

Entiat Subbasin Gain-Loss Analysis
Chelan County Conservation District/Entiat WRIA Planning Unit
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INTRODUCTION

The Entiat River sub-basin extends nearly 42 miles in a northwest-southeast direction from the eastern slopes of the Cascade Mountains to the Columbia River. The sub-basin drains the northern slopes of the Entiat Mountains and southern slopes of the Chelan Mountains. Overall relief within the sub-basin is over 8,500 feet from the top of Mt. Fernow, 9,249 feet, to the mouth of the Entiat River at about 700 feet. Climatic conditions vary widely from the upper to the lower portions of the sub-basin, especially in terms of precipitation.

Shrub-steppe type vegetative cover dominates the lower reaches of the Entiat valley and annual precipitation averages less than 10 inches. Forest and some alpine meadows occur higher up and can receive as much as 90 inches of annual precipitation, mostly in the form of winter snowpacks that can reach heights of 20 feet and remain on the ground from November through June. Details on the characteristics and resources of the Entiat sub-basin are in Entiat Valley Watershed Study Coordinated Resource Management Plan (WRIA 46 Management Plan 2002, *draft*).

Major tributary streams to the Entiat River are the North Fork Entiat and the Mad Rivers, which join the mainstem Entiat at river miles 33 and 10.5, respectively. Both the Entiat and the Mad River host anadromous and resident species of fish. In addition, the Entiat and Mad Rivers supply irrigation water to local agriculturists.

Purpose and scope of gain/loss study

The Entiat WRIA Planning Unit is an organization of stakeholders and concerned representatives of state, federal and local agencies, as well as the Confederated Tribes of the Colville and Yakama Indians. These entities are involved in the process of watershed planning and management as outlined in Washington's Watershed Management Act (RCW 90.82/ESHB 2514). The four elements of watershed planning as outlined in ESHB 2514 are water quantity, water quality, habitat and instream flows. In September 2002 a gain/loss study was implemented for the Entiat and Mad Rivers, with the objective of quantifying surface water contributions and losses to the mainstems of both rivers, as well as identifying reaches where surface-water/ground-water interchanges were taking place. The results of this investigation are applicable to all four components of the watershed planning process but are primarily intended for use in the water quantity and instream flow elements.

Current stream gaging efforts within the Entiat sub-basin

The USGS operates 2 continuous-recording stream gages on the mainstem Entiat River and 1 on the mainstem Mad River. In addition to the USGS gages, the Washington Department of Ecology Stream Hydrology Unit (WDOE/SHU) recently (September 2002) installed an enhanced

gaging network of 8 continuous recording gages and 6 miscellaneous staff gages in the sub-basin. Four of the WDOE continuous recorders are on the mainstem Entiat, one is located on the mainstem Mad River, and 3 others are located on major tributary streams to both the Entiat and the Mad. All active gaging sites are shown on figure 1 on the following page, and summarized in table 1, below.

Table 1. Existing stream gaging network, Entiat and Mad Rivers, September 2002.

Agency	Gage number	Station Name	River Mile
Mainstem continuous-recording gages			
USGS	12452990	Entiat River near Entiat	1.5
USGS	12452800	Entiat River near Ardenvoir	18
WDOE	46A110	Entiat River at Dill Creek Bridge	21
WDOE	46A150	Entiat River at Tommy Trail Bridge	31.5
WDOE	46A160	Entiat River below Entiat Falls	33.5
WDOE	46A170	Entiat River at North Fork campground	34
Tributary continuous-recording gages			
agency	gage number	station name	
WDOE	46B060	Roaring Creek	
WDOE	46D050	Tillicum Creek near mouth	
USFS	n/a	Tillicum Creek above Indian Creek confluence	
USFS	n/a	Potato Creek above Entiat River Road	
WDOE	46K050	Lake Creek	
Tributary miscellaneous sites (staff gages)			
agency	gage number	station name	
WDOE	46 E070	Mud Creek	
WDOE	46F060	Potato Creek	
WDOE	46G060	Stormy Creek	
WDOE	46H060	Preston Creek	
WDOE	46J080	Tommy Creek	
WDOE	46L050	Pope Creek	

METHODS

General background

A gain/loss study (also referred to as a seepage run or synoptic flow study) involves the direct measurement, over a fairly short time period, of all surface water inputs and outputs to a stream system as well as multiple mainstem measurements that break the stream into reaches. Once these measurements are completed and checked and the results are available, it is possible to construct a simple surface water budget for the stream, identify gaining or losing reaches and quantify the gains and losses. It is most meaningful to conduct the measurements when the stream is at or near “baseflow” condition- that is, most or all of the flow in the system is derived from groundwater sources versus precipitation runoff or snowmelt. Baseflow condition in the

Entiat system generally occurs in the fall, after the annual snowpack has entirely melted and the basin has been without substantial precipitation for some time. The late September 2002 flows at the USGS gage Entiat River near Ardenvoir were slightly below the long-term mean flows for that station (44 year period of record).

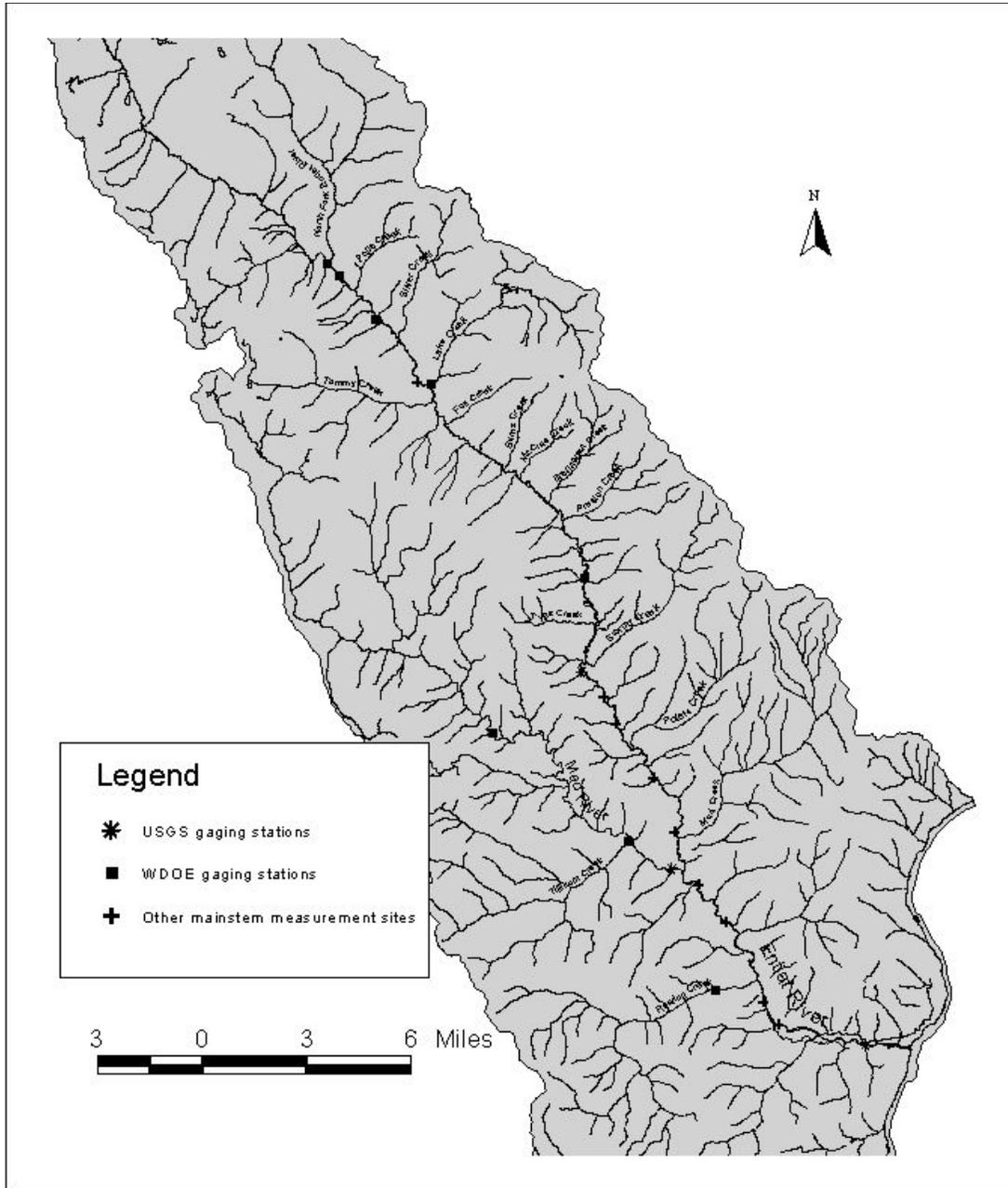


Figure 1. Map of Entiat sub-basin showing locations of all continuous-recording USGS and WDOE/SHU gaging stations and other mainstem Entiat gain/loss measurements taken 9/25/2002-9/28/2002.

The gain-loss measurements were taken September 25-28, 2002, with the highest priority mainstem and tributary measurements being taken during the first two days. Most minor tributary and ditch-related flows were done during the second two days of the measurement period. During the four day period of measurement, mean daily flow for the mainstem Entiat River at the USGS gage near Entiat (12452990; RM 1.5) ranged from 100-102 ft³sec⁻¹, and at the USGS gage near Ardenvoir (12452800; RM 18), mean daily flow ranged from 69-72 ft³sec⁻¹. Weather remained stable except for a minor amount of rainfall on September 26 that did not affect streamflows. The study was conducted during the last part of the irrigation season. Although it would have been preferable to wait until all irrigation diversions were inactive, which is usually the case by mid-October, the risk of the study being complicated by a significant precipitation event at the later date was considered too high.

Personnel from the U.S. Forest Service (USFS), U.S. Geological Service (USGS) and Chelan County Conservation District (CCCD) conducted the study. Two USGS hydrographers were assigned to make all measurements on the mainstem Entiat and Mad Rivers. USFS and CCCD personnel were assigned to make all tributary and ditch-related measurements. However, the study was made possible only through the cooperation of the many landowners associated with the 56 measurement sites involved in the effort.

Study Area and Site selection

The intent of the study was to measure surface flows at significant mainstem sites and all surface inflows/outflows between mainstem sites in the study area. The study area for this effort included the Entiat River to just above the North Fork Entiat River confluence (RM 34) and the Mad River to just above the Tillicum Creek confluence (RM 2; see figure 1 on previous page).

Mainstem Entiat River locations included reaches previously identified through geological interpretation as being likely areas of surface water-ground water interchange based on alluvial aquifer depth, proximity to alluvial fans, bedrock pinch points and faults (R. Dixon, J. Monohan and R. Hendrick, WDOE, pers. comm., September 2002; see figures 2-4 on pages 5-7). Sites of long-term or recently installed continuous recording stream gages were all measured. Summaries of the selected mainstem and tributary measurement sites for the Entiat and Mad rivers are contained in table 2a/b (see results section on p. 8).

Tributaries were classified as either primary or secondary based on the significance of their alluvial fans and their degree of connectivity, with respect to fish, with the mainstem. Whenever practical, discharge measurements for primary tributaries were made at or above the apex of the fan and at the mouth, in order to quantify gains and losses in the tributary flow across the alluvial fans/valley floor.

Data collection methods

Standard USGS protocols and equipment were used by USGS and USFS personnel involved in the study, while the CCCD personnel utilized flow measurement protocols and equipment provided by the Stream Hydrology Unit (SHU) of the WDOE. In some cases, tributary flows were so low as to make measurement with standard gear (wading rod and current meter)

impossible; in those cases, volumetric means were employed. Due to difficulties of access, some minor tributary flows were visually estimated from a distance.

Spatial coordinates for most measurement sites were determined using a global positioning system (GPS) receiver. Data were used to create a geographic information system (GIS) database of the study.

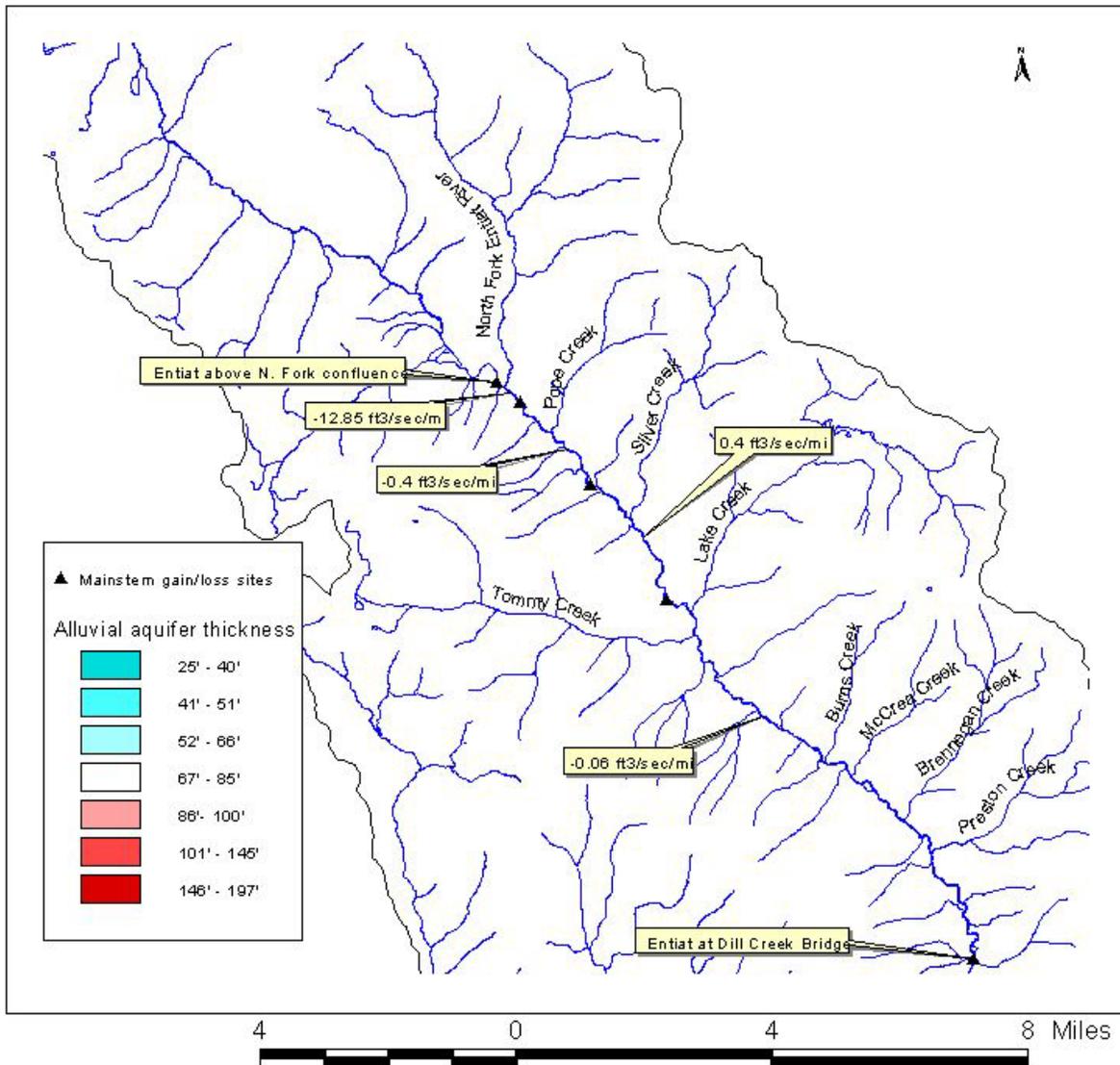


Figure 2. Upper Entiat River gain/loss, showing net change in discharge per unit channel length for mainstem segments 9/25/2003-9/28/2003.

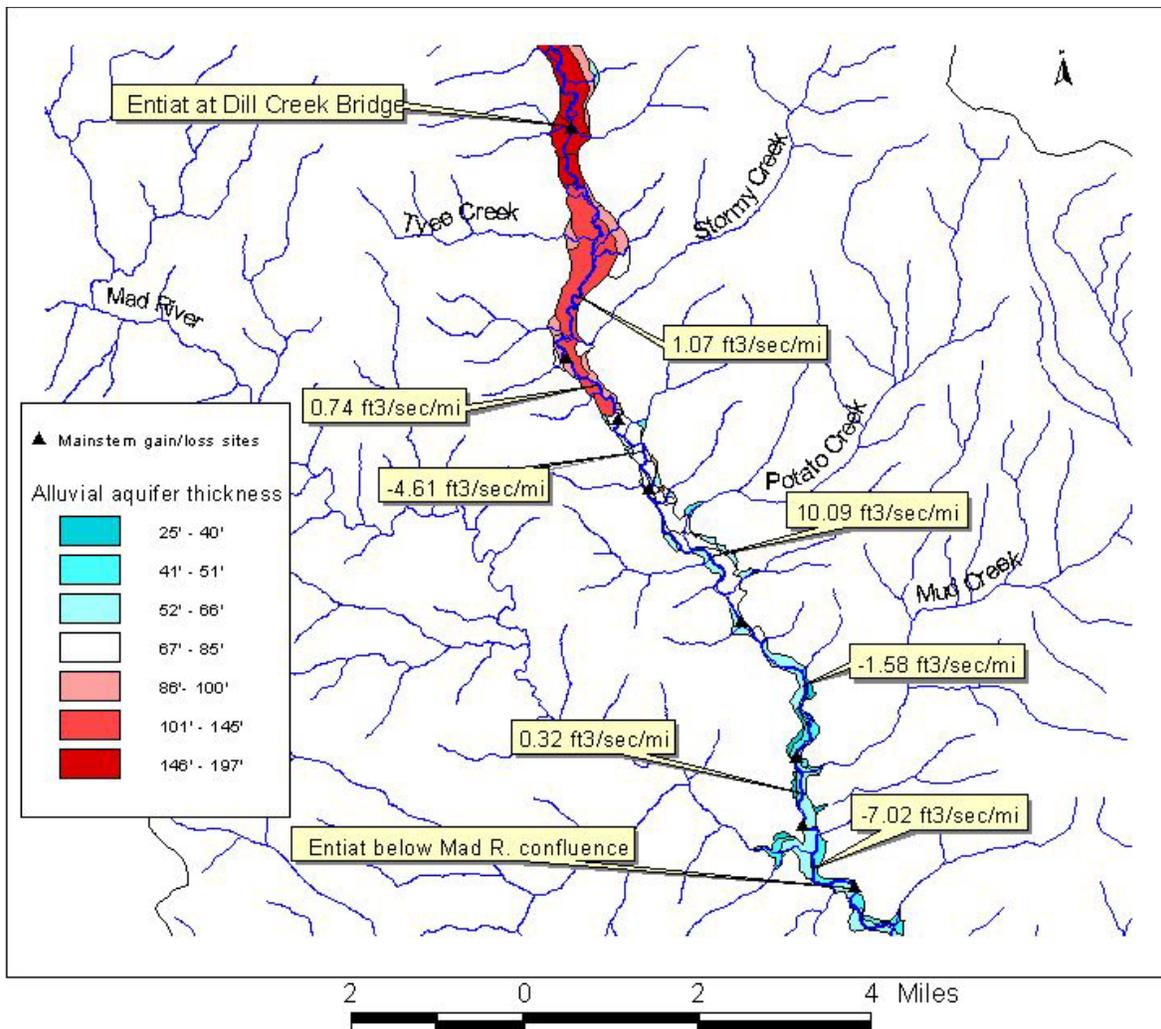


Figure 3. Middle Entiat River gain/loss, showing net change in discharge per unit channel length for mainstem segments 9/25/2003-9/28/2003.

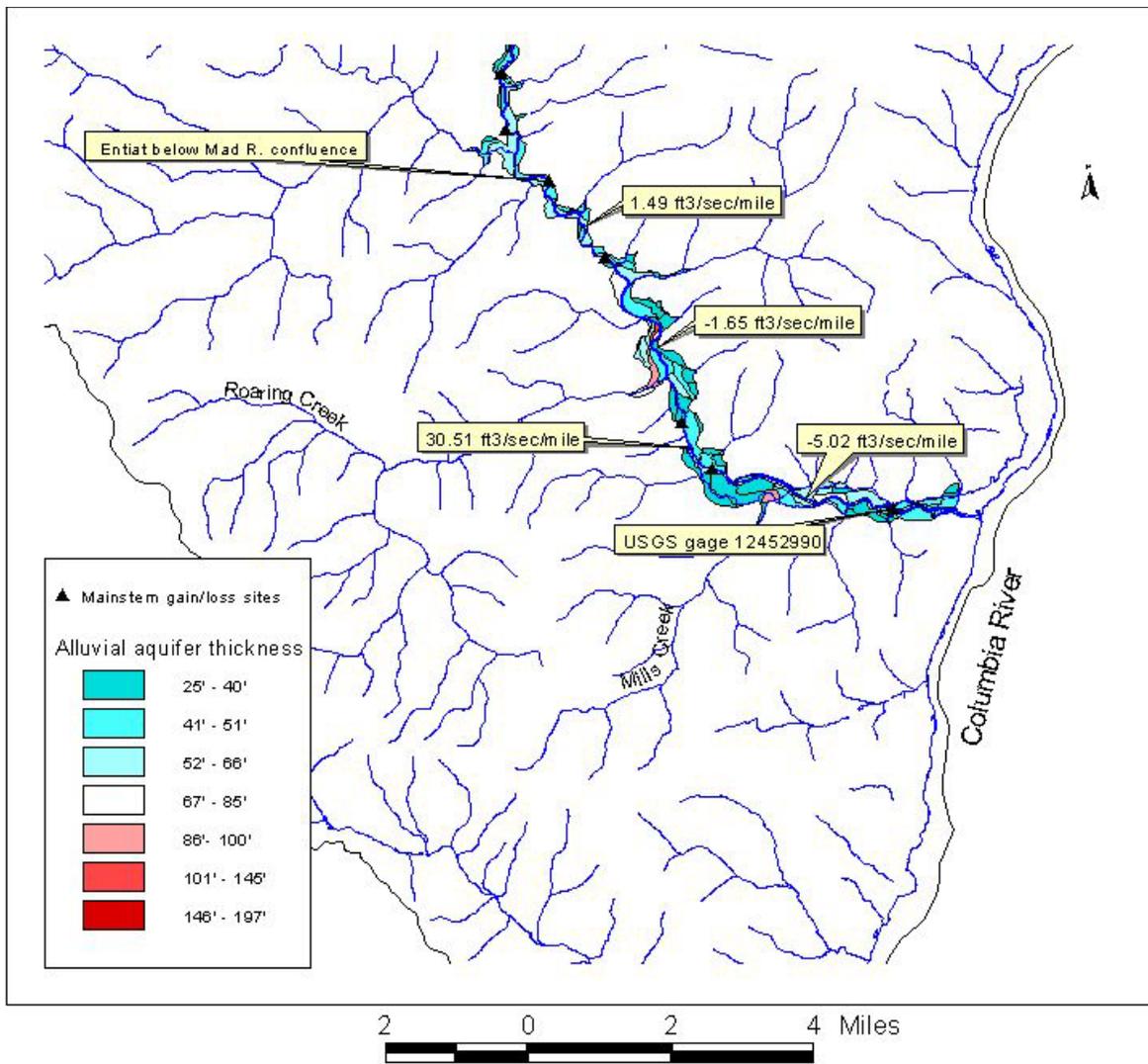


Figure 4. Lower Entiat River gain/loss, showing net change in discharge per unit channel length for mainstem segments 9/25/2003-9/28/2003.

RESULTS

Figures 2-4 on the preceding pages show the upper, middle and lower reaches of the Entiat sub-basin with all mainstem measurements and the net rates of gain/loss per unit channel length. Also shown are the estimated depths of the alluvial aquifer within the valley bottom (Dixon et al., pers. comm., 2002)

Tables 2a and 2b present simple surface water budgets for the Entiat and Mad Rivers. Tables 3a and 3b summarize the net changes in discharge and the net changes per unit channel length for all study reaches for both rivers. It is clear that the Entiat River experiences significant, though widely varying, ground water/surface water interchanges within its identified reaches. Overall, areas of measured gains and losses agree well with predictions based on geologic interpretation (mentioned above). The Mad River also has significant groundwater/surface water interchange within the study reaches.

Table 2a. Surface water budget for Entiat River gain/loss study, September 25-28, 2002

Site	Discharge (Q) [ft ³ /sec]		Cumulative inputs/outputs to mainstem flow [ft ³ /sec]	Downstream Q divided by upstream Q plus inputs/outputs % difference
Entiat R. at North Fork confluence	47.6			
North Fork Entiat R.	9.76			
Snowshoe Spring	0.08		9.84	
Entiat R. at Entiat Falls	52.3			-9.10%
Pope Creek	2.08		2.08	
Entiat R. at Tommy Trail Bridge	53.6			1.40%
Jungle Creek	0.05			
Silver Creek	2.93		2.98	
Entiat R. above Box Canyon	57.5			1.60%
Lake Creek	5.58			
Tommy Creek	1.55			
Fox Creek	0.52			
unnamed trib	0.5	estimated		
Burns Creek	0.4	estimated		
Grandma Creek	0.15			
McCrea Creek	0.24			
Preston Creek	1.06		10	
Entiat R. at Dill Creek Bridge	67			-1.00%
Stormy Creek	0.5		0.5	
Entiat R. at Ardenvoir gage	71.3	(USGS 12452800)		6%
Entiat R. above Gray Canyon	72.1			1.00%
McKenzie ditch intake	-4.02		-4.02	
Entiat R. below McKenzie intake	62.6			-8.10%

McKenzie interm. outfall	0.075			
McKenzie end outfall	0.61		0.685	
Entiat R. below McKenzie Canyon	85.5			35.10%
Entiat R. above Mud Creek	82.1			-4.00%
Mud Creek	0.23		0.23	
Entiat R. above Mad R. confluence	82.6			0.30%
Mad R.	22.3		22.3	
Entiat R. below Mad R. confluence	95.7			-8.80%
Entiat R. above Ringstead Canyon	98.4			2.80%
Gollaher ditch intake	-1.24			
Fish Hatchery outfall	4.76			
Gollaher ditch interm. outfall	0.53			
Gollaher ditch end outfall	0.11			
Gains ditch intake	-1.09			
Gains ditch outfall	0.61			
Roaring Creek	1.39		5.07	
Entiat R. below Dissmore Canyon	98.4			-4.90%
Knapp-Wham ditch intake	-4.83			
		Table 2a cont.		
Knapp-Wham outfall	0.63			
Hanan-Detwiler ditch intake	-2.51			
Hanan-Detwiler bypass ditch	0.29		-6.42	
Entiat R. at Dinkleman Canyon	117			27.20%
PUD ditch intake	-10.1			
PUD ditch interm. outfall	4.43			
Mills Creek	1.57			
PUD ditch end outfall	3.75		-0.35	
Entiat R. at Keystone Bridge	102	(USGS 12452990)		-12.60%
Hanan-Detwiler ditch outfall	0.99			

Table 2b. Surface water budget for Mad River gain/loss study, September 25-28, 2002

Site	Discharge (Q) [ft ³ /sec]		Cumulative inputs/outputs to mainstem flow [ft ³ /sec]	Downstream Q divided by upstream Q plus inputs/outputs
Mad R. above Tillicum Creek	18.3			% difference
Tillicum Creek	2.88		2.88	
Mad R. above Ardenvoir	24.9			17%
Mad R. at Mill Camp	22.1			-11.30%
		(USGS 12452890)		
Mad R. 200 ft above mouth	22.3			0.90%

Table 3a. Entiat River gain/loss study: Net change in flow between mainstem measurement sites, September 25-28, 2002.

Entiat River Reach	Net change [ft³/sec]	Distance [miles]	Net change per unit channel length [ft³/s/mi]
North Fork Entiat confluence to below Entiat Falls	-5.14	0.4	-12.85
Entiat Falls to Tommy Trail Bridge	-0.78	1.95	-0.4
Tommy Trail Bridge to above Box Canyon	0.92	2.32	0.4
Box Canyon to Dill Creek Bridge	-0.5	8.63	-0.06
Dill Creek Bridge to Ardenvoir gage (USGS 12452800)	3.8	3.54	1.07
Ardenvoir gage to above Gray Canyon	0.8	1.08	0.74
Gray Canyon to below McKenzie ditch intake	-5.48	1.19	-4.61
McKenzie ditch intake to below McKenzie Canyon	22.2	2.2	10.09
McKenzie canyon to Mud Creek	-3.4	2.15	-1.58
Mud Creek to above Mad River confluence	0.27	0.85	0.32
above Mad confluence to below Mad confluence	-9.2	1.31	-7.02
below Mad confluence to above Ringstead Canyon	2.7	1.81	1.49
Ringstead Canyon to below Dissmore Canyon	-5.07	3.07	-1.65
Dissmore Canyon to Dinkleman Canyon	25.02	0.82	30.51
Dinkleman Canyon to Keystone gage (USGS 12452990)	-14.65	2.92	-5.02
Entire study reach	11.51	34.24	0.34

Table 3b. Mad River gain/loss: Net change in flow between mainstem measurements, September 25-28, 2002.

Mad River Reach	Net change [ft³/sec]	Distance [miles]	Net change per unit channel length [ft³/s/mi]
Above Tillicum Creek fan to above Ardenvoir fan	3.72	0.97	3.84
Ardenvoir fan to Mill Camp (USGS gage 12452890)	-2.8	0.77	-3.64
Mill Camp to 200 ft. above mouth	0.2	0.26	0.77
Entire study reach	1.12	2	0.56

Net changes per unit channel length for the mainstem Entiat River ranged from 30.51 ft³/sec/mi to -12.85 ft³/sec/mi, with the mean value being 0.76 ft³/sec/mile and the median value being -0.06 ft³/sec/mile. The changes per unit channel length for the Mad River ranged from 3.84 ft³/sec/mi to -3.64 ft³/sec/mi, with the mean and median values being 0.32 and 0.77 ft³/sec/mi, respectively.

There are areas of groundwater/surface water interchange along both the Entiat and Mad Rivers. Most notable on the Entiat River are the -12.85 ft³/sec/mi (-9.1%) loss from the North Fork confluence to Entiat Falls, the 10.09 ft³/sec/mi (35.1%) gain from below the McKenzie ditch intake to below McKenzie Canyon, the -7.02 ft³/sec/mi (-8.8%) loss from above the Mad River confluence to below the Mad River confluence and the 30.51 ft³/sec/mi (27.2%) gain from below Dissmore Canyon to Dinkleman Canyon. The remaining Entiat River mainstem reaches had net changes ranging from -5.02 to 1.49 ft³/sec/mi. The largest net change on the Mad River is a -3.64 ft³/sec/mi (-11.30%) loss from above Tillicum Creek confluence to above the town of Ardenvoir.

Overall, the Entiat River had a net change in discharge of 11.51 ft³/sec and a net change per unit channel length of 0.34 ft³/sec/mi. The net change for the Mad River was 1.12 ft³/sec and its net change per unit channel length was 0.56 ft³/sec/mi.

Table 4 summarizes the net changes and net changes per unit channel length for primary tributaries of both the Entiat and Mad Rivers. Potato Creek, considered a primary Entiat tributary due to its connection to the river (accessible to fish), had no surface flow at the mouth. The entire 0.37 ft³/sec flow measured at the apex of its alluvial fan was being lost to subsurface flow at the time the measurements were made. The net change in flow per unit channel length for Potato Creek is somewhat underestimated, as the actual point of zero surface flow was not located due to access problems on private property, and occurred somewhere upstream of the confluence with the Entiat River. The largest groundwater/surface water interaction noted in the primary tributaries was on Tillicum Creek, which flows into the Mad River and had a net change per unit channel length of -2.73 ft³/sec/mi.

Table 4. Entiat/Mad River gain/loss study: Net change in tributary flows across tributary fans/valley floor, September 25-28, 2002.

Tributary Reach	Net change [ft ³ /sec]	Distance [miles]	Net change per unit channel length [ft ³ /s/mi]
<i>Entiat tributaries</i>			
Stormy Creek, above fan to mouth	-0.11	0.25	-0.44
Potato Creek, above fan to mouth	-0.37	0.66	-0.56
Mud Creek, above fan to mouth	0.06	0.35	0.17
Roaring Creek, above fan to mouth	0.02	0.91	0.02
<i>Mad River Tributary</i>			
Tillicum Creek	-0.3	0.11	-2.73

CONCLUSIONS

The results of this gain/loss study are an important component of the efforts to quantify ground water and identify ground-water/surface-water interaction within the Entiat sub-basin. This study represents one element of a “three-pronged” approach to the ground water quantity question within WRIA 46. Estimation of groundwater present by hydrogeologic interpretation and analysis, as well as by hydrograph separation, has been done.

Two mainstem Entiat reaches had net gains in discharge per unit channel length of over 10 ft³/sec/mile (table 3a). Both of these reaches occur in the lower portion of the river, where most land is privately owned and continues to be developed.

While the Entiat River as a whole underwent a net gain in flow during the course of this gain/loss study, the rate of gain was not overwhelming at 0.34 ft³/sec/mile. Assuming this is a typical rate of recharge for the system at this time of year, relatively small additional withdrawals from the mainstem or from the surrounding alluvial aquifer could potentially result in a transition to a losing condition.