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Memorandum

Date: September 13, 2012

To: Millie Heffner, Water Rights Bureau Chief

From: Mike Roberts, Hydrologist, Water Management Bureau

James Heffner, Hydrologist, Water Management Bureau

Re: Development of standardized methodologies to determine Historic Diverted Volume

The Montana Department of Natural Resources and Conservation (DNRC) Water Management Bureau (WMB) was tasked with developing standardized guidelines to estimate historic diverted volume for DNRC rule-making as it pertains to water rights changes and permit applications. In addition, guidelines for estimating historic use associated with surface water permit applications are included.

This document outlines the methods used and how the procedures will be applied. The majority of the data used herein were either taken from the United States Department of Agriculture (USDA) National Agricultural Statistics Service (NASS), generated using the USDA Natural Resources Conservation Service (NRCS) Irrigation Water Requirements (IWR) program, or derived from equations taken directly from the National Engineering Handbook (1993).

These approaches are similar to those used for estimating historic consumptive use (ARM 36.12.1902) enacted in 2010. They are methods supported by literature and data to be used by DNRC during application review under the new reform process.

Historic Diverted Volume

Three components require quantification to determine the historic diverted volume:

- Historic consumptive use
- Historic conveyance losses

- Historic on-farm efficiency

Historic Diverted Volume =

$$(\text{Volume}_{\text{historic consumptive use}} / \text{On-farm efficiency}) + \text{Volume}_{\text{conveyance loss}}$$

Historic Consumptive Use

Historic consumptive use is determined using the existing rules (ARM 36.12.1902).

Conveyance Loss

Conveyance loss is defined as the portion of water diverted at the headgate that does not arrive at the irrigated place of use due to seepage and evapotranspiration from the ditch. The total conveyance loss is the summation of the seepage and evapotranspiration components estimated using the following equations and constants which were taken directly from the National Engineering Handbook (1993). While ditch evaporation is typically less than 1% of the total conveyance loss, it is included in these calculations.

Seasonal Conveyance Loss = Seepage Loss + Vegetation Loss + Ditch Evaporation

$$\text{Seepage Loss} = \frac{(\text{wetted perimeter})(\text{ditch length})(\text{loss rate})(\text{days})}{43,560 \text{ ft}^2/\text{acre}}$$

Where: Wetted perimeter: Determined from user supplied ditch dimensions (feet)

Ditch length: Distance from headgate to field (feet)

Loss rate: Based on soil type (from Web Soil Survey) and Figure 2-50 (from NEH 1993). Note: Soil type should reflect soils below flow level of ditch.

Days: Number of days during the season the ditch supports flow. (This value is based on information provided by the applicant on Form 606, Section 3(B))

$$\text{Vegetation Loss} = (\% \text{ loss/mile})(\text{flow})(\text{days})(\text{ditch length}) * 2 \text{ (unit conversion constant)}$$

Where: Percent loss/mile: 0.75 % (NEH standard, 1993)

Flow: user supplied or estimated flow rate of ditch

Days: Number of days during the season the ditch supports flow (user supplied)

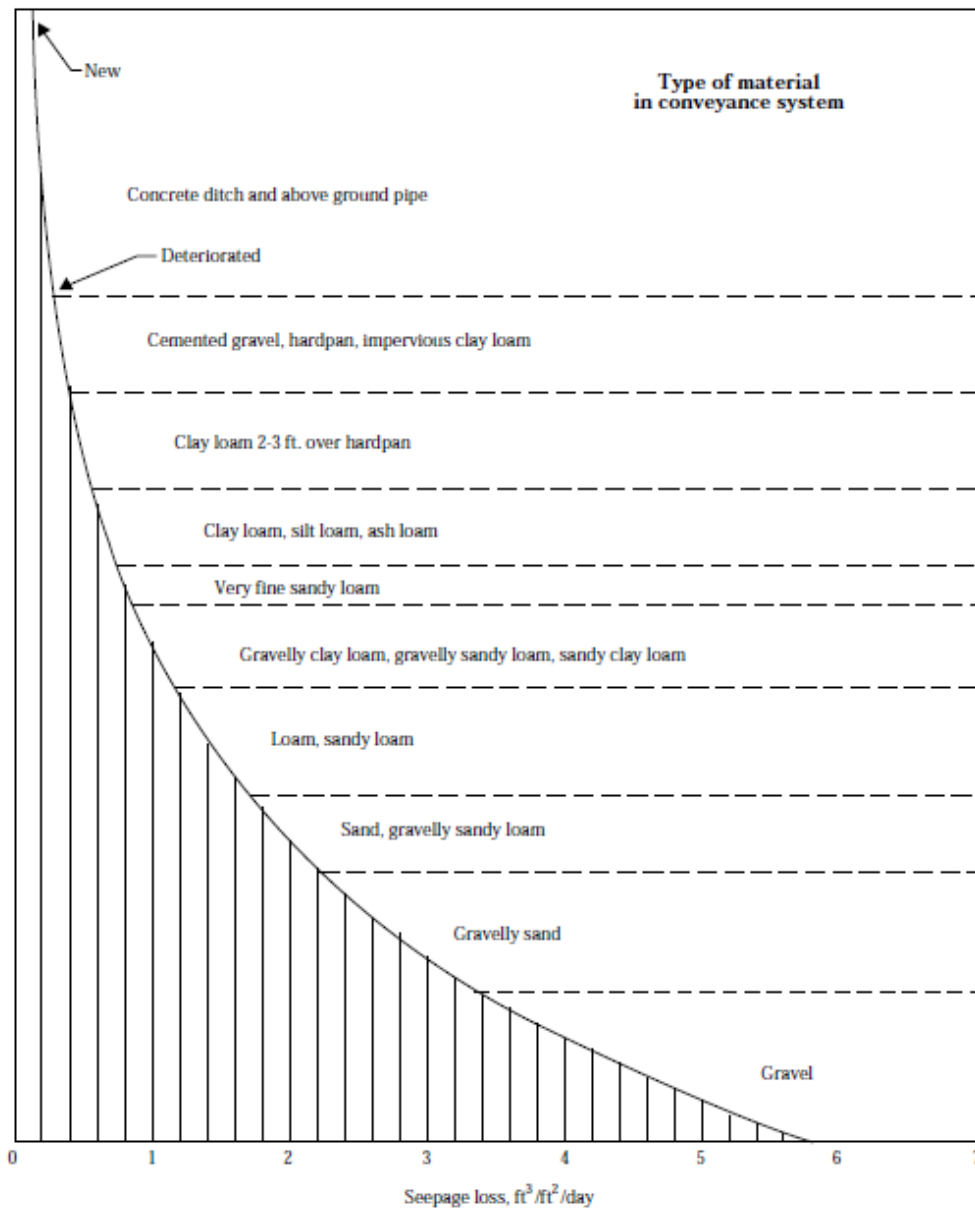
Ditch length: Distance from headgate to field (miles)

Ditch Evaporation = (surface area of ditch)(evaporation rate)/43,560 ft²/acre

Where: Surface area = wetted width (ft) * length of ditch (ft)

Evaporation rate = From Potts (1988)

Figure 2-50 Method to estimate seepage losses from irrigation delivery systems (adapted from USDA 1985)



On-Farm Efficiency

On-Farm efficiency refers to the percent of the water delivered to the field that is used by the crop. Values presented in the table below are similar to those percentages associated with the Irrigation Standards presently in rule for permit applications (ARM 36.12.115). An additional value for wild flood on-farm efficiency is presented as 25% (Neibling 1997, Utah State 2008).

<u>Irrigation Method</u>	<u>Percent Efficiency</u>
Sprinkler	70
Level Border	60
Graded Border (<i>Design Slope = .1-.4%</i>)	70
Graded Border (<i>Design Slope = .75-1.5%</i>)	65
Graded Border (<i>Design Slope = 3%</i>)	60
Furrow (<i>Design Slope = .1-.4%</i>)	70
Furrow (<i>Design Slope = .75-1.5%</i>)	65
Furrow (<i>Design Slope = 3%</i>)	60
Contour Ditch (<i>Design Slope = .75%</i>)	60
Contour Ditch (<i>Design Slope = 1.5-3%</i>)	55
Contour Ditch (<i>Design Slope = 6%</i>)	45
Wild Flood	25

Historic Use – Permit Applications

Historic consumptive use associated with change applications for permits will use the existing rules as stated in ARM 36.12.1902 with the exception of employing a management factor derived from more recent production data. A new column (G) is included in Table 1 to provide management factors developed for the period 1973 to 2006.

The following hypothetical scenario provides an example how historic diverted volume, new consumptive use, and new diverted volume would be calculated.

A Helena valley applicant proposes to change their place of use of 150 acres of flood irrigated alfalfa (contour ditch, flat slope) to a center pivot with similar acreage. The applicant submits ditch cross-section data (wetted width = 7 ft, wetted perimeter = 8.5 ft). Determine (1) historic consumptive volume, and (2) historic diverted volume

(1) Historic consumptive volume:

$$\begin{aligned}
 & (20.23 \text{ in}) * (1 \text{ ft} / 12 \text{ in}) * (0.601) * (150 \\
 = & \text{ acres)} \\
 = & \mathbf{152 \text{ acre-feet}} \qquad \qquad \qquad (\text{ARM } 36.12.1902)
 \end{aligned}$$

(2) Historic diverted volume:

$$(\text{Vol.}_{\text{historic consumptive use}} / \text{On-farm effic.}) + \text{Vol.}_{\text{conveyance loss}}$$

historic consumptive volume = 152 acre feet

on-farm efficiency = 0.6

seasonal conveyance loss = seepage loss + vegetation loss + ditch evaporation

$$\begin{aligned}
 \text{seepage loss} = & \frac{(\text{wetted perimeter})(\text{ditch length})(\text{loss rate})(\text{days})}{43,560 \text{ ft}^2/\text{acre}}
 \end{aligned}$$

wetted perimeter =	8.5 ft	
		(determined from
ditch length =	3000 feet	map)
loss rate =	1.2 ft ³ /ft ² /day	(based on web soil survey dominant soil
		type and Figure 2-
		50)
days irrigated =	100	(applicant supplied, Form 606)

$$\begin{aligned}
 \text{seepage loss} = & \frac{(8.5 \text{ ft})(3000 \text{ ft})(1.2 \text{ ft}^3/\text{ft}^2/\text{day})(100 \text{ days})}{43,560 \text{ ft}^2/\text{acre}} = 70.3 \text{ acre-feet}
 \end{aligned}$$

$$\text{vegetation loss} = (\% \text{ loss/mile})(\text{flow})(\text{days})(\text{ditch length})(2 \text{ ft}/\text{ft}^3/\text{s}/\text{d})$$

% loss/mile =	0.0075	(NEH standard, 1993)
est. flow rate =	6 ft ³ /s	(estimated from applicant or water right)
days irrigated =	100	(applicant supplied, Form 606)
ditch length =	0.57 miles	(converted to miles)

vegetation loss = $(0.0075)(6 \text{ ft}^3/\text{s})(0.57 \text{ mi})(100 \text{ days})(2 \text{ ft}^3/\text{s}/\text{d}) = 5.13 \text{ acre-feet}$
 ditch evaporation = $(\text{surface area})(\text{evaporation rate})/43,560 \text{ ft}^2/\text{acre}$
 ditch evaporation = $(7 \text{ ft} \times 3000 \text{ ft})(3.2 \text{ ft})/43,560 \text{ ft}^2/\text{acre} = 1.54 \text{ acre-feet}$
 seasonal conveyance loss = $(70.3 \text{ acre-feet}) + (5.13 \text{ acre-feet}) + (1.54 \text{ acre-feet}) = 77.0 \text{ acre-feet}$
 Historic diverted volume = $(152 \text{ acre-feet}/0.6) + (77 \text{ acre-feet}) = 330.3 \text{ acre-feet}$

Conversion from Seasonal Volumes to Monthly Volumes

The approaches describe above provide seasonal volumes. Surface water diversions are assumed to be, at the monthly scale, identical in timing to the monthly crop irrigation requirements.

Irrigation Water Requirements Summary

Job: Example Crop: Alfalfa Hay
 Location: Helena County: Lewis And Clark, MT
 By: MR Date: 04/12/12
 Weather Station: HELENA WSO Sta No: MT4055
 Latitude: 4636 Longitude: 11200 Elevation: 3830
 Computation Method: Blaney Criddle (TR21) Net irrigation application: 4 inches
 Crop Curve: Blaney Criddle Perennial Crop Estimated carryover moisture used at season:
 Begin Growth: 5/5 End Growth: 9/27 Start: 1 End: 1 inches

Month	Total Monthly ET (3)	Dry Year 80% Chance (1)		Normal Year 50% Chance (1)		Average Daily ETc	Peak Daily ETPk
		Effective Precipitation	Net Irrigation Requirements	Effective Precipitation	Net Irrigation Requirements		
	(inches)	(inches)	(inches)(2)	(inches)	(inches)(2)	(inches)	(inches)
January							
February							
March							
April							
May	2.75	0.71	1.03	0.98	0.77	0.10	
June	6.04	1.02	5.02	1.40	4.64	0.20	0.21
July	7.67	0.84	6.83	1.16	6.52	0.25	0.28
August	6.46	0.76	5.70	1.04	5.42	0.21	0.23
September	3.11	0.46	1.65	0.63	1.48	0.12	
October							
November							
December							
TOTALS	26.03	3.80	20.23	5.21	18.82		

Using outputs from IWR, monthly irrigation requirement percentages can be applied to diverted volume to estimate monthly diverted volume estimates. For example:

Historic Diverted Volume (ac-ft) =		330	
	<u>Net Irrig. Req (in)</u>	<u>Percent of Total</u>	<u>Diverted Vol. (ac-ft)</u>
May*	1.03	5.1	16.8
June	5.02	24.8	81.8
July	6.83	33.8	111.5
August	5.7	28.2	93.1
<u>September</u>	<u>1.65</u>	<u>8.2</u>	<u>27.1</u>
Total =	20.23	100	330

*Example: $(\text{May}_{\text{net Irrig. Req}} / \text{Total}_{\text{Irrig. Req}}) * \text{Historic Diverted Volume}$
 $(1.03 \text{ in} / 20.23 \text{ in}) * 330 \text{ ac-ft} = 16.8 \text{ ac-ft}$

Table 1 - Montana County Weather Station IWR Data for Seasonal Alfalfa Evapotranspiration and Montana County Management Factor. Season ET derived from Irrigation Water Requirements Program (Dalton, 2003)

Column A	Column B	Column C	Column D	Column E	Column F	Column G
County	Weather Station	Elevation	IWR Flood Irrigation, Wheeline & Handline Seasonal ET (inches)	IWR Center Pivot Irrigation Seasonal ET (inches)	Management Factor Percentage 1964 - 1973	Management Factor Percentage (for Permit Hist. CU only) 1973 - 2006
Beaverhead	Dillon	5239	18.34	20.74	63.7%	82.8%
	Wisdom	6060	7.34	9.29		
	Jackson	6480	8.35	10.30		
	Lakeview	6710	8.39	10.67		
	Lima	6583	13.75	16.01		
Big Horn	Busby	3430	20.32	22.88	55.4%	78.7%
	Hardin	2905	27.46	29.96		
	Hysham 25	3100	20.25	22.86		
	Wyola	3750	19.19	21.89		
Blaine	Yellowtail Dam	3305	28.07	31.30		
	Chinook	2420	20.80	23.57	58.7%	63.6%
	Harlem	2362	21.62	24.27		

Column A	Column B	Column C	Column D	Column E	Column F	Column G
County	Weather Station	Elevation	IWR Flood Irrigation, Wheeline & Handline Seasonal ET (inches)	IWR Center Pivot Irrigation Seasonal ET (inches)	Management Factor Percentage 1964 - 1973	Management Factor Percentage (for Permit Hist. CU only) 1973 - 2006
Broadwater	Townsend	3840	19.42	21.88	69.2%	79.5%
	Trident	4040	20.64	23.31		
Carbon	Joliet	3776	22.41	25.12	58.3%	66.8%
	Red Lodge	5500	15.57	18.41		
Carter	Ekalaka	3425	20.13	23.14	38.4%	54.7%
	Ridgeway	3320	20.28	23.01		
Cascade	Cascade 20	4600	14.12	16.63	57.3%	70.0%
	Cascade 5	3360	17.90	20.75		
	Great Falls	3675	19.78	22.55		
	Neihart	4945	12.17	15.08		
	Sun River	3340	18.10	20.65		
Chouteau	Big Sandy	2700	21.52	24.37	52.5%	64.9%
	Fort Benton	2640	21.98	24.75		
	Geraldine	3130	20.30	23.27		
	Iliad	2950	21.55	24.27		
	Loma	2700	22.64	25.37		
	Shonkin	4300	13.32	16.70		
Custer	Miles City	2628	26.68	29.55	54.5%	72%
	Mizpah	2480	23.80	26.57		
	Powderville	2800	24.83	27.68		
Dawson	Glendive	2076	26.01	28.99	56.8%	63.6%
Deer Lodge	No weather station				See appropriate adjacent county	
Fallon	Plevna	2780	22.48	25.34	47.6%	47.8%
Fergus	Denton	3620	15.39	18.12	48.8%	65.8%
	Grass Range	3490	18.93	21.93		
	Lewistown	4167	15.54	18.44		
	Roy	3450	19.94	22.78		
	Winifred	3240	17.86	20.75		
Flathead	Creston	2949	14.97	17.81	87.6%	94.5%
	Hungry Horse Dam	3160	14.66	18.06		
	Kalispell	2972	16.45	19.03		
	Olney	3165	12.50	15.16		
	Polebridge	3600	10.20	12.50		
	West Glacier	3154	13.74	16.78		
	Whitefish	3100	15.74	18.61		
Gallatin	Bozeman Exp	4775	16.84	19.55	73.5%	92.1%

Column A	Column B	Column C	Column D	Column E	Column F	Column G
County	Weather Station	Elevation	IWR Flood Irrigation, Wheeline & Handline Seasonal ET (inches)	IWR Center Pivot Irrigation Seasonal ET (inches)	Management Factor Percentage 1964 - 1973	Management Factor Percentage (for Permit Hist. CU only) 1973 - 2006
	Farm					
	Bozeman MT State	4913	18.42	21.39		
	Hebgen Dam	6667	10.09	12.77		
Garfield	Cohagen	2710	22.36	24.99	43.4%	50.6%
	Jordan	2661	23.58	26.32		
	Mosby	2750	24.51	27.34		
Glacier	Babb	4300	12.12	14.87	59.7%	73.6%
	Cut Bank	3855	16.01	18.60		
	Del Bonita	4340	14.61	17.30		
	East Glacier	4810	10.60	13.26		
	St Mary	4560	13.64	16.60		
Golden Valley	Ryegate	4440	17.60	20.17	62.6%	65.5%
Granite	Philipsburg Ranger Station	5270	12.90	15.26	86.5%	87.4%
Hill	Fort Assinniboine	2613	22.42	25.20	54.1%	59.8%
	Guilford	2820	19.54	22.06		
	Havre	2585	20.94	23.46		
	Simpson	2815	19.67	22.13		
Jefferson	Boulder	4904	17.08	19.47	61.0%	77.9%
Judith Basin	Moccasin Exp Station	4243	16.17	19.06	49.3%	68.0%
	Raynesford	4220	16.14	19.05		
	Stanford	4860	16.74	19.69		
Lake	Bigfork	2910	17.37	20.61	55.0%	69.2%
	Polson	2949	20.46	23.23		
	Polson Kerr Dam	2730	21.37	24.08		
	St Ignatius	2940	19.53	22.33		
Lewis & Clark	Augusta	4070	17.51	20.13	60.1%	79.0%
	Austin	4790	15.41	17.96		
	Helena	3828	20.23	22.69		
	Holter Dam	3490	23.88	26.61		
	Lincoln Ranger Station	4575	12.87	15.22		
Liberty	Chester	3132	19.28	21.74	54.8%	65.7%
	Joplin	3300	19.01	21.40		
	Tiber Dam	2850	22.98	25.46		
Lincoln	Eureka Ranger	2532	20.63	23.26	47.1%	56.3%

Column A	Column B	Column C	Column D	Column E	Column F	Column G
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	Station					
	Fortine	3000	16.09	18.69		
	Libby Ranger Station	2096	21.20	23.71		
	Libby	3600	11.06	13.36		
	Troy	1950	19.90	22.68		
Madison	Alder	5800	14.33	16.75	65.2%	79.0%
	Ennis	4953	17.19	19.71		
	Glen	5050	17.81	20.01		
	Norris	4750	20.88	23.97		
	Twin Bridges	4777	16.98	19.22		
	Virginia City	5770	15.57	18.13		
McCone	Brockway	2630	20.74	23.35	43.7%	55.0%
	Circle	2480	22.23	25.01		
	Fort Peck Power Plant	2070	25.37	28.16		
	Vida	2400	21.74	24.65		
Meagher	Lenep	5880	11.93	14.38	57.3%	70.4%
	Martinsdale	4800	15.19	17.73		
	White Sulphur Spr	5060	16.41	18.89		
Mineral	St Regis Ranger Stn	2680	17.61	20.05	56.1%	63.3%
	Superior	2710	21.94	24.54		
Missoula	Lindbergh Lake	4320	14.63	17.22	69.5%	67.5%
	Missoula	3420	18.85	21.49		
	Missoula WSO AP	3199	19.45	21.89		
	Potomac	3620	14.05	16.26		
	Seeley Lake Ranger Station	4100	14.86	17.31		
Musselshell	Melstone	2920	24.22	27.17	50.0%	58.7%
	Roundup	3386	23.98	26.79		
Park	Cooke City	7460	8.68	11.63	56.9%	66.1%
	Gardiner	5275	22.46	24.70		
	Livingston	4870	16.59	19.41		
	Livingston FAA AP	4656	18.63	21.39		
	Wilsall	5840	13.20	16.01		
Petroleum	Flatwillow	3133	22.27	25.01	44.0%	50.0%
Phillips	Content	2340	21.15	23.97	54.7%	54.7%

Column A	Column B	Column C	Column D	Column E	Column F	Column G
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	Malta 35	2650	20.28	22.99		
	Malta 7	2262	21.61	24.39		
	Port of Morgan	2830	20.15	22.72		
	Saco	2180	20.13	22.70		
	Zortman	4660	14.38	17.40		
Pondera	Conrad	3550	16.93	19.42	71.4%	81.0%
	Valier	3810	18.31	20.96		
Powder River	Biddle	3597	21.87	24.66	38.5%	49.3%
	Broadus	3032	23.03	25.69		
	Moorhead	3220	23.72	26.42		
	Sonnette	3900	18.32	20.96		
Powell	Deer Lodge	4678	13.14	15.32	77.6%	90.0%
	Ovando	4109	12.28	14.43		
Prairie	Mildred	2510	22.92	25.58	59.6%	73.6%
	Terry	2248	22.82	25.47		
	Terry 21	3260	18.65	21.34		
Ravalli	Darby	3880	18.91	21.44	79.5%	88.6%
	Hamilton	3529	19.93	22.34		
	Stevensville	3380	19.19	21.44		
	Sula	4475	12.09	14.42		
	Western Ag Research	3600	19.82	22.15		
Richland	Savage	1990	23.61	26.59	56.0%	72.9%
	Sidney	1931	22.49	25.45		
Roosevelt	Bredette	2638	19.99	22.86	46.5%	64.9%
	Culbertson	1942	20.84	23.73		
	Wolf Point	1985	24.16	27.03		
Rosebud	Birney	3160	24.57	27.29	47.7%	67.7%
	Brandenberg	2770	23.83	26.52		
	Colstrip	3218	23.32	26.10		
	Forsythe	2520	25.17	28.04		
	Ingomar	2780	23.18	25.83		
	Rock Springs	3020	21.35	23.93		
Sanders	Heron	2240	14.82	17.73	58.8%	69.1%
	Thompson Falls Power	2380	22.49	25.36		
	Trout Cr Ranger Station	2356	16.60	19.40		
Sheridan	Medicine Lake	1975	21.64	24.49	44.8%	68.5%

Column A	Column B	Column C	Column D	Column E	Column F	Column G
County	Weather Station	Elevation	IWR Flood Irrigation, Wheeline & Handline Seasonal ET (inches)	IWR Center Pivot Irrigation Seasonal ET (inches)	Management Factor Percentage 1964 - 1973	Management Factor Percentage (for Permit Hist. CU only) 1973 - 2006
	Plentywood	2063	20.64	23.48		
	Raymond Border Station	2384	19.13	22.04		
	Redstone	2300	17.86	20.58		
	Westby	2120	18.10	21.033		
Silverbow	Butte FAA AP	5545	14.73	17.06	68.8%	90.3%
	Divide	5350	15.25	17.58		
Stillwater	Columbus	3602	22.31	25.09	46.5%	62.9%
	Mystic Lake	6544	13.57	16.57		
	Nye	4840	15.00	17.93		
	Rapelje	4125	20.35	23.07		
Sweet Grass	Big Timber	4100	20.60	23.47	44.7%	53.6%
	Melville	5370	12.83	15.49		
Teton	Blackleaf	4240	14.74	17.34	68.8%	80.2%
	Choteau Airport	3845	20.53	23.07		
	Fairfield	3980	19.10	21.76		
	Gibson Dam	4724	13.57	16.22		
Toole	Goldbutte	3498	16.30	18.96	51.8%	66.5%
	Sunburst	3610	18.74	21.46		
	Sweetgrass	3466	18.22	21.22		
Treasure Valley	Hysham	2660	25.01	27.78	53.4%	75.2%
	Glasgow WSO AP	2293	23.48	26.12	57.9%	66.6%
	Hinsdale	2670	22.18	25.25		
	Opheim 10	2878	16.19	18.86		
	Opheim 16	3258	16.73	19.34		
Wheatland	Harlowton	4162	17.83	20.56	46.6%	58.7%
	Judith Gap	4573	13.77	16.40		
Wibaux	Carlyle	3030	19.87	22.75	See appropriate adjacent county	
	Wibaux	2696	18.69	21.50		
Yellowstone	Billings Water Plant	3097	26.16	28.92	59.5%	71.4%
	Billings WSO	3648	25.49	28.22		
	Huntley Exp Station	3034	21.92	24.61		

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