

# Selected Groundwater Budget Components for the Billings Aquifer

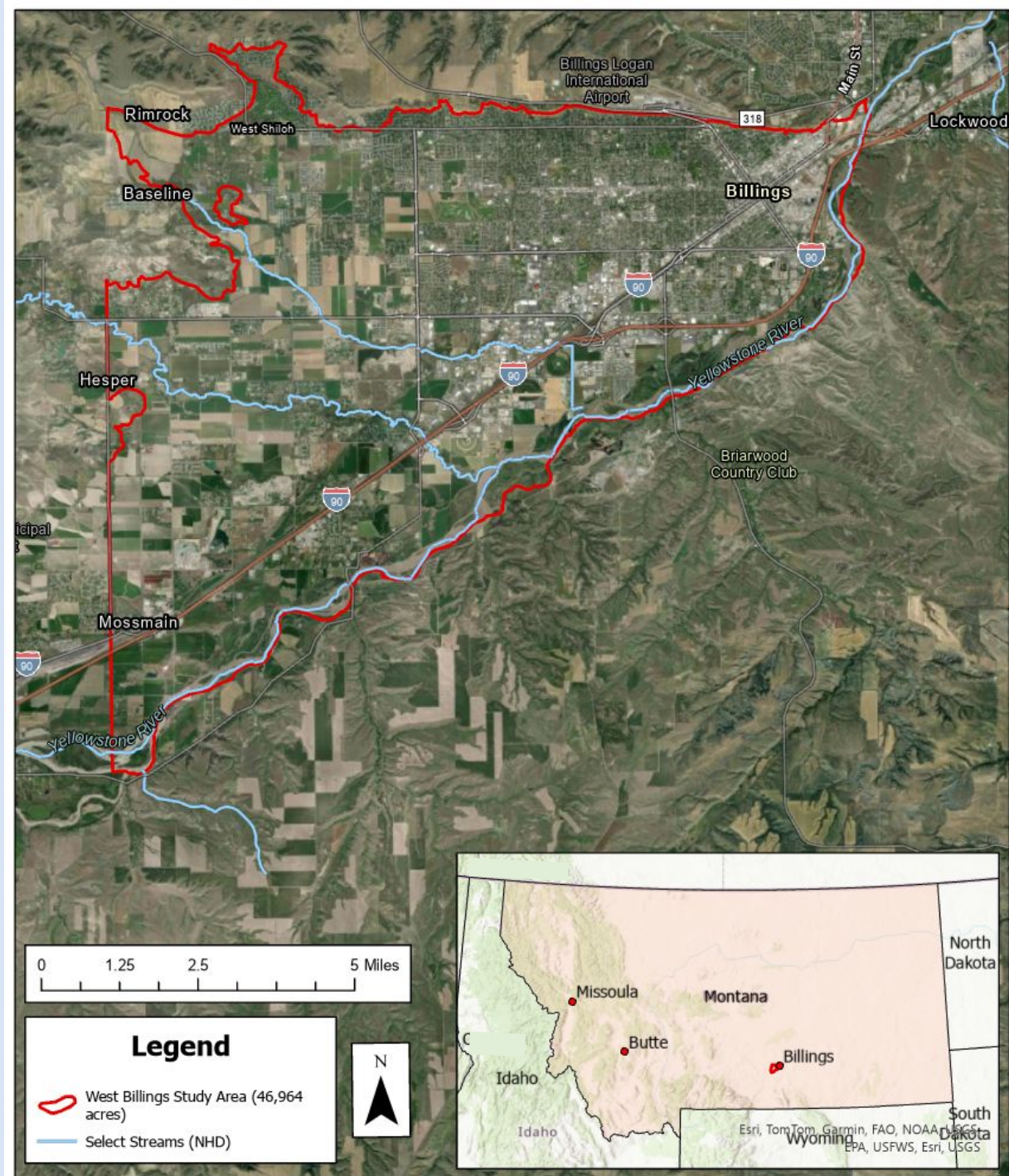
The Montana Bureau of Mines and Geology



Photo: BBWA  
Don Sasse

# Outline

- Project Overview
  - Motivation to study the Billings aquifer
  - Physical character of the aquifer
- Selected Components of the Water Budget
  - Ditch loss
  - Wetland & riparian evapotranspiration (ET)
  - Consumptive well use
  - Darcian Flux



# Motivation

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WSJ NEWS EXCLUSIVE

## Montana Boomtown Jumps to No. 1 on WSJ/Realtor.com Housing Market Index

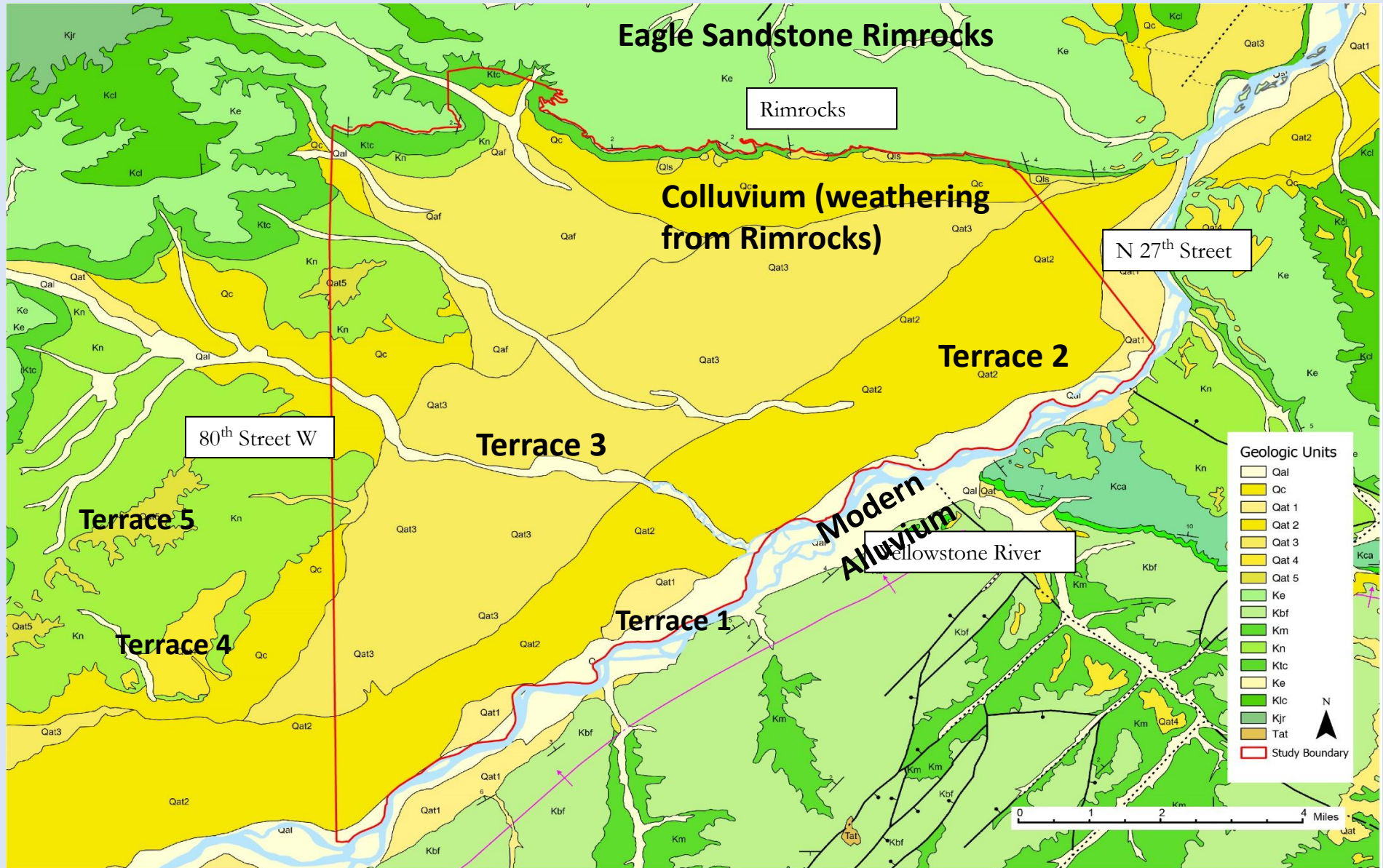
Rankings show how the housing boom has ignited homebuying in smaller to midsize cities around the U.S.

By *Nicole Friedman* [Follow](#) | *Photographs by Louise Johns for The Wall Street Journal*

July 20, 2021 5:30 am ET

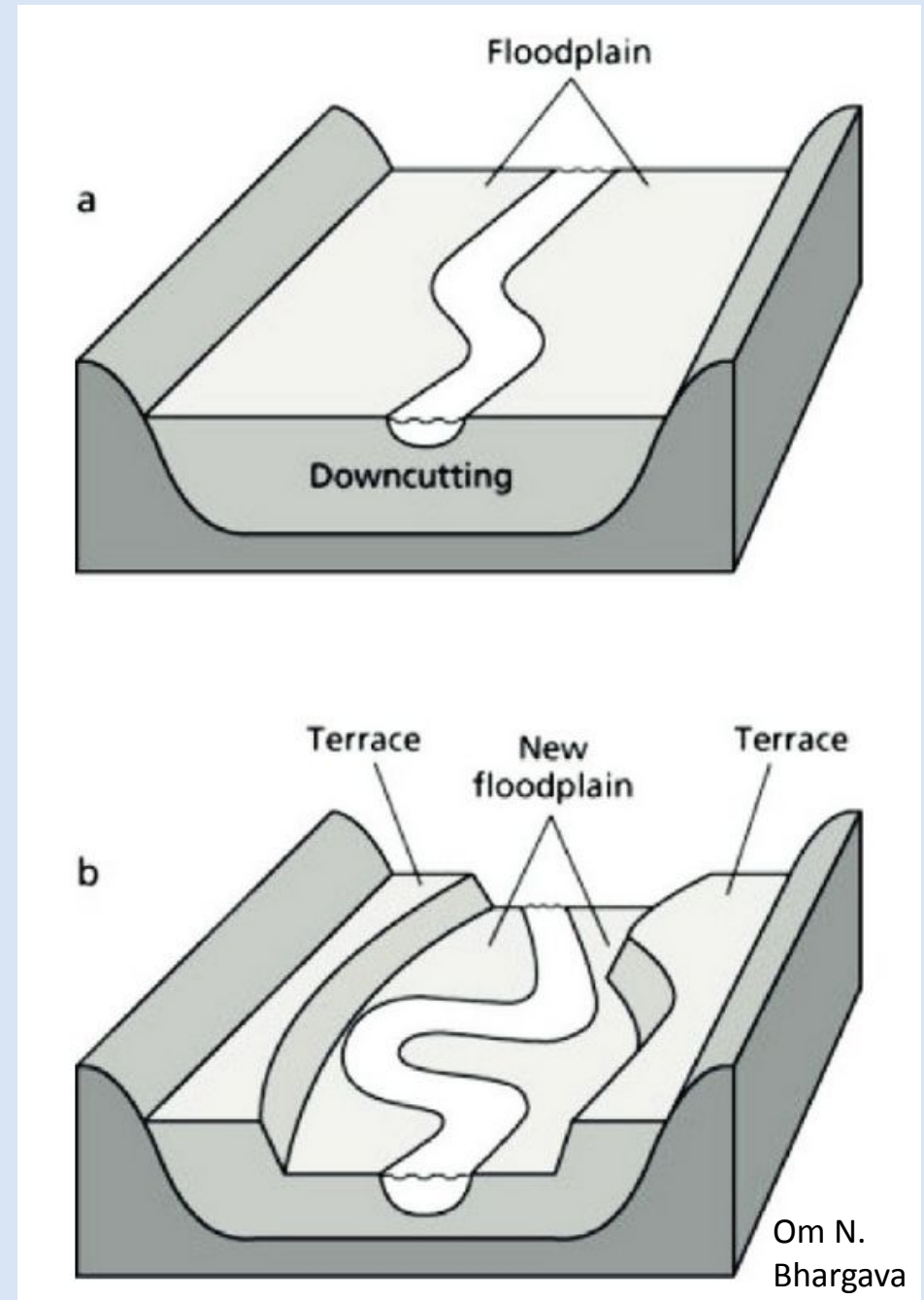
Billings, Mont., is the new No. 1 on The Wall Street Journal/Realtor.com Emerging Housing Markets Index, boosted by its affordability and appeal to remote workers.

# Billings Geology



# Terrace Formation

- Terrace formation occurred as the Yellowstone River incised quaternary sediments and formed meanders across the floodplain to widen the terrace surfaces
- Coarse grained sands and gravels of the terraces form the modern Billings Aquifer
- Average saturated thickness: ~15 ft



Om N.  
Bhargava

# The Water Budget

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## Inflows

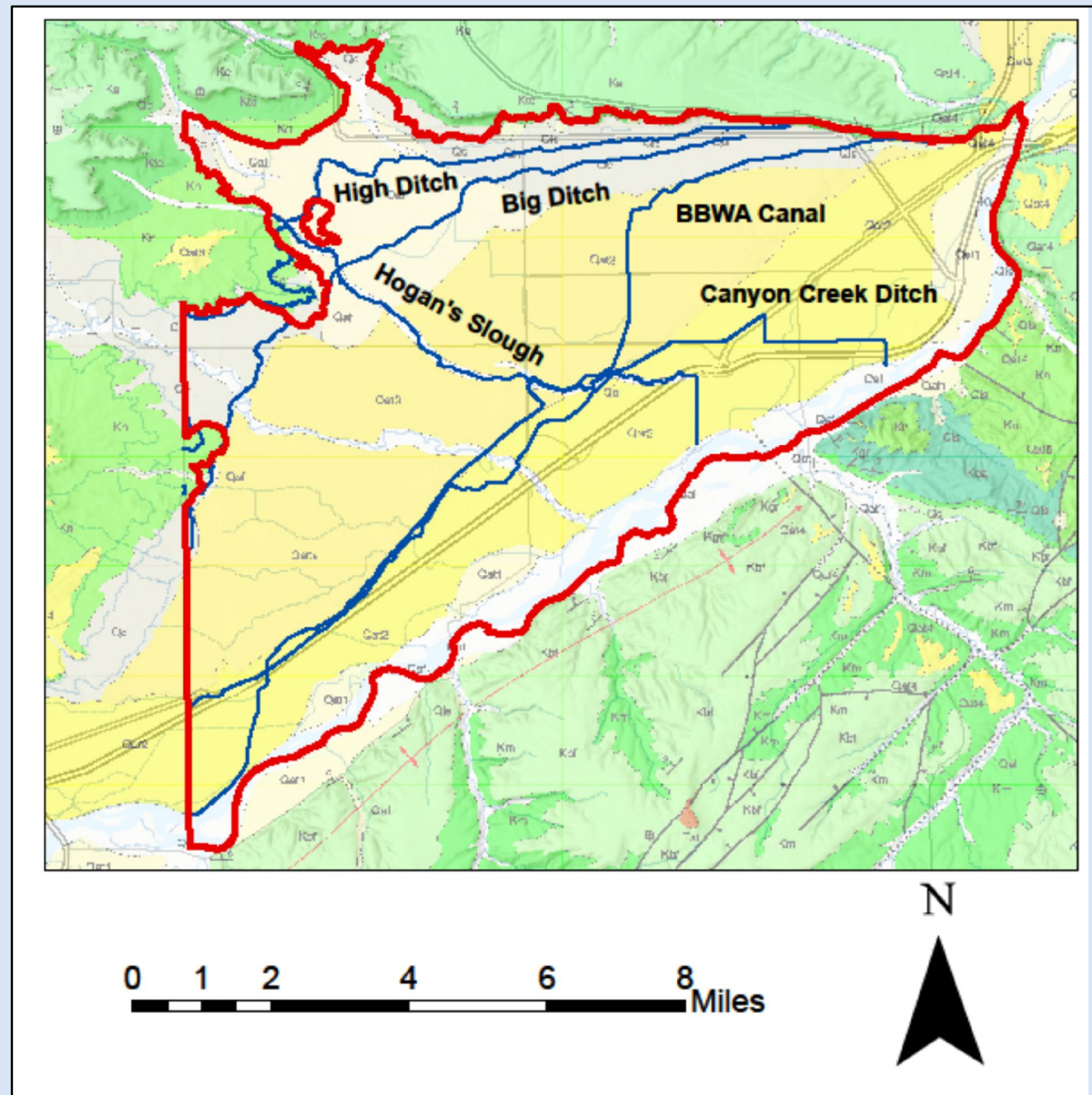
- Darcian flux
- Ditch loss
- Stream and drain loss
- Precipitation recharge
- Irrigation recharge
- Changes in storage

## Outflows

- Darcian Flux
- Consumptive well use
- Wetland and riparian evapotranspiration (ET)
- Changes in storage

# Ditch Loss

- Estimated using stage data for:
  - Billings Bench Water Association Canal (BBWA)
  - Big Ditch
  - Canyon Creek Ditch
  - High Ditch
- Assumptions
  - Homogeneous and isotropic aquifer
  - Canal fully penetrates the aquifer



# 2023 Ditch Loss (acre-ft)

Storativity	K (ft/day)	April	May	June	July	August	September	October	Total
0.008 (specific storage)	20	102	201	111	159	142	109	53	<b>900</b>
0.008 (specific storage)	90	216	425	235	337	301	231	111	<b>1900</b>
0.008 (specific storage)	200	322	634	351	503	449	344	166	<b>2800</b>
0.1 (specific yield)	20	360	709	392	562	502	384	186	<b>3100</b>
0.1 (specific yield)	90	763	1504	833	1192	1065	815	394	<b>6600</b>
0.1 (specific yield)	200	1138	2242	1241	1777	1587	1215	587	<b>9800</b>

# Wetland & Riparian ET

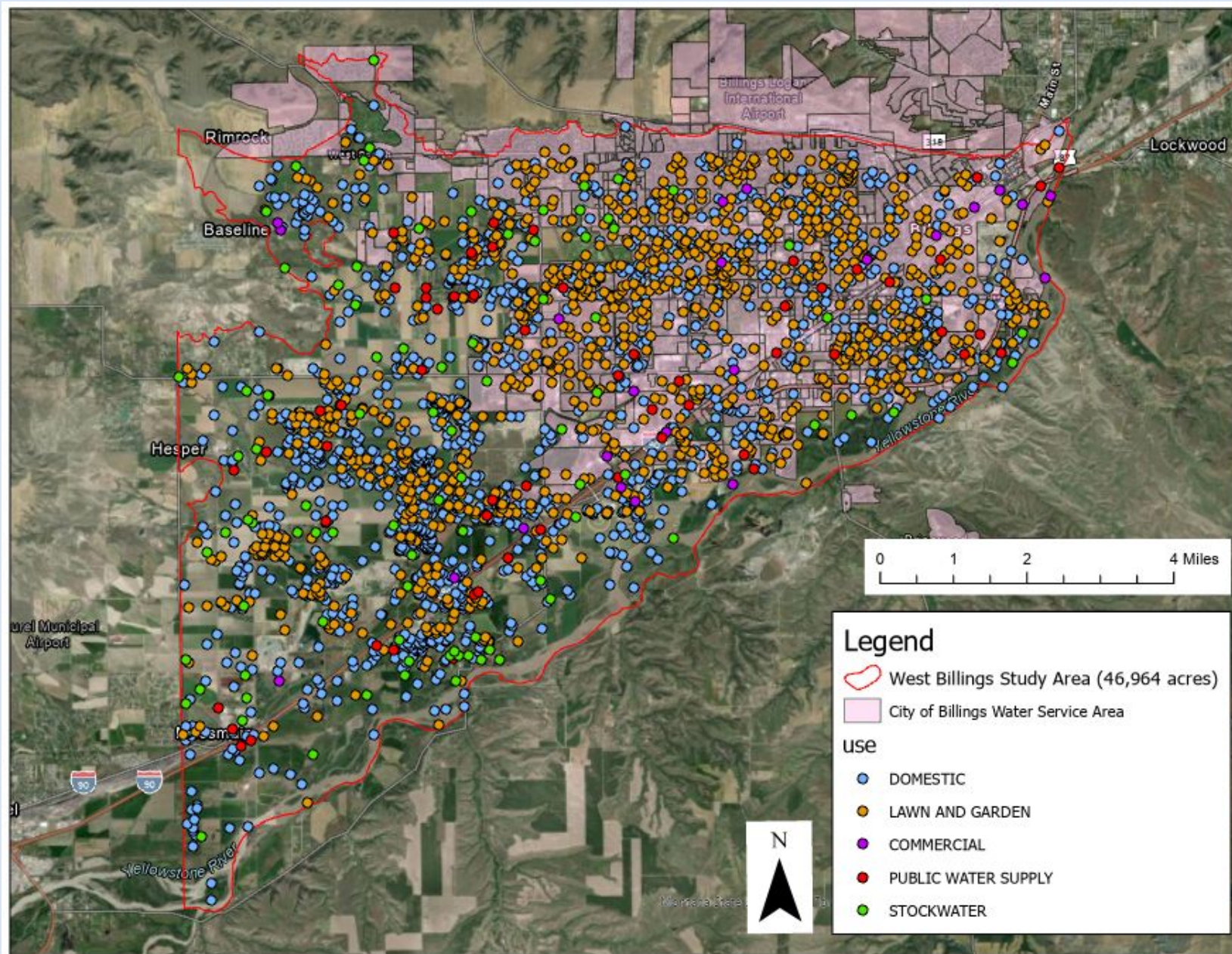
- Queried the OpenET model for monthly ensemble min, mean, and max ET in wetland and riparian areas between 2016 and 2023
- Calculated average ET on a monthly timestep

Month	Minimum ET [acre-ft]	Mean ET [acre-ft]	Maximum ET [acre-ft]
Jan	88.8	159.9	243.5
Feb	142.4	242.2	350.6
Mar	341.4	574.7	810.4
Apr	587.4	916.7	1238.5
May	1157	1535.3	1864.2
Jun	1759.8	2183.6	2544
Jul	1933	2308.8	2664.8
Aug	1452.3	1806.5	2150.1
Sep	858	1149.9	1438.9
Oct	400.6	627.8	861.5
Nov	114.7	294	498
Dec	48.1	175.4	320.6
<b>Total (acre-ft per yr)</b>	<b>9,200</b>	<b>12,100</b>	<b>15,000</b>

# Well Use

Wrote custom software to:

- Combine GWIC and DNRC water rights databases
- Identify domestic wells within City of Billings water services and only apply water use for lawn/garden irrigation
- Identify “improved” parcels outside of the water services area in the CADASTRAL database and apply domestic use for every parcel
- Perform a keyword search on commercial wells to identify the use (restaurants, aggregates, hotels, etc.)
- Match public supply wells with GWIC ID numbers to identify population served

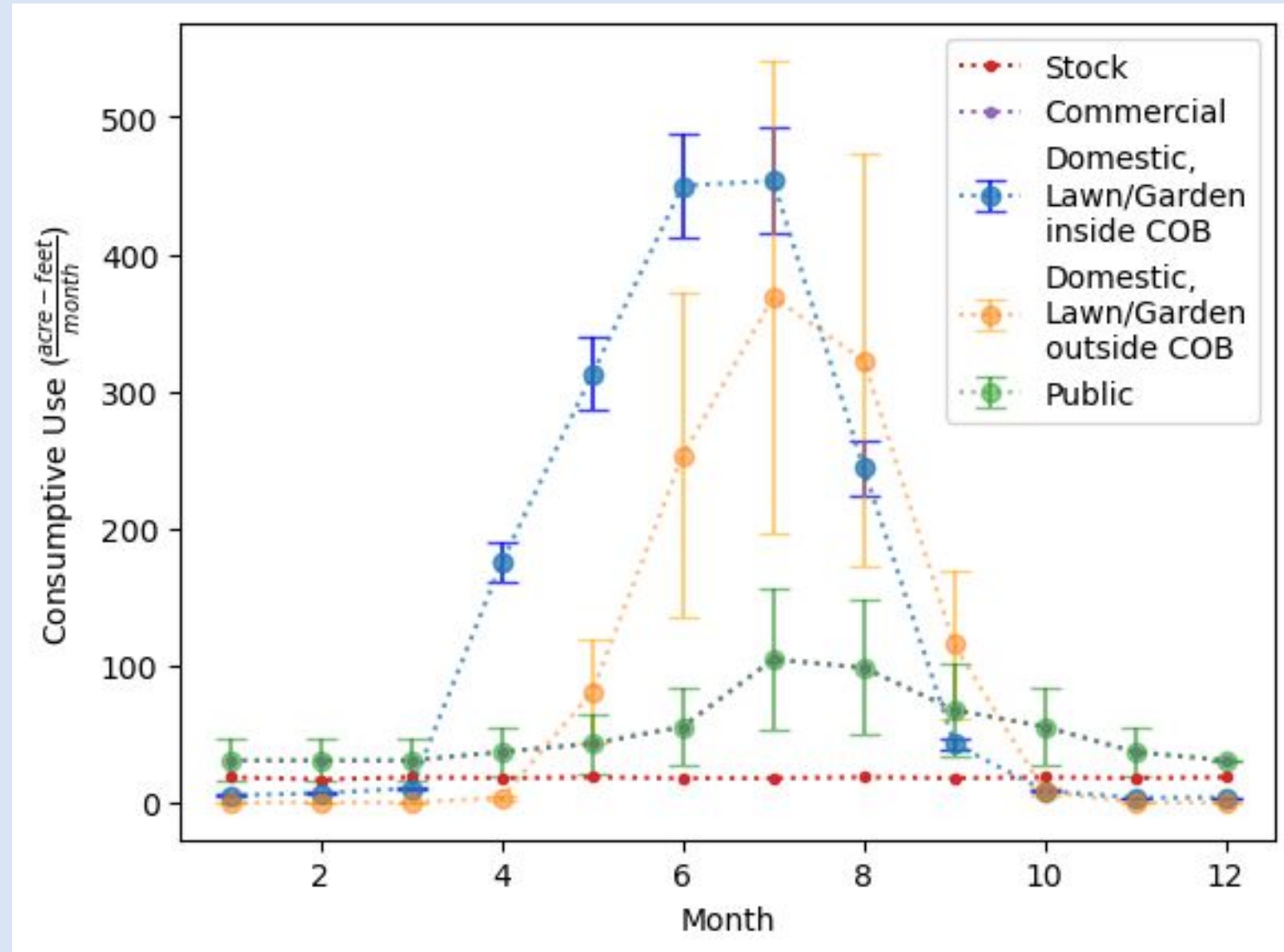


# Well Use

## Consumptive Well Use (95% C.I.)

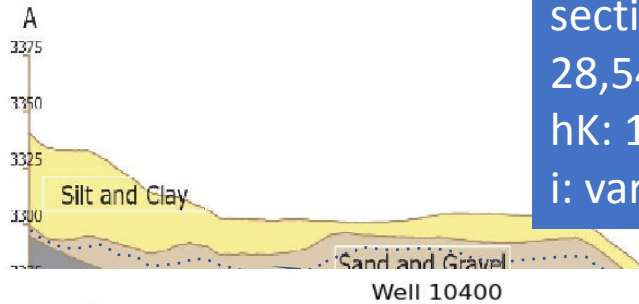
### Annual Consumptive Well Use:

- Min: 3,000 acre-ft/yr
- Mean: 3,700 acre-ft/yr
- Max: 4,200 acre-ft/yr



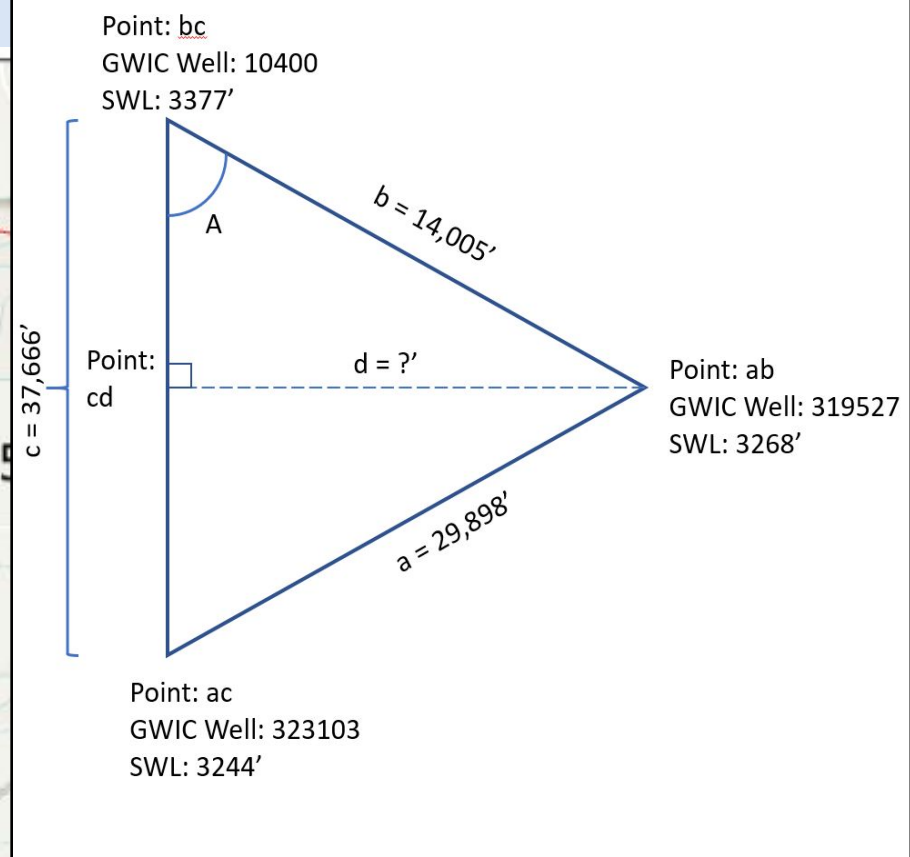
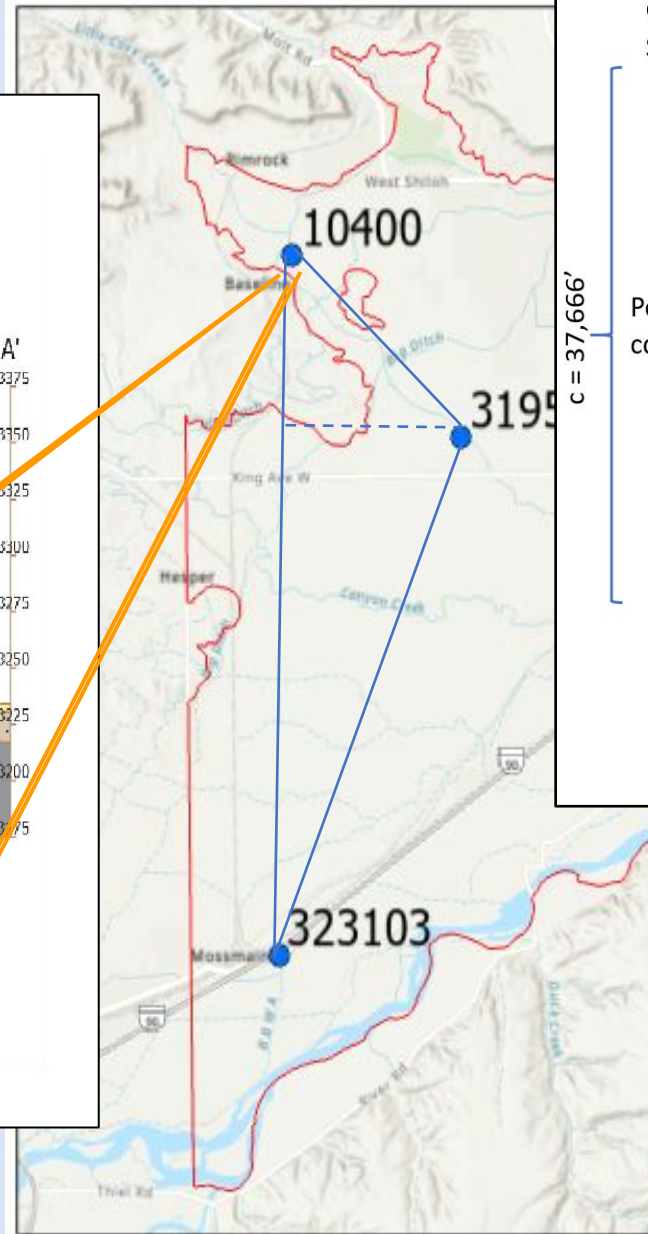
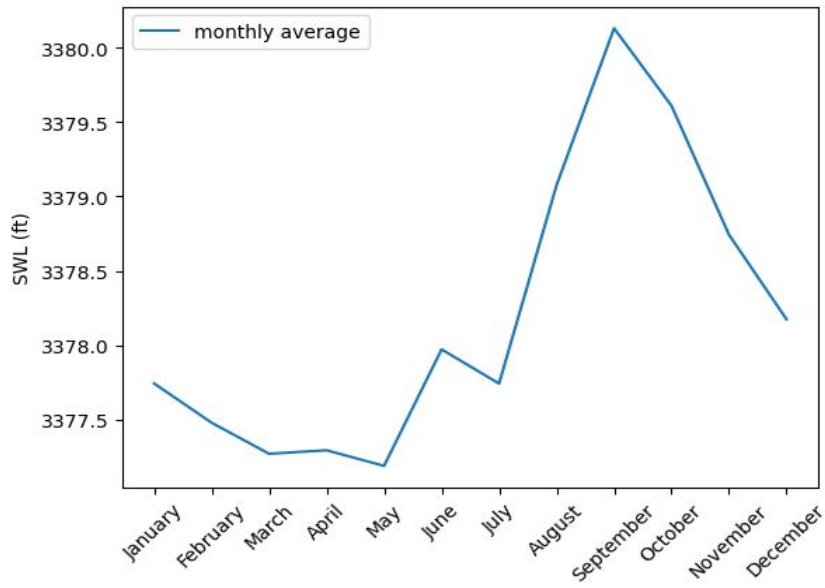
# Darcian Flux

Cross Section at 80th Street



Aquifer cross sectional area: 28,546,600 ft<sup>2</sup>  
 hK: 100 ft/d  
 i: varies by month

Well 10400



## Monthly Darcian Flux:

- $Q = K * i * A * \theta$ 
  - K: horizontal hydraulic conductivity
  - I: hydraulic gradient perpendicular to line c
  - A: cross sectional area of the aquifer
  - $\theta$ : Saturation of the aquifer

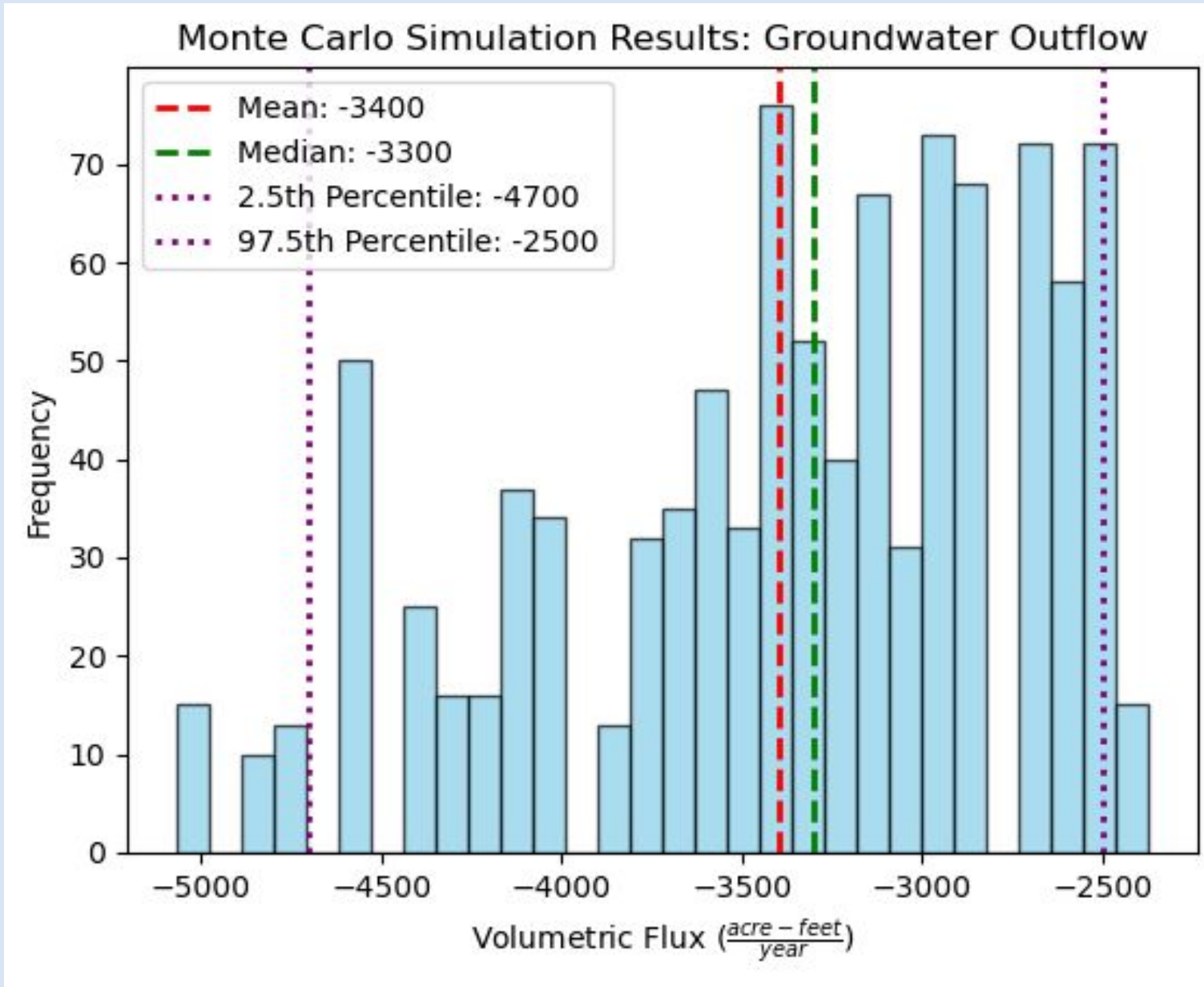
# Darcian Flux Uncertainty

## Monte Carlo Simulation:

- Found all possible bc, ac, and ab combinations for both inflow and outflow calculations
- Randomly selected 1,000 well combinations and solved the three point problem to calculate Darcian flux

Net Mean Darcian Flux:

**2,100 acre-feet per year**



# Selected Water Budget (Preliminary)

Component	Inflow (acre-feet per year)	Outflow (acre-feet per year)
Ditch Loss	900 – 9,800	
Evapotranspiration		9,000 – 15,000
Consumptive Well Use		3,000 – 4,200
Darcian Flux	400 – 2,900	2,500 – 4,700
Precipitation	3,600 – 12,200	
Irrigation Recharge	2,000 – 11,300	
Changes in Storages	--	--
Stream and Drain Loss	--	

# Billings Team

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Liddi Meredith



Kurt Zeiler



Skye Keeshin

Catch Kurt Zeiler's talk at 11:20 in session 5, modelling

# Ditch Loss Calculations

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$$Q = \frac{2s_0\sqrt{ST}}{\sqrt{\pi t}}$$

Eq. 1: constant drawdown line-source method (Ferris et al., 1962)

$Q$ : discharge from the canal ( $L^3T^{-1}L^{-1}$ )

$s_0$  = change in drain level (L)

$S$  = storativity  $\left(\frac{L^3}{L^3}\right)$

$T$  = transmissivity  $\left(\frac{L^2}{T}\right)$

$t$  = time (T)

# Consumptive Well Use Comparison

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## Well-based approach

Purpose	Consumptive Use (acre-feet per year)
Domestic	1900
Lawn/Garden	1500

## Parcel-based approach

Purpose	Consumptive Use (acre-feet per year)
Domestic	1600
Lawn/Garden	1500

# Well Use

Month	Domestic min	Domestic mean	Domestic max	Lawn garden min	Lawn garden mean	Lawn garden max	stock	Public min	Public mean	Public max
1	4.7	5.2	5.6	0.0	0.0	0.0	18.5	23.0	30.7	38.4
2	6.3	6.9	7.5	0.0	0.0	0.0	16.7	23.0	30.7	38.4
3	9.4	10.3	11.2	0.0	0.0	0.0	18.5	29.2	30.7	44.5
4	160.2	175.2	190.1	2.6	3.4	4.2	17.8	33.8	36.9	52.2
5	285.9	312.6	339.2	60.3	79.0	97.7	18.5	44.5	43.0	66.1
6	411.6	450.0	488.4	189.6	248.4	307.2	17.8	90.6	55.3	118.3
7	414.8	453.4	492.1	275.8	361.3	446.8	17.8	72.2	104.5	124.4
8	223.1	243.9	264.7	241.3	316.2	391.0	18.5	43.0	98.3	92.2
9	39.3	42.9	46.6	86.2	112.9	139.6	17.8	38.4	67.6	72.2
10	7.9	8.6	9.3	6.0	7.9	9.8	18.5	23.0	55.3	50.7
11	3.1	3.4	3.7	0.0	0.0	0.0	17.8	21.5	36.9	39.9
12	3.7	3.7	3.7	0.0	0.0	0.0	18.5	30.7	30.7	30.7
<b>Total</b>	<b>1570.1</b>	<b>1716.1</b>	<b>1862.1</b>	<b>862.0</b>	<b>1129.1</b>	<b>1396.3</b>	<b>216.4</b>	<b>473.1</b>	<b>620.6</b>	<b>768.1</b>