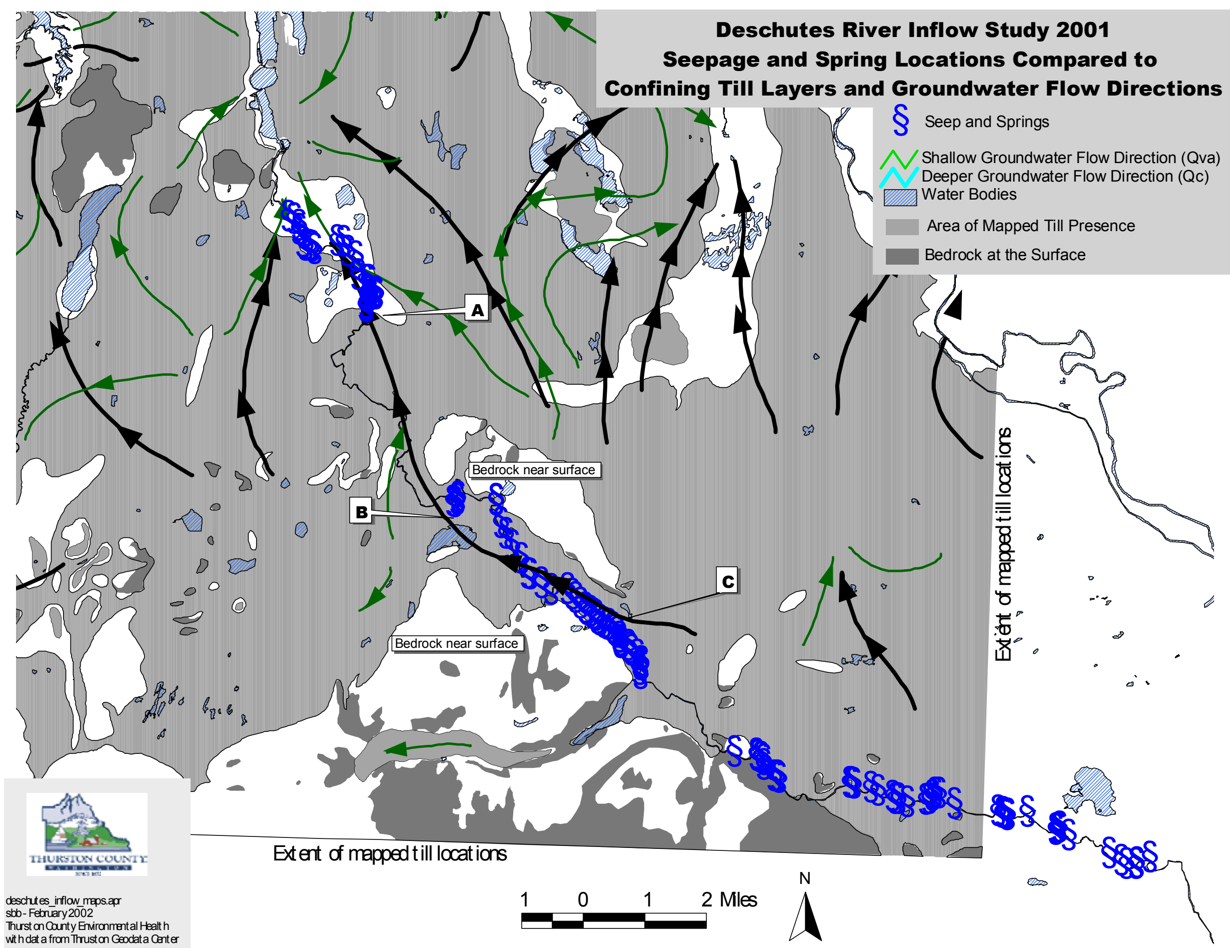
[5] 2001 Deschutes Groundwater Inflow Survey, February 2002, Thurston County Department of Public Health and Social Services, Environmental Health Division

In addition to the seven mainstem sites used in previous studies (at bridge crossings), the 1991 study measured flow at eight additional sites corresponding with location of input from groundwater seeps and springs. Three major areas of groundwater input to the river were identified:

- The area north of Highway 507 in the McIntosh Lake vicinity (10.5 cfs or 44% gain);
- A ¼ mile stretch just north of Offut Lake (10.4 cfs or 27% gain); and
- Rich Road to Henderson Blvd (18.8 cfs or 48% gain).

All three stretches can be linked to local geology. The Highly 507 and Offut Lake stretches are at either end of a channel created by bedrock at or near the surface, constraining groundwater flow. The Rich/Henderson gaining reach corresponds with the absence of a confining till layer, which allows groundwater from the Vashon Advance aquifer to flow to the river. This influx of groundwater also corresponds to aquifer low directions mapped by USGS. The geologic features and groundwater flow directions are displayed in the following figure from the 1991 study.

Figure 7



High Flow

Precipitation events trigger high flows in the Deschutes, followed fairly rapidly by a return to "baseflow" conditions. Peak daily recorded flow is 6,000 cfs at Rainier (on January 1, 1990) and 8,150 cfs at Tumwater (on February 9, 1996). However, only 10% of the time does daily flow exceed 614 cfs at Rainier or 880 cfs at Tumwater.

Table 3
Peak flow data for the Deschutes:

Peak flow data	**Upper Deschutes**	**Lower Deschutes**
USGS station location	Near Rainier (Vail Loop Rd)	E Street Bridge (Tumwater)
Peak instantaneous flow	9,600 cfs (1/9/90)	10,700 cfs (2/9/96)
Peak daily flow	6,000 cfs (same)	8,150 cfs (same)
10% of the time, flow is in excess of:	614 cfs	880 cfs

Monthly high and low daily flows from the Rainier gaging station are illustrated below for the years 1987-1998. During the typical peak rainfall months, daily flows fall from highs of 2,000 to 4,000 cfs to lows of around 200 to 400 cfs – within the same month.

Figure 8
Deschutes Monthly High and Low Flows
Station #12079000 (near Rainier) from 1987 -1998

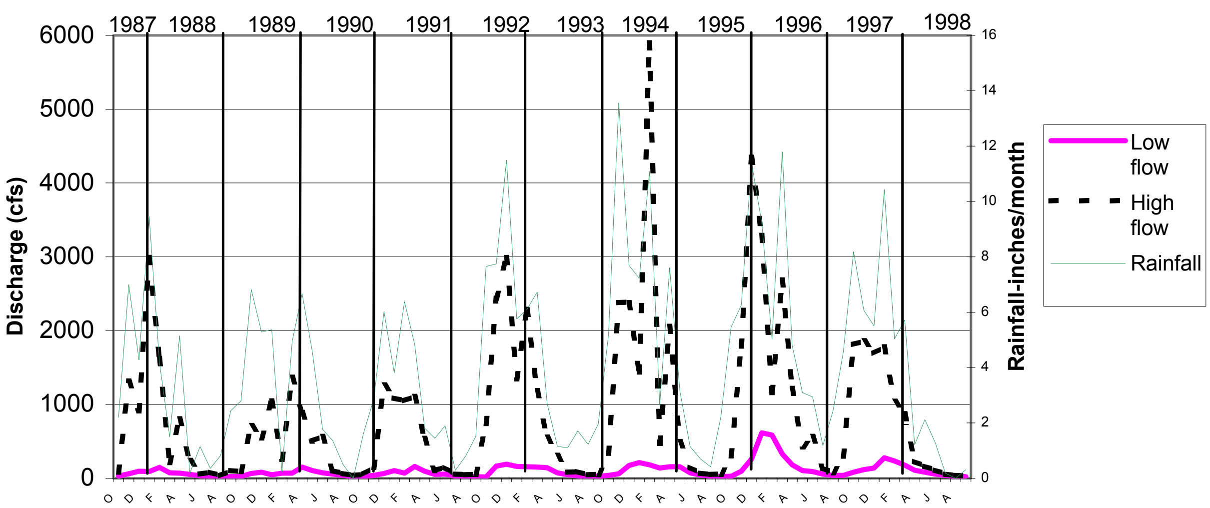
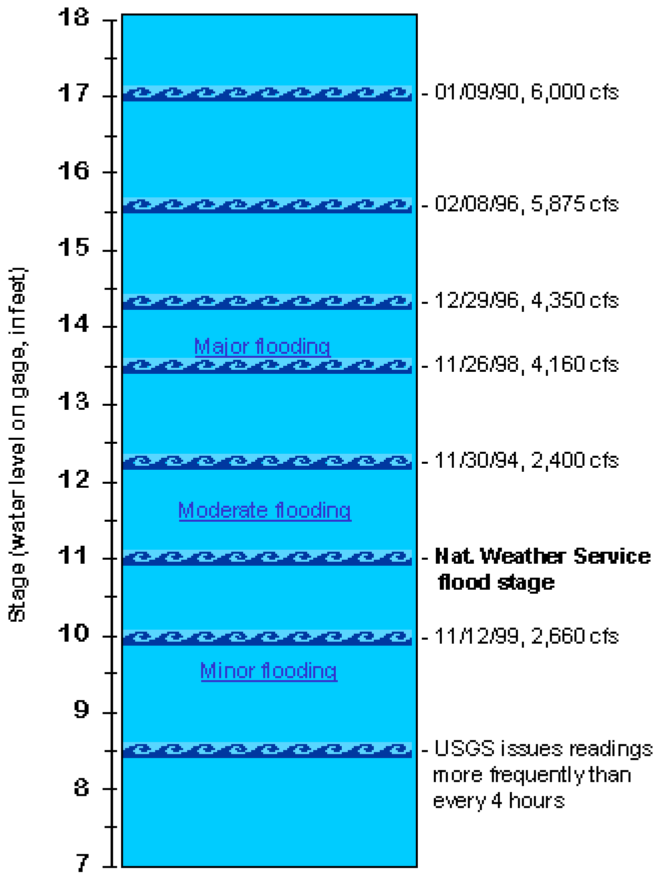


Figure 9 - Deschutes Flooding Benchmarks



The Deschutes is the fastest rising (and falling) river in Thurston County, responding quickly to local rainfall and runoff.

According to Thurston County Emergency Services, minor flooding (low-lying roads and pasturelands) occurs at a gage height of about 9.5 feet. Moderate flooding (individual residences are threatened) occurs at about 11.5 feet, and major flooding (widespread threat to communities and major thoroughfares) at 13.5 feet (about 4,200 cfs.)[6]

Trends in Deschutes Streamflow

A core question for water resource management is whether the Deschutes River flows have been negatively impacted by human activities over time. Available data from the USGS E Street station for base flow, surface water runoff, and seven-day high and low flow was examined to attempt to answer this question. Data was from the Baseflow Characteristics report prepared by DOE.[7]

Unfortunately, year-around streamflow data collection on the Deschutes has been markedly inconsistent. Data is available from the E Street station for 1949-1954, 1958-1963 and 1991-1997. Since there is only a small gap between the first and second time periods these two data sets were combined into one. This data set was then statistically compared to the 1991-97 data set.[8]

[6] Thurston County Emergency Services website at www.co.thurston.wa.us/em/Rivers/Deschutes.htm
[7] Estimated Baseflow Characteristics of Selected Washington Rivers and Streams, Washington Department of Ecology Water Supply Bulletin No. 60, October 1999
[8] For the Rainier gaging station, the data set is somewhat more complete. However, the thin soils above this station do not support significant baseflow. In addition, many of the human activities that

To improve analysis of mean flow changes over time, streamflow data was normalized to precipitation data. To do this the total precipitation for each water year was divided by the 30-year average for Olympia (50.96in. from NOAA). This showed us the deviation from the mean precipitation for each year in the data sets. After these deviations were known the flow rates were divided by this percentage to give a normalized flow rate with the effects of current year precipitation removed. [9]

Streamflow Variability: 1949-63 Compared to 1991-97

Streamflow data from 1949-63 and 1991-97 normalized to precipitation indicates the following statistically significant changes:

- The "baseflow" component as analyzed by DOE declined from a mean of 293 for 1949-63 to 258 for 1991-97.
- Similarly, the mean 7-day low flow declined from 89 cfs for the 1949-63 period to 73 cfs during 1991-97. Baseflow and 7-day low flow are illustrated on Chart 1.
- Corresponding to the reduction in baseflow, the "surface runoff" component of flow increased from a mean of 100 cfs for 1949-63 to 130 cfs for 1991-97. See Chart 2.

Mean streamflow values did *not* exhibit a statistically significant variation between the two periods (393 cfs for 1949-63 and 388 for 1991-97). Thus, changes in mean streamflow do not appear to account for the differences in baseflow and runoff flow components summarized above. The 7-day high flow mean data was also analyzed but did not exhibit statistically significant variation in the two time periods.

Several important limitations must be recognized:

- The data gap from 1963 to 1991 precludes a solid understanding of streamflow trends. The resulting data only shows the differences in mean values for the two data sets in question, '49-'63 and '91-'97.
- The limited size of the data sets poses a challenge for valid statistical analysis.
- A simplistic approach utilizing current year rainfall data was taken to normalizing high and low streamflow data to precipitation.

Within the limitations of available data, a small but statistically significant shift was identified toward reduced "baseflow" and increased "runoff" in the data set from the Department of Ecology. A similar small shift was identified in lower 7-day minimum flows when adjusted for one-year precipitation.

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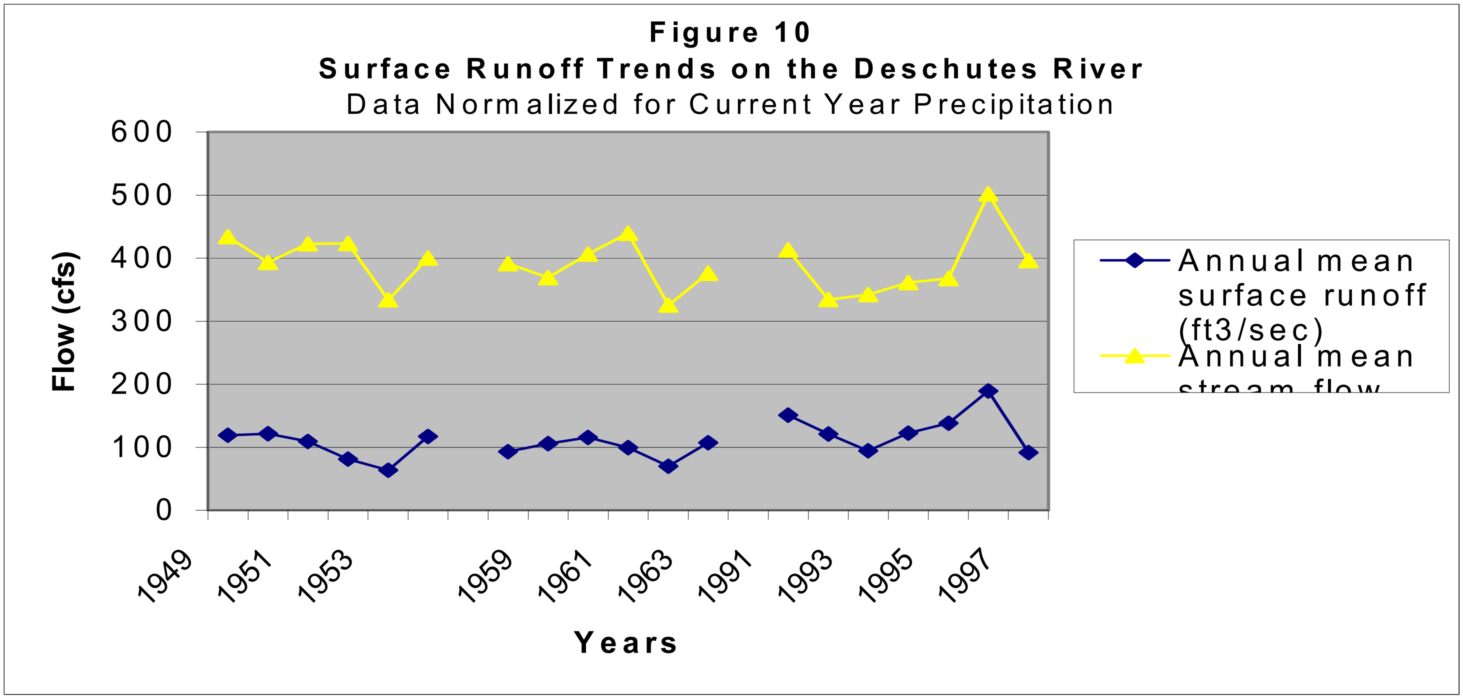
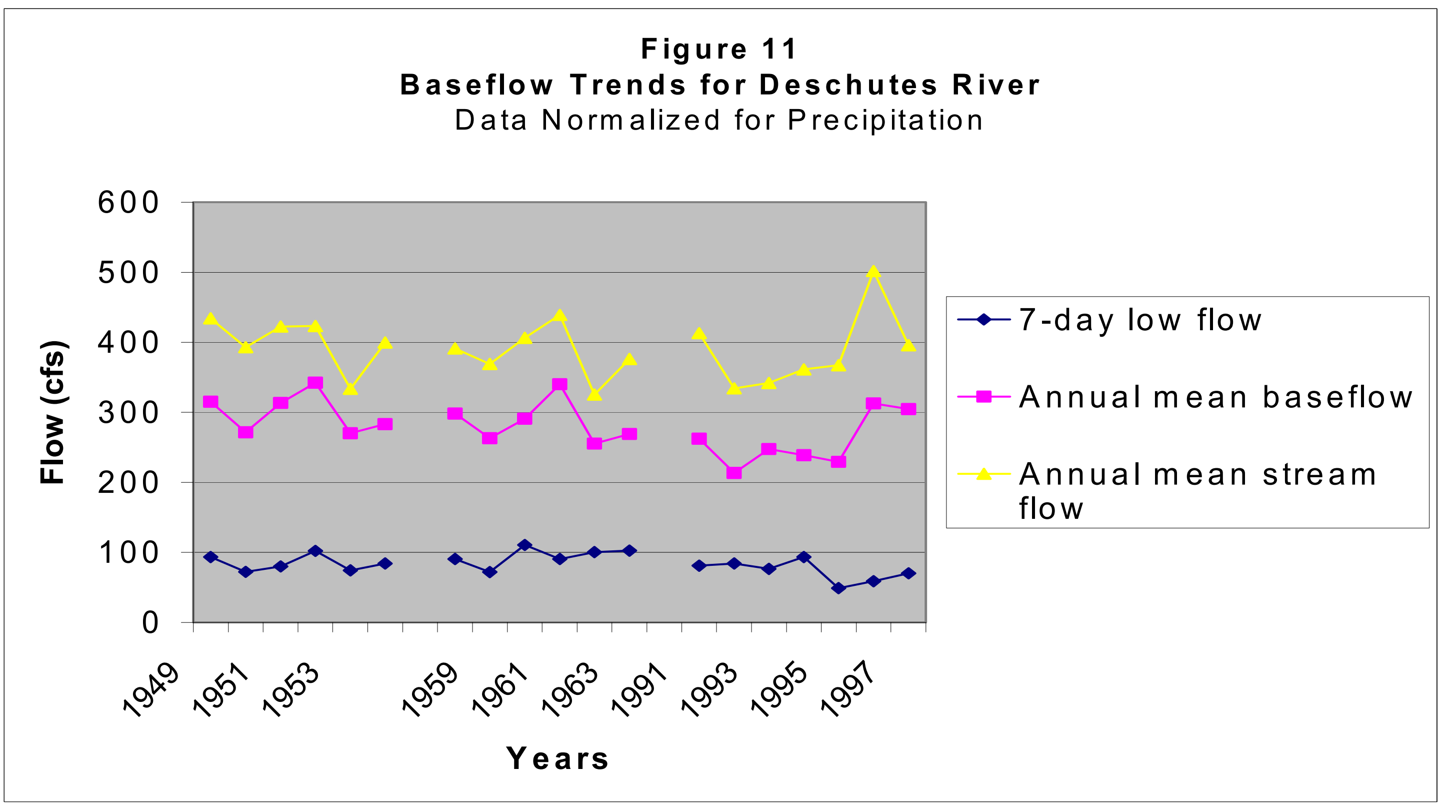
may affect streamflow occur below this gaging station. Thus, E Street data was used for this analysis.

[9] "Deschutes Stream Flow Analysis – WRIA 13 Watershed Planning", Thurston County Water & Waste Management, November 2001.





Source: "Deschutes Stream Flow Analysis – WRIA 13 Watershed Planning", Thurston County Water & Waste Management, November 2001.

Deschutes Minimum Flows: 1980 Instream Resource Protection Program

The Deschutes is included in the Instream Resource Protection Program for WRIA 13 adopted as WAC 173-513 in 1980. Specific winter flow values are included.

Summer Closure

The river is closed to all additional "consumptive appropriation" during the entire summer season (April 15 – October 31). Due to this full closure, no "minimum" summer flows are stipulated. The 1980 closure supplanted low flows set in 1954 as a basis for conditions on surface water rights issued for the Deschutes.

The technical study accompanying the 1980 closure noted that summer flows warranted closure to protect Chinook salmon, Olympic mudminnow, steelhead and cutthroat trout. The Department of Fisheries comments in the 1980 report emphasized the importance of streamflow protection to both artificial and natural Chinook production:

> "The Department of Fisheries considers the highest priority for this basin to be the maintenance of water quality at the mouth of the Deschutes River, Capitol Lake, Percival Cover and Budd Inlet. The obvious reasons are to protect the sizeable investment in artificial, as well as natural, fiery production that occurs in those areas. Maintenance of water quality is directly related to instream flows"[10]

Winter Minimum Flows for "Environmentally Sound Storage" Options

WAC 173-513 set minimum streamflows for the Deschutes from November 1 to April 1. Minimum flows ramp up from 150 cfs November 1 to 400 cfs December 1.

This winter-period minimum flow was expressly linked to the potential for storage on the Deschutes in the technical report for the WRIA 13 Instream Resources Protection Program. In the years preceding the IRPP, the City of Olympia filled water rights applications for a proposed reservoir near Clear Lake. However, these applications were withdrawn prior to the IRPP. As described in the 1980 IRPP Report:

> "The reason for not proposing closure of the Deschutes River year round is to retain the option of development of environmentally sound storage projects in future years that could make use of winter flows for a variety of potential uses, including Hydroelectric power generation, municipal and industrial water supply, release of stored water to support fish, wildlife and water quality enhancement during low flow periods.
>
> During 1968-69, a proposal to construct the Shellrock Dam was reviewed by DOE at the request of the City of Olympia. The City of Olympia no longer has

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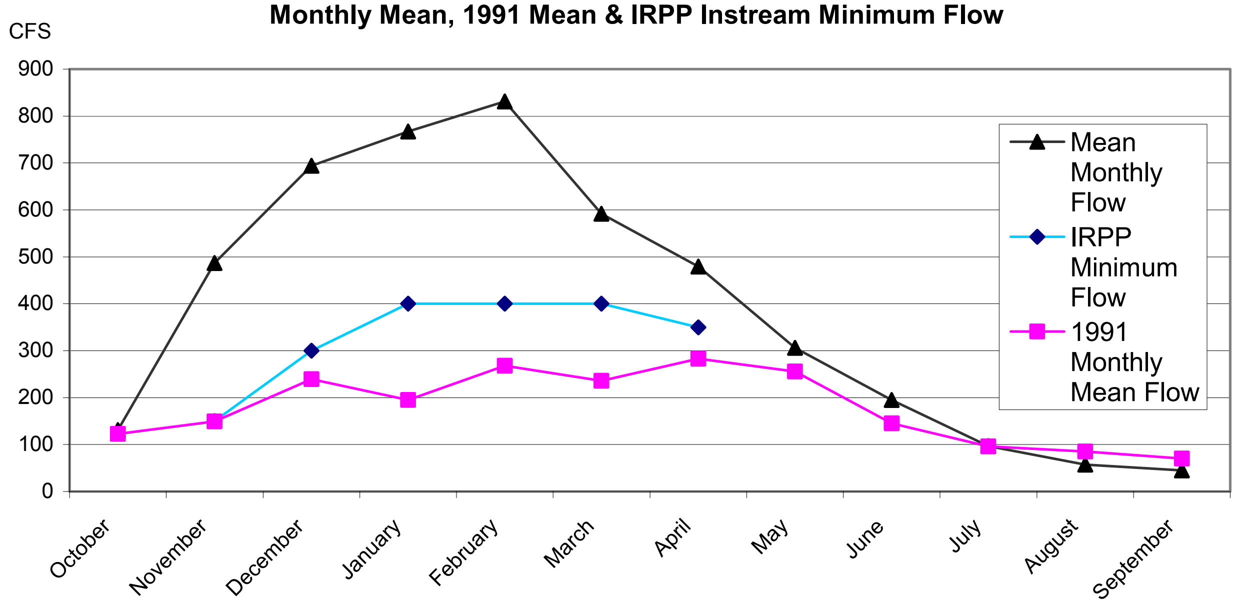
[10] Deschutes River Basin Instream Resources Protection Program Including Proposed Administrative Rules (WRIA 13), DOE, June 1980.

any plans to construct the Shellrock Dam. Recent city plans call for the development of ground water resources in the vicinity of East Olympia and additional withdrawals from McAllister Creek in nearby WRIA 11(Nisqually Basin.)" [11]

In the following graph, mean monthly stream flow values are compared to the IRPP winter values set for potential storage facilities. Mean values over the period of record are all above the IRPP minimum discharge values. 1991 values are provided for comparison: In 1991, winter month mean flow was the lowest on record. 1991 winter flows were virtually all below the IRPP winter storage discharge values.

Figure 12 - Tumwater Station, Deschutes River
Monthly Mean, 1991 Mean & IRPP Instream Minimum Flow



Monthly volume "shortfall" between 1991 stream flow and the IRPP minimum flow is:

	Dec	Jan	Feb	Mar	Apr	TOTAL
Acre Ft "Short"	3,751	12,609	8,116	10,084	4,120	38,676

In comparison, the "Shellrock Dam" proposed by the City of Olympia in the 1960's had a conceptual volume of 10,000 acre feet (556 acres at 18 feet average depth.)

Instream Flow on 303(d) List

Deschutes instream flow conditions were included on the 1998 Final Section 303(d) List for WRIA 13. Listing was based on:

- Low flow conditions "consistently below minimum flows established in WAC 173-513-030."
- "Intensified peak flows likely due to silvicultural activities in the upper watershed."

[11] Same source.

- Linkage of flow issues with depressed Coho salmon populations.[12]

5.2.2 PERCIVAL CREEK

The second largest watershed in the Budd/Deschutes basin is Percival Creek. This system is comprised of Percival Creek with 3.6 stream miles and Black Lake Ditch with about 2 stream miles. Basic stream and watershed characteristics are provided below.

BASIN	Watershed Characteristics				Stream Characteristics					
	Basin Size	% Forest	% Urban	Within UGA (Future Growth)	Mainstem Stream Miles	Salmon Usage (includes tribs)	Riparian Forest Cover (150')	Stream Flow (cubic ft sec.) Average	Peak	Min.
	Acres	Current % Cover		Percent	Stream Miles		% Cover	Flow in Cubic Ft Per Second		
RCIVAL/CAPITOL LK	6,375	24%	31%	95%	5.6	5.5	40%	47	335	0

Subbasins within the drainage are:

PERCIVAL CREEK SUBBASINS	
Acres	
2,038	Percival Creek
1,311	Black Lake Ditch
1,141	Cooper Pt Blvd/Capital Mall
739	Ken Lake
5,229	**TOTAL**

Percival Creek proper begins at 18-acre Trosper Lake, flowing north approximately 2.4 miles to the confluence with Black Lake Ditch. The initial reach has a low gradient and flows through some wetland areas to the 200-foot deep Percival Creek canyon. In most storm events, the upper portion of Percival Creek contributes roughly 25% of total stream flow at the mouth of the system.

Black Lake Ditch was constructed in 1922 to drain potential agricultural land north of the lake. Flows from Black Lake to Percival Creek via the ditch have a pronounced affect on the hydrology of the creek system. Prior to this time, the hydrologic connection between

[12] Final 1998 Section 303(d) List – WRIA 13, WA Department of Ecology, April 2000.

Black Lake and Percival Creek was minimal.[13] The ditch has a very low gradient before reaching Mottman Road, where it enters the confined Percival Creek canyon. During various storm events, Black Lake Ditch is calculated to provide 50% to 70% of the total flows in Percival Creek. Black Lake does not effectively store flood flows.[14] During the winter months, mean monthly flows at the Black Lake outlet are typically ½ - 2/3 of flows at the Mottman Road gaging station on Black Lake Ditch. Summer mean flows leaving the lake are ¼ or less of streamflow at Mottman Road.[15]

Flow from the Cooper Point Road commercial area contributes 20% to 27% of total flow. Runoff impacts from widespread intense development of this basin are ameliorated in part by the large stormwater storage capacity of multi-use Yauger Park.

Ken Lake sub-basin was found by the Basin Plan to have the largest percent increase in discharge with increasing intensity of storm events. The 27-acre lake does not provide effective storage of runoff from the watershed.

Overall, the Basin Plan found that flood flows are higher and summer flows are lower under existing land use conditions compared to pre-development forested conditions. [16]

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[13] Percival Creek Comprehensive Drainage Basin Plan, May 1993. Basin acreages and flow information is also from this report.

[14] Percival Creek Comprehensive Drainage Basin Plan, May 1993. Basin acreages and flow information is also from this report.

[15] Thurston County Water Resources Monitoring Report, Thurston County, prepared each water year. The Percival Creek station data from 1988 to 1995 (when station was lost) is reported in the `1994-1995 Water Year Report. Mottman Road station data is reported through the 199-2001 Report (some gaps in record.)

[16] Same cite.

5.2.3 SMALL BUDD INLET TRIBUTARIES

Several small streams flow into Budd Inlet. Stream and watershed characteristics are summarized below.

BUDD/CAPITOL LAKE TRIBUTARIES: SUMMARY OF STREAM AND WATERSHED CHARACTERISTICS

BASIN	Watershed Characteristics				Stream Characteristics					
	Basin Size	% Forest	% Urban	Within UGA (Future Growth)	Mainstem Stream Miles	Salmon Usage (includes tribs)	Riparian Forest Cover (150')	Stream Flow (cubic ft sec.) Average	Peak	Min.
	Acres	Current % Cover		Percent	Stream Miles		% Cover	Flow in Cubic Ft Per Second		
RCIVAL/CAPITOL LK	6,375	24%	31%	95%	5.6	5.5	40%	47	335	0
BUDD INLET										
ELLIS CREEK	1,472	46%	5%	30%	1.1	0.4	60%	Range 0.4 to 16 cfs		
INDIAN CREEK	1,500	20%	29%	100%	3.0	1.2	47%	Range 0.5 to 30 cfs		
MOXLIE CREEK	1,463	17%	47%	100%	1.8	1.1	60%	Range 3 to 15+ cfs		
MISSION CREEK	359	30%	26%	92%	1.5	0.4	63%	Range 0.15 to 22 cfs		
SCHNEIDER (EAST BAY)	680	19%	35%	100%	1.2	0.2	66%	Range 1.8 to 8.6 cfs		
DANA PASSAGE	1,146	60%	3%	0%			63%			
EAST BAY DRAINAGES	2,761	43%	10%	0%		1.8	52%			
WEST BAY	1,918	38%	14%	46%			38%			
BUDD INLET TOTAL/AVERAGE	11,300	36%	19%	47%	3.0	1.3	46%			

Watershed and stream corridor cover: "Land Cover Mapping of Thurston County", TRPC, June 2001
Percent impervious: "Aquatic Habitat Evaluation and Management Report", 1999, City of Olympia and Thurston Geodata Center GIS data (non-urban streams)
Salmon usage: "WRIA 13 Salmon Habitat Limiting Factors Final Report",1999, Washington Conservation Commission
Streamflow: "Thurston County Water Resources Monitoring Reports" issued by Water Year, Thurston County. "Percival" station is Black Lake Ditch at Mottman Rd.
Deschutes streamflow: USGS Water Resources Data Washington: Water Year 1999", Water-Data Report WA-99-1. Instantaneous peak flow given.

An assessment of basin and stream conditions for the above streams is included in a 1999 “Aquatic Habitat Evaluation and Management Report” from the City of Olympia. An excellent summary of conditions is provided for each stream. The report includes several options for levels of stream protection intended to “define the balance between human activities and protecting habitat in Olympia’s watersheds”. Recommendations for streams in Budd Inlet basin are as follows:

- Ellis Creek: Protecting habitat is the proposed primary management goal for Ellis Creek and it’s watershed, based on relatively low-density existing and anticipated development. Key actions include restrictions on development, retaining existing forest and riparian vegetation, and replanting cleared areas. Intent is self-sustaining health trout and salmon populations.

- Percival Creek and Bigelow Lake wetlands (headwaters of Indian Creek): "Accommodating growth while protecting existing habitat" is the recommended management goal for these waterbodies in the Olympia report. Intended fish management outcome is maintaining salmon and trout populations with human intervention.

- Indian Creek, Moxlie Creek, Mission Creek and Schneider Creek: "Accommodate growth, maintain aesthetic amenities and water quality" is the recommended strategy for these urban or urbanizing watersheds. It is not considered feasible to protect healthy salmon populations in these creeks in the long run due to impacts of existing and future urbanization, particularly impacts on stream flows. As stated by the Report, "for these basins the goal would be to accommodate urban growth and maintain isolated habitat areas for aesthetic, open space, wildlife habitat and educational purposes."

5.2.4 LAKES IN THE DESCHUTES WATERSHED

LAKE	Lake Characteristics										
	Lake Area	Basin Size	Basin Size	Outlet	Depth		Typical High/Low Annual Range	Volume	Average Residence Time	Uses	
					Mean	Max.				Public Launch	Other Access
	Acres	Sq Miles	Acres		Feet		Feet	Acre-Feet	Days		
DESCHUTES BASIN											
BARNES	14			Deschutes R.							
BIGELOW	13	0.4	243	Indian Crk	10	15		124			
CAPITOL LAKE	270	`	88,339	Budd Inlet	9	20		2,400	2	X	State/city parks
CHAMBERS LAKE	60	0.8	512	Chambers Ditch	5	8	2.5	270		X	
HEWITT	26	0.2	128	(No outlet)	28	56	6.0	710			
KEN (SIMMONS)	27	0.6	397	Black Lk Ditch	7	11		200			
LAWRENCE	330	3.4	2,144	Deschutes	13	26	2.0	4,400	110	X	Co. preserve
MCINTOSH	93	2.3	1,446	Deschutes	8	11		700		X	
MUNN	34	0.7	429	Deschutes	10	19		350		X	
OFFUT	200	2.7	1,728	Deschutes	15	25	3.0	2,900		X	
SMITH	15			(No outlet)							
SOUTHWICK	36	0.9	589	(No outlet)	7	17		250			
SUNWOOD	21	0.4	256	(No outlet)	4	7	4.0	81			
TEMPO	32	1.0	640	Deschutes	13	24		400			
TRAILS END	12	0.4	230	Munn Lake	16	40		194			Private camp
TROSPER	18	1.4	896	Percival Ck	11	15		189			Undev Tum park
WARD	65	1.0	640	(No outlet)	33	67	3.0	2,100		X	
Subtotal	**1,266**	**acres**	**acres**					**15,268**	**acre-feet**		

DRAFT WRIA 13 ASSESSMENT SECTION
11/02
Tom Clingman, Thurston Co Water & Waste Mgt

SECTION 5.2.5 BUDD INLET

Budd Inlet is a prominent feature in the WRIA 13 landscape. It is the receiving water for the Deschutes River basin and for the regional LOTT wastewater treatment plant. Proximity to Olympia has created significant water quality problems from past industrial uses and current urban land uses. This proximity to the urban population also facilitates much greater public access and public enjoyment of Budd Inlet compared to the other inlets in north Thurston County.

Consideration of freshwater impacts on marine waters is a required component of Watershed Planning under RCW 90.82. As discussed in this section, freshwater inputs to Budd Inlet – particularly the Deschutes River/Capitol Lake system – influence circulation and several water quality parameters of the inlet.

Budd Inlet is one of the most studied inlets in Puget Sound. Particularly important is the exhaustive water quality study financed by the LOTT Wastewater Alliance related to the treatment plant discharge permit. This study is utilized extensively in this section.[17]

PHYSICAL CHARACTERISTICS AND CIRCULATION

Budd Inlet is 7 miles in length and 1 – 2 miles wide. Depth is only about 30 feet in most areas. This shallow depth is an important factor in circulation and water exchange in the inlet.

Circulation and other physical characteristics of Budd Inlet were studied in depth in the late 1990's by the LOTT wastewater partnership. "Conventional wisdom" about Budd Inlet held that it would have poor circulation due to location at the "bottom" of the entire Puget Sound. However, the LOTT-funded studies indicated a very different picture.

Tidal circulation in Budd Inlet is among the most active in Puget Sound. Flushing times range seasonally from 8 – 12 days. In comparison, estimates for various bays in Puget Sound range from 1 day (at Port Ludlow) to 700 days at Dabob Bay. The entire Puget Sound flushing rate is calculated at 90 days.

Relatively high flushing rates for Budd Inlet are created by several factors:

- High percentage of tidal input compared to inlet volume. Inlet depth is only about 30 feet, while tidal range averages over 14 feet. Thus, nearly 50% of Budd Inlet volume is added with each tidal cycle (Mean High High Water volume of 230 million cubic meters compared to Mean Low Low Water volume of 119 million cubic meters.) Tidal volume change is greater in the

[17] Budd Inlet Scientific Study Final Report, August 1998, prepared for LOTT Partnership by Aura Nova Consultants and several others. This report is the source of nearly all information in this assessment on Budd Inlet.

Inner Inlet (below Priest Point), with volume at high tide over 2 ½ times the volume remaining at low tide.
- Tidal currents in Budd Inlet are affected by the “bellows” affect of the Dana Passage and likely the Tacoma Narrows. A strong inflow of Puget Sound water runs along the western shore, with outflow along the eastern shoreline (see circulation figure).
- Capitol Lake freshwater input is an important circulation factor, particularly in the Inner Inlet during tide gate opening. Capitol Lake flows are episodic rather than constant. When the tide gates are open, discharge can exceed 3,500 cfs – about equivalent to the average discharge from the Snohomish River, which is the second largest river entering Puget Sound.

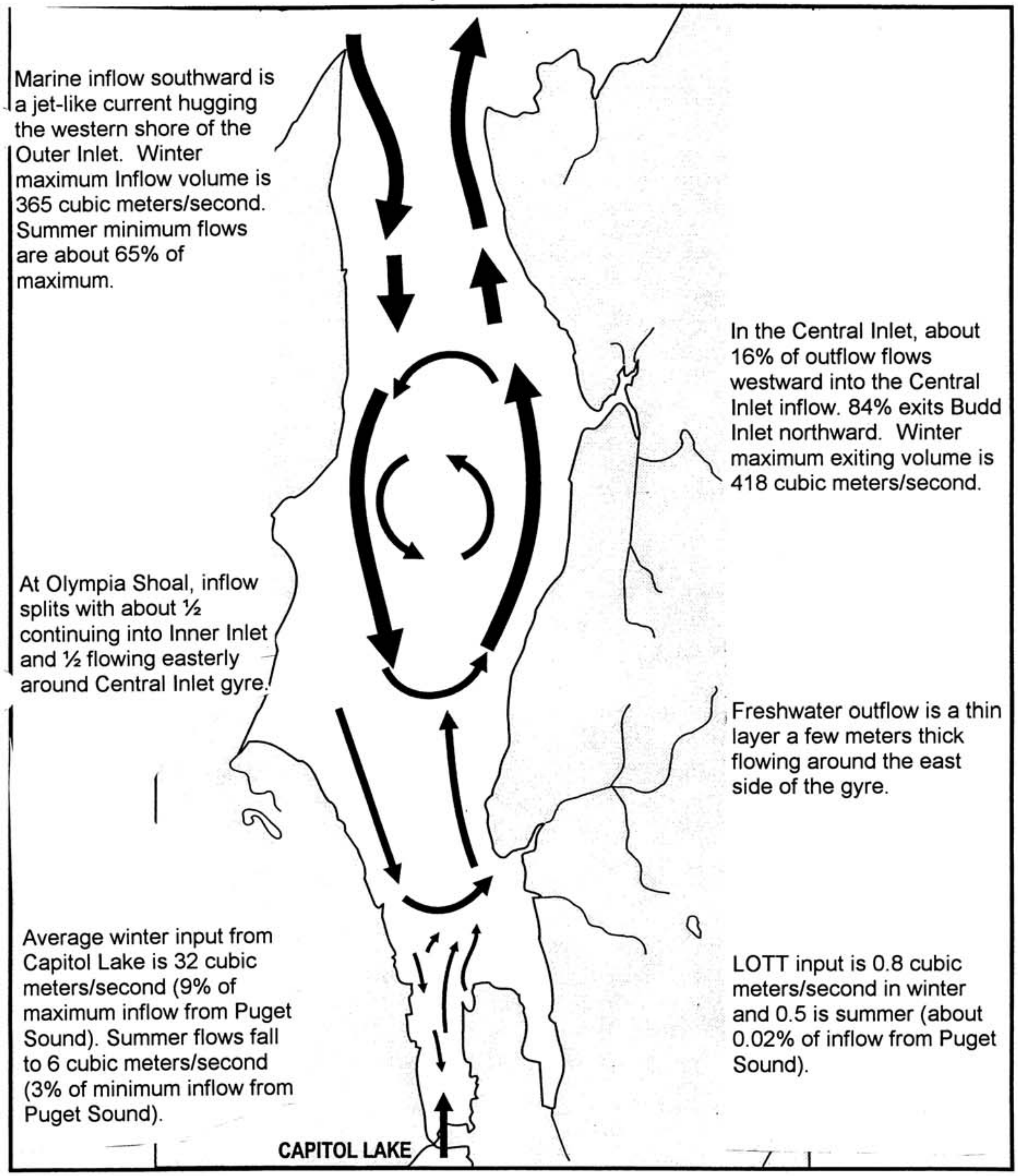
As shown on the “Budd Inlet Net Circulation” diagram, inflow water runs at depth along the western shore. At the Olympia Shoal, about ½ the flow is diverted easterly into the Central Inlet gyre (circulation pattern.) The remaining ½ continues along the western shore into the Inner Inlet. The lighter freshwater from Capitol Lake flows north in a shallow plume along the eastern shore of Budd Inlet.

Circulation between Budd Inlet and other parts of Puget Sound was investigated in a “drift card” study. In the LOTT-funded study, nearly 9,000 postcard-sized wooden drift cards were released at monthly intervals at sites throughout Budd Inlet.

Results of the drift card study are illustrated on the “Drift Card Pathways From Budd Inlet” figure: Tidal “pumping” created by the Dana Passage and the Tacoma Narrows was documented to have a strong interaction with Budd Inlet. In contrast, very little circulation occurs with other inlets in our immediate area. Key results:

- Less than 1% of Budd Inlet cards were found in Henderson, Eld or Totten Inlets.
- 45% of cards exited past the Dana Passage.
- 27% of cards exited beyond Nisqually.
- 18% of cards exited north of the Tacoma Narrows.

Drops in Totten and Hammersley inlets confirmed the Budd Inlet drift card results. Nearly 10% passed north of Harstene Island via the Pickering Passage. About 20% moved southeasterly through the Dana Passage. Less than 1% of the Totten/Hammersley cards were found in Eld Inlet and none of the cards were found in Budd Inlet.



NORTH

No Scale

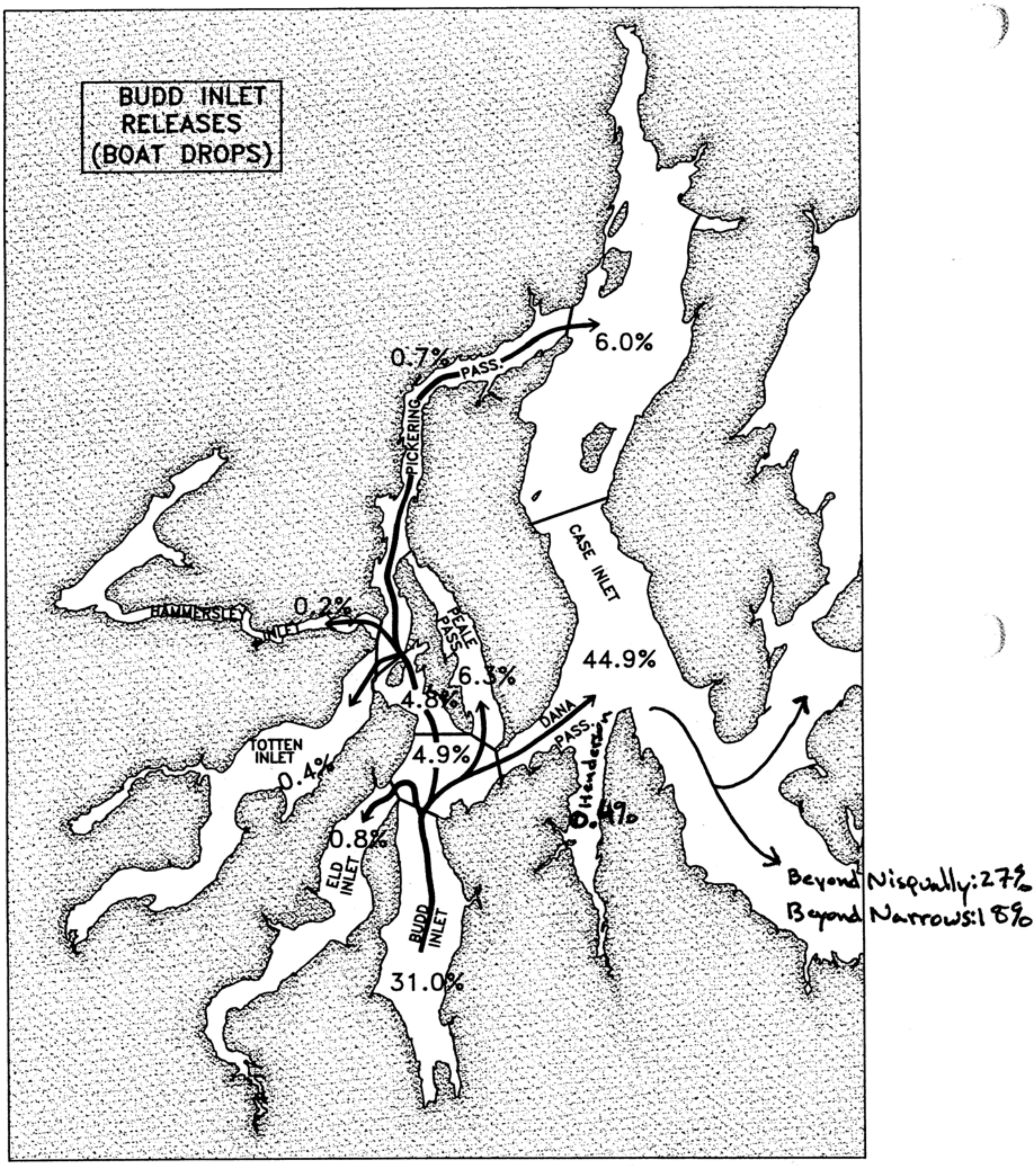
Budd Inlet Net Circulation

FIGURE 9-11

ADOLFSON ASSOCIATES, INC.

97121cir.cdr

Figure 3-134. Drift Card Pathways from Budd Inlet



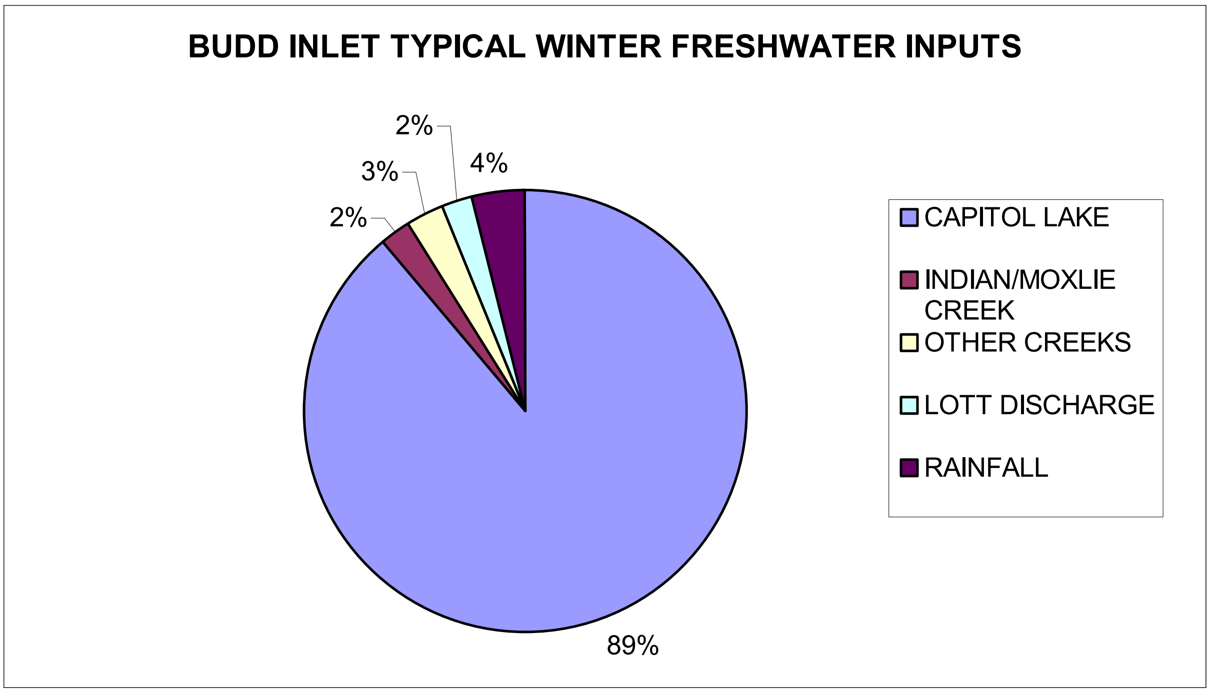
Shown are percentages of the total number of cards recovered (4,609) from 8,950 total cards released in Budd Inlet during October 1996 through September 1997. Lines represent divisions between water bodies. Most cards were either found in Budd Inlet (31.0%) or exited through Dana Passage into Case Inlet (44.9%), wereas a smaller percentage traveled via Squaxin (4.8%) and Pickering (0.7%) passages to reach Case Inlet (6.0%). Very few cards were found in Eld (0.8%), Totten (0.4%), and Hammersley (0.2%) inlets.

FRESHWATER INPUT

By far the dominant freshwater input is Capitol Lake. Flow from Capitol Lake is episodic and varies over the seasons. Capitol Lake average summer discharge is 200 cfs for 3.2 hours. For the winter months, average flow is 1,150 cfs for a 4.4 hour duration.

Typical winter freshwater input to Budd Inlet is 89% Capitol Lake, with much smaller input from rainfall (4%), small streams (5%) and LOTT (2%). In summer, both LOTT and the small streams roughly double in percent contribution with Capitol Lake about 75% of total input.

In the Inner Inlet, Capitol Lake is even more dominant, supplying 80% - 93% of all freshwater input.



BUDD INLET WATER QUALITY

The Inner Inlet below Priest Point is Class B water, reflecting the degraded conditions on this part of the inlet. The remainder of the Inlet is Class A.

Freshwater inflows have significant influence on water quality conditions, particularly in the Inner Inlet. Some types of pollution – such as fecal coliform – are directly linked to freshwater flows from Capitol Lake and smaller streams. Nitrogen, which is the critical nutrient linked to summer low oxygen conditions, has been documented to mainly be supplied by marine inflow water from Puget Sound.

Fecal coliform bacteria

Fecal coliform is an important water quality indicator. These bacteria may indicate the presence of fecal waste from human sources (sewer and septic systems), livestock and wildlife. Shellfish harvesting activities are particularly sensitive to fecal coliform levels.

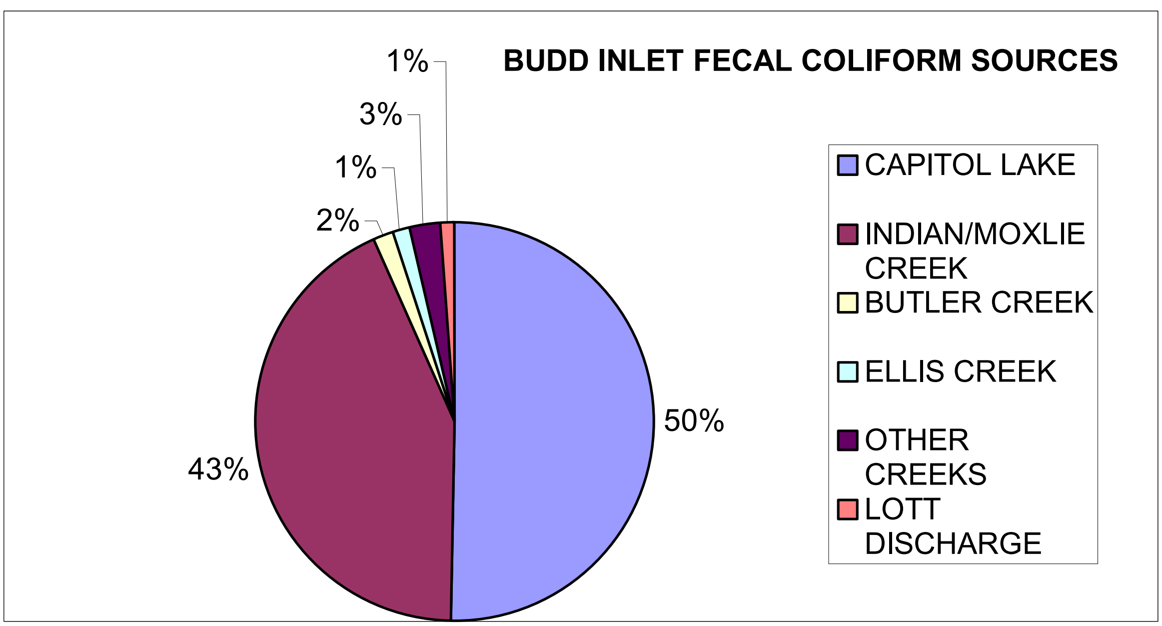
Fecal coliform levels were monitored throughout the Budd Inlet shoreline and marine stations. As shown on the attached figure "Geometric Mean Fecal Coliform Levels in Budd Inlet", Inner Inlet stations met Class B standards but generally exceeded Class A marine water quality standards (mean value standard of 14 colonies/100 mL). One station beyond the Class B boundary violated Class A standards.

In the middle and outer inlet, fecal coliform levels tended to be greater along the eastern shoreline. This reflects the dominant outflow current along the eastern side of the inlet.

Freshwater influence

Freshwater entering Budd Inlet is a significant source of fecal coliform loading. Shoreline sites and streams were intensively sampled during the 1997-98 LOTT study. The highest concentrations were along the Inner Inlet shoreline, with Indian/Moxlie Creek having the highest concentrations at 472 fecal coliform per 100 mL. Capitol Lake had a concentration of 28.6. See attached figure.

Annual loading in 1996-97 from freshwater sources is summarized in the chart below. Capitol Lake and Indian/Moxlie Creek were by far the dominant sources on an annual loading basis. Contrary to some perceptions, the LOTT treatment plant is a very small contributor to fecal coliform pollution in Budd Inlet, with about 1% of annual contribution. Both Ellis Creek and Butler Creek contributed over 1%.



Another intensive data collection effort was sponsored by Thurston County in 1991-94. The Budd Inlet/Deschutes River Water Quality Study was conducted as part of the Budd/Deschutes Watershed Action Plan. The non-point pollution control plan was completed in June 1995. Data was collected in the initial two years from six mainstem Deschutes stations from near Deschutes Falls to Tumwater Falls; seven Deschutes River tributaries; Capitol Lake; Budd Inlet; and two urban Budd Inlet tributaries.[18] Five additional Budd tributaries were added for the 1993-94 sampling and analysis.[19]

Direct comparison between the LOTT and Thurston County studies is somewhat limited by absence of Capitol Lake and Indian/Moxlie discharge monitoring in the county study. However, several important outcomes of the Thurston County study include:

- Urban stream fecal coliform levels are generally consistent in the two studies.
- Inner Budd Inlet stations met Class B but failed Class A standards, consistent with the LOTT study.
- Three Deschutes reaches were identified with particularly high fecal coliform values:
    - 1000 Road to Lake Lawrence reach
    - Rich Road to Henderson Blvd reach
    - E Street to bottom of Tumwater Falls reach.
- Deschutes tributaries with high loading were Chambers, Spurgeon, Reichel and Ayers.

Water quality improvement actions

Since the Budd Inlet Study, the City of Olympia and Thurston County Environmental Health investigated pollution sources in the Indian/Moxlie Basin. The piped section of the creek – from Plum Street/Union to the bay – was identified as having high fecal coliform loading. A total of 54 pipes enter this section of piped creek. An intensive effort including water quality sampling and video recording in the pipe network identified four direct sewage connections to stormwater pipes. These connections occurred when stormwater pipes were misidentified as sewer pipes. All four connections have been corrected. Dye tracing was also performed on septic systems in an older neighborhood along Indian Creek. No dye was recovered in any of these tests. [20]

Stormwater discharges to Capitol Lake also contribute to fecal coliform loading in the Inner Inlet. Olympia staff is pursuing a grant-funded effort in 2002-03 to identify potential water quality problems and corrective actions. Sampling of stormwater pipes was conducted during the 2002 Capitol Lake drawdown for Deschutes

[18] Budd Inlet/Deschutes River Final Report: Part II – Water Quality Study, March 1993, Thurston County Environmental Health
[19] Addendum - Budd Inlet/Deschutes River Final Report: Part II – Water Quality Study, October 1995, Thurston County Environmental Health
[20] Personal communication with Andy Haub, City of Olympia, September 11, 2002.

Parkway reconstruction. No blatant problems were revealed in this initial sampling. [21]

Nitrogen

Nitrogen is the key nutrient in the Budd Inlet system. Its availability enhances or limits phytoplankton productivity. Nitrogen supports summer algae blooms that can lead to depressed dissolved oxygen conditions.

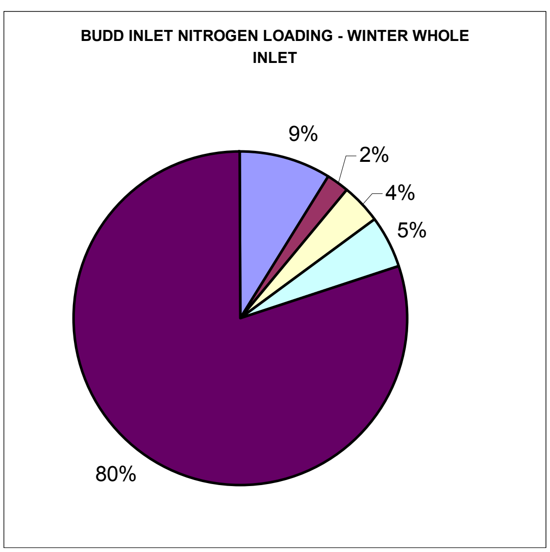
Freshwater influence

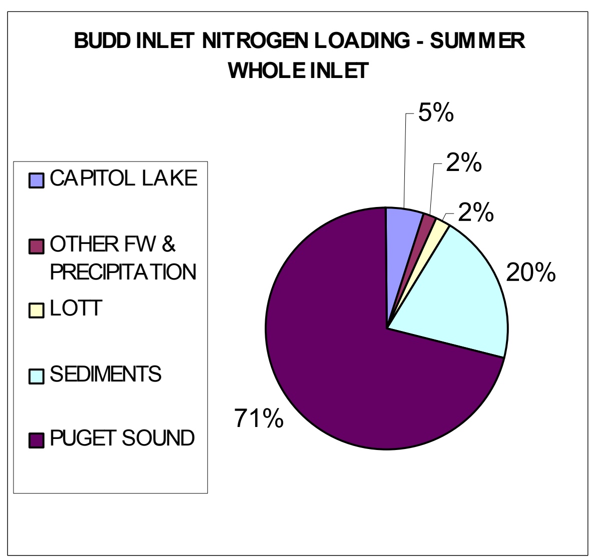
For the inlet as a whole, all freshwater sources contributed 9% to 15% of nitrogen loading. Within the Inner Inlet, total freshwater contribution increased to 15% - 21% of nitrogen loading. Capitol Lake was the major freshwater source of nitrogen to the inlet. LOTT discharge was 2% - 4% of total nitrogen loading to the inlet.

Inflowing water from Puget Sound was the dominant nitrogen source during both winter (80%) and summer (71%). In summer, release from sediments was calculated to be the second-highest source. Sediment measurements during the LOTT study indicated that sediment storage was short-term (2-6 weeks) and that nutrients reaching the sediments during winter would not fuel plankton blooms in summer. [22]

Whole Inlet Seasonal Loading

The following charts illustrate seasonal nitrogen loading to the inlet as a whole. Data is from the LOTT Budd Inlet study. Sediment release is a higher percent of summer load; Capitol Lake contribution decreases in summer – consistent with lower discharge.

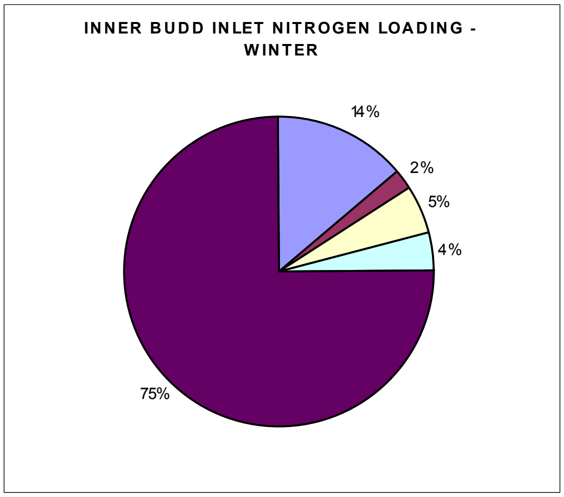


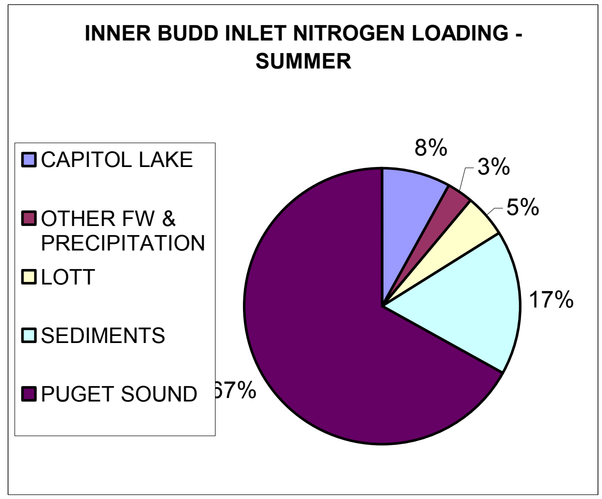


[21] Ibid.
[22] Budd Inlet Scientific Study Final Report, August 1998. Chapter 3 page 3-138.

Inner Inlet Seasonal Nitrogen Loading

In the Inner Inlet (below Priest Point), LOTT and Capitol Lake were somewhat higher contributors to nitrogen loading. Capitol Lake supplied 8 – 14% of loading and LOTT was the source of about 5% of Inner Inlet loading.





Temperature

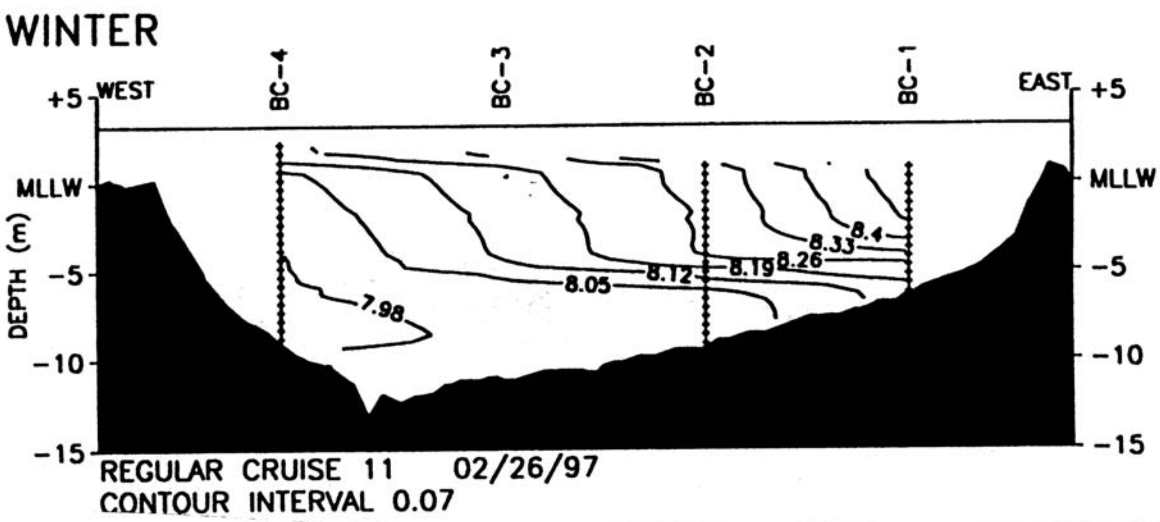
Documented summer temperatures exceed the marine standards of 13.0 degrees C. However, the Department of Ecology has determined that high temperature levels in Inner and Outer Budd Inlet are "a natural condition with no direct human caused influence due to solar heating of the surface water." [23] Thus, the water body is not included on the list of "impaired" waterbodies for temperature conditions.

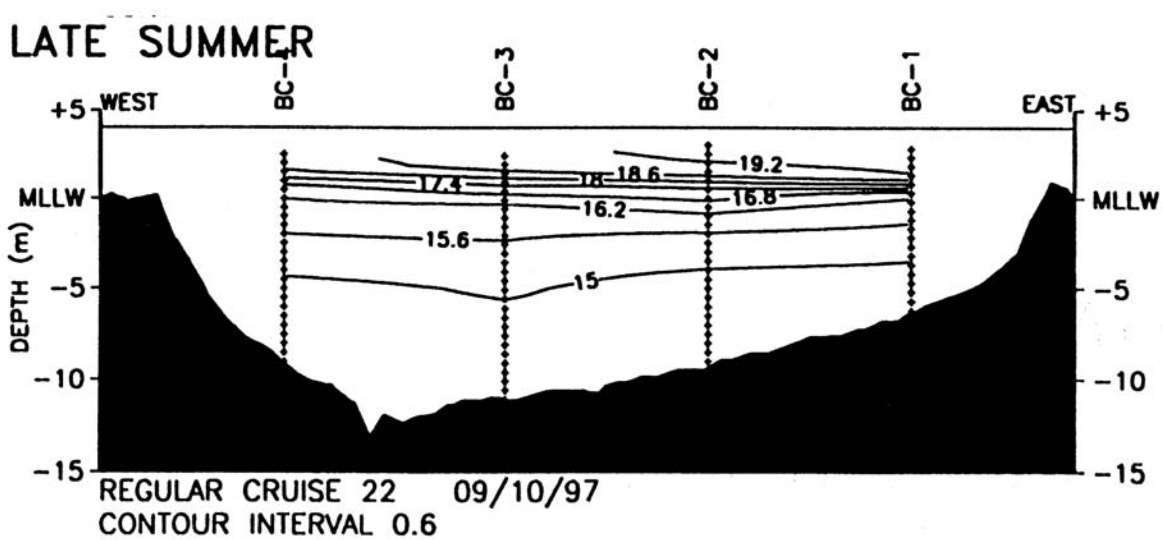
Freshwater influence

Freshwater sources would have very minor influence on Budd Inlet temperature. Streams were typically 4-6 degrees in winter. Summer values were 11-15 degrees for the streams, with Capitol Lake outflow up to 21 degrees C.

[23] Final 1998 Section 303(d) List – WRIA 13, Department of Ecology, April 2000.

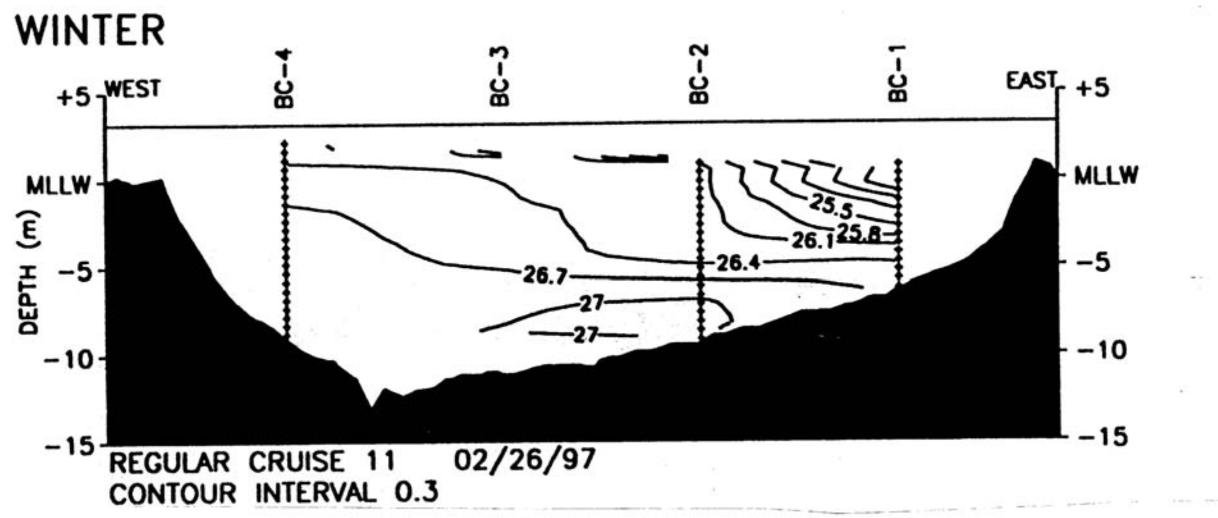
Temperature profiles for winter and late summer are shown on the following graphs. The mid-inlet ("BC") transect from the LOTT study extends from Tykle Cove on Cooper Point to Seashore Villa/DNR dock facility north of Priest Point Park on the eastern shore. Winter temperature is consistently near 8 degrees Celsius. Summer temperature was 15 degrees in the deeper water to over 19 degrees near the surface on the east side of the inlet. In both summer and winter, influence of the dominant circulation pattern is evident in the slightly higher temperatures on the eastern edge of the inlet.

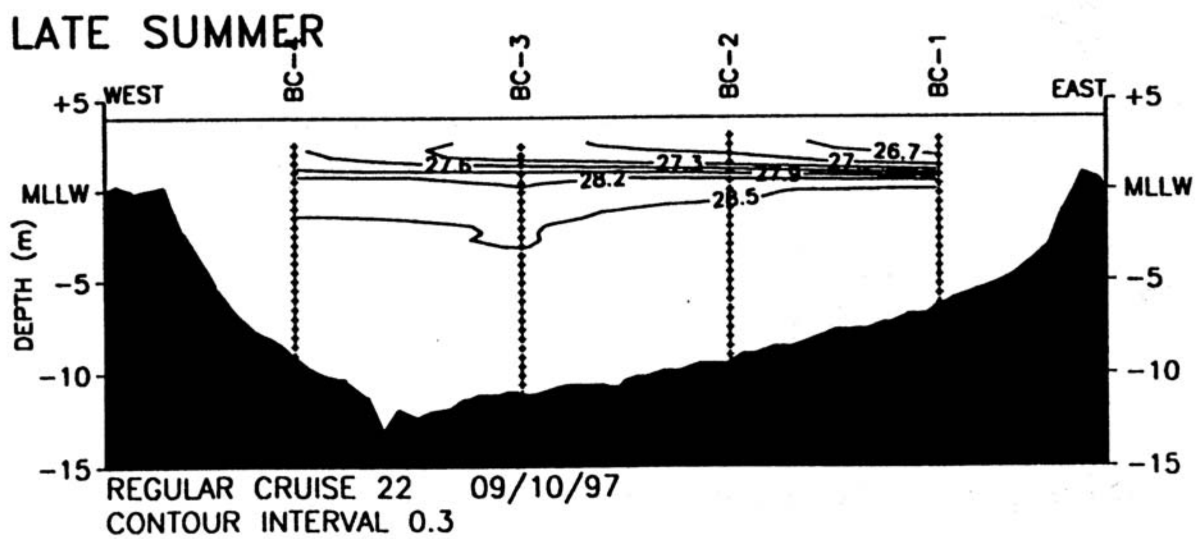




Salinity

Average salinity in South Sound is 27 – 29 parts per thousand (ppt). Budd Inlet values at the mid-inlet transect are lower in winter, especially along the eastern shore where the freshwater plume extends. Summer concentrations are near South Sound averages, with the freshwater plume still discernable along the east shore.

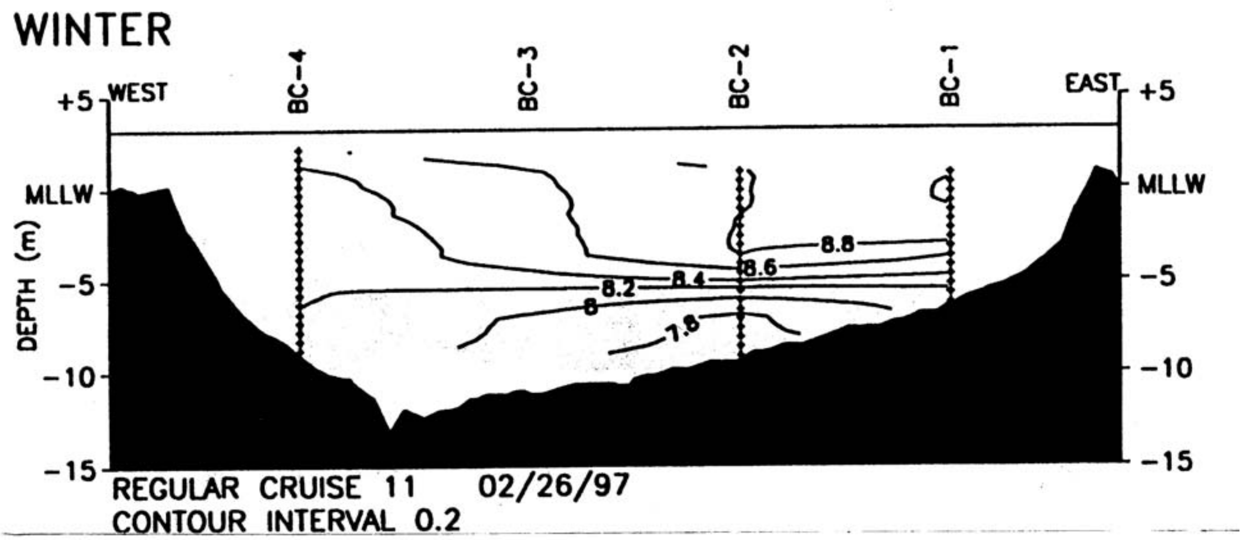


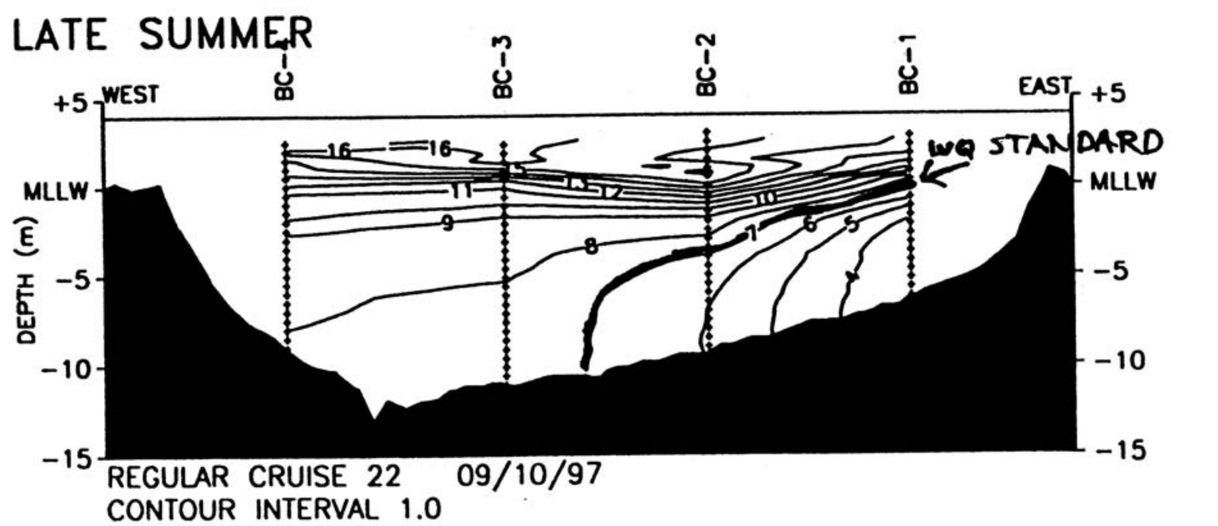


Dissolved Oxygen

Dissolved oxygen is an important water quality parameter in Budd Inlet. Both the Inner and Outer Inlet are included on the 303(d) List for dissolved oxygen. In the Outer Inlet, DOE found between 17% and 43% of samples in 1992-94 violated the standard of 7 ppm (Class A).

Mid-inlet conditions are illustrated below. Winter levels are relatively uniform at 7.8 to 8.8 ppm. In Late Summer, the eastern portion of the inlet below the surface had oxygen levels below the 7 ppm Class A standard. The graph also illustrates that low oxygen levels in deeper water can be accompanied with very high levels (16 ppm) near the surface water during to algae blooms. Algae blooms generate dissolved oxygen during the day by photosynthesizing, and then consume oxygen at night. Decomposing algae sink and decaying processes consume oxygen throughout the day – resulting in an overall reduced level of DO through much of the water column. , as illustrated below..

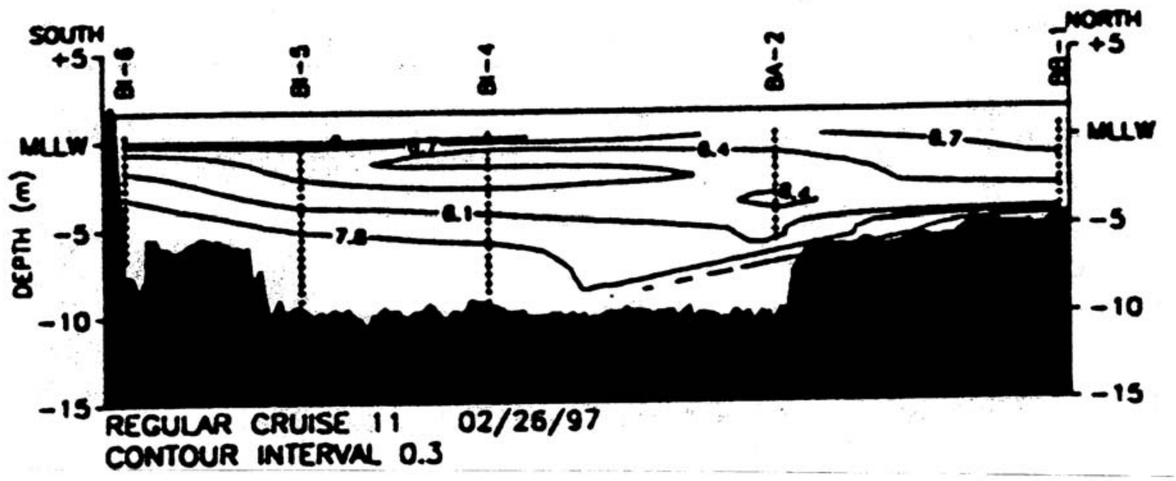




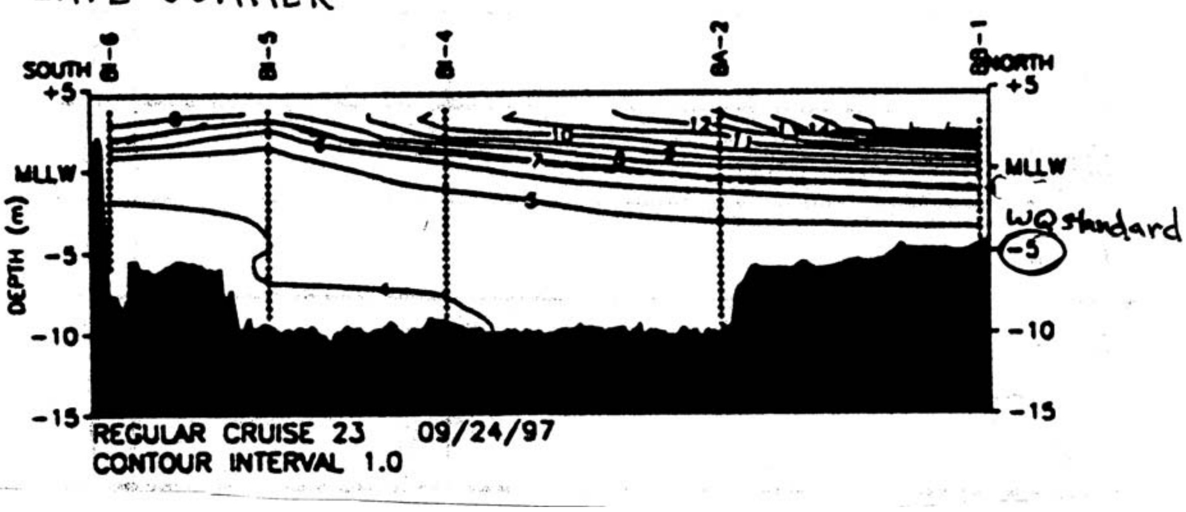
Budd Inlet dissolved oxygen concentrations are the lowest in the Inner Inlet. Declining oxygen levels appear to coincide with an increase in algae growth and decrease in circulation – an increase in consumption of oxygen with less opportunity for re-oxygenation from "fresh" input of marine water circulating from Puget Sound.[24]

The graphs illustrate Winter and Late Summer conditions in the Inner Inlet. The transect runs north to south through the turning basin at the Port of Olympia. A significant portion of the water body fell below the 5 ppm Class B standard in late summer. Winter levels were the same as the mid-inlet conditions, achieving Class A dissolved oxygen standards of 7 ppm.

WINTER



LATE SUMMER



[24] LOTT Wastewater Resource Management Plan and Supplemental EIS, August 1998, Brown and Caldwell.

Freshwater influence on dissolved oxygen in Budd Inlet

The greatest influence on dissolved oxygen may be indirect – through contributing to the biological processes that consume oxygen during the decay process. Streams and Capitol Lake flows add extra nitrogen (the limiting marine nutrient) that feeds algae blooms, consuming oxygen at night and during decay. Nitrogen loading is discussed in the earlier section.

Freshwater algae and plant matter carried into the Inner Inlet also contribute to oxygen demand during the decay process.

Freshwater inputs to Budd Inlet were nearly always higher in oxygen than marine water conditions. Stream values range from 15 mg/L in winter to 11-12 mg/L in summer and fall. LOTT D.O. levels are 4-8 mg/L, with lower levels often recorded at the smaller treatment plants. These very small discharges may have localized influence on dissolved oxygen levels at their outlet pipes.

For Capitol Lake, the former practice of summer drawdown and backfilling with marine water appears to have had negative consequences for water quality conditions in the Inner Inlet. The lowest D.O. value from Capitol Lake during the 1996/97 study year was in late summer, when the lake was backflushed with salt water. The decline in dissolved oxygen to around 7 ppm was accompanied with a significant spike in salinity in the Capitol Lake discharge. [25]

The Inner Inlet was extensively modeled to identify dissolved oxygen conditions under various management scenarios for the Capitol Lake and LOTT discharges. The Capitol Lake summer drawdown was modeled to decrease the minimum dissolved oxygen concentrations during summer by 0.04 mg/L in the western basin.[26]

The saltwater backflushing of Capitol Lake has been discontinued in recent years.

Recent monitoring confirms that low dissolved oxygen conditions in Capitol Lake coincide with saltwater intrusion. Capitol Lake was sampled monthly in 2000 and 2001 for dissolved oxygen. Only in September and October 2001 were low oxygen levels (below the 8 ppm freshwater standard) identified in the deeper portion of the lake. High saline levels were also present on these days, indicating inflow from Budd Inlet. At tides above 14 feet, saltwater flows into the lake through the fish ladder. [27]

Seasonal low dissolved oxygen conditions common in area lakes are not observed at Capitol Lake. The lake does not thermally stratify as do most Thurston County lakes, due to shallow depth and short residence time. Stratification creates separate

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[25] Budd Inlet Scientific Study Final Report, 1998. Volume 2 Appendix F.
[26] Budd Inlet Scientific Study Final Report, August 1998, Chapter 12 Conclusions page 12-9.
[27] Thurston County Water Resources Monitoring Report – 1999-2001 Water Years, May 2002, Thurston County Environmental Health Division

non-mixing layers of warmer upper water and denser cold deeper water – with oxygen depletion common in the deeper area. Capitol Lake does not exhibit these conditions.

Diurnal (day/night) oxygen sags – another common lake phenomenon – also do not appear to apply to Capitol Lake. In previous years, low dissolved oxygen levels in the lake were suspected of contributing to fish kills. During this earlier period, regular saltwater backflushing greatly reduced freshwater aquatic plants and created favorable conditions for algae growth. To evaluate whether low dissolved oxygen is a current concern, Thurston County Environmental Health deployed a dissolved oxygen data meter for two 24-hour periods in late summer 2000. Pre-dawn dissolved oxygen measurements were also made on 7/21/99 in response to a stickleback fish die-off. In all these cases, dissolved oxygen remained within water quality standards. In the 2000 24-hour studies, dissolved oxygen levels were above 11 mg/L.[28]

[28] Ibid.

5.4 HENDERSON INLET SUB-BASIN

There are about 28 total miles of named streams in the Henderson Inlet basin. The two major stream systems are Woodland Creek (16 miles including tributaries) and Woodard Creek (7 ½ miles). Several short streams are direct tributaries to Henderson Inlet. Stream and watershed characteristics are summarized in the preceding table.

5.4.1 WOODLAND CREEK

The Woodland Creek basin constitutes nearly 2/3 of the 30,000 Henderson Inlet basin. The basin is flat to gently rolling, mainly lying less than 200 feet above sea level. The highest point is in the low indistinct hills south of Pattison Lake at about 320 feet elevation. Total length of the stream is about 11 miles plus about 51/2 miles of tributary streams. Three distinct reaches of the Woodland Creek system are briefly described below: the Lakes area, Lake Lois reach and the lower creek.

Lakes area
Woodland Creek originates in the Hicks-Pattison-Long chain of lakes. The lakes are joined by old drainage ditches dug in the late 1890's – early 1900's through wetland areas. These ditches have not been significantly maintained since the 1940's.[29] The horseshoe-shaped route through the lakes chain takes about 6 miles – one-half the total 12-mile length of Woodland Creek.

Hicks Lake is 160 acres in size, with an average depth of 18 feet. Water source is largely supplied by groundwater input (about 65%), with surface runoff from the surrounding area supplying nearly 20% of the estimated water budget shown below.[30] Much of this runoff is concentrated at the storm sewer outfall on Ruddle Road [31] The lake typically experiences about 4 feet of fluctuation in water level over the year. In the period since record keeping began in 1988, the difference between highest and lowest lake elevation is over 8 feet. [32]

Pattison Lake is 270 acres with average depth of 13 feet. The lake is largely fed by groundwater (73%). This groundwater input to Pattison Lake in turn is the main source for Long Lake and thus the upper reach of Woodland Creek. The ditch from Hicks Lake supplies about 12% of the annual water budget. Pattison typically varies by only about 1 – 1 ½ feet per year.

Long Lake is 330 acres in size, with an average depth of 12 feet. Water is supplied mainly by the ditch from Pattison Lake (66%) and varies about 2 feet most years. Lake elevation fluctuates with season and longer-term precipitation trends.

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[29] Thurston County Lakes Restoration – Environmental Description, Entranco Engineers, 1977.
[30] Same cite. The study included preparation of a water budget for the lakes.
[31] Thurston County Lakes Water Quality and Restoration Analysis, Entranco Engineers, 1978. .
[32] Thurston County Water Resources Monitoring Report 1998-1999 Water Year, Thurston County Storm & Surface Water Program and Environmental Health. Lake stage data for the lakes is collected by volunteers and included in the annual Thurston County monitoring report.

Figure 1 - Waterbodies in Henderson Inlet Watershed

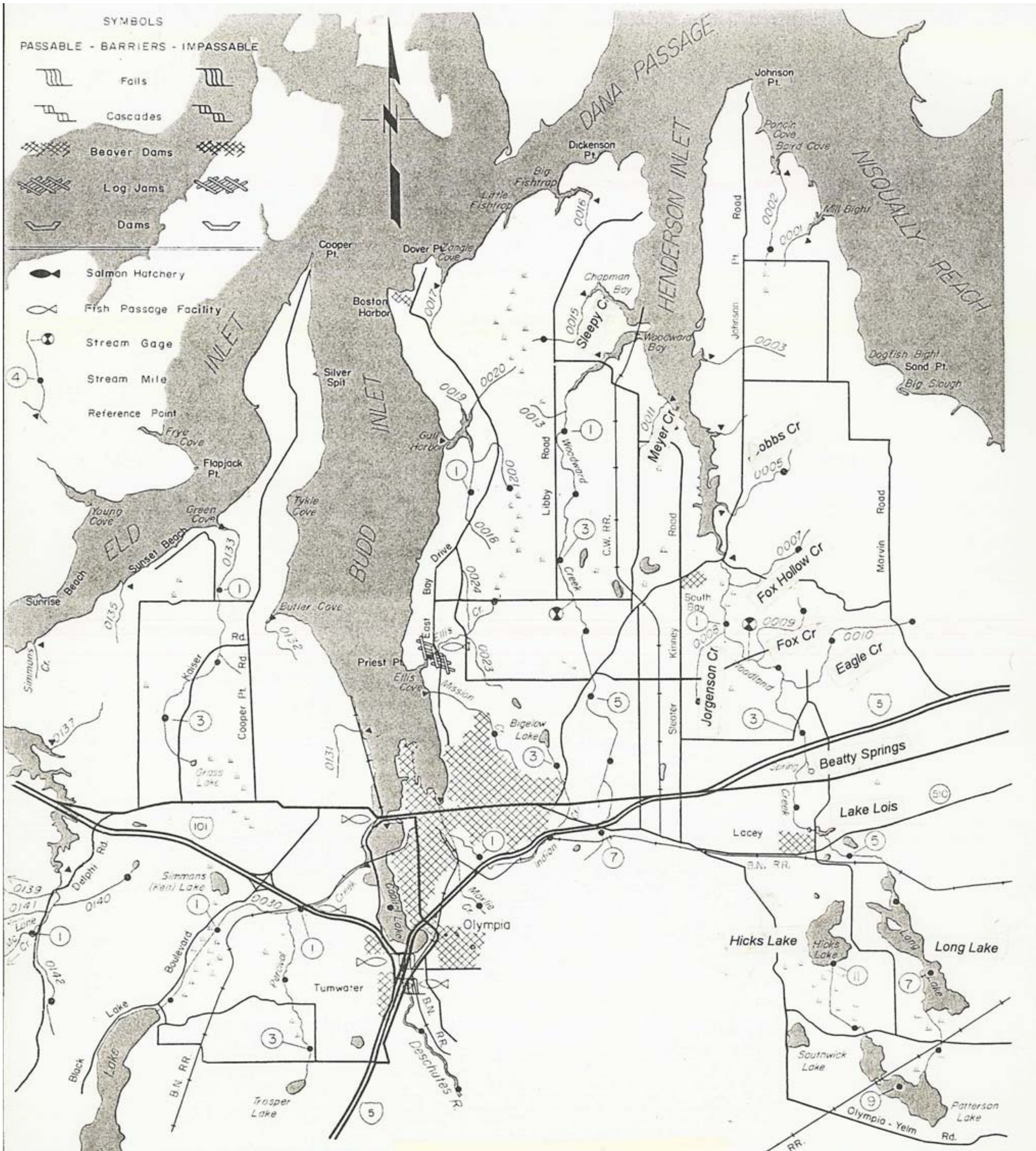


Figure 7 Streams in the Henderson Inlet Watershed

Source: "Catalog of WA Streams and Salmon Utilization, Puget ound Region", 1975, Department of Fish and Wildlife

Table 1
HENDERSON INLET: STREAM AND WATERSHED CHARACTERISTICS

BASIN	Watershed Characteristics				Stream Characteristics					
	Basin Size	% Forest	% Urban	Within UGA (Future Growth)	Stream Miles	Salmon Usage	Riparian Forest Cover (150')	Stream Flow (cubic ft sec.) Average	Peak	Minimum
CREEK NAME & WDFW NUMBER	Acres	Current % Cover		Percent	Stream Miles		% Cover	Flow in Cubic Ft Per Second		
SMALL MARINE DRAINAGES	7,335	52%	3%	0%						
DOBBS (#130005)	n/a		0%	0%	1.5	1.5	n/a	Range .75 to 16+ cubic feet/second		
MEYER (#130011)	n/a		0%	0%	1.0	0.0	n/a	Range dry to 7.4 cfs		
SLEEPY (#130015)	n/a		0%	0%	1.1	1.0	n/a	Range .01 to 64 cfs		
WOODARD (#130012)	4,479	36%	17%	45%	7.5	7.0	62%	9	97	0.9
WOODLAND (#130006)	18,873	30%	21%	79%	11.0	5.1	54%	22	160	8.1
FOX HOLLOW (#130007)					1.3	0.4				
JORGENSON (#130008)					1.0	0.4				
FOX (#130009)					1.2	0.3				
EAGLE (#130010)					2.0	1.1				
TOTAL & AVERAGE PERCENT	**30,687**	**31%**	**20%**	**72%**	**27.6**	**16.8**	**44%**			

Watershed and stream corridor cover: "Land Cover Mapping of Thurston County", TRPC, June 2001
Percent impervious: "Aquatic Habitat Evaluation and Management Report", 1999, City of Olympia and Thurston Geodata Center GIS data (non-urban streams)
Salmon usage: "WRIA 13 Salmon Habitat Limiting Factors Final Report",1999, Washington Conservation Commission
Streamflow and water quality: "Thurston County Water Resources Monitoring Reports" issued by Water Year, Thurston County.

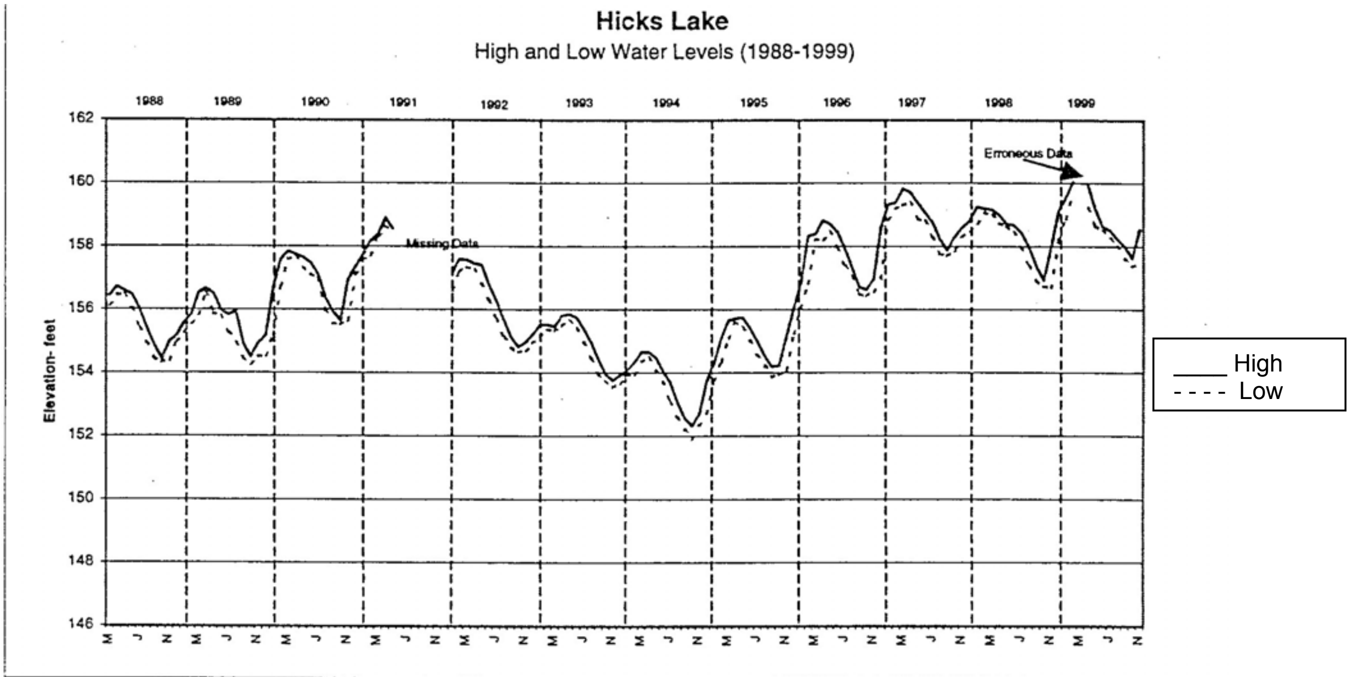
The water budgets prepared in the 1977 Lake Restoration study are delineated in Table 2. The following figures identify lake elevation trends on Hicks, Pattison and Long Lakes.

Table 2 Lakes Water Budgets

Source: Thurston County Lakes Restoration Environmental Description, Entranco, 1977

	HICKS LAKE		***PATTISON LAKE***		***LONG LAKE***	
	Volume (M3/YRX10 3)	Percent	Volume (M3/YRX10 3)	Percent	Volume (M3/YRX10 3)	Percent
WATER INPUTS						
Precipitation	475	16%	795	11%	982	12%
Ground Water	1,947	67%	5,448	73%	1,486	18%
Surface Water	0	0%	897	12%	5,499	66%
Surface Runoff	478	17%	286	4%	294	4%
TOTAL	2,901	100%	7,426	100%	8,261	100%
WATER OUTPUTS						
Evaporation	427	15%	841	11%	1,144	14%
Ground Water	2,473	85%	1,033	14%	3,288	40%
Surface Water	0	0%	5,510	75%	3,829	46%
TOTAL	2,901	100%	7,384	100%	8,261	100%
	Estimated Hydraulic Resident Time for a typical year = 1.13 volume/year		Estimated Hydraulic Resident Time for a typical year = 2.63 volume/year		Estimated Hydraulic Resident Time for a typical year = 2.5 volume/year	

Figure 2 - Hicks Lake Elevation



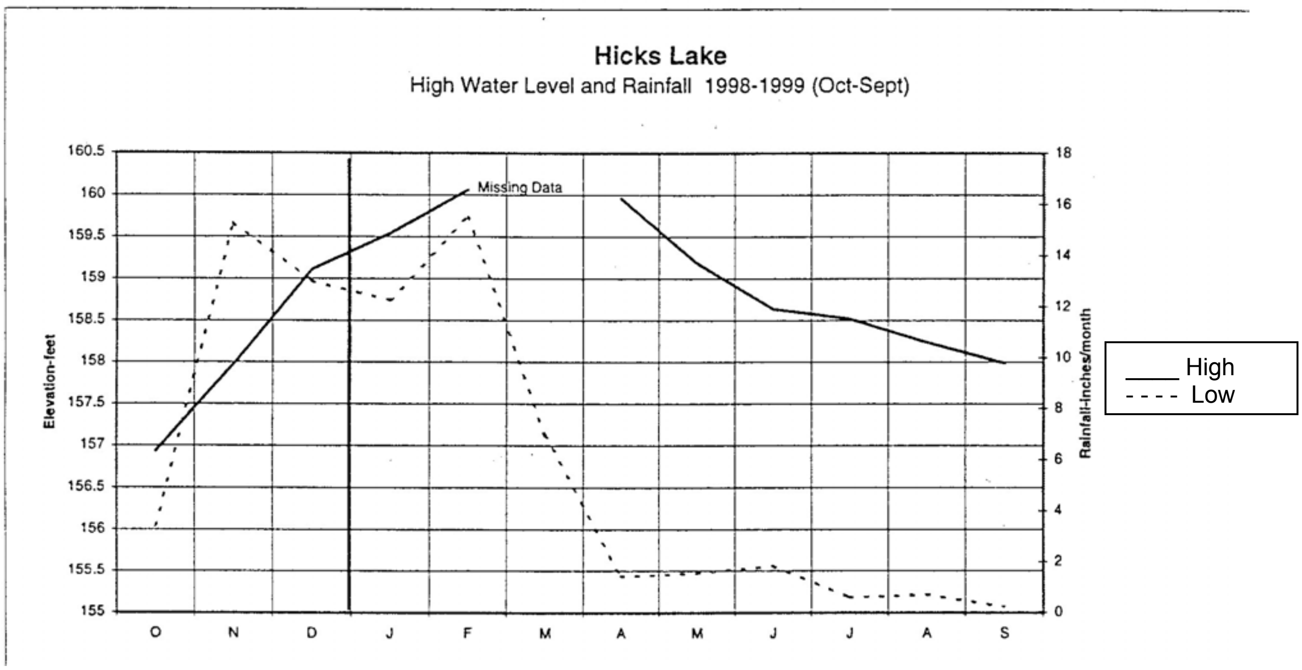
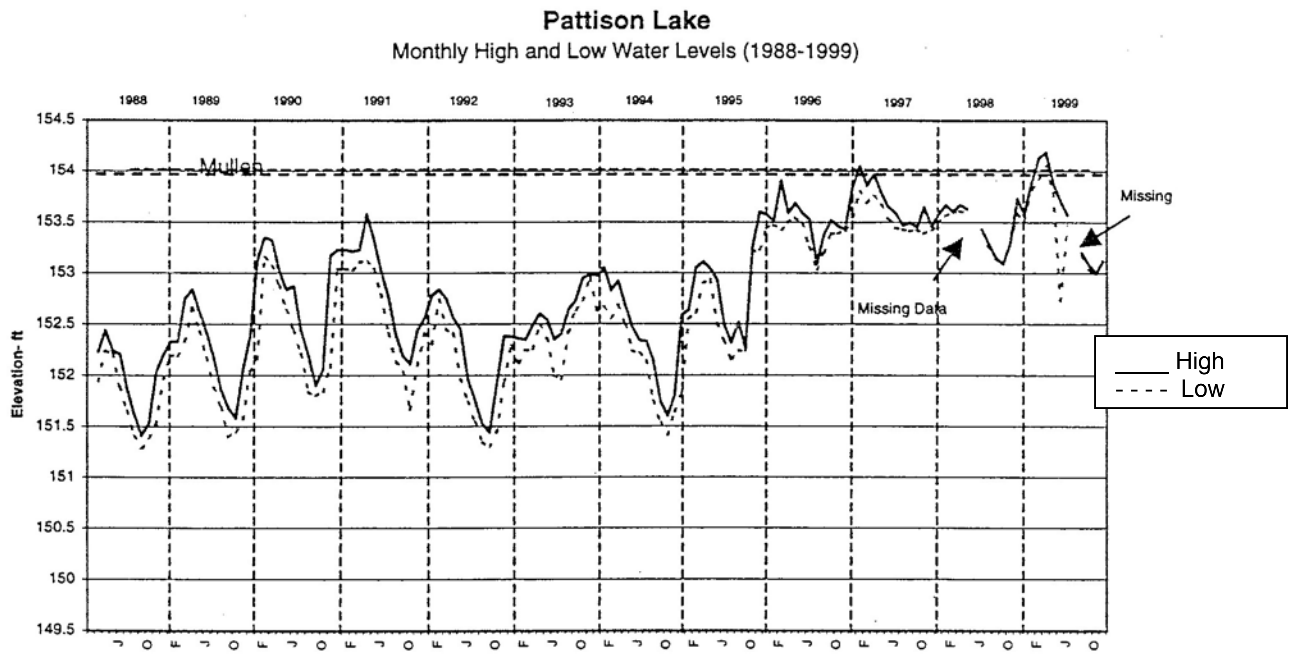


Figure 3 - Pattison Lake Elevation



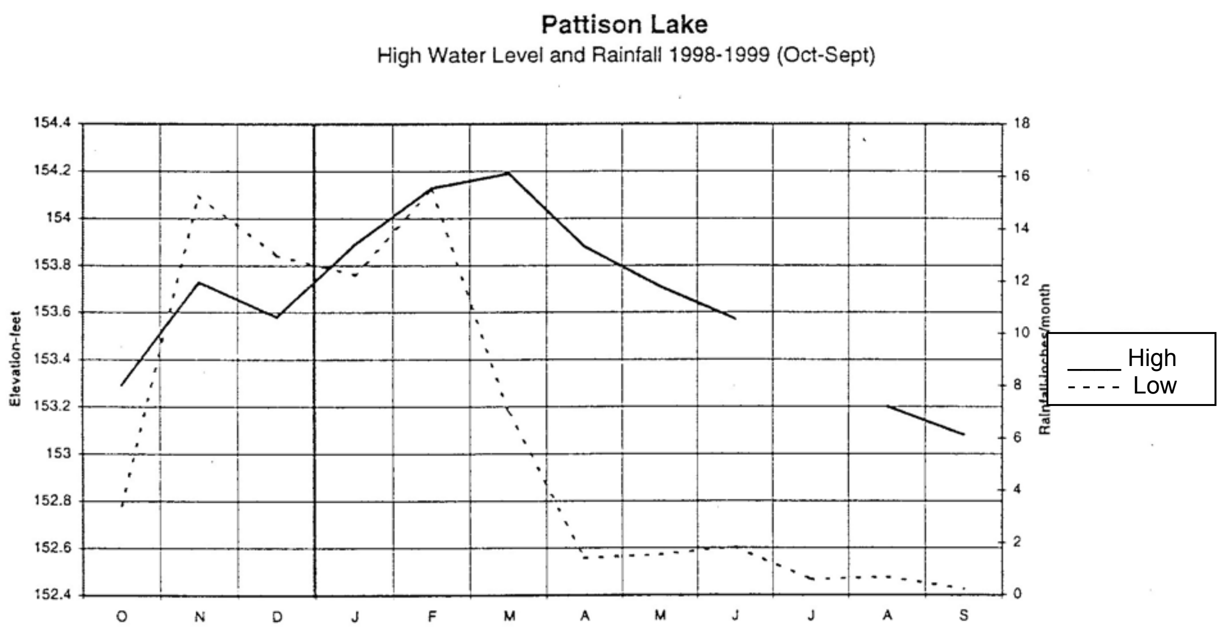
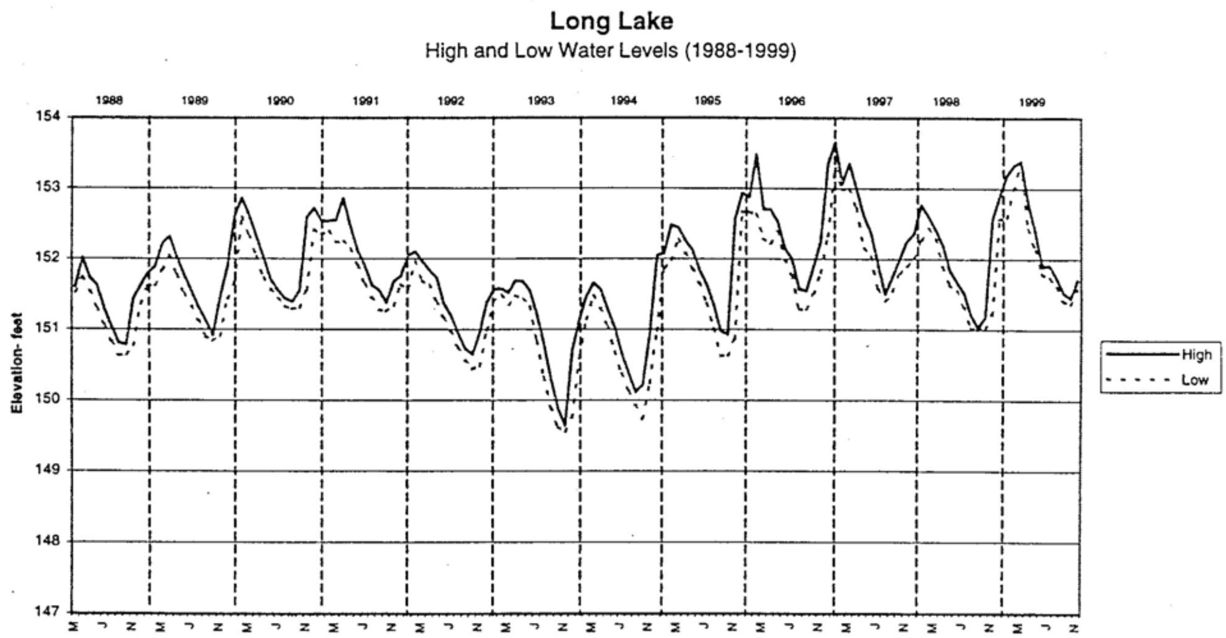
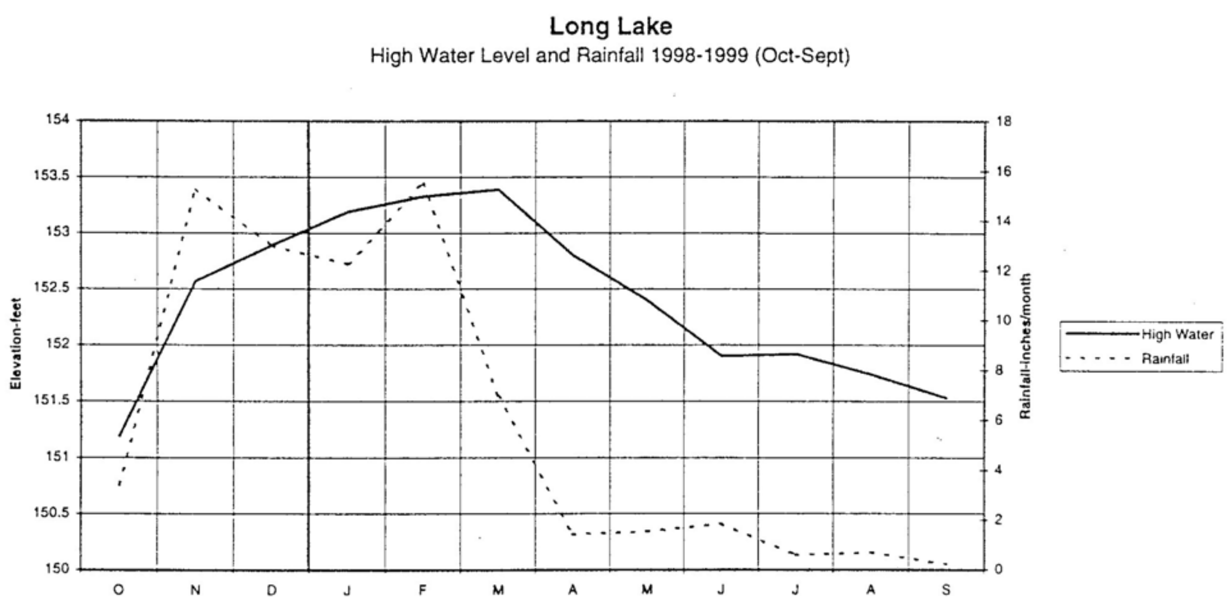


Figure 4 - Long Lake Elevation





Lake Lois Reach: Long Lake to Martin Way

Woodland Creek proper begins at the outlet from Long Lake. The one-mile section from Long Lake to Lake Lois (river mile 5.5 to 4.5) is largely a long-established ditch section with perennial flow. Between Lake Lois and just above Martin Way (stream miles 4.5 to 3.8) the stream channel often goes dry during the summer, becoming subsurface flow contributing to springs below Martine Way.

Streamflow continuous recording was collected by Thurston County at Martin Way for the water years from 1989 to 1993.[33] DOE collected monthly data at three stations between Lake Lois and Martin Way from January 1991 to September 1993.[34]

Mean flow

Stream flows in the Lake Lois reach vary widely according to season and overall precipitation. During 1993, there were 49 inches of precipitation. Average daily flow at Martin Way was 1.1 cfs, with the stream essentially dry for 278 days. In contrast, the 66 inches of rainfall in 1991 supported average flow of nearly 13 cfs, with the stream below 1 cfs for only 45 days.

There is anecdotal reference to earlier years when this reach of the stream is reported to have flowed year-around. However, there is no known stream gaging data to document or analyze this reported change in summer-flow conditions.

Peak flow

Peak flows in the Woodland Creek system above Martin Way are significantly attenuated due to storage in lakes and wetlands and infiltration into the porous soils. Hydrologic modeling was utilized for the Woodland/Woodard Creek Basin Plan to help analyze the effect of past human activities on existing streamflow. As shown on Figure 11, modeling indicates land use changes have had relatively little effect on peak flows at Long Lake or Martin Way.

As stated in the 1995 <u>Woodland and Woodard Creek Comprehensive Drainage Basin Plan</u>,

> Woodland Creek flows out of a large wetland and lakes complex that includes Hicks, Pattison and Long Lakes. The soils, lakes, wetlands and flat topography of this area absorb large quantities of rainfall and help to mitigate the impacts of development on the headwaters of the creek. Downstream from Long Lake, the creek enters Lake Lois, which stores and detains most of the stream flow. Figures 3-1- and 3-2 *(attached)* illustrate the effects of development on

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[33] <u>Woodland and Woodard Creek Comprehensive Drainage Basin Plan</u>, Thurston County et al, 1995.
[34] <u>Woodland Creek Water Quality Assessment Final Report: Ecology Building Project,</u> DOE Report # 94 – 62, April 1994.

Woodland Creek stream flows. The peak flows at the first two locations, Long Lake and Martin Way, exhibit relatively small increase over natural flows compared to downstream locations, because of the buffering effects of the wetlands.

In 1991, a regional stormwater facility was installed just downstream from Lake Lois to treat and store stormwater from an extensive area around Lacey Boulevard. This facility further attenuated the immediate effect of storm events on this reach of the stream.[35]

There is a location of active bank erosion between Lake Lois and Martin Way near the DOE building. Banks at this site are 10-15 feet of vertical eroding sand, but the stream corridor in the vicinity is otherwise well vegetated and generally undisturbed. This bank erosion appears to have been going on for many years. [36] The impact of this particular bank erosion on salmonids is undetermined at this time, as the erosion is occurring in a reach that is dry most ears during summer low flow. Eroded sediments have the potential to affect the substrate downstream from the erosion site. [37]

Lower Woodland Creek

The lower reaches of Woodland Creek are very distinct from the upper section. Major springs just below Martin Way provide year-around flow to the creek. North of I-5 till soils are common. Till soils do not infiltrate rainfall as readily as the outwash soils in the upper watershed. Thus, several tributary streams provide seasonal or year-around flow to lower Woodland Creek, including Eagle Creek, Fox Creek and Fox Hollow Creek on the east and Jorgenson Creek on the west.

Mean flow

From the perspective of total annual streamflow, the major springs below Martin Way are the dominant source of water for the stream. Streamflow response to low-flow conditions is much less dramatic downstream from Martin Way due to extensive, groundwater-fed wetlands and a large, spring-fed tributary (Beatty Springs) providing year-around base flow. [38] Flow for Beatty Springs alone was estimated by the USGS at over 6 cfs (about ¼ of McAllister Springs flow). Beatty Spring is supplied by the Qvr aquifer.[39]

The 1999 DOE Baseflow Report analyzed Pleasant Glade station data from 1949-1969 and 1988-1990, which is all available record for this station (see Figure 12). Baseflow –

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[35] Woodland/Woodard Basin Plan 1995 cited above. See page 3-16.
[36] Communication with Lisa Dennis-Perez, City of Lacey, 2/6/01.
[37] Salmon Habitat Limiting Factors Final Report, Water Resource Inventory Area 13, July 1999, Washington State Conservation Commission
[38] Woodland/Woodard Basin Plan 1995 cited above. See page 3-16.
[39] Conceptual Model and Numerical Simulation of the Groundwater Flow System in the Unconsolidated Sediments of Thurston County, Washington, USGS, 1999. Table 4 lists major springs and the associated geohydrologic units.

essentially, contribution from groundwater - is estimated to provide 96% of total mean annual streamflow to Woodland Creek at Pleasant Glade. (In contrast, for the 294 stream stations statewide evaluated in the DOE Baseflow report, median annual baseflow averaged 68% of total flow.) [40]

The median 7-day low flow (median daily flow during the lowest continuous 7-day period) for the years 1949-69 was 11 cfs – i.e. about 50% of the median flow during this period. This is a relatively steady baseflow: in contrast, median Deschutes River 7-day low flow is about 20% of the median flow. [41] .

Peak flow

Peak flows can have a significant affect on habitat and water quality conditions. Increased peak flow can increase fine sediment loads and alter natural flow regimes that are vital to maintenance of stream habitat. Lower Woodland Creek is subject to high peak flows due to rainfall events, followed by rapid return to baseflow when rain slackens. Downstream from Martin Way, the creek responds more quickly to individual rain events due to less porous soils, absence of detention area in wetlands or lakes, and runoff associated with the large stormwater systems draining the College Street/7th Avenue area and I-5.[42]

Annual peak flow from the 1950s-60s and the early 1990s is shown on Figure 13. As shown, peak flow was generally 50-150 cfs, with highest flow in 1951 (200 cfs).

The peak discharge at measured at Pleasant Glade during the basin plan intensive data collection was 160 cfs on November 24, 1990 – almost 12 times the average flow for November. In contrast, peak flow was significantly attenuated in the Lake Lois reach. Flow at Martin Way during the same rain event peaked at about 16 cfs, only 10% of the peak flow at Pleasant Glade and only about 2 ½ times the average November flow at the site.[43]

Lower Woodland Creek is cited on the 1998 303(d) List as low-impaired based on evidence of 1.) “Intensified peak flows likely due to the storm water effect of suburban development” and 2.) coho salmon decline. The basis for the listing was a Squaxin Island Tribe letter, which included analysis of streamflow from two periods – 1950-53 and 1988-94. These two periods were analyzed for the 2-day streamflow increase on current plus previous day precipitation sums. See SIT submittal at Attachment 1. [44]

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[40] Estimated Baseflow Characteristics of Selected Washington Rivers and Streams, Water Supply Bulletin No. 60, Washington Department of Ecology, 1999

[41] [41] Estimated Baseflow Characteristics of Selected Washington Rivers and Streams, Water Supply Bulletin No. 60, Washington Department of Ecology, 1999

[42] Woodland and Woodard Creek Comprehensive Drainage Basin Plan, Thurston County et al, 1995. See page 3-16.

[43] See above, page 3-16 – 1-17.

[44] Letter from Jeff Dickison for Squaxin Island Tribe on 2/27/96, submitted to Department of Ecology in support of 303(d) listings. Referenced in Final 1998 Section 303(d) List – WRIA 13, dated 4/4/00.

The City of Lacey is in design phase for a stormwater treatment facility on the College/7th Avenue stormwater system. This is the last untreated stormwater outfall discharging to Woodland Creek. [45]

Current and future stream response to rainfall events

Hydrologic modeling of stream response to rainfall events was conducted for pre-development, current conditions and future build out. The modeling explored stream response to both infrequent (100-year storms) and more common storm events (2-year storm), as illustrated on Figure 11. The smaller but more frequent storm events have been documented to have a greater influence on channel morphology and stream habitat than the large infrequent events such as the 100-year storm. [46]

Additional impacts are anticipated at full development even with the current (1995) drainage design standards for new development. As shown on Figure 11, significant impacts are modeled to occur on the lower creek. However, the model indicates little change over current flow conditions at Martin Way due to the significant upstream storage in lakes and wetlands and extensive infiltration of rainfall in the upper watershed, as discussed above.[47]

[45] Communication with Lisa Dennis-Perez, City of Lacey, 2/6/01
[46] Woodland and Woodard Creek Comprehensive Drainage Basin Plan, Thurston County et al, 1995.
[47] Woodland and Woodard Creek Comprehensive Drainage Basin Plan, Thurston County et al, 1995.

Figure 5 - Woodland Creek 2-Year and 100-Year Peak Flows

Figure 4-1 Impact of future development on Woodland Creek 2-year peak flows

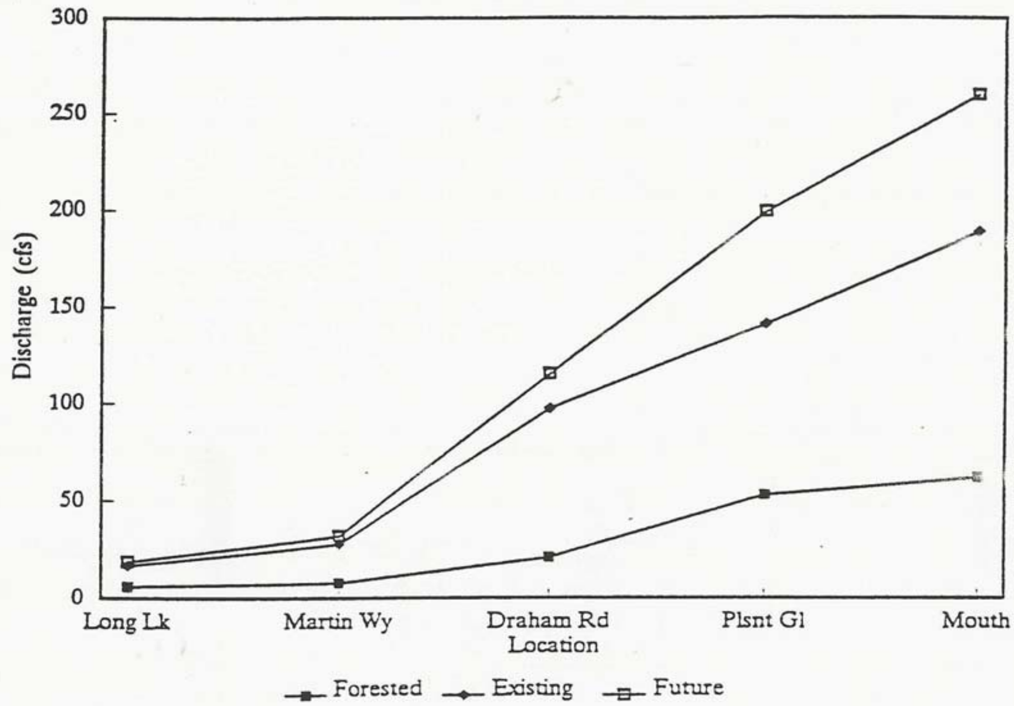


Figure 4-2 Impact of future development on Woodland Creek 100-year peak flows

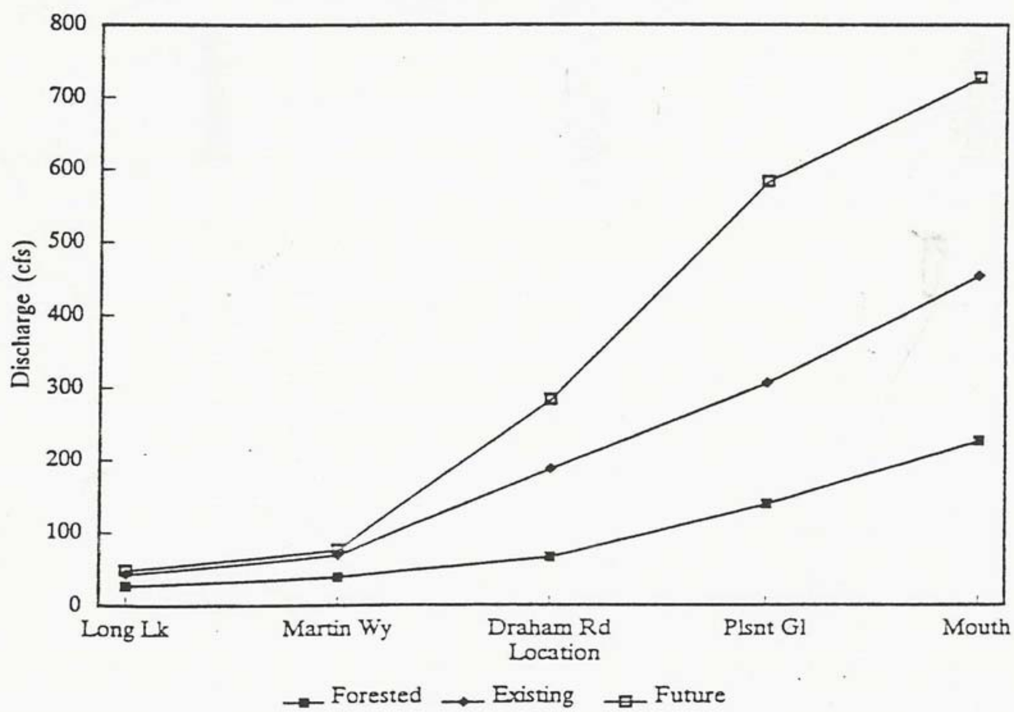


Figure 6 - Woodland Creek Monthly Mean Baseflow and Surface Runoff

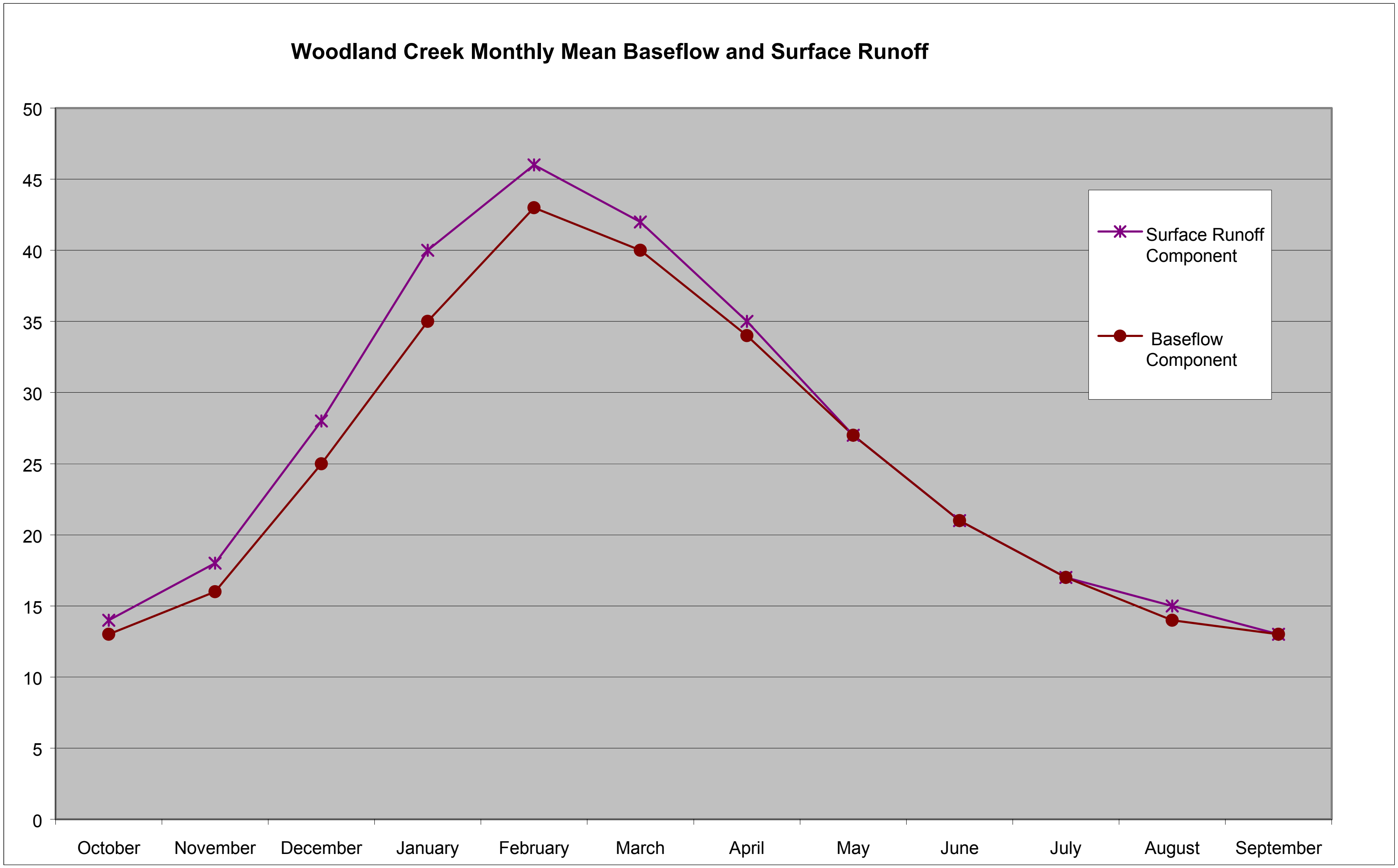


Figure 7 - Woodland Creek Annual Peak Flows

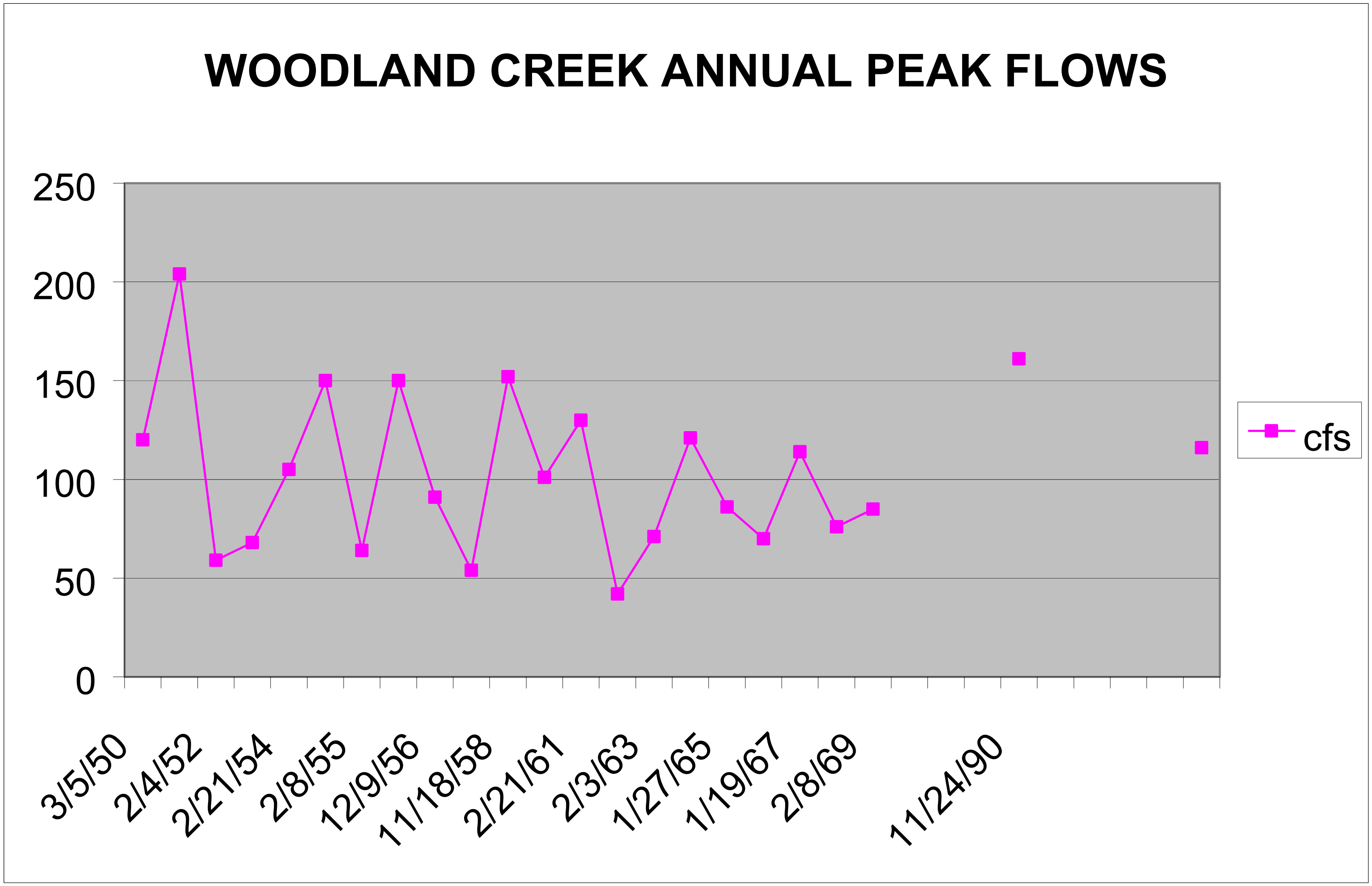
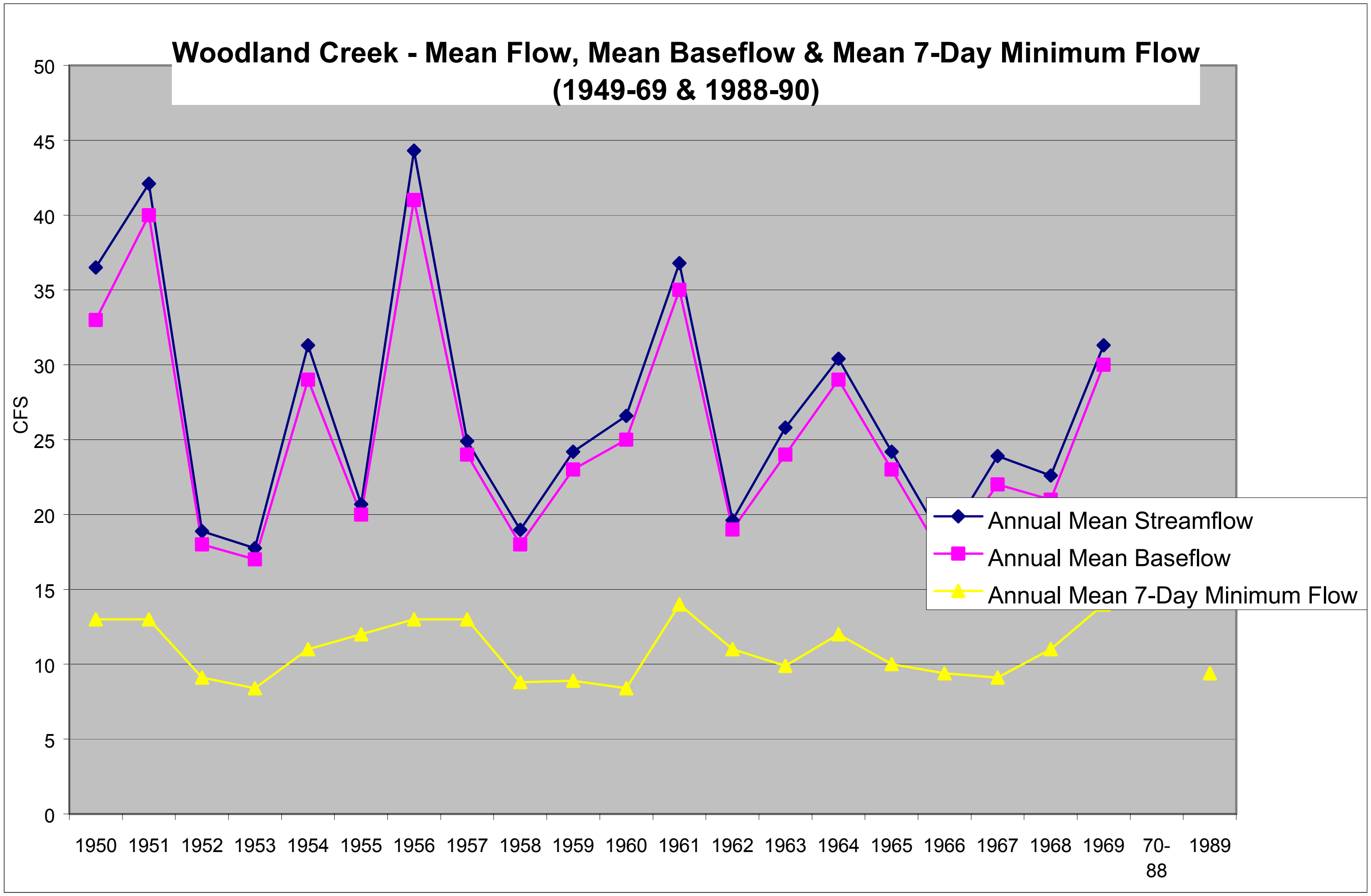


Figure 8 – Mean Flow, Base Flow and 7-Day Minimum Flow



Seepage Data

Seepage run data is useful in identifying "gaining" and "losing" reaches of a stream. During low-flow conditions, streamflow measurements are obtained at multiple points along the mainstem; tributary flows are also measured. Tributary flows are subtracted to derive change in mainstem flow between stations.

For Woodland Creek, three seepage data sets were identified as summarized on Table 1:

- 8/11/88 data collected as part of the USGS study. Stations ranged from Pattison Lake inlet (RM 10) to Pleasant Glade Road (RM 1.5). [48]
- 7/17/90 data from Long Lake outlet to Hollywoods (RM .5) by Thurston County Environmental Health (TCEH).
- 8/22/01 data from the same section of the stream by TCEH.

The "mainstem" Woodland Creek system has distinct "gaining" and "losing" reaches, as illustrated in Figures 1 and 2. In Figure 2, Beatty Springs inflow is excluded from the assessment of gaining and losing reaches. The USGS Groundwater Model Report indicated the spring input to Woodland Creek exceeded 6 cfs. Key findings from the seepage runs:

- Pattison Lake is a "gaining" reach with significant groundwater input. This water in turn provides significant surface water streamflow into Long Lake. About 73% of the input to Pattison Lake is calculated to come from groundwater and becomes surface flow into Long Lake. Conversely, Long Lake obtains only about 18% of its water budget from groundwater – but 40% of the lake water output is estimated to be flow to groundwater.[49]

- The Long Lake – Lake Lois reach (RM 5.5 to 4.5) is a markedly losing reach. In 1988 and 2001, the stream was dry or very low from Long Lake outlet to Lake Lois outlet (also dry at Martin Way.) In contrast, Long Lake outflow had nearly 8 cfs in the July 1990 survey. In 1990, flow declined slightly at Pacific Avenue to about 5.8 cfs. However, in the short Pacific Avenue to Lois outlet section, flow dropped to just over 1 cfs. On a per-stream mile basis, the Lake Lois section loss equates to over 17 cfs/mile.

- Below Martin Way, large springs support strong baseflow in Woodland Creek. As shown on Figure 1, similar flow in lower Woodland Creek was measured in all three study years. The principle source for the dramatic increase below Martin Way is Beatty Springs (Nisqually Trout Farm). USGS assumed 6.4 cfs flow from this source (see Table 1). Other springs are located between Martin Way and I-5, although these are difficult to gauge due to the extensive wetlands.

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[48] [48] Conceptual Model and Numerical Simulation of the Groundwater Flow System in the Unconsolidated Sediments of Thurston County, Washington, USGS, 1999. See Table B-2 for USGS seepage data.
[49] Thurston County Lakes Restoration – Environmental Description, Entranco Engineers, 1977.

- Significant additional groundwater input is provided below Draham Road. In all three seepage studies, about 4 cfs was added between Draham and Pleasant Glade (about 1 river mile distance). Particularly in the 2001 study, strong input continued downstream to Hollywoods (about ½ mile from the stream mouth at South Bay Road.) In the lower 3 miles of the creek, gain was roughly 3 – 5 cfs/mile in all three study years.

  Groundwater input to the “mainstem” is likely overstated for this reach, as both Fox Creek and Eagle Creek enter the stream in the Draham/Pleasant Glade reach. These are generally perennial streams but were not measured in any of the three seepage runs.

The strong groundwater input to lower Woodland Creek is also evidenced in the “baseflow” analysis performed by DOE, as part of a statewide streamflow analysis project.[50] As shown on Figure 12, the DOE analysis found baseflow comprised a very large part of total streamflow – in winter months as well as summer. During the low-flow period, Beatty Springs and other groundwater seepage sustain flows in lower Woodland Creek. As shown on Figure 13A, annual mean 7-day minimum flow was sustained at about 8 – 14 cfs from 1949-1969. This consistent low-flow condition contrasts with variation in annual precipitation and in annual mean streamflow. During the 1949-69 period, annual mean streamflow varied from under 20 cfs to nearly 45 cfs.

[50] Estimated Baseflow Characteristics of Selected Washington Rivers and Streams, Water Supply Bulletin No. 60, Washington Department of Ecology, 1999

TABLE 1: WOODLAND CREEK SEEPAGE STUDIES - 1988 TO 2001

		8/11/88 USGS			7/16/90 TCEH			8/22/01 TCEH		
Location	**River Mile**	**Flow**	**Change Minus Tribs**	**Change/mile**	**Flow**	**Change Minus Tribs**	**Change/mile**	**Flow**	**Change Minus Tribs**	**Change/mile**
Pattison inlet	RM 10	0.19 cfs								
Pattison outlet	RM 8	3.20 cfs	3.01 cfs	1.5 cfs/mile						
Long outlet	RM 5.5	0.69 cfs	-2.51 cfs	-1.0 cfs/mile	7.45 cfs			no flow		
Pacific Ave	RM 4.75	0.43 cfs	-0.26 cfs	-0.3 cfs/mile	5.79 cfs	4.75 cfs	-2.2 cfs/mile	0.00 cfs		
Lake Lois outlet	RM 4.5	0.00 cfs	-0.43 cfs	-1.7 cfs/mile	1.42 cfs	4.50 cfs	-17.5 cfs/mile	0.00 cfs		
Martin Way	RM 3.75	0.00 cfs	0 cfs	0.0 cfs/mile						
Trib - Beatty Springs (1)		6.4 cfs								
Draham Rd	RM 3	8.00 cfs	1.60 cfs	2.1 cfs/mile	12.20 cfs	4.38 cfs	4.4 cfs/mile	9.27 cfs	2.87 cfs	1.9 cfs/mile
Pleasant Glade Rd	RM 1.5	12 cfs	4 cfs	2.7 cfs/mile	17.53 cfs	5.33 cfs	4.3 cfs/mile	13.88 cfs	4.61 cfs	3.1 cfs/mile
Trib - Jorgenson Crk (2)		0.61 cfs								
Hollywoods					18.32 cfs	0.79 cfs	0.8 cfs/mile	17.56 cfs	3.68 cfs	3.7 cfs/mile

Notes:

(1) Beatty Springs data from USGS Thurston County GW Model Report Table 4. Citation is 7/26/89, source shown as "reported".

(2) Jorgenson Creek flow from 1988 USGS seepage study. Not subtracted from 1990 and 2001 Thurston County Environmental Health data.

Other tributaries with likely flow not included in studies include Eagle Creek and Fox Creek (enter Woodland Creek between Draham and Pleasant Glade stations)

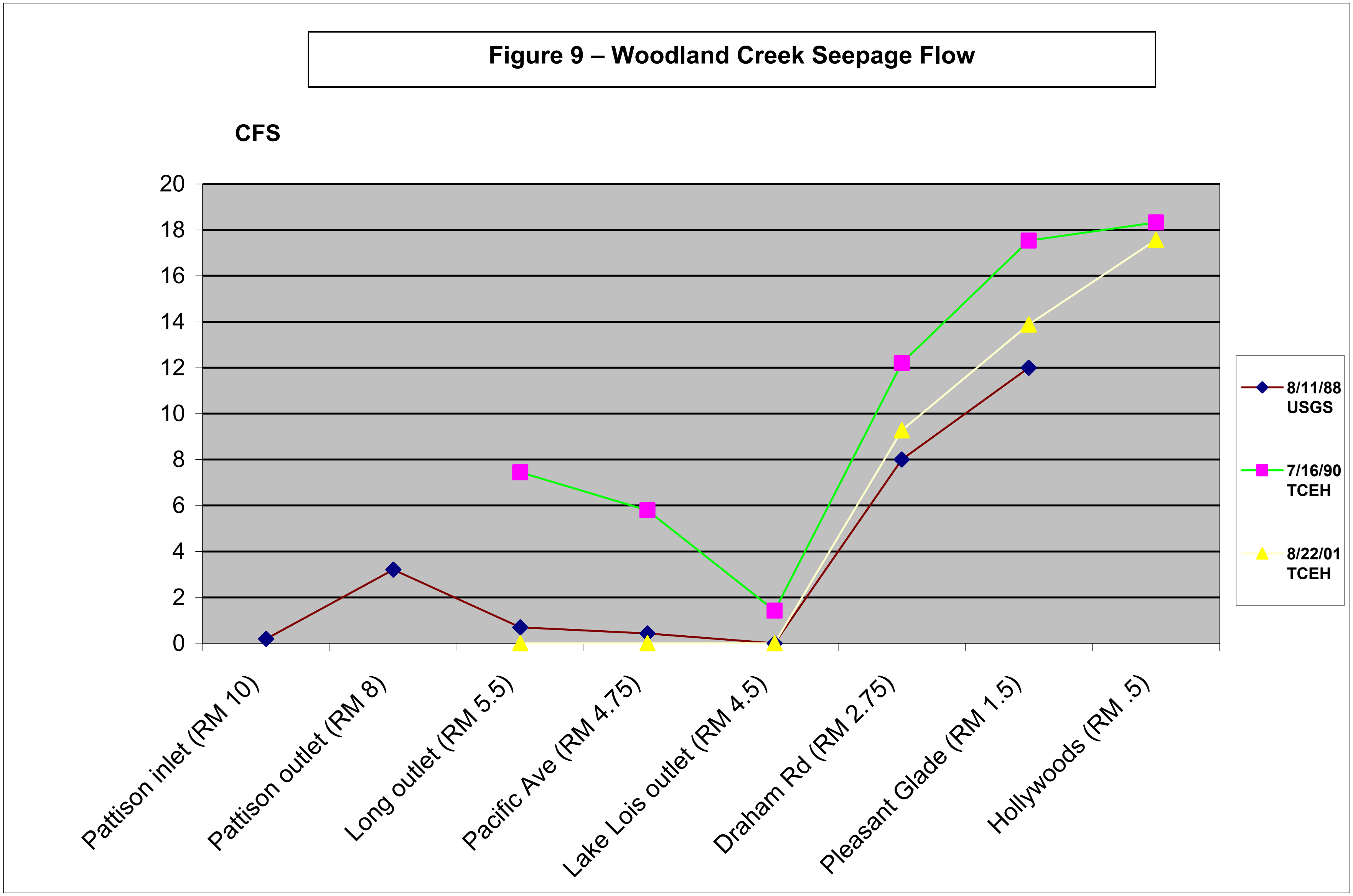


Figure 9 – Woodland Creek Seepage Flow
CFS
20
18
16
14
12
10
8
6
4
2
0
Pattison inlet (RM 10)
Pattison outlet (RM 8)
Long outlet (RM 5.5)
Pacific Ave (RM 4.75)
Lake Lois outlet (RM 4.5)
Draham Rd (RM 2.75)
Pleasant Glade (RM 1.5)
Hollywoods (RM .5)
8/11/88 USGS
7/16/90 TCEH
8/22/01 TCEH

5.4.2 Woodard Creek

Woodard Creek flows north from near the I-5/Pacific interchange for 7 ½ miles to Woodard Bay, about mid-way up the west side of Henderson Inlet. The watershed is very narrow, covering an area 1 – 1 ½ miles wide and about 6 miles long. Five short tributaries provide seasonal flow to Woodard Creek.

The creek originates in an extensive wetland south of I-5 and west of Fones Road. The groundwater-fed springs maintain year-around base flow in Woodard Creek. Average flow for the period of record for Woodard Creek at 36th Avenue NE (1988-1997) was 11.9 cfs. Peak flow during the period of record is 90 cfs recorded on 4/5/91. Minimum flow of 1.5 cfs was recorded several times in 1994 and 1995. [51] During typical years, the stream flow generally stays above 9 cfs. [52]

Extreme peak flows during heavy rains characterize the hydrology of Woodard Creek, but the effect is more pronounced near the headwaters. A major stormwater ditch draining South Sound Center and the Pacific Avenue/Fones Road commercial area (Fones Road Ditch) discharges near the headwaters of the creek. Further downstream, peak flows are somewhat attenuated by extensive wetlands between Fones Road and St. Peters Hospital, and the "impoundments" created by the fills for I-5, Pacific Avenue and Martin Way.[53]

Development and clearing are modeled to have had a significant impact on the more frequent flows, such as the 2-year events, which are more damaging to habitat than the rarer very high (100-year) flows. Current versus pre-development (forested condition) flows are illustrated on Figure 2.3-7. This figure includes modeled future peak flows at full build out. The predicted increases in 2-year storm flow are greater downstream because of tributaries that enter below Ensign Road. The peak 100-year storm flows are greater upstream due to runoff from the commercial area near the headwaters.[54]

[51] Thurston County Water Resources Monitoring Report 1996-1997 Water Year, Thurston County Storm & Surface Water Program and Environmental Health.
[52] Woodland and Woodard Creek Comprehensive Drainage Basin Plan, Thurston County et al, 1995. See page 3-18.
[53] Same cite.
[54] Same cite.

Figure 10 - Woodard Creek 2-Year and 100-Year Peak Flows

Figure 4-3 Impact of future development on Woodard Creek 2-year peak flows

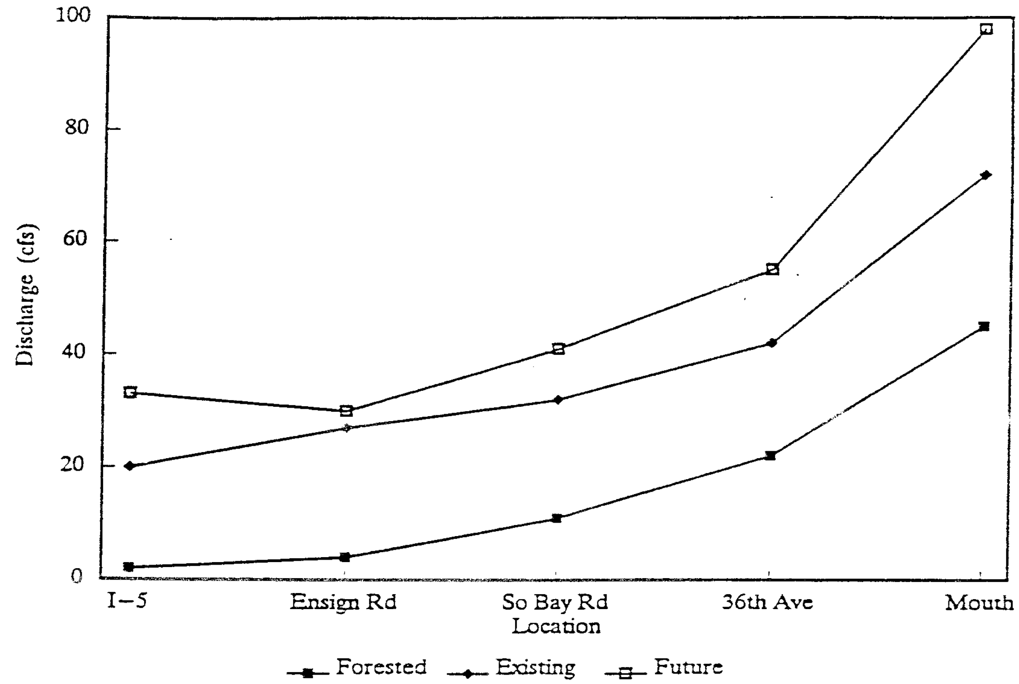
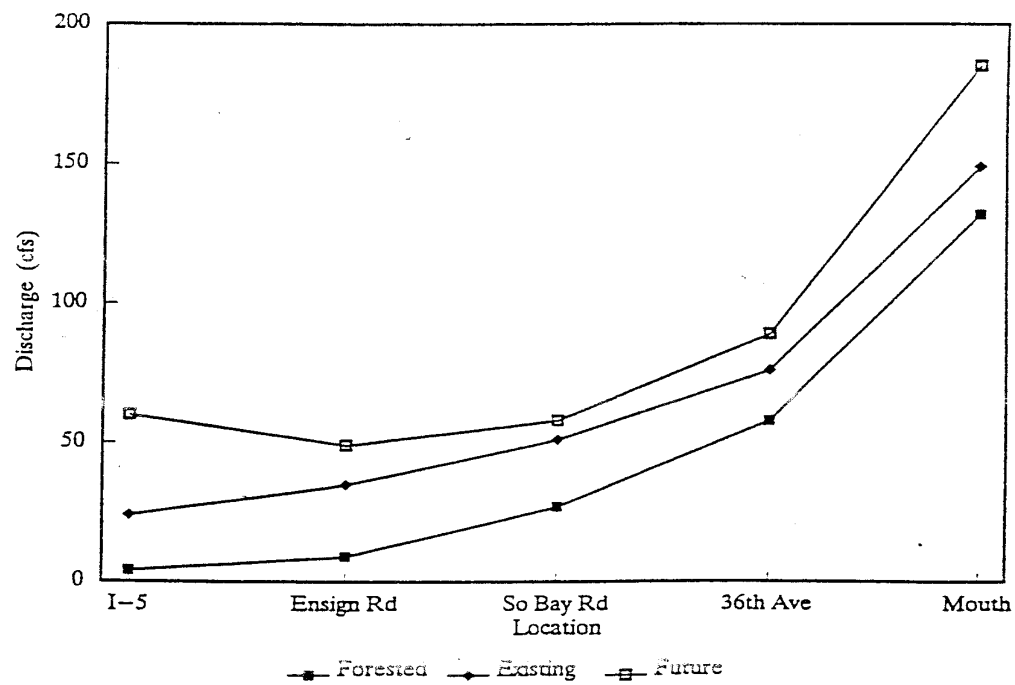


Figure 4-4 Impact of future development on Woodard Creek 100-year peak flows



5.4.3 Smaller Marine Drainages

Several smaller streams discharge directly to Henderson Inlet, as shown on the table at the beginning of the Henderson Inlet section. These streams drain an area of relatively poorly drained soils formed under glacial lake and till conditions (such as Kapowsin and Skipopa), compared to the deeper rapidly draining outwash soils in the southern portion of the watershed (such as Everett soils).[55] Kapowsin and Skipopa are classed in Hydrologic Soil Group D, while Everett is in Group A. Group D maximum infiltration rates with dense vegetation are calculated at 0.60 inches/hour, which contrasts sharply with Group A infiltration with dense vegetation at 6.00 inches/hour. Thus, even in undeveloped conditions these low-permeability soils can generate significantly more runoff than the outwash soils. With clearing for pasture and other low-density uses, infiltration is further reduced (.30 inches/hour infiltration for Group D under light vegetation conditions). [56]

Due to their potential for conveying residential and agricultural pollutants to the Inlet, Dobbs, Meyer and Sleepy Creeks were intensively monitored for several years by the Thurston County Health Department. Generally, sampling included discharge measurements performed four times during winter and once or twice during the summer months.

Dobbs Creek

This 1.5-mile creek originates near Puget Road on the east side of Henderson Inlet. The creek flows through woodlands and open pastures, with gently rolling terrain.

Flows of 4 to 8 cfs were commonly measured in winter. Peak flows exceed 16 cfs (highest measured flow before the creek became too deep to measure). September flows were around .75 cfs.

Meyer Creek

This is a small (one mile long) seasonal drainage into the west side of Henderson Inlet near the end of Shincke Road. It is impacted mainly by agricultural practices. Measured flows were mainly less than 1 cfs, with flows in excess of 7 cfs occasionally measured.

Sleepy Creek

This is a 1.1-mile seasonal drainage into Chapman Bay (just north of Woodard Bay) on the west side of Henderson Inlet. The stream originates in a wetland and flows through a series of gullies and ravines to Chapman Bay. Winter flows of 6 – 13 cfs were commonly recorded. Flow was commonly absent or very minimal during the summer sampling periods.

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[55] Soil Survey of Thurston County, Washington, 1990, USDA Soil Conservation Service
[56] Drainage Design and Erosion Control Manual for Thurston County, 1994