Appendix C. Estimation of Groundwater Fluxes to Mosier Watershed Streams

Groundwater discharge to Mosier Creek was identified by seepage studies and by base flow separation. Seepage is the exchange between groundwater and surface water at the streambed forming the boundary between a stream and an aquifer system. A seepage study is an indirect method of quantifying groundwater discharge (streamflow gains) or recharge (streamflow losses) at the streambed at numerous locations along the stream. A seepage study consists of a series of streamflow measurements made at numerous locations along a stream reach over a short period. After accounting for tributary inflows and streamflow diversions, the gain or loss in streamflow between one location and the next location downstream is attributed to interaction with the groundwater system. Base flow separation uses daily mean streamflow, and separates rapid runoff during storm events from the groundwater discharge component of streamflow. The base flow component of streamflow may be compared to recharge estimates by PRMS and RORA.

One finding of the recharge estimates from PRMS is the need to invoke the groundwater sink component, indicating that part of the groundwater recharge bypasses the gaging station site. Seepage studies can help identify the location where this groundwater discharges downstream of the stream gage.

In addition to streamflow measurements, water quality data were collected during some of the seepage studies. These data consisted of measurements of specific conductance at the time of streamflow measurement and continuous stream temperature data for several weeks surrounding the seepage study. An increase in specific conductance from one location to the next location downstream is an indication of groundwater discharge to the stream, owing to the relatively high (compared to that of stream water) specific conductance of groundwater in the Mosier basin. Similarly, during warm months, a decrease in stream temperature at subsequent sites downstream indicates discharge of relatively cool groundwater to the stream.

The low streamflow measured in summertime is base flow derived from groundwater discharge to the stream. Base flow separation is a semi-automated technique for separating the surface-runoff component of streamflow from the groundwater discharge component. It is based on daily mean streamflow at the Mosier Creek stream gage, and provides an annual estimate of the base flow component of streamflow at that location.

C.1—Seepage

Seepage studies of Mosier Creek were done in 1962 in a regional groundwater study (Newcomb, 1969), in 1986 as part of a water-availability study by the Oregon Water Resources Department (Lite and Grondin, 1988), and for the current study in 2005 and 2006. The 1962 seepage study extended far upstream of the current study, with limited detail in the current study area. The primary focus area of both the 1986 and the current study is the part of the basin from the confluence of West Fork Mosier Creek toward the mouth of Mosier Creek. In the current study, streamflow measurements were also made of Rock and Rowena Creeks. All measurement sites are listed in table C1 and their locations are shown on figure 1.

Two primary factors impose uncertainty in seepage studies—uncertainty in the streamflow measurements, and fluctuations in streamflow during the time of the study. The uncertainty of an individual streamflow measurement is affected by the uniformity of velocity, channel characteristics, and limitations of the meter in use. Most streamflow measurements made as part of this study were rated as “fair” using standard USGS qualitative rating methodology (Rantz, 1982), which assumes the streamflow is within 8 percent of the actual value. The accuracy of streamflow measurements of Mosier Creek was limited by the shallow depth of flow and low velocity. Considering the uncertainty associated with each streamflow measurement, the measured value represents a range of streamflow. If the magnitude of streamflow is large compared to the difference between streamflow at one location and the next location downstream, the net difference is often within the measurement uncertainty and therefore inconclusive. Second, accuracy of the seepage study is affected by temporal fluctuations in streamflow at each measurement location. At best, temporal flow fluctuation in a seepage study is known at a single location: the stream gage site. The gaging station was in operation during the seepage studies of July and September 2005, and in 2006. During summertime, and absent rainfall or withdrawals, streamflow is expected to be fairly steady; however, some natural diurnal fluctuations in streamflow do occur, typically caused by riparian evapotranspiration.

Table C1. Streamflow and spring measurement sites in the Mosier, Oregon, study area.

[**Streamflow measurement site:** Refer to number in figure 1. **USGS site number**: Using this number, additional information is available from the USGS National Water Information System online at http://waterdata.usgs.gov/or/nwis. **Site name and location**: All sites near Mosier, Oregon, unless noted otherwise. **Abbreviations**: (a), daily mean streamflow; USGS, U.S. Geological Survey]

Streamflow measurement site	USGS site No.	Site name and location	River mile	Measurements made in years
1	453621121223200	Mosier Creek below Honeysuckle Creek	6.7	2005–06
2	453820121221500	Mosier Creek above Digger Road	4.1	1986, 2005–06
3	453853121223800	West Fork Mosier Creek at mouth		1962, 1986, 2005–06
4	14113200	Mosier Creek near Mosier	3.2	1962, 1963–81 (a), 2005–09 (a)
5	453922121223000	Mosier Creek at 1820 Mosier Creek Road	2.7	1986, 2005–06
6	453940121224200	Mosier Creek above Tanawasher Spring	2.1	1986, 2005–06
7	453951121224600	Mosier Creek below Tanawasher Spring	1.9	1986, 2005–06
8	454014121225200	Mosier Creek above dam	1.4	1986, 2005–06
9		Mosier Spring		1986, 2005–06
10	454041121230300	Mosier Creek above Dry Creek	0.9	1986, 2005–06
11	454042121230200	Dry Creek at mouth		4-05-05
12	454050121230600	Mosier Creek below Dry Creek	0.7	1962,1986, 2005–06
13	454105121233600	Mosier Creek at mouth between I-84 and highway 30	0.1	2006
14	454045121242800	Rock Creek near east tunnel portal		2005–06
15	454041121184800	Rowena Creek at Highway 30 near Rowena, Oregon		2005–06

A seepage study was done in September 1962 (table C2, fig. 11). Streamflow was measured at two locations coincident with the current study. Streamflow increased 0.4 ft^3/s between the current (2009) stream gage site (streamflow measurement site number 4) and streamflow measurement site number 12, and of all seepage studies discussed in this report, represents the only gain during summertime in this reach. In addition, the magnitude of flow was greater than all other summertime streamflow measurements. These measurements were made prior to the installation of the gaging station, so it is unknown how representative these measurements are of low flow conditions, however weather conditions during the month prior to the 1962 measurements were seasonably warm and dry.

In 1986, seepage studies were done in June and August. The study done in June was disregarded due to uncertainty in methods. In August, streamflow measurements were made between site numbers 2 and 12 (table C2, figs. 1 and 11). Gains and losses in this reach from one measurement location to the next location downstream were as large as 0.5 ft^3/s, greater than the measurement uncertainty. In the reach between site numbers 4 and 12, the loss in streamflow was about 0.1 ft^3/s (10 percent), and was less than the measurement uncertainty of streamflow. The stream gage was not in operation during this study, however streamflow measurements at that site on two subsequent days indicated about a 50 percent fluctuation, suggesting caution regarding interpretations of gains and losses of similar magnitude during this study.

Seepage studies were made in April, July and September 2005, and May and August 2006, beginning at streamflow measurement site number 1. For consistency with previous studies, the upstream extent of the following analysis is at the stream gage site (streamflow measurement site number 4) (table C1), even though measurements were collected at locations upstream of the gaging station. Upstream seepage data were used during development of the conceptual model of groundwater flow and to aid in estimation of base flow flux calibration targets. The study of April 2005 was done prior to the re-installation of the gage.

During the July 2005 study, there were streamflow fluctuations owing to infiltration to the streambed and possibly to pumping from the stream. On the day of measurement, a tanker truck positioned just upstream of the Mosier Creek gaging station pumped from the creek four times for 15- to 30-minutes during the day. These withdrawals were evident in the streamflow record, where streamflow declined (and recovered) by about 50 percent each time. Translation of these pulses in streamflow may account for some of the fluctuation in measured streamflow at sites downstream. During the July 2005 study, no measurement was made at streamflow measurement site number 12 due to ponded conditions. The most downstream measurement location was the site upstream from the confluence with Dry Creek (streamflow measurement site number 10), and Dry Creek was dry during this study.

Table C2. Streamflow measurements and seepage analysis, Mosier, Oregon, study area.

[**Streamflow measurement site:** Refer to number in table C1. **Measured streamflow**: Tributaries are in italics and underlined. **Gain (+) or loss (-) from next Mosier Creek measurement upstream**: Values in bold are greater than measurement uncertainty. **Abbreviations**: ft^3/s, cubic foot per second; **(b),** tributary treated as contribution, not a gain; **(e)**, estimated]

Streamflow measurement site	Stream or spring	River mile	Measurement date and time	Measured streamflow (ft^3/s)	Measurement uncertainty (percent)	Gain (+) or loss (-) from next Mosier Creek measurement upstream (ft^3/s)	Gain (+) or loss (-) range of uncertainty from next Mosier Creek measurement upstream (ft^3/s)
4	Mosier Creek	3.2	09-12-62	2.84	5 (e)		
12	Mosier Creek	0.7	09-12-62	3.24	5 (e)	**+0.40**	+0.10 to +0.70
Summary		**3.2 to 0.7**	**September 1962**		5 (e)	**+0.40**	+0.10 to +0.70
2	Mosier Creek	4.1	08-19-86	1.30	8 (e)		
3	West Fork Mosier Creek (b)		08-19-86	***0.05***	8 (e)		
4	Mosier Creek	3.2	08-19-86	1.01	8 (e)	**-0.34**	-0.52 to -0.16
5	Mosier Creek	2.7	08-19-86	0.98	8 (e)	-0.03	-0.19 to 0.13
6	Mosier Creek	2.1	08-20-86	1.49	8 (e)	**0.51**	0.31 to 0.71
7	Mosier Creek	1.9	08-20-86	1.05	8 (e)	**-0.44**	-0.64 to -0.24
8	Mosier Creek	1.4	08-20-86	0.56	8 (e)	**-0.49**	-0.62 to -0.37
10	Mosier Creek	0.9	08-20-86	0.73	8 (e)	**0.17**	0.07 to 0.27
12	Mosier Creek	0.7	08-21-86	0.91	8 (e)	**0.18**	0.05 to 0.31
Summary		**3.2 to 0.7**	**August 1986**			-0.10	-0.25 to 0.05
1	Mosier Creek	6.7	04-05-05	13.6	8		
2	Mosier Creek	4.1	04-05-05	12.9	8	-0.7	-2.8 to 1.4
3	West Fork Mosier Creek (b)		04-05-05	***2.91***	8		
4	Mosier Creek	3.2	04-05-05	17.0	8	1.2	-1.4 to 3.8
5	Mosier Creek	2.7	04-05-05	16.6	5	-0.4	-2.6 to 1.8
6	Mosier Creek	2.1	04-05-05	16.9	8	0.3	-1.9 to 2.5
7	Mosier Creek	1.9	04-05-05	17.7	5	0.8	-1.4 to 3.0
8	Mosier Creek	1.4	04-05-05	16.9	5	-0.8	-2.5 to 0.9
9	Mosier Spring		04-05-05	0.10	5		
10	Mosier Creek	0.9	04-05-05	16.3	8	-0.6	-2.7 to 1.5
11	Dry Creek (b)		04-05-05	***0.57***	10		
12	Mosier Creek	0.7	04-05-05	17.7	5	0.8	-1.4 to 3.1
Summary		**3.2 to 0.7**	**April 2005**			0.1	-2.2 to 2.5
1	Mosier Creek	6.7	07-19-05	0.96	8		
2	Mosier Creek	4.1	07-19-05	1.10	8	0.14	-0.02 to 0.30
3	West Fork Mosier Creek (b)		07-19-05	***0.10***	10		
4	Mosier Creek	3.2	07-19-05	1.17	10	-0.03	-0.25 to 0.19
5	Mosier Creek	2.7	07-20-05	0.68	10	-0.49	-0.68 to -0.30
6	Mosier Creek	2.1	07-20-05	0.74	10	0.06	-0.08 to 0.20
7	Mosier Creek	1.9	07-20-05	1.07	10	0.33	0.15 to 0.51
8	Mosier Creek	1.4	07-20-05	0.41	5	-0.66	-0.79 to -0.53
9	Mosier Spring		07-20-05	0.00			
10	Mosier Creek	0.9	07-20-05	0.46	8	0.05	-0.01 to 0.11
11	Dry Creek (b)		07-20-05	0.00			
Summary		**3.2 to 0.9**	**July 2005**			-0.71	-0.87 to -0.55

Table C2. Streamflow measurements and seepage analysis, Mosier, Oregon, study area.—Continued

[**Streamflow measurement site:** Refer to number in table C1. **Measured streamflow**: Tributaries are in italics and underlined. **Gain (+) or loss (-) from next Mosier Creek measurement upstream**: Values in bold are greater than measurement uncertainty. **Abbreviations**: ft^3/s, cubic foot per second; **(b),** tributary treated as contribution, not a gain; **(e)**, estimated]

Streamflow measurement site	Stream or spring	River mile	Measurement date and time	Measured streamflow (ft^3/s)	Measurement uncertainty (percent)	Gain (+) or loss (-) from next Mosier Creek measurement upstream (ft^3/s)	Gain (+) or loss (-) range of uncertainty from next Mosier Creek measurement upstream (ft^3/s)
1	Mosier Creek	6.7	09-26-05	1.01	8		
2	Mosier Creek	4.1	09-26-05	1.01	10	0.00	-0.18 to 0.18
3	West Fork Mosier Creek (b)		09-27-05	***0.19***	10		
4	Mosier Creek	3.2	09-26-05	1.36	8	0.16	-0.07 to 0.39
5	Mosier Creek	2.7	09-26-05	1.08	8	-0.28	-0.48 to 0.08
6	Mosier Creek	2.1	09-26-05	1.03	10	-0.05	-0.24 to 0.14
7	Mosier Creek	1.9	09-26-05	1.07	8	0.04	-0.15 to 0.23
8	Mosier Creek	1.4	09-26-05	1.01	5	-0.06	-0.20 to 0.08
9	Mosier Spring		09-26-05	0.05	5		
10	Mosier Creek	0.9	09-26-05	1.13	5	0.12	0.01 to 0.23
11	Dry Creek (b)		09-26-05	***0.00***			
12	Mosier Creek	0.7	09-26-05	1.02	10	-0.11	-0.27 to 0.05
Summary		**3.2 to 0.7**	**September 2005**			-0.34	-0.55 to -0.13
1	Mosier Creek	6.7	05-16-06	6.05	8		
2	Mosier Creek	4.1	05-16-06	6.90	8	0.85	-0.19 to 1.89
3	West Fork Mosier Creek (b)		05-15-06	***0.94***	8		
4	Mosier Creek	3.2	05-16-06	7.66	8	-0.18	-1.42 to 1.06
5	Mosier Creek	2.7	05-16-06	8.56	5	0.90	-.14 to 1.94
6	Mosier Creek	2.1	05-16-06	7.95	5	-0.61	-1.44 to 0.22
7	Mosier Creek	1.9	05-16-06	7.32	8	-0.63	-1.61 to 0.35
8	Mosier Creek	1.4	05-16-06	7.31	5	-0.01	-0.96 to 0.94
9	Mosier Spring		05-15-06	0.08	5		
10	Mosier Creek	0.9	05-16-06	8.56	8	1.25	0.20 to 2.30
11	Dry Creek (b)		05-15-06	***0.33***	10		
12	Mosier Creek	0.7	05-16-06	8.50	8	-0.39	-1.78 to 1.00
13	Mosier Creek	0.1	05-16-06	8.81	5	0.31	-0.81 to 1.43
Summary		**3.2 to 0.7**	**May 2006**			0.51	-0.81 to 1.83
1	Mosier Creek	6.7	08-01-06	1.38	8		
2	Mosier Creek	4.1	08-01-06	1.19	10	-0.19	-0.42 to 0.04
3	West Fork Mosier Creek (b)		08-01-06	***0.05***	10		
4	Mosier Creek	3.2	08-01-06	1.26	8	0.02	-0.21 to 0.25
5	Mosier Creek	2.7	08-01-06	0.93	8	-0.33	-0.51 to -0.15
6	Mosier Creek	2.1	08-01-06	1.12	10	0.19	0.00 to 0.38
7	Mosier Creek	1.9	08-01-06	0.92	8	-0.20	-0.39 to -0.01
8	Mosier Creek	1.4	08-01-06	0.66	8	-0.26	-0.39 to -0.13
9	Mosier Spring		07-31-06	0.00			
10	Mosier Creek	0.9	08-01-06	0.59	10	-0.07	-0.18 to 0.04
11	Dry Creek (b)		08-01-06	***0.00***			
12	Mosier Creek	0.7	08-01-06	0.79	10	0.20	0.06 to 0.34
13	Mosier Creek	0.1	08-10-06	0.59	8	-0.20	-0.33 to -0.07
Summary		**3.2 to 0.7**	**August 2006**			-0.47	-0.65 to -0.29

Streamflow decreased 0.71 ft^3/s between streamflow measurement sites 4 and 10, and this decrease was greater than the measurement uncertainty. Despite the pumping, losses of about 0.5 ft^3/s between streamflow measurement site numbers 8 and 10 are considered accurate owing to the consistently low streamflow measured at these sites about 2 mi downstream of the location of withdrawal.

The streamflow measurements of September 2005 and August 2006 were made during relatively stable, low streamflow. The loss observed between streamflow measurement site numbers 4 and 12 in September 2005 (–0.34 ft^3/s) and August 2006 (–0.47 ft^3/s) were both greater than the measurement uncertainty.

Although the 2005 and 2006 seepage studies indicated net losses over the length of the study reach, changes in specific conductance and continuous stream-temperature data measured upstream and downstream of Mosier Spring (streamflow site 9) indicated some groundwater inflow. However, the groundwater inflow was not of a sufficient magnitude to be detected in the streamflow measurements. Specific conductance measurements (fig. 11) indicated generally similar values at sites upstream of streamflow measurement site number 8 and increases at streamflow measurement site numbers 10 and 12. The specific conductance of springs, seeps and Dry Creek was measured, and ranged from two to three times the value of Mosier Creek. Of particular interest is the relatively sharp increase in specific conductance in late summer of 2005 and 2006 between streamflow measurement site numbers 10 and 12, encompassing the tributary Dry Creek, which was dry during these times. Although streamflow measurements at these sites indicated a slight loss in 2005 and a slight gain in 2006, specific conductance increased sharply in both years. The only decrease in specific conductance from one location to the next location downstream was in August 2006, between streamflow measurement site number 12 and streamflow measurement site number 13. Streamflow measurement site number 13 is located at the mouth of Mosier Creek, near the elevation of the Columbia River. The decrease in specific conductance at this site suggests interaction with the Columbia River. Stream temperature was another indicator of interaction of the stream and the surrounding aquifer. At sites upstream, stream temperature gradually increased at each subsequent location downstream. Between streamflow measurement site numbers 8 and 10, in both late summer 2005 and 2006, stream temperature decreased between 1 and 2 °C, indicating groundwater contributions to the creek.

In addition to seepage studies of Mosier Creek, measurements of flow in other streams in the study area were made and used to verify flow simulated by the PRMS models for those locations. These consisted of a single streamflow measurement of both Rowena and Rock Creeks in 2005 and 2006. Streamflow of Rowena Creek at Highway 30 (streamflow site 15) in April 2005 and May 2006 was 0.08 and 0.18 ft^3/s, respectively, and was zero (dry) during the summer seepage studies. Streamflow of Rock Creek (streamflow measurement site number 14) was measured upstream of a large quarry, and the creek was flowing during all seepage studies. Streamflow in 2005 (the average of the July and September measurements) was about 0.10 ft^3/s, and was 0.05 ft^3/s in July 2006.

Comparing the September 1962 streamflow measurements to later measurements, there is an apparent reduction in total base flow and a shift from net gaining to losing in the reach between the stream gage site and the Rocky Prairie thrust fault (fig. 11). Although these patterns of base flow are the expected result of groundwater declines to the south of the Rocky Prairie thrust fault, precipitation at the proximal Hood River rain gage was significantly higher during August and September of 1962 than for the periods preceding all other measurements, obfuscating clear linkages between the declining groundwater levels and the magnitude of base flow reduction in this area.

C.2—Base Flow Separation

The base flow component of stream flow was determined using the program PART using default parameter settings (Rutledge, 1998). PART uses streamflow partitioning to estimate a daily record of base flow from the stream flow hydrograph. The method assumes base flow equals streamflow on successive days when the streamflow is slowly receding, and linearly interpolates base flow for other days. Applied to multi-year periods, base flow separation provides an estimate of groundwater discharge. Expressed in inches, annual base flow totals were computed by summing monthly base flow totals by water year (October 1 to September 30). The lowest (1.0 in. in 1977) and highest (13.3 in. in 1974) annual totals were coincident with the lowest and highest occurrences of annual precipitation and streamflow for the period of record (WYs 1964–81 and 2006–07). Mean annual base flow for the same period was 6.9 in. (21.1 ft^3/s), or about 70 percent of stream flow. During low-flow years almost the entire stream flow for the year was base flow. During summertime (July through September) base flow was 0.14 in., (1.7 ft^3/s) or about 95 percent of streamflow.