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DEPARTMENT OF
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Relationship Between the Upper Dungeness River and the Bedrock Aquifer, Clallam County

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Relationship Between the Upper Dungeness River and the Bedrock Aquifer, Clallam County

by
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Abstract

In September and October 2000, the Department of Ecology's Stream Hydrology Unit conducted geologic and hydrologic reconnaissance and a synoptic-flow (seepage-run) study on the upper Dungeness River in Clallam County, Washington. The study reach lies between the U.S. Geological Survey cable-way gage at river mile 11.8 and the confluence with the Gray Wolf River at river mile 15.9. The study purpose was to evaluate the interaction between the upper Dungeness River and the underlying bedrock aquifer.

The synoptic-flow study, combined with the geologic and hydrologic reconnaissance, revealed an overall gain in the river discharge of 7.8 cfs across the four-mile study reach. The study also showed five intermediate gains and four intermediate losses within the study reach, indicating a complex relationship between ground water and surface water.

The intermediate gains and losses are attributed to exchange of water within the hyporheic zone, rather than to permanent losses to or gains from bedrock. The overall gain (7.8 cfs) across the four-mile study reach is attributed to gradual (1.95 cfs/mile) ground-water discharge to the river from the bedrock and colluvium along the steep sides of the river valley.

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Summary

In September and October 2000, the Washington State Department of Ecology (Ecology) Stream Hydrology Unit (SHU) conducted geologic and hydrologic reconnaissance and a synoptic-flow (seepage-run) study on the upper Dungeness River in Clallam County, Washington. The study reach lies between the U.S. Geological Survey cable-way gage (USGS 12048000) at river mile (RM) 11.8 on the Dungeness River and the confluence with the Gray Wolf River at RM 15.9.

The purpose of this study was to 1) evaluate the interaction between the upper Dungeness River and the underlying bedrock aquifer and 2) provide synoptic-flow data to evaluate the river gains and losses in the study reach.

Upstream of the USGS gage, the river flows across bedrock which, in many areas, is overlain by course, gravelly alluvium and colluvium. It has generally been assumed over the years that the upper surface of the bedrock is essentially a no-flow boundary across which there is very little interaction between the river and the bedrock aquifer.

It has been postulated, however, that a significant amount of river water may be lost from the study reach to bedrock joints or fractures. It has also been postulated that the suspected lost river water may recharge deep aquifers in the lower Dungeness Valley via bedrock fractures.

The synoptic flow measurements indicated an overall gain in the river discharge of 7.8 cubic feet per second (cfs) across the four-mile study reach. The results also showed five intermediate gains and four intermediate losses in sub-reaches of the study reach. As shown in Figure 4, the most significant gain was in Reach #2, where the river gained 11 percent of its volume or 12.7 cfs (3.63 cfs/0.1 mile). Two significant losses were detected: the river lost 10.2 cfs (-10.2 cfs/0.1 mi.), or 7.84 percent of its total volume, in Reach #3; and lost 6.6 cfs (-3.32 cfs/0.1 mi.), or 6.47 percent of its total volume, in Reach #9. These intermediate gains and losses indicate an underlying complexity in the ground-water/surface-water relationship that is not apparent when one looks only at the overall measured gain.

The intermediate gains and losses are attributed to exchange of water to and from the hyporheic zone, rather than permanent losses to or gains from bedrock. The overall gain (7.8 cfs), along the four-mile reach, is attributed to gradual (1.95 cfs/mile) ground-water discharge to the river from the bedrock and colluvium along the steep sides of the river valley.

Acknowledgements

Many people contributed to this report and the associated field work necessary to complete the project. The authors would like to thank:

- *Ann Soule*, Clallam County Natural Resources Division, for help in planning this study and for technical peer reviews of the Quality Assurance Project Plan (QAPP) and the draft report.

- *Mike Jeldness*, Dungeness River Management Team, for assistance with river-access questions and for his local expertise and knowledge.

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- *Cynthia Nelson*, Ecology's Shorelands and Environmental Assistance Program, for help in coordinating the project with Clallam County and the Dungeness River Management Team, and for review of the QAPP.

Introduction

As the human population increases in the city of Sequim and the Dungeness River watershed, demands for surface water and ground water increase as well. Surface-water and ground-water resources are being stretched to their limits. Not only is water needed for a myriad of uses deemed beneficial to humans, but also to maintain streamflow necessary to support salmon and other species. It is becoming increasingly necessary to manage the water resources of the watershed efficiently and wisely to satisfy these competing resource needs.

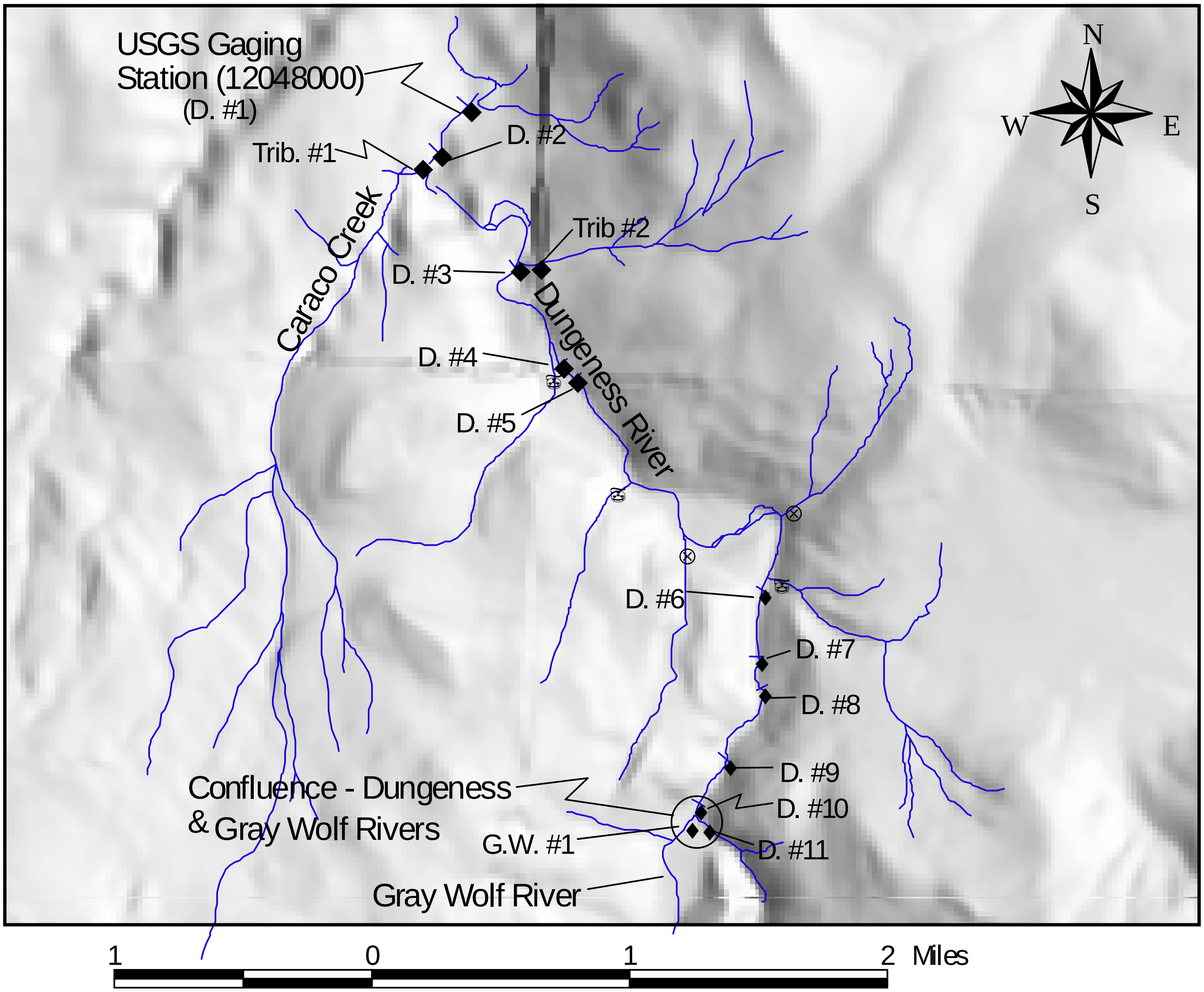
The river flows on a bedrock base in the study reach, upstream of the U.S. Geological Survey (USGS) gage. In many areas along this reach the river flows on and through a hyporheic zone of course, gravelly alluvium and colluvium overlying the bedrock. It has generally been assumed over the years that the upper surface of the bedrock is essentially a no-flow boundary across which there is very little interaction between the river and the bedrock aquifer.

It has recently been postulated, however, that a significant amount of river water may be lost to bedrock fractures upstream of the USGS gage. This theory is based partially on local lore and partially on an unpublished measurement of the Dungeness River at about mile 15.8, below the confluence with the Gray Wolf River, and river discharge based on the flow-rating curve for the USGS gage (USGS 12048000), at about mile 11.8 (Figure 1). This discharge comparison was conducted on September 4, 1998, and indicated an apparent loss of about 16 cubic feet per second (cfs), or about 13 percent of the total river volume on that date (Jeldness, 2000).

It has also been postulated that the “lost” river water may recharge deep, unconsolidated aquifers in the lower Dungeness Valley via bedrock fractures, at depth. The cross sections in Appendix A illustrate the relationship between bedrock and the deep aquifers in the lower Dungeness River valley.

In September and October 2000, the Stream Hydrology Unit (SHU) of Ecology’s Environmental Assessment Program conducted geologic and hydrologic reconnaissance and a synoptic-flow study (seepage-run) on the Dungeness River reach between river miles 15.8 and 11.8 to determine if the loss of river water in fact occurs.

The project was conducted at the request of and in support of the goals of the Dungeness River Management Team and Clallam County. Currently, there are at least two other research projects being conducted in the Dungeness River watershed which are designed to: 1) define the relationship between the Dungeness River and ground water (Simonds et al, 1999); and 2) measure surface-water flow, and monitor surface-water quality (Sargeant, 2000). The project by Simonds et al (1999) focuses on the river/aquifer relationships of the Dungeness River watershed downstream of the USGS gage. Here, the river flows north across an eight-mile wide, north-sloping plain of glacial deposits before emptying into the Strait of Juan de Fuca. The project by Sargeant (2000) is a Total Maximum Daily Load (TMDL) study designed to identify bacterial sources in the Dungeness River watershed that contribute to poor water quality in Dungeness Bay.



Legend

- ♦ Flow Measurement Site - Showing station ID, where "D." = Dungeness R. and "G. W. " = Gray Wolf R.
- ⊗ Dry Tributary - No flow measurement.

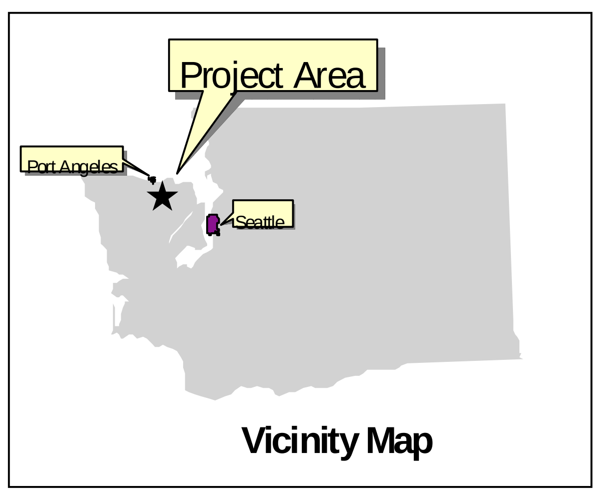


Figure 1
Upper Dungeness Project Area and Flow-Measurement Locations

A valuable bonus to this study is that the upper Dungeness synoptic-flow study was conducted the day after SHU personnel assisted the USGS with a fall, low-flow, synoptic-flow study of the Dungeness River downstream of the USGS gage at river mile (RM) 11.8 (Simonds et al, 1999). This means that essentially one seepage run study was conducted on a 15-mile reach of the river (RM 15.8 to RM 0.73) in two days. These two studies combined include instantaneous flow measurements at a total of 30 sites, including 17 on the mainstem plus all of the flowing tributaries, outflows, and return flows along the 15-mile reach. Data of this caliber and completeness is unprecedented in the history of work in the watershed and should prove to be very valuable to those studying water issues in the watershed.

Study Objective

The objective of this study is to 1) evaluate the interaction between the upper Dungeness River and the underlying bedrock aquifer and 2) provide synoptic-flow data to evaluate the river gains and losses in the study reach. A direct connection between bedrock fractures in the river bed and recharge to deep, unconsolidated aquifers in the lower Dungeness River valley would be very difficult to prove and is outside the scope of this project.

Study-Area Description

The study area encompasses an approximately four-mile reach of the Dungeness River bounded on the south (upstream end) by the confluence with the Gray Wolf River and on the north by the USGS stream gage number 12048000 (Figure 1). The river flows to the north from the Olympic National Forest and the Buckhorn Wilderness. Through the study reach, it descends from an elevation of about 830 feet above mean sea level (msl) at the Gray Wolf/Dungeness confluence, to 569 feet above msl at the USGS cable-way gage – a total drop of approximately 260 feet – an average gradient of about 65 feet per mile. The USGS gage defines the southern (upstream) termination of stream gaging associated with the Simonds (1999) study of ground-water/surface-water interaction on the Dungeness River.

Within the study reach, the Dungeness River flows through a narrow, remote, roadless valley with mostly high, steeply sloping, vegetated sides. According to Tabor and Cady (1978), the river flows on bedrock through the upper three miles of this reach and then on thin river alluvium and colluvium, underlain by bedrock, through most of the lower mile of the study reach.

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Methods

Geologic and Hydrologic Reconnaissance

To complete the geologic and hydrologic reconnaissance, the authors walked the entire length of the study reach in three segments over a three-day period. Geologic features and outcrops observed along the river were compared to published geologic information (Tabor and Cady, 1978; Schasse and Logan, 1998; Othberg and Palmer, 1979). We did not venture out of the valley, nor did we do independent mapping of geologic units, as the project scope did not allow for comprehensive geologic mapping or assessment. All bedrock outcrops were visually inspected and physical features – such as composition, color, layering, blockiness, presence or absence of fracturing, and fracture orientation – were noted. To supplement the field notes, photographs were taken of many outcrops. The locations of major bedrock outcrops and other features were marked on the 1:24,000 topographic quadrangle map by inspection of the topography and with the aid of stereo-pair aerial photographs.

The hydrologic reconnaissance was conducted in conjunction with the geologic reconnaissance. Hydrologic features were noted, described, and photographed. River flow and the river's relationship to the river-bed substrate (bedrock; gravel bars; thin gravel layers; or course, thick gravel layers) were noted. Morphologic features of the river such as braided segments, straight stretches, and relative slope of the river bed were also noted and photographed.

River-discharge measurement sites for the synoptic flow study were located during the reconnaissance study. These locations were based on the flow-section-selection criteria outlined in SHU (1999, p. 4) and on the relationship of the river with the substrate. For instance, if the river formed a deep pool against a large, fractured bedrock outcrop, we tried to locate flow sections above and below the outcrop – to see if the river lost water to the bedrock fractures. Likewise, measured section locations were placed to bracket a variety of representative flow regimes and geologic river-bed conditions. No measured sections were located in braided stream areas, because they do not fit the selection criteria for acceptable flow-measurement cross sections. However, cross sections were sited above and below braided areas to identify changes in discharge across those areas.

Flow Measurement Methods

On October 5, 2000, six members of the SHU conducted a synoptic flow study of the Dungeness River between river miles 15.8 and 11.8. The study consisted of eleven instantaneous discharge measurements on the mainstem of the Dungeness River, measurements of two tributaries, and one measurement at the mouth of the Gray Wolf River (Figure 1). SHU personnel split up into three two-person teams, and the three teams worked simultaneously on specific segments of the river.

1. Team 1 started at the lower end of the reach by first establishing a reference measuring point at the USGS gage at RM 11.8, herein referred to as Dungeness #1 (Figure 1). The established USGS staff gage at the site was high and dry of the water surface, so a measuring point was established on a stable log overhanging the water. The distance from the reference point down to the water surface was measured and noted as the reference point measurement for the beginning of the day (See River Stage Flux, Table 1). The team then hiked to the measurement site designated as Dungeness #3 at about RM 12.75 where the first flow was measured at 09:15. The flow of Tributary #2 was measured next. The team then proceeded downstream to the three remaining measurement sites, Tributary #1 (Caraco Creek), Dungeness #2 (RM 12.0), and Dungeness #1 where flows were measured at 11:00, 11:35, and 13:40, respectively (Figure 1 and Table 1). A replicate measurement of Dungeness #1 was made, for quality assurance purposes, immediately afterwards at 14:50. After the last flow measurement, the reference point height at Dungeness #1 was measured and noted. This identified the change in river stage that had occurred throughout the day (River Stage Flux, Table 1).

Table 1 - Upper Dungeness River Seepage Run - Data Summary Sheet - October 5, 2000

Station Name	Measurement ID	Measurement Date	Measurement Time	River Stage Flux(1)	Discharge (cfs)	Percent Difference from Mean	Average Discharge	Gain or Loss (cfs)(2)	Overall Gain or Loss (cfs)(2)
Gray Wolf River near mouth	Gray Wolf #1	10/5/00	16:55	NC	53.78				
Dungeness R. at bridge above Gray Wolf at about RM 15.95	Dungeness #11a	10/5/00	15:00	NC	63.48				
Dungeness R. at bridge above Gray Wolf at about RM 15.95	Dungeness #11b	10/5/00	15:40	NC	63.05	0.680	63.27		
Dungeness R., below Gray Wolf at about RM 15.8	Dungeness #10	10/5/00	13:30	NC	118.17				
Dungeness R. at about RM 15.6	Dungeness #9a	10/5/00	16:10	NC	116.57				
Dungeness R. at about RM 15.6	Dungeness #9b	10/5/00	17:15	NC	119.29	-2.306	117.93	**-0.24**	
Dungeness R. at about RM 15.25	Dungeness #8	10/5/00	14:45	NC	130.64			**12.71**	
Dungeness R. at about RM 15.15	Dungeness #7	10/5/00	13:30	-0.02	120.40			**-10.24**	
Dungeness R. at about RM 14.9	Dungeness #6	10/5/00	10:30	NC	123.74			**3.34**	
Dungeness R. above old Clink Bridge at about RM 13.35	Dungeness #5	10/5/00	8:40	NC	124.09			**0.35**	
Dungeness R. below old Clink Bridge at about RM 13.28	Dungeness #4	10/5/00	10:15	NC	128.41			**4.32**	
Dungeness R. at about RM 12.75	Dungeness #3	10/5/00	9:15	NC	128.15			**-0.26**	
Un-named tributary at about RM 12.75	Tributary #2	10/5/00	10:05	NC	0.03				
Caraco Creek near mouth	Tributary #1	10/5/00	11:00	NC	0.12				
Dungeness R. at about RM 12.0	Dungeness #2	10/5/00	11:35	NC	132.61			**4.31**	
Dungeness R. at USGS gage, at about RM 11.8	Dungeness #1	10/5/00	8:00 - 14:50	-0.01	--				
Dungeness R. at USGS gage, at about RM 11.8	Dungeness #1a	10/5/00	13:40	NC	125.55				
Dungeness R. at USGS gage, at about RM 11.8	Dungeness #1b	10/5/00	14:50	NC	126.40	-0.675	125.98	**-6.64**	**7.80**

(1) -- Shows change in river stage during each discharge measurement. NC = No Change in river stage;
A negative value indicates the river stage fell during the course of the discharge measurement, or during the time frame shown.

(2) -- Positive values indicate a gain, negative values indicate a loss.

2. Team 2 hiked to the river on the trail that leads to the Old Clink bridge at about RM 13.29 and measured flow sections at Dungeness #5 (RM 13.35) and Dungeness #4 (RM 13.28) at 08:40 and 10:15, respectively (Figure 1). They then hiked back to their truck and drove to the Dungeness Forks Campground at the confluence of the Dungeness and Gray Wolf rivers. They measured Dungeness River discharge at two more sites, Dungeness #10 (RM 15.8) and Dungeness #11 (RM 15.95) at 13:30 and 15:00, respectively (Figure 1). A replicate measurement was made at Dungeness #11 at 15:40. Team 2's last measurement was at GW #1 on the Gray Wolf River above its confluence with the Dungeness River at 16:55 (Figure 1 and Table 1).

3. Team 3 drove to the Dungeness Forks Campground and hiked downstream to Dungeness #6 at about RM 14.9 and measured their first flow of the day at 10:30. The team then worked their way back upstream measuring flow at Dungeness #7 (RM 15.15), Dungeness #8 (RM 15.25), and Dungeness #9 (RM 15.6) at 13:30, 14:45, and 16:10, respectively. A replicate measurement was made at Dungeness #9 at 17:15 (Figure 1 and Table 1).

All discharge measurements were made by wading, using Swoffer Model 2100 meters and top-set wading rods (http://www.swoffer.com/). All Swoffer propellers were calibrated prior to the project using a prop-calibration tube especially designed by SHU personnel. All three flow-measurement teams followed the flow-measurement protocols as described in SHU (1999). One discharge measurement was made at each measurement cross section. In addition, each two-person team made one replicate flow measurement as a check of measurement precision. A minimum of 20 measurement points (verticals) were used to define each measurement cross section. Spacing of the verticals was structured to ensure that no more than 10 percent of the total flow was contained within any one vertical. Discharge at each vertical was determined by taking 20-second average velocity measurements until two measurements were within 0.05 feet per second of each other, or at least four measurements had been recorded (see data compilation sheets and river-bed profiles in Appendix B).

In addition to the standard protocols, each team established a temporary staff gage at each measurement site by driving a stake into the stream bed. The distance from the top of the stake to the water surface was measured and recorded at the beginning and end of each flow measurement. These tape-down measurements provided the information necessary to determine river stage flux during the course of individual flow measurements and during the course of the synoptic flow study, overall (Table 1).

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Results

Geologic/Hydraulic Reconnaissance

Geology

The geologic units observed during the field reconnaissance were consistent with the published geologic maps. The only observed difference was that there were more bedrock outcrops in the areas mapped as colluvium than shown on the published maps. That, however, is a function of the outcrops along the river being too small to be shown on the geologic map at the published scale of 1:125,000 (Tabor and Cady, 1978).

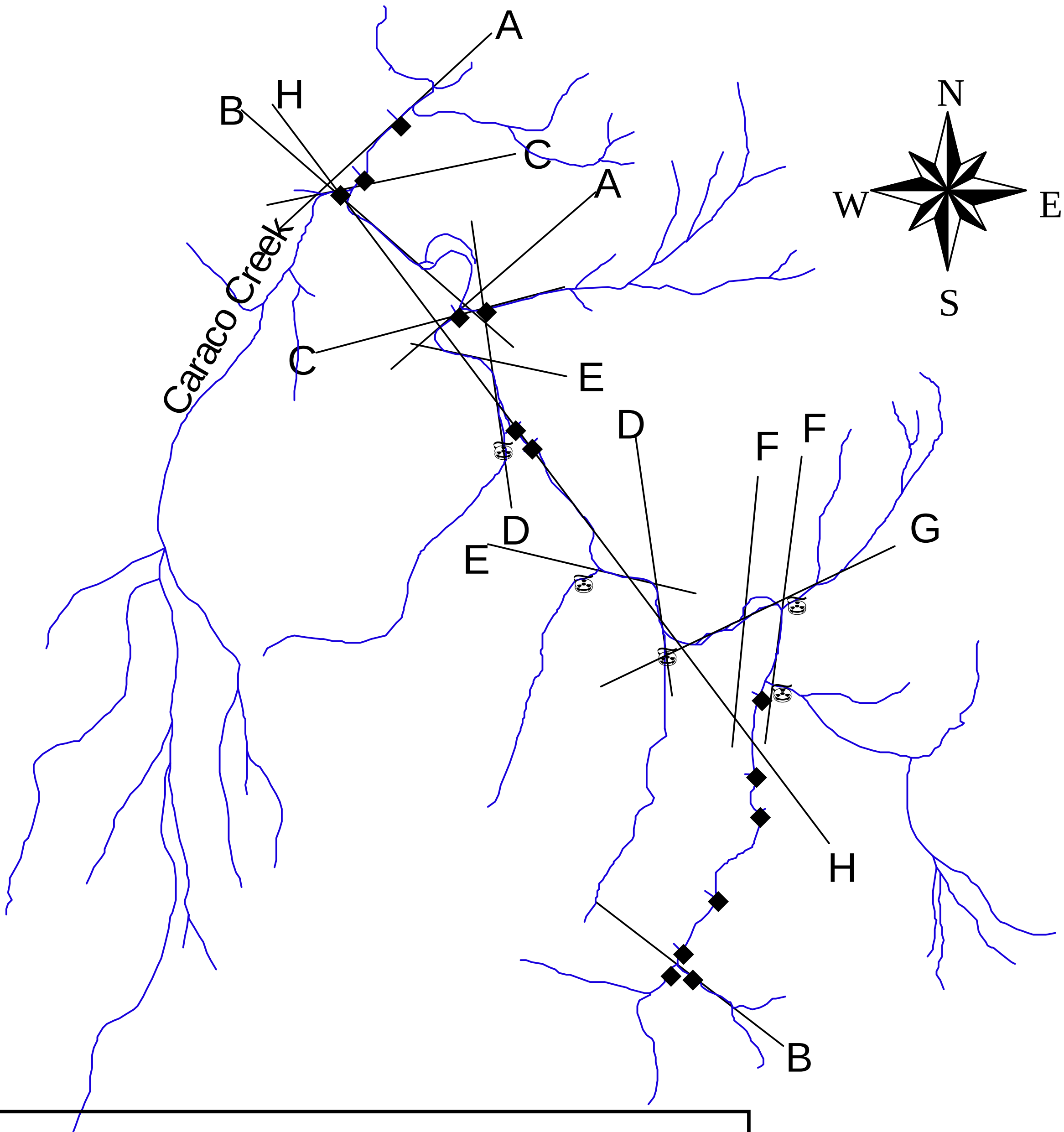
Most of the outcrops observed are black to dark-gray, massive to fractured basalt of the Crescent Formation (Tabor and Cady, 1978). The basalt outcrops are often fractured, sometimes extensively. In some cases, however, the outcrops are massive and no significant fractures are apparent. All of the outcrops observed to be associated with deep pools in the river are composed of basalt.

In some locations it appears that faults or joint systems in the bedrock may structurally control the orientation of the river channel. This observation is based on field observations of the apparent orientation of bedrock fractures, and on the tendency of the river to flow in a generally straight line and then abruptly change direction to a radically different bearing and follow a generally straight line along this new bearing. The river also roughly exhibits an angulate drainage pattern, which is indicative of structural control by joint or fault systems (Thornbury, 1969, p. 120). Figure 2 shows the orientation of some of the more obvious joint systems along which the river and some of the tributaries seem to be flowing. Certain joint sets, such as those depicted by traces A, B, C, D, E, and F on Figure 2, are approximately parallel to each other. This appears to indicate the presence of conjunctive joint sets over a fairly large area. The angles through which the river has turned, in order to follow a new joint set, are both acute and obtuse and range from about 69 to 125 degrees (Figure 2). The joint set shown on Figure 2 as trace “H” appears to be one of the primary joint sets, based on the tendency of the river to generally follow the northwest-trending bearing from about RM 14.3 to RM 12.2.

A detailed study of joint orientation and attitude in the basalt outcrops might provide valuable information related to the relationship between the river and the fractured bedrock. However, that level of detailed geologic work was outside the scope of this project.

Hydrology

The hydrologic character of the study reach is typical of a mountain-valley stream. The study reach consists essentially of a long, repetitive series of riffles, pools, and glides, the formation of which is largely dependent upon changes in the slope of the river and the geology of the river-bed substrate.



Legend

A — Trace of Bedrock Joint. - Letter designation indicates joints of similar orientaion. Trace extends well beyond river manifestation of the joint for visual clarity.

Joint Bearings (as related to direction of river flow):

A = N 48 E
B = N 49 W
C = N 75 E
D = N 8 W
E = N 77 W
F = N 8 E
G = N 64 W
H = N 37 W

Acute angles between intersecting joints (in degrees):

A - B = 87	B - C = 53
A - E = 55	D - E = 69
D - G = 72	F - G = 56
A - H = 86	E - H = 39
B - H = 11	F - H = 42
C - H = 67	G - H = 78
D - H = 29	

Figure 2

Bedrock Joint Orientation

Two large, braided-channel segments are present in the study reach. These braided-channel segments are located in Reach #5 and Reach #8. Multiple flow channels through longitudinal gravel bars and considerable debris such as log jams characterize both braided-channel segments. Some of the gravel-bar "islands" between the channels are vegetated with growths of brush.

Only two flowing tributaries were found during the seepage run study. Caraco Creek (Trib #1) was flowing at about 0.12 cfs, and Trib #2 (an unnamed tributary) was flowing at about 0.03 cfs.

Synoptic Flow Study

Tables 1 and 2 and Figures 3 and 4 show the results of the seepage run study. Complete flow-measurement data and river-bed profiles for each site are presented in Appendix B. The study identified an overall gain in river-discharge of 7.8 cfs (1.95 cfs/mi.) between the Dungeness/Gray Wolf River confluence (Dungeness #10) and Dungeness #1 at the USGS gage (Tables 1 and 2). However, the flow data (Figure 4 and Table 2) show four intermediate losses and five intermediate gains within the four-mile reach.

The most significant gain was in Reach #2 between Dungeness # 9 and #8, where the river gained 11 percent of its volume or 12.7 cfs (3.63 cfs/0.1 mile). The long reach between Dungeness #7 and Dungeness #2, (composed of Reaches #4 - #8) is essentially a long gaining reach made up of three relatively significant gains, and one each of a very minor gain and loss. Both the minor gain and loss are statistically insignificant compared to the overall river volume and the inherent accuracy of flow measurements (see Data Quality Objectives discussion in Appendix C).

The most significant loss occurred in Reach #3 between Dungeness #8 and #7, where the river lost 7.84 percent of its total volume or 10.2 cfs (10.2 cfs/0.1 mi.). Another significant loss was measured in Reach #9 between Dungeness #2 and #1, where the river lost 6.47 percent of its total volume or 6.6 cfs (-3.32 cfs/0.1 mi.).

Gaining and Losing Reaches as Compared to River-Bed Substrate

For the purposes of this report, river-bed substrate has been divided into two primary, generalized types: 1) Reaches dominated by heavy cobbles to fine gravel and 2) reaches dominated by bedrock outcrops. The flow characteristics of the river on cobble/gravel substrate tend to be long stretches of riffles, glides, and relatively shallow pools. The flow characteristics of the bedrock-dominant areas tend to be deep pools against a bedrock substrate bounded by riffles above and below the pools.

As shown on Table 2 and Figure 4, there are identifiable correlations between the predominant type of river-bed substrate in a reach and whether that reach is a losing or gaining reach. Gaining reaches tend to occur in reaches where the river character is dominated by gravel substrate and long reaches of riffles, pools, and glides. Losing reaches, on the other hand, seem to occur in reaches where the river character is dominated by bedrock outcrops and deep pools (Figure 4).

A significant exception occurred in Reach #6 where a gain of 4.32 cfs (3.48 percent of the total river volume) was realized through a short reach in which the river-bed substrate is dominated by a narrow, funnel-shaped, fractured-basalt outcrop (Table 2). A deep pool, possibly the deepest observed in the river, lies against the bedrock at this site.

Table 2 - Gain and Loss per River Reach and Associated River Characteristics

Reach Number	Measurement ID	River Mile	Reach Length (miles)	Gain(+) or Loss(-) (cfs)(1, 2)	Percent Gain or Loss(3 & 4)	Gain or Loss (cfs(2) per 0.1 mile)(1)	Primary Stream-Bed Characteristics
1	Dungeness # 10 Dungeness # 9	15.8 15.6	0.2	-0.24	-0.20	-0.12	Thin, course gravel & cobble over basalt. No significant bedrock outcrops or pools.
2	Dungeness # 9 Dungeness # 8	15.6 15.25	0.35	**12.71**	**10.78**	**3.63**	Thin, course gravel & cobble over basalt. No significant bedrock outcrops or pools.
3	Dungeness # 8 Dungeness # 7	15.25 15.15	0.1	-10.24	-7.84	-10.24	Short reach mostly on fractured bedrock. Significant, deep pools on bedrock.
4	Dungeness # 7 Dungeness # 6	15.15 14.9	0.25	**3.34**	**2.77**	**1.34**	Straight reach of course gravel & cobble with series of riffles, glides, & shallow pools.
5	Dungeness # 6 Dungeness # 5	14.9 13.35	1.55	**0.35**	**0.28**	**0.02**	Long reach of course gravel & cobble, gravel bars and braided sections on colluvium. Series of riffles, glides, and shallow pools.
6	Dungeness # 5 Dungeness # 4	13.35 13.28	0.07	**4.32**	**3.48**	**6.17**	Short reach through narrow bedrock chute at old Clink Bridge site. Deep pool on fractured bedrock.
7	Dungeness # 4 Dungeness # 3	13.28 12.75	0.53	-0.26	-0.20	-0.05	Course gravel and bedrock intermixed. Two bedrock outcrops with deep, pools, but mostly course gravel & colluvium.
8	Dungeness # 3 Dungeness # 2	12.75 12.0	0.75	**4.31**	**3.36**	**0.57**	Course gravel and cobble with gravel bars and braided sections. Series of riffles, glides, and shallow pools.
9	Dungeness # 2 Dungeness # 1	12.0 11.8	0.2	-6.64	-5.00	-3.32	Mostly bedrock base, especially at down-stream end, with thin, course gravel over bedrock. Some deep pools on fractured bedrock.
Total Reach	Dungeness # 10 Dungeness # 1	15.8 11.8	4.0	**7.80**	**6.47**	**0.20**	Mixed as described above

[shaded box] -- Shaded areas indicate that the river-bed substrate in the reach is composed primarily of bedrock.

(1) -- Values in bold indicate a gaining reach, a negative value indicates a losing reach.

(2) -- cfs = cubic feet per second (ft^3/second)

(3) -- Shows the gain or loss as a percent of the total discharge of the river at the up-stream discharge measurement site.

(4) -- Any value here that is <2.5 and > -2.5 is statistically insignificant because it is smaller than the range of measurement error inherent in stream-flow measurements (see Appendix C for discussion of flow-measurement accuracy).

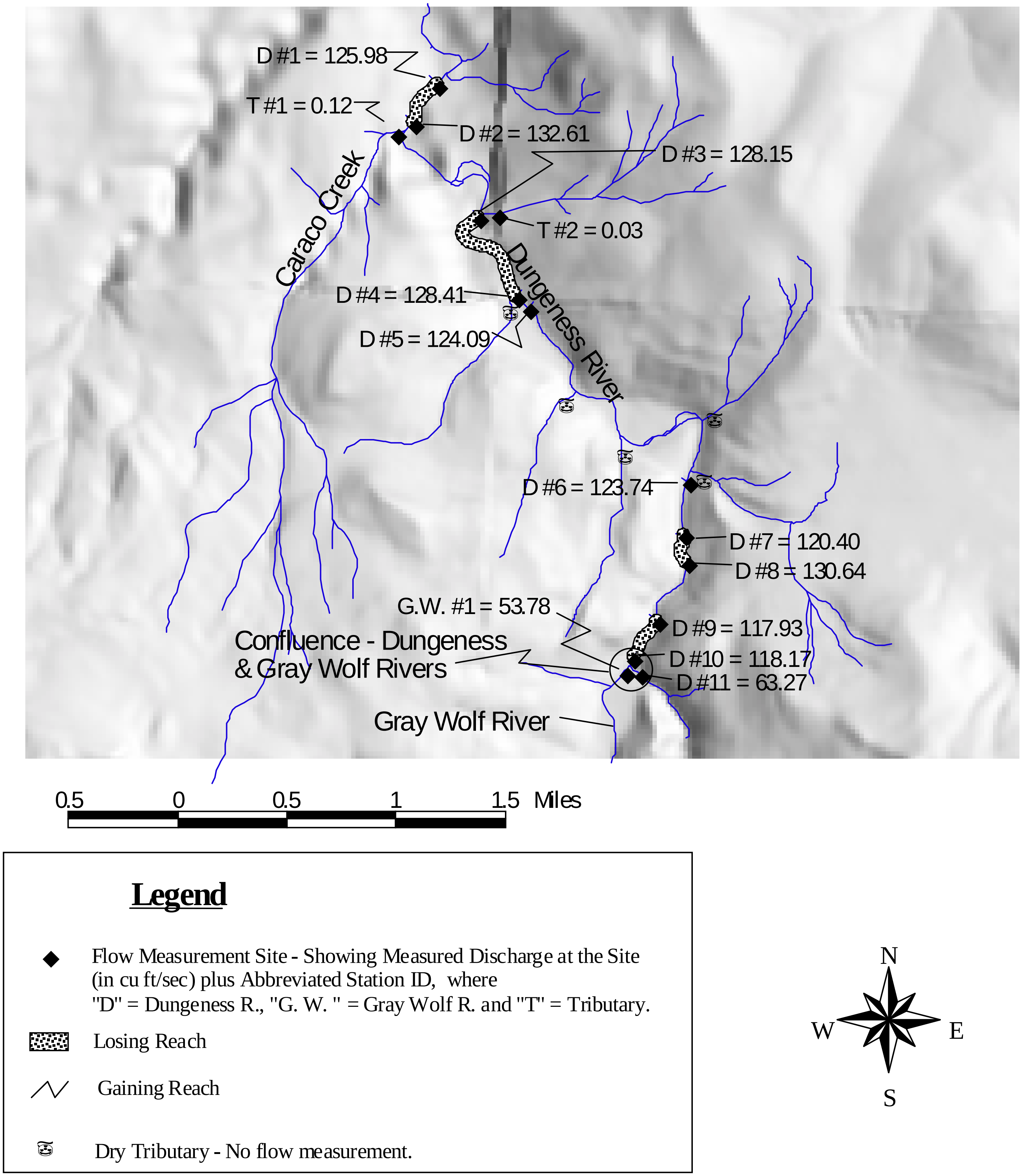
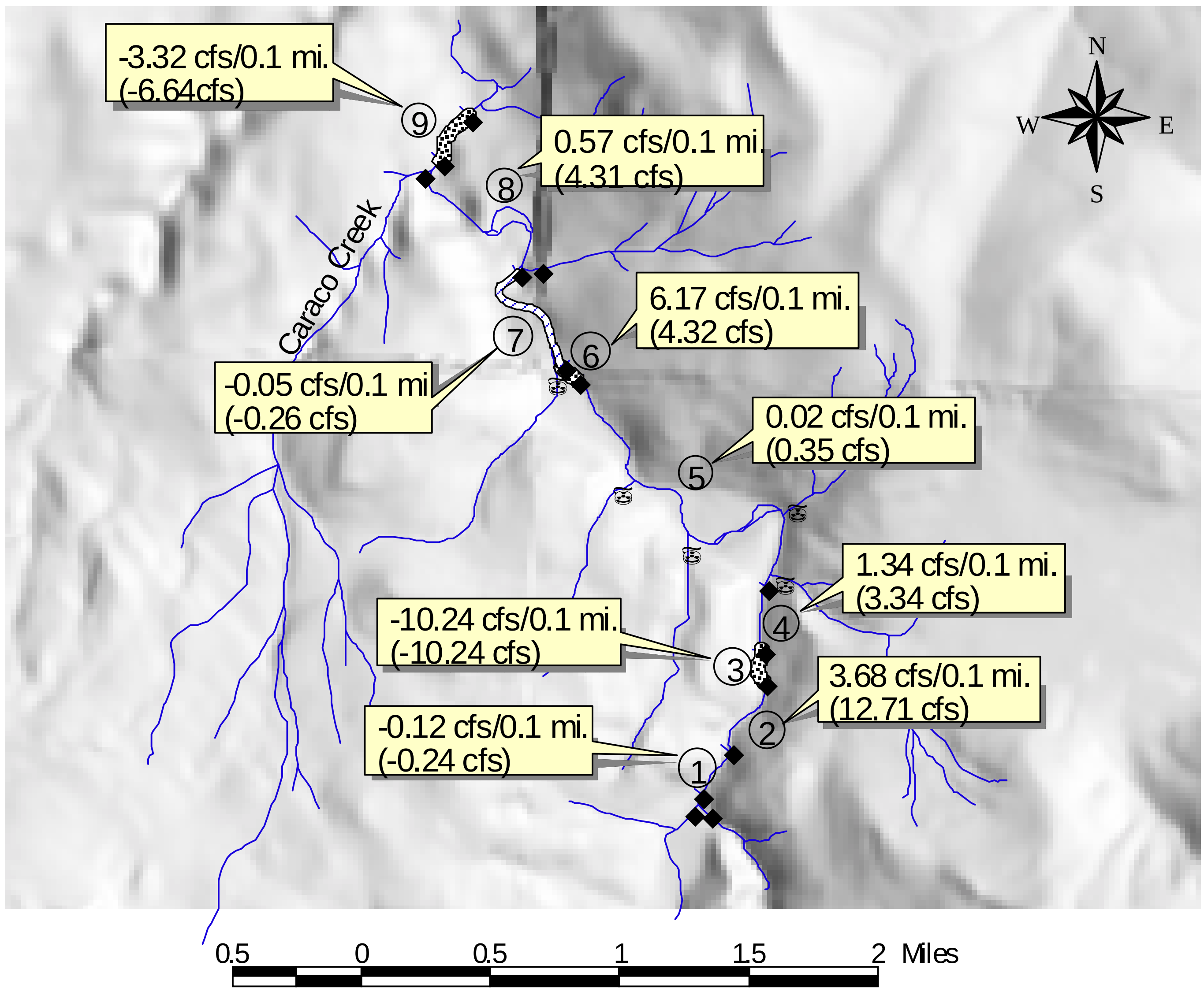


Figure 3
Upper Dungeness Project Area
Synoptic-Flow Discharge Values



Legend

② Reach Number - As defined by the river reach between discharge-measurement sites and as described on Table 2.

[3.68 cfs/0.1 mi. (12.71 cfs)] Gain or Loss, in cfs/0.1 mi., measured in the designated river reach. Also shows actual measured gain or loss, in parenthesis.

Bedrock Reach – River-bed substrate is dominated by bedrock.

Gravel Reach – River-bed substrate is dominated by course sand, gravel, and cobbles.

Mixed River-Bed Substrate -- River-bed substrate in this reach is composed of both course gravel and bedrock.

Figure 4
River-Bed Substrate vs. Gains and Losses

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Discussion

At first glance, the seepage run data seem to provide evidence of river losses to fractured bedrock. However, upon further scrutiny, the river system seems to be rather typical of a mountain-valley river. Repeating reaches of riffles, pools, and glides are intermixed with gravel bars and braided sections.

The study reach of the river was divided into nine reaches, with each reach being defined as the river segment between discharge-measurement sites. Flow measurements above and below these nine reaches yielded an almost even split in the number of gaining and losing reaches. Although the measurement sites were chosen based on specific criteria as discussed in the Methods section, the result was still, more or less, a random division of the river into nine reaches. It is probable that if the river were divided into different reaches, or subdivided into more reaches the gain/loss results would be essentially the same – a mix of gaining and losing reaches.

In spite of the apparent correlations between losses and gains and river-bed substrate, it is likely that the gains and losses are, for the most part, local movement of water into and out of the hyporheic zone – rather than an indication of major interactions between the river and the bedrock aquifer. As illustrated in Figure 5, a mountain stream tends to have a mix of gaining and losing reaches. Whether a reach is gaining or losing is often related to abrupt changes in the slope of the river bed or to meanders in the stream channel (Winter et al, 1998). In essence, where the flow was measured (above or below a pool, riffle, or glide, or even a bend in the river) may have as much or more to do with the resulting measured gains or losses as with relationships between river-bed substrate and bedrock.

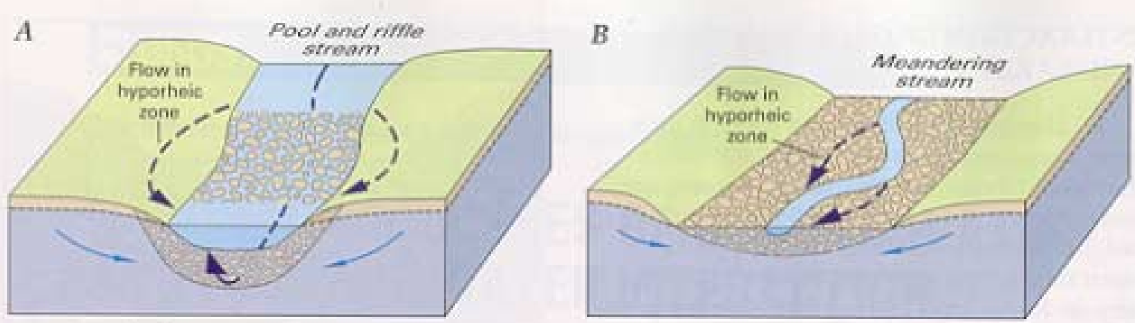

Figure 14. *Surface-water exchange with ground water in the hyporheic zone is associated with abrupt changes in streambed slope (A) and with stream meanders (B).*

From: Winter et al (1998), p. 17

Figure 5 - Interaction with the Hyporheic Zone

As illustrated in Figure 6, there can be a strong relationship between river-bed slope and gains from and loses to the hyporheic zone in mountain streams (Winter et al (1998, p. 37). As explained by Winter et al (1998, p. 37), " … hyporheic exchange in mountain streams is caused to a large extent by the irregular topography of the streambed, which creates pools and riffles characteristic of mountain streams. Ground water enters streams most readily at the upstream end of deep pools, and stream water flows into the subsurface beneath and to the side of steep sections of streams (riffles). Channel irregularity, therefore, is an important control on the location of ground-water inflow to streams and on the size of the hyporheic zone in mountain streams, because changes in slope determine the length and depth of hyporheic flow paths."

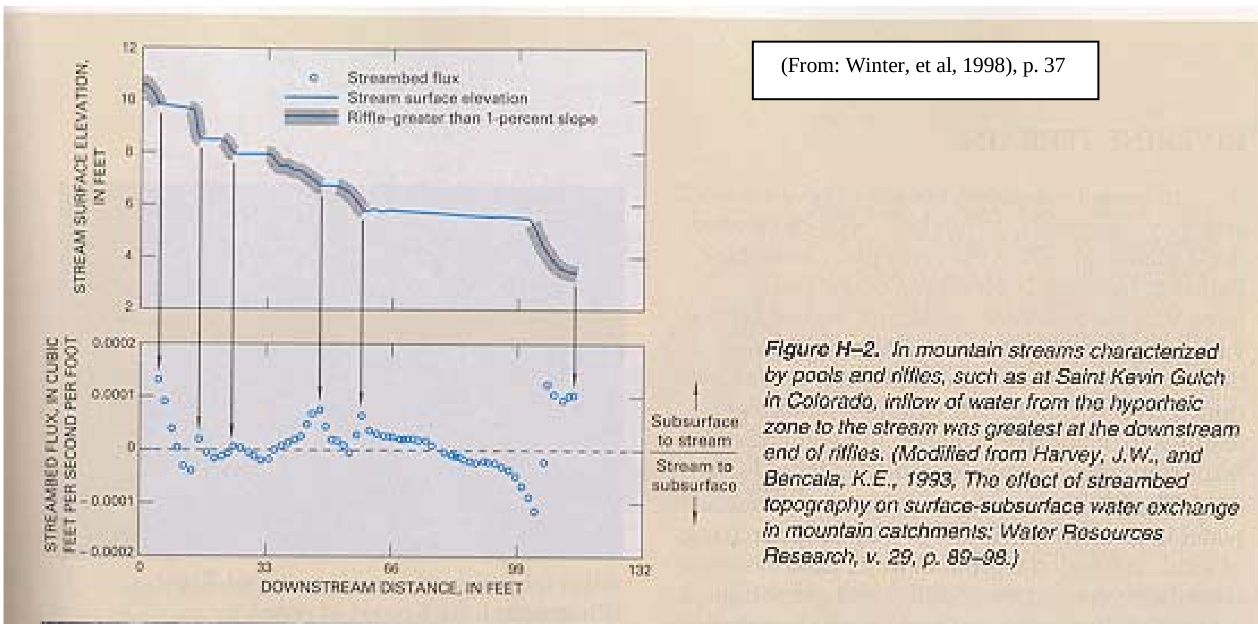

Figure 6 - Gains to River from Hyporheic Zone

The mountain-stream characteristics described above appear to apply quite well to the topographic characteristics of the study reach of the Dungeness River. It follows that the gains and losses measured in the Dungeness River may well be due to the irregular mountain-valley topography and the water interaction with the hyporheic zone.

The overall gain (7.8 cfs) along the four-mile reach is probably due to gradual (1.95 cfs/mile) ground-water discharge to the river from the bedrock and colluvium along the steep sides of the mountain valley. This measured overall gain seems to indicate that there is no permanent loss of river water to bedrock fractures.

That being said, there is still evidence suggesting that the river course is controlled, in part, by joint sets in the bedrock (Figure 2). Given the apparent connection between the river and bedrock joint system, it seems likely that there is some degree of interaction between the river and the bedrock aquifer. Winter et al (1998, p 36), indicates that ground-water flow systems in fractured bedrock, which contribute to surface-water bodies, can be considerably larger than the topographically defined watershed and that ground water in fractured bedrock systems can have extensive, deep, complex flow paths.

It is interesting, and possibly coincidental, that the largest loss from the river (-10.24 cfs/0.1 mi.) and the largest gain (6.17 cfs/0.1 mi.) occurred in Reach #3 and #6, both of which are dominated by large bedrock outcrops (Figure 4 and Table 2). As shown in Figure 2, it also happens that these two bedrock outcrops lie generally on the trace for joint set "H". Although this is not definitive evidence, it seems possible that the water lost at Reach #3 flows along joint set "H" and reappears at Reach #6.

While such information makes speculation about possible interactions between the Dungeness River and the bedrock aquifer tempting, the present study of the upper Dungeness River provided no data that would lead to any conclusions about significant interaction between the river and the underlying bedrock aquifer. A detailed study of the bedrock joint and fracture systems, ground-water flow paths, and ground-water quality would be needed to further evaluate ground-water/surface-water interaction relative to the bedrock jointing or fracture systems.

It is important to note that the accuracy of the measured gains and losses must be evaluated based on the field conditions, discharge-measurement protocol, and the errors inherent in river-discharge measurements. Based on SHU experience with discharge measurements on the Dungeness River and other synoptic flow studies, the overall measured gain, as well as two-thirds of the measured intermediate gains and losses are, herein, considered significant, measurable values (see Appendix C for more detail). Relative gains and losses are easily compared in Table 2 where they are shown as a percent of the total river discharge.

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Recommendations

Two avenues of follow-up study could be pursued to clarify ground-water/surface-water interaction in the upper Dungeness River, and how that might relate to the glacial aquifers under Sequim Prairie.

1. A detailed study of the relationship between the upper Dungeness River and the hyporheic zone. The purpose would be to test the theory, put forth in this report, that the intermediate gains and losses are due to water exchange to and from the hyporheic zone rather than major interactions with the bedrock aquifer. The study would involve installation of temporary piezometers in the hyporheic zone along the upper Dungeness study reach and a simultaneous low-flow, synoptic-flow study.

2. A detailed study of the bedrock joint/fracture systems which may be controlling the drainage pattern of the river and interaction between the river and the bedrock aquifer. To be effective, this study would need to be quite comprehensive. Study components would probably need to include:

   - A detailed field mapping of bedrock joint/fracture orientation and attitude all along the present study reach and including north beyond the USGS cable-way gage to the point where the river flows onto glacial deposits in Sequim Prairie.

   - A detailed geologic analysis of well logs along the bedrock-glacial deposit transition zone to establish, as well as possible, a picture of the geologic cross section across the transition zone.

   - A detailed comparative study of bedrock-aquifer and glacial-aquifer water quality designed to identify the ground water source in glacial aquifers.

Probably the most effective way to address the questions about ground-water/surface-water interaction in the study area and in the transition zone from bedrock to glacial deposits would be to commit resources to both the study efforts described above.

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Appendix A

Geologic Cross Sections

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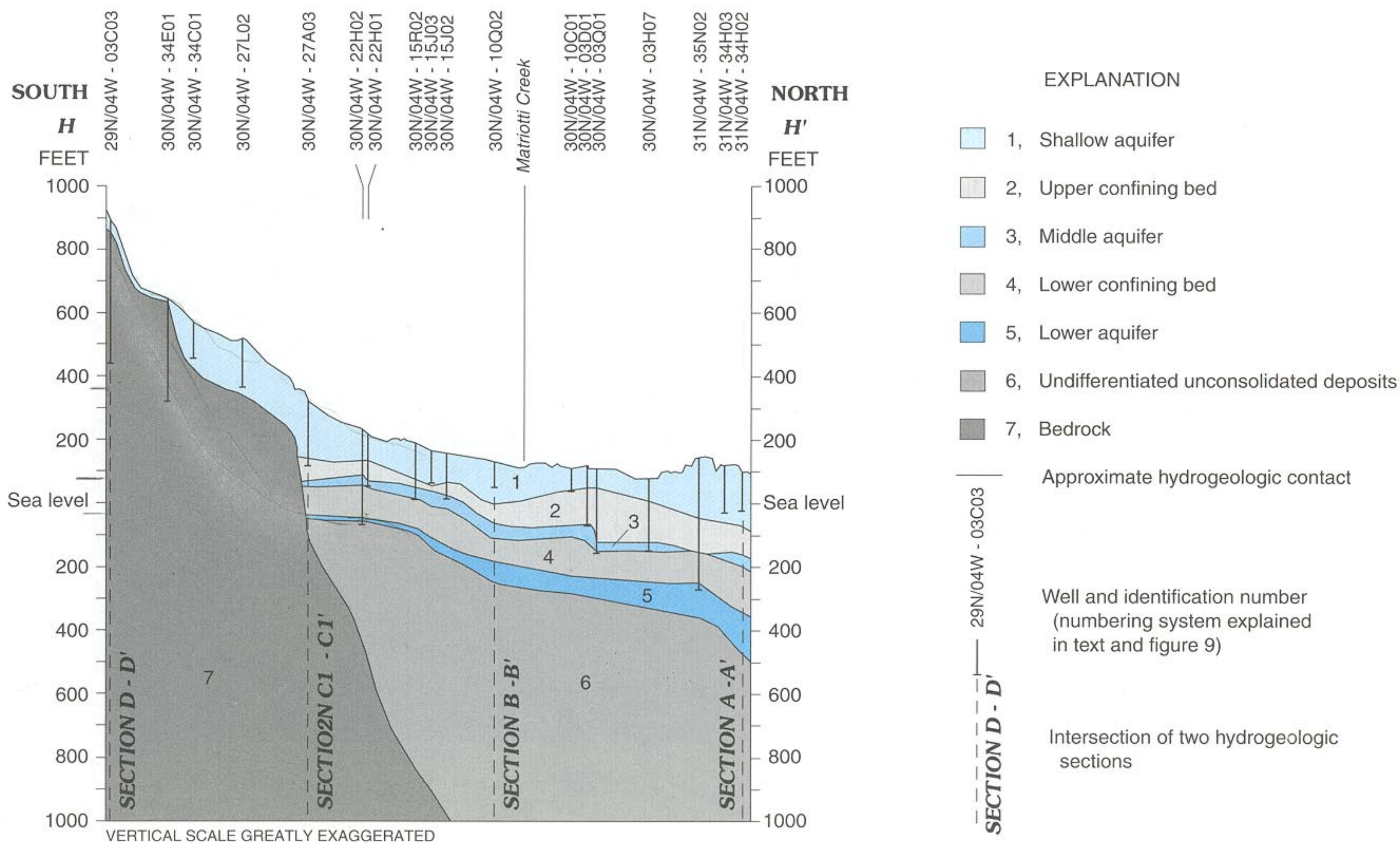

Figure 17i. Hydrogeologic cross section ***H-H'***, Sequim-Dungeness area, Washington .

From: Thomas et al. (1999), p. 39

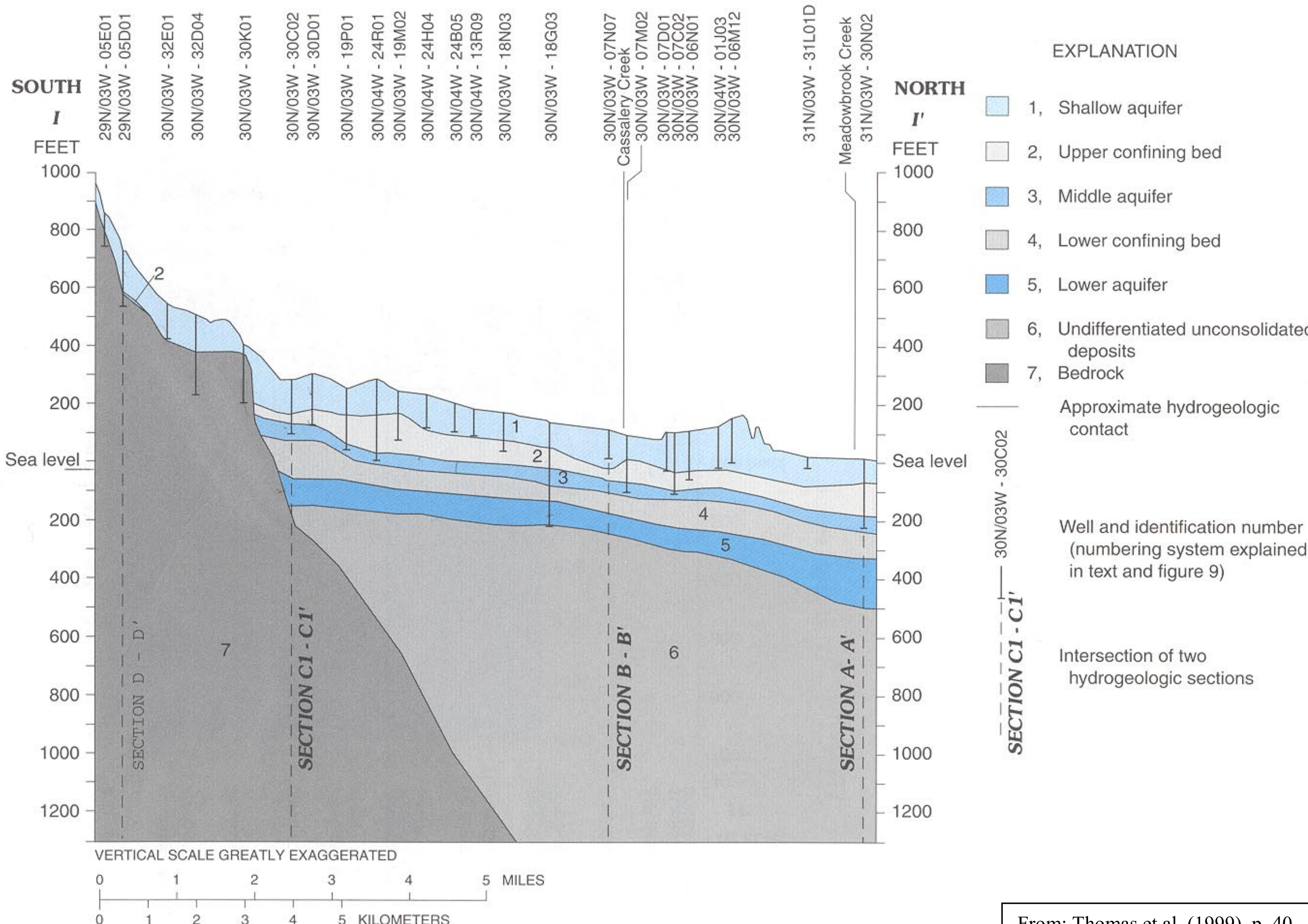

Figure 17j. Hydrogeologic cross section ***I-I′***, Sequim-Dungeness area, Washington .

From: Thomas et al. (1999), p. 40

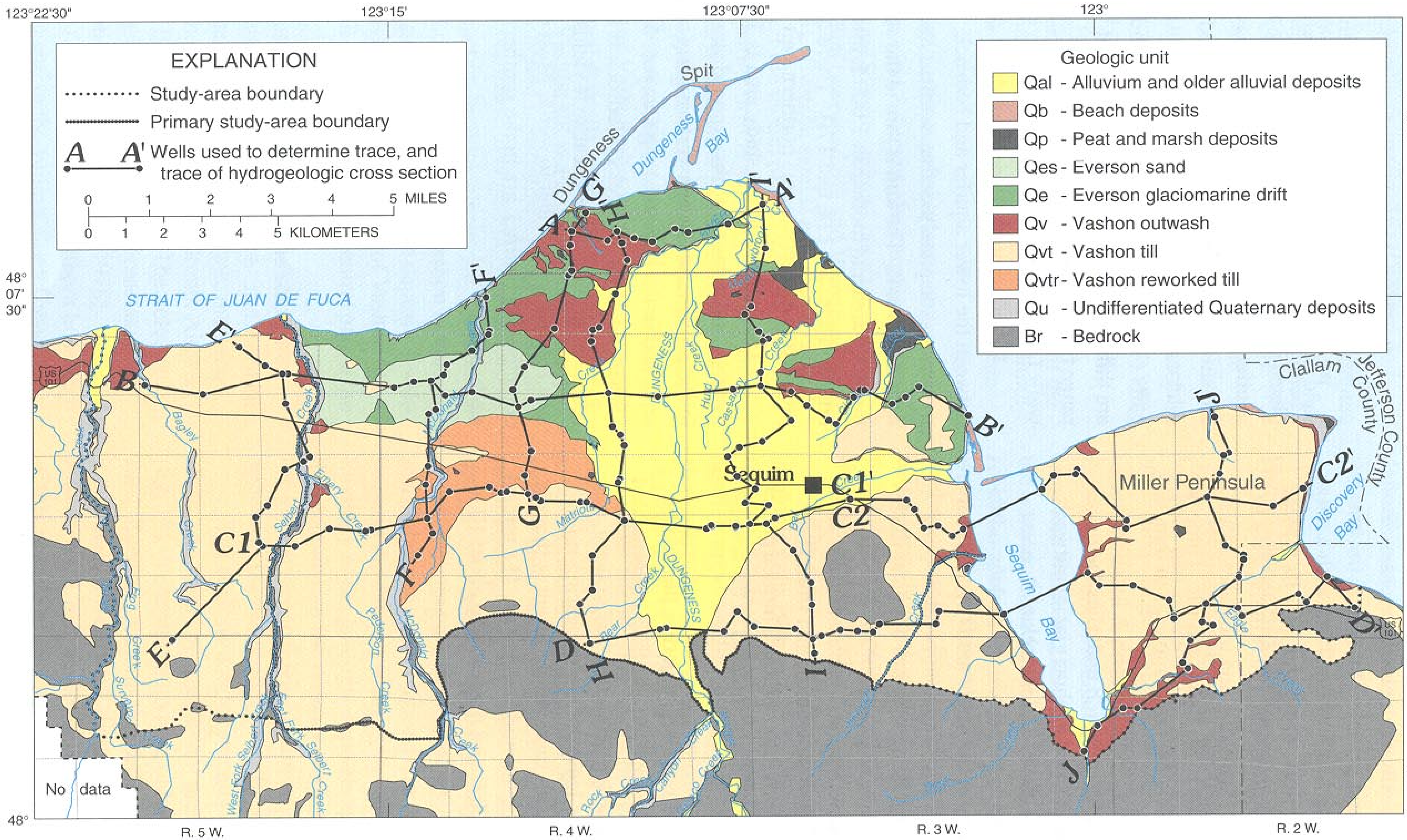

Figure 16. Generalized surficial geology and locations of hydrogeologic sections (Othberg and Palmer, 1980a,b,c,d).

From: Thomas et al. (1999), p. 30

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Appendix B

Stream Discharge Calculations

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Stream Discharge Calculation

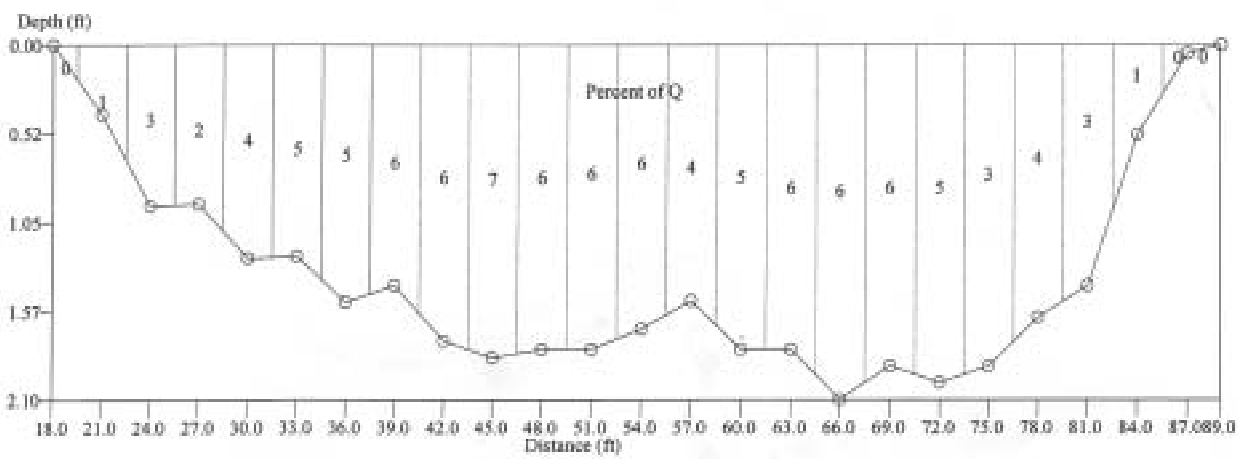
Site ID = Dung # 1a
Site Name = Dungeness River at USGS Gage
Stage: 1.50 ft.   Date: 10/05/2000   Time: 1340

Comment:
Stage is tape down from temporary reference point to check stage change during flow measurement.

Point	Distance	Depth	Area	Velocityl	Velocity2	q
1	18.00	0.00	0.00	0.00	0.00	0.00
2	21.00	0.41	1.23	0.59	0.00	0.73
3	24.00	0.95	2.85	1.18	0.00	3.36
4	27.00	0.94	2.82	1.11	0.00	3.13
5	30.00	1.26	3.78	1.28	0.00	4.84
6	33.00	1.25	3.75	1.56	0.00	5.85
7	36.00	1.52	4.56	1.18	1.76	6.70
8	39.00	1.42	4.26	1.66	0.00	7.07
9	42.00	1.75	5.25	1.32	1.71	7.95
10	45.00	1.85	5.55	1.30	1.71	8.35
11	48.00	1.80	5.40	1.12	1.67	7.53
12	51.00	1.80	5.40	1.26	1.71	8.02
13	54.00	1.68	5.04	1.21	1.61	7.11
14	57.00	1.51	4.53	0.84	1.53	5.37
15	60.00	1.80	5.40	0.93	1.58	6.78
16	63.00	1.80'	5.40	1.27	1.64	7.86
17	66.00	2.10	6.30	0.99	1.56	8.03
18	69.00	1.90	5.70	1.16	1.57	7.78
19	72.00	2.00	6.00	0.74	1.41	6.45
20	75.00	1.90	5.70	0.44	1.05	4.25
21	78.00	1.61	4.83	0.70	1.17	4.52
22	81.00	1.42	4.26	0.75	0.00	3.19
23	84.00	0.53	1.59	0.43	0.00	0.68
24	87.00	0.05	0.13	0.00	0.00	0.00
25	89.00	0.00	0.00	0.00	0.00	0.00

Total Area = 99.72 sq. ft.
Average Velocity = 1.26 ft./sec.

Total Discharge = 125.55 cfs



Stream Discharge Calculation

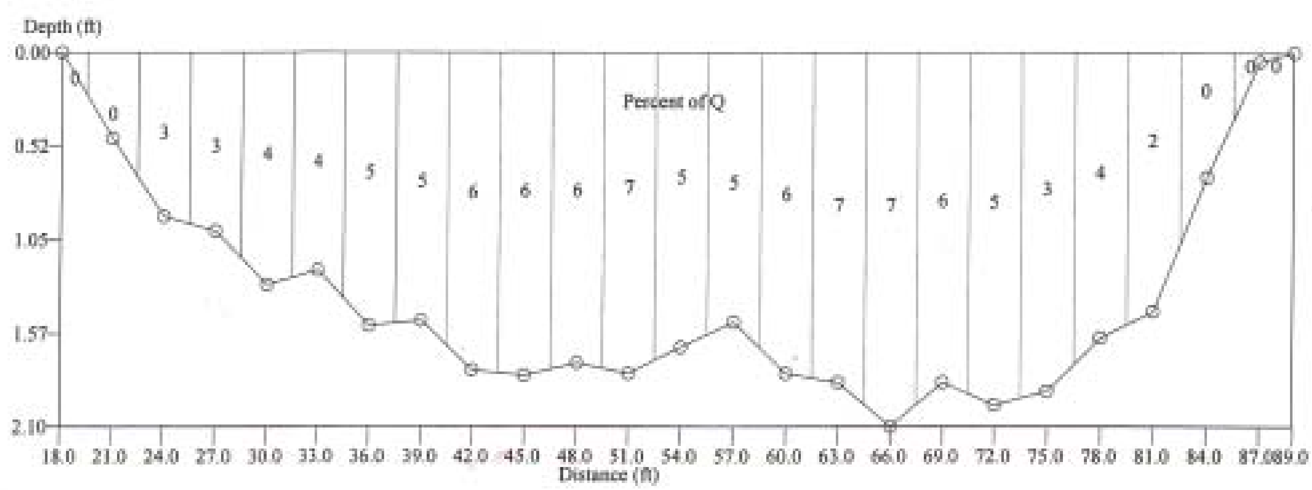
Site ID = Dung # 1b
Site Name = Dungeness River at USES Gage (Repeat)
Stage: 1.50 ft.   Date: 10/05/2000   Time: 1450

Comment:
Repeat measurement at same site. Stage is tape down from temporary reference point to check stage change during flow measurement.

Point	Distance	Depth	Area	Velocityl	Velocity2	q
1	18.00	0.00	0.00	0.00	0.00	0.00
2	21,00	0.48	1.44	0.23	0.00	0.33
3	24.00	0.92	2.76	1.18	0.00	3.26
4	27.00	1.00	3.00	1.07	0.00	3.21
5	30.00	1.30	3.90	1.25	0.00	4.88
6	33.00	1.22	3.66	1.54	0.00	5.64
7	36.00	1.53	4.59	1.48	0.00	6.79
8	39.00	1.50	4.50	1.08	1.94	6.80
9	42.00	1.78	5.34	1.31	1.75	8.17
10	45.00	1.81	5.43	1.30	1.62	7.93
11	48.00	1.74	5.22	1.23	1.72	7.70
12	51.00	1.80	5.40	1.34	1.74	8.32
13	54.00	1.65	4.95	1.13	1.65	6.88
14	57.00	1.51	4.53	0.98	1.56	5.75
15	60.00	1.80	5.40	1.17	1.59	7.45
16	63.00	1.85	5.55	1.31	1.67	8.27
17	66.00	2.10	6.30	1.03	1.58	8.22
18	69.00	1.85	5.55	1.27	1.51	7.71
19	72.00.	1.98	5.94	0.80	1.43	6.62
20	75.00	1.90	5.70	0.39	1.14	4.36
21	78.00	1.60	4.80	0.78	1.15	4.63
22	81.00	1.45	4.35	0.68	0.00	2.96
23	84.00	0.70	2.10	0.25	0.00	0.52
24	87.00	0.05	0.13	0.00	0.00	0.00
25	89.00	0.00	0.00	0.00	0.00	0.00

Total Area = 100.53 sq. ft.
Average Velocity = 1.26 ft./sec.

Total Discharge = 126.40 cfs



Stream Discharge Calculation

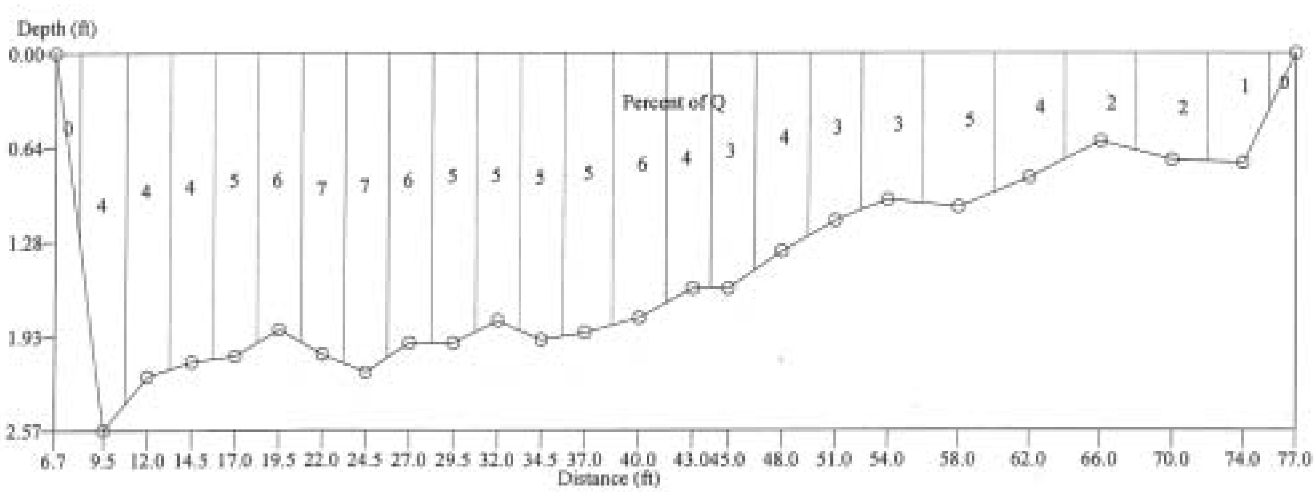
Site ID = Dung #2
Site Name = Dungeness River at about RM 12.0
Stage: 1.81 * ft.   Date: 10/05/2000   Time: 1135

Comment:
* No change in stage during flow measurement as determined by tape down measurement on temporary staff gage.

Point	Distance	Depth	Area	Velocityl	Velocity2	q
1	6.70	0.00	0.00	0.00	0.00	0.00
2	9.50	2.57	6.81	0.30	1.18	5.04
3	12.00	2.20	5.50	0.30	1.49	4.92
4	14.50	2.10	5.25	0.38	1.63	5.28
5	17.00	2.06	5.15	0.90	1.80	6.95
6	19.50	1.88	4.70	1.51	1.93	8.08
7	22.00	2.05	5.13	1.61	1.92	9.05
8	24.50	2.17	5.43	1.55	1.81	9.11
9	27.00	1.97	4.93	1.42	1.80	7.93
10	29.50	1.97	4.93	1.19	1.73	7.19
11	32.00	1.82	4.55	1.46	1.66	7.10
12	34.50	1.95	4.88	1.16	1.62	6.78
13	37.00	1.90	5.22	0.91	1.58	6.51
14	40.00	1.80	5.40	1.16	1.61	7.48
15	43.00	1.60	4.00	0.95	1.49	4.88
16	45.00	1.60	4.00	0.79	1.44	4.46.
17	48.00	1.35	4.05	1.34	0.00	5.43
18	51.00	1.14	3.42	1.22	0.00	4.17
19	54.00	1.00	3.50	1.29	0.00	4.51
20	58.00	1.05	4.20	1.56	0.00	6.55
21	62.00	0.85	3.40	1.40	0.00	4.76
22	66.00	0.60	2.40	0.88	0.00	2.11
23	70.00	0.73	2.92	0.92	0.00	2.69
24	74.00	0.75	2.63	0.62	0.00	1.63
25	77.00	0.00	0.00	0.00	0.00	0.00

Total Area = 102.38 sq. ft.
Average Velocity = 1.30 ft./sec.

Total Discharge = 132.61 cfs



Stream Discharge Calculation

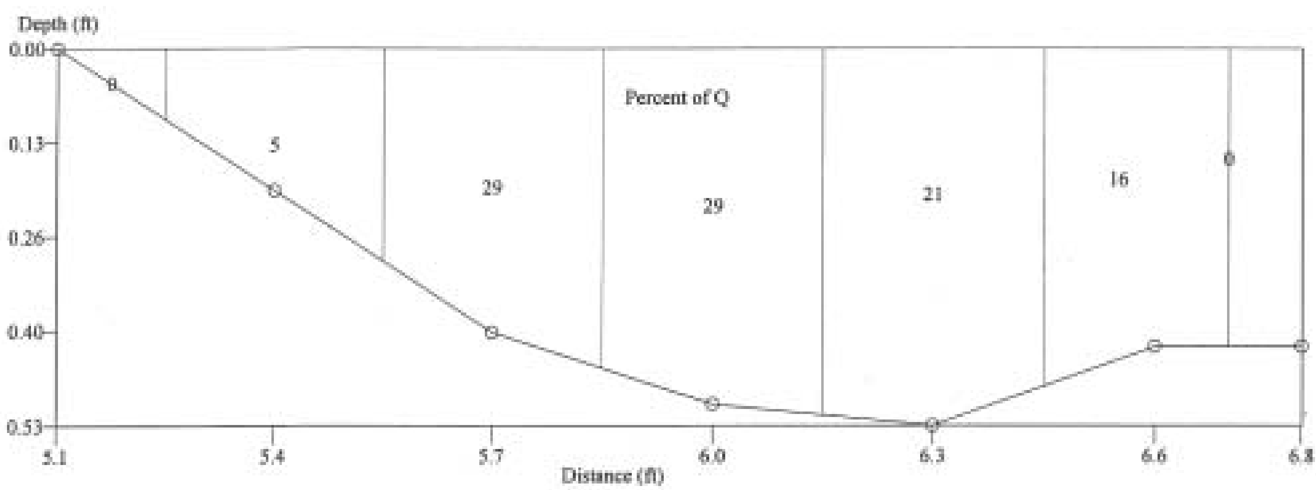
Site ID = Trib #1
Site Name = Caraco Creek
Stage: ft. Date: 10/5/2000 Time: 11:00

Comment:

Point	Distance	Depth	Area	Velocity]	Velocity2	q
1	5.10	0.00	0.00	0.00	0.00	0.00
2	5.40	0.20	0.06	0.10	0.10	0.01
3	5.70	0.40	0.12	0.29	0.28	0.03
4	6.00	0.50	0.15	0.23	0.23	0:03
5	6.30	0.53	0.16	0.16	0.15	0.02
6	6.60	0.42	0.10	0.18	0.18	0.02
7	6.80	0.42	0.04	0.00	0.00	0.00

Total Area = 0.64 sq. ft.
Average Velocity = 0.19 ft./sec.

Total Discharge = 0.12 cfs



Stream Discharge Calculation

Site ID = Dung #3
Site Name = Dungeness River at about RM 12.75
Stage: 1.55* ft. Date: 10/05/2000 Time: 0915

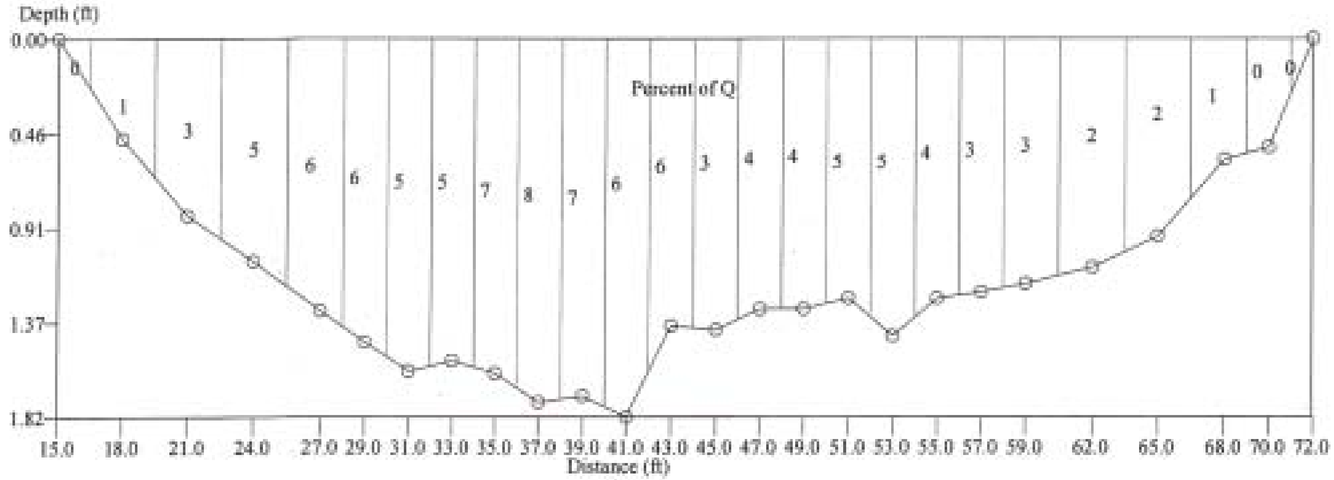
Comment:
* No change in stage during flow measurement as determined by tape down measurement on temporary staff gage.

Point	Distance	Depth	Area	Velocityl	Velocity2	q
1	15.00	0.00	0.00	0.00	0.00	0.00
2	18.00	0.48	1.44	0.76	0.00	1.09
3	21.00	0.85	2.55	1.38	0.00	3.52
4	24.00	1.07	3.21	1.80	0.00	5.78
5	27.00	1.31	3.27	2.27	0.00	7.43
6	29.00	1.46	2.92	2.58	0.00	7.53
7	31.00	1.60	3.20	1.73	2.64	6.99
8	33.00	1.55	3.10	1.49	2.80	6.65
9	35.00	1.61	3.22	2.43	3.43	9.43
10	37.00	1.75	3.50	2.03	3.51	9.69
11	39.00	1.72	3.44	1.90	3.13	8.65
12	41.00	1.82 '	3.64	1.50	2.96	8.12
13	43.00	1.38	2.76	2.66	0.00	7.34
14	45.00	1.40	2.80	1.44	0.00	4.03
15	47.00	1.30	2.60	2.05	0.00	5.33
16	49.00	1.30	2.60	2.18	0.00	5.67
17	51.00	1.25	2.50	2.36	0.00	5.90
18	53.00	1.43	2.86	2.05	0.00	5.86
19	55.00	1.25	2.50	1.86	0.00	4.65
20	57.00	1.22	2.44	1.67	0.00	4.07
21	59.00	1.18	2.95	1.50	0.00	4.42
22	62.00	1.10	3.30	0.80	0.00	2.64
23	65.00	0.95	2.85	0.75	0.00	2.14
24	68.00	0.58	1.45	0.56	0.00	0.81
25	70.00	0.52	1.04	0.36	0.00	0.37
26	72.00	0.00	0.00	0.00	0.00	0.00

Total Area = 66.14 sq. ft.
Average Velocity = 1.94 ft./sec.

Total Discharge = 128.15 cfs

Site ID = Dung #3
Site Name = Dungeness River at about RM 12.75
Stage: 1.55* ft. Date: 10/05/2000 Time: 0915



Stream Discharge Calculation

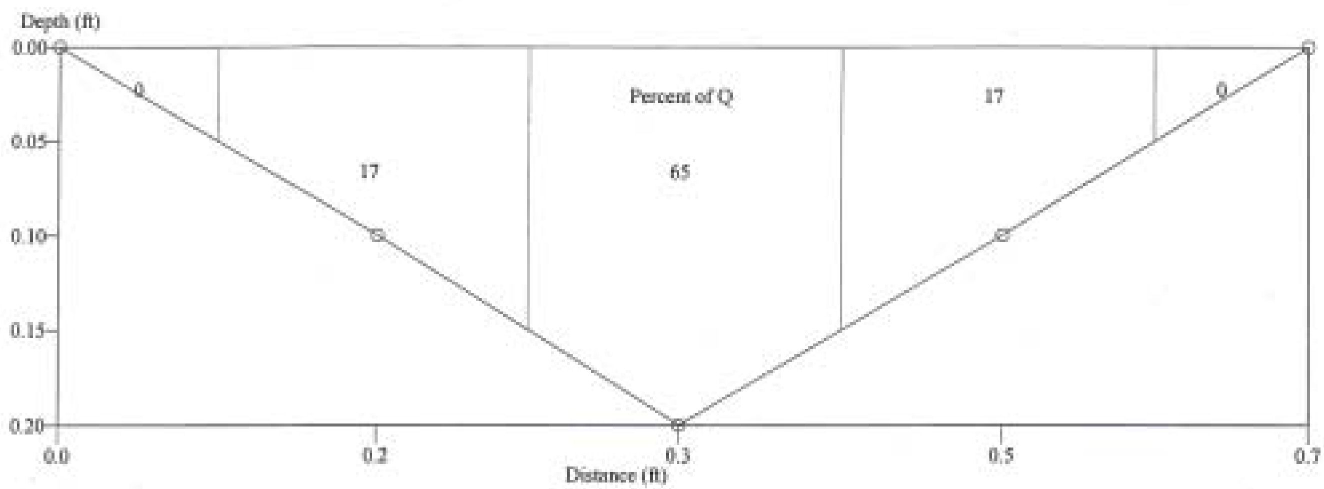
Site ID = Dung #2
Site Name = Dungeness River at about RM 12.75
Stage: 1.55* ft.   Date: 10/05/2000   Time: 0915

Comment:
Total width = 0.7 ft. Could only measure one flow velocity in center of channel. Flow values at distances of 0.18 and 0.53 are estimates. Values shown at 0.35 feet and stream edges are measured values, all others are estimates.

Point	Distance	Depth	Area	Velocityl	Velocity2	q
1	0.00	0.00	0.00	0.00	0.00	0.00
2	0.18	0.10	0.00	0.00	0.00	0.00
3	0.35	0.20	0.00	0.00	0.00	0.00
4	0.53	0.10	0.00	0.00	0.00	0.00
5	0.70	0.00	0.00	0.00	0.00	0.00

Total Area = 0.07 sq. ft.
Average Velocity = 0.36 ft./sec.

Total Discharge = 0.03 cfs



Stream Discharge Calculation

Site ID = Dung #4
Site Name = Dungeness R. Below old Clink Bridge at RM 13.28
Stage: ft. Date: 10/5/00 Time: 1015

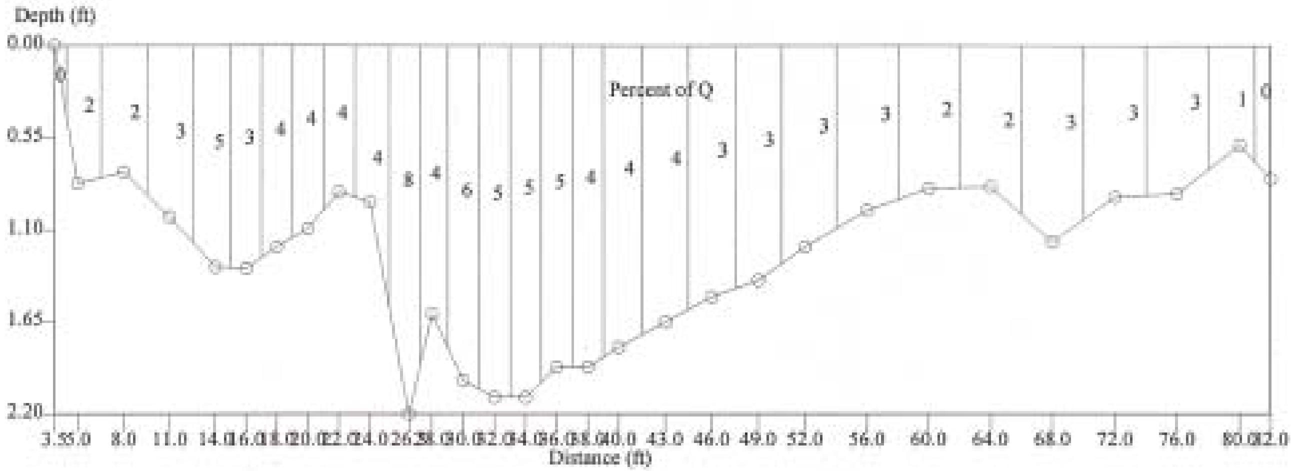
Comment:
No change in stage during flow measurement as determined by tape-down measurement on temporary staff gage (tape-down measurements not recorded for this site).

Point	Distance	Depth	Area	Velocityl	Velocity2	q
1	3.50	0.00	0.00	0.00	0.00	0.00
2	5.00	0.82	1.85	1.30	1.26	2.36
3	8.00	0.75	2.25	1.01	0.00	2.27
4	11.00	1.02	3.06	1.41	1.36	4.24
5	14.00	1.32	3.30	1.98	0.00	6.53
6	16.00	1.33	2.66	1.47	0.00	3.91
7	18.00	1.20	2.40	2.18	0.00	5.23
8	20.00	1.09	2.18	2.07	0.00	4.51
9	22.00	0.87	1.74	2.72	2.70	4.72
10	24.00	0.93	2.09	2.50	0.00	5.23
11	26.50	2.20	4.40	2.14	2.30	9.77
12	28.00	1.60	2.80	1.92	2.13	5.67
13	30.00	100	4.00	1.63	1.97	7.20
14	32.00	2.10	4.20	1.49	1.77	6.85
15	34.00	2.10	4.20	1.57	1.65	6.76
16	36.00	1.92	3.84	1.44	1.63	5.89
17	38.00	1.92	3.84	1.24	1.45	5.16
18	40.00	1.80	4.50	1.12	1.28	5.40
19	43.00	1.65	4.95	1.02	1.19 '	5.47
20	46.00	1.50	4.50	0.98	1.00	4.45
21	49.00	1.40	4.20	0.89	0.00	3.74
22	52.00	1.20	4.20	0.79	0.75	3.23
23	56.00	0.98	3.92	0.85	0.81	3.25
24	60.00	0.85	3.40	0.71	0.75	2.48
25	64.00	0.84	3.36	0.60	0.00	2.02
26	68.00	1.17	4.68	0.70	0.00	3.28
27	72.00	0.90	3.60	1.03	0.00	3.71
28	76.00	0.88	3.52	1.08	1.09	3.82
29	80.00	0.59	1.77	0.52	0.50	0.90
30	82.00	0.79	0.79	0.43	0.44	0.34

Total Area = 96.20 sq. ft.
Average Velocity = 1.33 ft./sec.

Total Discharge = 128.41 cfs

Site ID = Dung #4
Site Name = Dungeness R. Below old Clink Bridge at RM 13.28
Stage: ft. Date: 10/5/00 Time: 1015



Stream Discharge Calculation

Site ID = Dung #5
Site Name = Dungeness R. above old Clink Bridge at RM 13.35
Stage: ft. Date: 10/5/00 Time: 0840

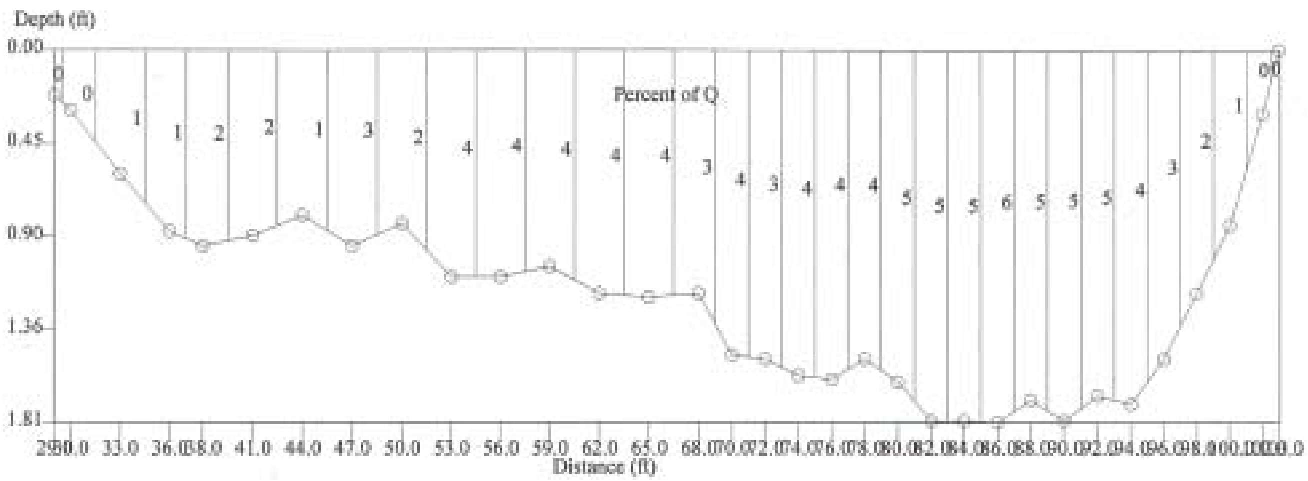
Comment:
No change in stage during flow measurement as determined by tape-down measurement on temporary staff gage (tape-down measurement not recorded for this site).

Point	Distance	Depth	Area	Velocityl	Velocity2	q
1	29.00	0.22	0.11	0.27	0.26	0.03
2	30.00	0.29	0.58	0.42	0.00	0.24
3	33.00	0.60	1.80	0.78	0.75	1.38
4	36.00	0.88	2.20	0.83	0.78	1.77
5	38.00	0.95	2.38	1.03	1.02	2.43
6	41.00	0.90	2.70	0.72	0.74	1.97
7	44.00	0.80	2.40	0.64	0.65	1.55
8	47.00	0.95	2.85	1.11	1.08	3.12
9	50.00	0.84	2.52	0.89	0.00	2.24
10	53.00	1.10	3.30	1.52	0.00	5.02
11	56.00	1.10	3.30	1.35	0.00	4.46
12	59.00	1.05	3.15	1.39	1.40	4.39
13	62.00	1.18	3.54	1.35	1.35	4.78
14	65.00	1.20	3.60	1.35	0.00	4.86
15	68.00	1.18	2.95	1.14	0.00	3.36
16	70.00	1.48	2.96	1.48	0.00	4.38
17	72.00	1.50	3.00	0.94	1.85	4.18
18	74.00	1.58	3.16	1.07	1.99	4.83
19	76.00	1.60	3.20	1.29	2.06	5.36
20	78.00	1.50	3.00	1.57	2.01	5.37
21	80.00	1.61	3.22	1.28	2.45	6.01
22	82.00	1.80	3.60	1.14	2.26	6.12
23	84.00	1.80	3.60	1.04	2.55	6.46
24	86.00	1.81	3.62	1.56	2.44	7.24
25	88.00	1.70	3.40	1.46	2.12	6.09
26	90.00	1.80	3.60	1.31	2.22	6.35
27	92.00	1.68	3.36	1.54	2.28	6.42
28	94.00	1.72	3.44	0.86	2.01	4.94
29	96.00	1.50	3.00	1.16	1.66	4.23
30	98.00	1.18	2.36	1.07	1.12	2.58
31	100.00	0.85	1.70	0.93	0.00	1.58
32	102.00	0.31	0.47	0.75	0.72	0.34
33	103.00	0.00	0.00	0.00	0.00	0.00

Total Area = 88.06 sq. ft.
Average Velocity = 1.41 ft./sec.

Total Discharge = 124.09 cfs

Site ID = Dung #5
Site Name = Dungeness R. above old Clink Bridge at RM 13.35
Stage: ft. Date: 10/5/00 Time: 0840



Stream Discharge Calculation

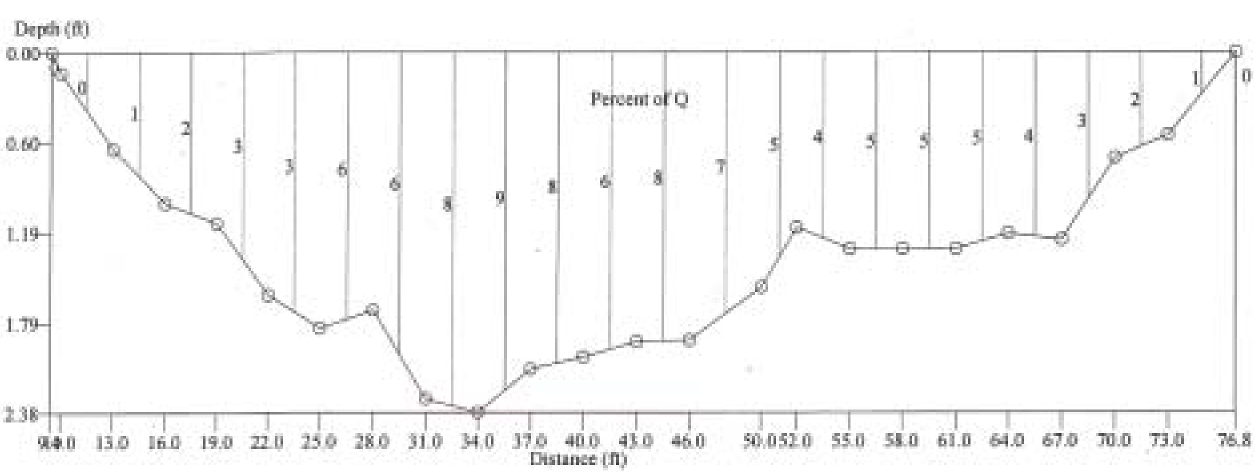
Site ID = Dung #6
Site Name = Dungeness River Station # 6 @ RM 14.9
Stage:.94* ft. Date: 10/5/00 Time: 1030

Comment:
No change in stage during flow measurement as determined by tape-down measurement on temporary staff gage.

Point	Distance	Depth	Area	Velocityl	Velocity2	q
1	9.40	0.00	0.00	0.00	0.00	0.00
2	10.00	0.14	0.25	0.24	0.00	0.06.
3	13.00	0.64	1.92	0.47	0.00	0.90
4	16.00	1.00	3.00	0.70	0.00	2.10
5	19.00	1.13	3.39	0.92	0.00	3.12
6	22.00	1.60	4.80	0.65	0.00	3.12
7	25.00	1.82	5.46	1.36	0.00	7.43
8	28.00	1.70	5.10	1.30	1.76	7.80
9	31.00	2.29	6.87	1.14	1.75	9.93
10	34.00	2.38	7.14	1.13	1.84	10.60
11	37.00	2.09	6.27	1.32	1.73	9.56
12	40.00	2.01	6.03	1.09	1.52	7.87
13	43.00	1.91	5.73	1.51	1.76	9.37
14	46.00	1.90	6.65	1.11	1.68	9.28
15	50.00	1.55	4.65	1.10	1.65	6.39
16	52.00	1.16	2.90	1.65	0.00	4.78
17	55.00	1.30	3.90	1.63	0.00	6.36
18	58.00	1.30	3.90	1.56	0.00	6.08
19	61.00	1.30	3.90	1.56	0.00	6.08
20	64.00	1.20	3.60	1.42	0.00	5.11
21	67.00	1.24	3.72	1.15	0.00	4.28
22	70.00	0.70	2.10	1.01	0.00	2.12
23	73.00	0.55	1.87	0.74	0.00	1.38
24	76.80	0.00	0.00	0.00	0.00	0.00

Total Area = 93.15 sq. ft.
Average Velocity = 1.33 ft./sec.

Total Discharge = 123.74 cfs



Stream Discharge Calculation

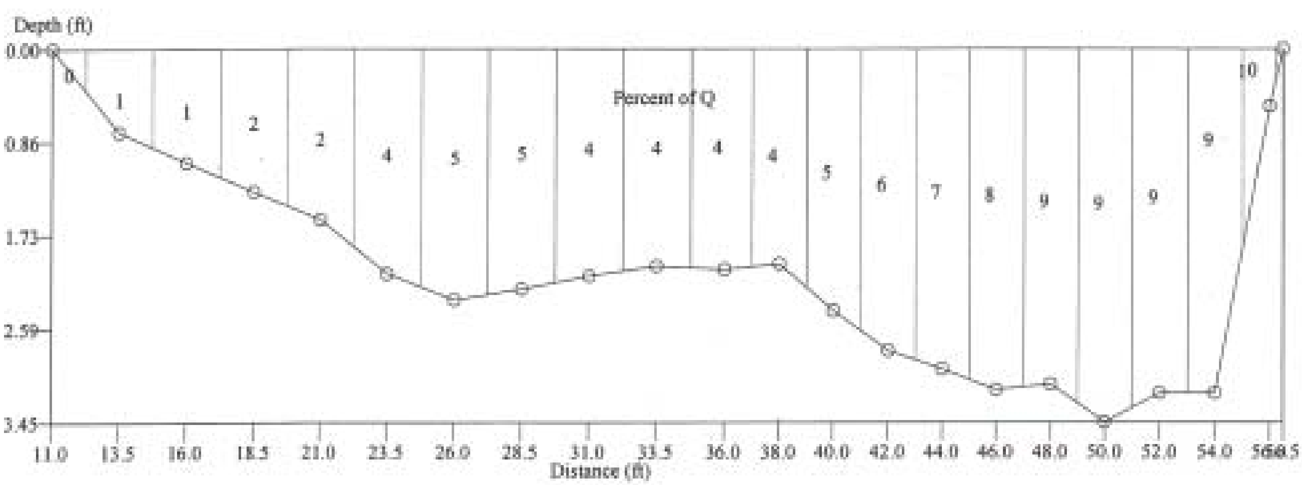
Site ID = Dung #7
Site Name = Dungeness River # 7 @ RM 15.15
Stage: .63* ft. Date: 10/5/2000 Time: 13:30

Comment: RP @ 1330=.62 ft. RP @ 1420=.64 ft. Stage changed -0.02 ft. during flow measurement as determined by tape-down measurement on temporary staff gage.

Point	Distance	Depth	Area	Velocity1	Velocity2	q
1	11.00	0.00	0.00	0.00	0.00	0.00
2	13.50	0.77	1.92	0.36	0.00	0.69
3	16.00	1.05	2.63	0.59	0.00	1.55
4	18.50	1.32	3.30	0.72	0.00	2.38
5	21.00	1.58	3.95	0.64	0.85	2.94
6	23.50	2.08	5.20	0.89	0.96	4.81
7	26.00	2.32	5.80	0.80	1.12	5.57
8	28.50	2.22	5.55	0.94 .	1.08	5.61
9	31.00	2.10	5.25	0.85	1.13	5.20
10	33.50	2.01	5.03	0.93	1.20	5.35
11	36.00	2.04	4.59	0.89	1.30	5.03
12	38.00	1.99	3.98	1.08	1.43	4.99
13	40.00	2.42	4.84	1.02	1.45	5.98
14	42.00	2.79	5.58	1.08	1.51	7.23
15	44.00	2.96	5.92	1.21	1.66	8.50
16	46.00	3.15	6.30	1.33	1.72	9.61
17	48.00	3.10	6.20	1.71	1.82	10.94
18	50.00	3.45	6.90	1.27	1.88	10.87
19	52.00	3.18	6.36	1.80	1.79	11.42
20	54.00	3.18	6.36	1.74	1.69	10.91
21	56.00	0.53	0.66	1.28	0.00	0.85
22	56.50	0.00	0.00	0.00	0.00	0.00

Total Area = 96.32 sq. ft.
Average Velocity = 1.25 ft./sec.

Total Discharge = 120.40 cfs



Stream Discharge Calculation

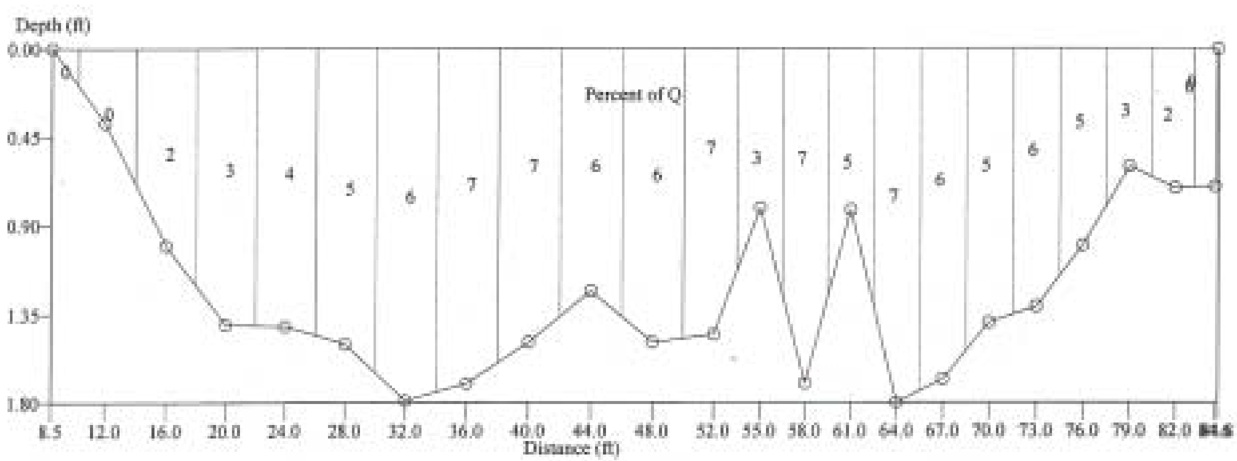
Site ID = Dung #8
Site Name = Dungeness River # 8 @ 15.25
Stage: 2.26* ft. Date: 10/5/2000 Time: 1445

Comment:
* 1445 RP=2.26 ft. 1535 RP=2.26 ft. No change in stage during flow measurement as determined by tape-down measurement on temporary staff gage.

Point	Distance	Depth	Area	Velocityl	Velocity2	q
1	8.50	0.00	0.00	0.00	0.00	0.00
2	12.00	0.38	1.42	0.35	0.00	0.50
3	16.00	1.00	4.00	0.58	0.00	2.32
4	20.00	1.40	5.60	0.68	0.00	3.81
5	24.00	1.41	5.64	0.85	0.00	4.79
6	28.00	1.50	6.00	1.02	0.00	6.12
7	32.00	1.79	7.16	1.04	1.30	8.38
8	36.00	1.70	6.80	1.15	1.43	8.77
9	40.00	1.49	5.96	1.59	0.00	9.48
10	44.00	1.23	4.92	1.67	0.00	8.22
11	48.00	1.49	5.96	1.31	0.00	7.81
12	52.00	1.45	5.08	1.89	0.00	9.59
13	55.00	0.81	2.43	1.36	0.00	3.30
14	58.00	1.70	5.10	1.76	2.06	9.74
15	61.00	0.82	2.46	2.43	0.00	5.98
16	64.00	1.80	5.40	0.89	2.30	8.61
17	67.00	1.68	5.04	0.92	2.15	7.74
18	70.00	1.39	4.17	1.41	0.00	5.88
19	73.00	1.31	3.93	1.92	0.00	7.55
20	76.00	1.00	3.00	2.00	0.00	6.00
21	79.00	0.60	1.80	1.97	0.00	3.55
22	82.00	0.71	1.99	1.09	0.00	2.17
23	84.60	0.70	0.98	0.35	0.00	0.34
24	84.80	0.00	0.00	0.00	0.00	0.00

Total Area = 94.84 sq. ft.
Average Velocity = 1.38 ft./sec.

Total Discharge = 130.64 cfs



Stream Discharge Calculation

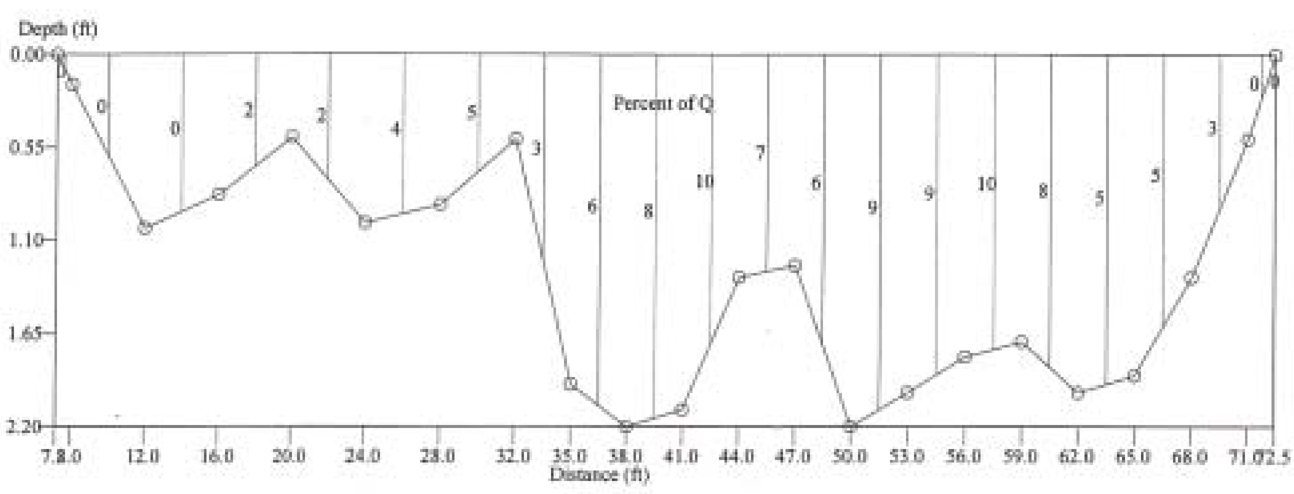
Site ID = Dung #9a
Site Name = Dungeness River #9 @ RM # 15.6
Stage: 1.24* ft. Date: 10/5/2000 Time: 1610

Comment:
* 1610 RP= 1.24 ft., 1715 RP=1.24 ft. No change in stage during flow measurement as determined by tape-down measurement on temporary staff gage.

Point	Distance	Depth	Area	Velocity1	Velocity2	q
1	7.20	0.00	0.00	0.00	0.00	0.00
2	8.00	0.18	0.43	-0.12	0.00	-0.05
3	12.00	1.03	4.12	-0.06	0.00	-0.25
4	16.00	0.83	3.32	0.74	0.00	2.46
5	20.00	0.49	1.96	1.31	0.00	2.57
6	24.00	1.00	4.00	1.26	0.00	5.04
7	28.00	0.89	3.56	1.58	0.00	5.62
8	32.00	0.50	1.75	1.80	0.00	3.15
9	35.00	1.95	5.85	0.27	1.96	6.52
10	38.00	2.20	6.60	1.12	1.76	9.50
11	41.00	2.10	6.30	1.46	2.09	11.18
12	44.00	1.32	3.96	1.93	0.00	7.64
13	47.00	1.25	3.75	1.77	0.00	6.64
14	50.00	2.20	6.60	1.04	2.20	10.69
15	53.00	2.00	6.00	1.40	2.14	10.62
16	56.00	1.79	5.37	1.85	2.34	11.25
17	59.00	1.70	5.10	1.74	1.99	9.51
18	62.00	2.00	6.00	0.48	1.28	5.28
19	65.00	1.90	5.70	1.01	0.00	5.76
20	68.00	1.32	3.96	0.88	0.00	3.48
21	71.00	0.50	1.13	-0.05	0.00	-0.06
22	72.50	0.00	0.00	0.00	0.00	0.00

Total Area = 85.46 sq. ft.
Average Velocity = 1.36 ft./sec.

Total Discharge = 116.57 cfs



Stream Discharge Calculation

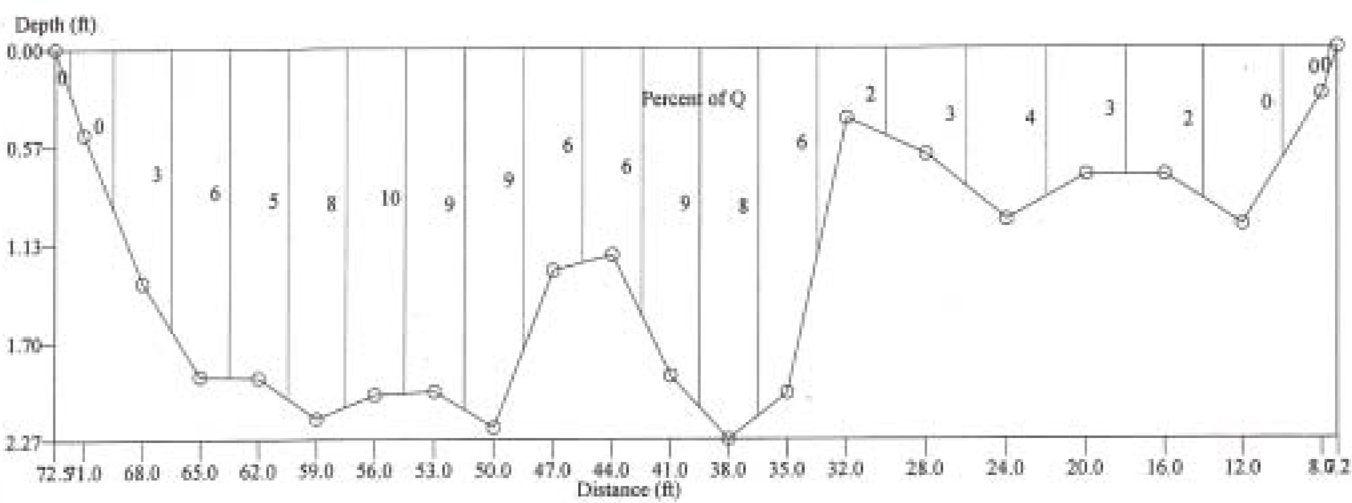
Site ID = Dung #9b
Site Name = Dungeness River #9 @ RM 15.6
Stage: 1.24* ft. Date: 10/5/2000 Time: 1715

Comment:
* 1715 RP= 1.24 ft., 1800 RP= 1.24 ft. Replicate flow measurement. No change in stage during flow measurement, as determined by tape-down measurement on temporary staff gage.

Point	Distance	Depth	Area	Velocityl	Velocity2	q
1	72.50	0.00	0.00	0.00	0.00'	0.00
2	71.00	0.50	1.13	-0.03	0.00	-0.03
3	68.00	1.36	4.08	0.87	0.00	3.55
4	65.00	1.90	5.70	1.07	1.50	7.32
5	62.00	1.91	5.73	0.72	1.39	6.05
6	59.00	2.15	6.45	1.01	1.89	9.35
7	56.00	2.01	6.03	1.63	2.32	11.91
8	53.00	1.99	5.97	1.35	2.12	10.36
9	50.00	2.20	6.60	1.11	2.13	10.69
10	47.00	1.29	3.87	1.98	0.00	7.66
11	44.00	1.20	3.60	2.04	0.00	7.34
12	41.00	1.90	5.70	1.75	2.02	10.74
13	38.00	2.27	6.81	1.00	1.76	9.40
14	35.00	2.00	6.00	0.25	1.97	6.66
15	32.00	0.41	1.43	1.86	0.00	2.67
16	28.00	0.62	2.48	1.65	0.00	4.09
17	24.00	1.00	4.00	1.29	0.00	5.16
18	20.00	0.74	2.96	1.35	0.00	4.00
19	16.00	0.74	2.96	0.85	0.00	2.52
20	12.00	1.03	4.12	-0.01	0.00	-0.04
21	8.00	0.27	0.65	-0.17	0.00	-0.11
22	7.20	0.00	0.00	0.00	0.00	0.00

Total Area = 86.27 sq. ft.
Average Velocity = 1.38 ft./sec.

Total Discharge = 119.29 cfs



Stream Discharge Calculation

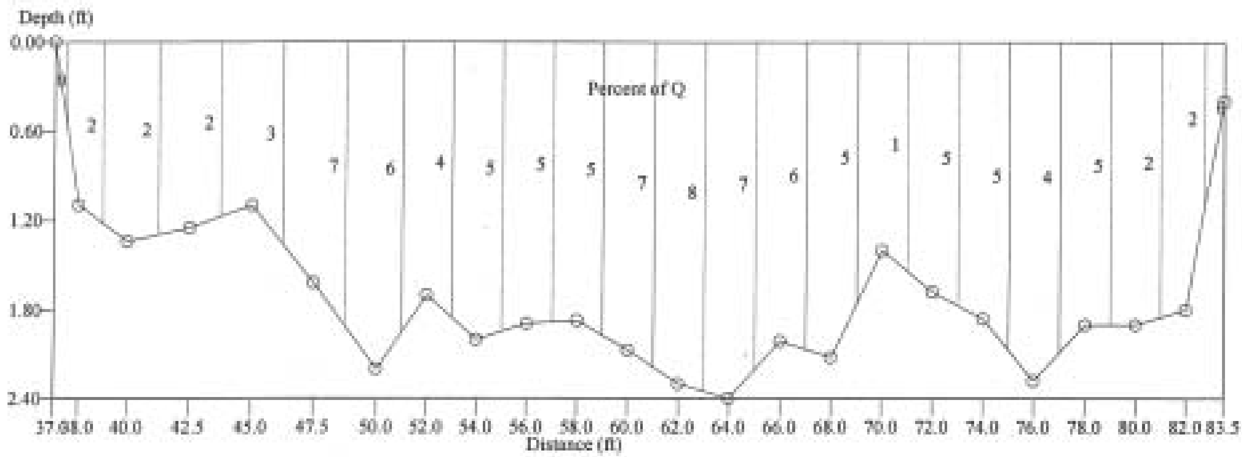
Site ID = Dung #10
Site Name = Dungeness R. below Gray Wolf R. at RM 15.8
Stage: * ft. Date: 10/5/00 Time: 1330

Comment:
* No change in stage during flow measurement as determined by tape-down measurement on temporary staff gage.

Point	Distance	Depth	Area	Velocity1	Velocity2	q
1	37.00	0.00	0.00	0.00	0.00	0.00
2	38.00	1.10	1.65	1.24	0.00	2.05
3	40.00	1.34	3.02	0.83	0.00	2.50
4	42.50	1.25	3.13	0.81	0.85	2.59
5	45.00	1.10	2.75	1.49	0.00	4.10
6	47.50	1.62	4.05	1.82	2.04	7.82
7	50.00	2.20	4.95	0.96	2.07	7.50
8	52.00	1.70	3.40	1.01	1.72	4.64
9	54.00	2.00	4.00	1.39	1.84	6.46
10	56.00	1.89	3.78	1.38	1.80	6.01
11	58.00	1.87	3.74	1.24	1.90	5.87
12	60.00	2.07	4.14	1.67	2.35	8.32
13	62.00	2.30	4.60	1.32	2.56	8.92
14	64.00	2.40	4.80	1.55	1.91	8.30
15	66.00	2.01	4.02	1.38	2.27	7.34
16	68.00	2.12	4.24	0.72	2.12	6.02
17	70.00	1.40	2.80	0.52	0.00	1.46
18	72.00	1.68	3.36	1.58	2.06	6.12
19	74 00	1.86	3.72	1.02	2.09	5.78
20	76.00	2.28	4.56	0.28	1.86	4.88
21	78.00	1.90	3.80	1.25	1.71	5.62
22	80.00	1.90	3.80	0.20	1.31	2.87
23	82.00	1.80	3.15	0.53	1.16	2.66
24	83.50	0.40	0.30	1.11	1.11	0.33

Total Area = 81.75 sq. ft.
Average Velocity = 1.45 ft./sec.

Total Discharge = 118.17 cfs



Stream Discharge Calculation

Site ID =Dung # 11a
Site Name = Dungeness R. above Gray Wolf R. at RM 15.95
Stage: * ft. Date: 10/5/2000 Time: 1500

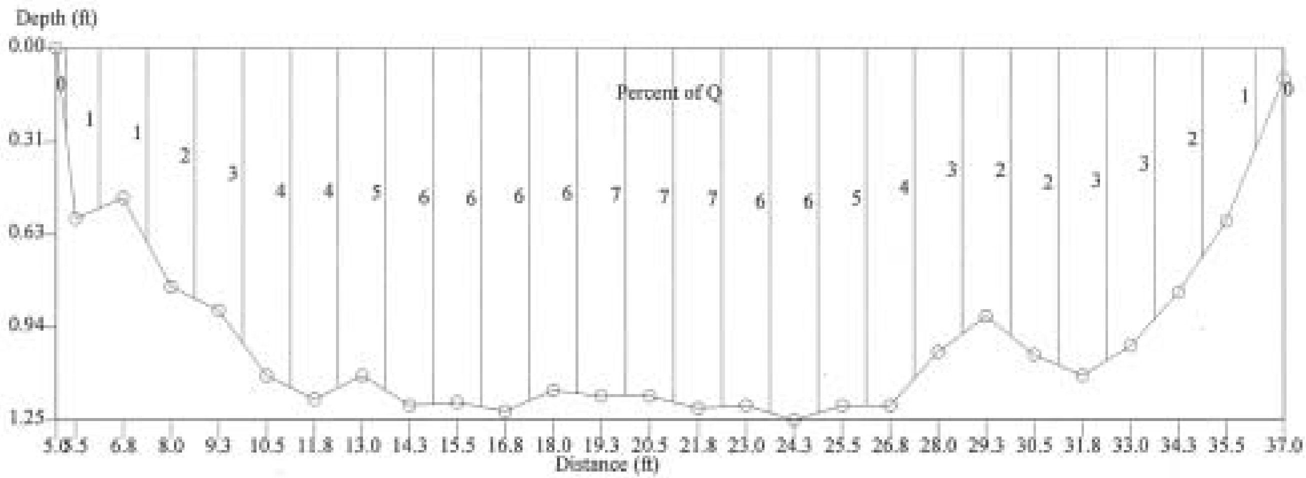
Comment:
* No change in stage during flow measurement as determined by tape-down measurement on temporary staff gage (tape-down measurements not recorded for this site).

Point	Distance	Depth	Area	Velocity l	Velocity2	q
1	5.00	0.00	0.00	0.00	0.00	0.00
2	5.50	0.57	0.50	1.17	0.00	0.58
3	6.75	0.50	0.63	1.38	1.35	0.85
4	8.00	0.80	1.00	1.16	1.21	1.18
5	9.25	0.88	1.10	1.48	0.00	1.63
6	10.50	1.10	1.38	1.75.	0.00	2.41
7	11.75	1.18	1.47	1.92	0.00	2.83
8	13.00	1.10	1.38	2.43	0.00	3.34
9	14.25	1.20	1.50	2.41	0.00	3.62
10	15.50	1.19	1.49	2.37	2.40	3.55
11	16.75	1.22	1.53	2.58	2.56	3.92
12	18.00	1.15	1.44	2.73	0.00	3.92
13	19.25	1.17	1.46	2.87	2.92	4.23
14	20.50	1.17	1.46	2.90	2.87	4.22
15	21.75	1.21	1.51	2.79	0.00	4.22
16	23.00	1.20	1.50	2.55	2.59	3.86
17	24.25	1.25	1.56	2.33	2.28	3.60
18	25.50	1.20	1.50	2.01	0.00	3.01
19	26.75	1.20	1.50	1.82	0.00	2.73
20	28.00	1.02	1.27	1.53	1.53	1.95
21	29.25	0.90	1.13	1.21	0.00	1.36
22	30.50	1.03	1.29	1.06	1.11	1.40
23	31.75	1.10	1.38	1.18	1.13	1.59
24	33.00	1.00	1.25	1.29	0.00	1.61
25	34.25	0.82	1.02	1.15	1.19	1.20
26	35.50	0.58	0.80	0.80	0.85	0.66
27	37.00	0.10	0.08	0.00	0.00	0.00

Total Area = 32.11 sq. ft.
Average Velocity = 1.98 ft./sec.

Total Discharge = 63.48 cfs

Site ID = Dung #11 a
Site Name = Dungeness R. above Gray Wolf R. at RM 15.95
Stage: * ft. Date: 10/5/2000Time: 1500



Stream Discharge Calculation

Site lfD = Dung #11b
Site Name = Dungeness R. above Gray Wolf R. at RM 15.95
Stage: * ft. Date: 10/5/2000 Time: 1540

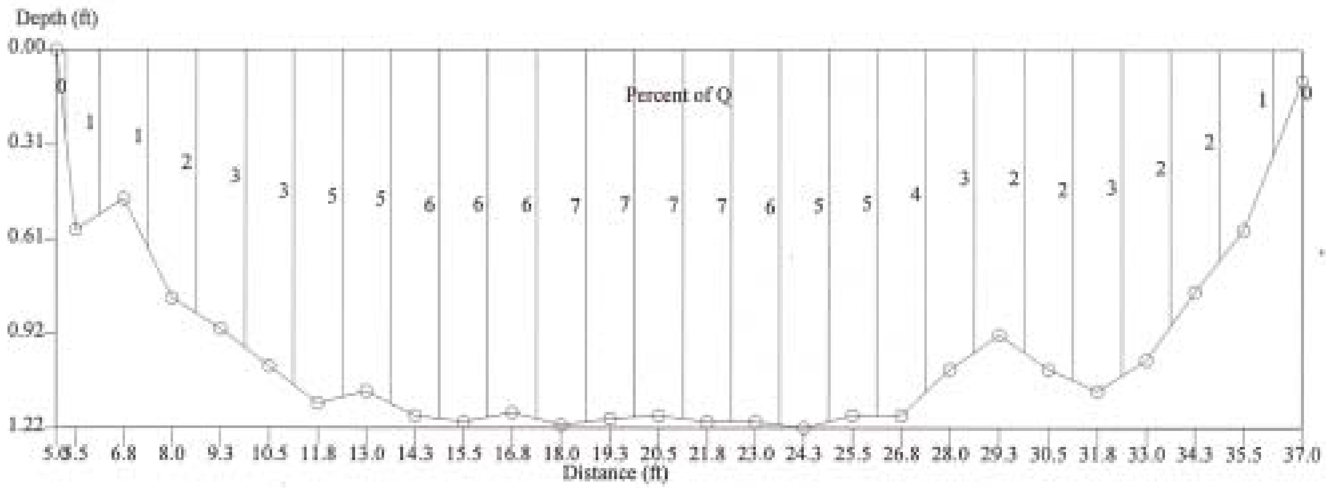
Comment:
* Replicate flow measurement. No change in stage during flow measurement as determined by tape-down measurement on temporary staff gage (tape-down measurements not recorded at this site).

Point	Distance	Depth	Area	Velocityl	Velocity2	q
1	5.00	0.00	0.00	0.00	0.00	0.00
2	5.50	0.58	0.51	0.93	0.91	0.47
3	6.75	0.48	0.60	1.28	1.30	0.77
4	8.00	0.80	1.00	1.21	0.00	1.21
5	9.25	0.90	1.13	1.45	1.43	1.62
6	10.50	1.02	1.27	1.67	1.64	2.11
7	11.75	1.14	1.42	2.02	1.99	2.86
8	13.00	1.10	1.38	2.29	0.00	3.15
9	14.25	1.18	1.47	2.41	2.36	3.52
10	15.50	1.20	1.50	2.69	2.71	4.05
11	16.75	1.17	1.46	2.79	2.76	4.06
12	18.00	1.21	1.51	2.90	2.87	4.36
13	19.25	1.19	1.49	2.81	0.00	4.18
14	20.50	1.18	1.47	2.81	0.00	4.14
IS	21.75	1.20	1.50	2.78	2.82	4.20
16	23.00	1.20	1.50	2.45	0.00	3.68
17	24.25	1.22	1.53	2.25	0.00	3.43
18	25.50	1.18	1.47	2.01	2.03	2.98
19	26.75	1.18	1.47	1.76	0.00	2.60
20	28.00	1.03	1.29	1.47	1.50	1.91
21	29.25	0.92	1.I S	1.29	0.00	1.48
22	30.50	1.03	1.29	1.07	0.00	1.38
23	31.75	1.10	1.38	1.19	1.15	1.61
24	33.00	1.00	1.25	1.25	0.00	1.56
25	34.25	0.78	0.97	1.15	0.00	1.12
26	35.50	0.58	0.80	0.75	0.00	0.60
27	37.00	0.10	0.08	0.00	0.00	0.00

Total Area = 31.89 sq. ft.
Average Velocity =1.98 ft./sec.

Total Discharge = 63.05 cfs

Site ID = Dung #1lb
Site Name = Dungeness R. above Gray Wolf R. at RM 15.95
Stage: * ft. Date: 10/5/2000 Time: 1540



Stream Discharge Calculation

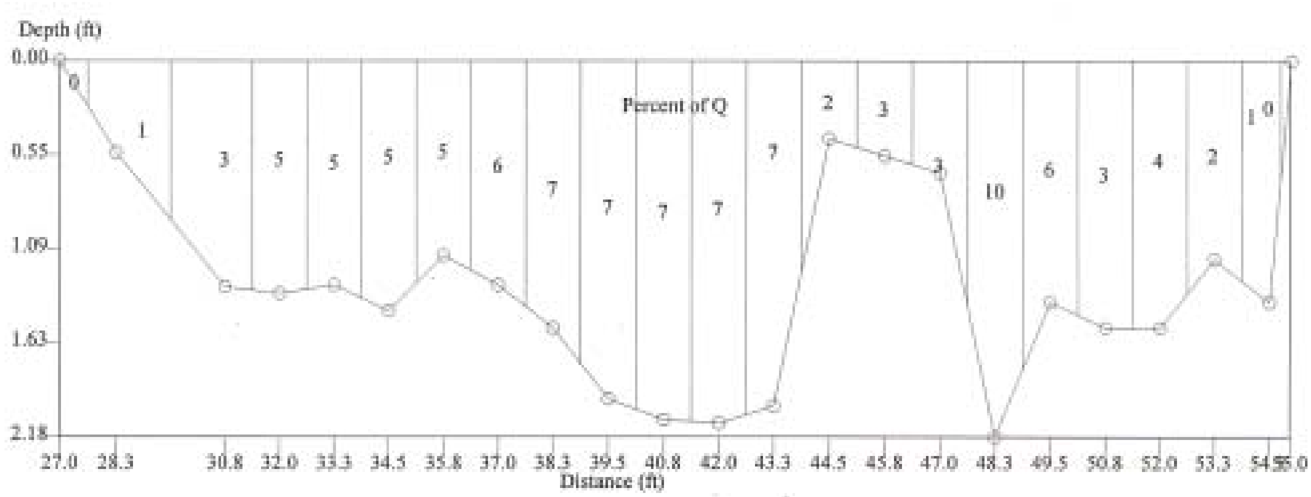
Site ID = GW #1
Site Name = Gray Wolf River near mouth above confluence w/ Dungeness R.
Stage: * ft. Date: 10/5/00 Time: 1655

Comment:
* No change in stage during flow measurement as determined by tape-down measurement on temporary staff gage (tape-down measurements not recorded at this site).

Point	Distance	Depth	Area	Velocity l	Velocity2	q
1	27.00	0.00	0.00	0.00	0.00	0.00
2	28.28	0.53	0.99	0.34	0.00	0.34
3	30.75	1.31	2.44	0.65	0.60	1.52
4	32.00	1.35	1.69	1.62	0.00	2.73
5	33.25	1.30	1.63	1.72	0.00	2.80
6	34.50	1.45	1.81	1.60	0.00	2.90
7	35.75	1.13	1.41	1.75	0.00	2.47
8	37.00	1.30	1.63	1.99	0.00	3.23
9	38.25	1.55	1.94	1.45	2.52	3.85
10	39.50	1.96	2.45	1.04	2.24	4.02
11	40.75	2.08	2.60	0.82	1.98	3.64
12	42.00	2.10	2.63	0.88	1.85	3.58
13	43.25	2.00	2.50	1.08	2.05	3.91
14	44.50	0.45	0.56	2.27	0.00	1.28
15	45.75	0.55	0.69	2.33	0.00	1.60
16	47.00	0.65	0.81	2.27	0.00	1.84
17	48.25	2.18	2.73	1.55	2.27	5.20
18	49.50	1.40	1.75	1.78	1.76	3.10
19	50.75	1.55	1.94	1.01	0.85	1.80
20	52.00	1.55	1.94	1.39	1.00	2.32
21	53.25	1.15	1.44	0.75	0.00	1.08
22	54.50	1.40	1.23	0.46	0.00	0.56
23	55.00	0.00	0.00	0.00	0.00	0.00

Total Area = 36.78 sq. ft.
Average Velocity = 1.46 ft./sec.

Total Discharge = 53.78 cfs



Appendix C

Data Quality Objectives

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Data Quality Objectives

Accuracy

Standard Stream Hydrology Unit (SHU) protocols for streamflow data collection were followed throughout this study (SHU, 1999). Replicate discharge measurements were conducted at representative flow-measurement sites on the mainstem of the Dungeness River and were used to estimate measurement precision. Replicate measurements were not conducted on minor tributaries, because tributary flows were so low as to be statistically insignificant compared to the discharge of the Dungeness River. Due to the number of variables involved in stream-flow measurements and the lack of reference measurements, it is impossible to set specific quantitative target values to assess measurement accuracy. In lieu of specific values, the replicate discharge measurements are herein used to assess measurement precision and estimate accuracy.

The SHU flow-measurement protocols are designed to produce the highest possible precision and accuracy for any given flow-measurement condition. The percent difference between the initial measurements and replicate measurements conducted by SHU during this project ranged from 0.67 to 2.3 percent (Table 1). These results indicate a high degree of precision at each flow measurement site.

Rantz (1982, p. 181-183) states that the standard error of a flow-discharge measurement made under average conditions and using USGS protocols – which are very similar to SHU protocols – is less than 2.2 percent. Based on the experience of SHU personnel and the replicate measurements made during this and other synoptic flow studies, as outlined in Simonds et al (1999), this standard error should be applicable to flow-discharge measurements made during this project. Therefore, given the flow conditions encountered and the demonstrated precision, we assume that the accuracy of the flow measurements for this project is within +/- 2 percent. Given that, flow measurements made during this project should be able to detect a difference in stream discharge of about +/- 2 percent of the measured discharge. Based on the mean flow of 125 cubic feet per second (cfs) during the seepage-run study, a two-percent error would equal a discharge of 2.5 cfs. Therefore, any reported gains or losses (Table 2) that are less than 2.5 cfs are statistically insignificant, because they are smaller than the range of measurement error.

Representativeness

The flow-measurement design was intended to ensure the data are representative of the river flow regime. The seepage run was conducted when prior weather conditions had been dry (<0.01 inches of precipitation) and streamflow conditions had been stable for the preceding two days. "Stable" streamflow conditions are defined as a less than

10 percent variation in total flow as measured at the USGS gage (12048000). The actual variation in river discharge over the 29-hour period prior to the seepage run was 6.7 percent (135.0 cfs at 0900 on 10/4/2000 and 126.0 cfs at 1400 on 10/5/2000).

There was a significant storm event in the week prior to the seepage run study, which raised discharge in the river considerably above the ideal low-flow. However, the study was delayed until one day later in the next week which gave the river time to come back to base-flow conditions. As shown in Table 1, river stage flux at station Dungeness #1 (the USGS gage) was only -0.01 ft. during the course of the synoptic flow study which indicates stable flow conditions.

Completeness

To ensure that data collected during this study are usable, we used only accepted SHU protocols for stream-flow data collection. All field equipment was appropriately maintained and calibrated.

Comparability

Data comparability between this study and others, particularly the in-progress study by Simonds et al (1999), is being assured by following standard SHU protocols for stream-flow measurements. The data formatting requirements of the Simonds et al. (1999) study and subsequent modeling exercises were considered during data reduction and report preparation.