APPENDIX C

PRELIMINARY GROUNDWATER BUDGET

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INTRODUCTION

A preliminary groundwater budget was developed for the valley-fill aquifers to provide initial estimates of reasonable ranges for the magnitude, timing, and geographic distribution of the major groundwater inflows and outflows within the study area. This budget provided insight into the magnitude and timing of sources and sinks of groundwater, and aided in development of numerical groundwater models. Monitoring data collected from June 2019 to December 2020 were used to develop some components of the budget; however, the budget was developed to represent long-term average values (e.g., 30-yr normals). Each water budget component was estimated on both a monthly and annual basis (table C1).

This appendix provides details on how the preliminary groundwater budget components were derived. A water budget for the Swan Mountain Block was developed to estimate the amount and timing of groundwater and surface-water inflow from the Swan Block to the east side of the valley-fill aquifer (fig. C1). The inflows from the mountain block were combined with other inputs and outputs to develop an overall groundwater budget for the unconsolidated valley-fill aquifers on the east side of the Flathead Valley (fig. C1).

SWAN BLOCK WATER BUDGET

The Swan Mountain Block includes 17,272 acres between the mountain front and the top of the Swan Range, along the east side of the study area (fig. C2). Recharge to the valley-fill aquifers from the Swan Mountain Block occurs from mountain block recharge (*MBR*; groundwater inflow from the mountain block to the valley aquifers), and surficial mountain front recharge (MFR_s, stream infiltration at the mountain front; Markovich and others, 2019; fig. C1). Note that *MBR* and MFR_s are conceptually combined in the main text of this report, and referred to as mountain front recharge (*MFR*; Wilson and Guan, 2004; Markovich and others, 2019).

The water budget for the Swan Block was estimated based on a volumetric balance within the mountain block between precipitation (*PCP*), actual evapotranspiration (*AET*), surface-water runoff (RO), and groundwater recharge (RCH; fig. C1). That is:

$$PCP = AET + RO + RCH. \qquad \text{eq. C1}$$

Analysis was conducted on a drainage basis (fig. C2). The areas between drainages along the mountain front, known as mountain front facets (MFFs; Markovich and others, 2019), were also digitized so that the entire mountain block was included. Drainages in the Swan Mountain Block were defined based on the USGS 1/3 arc-second digital elevation model (DEM; ~10 m resolution). An accumulation map was developed using the ArcMap > Spatial Analyst > Hydrology > “Flow Direction” and “Flow Accumulation” tools. Pore points, which are the points where water flows out of an area, were established at the mountain front for stream elements that had more than 10,000 contributing cells (fig. C2, table C2). Since the cells are 10 m x 10 m, the drainage areas above the pore points were greater than 100 hectares (247 acres). This provided pore points at all USGS National Hydrography Dataset (NHD; USGS, 2019) flowlines, which are based on “blue lines” from 1:24,000-scale topographic maps, plus two other small drainages. Drainage polygons for each pore point were defined using the ArcMap > Spatial Analyst > Hydrology > “Watershed” tool, and manual digitization. This resulted in a total of 21 drainage polygons that cover 81% of the area, and 21 MFFs (fig. C2, table C2).

Precipitation (*PCP*)

Long-term average precipitation values were obtained for each drainage or MFF in the Swan Block from the PRISM (parameter-elevation regressions on independent slopes model) 1981–2010 normal precipitation values dataset (PRISM Climate Group, 2015; https://prism.oregonstate.edu/). Results for each drainage and MFF are on table C2. The reported normal precipitation values within the Swan Block ranged from 22 in/yr near the valley bottom to over 70 in/yr at the top of the ridge (fig. C3). The area-weighted average precipitation for the Swan Block was 45.8 in/yr.

Actual Evapotranspiration (*AET*)

AET is the amount of water that is actually evaporated or transpired by vegetation to the atmosphere. Because *AET* is limited by water availability, it is not the same as potential evapotranspiration (*PET*). *AET* was estimated using the MOD16 *AET* algorithm (Mu and others, 2007, 2011; https://www.ntsg.umt.edu/project/modis/mod16.php). These estimates are based on MODIS satellite data and meteorological data. The datasets provide *AET* estimates over 1 km^2 pixels. This

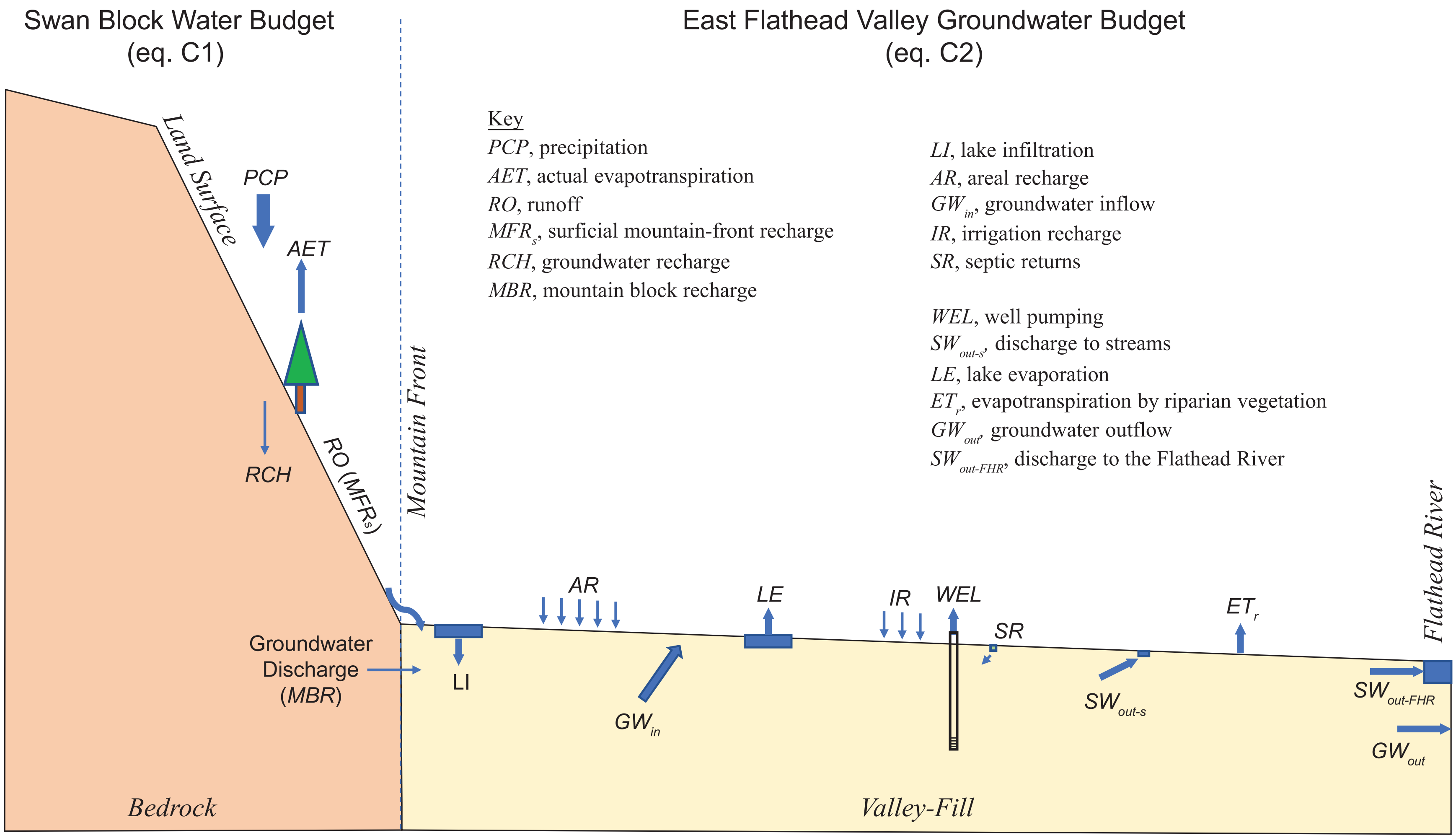

Figure C1. Schematic diagram of water budget components for the Swan Mountain Block and the East Flathead Valley. Designations in parentheses (*MFR_s* and *MBR*) reflect that the runoff (*RO*) and groundwater discharge, which are outputs from the mountain block, are inputs to the valley groundwater budget.

Table C1. Preliminary Groundwater Budget for the East Flathead Valley (ac-ft; long-term average values).

	O	N	D	J	F	M	A	M	J	J	A	S	Annual BE	Estimated Uncertainty for Annual Budget: 10% ε	LBE	UBE
MBR	891	863	891	891	812	891	863	891	863	891	891	863	10,503	1,050	9,452	11,553
MFR_s	886	796	703	504	404	518	1,433	4,695	6,156	3,152	1,311	841	21,399	2,140	19,259	23,539
LI	536	518	536	536	488	536	518	536	518	536	536	518	6,311	631	5,680	6,942
GW_{in}	878	850	878	878	800	878	850	878	850	878	878	850	10,346	1,035	9,311	11,380
AR	728	705	728	728	663	728	705	728	705	728	728	705	8,578	858	7,720	9,435
IR	0	0	0	0	0	0	0	0	917	1,334	896	548	3,695	370	3,326	4,065
SR	59	57	59	59	54	59	57	59	57	59	59	57	693	69	624	762
Total Inflows*	3,978	3,788	3,795	3,595	3,222	3,610	4,425	7,787	10,065	7,578	5,299	4,381	61,524	2,833	58,691	64,358
WEL	228	181	180	182	166	185	183	398	2,129	3,829	2,773	470	10,903	1,090	9,813	11,994
$SW_{out\text{-}s}$	2,354	2,279	2,354	2,354	2,146	2,354	2,279	2,354	2,279	2,354	2,354	2,279	27,741	2,774	24,967	30,515
LE	91	29	14	14	30	75	141	293	326	421	345	199	1,977	198	1,779	2,175
ET_r	34	0	0	0	0	45	46	77	78	109	109	73	572	57	515	629
Residual Outflow (GW_{out} + $SW_{out\text{-}FHR}$)	1,726	1,670	1,726	1,726	1,572	1,726	1,670	1,726	1,670	1,726	1,726	1,670	20,330	2,033	18,297	22,363
Total Outflows*	4,433	4,158	4,274	4,276	3,915	4,384	4,318	4,849	6,482	8,438	7,307	4,690	61,524	3,614	57,910	65,138
Change in Storage	-455	-370	-478	-681	-693	-774	107	2,938	3,583	-860	-2,008	-309	0	0	0	0

Note. BE, best estimate; e, error; LBE, lower bound estimate; UBE, upper bound estimate.
*Error for totals calculated using root mean square error propagation.

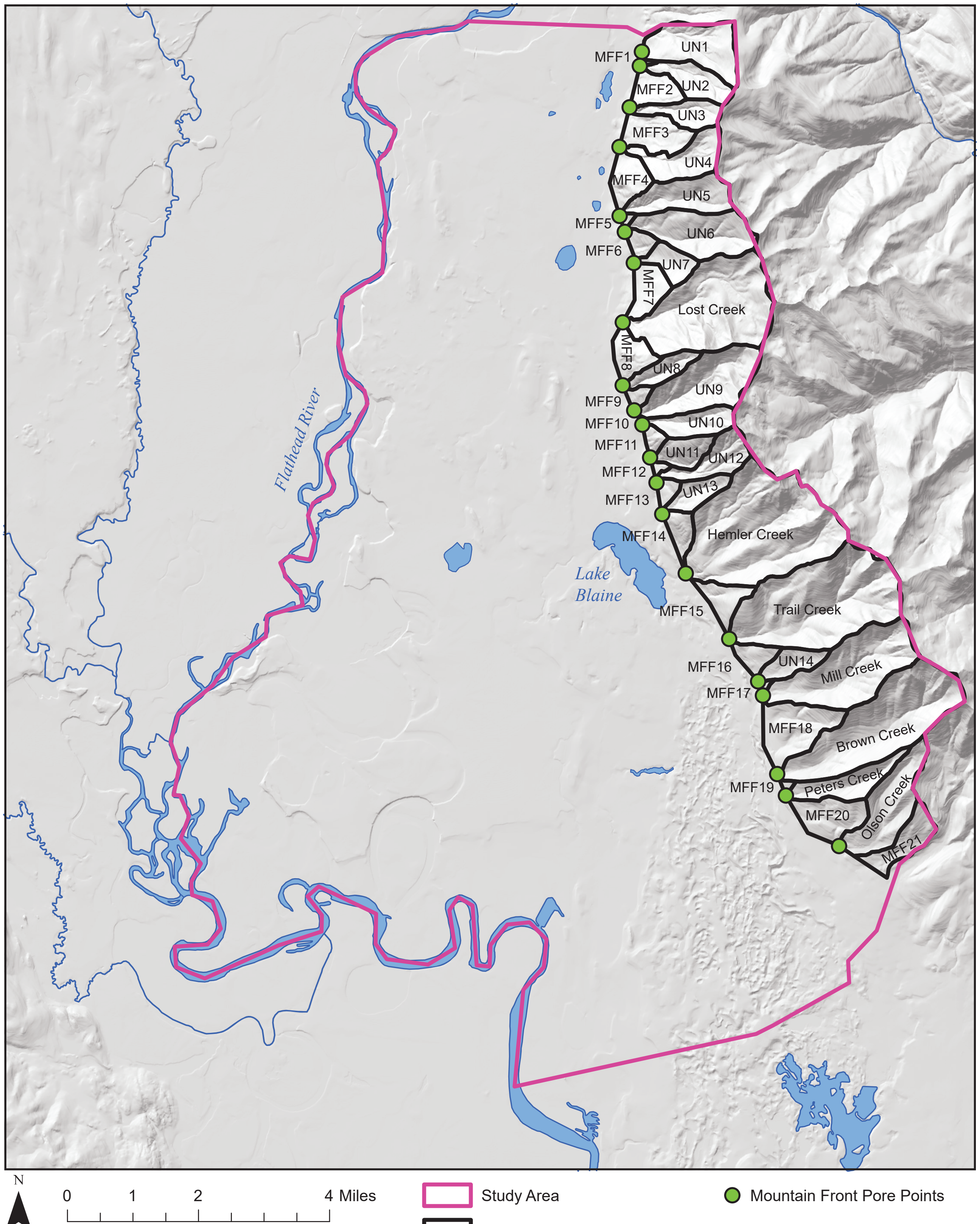

Figure C2. Drainages and mountain front facets (*MFFs*) in the Swan Block were defined based on the 10 m DEM. These areas were used to estimate *MBR* and MFR_s to the valley aquifers. Stream discharge (*RO*) was calculated at the mountain front pore points (MF Pore Points).

Table C2. Summary of Swan Block Water Budgets

Name	Acres	*PCP*	*AET*	Raw *RO*	Raw *RCH*	Adj *RO*	Adj *RCH*	*PCP*	*AET*	Adj *RO*	Adj *RCH*
		(acre-ft/yr)						(in/yr)			
Drainages											
UN1	572	2,107	1,009	1,183	-85	*1,098*	*0*	44	21	*23*	*0*
UN2	303	1,237	544	798	-105	*693*	*0*	49	22	*27*	*0*
UN3	250	1,049	464	678	-93	*585*	*0*	50	22	*28*	*0*
UN4	403	1,708	761	784	163	784	163	51	23	23	5
UN5	462	1,960	837	861	262	861	262	51	22	22	7
UN6	655	2,963	1,157	1,169	637	1,169	637	54	21	21	12
UN7	198	755	343	620	-208	*412*	*0*	46	21	*25*	*0*
Lost Creek	1,490	7,088	2,563	3,017	1,508	3,017	1,508	57	21	24	12
UN8	197	690	325	498	-133	*365*	*0*	42	20	*22*	*0*
UN9	774	3,610	1,318	1,942	350	1,942	350	56	20	30	5
UN10	286	1,216	478	778	-40	*738*	*0*	51	20	*31*	*0*
UN11	211	721	344	525	-148	*377*	*0*	41	20	*21*	*0*
UN12	322	1,404	550	842	12	842	12	52	20	31	0.4
UN13	206	638	369	217	52	217	52	37	22	13	3
Hemler Creek*	2,023	8,335	3,749	3,113	1,473	3,113	1,473	49	22	18	9
Trail Creek	1,813	7,920	3,579	2,908	1,433	2,908	1,433	52	24	19	9
UN14	208	573	421	133	19	133	19	33	24	8	1
Mill Creek	1,084	4,585	2,152	1,430	1,003	1,430	1,003	51	24	16	11
Brown Creek	1,481	5,962	2,970	2,315	677	2,315	677	48	24	19	5
Peters Creek	366	1,010	740	330	-60	*270*	*0*	33	24	*9*	*0*
Olson Creek	645	1,963	1,277	319	367	319	367	37	24	6	7
Mountain Front Facets											
MFF1	13	32	23	—	9	—	9	29	21	—	8
MFF2	213	633	357	—	276	—	276	36	20	—	16
MFF3	331	1,087	602	—	485	—	485	39	22	—	18
MFF4	242	610	376	—	234	—	234	30	19	—	12

Table C2. Summary of Swan Block Water Budgets—*Continued*.

Name	Acres	PCP	AET	Raw RO	Raw RCH	Adj RO	Adj RCH	PCP	AET	Adj RO	Adj RCH
		(acre-ft/yr)						(in/yr)			
MFF5	23	57	37	—	20	—	20	30	20	—	11
MFF6	93	261	162	—	99	—	99	34	21	—	13
MFF7	238	721	410	—	311	—	311	36	21	—	16
MFF8	228	579	351	—	228	—	228	30	18	—	12
MFF9	62	156	96	—	60	—	60	30	19	—	12
MFF10	6	15	10	—	5	—	5	29	19	—	10
MFF11	72	181	107	—	74	—	74	30	18	—	12
MFF12	28	67	47	—	20	—	20	29	20	—	9
MFF13	74	165	126	—	39	—	39	27	20	—	6
MFF14	151	330	253	—	77	—	77	26	20	—	6
MFF15	207	460	380	—	80	—	80	27	22	—	5
MFF16	143	296	274	—	22	—	22	25	23	—	2
MFF17	16	31	31	—	0	—	0	23	23	—	0
MFF18	515	1,207	996	—	211	—	211	28	23	—	5
MFF19	20	38	37	—	1	—	1	23	22	—	1
MFF20	364	804	685	—	119	—	119	26	23	—	4
MFF21	286	767	589	—	178	—	178	32	25	—	7

Note. *Shaded italic indicates values adjusted to prevent negative R values.*

*During high flows Hemler Creek discharges some of its water to Lake Blaine, so MFR_s were calculated as the RO shown here, minus the volume flowing past the gage, plus the infiltration estimated between the gage and Lake Blaine (MFR_s = 3,113 – 2,570 + 380 = 923 acre-ft/yr).

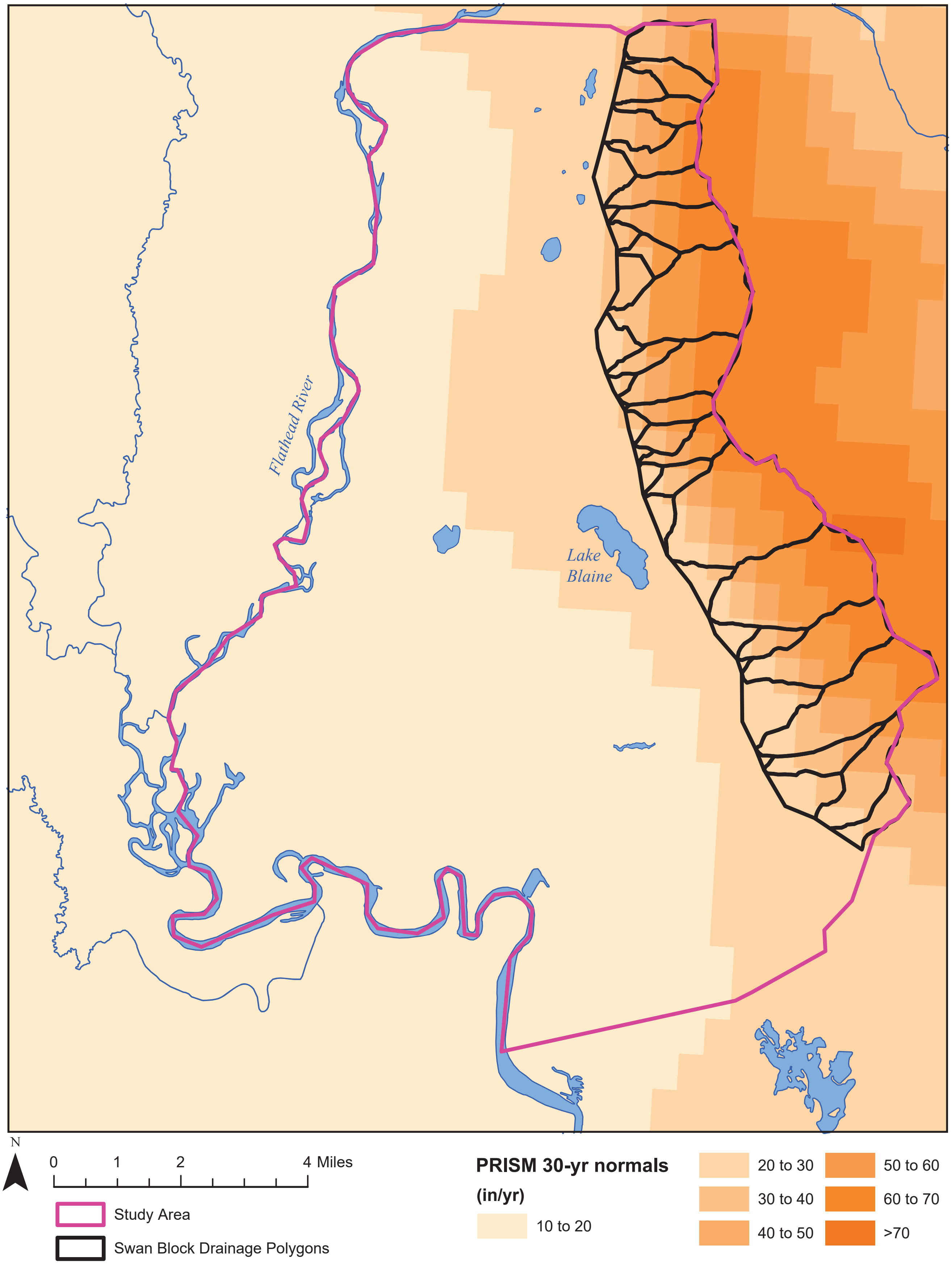

Figure C3. Average annual precipitation within the study area varied from 15 in in the valley bottom to 70 in at the top of the Swan Range. Average annual precipitation within the Swan Block ranged from 22 to over 70 in. Precipitation values based on PRISM 1981–2010 normals (PRISM Climate Group, 2015).

is an energy balance approach based on the Penman–Monteith equation (Monteith, 1965) that has been calibrated to many flux sites in natural vegetation regimes. This approach should provide reasonably accurate estimates of *AET* in areas of complex topography and varied natural vegetation types (D. Ketchum; MT-DNRC, written commun., 2021). The MOD16 average annual *AET* estimates for the Swan Block were calculated based on satellite data collected from 2001 to 2010 (Mu and others, 2011), and they show that mean *AET* values for the drainages and MFFs range from 17 to 25 in/yr, with higher values for those areas at higher elevations, and with higher precipitation (figs. C3, C4, table C2).

Runoff (*RO*)

Streamflows were monitored at eight sites within the Swan Block, with four near the mountain front, and four further upstream in the central portion of the block (fig. C5, table C3). The monitoring data used in this analysis were collected from April to November 2020. Discharge records were used to estimate the total amount of water that flowed past each station per month and over water year 2020 (WY20). Precipitation at the Creston Agrimet station and Noisy SNOWTEL sites was 89.1% and 93.0% of 1981–2010 normal precipitation values, respectively, so the observed yields from WY20 were multiplied by 1.099 (the inverse of the average percent precipitation during those years relative to normal) to provide an estimate of the long-term average annual yields for these sites (table C3).

StreamStats (McCarthy and others, 2016) was used to estimate average monthly runoff from gaged and ungaged drainages. The USGS developed the StreamStats program for Montana to provide users with access to an assortment of analytical tools for water-resources planning and management. It can be accessed at http://water.usgs.gov/osw/streamstats/. This web-based program uses historical records and regional regression equations to estimate streamflow statistics. The regression equations incorporate physical and climatic characteristics of the drainage basin such as drainage area, mean annual precipitation, and land cover.

The estimated long-term (~30 yr) average *RO* values based on our monitoring were compared to the values developed for these sites using the StreamStats program (table C3, fig. C6). The StreamStats model consistently overestimated flows. This overestimate appears to be due to higher rates of groundwater recharge within the Swan Block than was normally the case for those sites used to develop the regional regression equations. Since this relationship was reasonably consistent between watersheds (fig. C6), it was used to adjust the StreamStats model results to estimate the streamflow at each pore point (fig. C2, table C2). As shown in table C2 and discussed below, these estimates were slightly adjusted in some watersheds to prevent the calculated groundwater recharge being less than zero.

Groundwater Recharge (*RCH*)

Groundwater recharge was estimated based on an annual water budget equation for each drainage and mountain front facet (table C2, eq. C1). This approach provided initial *RCH* estimates (Raw *RCH* in table C2); however, in some smaller drainages, the resulting *RCH* values were negative. Since negative *RCH* values are not physically reasonable, the *RO* values (which are believed to be the most uncertain part of the calculation) were lowered in those areas so that *RCH* would not be less than zero. The total for the resulting *RO* values (Adj *RO* in table C1) was 96% of the original estimate, and the resulting total *RCH* value (Adj *RCH* in table C1) was 109% of the original estimate.

These calculations are also helpful in understanding the fate of precipitation in the Swan Block (table C2). The area-weighted average precipitation was 45.8 in/yr. Evapotranspiration caused 48% of that water (22.2 in/yr) to return to the atmosphere within the Swan Block. Streams carried 36% of that water to the mountain front (16.4 in/yr), and the estimated groundwater recharge in the Swan Block accounted for 16% of precipitation (7.3 in/yr).

EAST VALLEY GROUNDWATER BUDGET

Long-term average annual and monthly groundwater budgets were developed for the combined unconsolidated basin-fill aquifers in the East Flathead Valley (table C1). This includes all of the hydrogeologic units above the semi-consolidated Tertiary Sediments (i.e. the shallow, intermediate, and deep aquifers, plus confining units). The eastern boundary is at the Swan Mountain Front, and the western boundary is at the Flathead River (fig. C2). The northern boundary

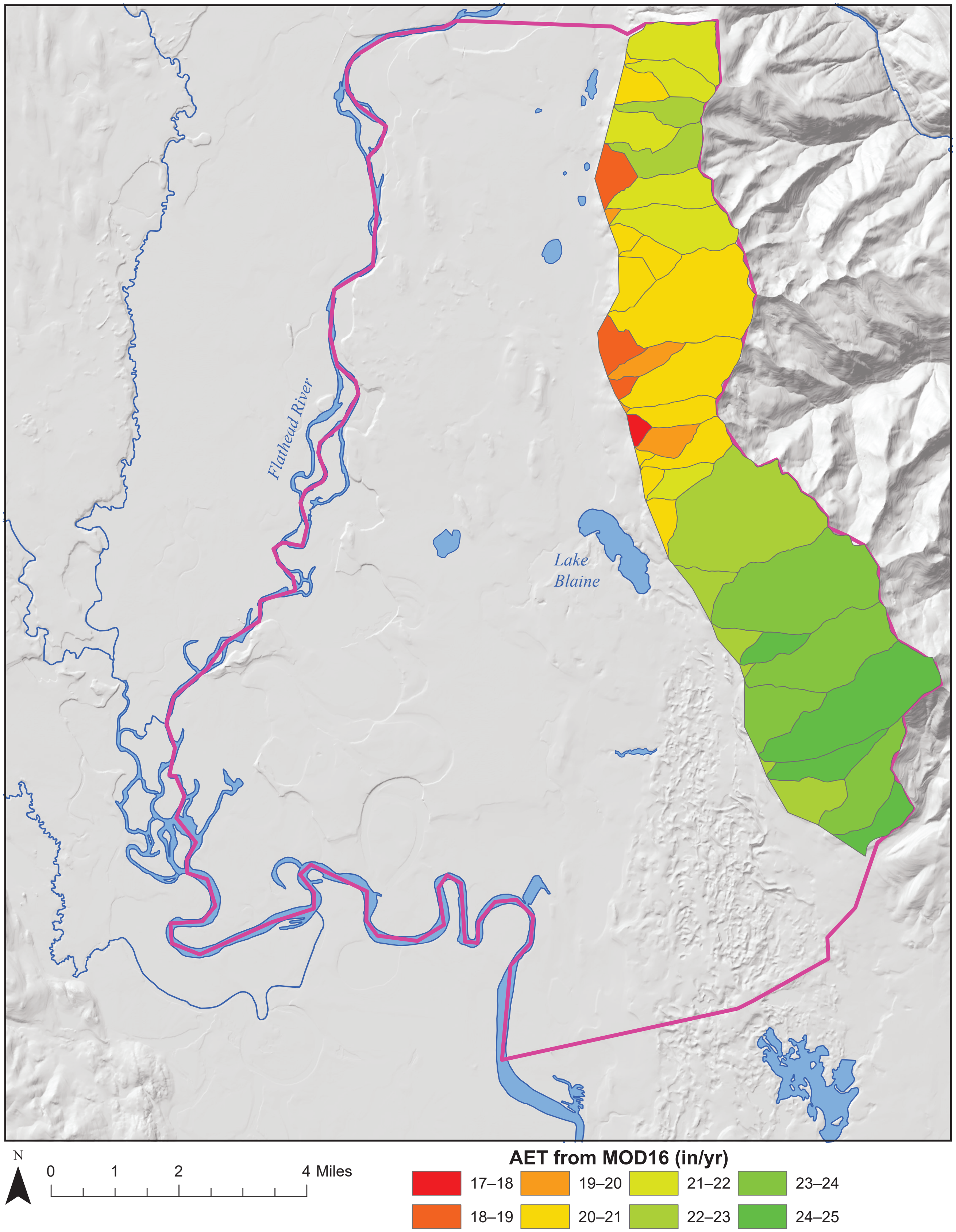

Figure C4. Average annual actual evapotranspiration (*AET*) within the drainages and *MFF*s in the Swan Block ranged from 17 to 25 in. AET values were based on MOD16 2001–2010 average values (https://www.ntsg.umt.edu/project/modis/mod16.php).

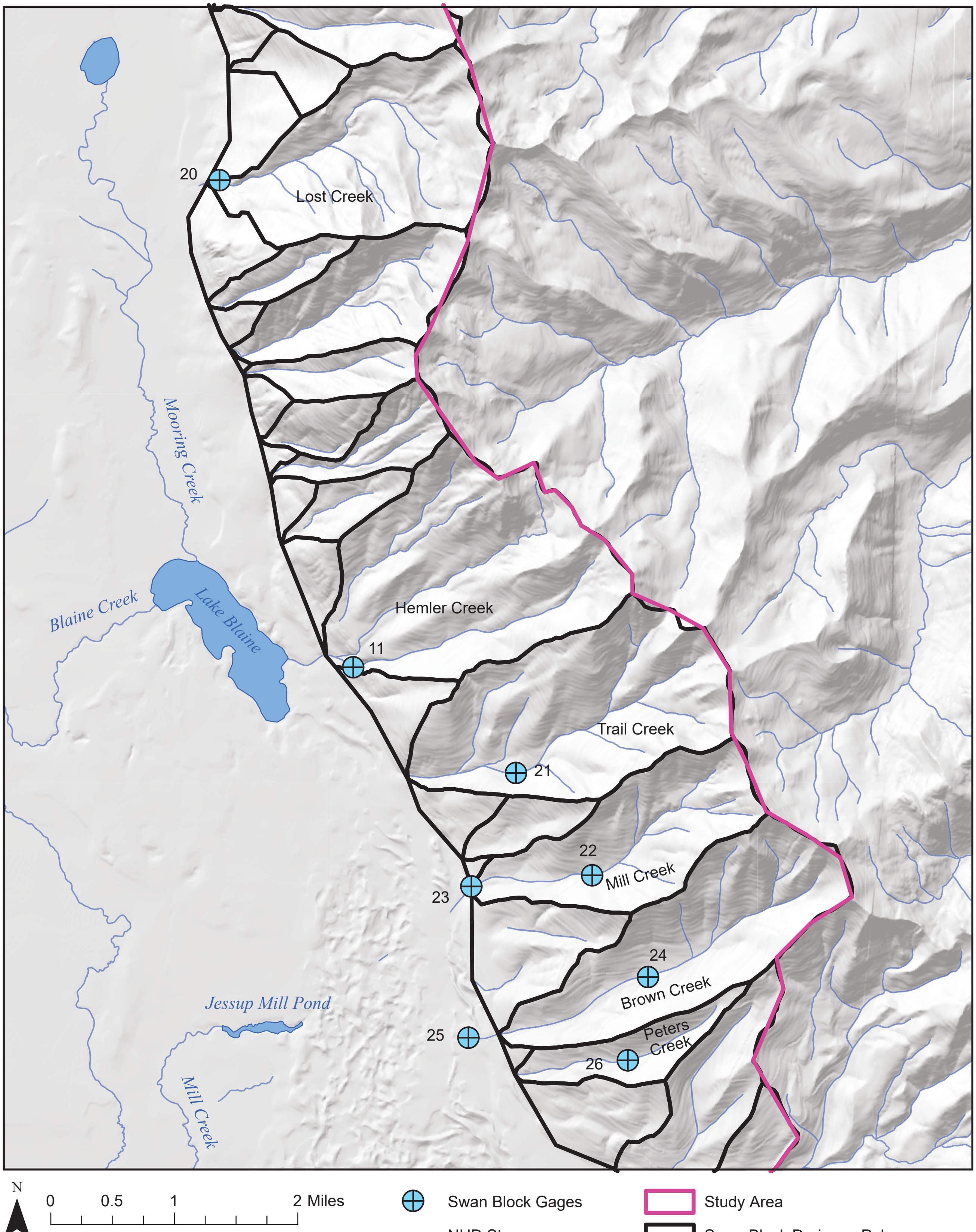

Figure C5. MBMG-monitored stream gages in the Swan Block. See table C3 and appendix B for additional site details. Labels are site numbers.

Table C3. Mountain block surface-water monitoring.

Site	Site No.	Drainage Area (acre)	WY2020 Obs Yield (acre-ft/yr)	Estimated Long-Term Average Yield (acre-ft/yr)	StreamStats Yield from Mean Annual Flow (acre-ft/yr)
Lost Creek	20	1,408	2,689	2,956	4,144
Hemler Creek above South Fork	11	704	1,471	1,616	1,898
Trail Creek	21	1,152	1,728	1,899	3,941
Upper Mill Creek	22	768	1,275	1,401	2,746
Lower Mill Creek	23	1,088	1,550	1,704	3,463
Upper Browns Gulch	24	960	2,061	2,265	3,398
Lower Browns Gulch	25	1,472	2,064	2,268	4,173
Peters Creek	26	218	16	18	531

Note. See appendix B and MBMG's GWIC database for additional site details.

follows a groundwater flow line (a hydraulic no-flow boundary; fig. C2; LaFave and others, 2004; Rose and others, 2022). The southern boundary follows a surface divide, which is also a groundwater divide in the shallow aquifers. In the deep aquifer, groundwater flow is across the southern boundary due to a bedrock high (northern extension of the Mission Range) forming a flow barrier along the west side of this boundary, near the Flathead River (Rose and others, 2022). This flow barrier forces groundwater in the deep aquifer from the Swan Valley to flow further north before turning west into the main Flathead Valley. While this budget is not inherently spatially explicit, where possible geographic and stratigraphic information was retained to aid in developing the numerical models.

The groundwater budget for the East Flathead Valley is represented by equation C2:

$$MBR + MFR_s + GW_{in} + LI + AR + IR + SR =$$

$$WEL + SW_{out\text{-}s} + LE + ET_r + GW_{out} + SW_{out\text{-}FHR} \pm \Delta S,$$

where (using units of acre-ft/yr for this analysis):

Inflows

MBR is mountain block recharge;

MFR_s is surficial mountain-front recharge;

GW_{in} is groundwater inflow;

LI is lake infiltration;

AR is areal recharge;

IR is irrigation recharge; and

SR is septic returns.

Outflows

WEL is well pumping;

$SW_{out\text{-}s}$ is discharge to streams;

LE is lake evaporation;

ET_r is evapotranspiration by riparian vegetation;

GW_{out} is groundwater outflow from the study area;

$SW_{out\text{-}FHR}$ is discharge to the Flathead River; and

ΔS is changes in storage (for the monthly budgets).

Inflows

The surface-water and groundwater flows out of the Swan Block (*RO* and *RCH*) flow into the east Flathead Valley. These inputs flow into the aquifer system via mountain block recharge (*MBR*), surficial mountain-front recharge (MFR_s), and lake infiltration (*LI*). Differentiating between *MBR* and MFR_s is important since *MBR* is assumed to occur at a near-constant rate, while MFR_s is strongly influenced by snowmelt. Also, MFR_s provides recharge to the shallow alluvial aquifers along stream channels, while recharge from the *MBR* occurs along the entire interface between the bedrock and the valley-fill aquifers (although likely not uniformly).

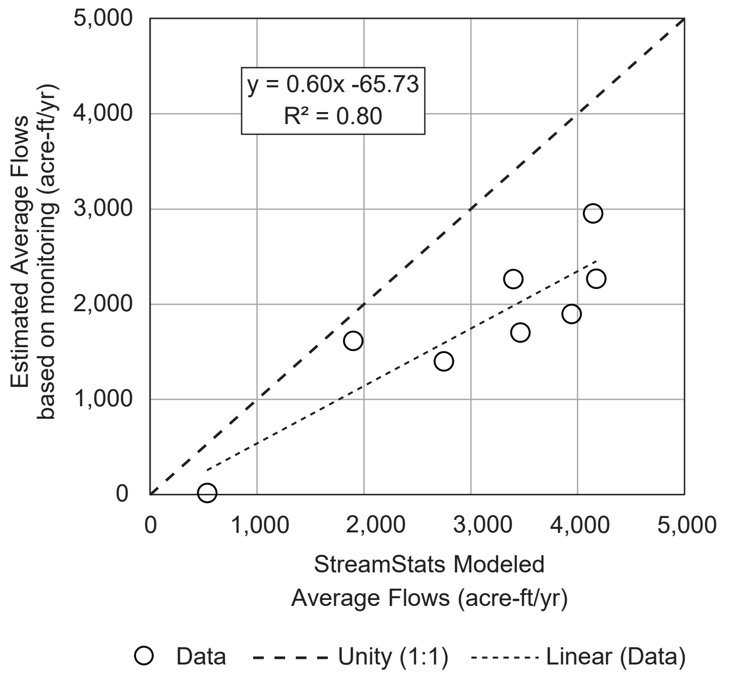

Figure C6. Comparison of our monitoring data to estimated flows from the USGS StreamStats program.

Mountain Block Recharge (MBR)

As discussed above, *MBR* is "the subsurface inflow of groundwater to the lowland aquifer that comes directly from the mountain block" (Wilson and Guan, 2004; Markovich and others, 2019). This includes groundwater inflow from the bedrock and from the "fingers/lenses of alluvium underlying the mountain streams" (Markovich and others, 2019). *MBR* includes both diffuse and focused *MBR* (Markovich and others, 2019), which are not differentiated in our study. *MBR* also includes groundwater inflow from the infiltration of non-channelized water from the MFFs above the mountain front fault (aka "front-slope flow"; Markovich and others, 2019).

MBR was estimated by assuming that over the long term (~30 years), the groundwater discharge to the valley aquifer will be equal to the *RCH* in the mountain block. That is, net changes in storage are negligible on a long-term basis, and there are no other significant sources or sinks in the mountain block. The adjusted recharge (Adj *RCH)* values in table C2 are the annual *MBR* values for each drainage and MFF, and they total 10,503 acre-ft/yr. Monthly *MBR* values were calculated assuming that *MBR* enters the valley aquifers at a near-constant rate, so the annual totals were distributed by the number of days in each month (table C1).

To provide for the geographic distribution of *MBR*, flux segments were defined along the mountain front, which generally begin and end at the midpoints of adjacent MFFs (fig. C7). Each segment was assigned the *MBR* from the drainage upgradient from it, and half of the *MBR* from each of the adjacent MFFs (table C4).

While this approach provides an estimate of the amount of *MBR*, it provides no information on how to proportion it vertically, since the inflow will occur along the entire interface between the valley aquifers and the mountain block (though likely not uniformly). This vertical segregation of mountain block recharge was part of the calibration process for the numerical groundwater flow models.

Surface Mountain Front Recharge (MFR_s)

The streams draining the Swan Mountain Block other than Hemler Creek all infiltrate at the mountain front, and defined channels do not extend beyond the mountain front zone (fig. C5). Therefore, for all drainages except Hemler Creek, annual *MFR* was assumed to be equal to the estimated adjusted *RO* (Adj *RO* in table C2). The percentage of the annual flow for each month was distributed based on the observed flows at Browns Gulch (table C5). This stream infiltration occurs into the shallowest aquifers (layer 1 of the numerical models) near the pore points (fig. C2).

Hemler Creek provides flow into Lake Blaine during high flows in the spring and early summer of most years. Analysis of monitoring data and modeled flows based on the adjusted StreamStats values suggest that about 100 acre-ft/mo (1.7 cfs) infiltrates from Hemler Creek over the 0.34-mi reach between the mountain front and Lake Blaine (4.9 cfs/mi) when the whole reach is wetted. During months where the flow was estimated to be less than 100 acre-ft, all the water is assumed to infiltrate prior to reaching Lake Blaine (table C5).

Lake Infiltration (LI)

Lake Blaine receives inflow from Hemler Creek on the east and Mooring Creek on the north. When lake levels are high enough, water will flow out the spillway into Blaine Creek (fig. C5). DNRC monitoring at the spillway (2017–2021) shows that outflow

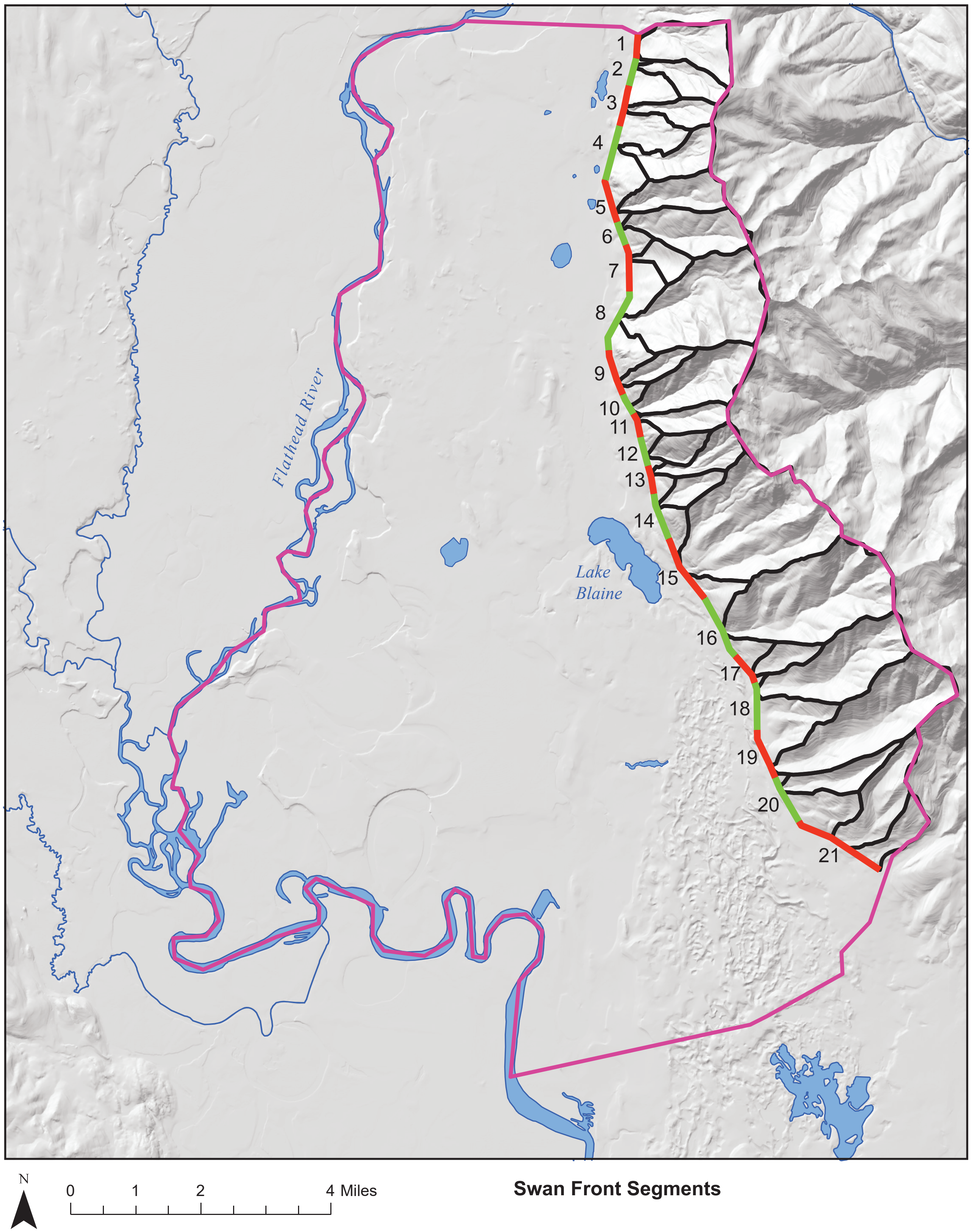

Figure C7. Mountain Front Segments for the distribution of MBR.

Table C4. MBR by mountain front segment and month.

	Annual MBR	O	N	D	J	F	M	A	M	J	J	A	S
Segment						(acre-ft)							
1	5	0.4	0.4	0.4	0.4	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4
2	143	12.1	11.7	12.1	12.1	11.0	12.1	11.7	12.1	11.7	12.1	12.1	11.7
3	381	32.3	31.3	32.3	32.3	29.4	32.3	31.3	32.3	31.3	32.3	32.3	31.3
4	523	44.3	42.9	44.3	44.3	40.4	44.3	42.9	44.3	42.9	44.3	44.3	42.9
5	389	33.0	32.0	33.0	33.0	30.1	33.0	32.0	33.0	32.0	33.0	33.0	32.0
6	696	59.1	57.2	59.1	59.1	53.8	59.1	57.2	59.1	57.2	59.1	59.1	57.2
7	205	17.4	16.8	17.4	17.4	15.9	17.4	16.8	17.4	16.8	17.4	17.4	16.8
8	1,777	150.8	146.0	150.8	150.8	137.4	150.8	146.0	150.8	146.0	150.8	150.8	146.0
9	144	12.2	11.8	12.2	12.2	11.1	12.2	11.8	12.2	11.8	12.2	12.2	11.8
10	382	32.5	31.4	32.5	32.5	29.6	32.5	31.4	32.5	31.4	32.5	32.5	31.4
11	40	3.4	3.2	3.4	3.4	3.1	3.4	3.2	3.4	3.2	3.4	3.4	3.2
12	47	4.0	3.9	4.0	4.0	3.6	4.0	3.9	4.0	3.9	4.0	4.0	3.9
13	41	3.5	3.4	3.5	3.5	3.2	3.5	3.4	3.5	3.4	3.5	3.5	3.4
14	110	9.3	9.0	9.3	9.3	8.5	9.3	9.0	9.3	9.0	9.3	9.3	9.0
15	1,552	131.7	127.4	131.7	131.7	120.0	131.7	127.4	131.7	127.4	131.7	131.7	127.4
16	1,484	126.0	121.9	126.0	126.0	114.8	126.0	121.9	126.0	121.9	126.0	126.0	121.9
17	30	2.6	2.5	2.6	2.6	2.3	2.6	2.5	2.6	2.5	2.6	2.6	2.5
18	1,108	94.1	91.0	94.1	94.1	85.7	94.1	91.0	94.1	91.0	94.1	94.1	91.0
19	783	66.4	64.3	66.4	66.4	60.5	66.4	64.3	66.4	64.3	66.4	66.4	64.3
20	60	5.1	4.9	5.1	5.1	4.6	5.1	4.9	5.1	4.9	5.1	5.1	4.9
21	604	51.3	49.6	51.3	51.3	46.7	51.3	49.6	51.3	49.6	51.3	51.3	49.6
Total	10,503	891	863	891	891	812	891	863	891	863	891	891	863

only occurred following periods of above-average precipitation. Outflow occurred in 2017 and 2018, following high-precipitation water years in 2016 and 2017 (112% and 127% of average, respectively, based on data from the Creston Agrimet Station). There was no outflow to Blaine Creek in 2019, 2020, or 2021. In water years 2018, 2019, 2020, and 2021, annual precipitation totals were 98%, 93%, 89%, and 101% of average (based on data from the Creston Agrimet Station). Therefore, during WY20 water entered Lake Blaine from the creeks and due to direct precipitation, and was removed by either infiltration or evaporation. Thus, the Blaine Lake water budget for WY20 is:

$$LI = C_{in} + PCP - Evap \pm \Delta S, \quad \text{eq. C3}$$

where (using acre-ft/yr):

LI is lake infiltration;

C_{in} is creek inflow;

PCP is precipitation;

Evap is lake evaporation; and

ΔS is change in lake storage.

This assumes that any surface runoff into the lake that is not from the creeks is negligible. This is consistent with the assumption that *RO* from the MFFs is also negligible. The effect is that any precipitation in excess of *AET* is assumed to recharge groundwater where the precipitation falls (see areal recharge below), while if it actually ran off it would still provide the same amount of groundwater recharge, but it would be as lake infiltration rather than areal recharge.

Creek Inflow (C_{in})

Monitoring on Mooring Creek and Hemler Creek (sites 8 and 12, appendix B) in WY20 shows that the discharge to Lake Blaine was about 5,200 acre-ft (an average of 7.2 cfs) from Mooring Creek, and about

Table C5. MFRs from the Swan Block, by month.

Pour Point	Annual MFRs	O	N	D	J	F	M	A	M	J	J	A	S
	(acre-ft)												
Monthly Distribution		3.9%	3.5%	3.1%	2.3%	1.8%	2.3%	6.5%	22.4%	29.6%	14.9%	5.9%	3.7%
UN1	1,098	43	39	34	25	20	26	71	246	325	164	65	41
UN2	693	27	24	22	16	13	16	45	156	205	103	41	26
UN3	585	23	21	18	13	11	14	38	131	173	87	35	22
UN4	784	30	28	24	18	14	18	51	176	232	117	46	29
UN5	861	33	30	27	20	16	20	56	193	255	128	51	32
UN6	1,169	45	41	36	27	22	27	76	262	346	174	69	43
UN7	412	16	14	13	9	8	10	27	92	122	61	24	15
Lost Creek	3,017	117	106	94	68	56	70	196	677	892	450	178	112
UN8	365	14	13	11	8	7	9	24	82	108	54	22	14
UN9	1,942	76	68	61	44	36	45	126	436	574	289	115	72
UN10	738	29	26	23	17	14	17	48	166	218	110	44	27
UN11	377	15	13	12	9	7	9	25	85	111	56	22	14
UN12	842	33	30	26	19	16	20	55	189	249	126	50	31
UN13	217	8	8	7	5	4	5	14	49	64	32	13	8
Hemler Creek	*923*	*89*	*78*	*65*	*39*	*26*	*41*	*100*	*100*	*100*	*100*	*100*	*83*
Trail Creek	2,908	113	102	91	66	54	68	189	653	860	433	172	108
UN14	133	5	5	4	3	2	3	9	30	39	20	8	5
Mill Creek	1,430	56	50	45	32	26	33	93	321	423	213	85	53
Brown Creek	2,315	90	81	72	53	43	54	151	520	685	345	137	86
Peters Creek	270	10	9	8	6	5	6	18	61	80	40	16	10
Olson Creek	319	12	11	10	7	6	7	21	72	94	48	19	12
Total MFRs	21,399	886	796	703	504	404	518	1,433	4,695	6,156	3,152	1,311	841

1,800 acre-ft (2.5 cfs on average, after accounting for downstream infiltration) from Hemler Creek. Therefore, the total inflow from creeks was about 7,000 acre-ft.

Precipitation (PCP)

The area of Lake Blaine varies through the year, but has a maximum area of about 385 acres. It is assumed that any precipitation that falls in this maximum area (even if the lake is at a lower level) will flow into the lake. During WY20 the Creston Agrimet station received a total of 14.7 in of precipitation. Thus, the total water added to the lake by direct precipitation in WY20 was about 471 acre-ft.

Evaporation (Evap)

The evaporation from Lake Blaine was estimated for WY20 using Sentinel 2 enhanced vegetation index (EVI) data, and potential evapotranspiration values from the Creston Agrimet station. The EVI data were used to estimate the area of the lake for each month, with EVI values less than 0.1 indicating open water. The grass PET values from the Creston Agriment station were multiplied by 1.1 to provide an estimate of the free water surface evaporation rate (Jensen, 2010). The surface area of the lake ranged from 292 to 385 acres, and total evaporation was 31.6 in. This resulted in the total annual calculated evaporation from Lake Blaine being 947 acre-ft.

Change in Lake Storage (∆S)

Measured stages and Sentinel 2 EVI data were used to evaluate changes in the amount of water stored in Lake Blaine during WY20. These data showed that from October 2019 to October 2020 the area of the lake increased from 334 to 369 acres (an increase of 35 acres), and the stage increased by 0.6 ft. This increase in water level was estimated to increase the amount of water stored in the lake by 212 acre-ft.

Summary Lake Infiltration

Lake infiltration for WY20 was calculated as the residual of the lake water budget (eq. C3). That is:

$$LI = 7{,}000 \text{ acre-ft} + 471 \text{ acre-ft} - 947 \text{ acre-ft} - 212 \text{ acre-ft} = 6{,}311 \text{ acre-ft.} \quad \text{eq. C4}$$

This equates to an average infiltration rate of 0.045 ft/d through the fine-grained sediments over the area of the lake. We assumed that this infiltration rate is constant through the year, and monthly values are assigned based on the number of days in each month (table C1).

There likely is a slight seasonal pattern to the infiltration since the lake area and stage were highest in July following snowmelt, then decreased following a near-linear pattern until December, stayed at that low level until May, and then increased again as snowmelt filled the lake. Throughout the year the area of the lake varied from 292 to 385 acres, and the stage of the lake increased from a winter baseline level of about 2,992 ft-amsl to a maximum level of 2,997 ft-amsl in July.

Groundwater Inflow to the Study Area (GW_{in})

There is groundwater flow into the study area in the deep aquifer along the southern boundary. The potentiometric surface of the deep aquifer and mapped bedrock elevations show that in the southeast corner of the study area, groundwater flows north into the study area through the deep aquifer (see fig. G4 in appendix G). In the shallow aquifer flow is parallel to the southern boundary (fig. G1). Groundwater in the shallow aquifer flows to the west so we assumed no flow into the study area.

The amount of groundwater flow entering the study area was estimated as a Darcy Flux:

$$Q = KiA, \quad \text{eq. C5}$$

where:

Q is discharge (ft^3/d);

K is hydraulic conductivity (ft/d);

i is potentiometric surface gradient along flow (ft/ft); and

A is cross-sectional area of the aquifer perpendicular to flow (ft^2).

Hydraulic conductivity (K) was estimated from aquifer tests and literature values for sand and gravel. Gradient (i) was based on monitoring data (see fig. 4 of the main body of this report, and appendix A). Cross-sectional area (A) was determined from well logs used to interpret the geometry of the aquifer in the southeast portion of the study area. The following parameters were used in the initial estimation of flow:

K is 100 ft/d;

i is (40 ft)/(36,500 ft) = 0.00109 = 1.09×10^{-3} ft/ft; and

A is 11,258,883 ft^2.

The above parameters resulted in an initial discharge estimate (Q) of 1,233,850 ft^3/d (10,346 acre-ft/yr) through the deep aquifer in the southeast corner of the study area. This inflow was assumed to be evenly distributed throughout the year (table C1).

Areal Recharge (AR)

Areal recharge was estimated as the difference between precipitation and the combined total of *AET* and runoff. To evaluate *AR* we began by comparing the total *AET* during WY20 to the observed precipitation at the Creston Agrimet station (14.7 in. in WY20).

To estimate *AET* we obtained EVI data from the Sentinel 2 satellites from the Climate Engine website (http://climateengine.org/). EVI is an indication of vegetation health, and is calculated from red, near-infrared, and blue reflectance values (Nagler and others, 2009).

The data from the Sentinel 2 satellites have a 10 m pixel resolution, and the satellites provide imagery every 5 days. We used the climate engine website to obtain the mean monthly EVI imagery for the study area from March to October 2020. The Sentinel 2 data are more appropriate than the MOD16 approach (with 1,000 m pixels) used in the mountain block since the valley is relatively flat, and has more heterogeneous land cover.

EVI values were rescaled so that values from 0 to 1 spanned from bare ground to well-watered crops by using the following equation (Choudhury and others, 1994; Nagler and others, 2005, 2009; Glenn and others, 2010):

$$EVI^* = 1 - \left[\frac{EVI_{max} - EVI}{EVI_{max} - EVI_{min}}\right], \quad \text{eq. C6}$$

where:

EVI^* is the normalized EVI value for a particular pixel;

EVI is raw EVI value for a particular pixel;

EVI_{max} is EVI value for well-watered crops; and

EVI_{min} *is* EVI value for bare ground.

For each month's image EVI_{max} was obtained by evaluating the highest values for irrigated fields and EVI_{min} was obtained from large areas of bare ground, including gravel quarries and talus slopes. These values were used to create monthly *EVI** rasters. Areal recharge was evaluated on non-irrigated cropland. A total of 365 fields (14,326 acres) were identified using the Montana Department of Revenue's final land use layer (MDOR, 2019). The mean *EVI** values from the monthly *EVI** rasters were extracted to each of the non-irrigated polygons.

The monthly mean *EVI** values were combined with the monthly PET value for alfalfa from the Creston Agrimet station to estimate the monthly *AET* for each area using the equation (Glenn and others, 2010):

$$AET = PET\,(EVI^*). \qquad \text{eq. C7}$$

The monthly values for March to October were summed to obtain the total *AET* during the 2020 growing season (assuming *AET* is zero during November–February). The *PET* value for 2020 was 34.41 in. While this value is more than double the actual precipitation (14.7 in), plants in non-irrigated areas rarely have sufficient water to transpire at the *PET* rate.

AET values in the analyzed non-irrigated polygons averaged 11.2 in. Thus, on average, precipitation exceeds *AET* by about 3.5 in/yr. Note that in irrigated areas (8,622 acres), this water is accounted for in the irrigation recharge calculation, and over Lake Blaine (385 acres), this water is accounted for in the lake infiltration calculation. This leaves 68,620 acres receiving areal recharge. If we assume that the ratio of runoff to infiltration in non-irrigated areas is similar to that in wild flood areas (NRCS, 1997; Smesrud and Madison, 2007), about 43% of this excess water will infiltrate. This results in a calculated *AR* of 8,578 acre-ft/yr (a mean rate of 0.00034 ft/d; 10.2% of precipitation; table C1). Since the timing of movement of water through the unsaturated zone is difficult to predict without detailed monitoring and modeling, it is assumed that the rate of recharge to the groundwater is constant throughout the year, so *AR* was split between months based on the number of days in each month (table C3). We assumed this recharge enters the shallowest aquifer.

Irrigation Recharge (IR)

Irrigation recharge occurs when the amount of water applied to crops (including precipitation) exceeds *AET* and runoff. This includes fields that are irrigated from groundwater as well as surface water, so there is not a direct link to the irrigation well pumping rates discussed below. Irrigation recharge by month was estimated based on the irrigation method efficiency (flood, pivot, or sprinkler) and acreage from the final land units (FLU) layer, and *AET* based on Sentinel 2 EVI data.

Irrigation efficiency represents the portion of the applied water that is consumptively used by plants (*AET*). Center pivot irrigation typically has an efficiency of about 80%, with 20% of the applied water infiltrating below the root zone and providing irrigation recharge (NRCS, 1997). Sprinkler irrigation is typically about 70% efficient, with 30% of the water infiltrating to groundwater (NRCS, 1997). Flood irrigation is highly variable; however, it is typically about 30% efficient, with 40% of the applied water running off and about 30% infiltrating (NRCS, 1997; Smesrud and Madison, 2007).

The irrigation method for each field was based on the Montana Department of Revenue's FLU coverage (MDOR, 2019). Slight modifications were made based on 2019 NAIP aerial photographs (downloaded from https://nris.msl.mt.gov/), and field recognizance.

The *AET* for irrigated fields was calculated using the same approach discussed in the AR section, using the EVI values from Sentinel 2 imagery. These *AET* values were then used with irrigation efficiencies to estimate irrigation recharge. Irrigation recharge was estimated as follows:

$$IR_{pivot} = (20/80)*AET = 25\% \text{ of } AET, \qquad \text{eq. C8}$$

$$IR_{sprinkler} = (30/70)*AET = 43\% \text{ of } AET, \text{ and} \qquad \text{eq. C9}$$

$$IR_{flood} = (30/30)*AET = 100\% \text{ of } AET. \qquad \text{eq. C10}$$

Note that for flood irrigation it is assumed that 40% of the applied water runs off, so the fractions do not equal 100.

Of the 8,622 irrigated acres, 1,950 acres are pivot irrigated, 5,999 acres are sprinkler irrigated, and 673 acres are flood irrigated. In the pivot-, sprinkler-, and flood-irrigated fields the mean *AET* values were 12.1, 11.8, and 11.9 in/yr, respectively. The total calculated *IR* was 3,695 acre-ft/yr, which was applied June to September based on the distribution of *AET* during those months (table C1).

<u>Septic Returns (SR)</u>

While wells pump groundwater, a substantial portion of the water used inside homes and businesses is not consumed, but returns to the groundwater system through septic systems. This includes water used for toilets, bathing, cooking, and cleaning. While pumping rates for wells vary due to irrigation uses in the warmer months, the amount of water returned to the groundwater system by septic systems is fairly constant. Based on data from the Townview subdivision near Helena, MT (Bobst and others, 2014), a reasonable estimate of septic returns is about 168 gpd/home. There are 3,585 homes within the study area (MSL, 2019), for an overall septic return rate of 602,280 gpd (675 acre-ft/yr). In addition, there are 97 other occupied structures in the study area (primarily commercial and retail sites), which we assumed discharged septic effluent at rates similar to homes, resulting in an additional 16,296 gpd (18 acre-ft/yr) of septic returns, for an overall total of 693 acre-ft/yr. This recharges the uppermost aquifer, and was distributed by month based on the number of days in each month (table C1).

Outflows

<u>Well Pumping (WEL)</u>

Domestic Wells

The GWIC database showed 2,607 domestic wells (http://mbmggwic.mtech.edu/). An average pumping rate per well of 603 gpd was used to estimate average annual pumping (Bobst and others, 2014; Helena area). Monthly average pumping rates were also estimated (based on Bobst and others, 2014; Helena area) and ranged from 173 to 1,510 gpd per residence. These calculations suggest a total of about 1,762 acre-ft/yr pumped via domestic wells.

Public Water Supply Wells

There were 37 public water supply wells identified in the study area. The amount of water supplied by each public water supply well was based on the number of residences served by the well (Montana DEQ Drinking Water Watch database; http://sdwisdww.mt.gov:8080/DWW/). Nearly every homeowner's association (HOA) with multiple wells reports the total number of homes in the HOA as connections for each well, which results in residences being counted repeatedly. To correct for this, air photos were used to determine the actual number of homes in each HOA, which showed 578 connections to public water supply wells. Similar to individual domestic wells, the annual and monthly rates per residence were estimated (Bobst and others, 2014), resulting in an annual rate of 391 acre-ft/yr.

Irrigation Wells

There were 21 irrigation wells identified in the study area using GWIC (http://mbmggwic.mtech.edu), the DNRC water rights database (http://wrqs.dnrc.mt.gov), remote sensing, and areal imagery. In most cases each of these wells supply water to several fields. The amount of water pumped by each irrigation well was based on the area irrigated (acres from FLU), and the amount of irrigation water applied (*IW*; inches).

Each irrigated field was associated with an irrigation well using the DNRC water rights database and MBMG GWIC well records. The total amount of pumping needed to irrigate the fields was summed to provide a pumping schedule for each well.

The amount of water applied was estimated based on *AET*, *IR* to the groundwater system, and effective precipitation (P_e). Since all the fields with groundwater as the source were irrigated using sprinkler or pivot systems, it was assumed that there was no runoff. Therefore, the monthly linear flux for each field was estimated by:

$$IW = (AET + IR) - P_e, \qquad \text{eq. C11}$$

where all terms are in inches.

The same process used to estimate monthly *AET* values for non-irrigated areas was also used for each irrigated field (see areal recharge section). That is, for each field, 2020 EVI values from Sentinel 2 satellite imagery and *PET* values from the Creston Agrimet station were used to estimate *AET*.

Irrigation recharge (*IR*) was estimated using the same approach as in the Irrigation Recharge section for inflows. That is, the efficiency of the irrigation method was used along with the *AET* to estimate the amount of water percolating through the root zone.

Effective precipitation (P_e) is the amount of moisture available for use by plants. For instance, water that evaporates or runs off cannot be used by plants since it does not reach the root zone. Since crop needs can be satisfied in part by effective precipitation, this reduces the amount of water that needs to be applied from the irrigation wells. P_e was estimated for 2020 using meteorological data from the Creston Agrimet station following the approach specified in the Soil Conservation Service's National Irrigation Handbook (SCS, 1993, p. 2-146 to 2-153).

The total area irrigated with wells in the study area includes 1,641 acres of pivot irrigation and 1,179 acres of sprinkler irrigation. Area-weighted average *IW* values were 28.4 in/yr. The total calculated pumping for irrigation wells was 6,679 acre-ft/yr. Pumping was applied in June, July, and August, with the distribution based in the Montana Irrigation Guide for Creston, using alfalfa in a normal year (NRCS, 1996).

Commercial and Industrial Wells

Pumping rates for commercial and industrial wells were based on water rights for each well. For the commercial and industrial wells the annual total diversion volume was distributed throughout the year based on the number of days in each month for a total pumping amount of 2,072 acre-ft/yr.

In summary, all types of wells are estimated to pump about 10,903 acre-ft/yr from aquifers in the study area (table C3). Of that total, about 61% is used for irrigated agriculture, 19% is for commercial or industrial uses, and 20% is for domestic use.

Discharge to Streams ($SW_{out\text{-}s}$)

Groundwater discharges to Mill Creek and Mooring Creek. Groundwater discharge to Blaine Creek was considered; however, DNRC monitoring data (site 14; appendix B; fig. 2 in the main body of this report) from WY20 show that streamflow only occurred in direct response to precipitation (see GWIC for data). This suggests that groundwater discharges to Blaine Creek are likely negligible.

The largest groundwater outflow to streams is the discharge of many springs through the bottom of Jessup Mill Pond. The outflow from Jessup Mill Pond is Mill Creek (site 16; appendix B). It should be noted that there is also a Mill Creek in the Swan Block that flows out to the valley approximately 1.5 mi northeast of Jessup Mill Pond; however, they are not connected by a surface channel. The USFWS Creston Fish Hatchery uses some of the water from Jessup Mill Pond in its operations, and monitoring site 16 was established on Mill Creek at the downstream end of the hatchery operations. This site has been monitored from 2011 to present by the MBMG (GWIC 262326) and the DNRC (SWAMP ID 76LJ 07500). The flow is stable, reflecting the groundwater-fed nature of the stream. Mean monthly flow from 2011 to 2021 ranged from 23.4 cfs in February to 32.0 cfs in June, and the average annual flow rate is 26.6 cfs (from https://mbmg.mtech.edu/WaterEnvironment/SWAMP; on 3/1/21). We assume the groundwater discharge rate is near constant, so the lowest flows reflect the groundwater discharge, and higher flows reflect a combination of groundwater, surface runoff, and soil water discharge. Thus, the total annual groundwater discharge to Jessup Mill Pond was calculated as 16,916 acre-ft, based on the lowest mean monthly flow rate.

As Mill Creek flows from Jessup Mill Pond to the Flathead River, monitoring shows additional net stream gains (sites 17–19; appendix B). Along this 3.9-mi reach, net stream gains of about 3 cfs/mi occur, which results in an overall gain of 8,476 acre-ft/yr.

Mooring Creek also receives groundwater discharge. Some of the groundwater discharged into Mooring Creek flows back into the aquifer through the bottom of Lake Blaine (see Lake Infiltration section). The gaging station at the Lake Blaine inlet (site 10; appendix B) was affected by high lake stages, so it was not possible to calculate continuous stream discharge at that site. Instead we used data from the DNRC gage approximately 1.7 mi upstream from the lake (site 8; appendix B). The mean monthly flows at this site in WY20 varied from 3.24 to 24.8 cfs. Assuming that the lowest flow rates reflect the groundwater inflows, while higher flows are supplemented by surface runoff and soil water inflows, this results in a calculated discharge of 2,349 acre-ft/yr.

In total, groundwater discharges to surface waters other than the Flathead River account for about 27,741 acre-ft/yr (table C1). These discharge rates are assumed to be near constant, so this total was distributed by month based on the number of days in each month (table C1).

<u>*Lake Evaporation (LE)*</u>

Evaporation from lakes other than Lake Blaine are included in this budget since groundwater monitoring near the lakes shows that groundwater levels and lake levels are very similar. This suggests a direct connection between the lakes and the shallow aquifer. Evaporation from Lake Blaine was included in the “Lake Infiltration from Lake Blaine” calculation. The other lakes are primarily in the Many Lakes area. They are pothole lakes without channelized inflow or outflow, so it is assumed that they are fed by and discharge to groundwater. The area of the lakes was determined by extracting lakes greater than 2 acres in size from the USGS National Hydrography Dataset (NHD; USGS, 2015). This resulted in 49 water bodies with a total delineated area of 601 acres. Areal and satellite imagery shows that the areas of the lakes are not constant, with the largest areas in the spring when groundwater levels are high, and then shrinking over the summer as groundwater levels drop. Since this same pattern is seen at Lake Blaine, the pattern of Lake Blaine area change was used to estimate the seasonal changes in the area of the other lakes. This caused the total lake area to vary in size from 455 to 601 acres.

The monthly lake areas were combined with monthly free water evaporation rates to estimate the monthly groundwater evaporation from the lakes. The free water evaporation rates were based on multiplying grass reference *ET* rates by 1.1 (Jensen, 2010). Grass reference *ET* rates were obtained for the Creston Agrimet station (https://www.usbr.gov/pn/agrimet/etsummary.html). This resulted in calculated evaporation rates ranging from 14 acre-ft in January to 421 acre-ft in July, and a total of 1,977 acre-ft/yr evaporated (table C1).

<u>*Riparian Evapotranspiration (ET_r)*</u>

Evapotranspiration of groundwater by riparian vegetation was calculated based on the *AET* in areas identified as riparian. There are about 4,878 acres of riparian vegetation in the study area (MNHP, 2017). The two most common community types are Emergent Wetlands and Riparian Forested, which account for 45% and 41% of the total, respectively (table C6). Emergent Wetlands are also called marsh, meadow, fen, prairie pothole, and slough (Cowardin and others, 1979). Riparian Forested areas contain woody obligate and facultative wetland species, such as willow and cottonwood.

AET was estimated for each riparian polygon using an approach similar to that used to estimate crop *AET*, except that the normalized difference vegetation index (NDVI) was used instead of EVI. The EVI approach appears to produce reasonable values within agricultural areas with relatively homogeneous and dense vegetation. Using the EVI approach within the riparian polygons resulted in *AET* values that were unreasonably low (less than precipitation). The low *AET* values from the EVI approach were likely due to the presence of water (which returns a negative EVI value), or bare ground (e.g., dry ponds). When NDVI was used instead of EVI, the average *AET* value was 16.1 in/yr, which is somewhat higher than precipitation (14.7 in/yr). Therefore, the amount of groundwater consumed by riparian vegetation (ET_r) was estimated to be 572 acre-ft/yr (table C6). This annual total was distributed by month based on the temporal distribution of calculated *PET* at the Creston Agrimet station.

<u>*Residual Outflow (GW_{out} + $SW_{out\text{-}FHR}$)*</u>

Groundwater outflow from the study area (GW_{out}) and groundwater discharge to the Flathead River and

Table C6. Riparian areas.

Community Type	Acres	% of Total	Area Weighted Mean AET (in/yr)	AET-PCP (in/yr)	ET_r (acre-ft/yr)
Freshwater Emergent Wetland	2,181	45%	15.2	0.51	92
Freshwater Forested Wetland	47	1%	15.1	0.38	1
Freshwater Scrub-Shrub Wetland	273	6%	15.2	0.55	12
Riparian Emergent	347	7%	16.9	2.20	64
Riparian Forested	1,979	41%	17.1	2.39	395
Riparian Scrub-Shrub	50	1%	16.6	1.89	8
Total	4,878	100%	16.1	1.41	572

associated springs ($SW_{out\text{-}FHR}$) are grouped together in this analysis as residual outflows. These water budget components were combined because these outflows are poorly constrained by monitoring data. Darcy flux calculations can be used to estimate groundwater outflow, but the thickness and hydraulic conductivity (*K*) of the deep aquifer are poorly constrained, and the entire residual could easily be accounted for by groundwater outflow. Similarly, the difference in streamflows in the Flathead River could be used to estimate groundwater outflow to the river; however, the Flathead River has a minimum mean monthly flow of 5,250 cfs (USGS Station 12363000; Flathead River at Columbia Falls, MT) and measurement errors make it difficult to quantify changes in discharge of less than ~5%, so changes of less than 262 cfs are within the margin of error (Carter and Anderson, 1963; Cey and others, 1998). Therefore, separating these budget components would be arbitrary.

For the annual budget, residual outflow was calculated as the difference between quantified inflows and outflows, since long-term groundwater monitoring suggests that on an annual basis ΔS is near zero. This was a total of 20,330 acre-ft/yr (28 cfs). Monthly budgets assumed that residual outflow occurs at a constant rate, so it was distributed based on the number of days in each month (table C1).

Changes in storage (ΔS)

Changes in storage are important in the monthly budgets; however, based on long-term groundwater-level monitoring data, they appear to be near zero on an annual basis. On a monthly basis ΔS was calculated as the residual from the other water budget components for that month (table C1).

SUMMARY

The total amount of groundwater moving through the East Flathead study area is about 60,000 acre-ft/yr (table C1, fig. C8). The Swan Mountain Block is an important source of water, with groundwater inflow from the Swan Block, infiltration of streams at the mountain front, and infiltration of water from Lake Blaine (which obtains most of its water from the Swan Block) together accounting for 62% of the recharge to the valley-fill aquifer. Groundwater inflow along the southern boundary (17%), areal recharge (14%), and irrigation recharge (6%) are the other main sources of groundwater recharge. Most groundwater leaving the area discharges to local streams (45%), is extracted by wells (18%), flows to the Flathead River, or flows out of the area as groundwater to downgradient portions of the shallow and deep aquifers (33%, combined).

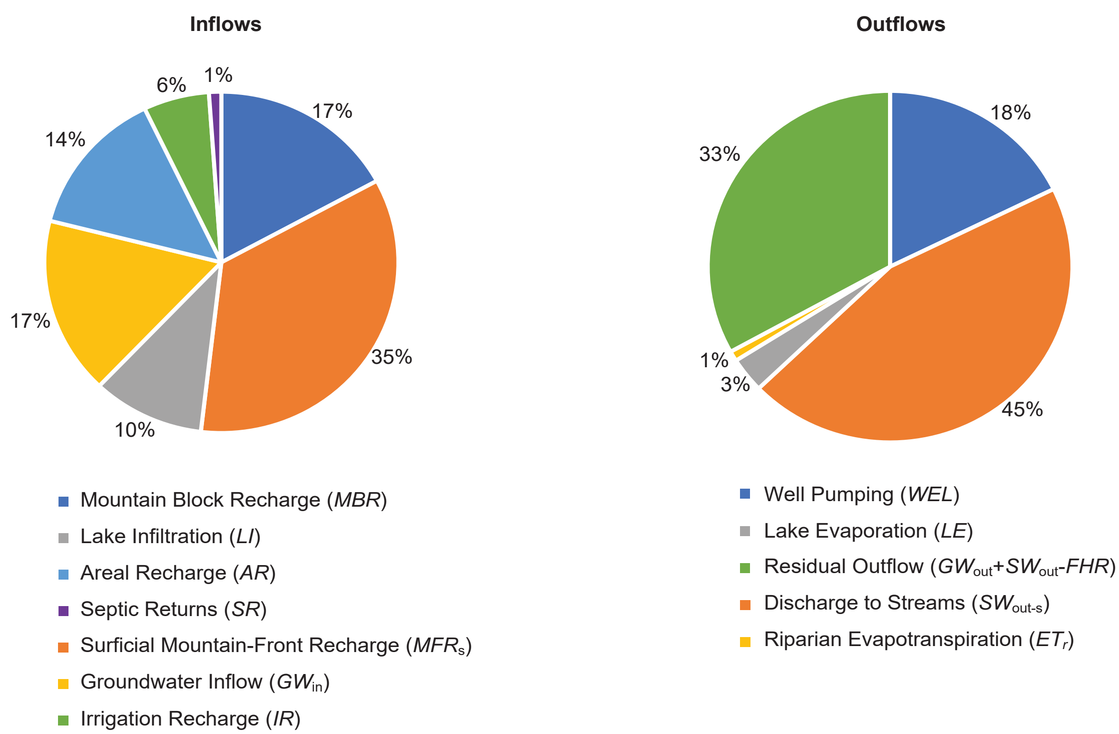

Figure C8. A summary of the average annual preliminary groundwater budget for the East Flathead Study Area.

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