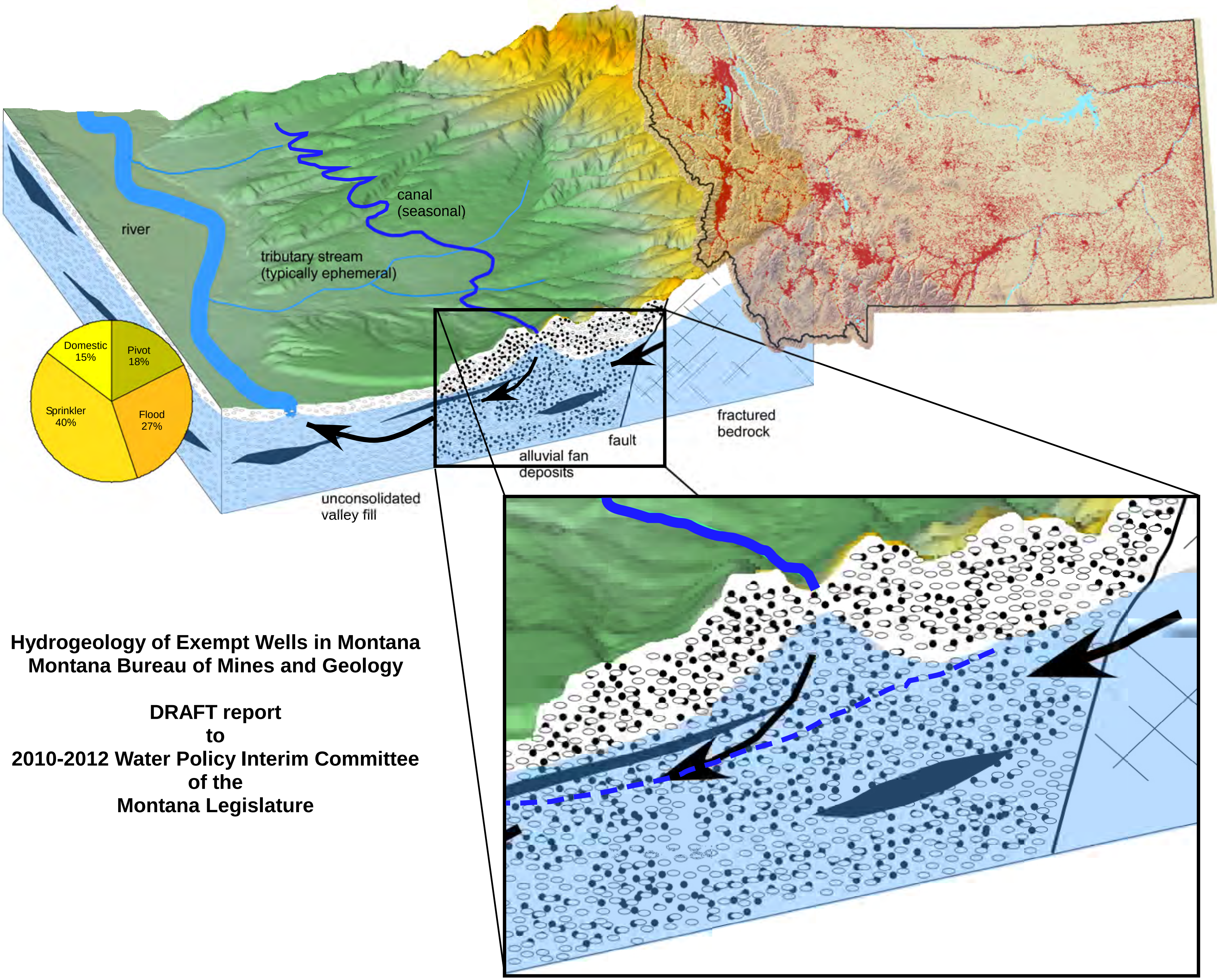
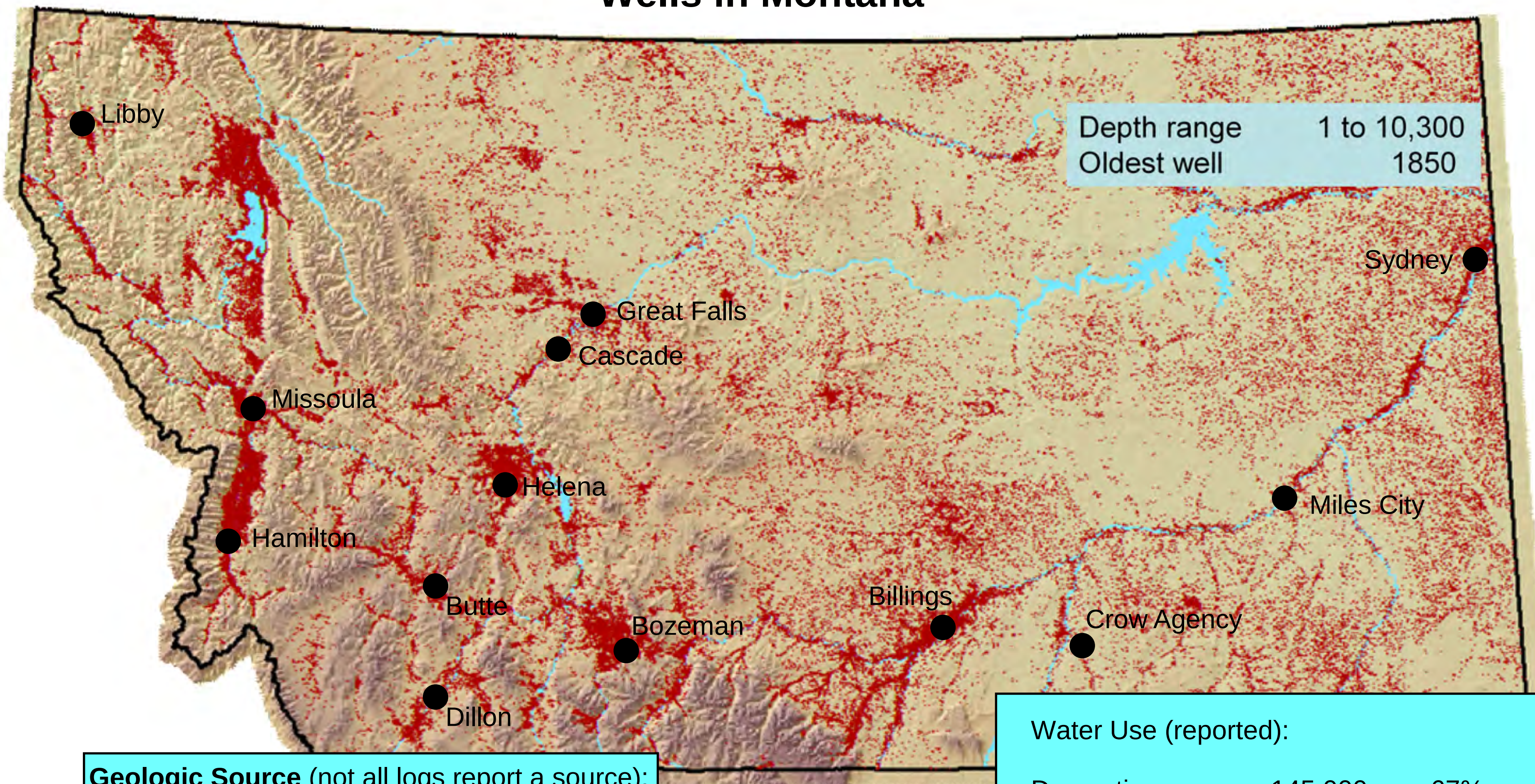


Hydrogeology of Exempt Wells in Montana
Montana Bureau of Mines and Geology

DRAFT report
to
2010-2012 Water Policy Interim Committee
of the
Montana Legislature

Wells in Montana



Geologic Source (not all logs report a source):

Alluvium	34,400
Glacial deposits	11,600
Fort Union	14,200
Fox Hills - Hell Creek	3,460
Judith River	2,550
Eagle - Virgelle	1,575
Kootenai - Madison	2,200
Other bedrock	4,700
Total	74,685

Water Use (reported):

Domestic	145,000	67%
Stock	51,000	24%
Irrigation	14,000	6%
Public	5,000	2%
Industrial	2,000	1%

Source: MBMG Ground Water Information System database

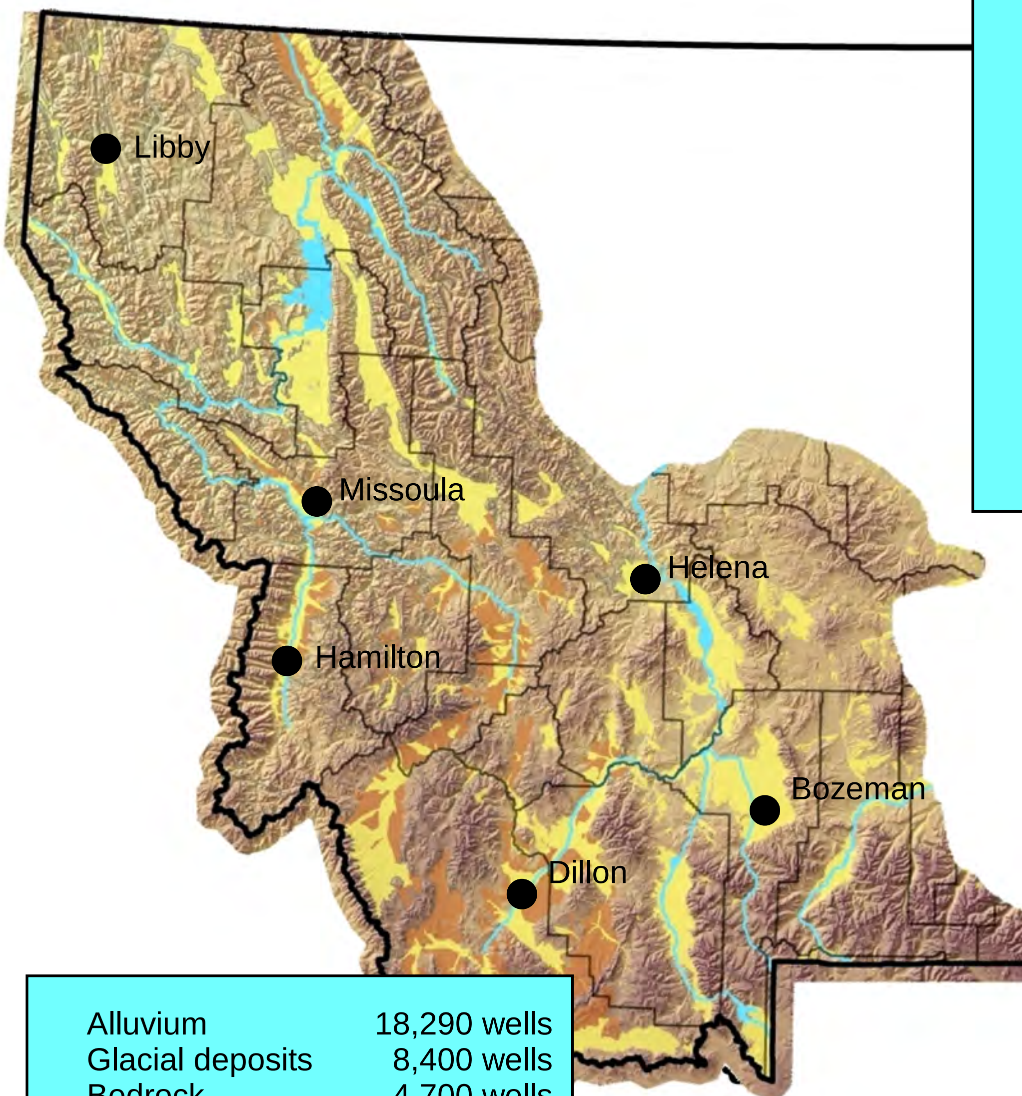
Hydrogeology related to exempt wells in Montana

Introduction

Montana has over 200,000 wells on record with the MBMG Ground Water Information Center database (GWIC) whose use has been identified as domestic. Some estimates show as much as 30% of the population relies on individual wells for water supply. For the purposes of this discussion, it is important to note the difference between the terms domestic and exempt. When a well log is filed, the driller or well owner indicates the intended use of the well – domestic use is one option; other options are stock, irrigation, public water supply, monitoring, or other. In its inventories of wells for various projects, the MBMG will make attempts to establish or verify the use of the well; again, domestic use is one option. The term exempt refers to a well that, based on the maximum annual volume pumped (currently 10 acre-feet per year) and the maximum pumping rate (currently 35 gallons per minute), is exempt from permitting; the water right is established by a certificate issued by the Montana Department of Natural Resources and Conservation. The use of the exempt well, whether it be domestic, irrigation, or stock does not affect the exemption. Due largely to changes in the regulatory requirements regarding well log and water-right filing, there are many wells for which a certificate does not exist.

The figure shows the distribution of all the wells across the state recorded in GWIC; each well is represented by a small red dot on the map. Population centers and river valleys are easily distinguished by areas of high well density. Although a geologic source is not reported for all the wells in the GWIC database, shallow alluvial aquifers along river and stream valleys are subject to the greatest development and 90 percent of all the wells, for which a use has been reported, are used for domestic or stock.

Major Aquifers of Western Montana



Alluvium:

Sand and gravel along major and tributary valleys, thick basin-fill deposits in intermontane basins

Unconfined aquifers

Thickness: 30 to >1,000 feet

Yield: 1 to 3,500 gpm; average is 35 gpm

Transmissivity: 500 to 200,000 feet^2/day

Quality: < 500 mg/L (total dissolved solids)

Use: domestic and stock, some irrigation

Bedrock:

metamorphic rocks, shale, limestone, granite, volcanic rocks, shallow on valley margins

Unconfined on valley margins

Thickness: generally unlimited, but yield decreases with depth

Yield: 1 to 5,000 gpm; average is 5 gpm

Transmissivity: 50 to 10,000 feet^2/day

Quality: < 100 mg/L (total dissolved solids)

Use: domestic and stock, rare irrigation

Alluvium	18,290 wells
Glacial deposits	8,400 wells
Bedrock	4,700 wells
Total	31,390

Groundwater sources

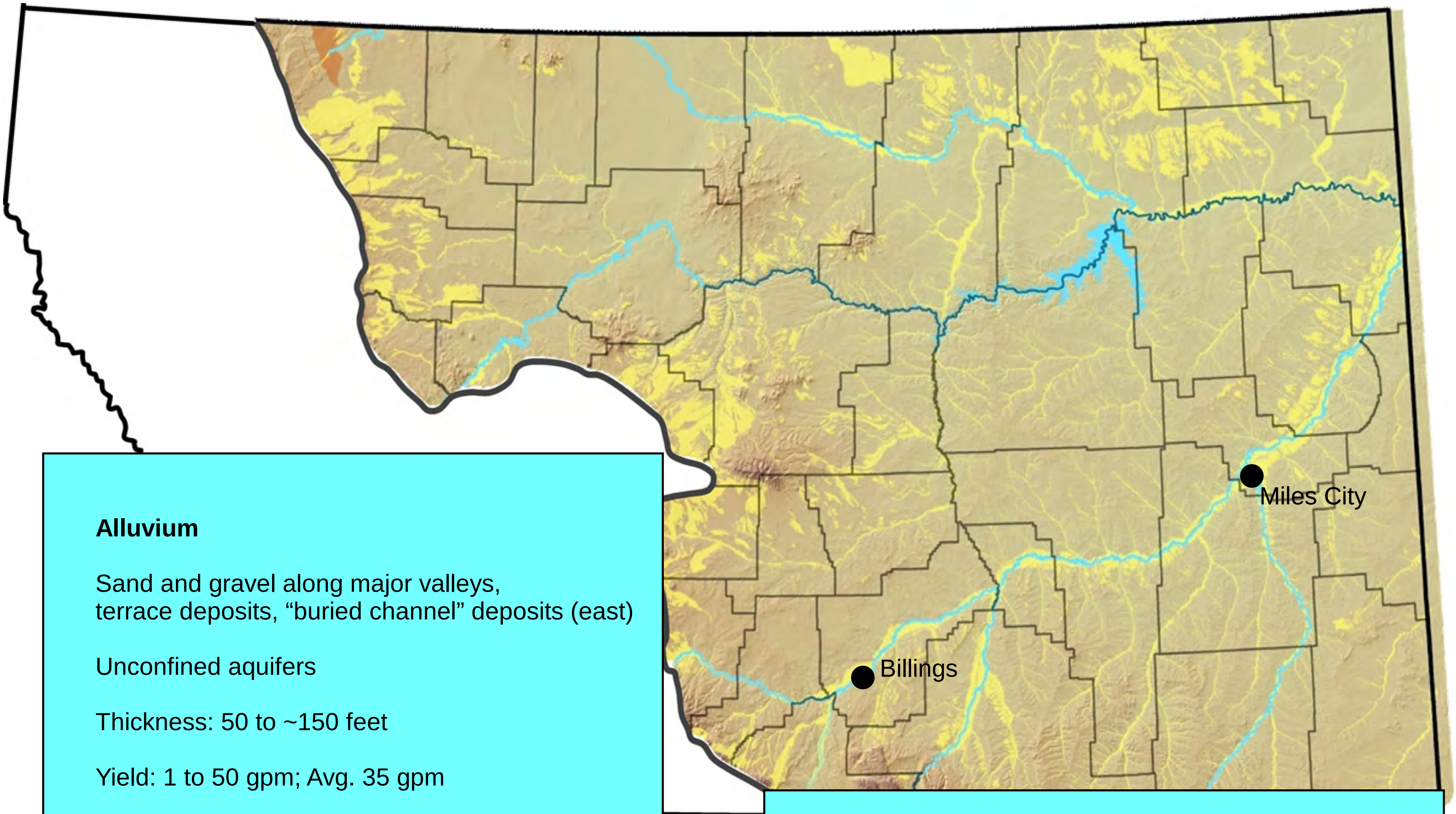
Montana is often described in terms of its contrasting physiographic or geologic province of the mountainous western third and the plains of the eastern two-thirds of the state. The great majority of domestic wells in both provinces are completed in a few aquifers.

Western Montana

Domestic wells in western Montana are most often completed in shallow aquifers often comprised of unconsolidated clay, sand, and gravel in the major valleys or along tributary valleys. These aquifers, shown as yellow on the maps, are most often unconfined and are typically thick (>1,000 feet); well yields are usually far greater than the demand of a typical domestic user. Natural water quality is generally very good, but the shallow unconfined nature of these aquifers make them vulnerable to contamination. Glacial deposits, shown as tan areas on the map, are glacial sand and gravel deposits of varying thickness that support moderate to high yield wells in the foothills of many valleys.

As population growth continues, more development warrants expansion of housing into the foothills and valley margins; bedrock wells become an important source for domestic use. With a few exceptions like the Madison Formation, wells in the bedrock aquifers tend to be low yield, if not marginal, for domestic use. The low yield of some of the bedrock aquifers will likely limit growth in several areas.

Major Aquifers of Eastern Montana



Alluvium

Sand and gravel along major valleys,
terrace deposits, “buried channel” deposits (east)

Unconfined aquifers

Thickness: 50 to ~150 feet

Yield: 1 to 50 gpm; Avg. 35 gpm

Transmissivity: 500 to 1,000 $feet^2$/day

Quality: 500 to ~5,000 mg/L total dissolved solids

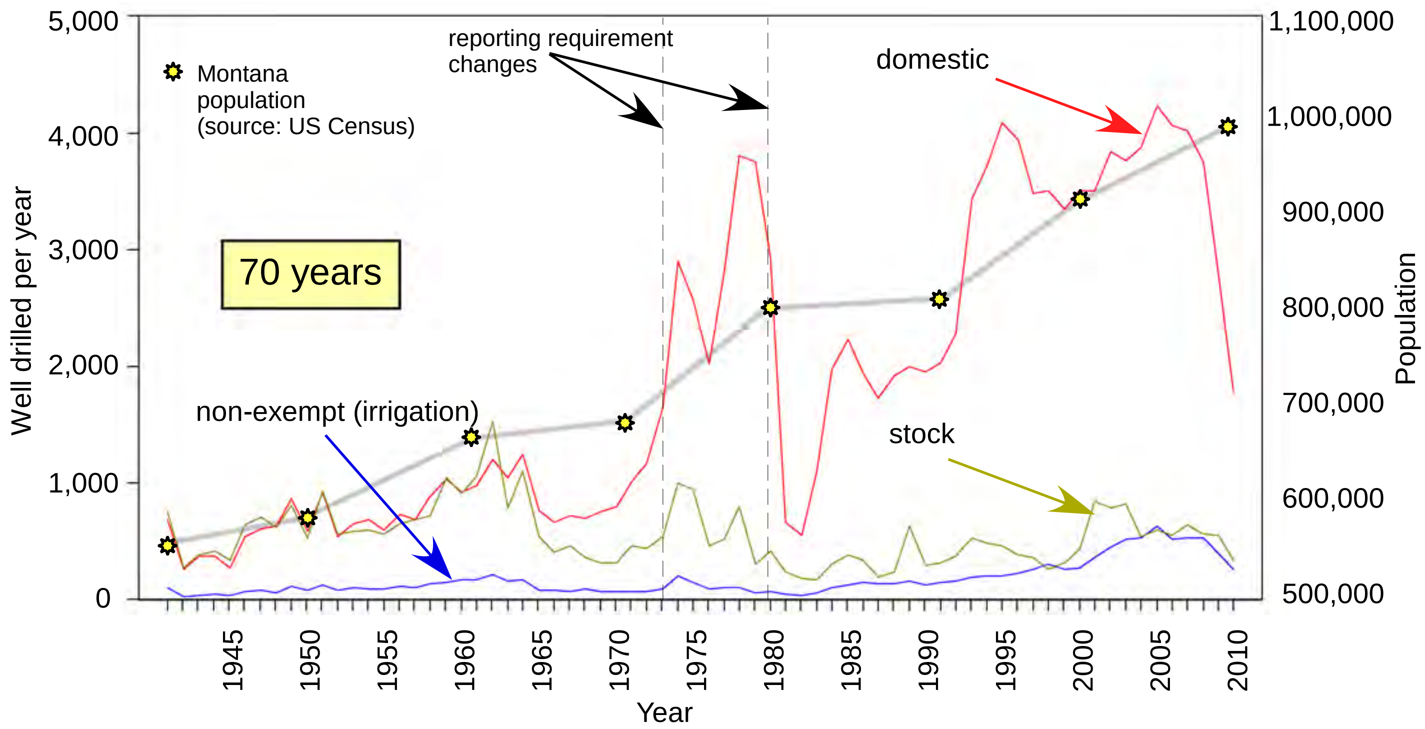
Use: domestic, stock, and some irrigation

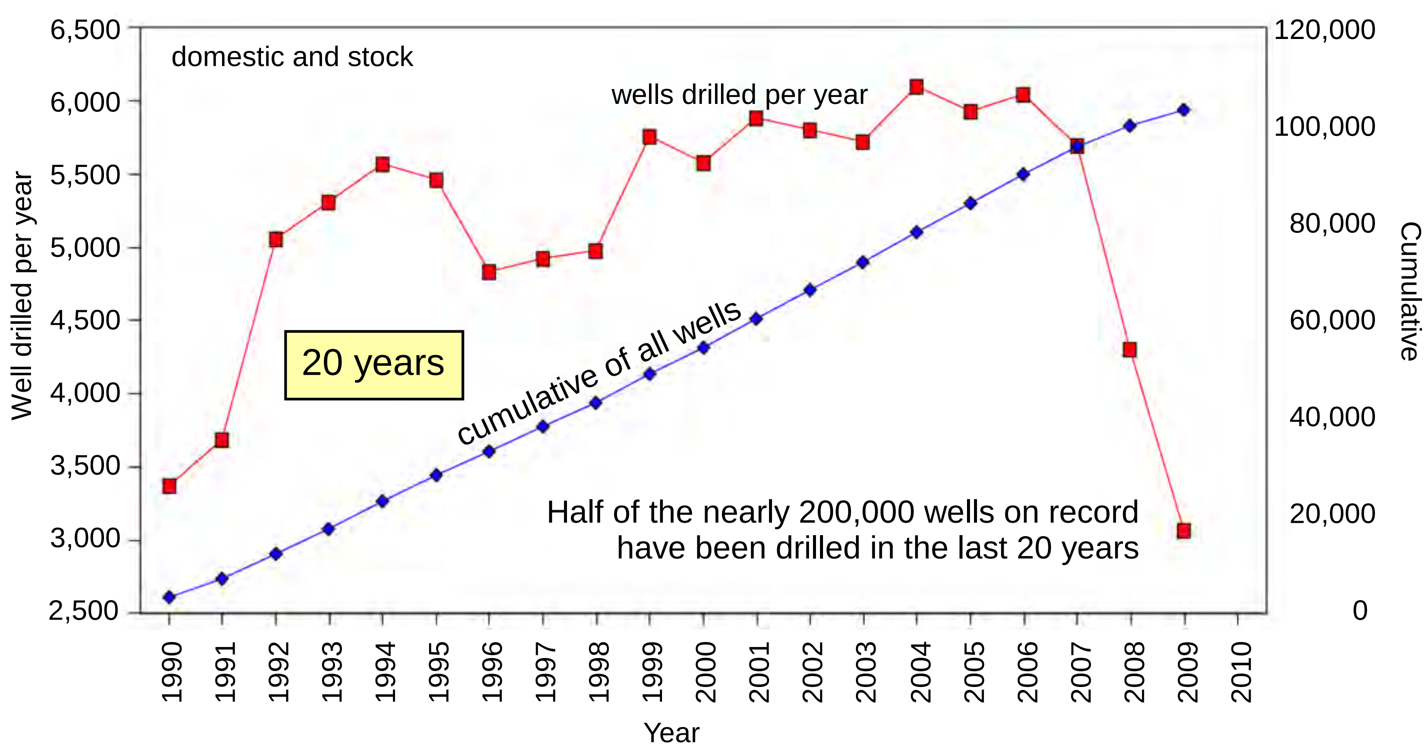
Alluvium	16,110 wells
Glacial deposits	3,200 wells
total	19,310 wells

Eastern Montana

Population centers in central and eastern Montana have developed along the major river valleys; surface water is the typical source for larger cities and towns. However, domestic wells have become increasingly important as the population moves to the valley margins outside the service area of the surface-water systems. The alluvial aquifers of eastern Montana are notably thin compared to those of the western valleys; although typically well connected to the large rivers, these thin aquifers are vulnerable to over pumping and contamination by surface sources.

There are several important bedrock aquifers in eastern Montana (not shown); these include the sandstone beds of the Fort Union (14,000 wells), the sandstone beds of the Fox Hills – Hell Creek (3,500 wells), the Judith River (2,600 wells), and the Eagle – Virgelle (1,600 wells) Formations. The bedrock formations in the central and eastern part of the state are generally flat lying and extensive; many wells in the eastern part of the state are under artesian pressure. These aquifers are the sole source of fresh water for domestic and stock use throughout eastern Montana.



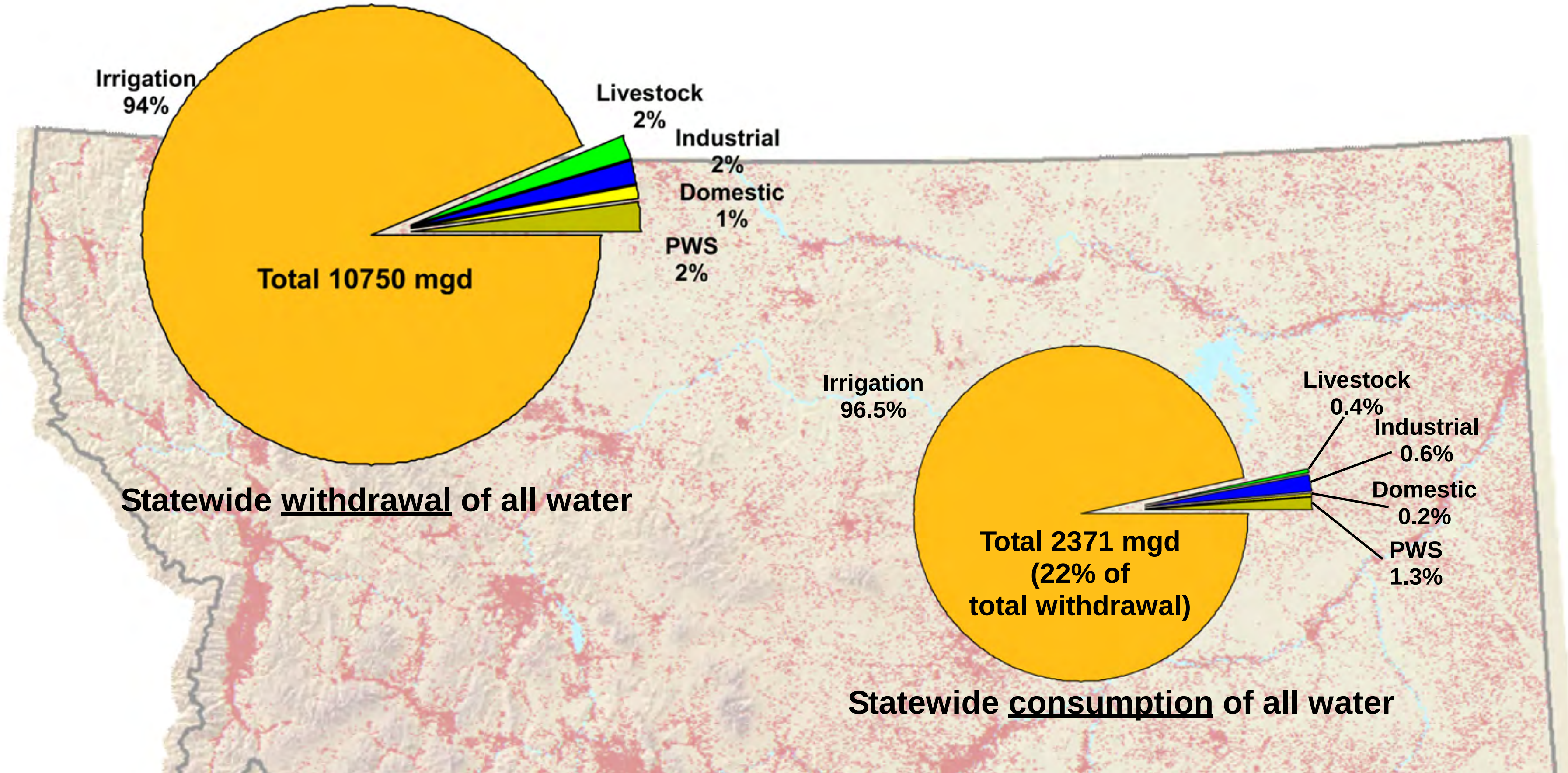


Growth trends of wells in Montana
(source: GWIC database)

Growth trends

More than half of the 200,000 wells in Montana were drilled in the last 20 years and more than 6,000 wells were drilled in 2004 – a trend that appeared likely to continue, but was disrupted by the (temporary?) economic downturn of 2008.

Although changes in reporting requirements over the past 70 years affect the accurate account of well drilling activity, the trend in well drilling appears to mimic population growth. By far, the highest rate of growth has been for domestic wells, but there is also an increasing reliance on groundwater for irrigation.



Global Water distribution:

2.5% of all water is fresh (non-saline)

of that, 1.3% is surface water and 30% is ground water
(the rest is in glaciers and ice caps)

that means that 99% of the world's usable water is groundwater

Source: Gleick (1996)

Water budgets - the importance of scale

A budget, whether it relate to finances or water, relates the income/inflow to expenses/outflow as it relates to a defined scope at specific scale of time or space. A change in the scope of the budget can drastically change the message delivered. A simple example of scope is to compare the financial budget of Montana (about $4 billion) to that of the US (about $1.4 trillion). Montana's budget is much smaller than that of many Federal agencies, but few in Montana would characterize our budget, which is 3% of national budget, as insignificant. Similarly, farmers and businessmen appreciate that the amount of money in the bank, or in the field, or in stock differs widely on a daily, monthly, or annual scale. Just like comparing a small business budget to that of large corporation, the monthly financial budget for a retail business can tell a much different story than that of the annual budget. The same is very true for water. It is critical for in the discussion of budgets to examine the scope and scale, both temporal and spatial, of the budget and to appreciate the method as well the source of data used.

Large area budgets

In its 2004 report the U.S. Geological Survey (USGS) (Cannon and Johnson, 2004), estimated that, on an annual basis, 94% of groundwater and surface water withdrawn in Montana was for irrigation and 1% was for domestic purposes. Consumption of that water followed a similar pattern; irrigation consumed almost 96% of the water withdrawn and domestic use was about 0.2%. The report also points out that about 2.5% of all the water withdrawn is groundwater, the rest is surface water. On the scope of the entire state, on an annual basis, it appears that groundwater withdrawal or consumptive use, for any purpose, is a minor component of the budget. However, if the scale of the budget is changed, the importance of groundwater can drastically change. Consider the global scale of water storage: only 2.5% of all the water on the planet is fresh, almost 69% of that fresh water is inaccessible as ice. Of the remaining, useable water, 99% is available as groundwater and only 1% is surface water.

Exempt wells - the big picture (?)

Montana total withdrawal (million gallons per day)

Surface water = 10,480 (97.5%)

Groundwater = 272 (2.5%)

Groundwater uses (million gallons per day)

Irrigation	=	140	(52%)
Public water	=	65	(24%)
Industrial	=	32	(12%)
Exempt (domestic)	=	22	(8%)
Exempt (stock)	=	12	(4%)

Source:
Cannon and Johnson (2004)

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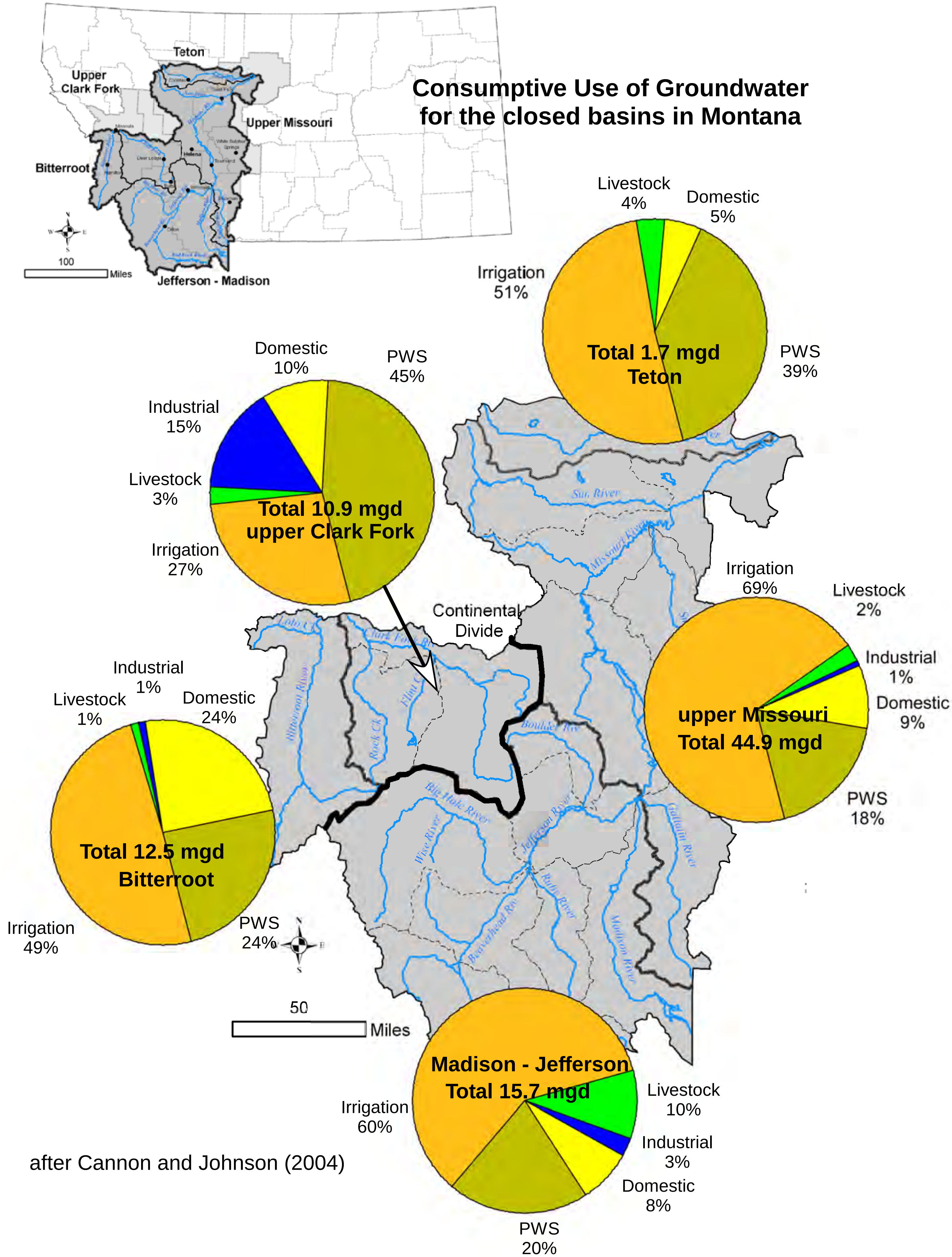
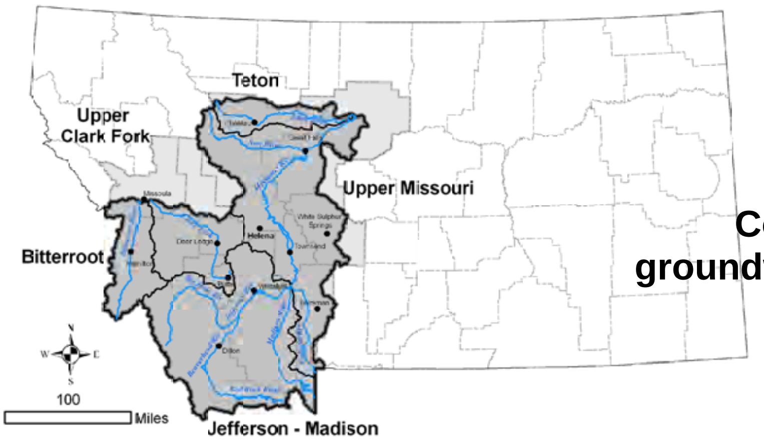


after Cannon and Johnson (2004)

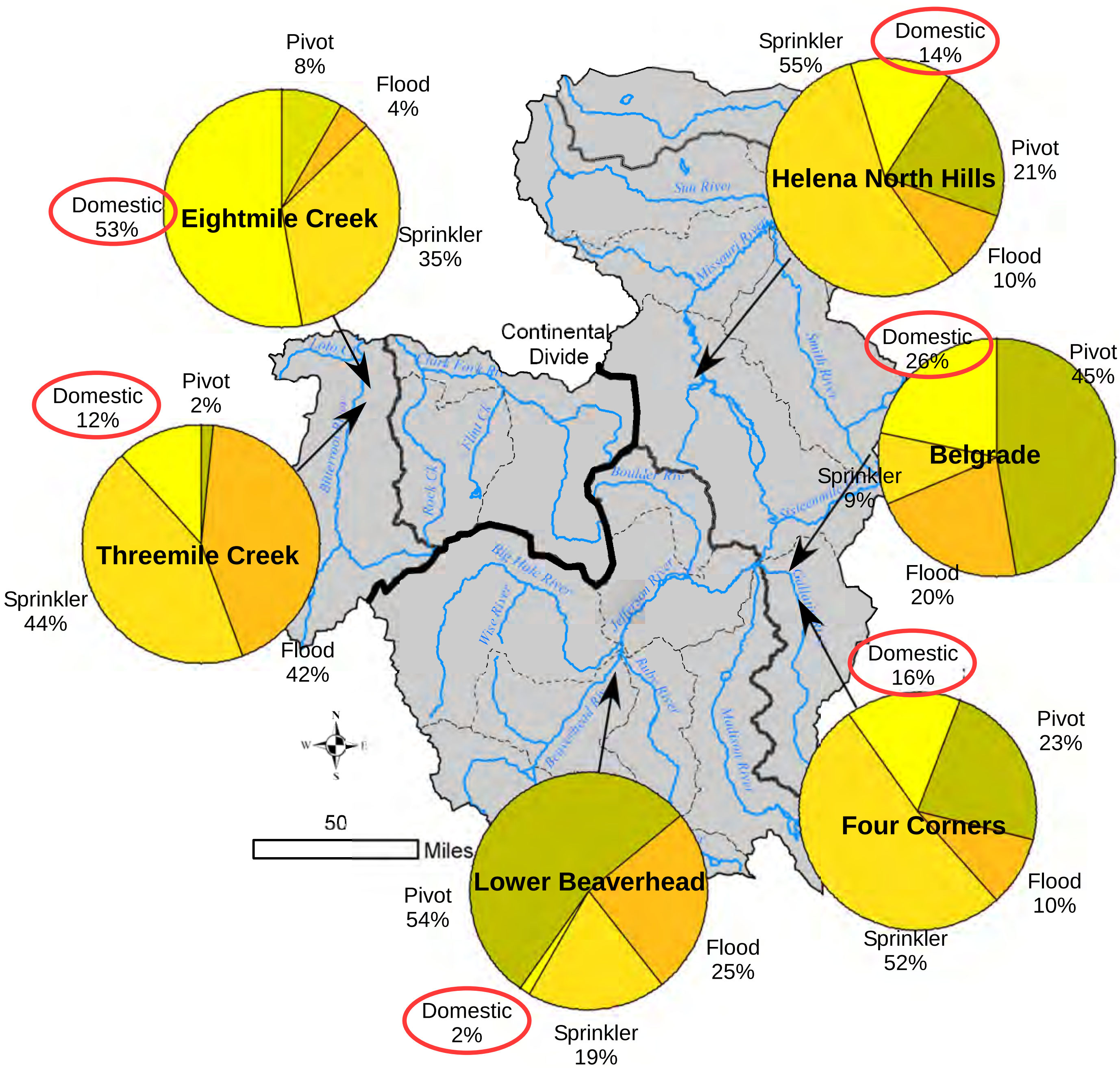
Groundwater consumptive use

Consumptive use is water removed from the hydrologic system without replacement or return. Water consumed use by plants, known as transpiration, and evaporation from the soil and surface water bodies are the largest consumptive use activities; plant transpiration and soil evaporation is typically termed evapotranspiration. Estimates of the evapotranspiration component of a water budget is typically taken as the consumptive use.

As noted, The USGS estimates that 2.5% of all the water withdrawn in Montana, on an annual statewide basis, is groundwater. Within that 2.5%, irrigation accounts for at least half of the groundwater consumed in four of the five basins in southwest Montana. Domestic consumption of groundwater accounts for less than 10% in all but one basin. Note: the USGS report assumed that all water withdrawn for domestic use was consumed.



Consumptive use of groundwater and surface water in 6 sub-basins



Consumptive use (surface water and groundwater) at the sub-basin scale

Method: Consumptive use for domestic is largely attributed to water applied to lawns; in-house consumptive use is small. In this analysis, the in house consumptive use is considered zero; that is, domestic consumptive use is attributed entirely to lawns. Consumptive use of both surface water and groundwater was estimated for each of six MBMG Ground Water Investigation Program areas for each of the three agriculture land-use categories and for domestic/lawn land use. The monthly crop-water demand multiplied by the area irrigated by each method determined the consumption. Crop-water demand data for each area was obtained from the local AgriMet station (US Bureau of Reclamation: www.usbr.gov/gp/agrimet) for the 2010 water year; alfalfa was used to represent agricultural use and lawn was used to represent domestic use. The area of each agricultural application was determined from GIS coverages (MT Department of Revenue via Montana State Library's Natural Resource Information System, http://nris.mt.gov/gis/). The area assigned to domestic was determined from air photos showing late summer or fall irrigation for a randomly selected 10% of the total number of lots in the sub-basin. Where data were available, the average irrigated area for domestic use estimated from the air photos for the entire area was compared to data from local subdivisions.

The pie charts present the total annual consumptive use by each land use type. At this scale, with project sub-basins ranging from 7,000 to 78,000 acres, the impact of domestic wells used for lawn irrigation is markedly different from that presented at a statewide scale. The table presents the total acreage of the study area, the average irrigated area per domestic well along with the total acreage of lawns in the study area, and the total irrigated acreage of agriculture land in the study area.

Project	Total Acreage*	Irrigated acreage: lawns (average lawn / total)	Irrigated acreage: agricultural
L Beaverhead	78,000	0.5 / 450	29,000
Four Corners	12,000	0.8 / 635	3,500
Belgrade	31,000	0.61/ 1100	4,000
Helena	19,000	0.23/ 475	3,000
Eightmile	7,000	0.91/ 600	500
Threemile	19,000	0.89/ 800	5,600

* values are approximate and based on each study area boundary

The Helena (North Hills) project area included several subdivisions with public water supplies. In their evaluation of the water budget, Waren and Bobst (2010) determined a consumptive use equivalent to 0.25 acres irrigated. This compares well to the 0.23 acres determined by the method used here. Similar comparisons showed good agreement in the lower Beaverhead and Belgrade.

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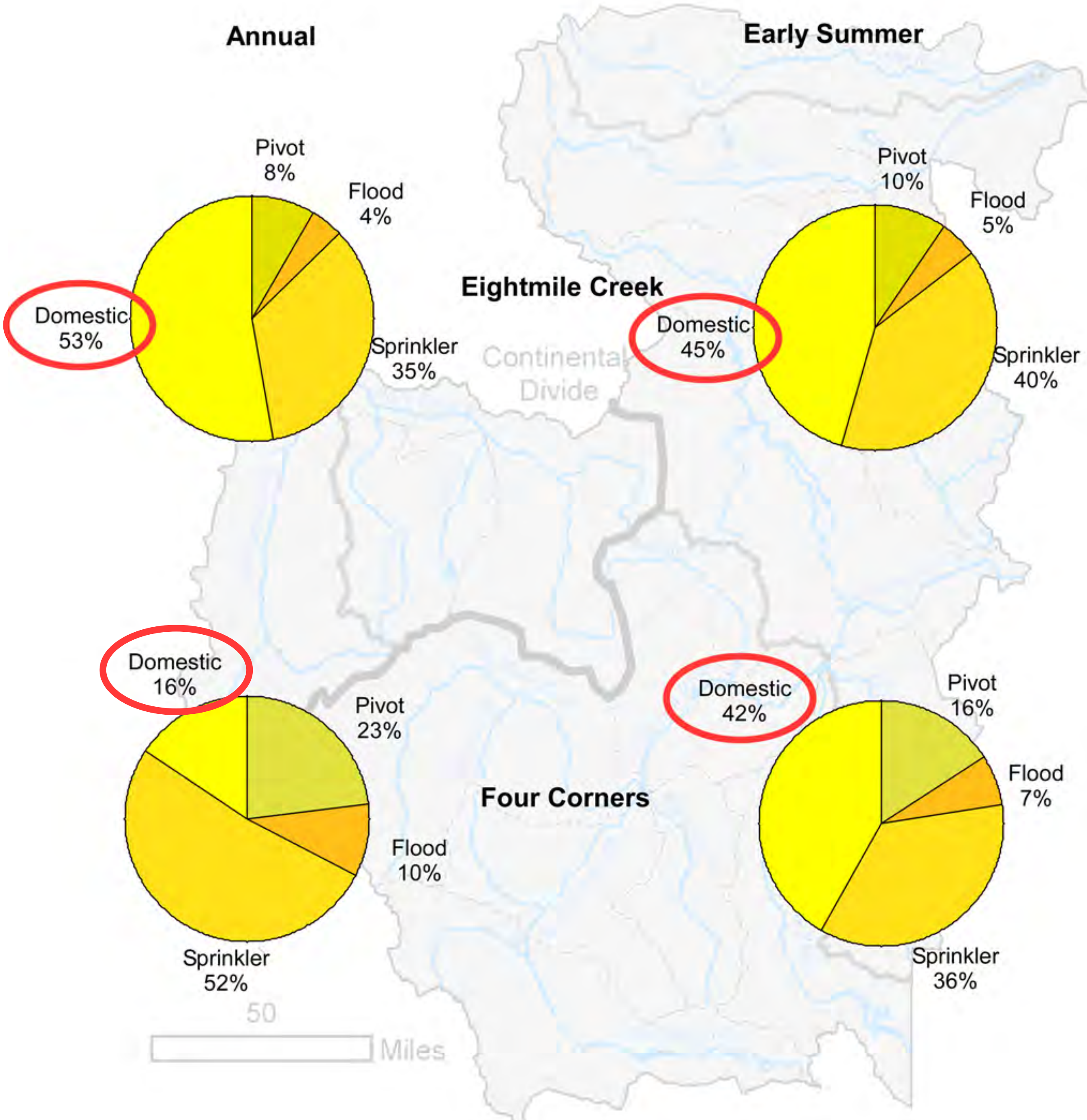
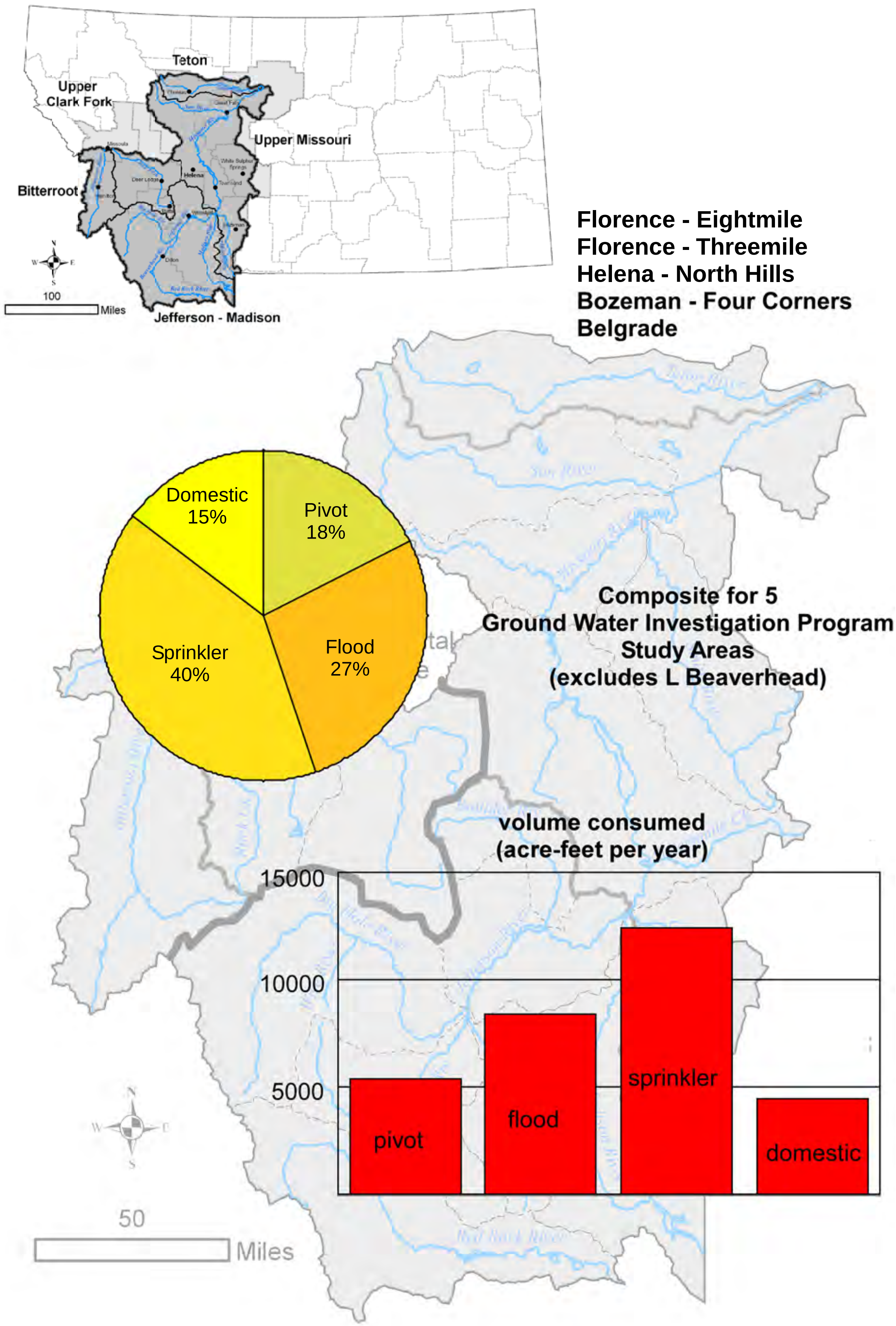
**Comparison of
annual consumptive use
to early summer consumptive use**



The importance of the temporal scale

Water budgets are most often presented on an annual basis; generally the changes in the hydrologic system respond to the annual cycle of climate. Consumptive use, particularly by human activities can vary significantly on a daily or monthly basis, depending on local conditions, and the activity. Overall, consumptive use by lawns in the six study areas showed the greatest variance on a monthly basis, but there did not appear to be correlation with domestic well density. Of course, with the exception of the lower Beaverhead, all the study areas were focused in areas of high domestic well density.

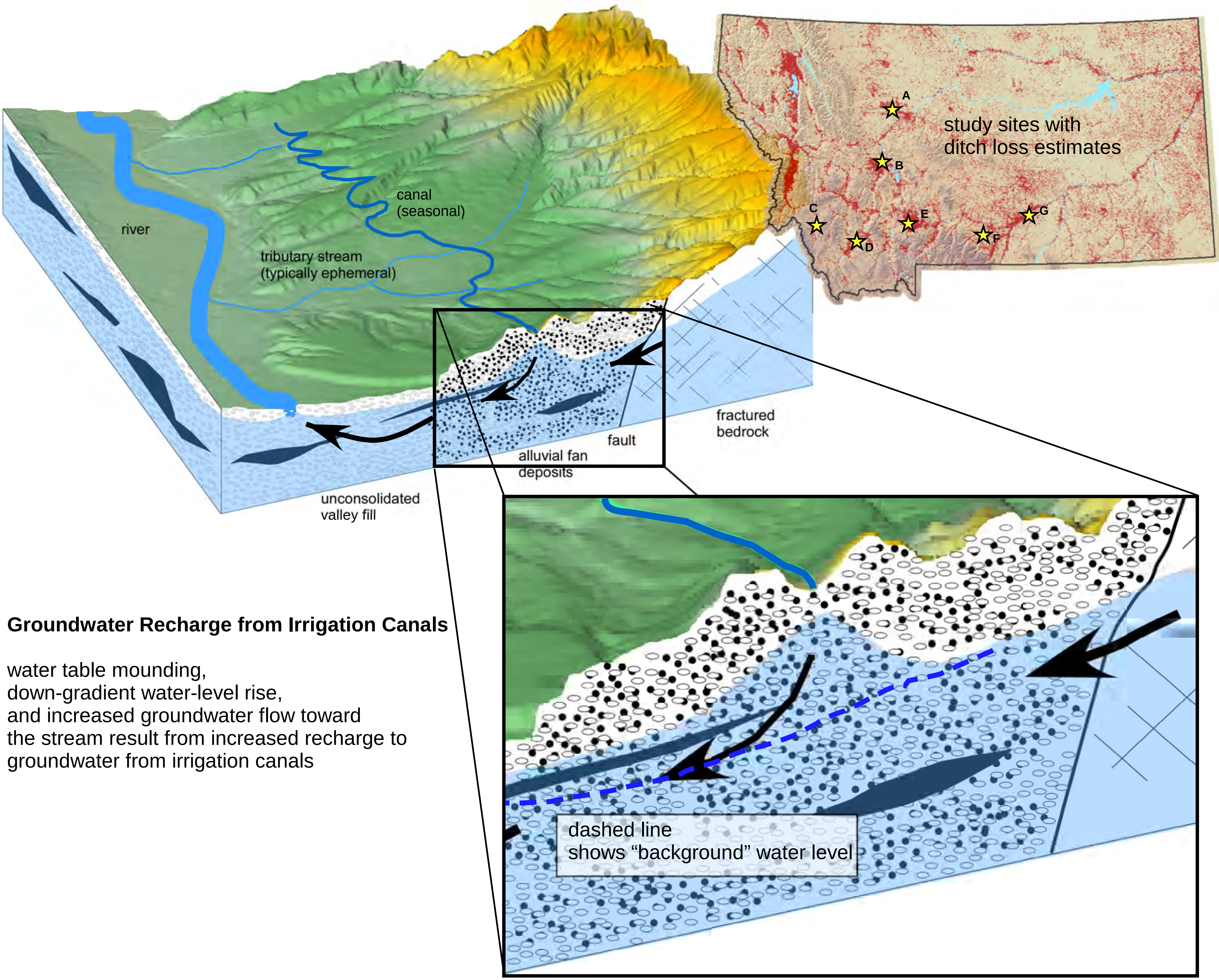
The pie charts compare the annual consumptive use to an early summer, monthly consumptive use. In Eightmile Creek the peak consumptive use month did not vary much from the annual, but in the Four Corners area, there is considerable difference. These differences, when identified, can used to manage water use more effectively during the months of high demand and low supply.



Teton
Upper Clark Fork
Upper Missouri
Bitterroot
100
Miles
Jefferson - Madison
Florence - Eightmile
Florence - Threemile
Helena - North Hills
Bozeman - Four Corners
Belgrade
Domestic 15%
Pivot 18%
Sprinkler 40%
Flood 27%
Composite for 5
Ground Water Investigation Program
Study Areas
(excludes L Beaverhead)
volume consumed
(acre-feet per year)
15000
10000
5000
pivot
flood
sprinkler
domestic
50
Miles

Summary of study area budgets

A composite of data for the five sub-basins shows that domestic lawn use accounts for 15% of the annual consumptive use. This is much higher than the 0.2% consumptive use based on a statewide average. That is not to say the data or analyses of the data are in conflict; it demonstrates the importance of the scale of observation. Data collected and analyzed for local conditions in a sub-basin will likely reveal potential issues sooner than those of the basin scale.



Groundwater Recharge from Irrigation Canals

water table mounding,
down-gradient water-level rise,
and increased groundwater flow toward
the stream result from increased recharge to
groundwater from irrigation canals

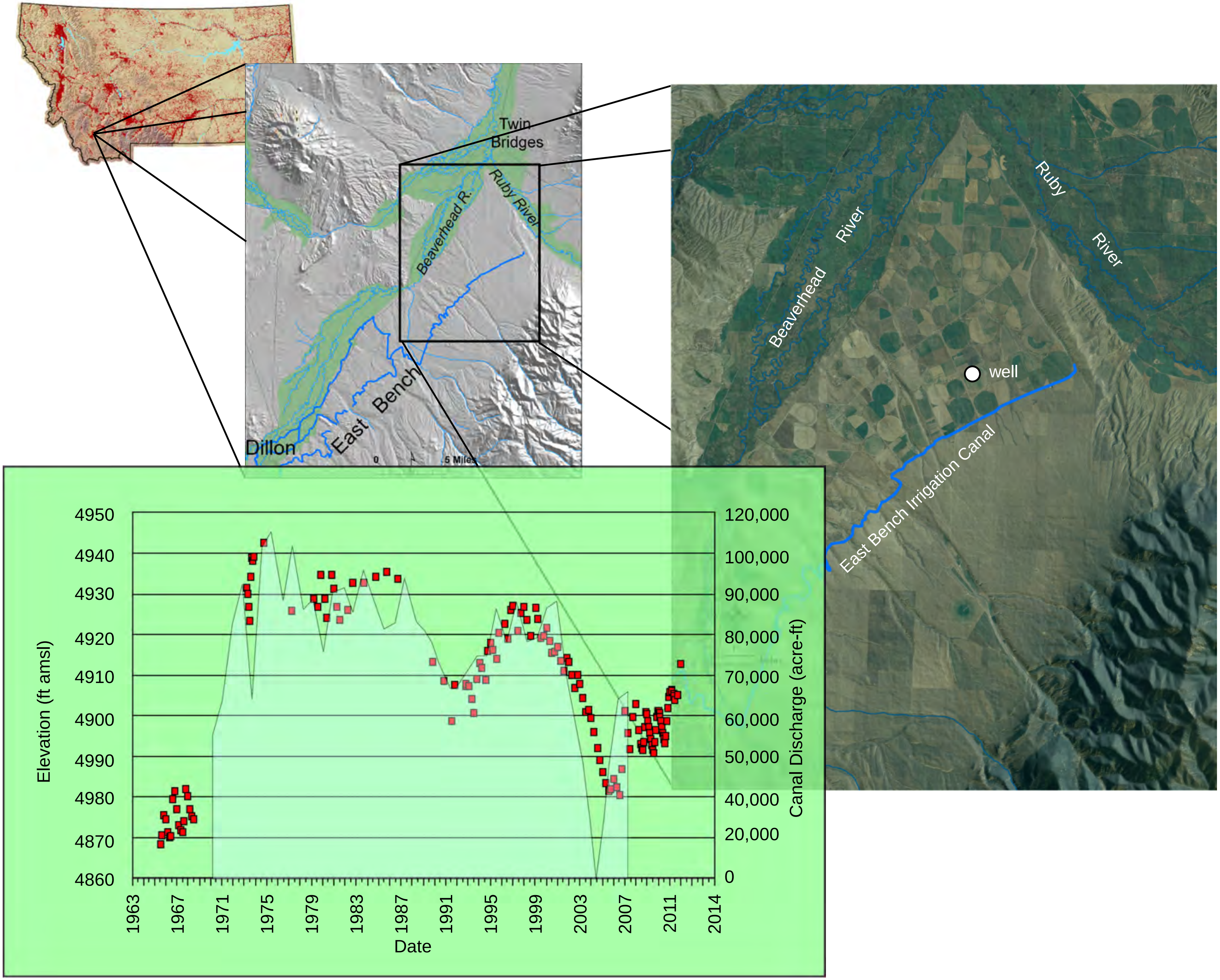
Altered watersheds

Montana has more than 3000 miles of irrigation canals that carry 11.6 million acre-feet to irrigate about 2.2 million acres of crop and pasture on an annual basis. Crop water demand ranges from 1 to 3 acre-feet per year (Bauder and others, 1983); the average consumptive use rate for all crops and pasture is about 1.2 acre-feet per year (Cannon and Johnson, 2000). Thus, on an average annual basis, almost 9 million acre-feet of the 11.6 million acre-feet, or 77%, of the water diverted for irrigation is available for return flow as surface water or recharge to groundwater. The table shows the ditch loss reported by MBMG investigations throughout the state.

Map reference: source	Ditch loss (cubic feet per second per mile)	Ditch loss (acre-feet per year per mile)*
A: Osborn and others (1983)	0.45 – 4.7	81 – 850
B: Madison (2006)	0.6	114
C: Abdo and Metesh (2005) Abdo and Roberts (2008)	0.15 – 1.5	27 – 271
D: Abdo and others (2012)	2.2	398
E: Michalek and others (2012)	0.40 – 4.3	72 – 778
F: Kuzara and others (2012)	1.1 – 1.8	199 – 326
G: Olson and Reiten (2002)	0.05 – 0.5	9 – 90

*assumes the ditch is active 3 months per year

The local ground-water recharge from irrigation ditch loss often overwhelms the natural recharge processes. For example, the East Bench Irrigation Canal in the lower Beaverhead River has the potential to add as much as 398 acre-feet per season; with a length of about 17 miles between Dillon and Beaverhead Rock, the seasonal ditch loss would be about 6,800 acre-feet. This is, of course, in addition to recharge from direct flood irrigation.



Twin Bridges
Ruby River
Beaverhead R.
East Bench
Dillon
0
5 Miles
Ruby
River
Beaverhead
River
well
East Bench Irrigation Canal
Elevation (ft amsl)
Canal Discharge (acre-ft)
Date
4950
4940
4930
4920
4910
4900
4990
4980
4870
4860
120,000
100,000
90,000
80,000
70,000
60,000
50,000
40,000
20,000
0
1963
1967
1971
1975
1979
1983
1987
1991
1995
1999
2003
2007
2011
2014

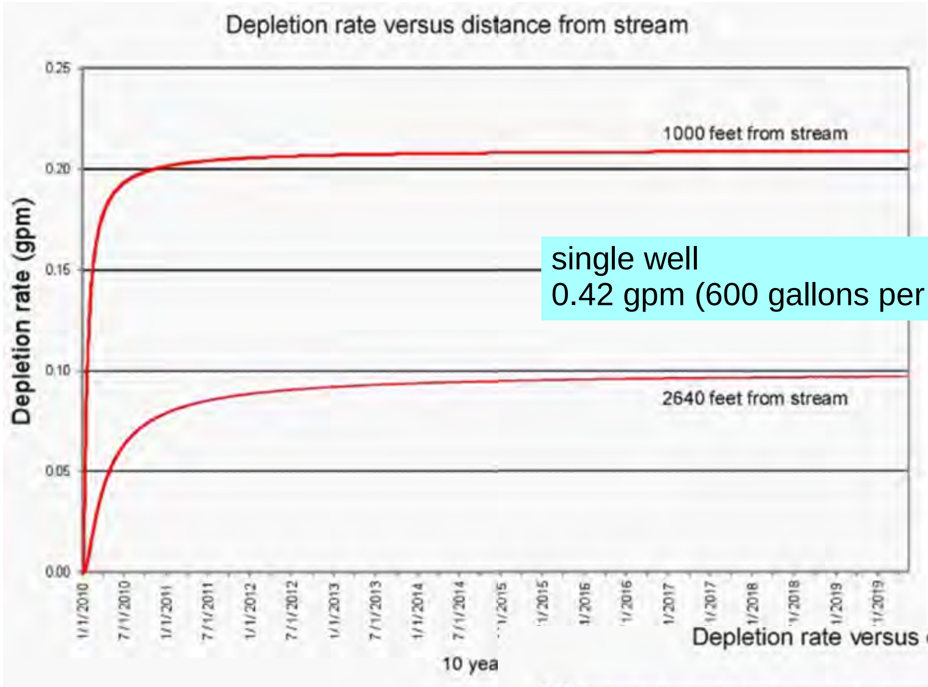
Effects of irrigation canals on ground-water levels

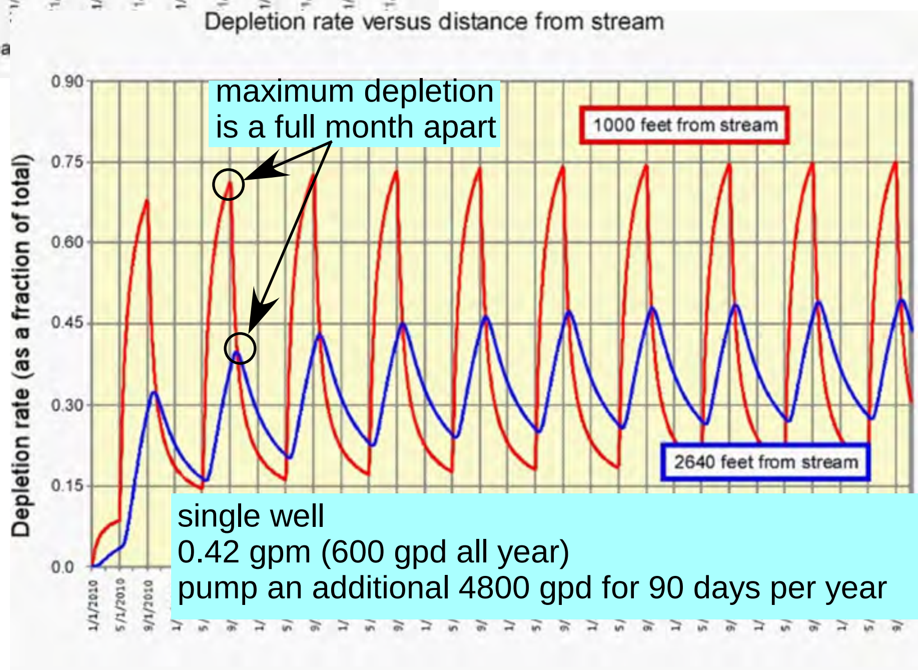
There are few, if any, natural groundwater flow systems in western Montana. Nearly all of the intermontane valleys are irrigated and sub-irrigated (recharged) by surface water diversions. Changes in surface water diversions used to offset groundwater development will certainly affect this new equilibrium. At some point in time, an artificial recharge system becomes the new baseline and there are several examples of wetlands and groundwater dependent ecosystems that rely on irrigation return flows.

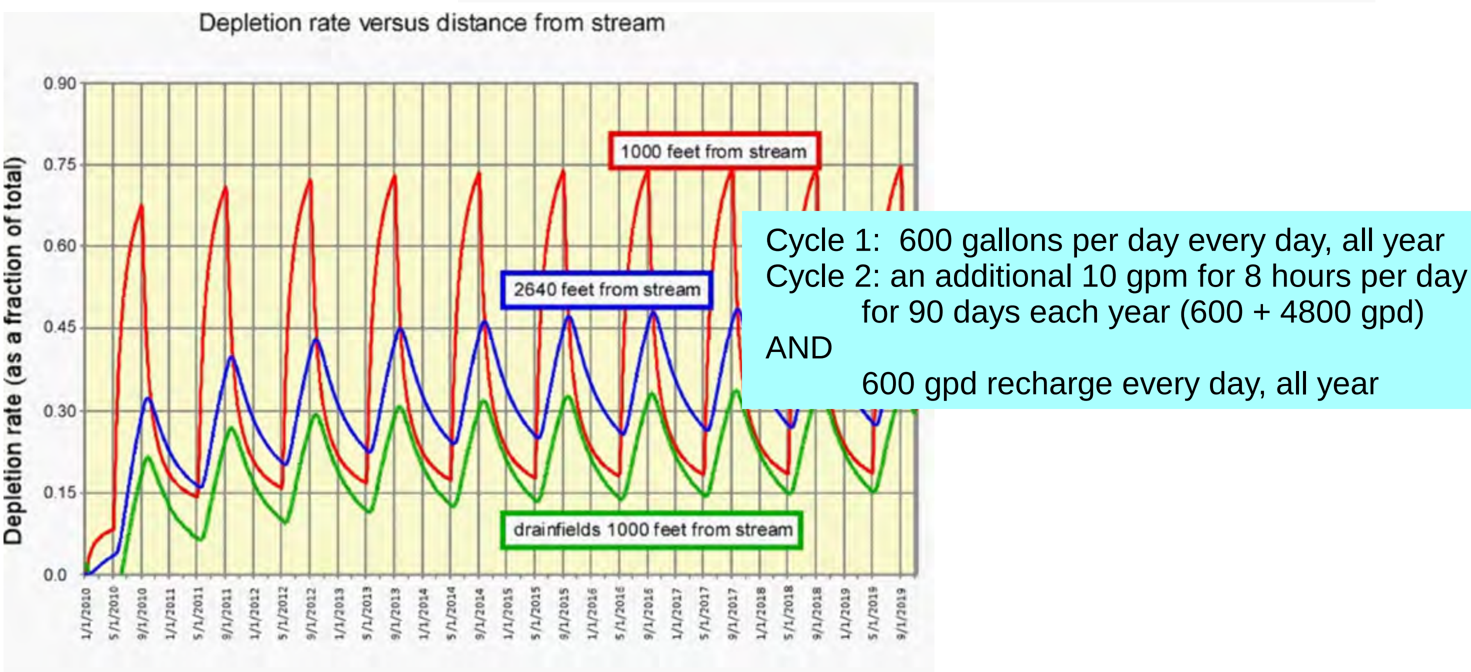
The hydrograph shows water levels in a well within the influence of the East Bench Irrigation Canal in the lower Beaverhead River drainage. The water-levels (red squares) show a 40 foot rise in response to flow in the canal; even after several decades of operation, one about two years of inactivity (2003 through mid-2005) resulted in at least 6 feet of water-level decline.

Similar water-level responses to irrigation canals have been observed throughout the state. Waren and Bobst (2012) observe a 15-to 20-foot response near the Helena Valley Irrigation District canal, Kuzara and others (2011) observed an 18-foot response in the Stillwater River drainage.

As land use changes from one type of irrigation to another or from irrigation to domestic, recharge to the local ground-water flow system is likely to be affected. Water levels in wells may decline, even to the point of wells going dry, groundwater flow to tributary streams and wetlands can be reduced, and the effects of stream depletion by existing pumping projects can be exacerbated.


Depletion rate versus distance from stream
Depletion rate (gpm)
1000 feet from stream
2640 feet from stream
single well
0.42 gpm (600 gallons per day)
10 yea

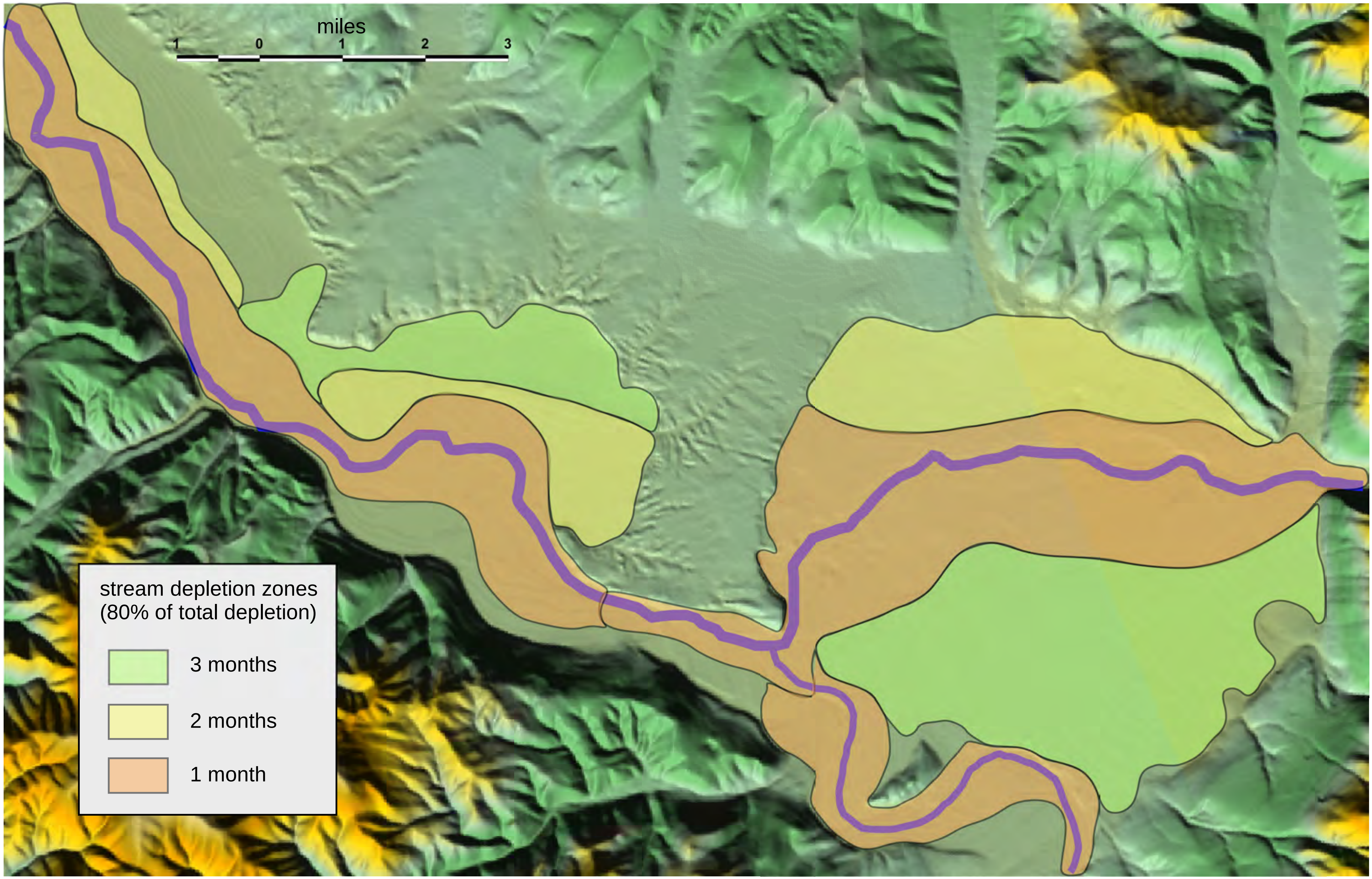

Depletion rate versus distance from stream
Depletion rate (as a fraction of total)
maximum depletion
is a full month apart
1000 feet from stream
2640 feet from stream
single well
0.42 gpm (600 gpd all year)
pump an additional 4800 gpd for 90 days per year


Depletion rate versus distance from stream
Depletion rate (as a fraction of total)
1000 feet from stream
2640 feet from stream
drainfields 1000 feet from stream
Cycle 1: 600 gallons per day every day, all year
Cycle 2: an additional 10 gpm for 8 hours per day
for 90 days each year (600 + 4800 gpd)
AND
600 gpd recharge every day, all year

Stream depletion by one well or many

From a mass balance point of view, there is no difference between pumping from one or many wells; one well pumping at 1,000 gallons per minute (gpm) is equivalent to 100 wells pumping at 10 gpm. From the stream depletion point of view, the location of the well(s) can be very important. Stream depletion is ultimately equal to the discharge rate of the well as it relates to the periodicity of that discharge. For example, pumping 400 gpm for 3 of every 12 months will establish a depletion rate of 100 gpm. Stream depletion is independent of stream discharge; the 100 gpm depletion in the example will be the same whether the stream discharges 1000 cfs or 10 cfs – unless the stream runs dry, of course. The ultimate depletion is independent of distance from the stream, but, the rate and timing of depletion is very dependent on distance, aquifer properties (transmissivity and storage coefficient), as well as the pumping rate.

The figures examine how the placement of the well(s) and other factors such as septic drain fields can be used to manage stream depletion. The top figure shows the effect of placing a well pumping at a constant rate farther from the stream; 600 gallons per day (gpd) is commonly reported as the in-house use. The second figure shows the effect of diverting a constant 600 gpd and cyclical pumping for lawn irrigation for 90 days each year. All else (aquifer properties and discharge rate) being constant, moving the well from 1,000 to 2620 feet away from a stream changes the stream depletion peak by a full month. That is, instead of depleting the stream during critical flows in August every year, it could be delayed until September when stream flows are not as low. The third figure shows stream depletion rates for a case where the well is 2,460 feet from the stream, but the septic drain fields are 1,000 feet from the stream. This would be the case where a single public water supply well replaced the individual domestic wells in a subdivision 1,000 feet from the stream, with each household maintaining an individual septic system. In this example, moving the supply well away from the stream and using near-stream recharge from the drain field to offset consumption reduces stream depletion by 60 to 75% in a given year.


miles
1
0
1
2
3
stream depletion zones
(80% of total depletion)
3 months
2 months
1 month

Stream depletion zones

As discussed, stream depletion it affected by aquifer properties, the discharge of the well, and the distance of the well from the stream. Using data from hydrogeologic studies and establishing representative or anticipated values for well discharge, the rate and volume of stream depletion can be mapped.

The figure shows an example of a map where zone of stream depletion were estimated for various areas in the aquifer near the stream. The hydraulic conductivity and storage coefficient of the aquifer were used to map areas where stream 80% if the total depletion would occur within 1 month, between 1 and 2 months, and within 3 months at a specific pumping rate.

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