An Overview of the Boulder Valley Groundwater Investigation

Montana Bureau of Mines and Geology (MBMG)
Groundwater Investigations Program (GWIP)

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1/20/15

Background

- Portions of the Boulder River run dry during the late summer in most years.
  - There are more water rights than there is water in the river.
  - Under the Prior Appropriations Doctrine a water user can divert until the source is exhausted.
- Limits the ability to irrigate for junior water-rights holders
- Impacts the utility of the river for aquatic life and recreation

Background

- Dewatering has been documented since at least 1956.
- Attempts to supplement flows:
  - Surface Reservoir on the Boulder River near Basin (1968)
  - Supplement canals with groundwater (1968)
  - Surface Reservoir on the Little Boulder, near Boulder Hot Springs (1975)

Major Questions

- How would increased groundwater development affect stream flows?
- Can managed recharge be used to enhance late-summer stream flows?

Study Approach

- Field Observations
  - Groundwater Elevations
  - Surface Water Stage/Flow
  - Water Temperatures
  - Aquifer Tests
  - Geology/Soils
  - Vegetation
- Conceptual Model
  - Water Budget
- Numerical Model
  - Calibration
  - Test Scenarios

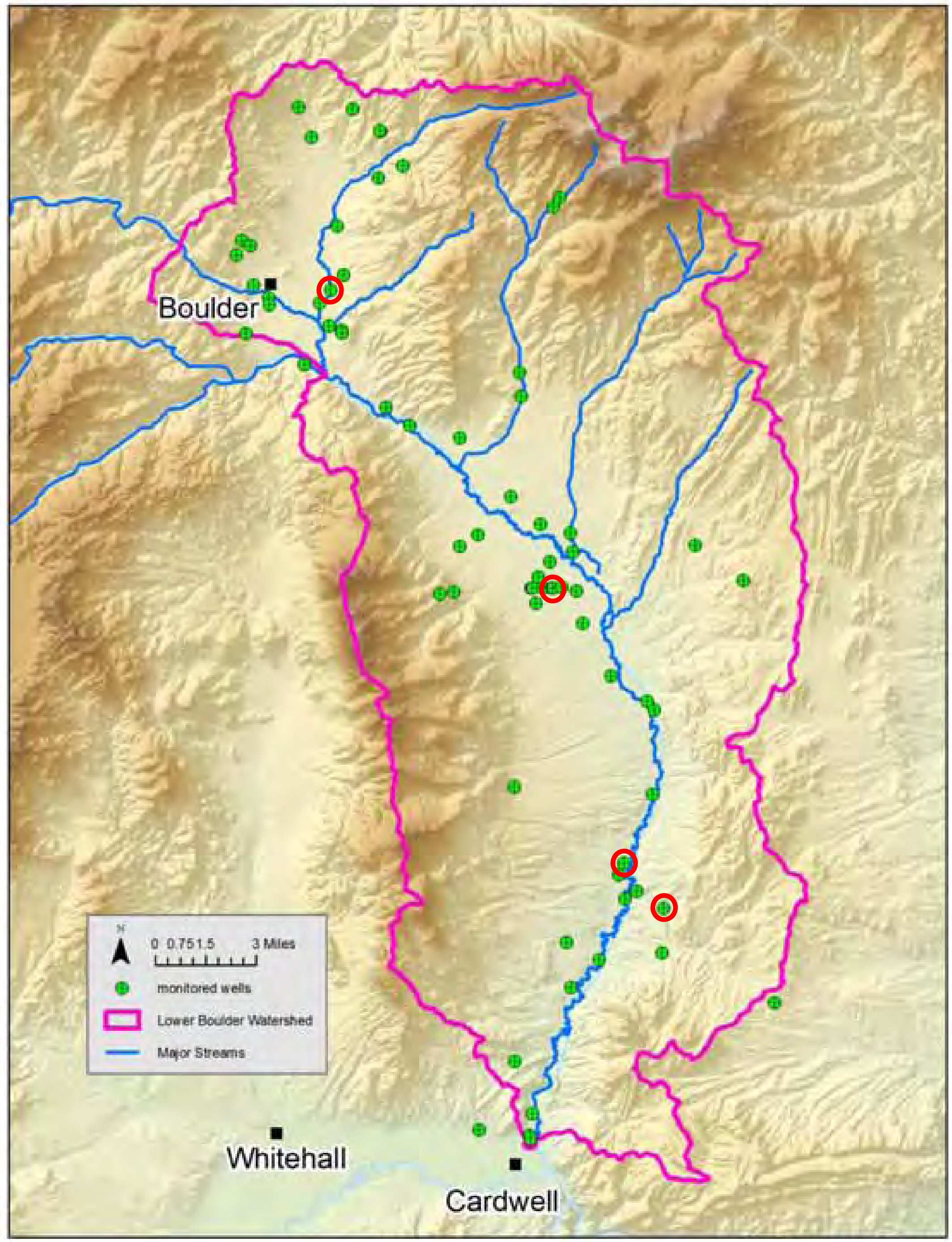
Field Observations – Groundwater Elevations

Field Observations – Depth to Water

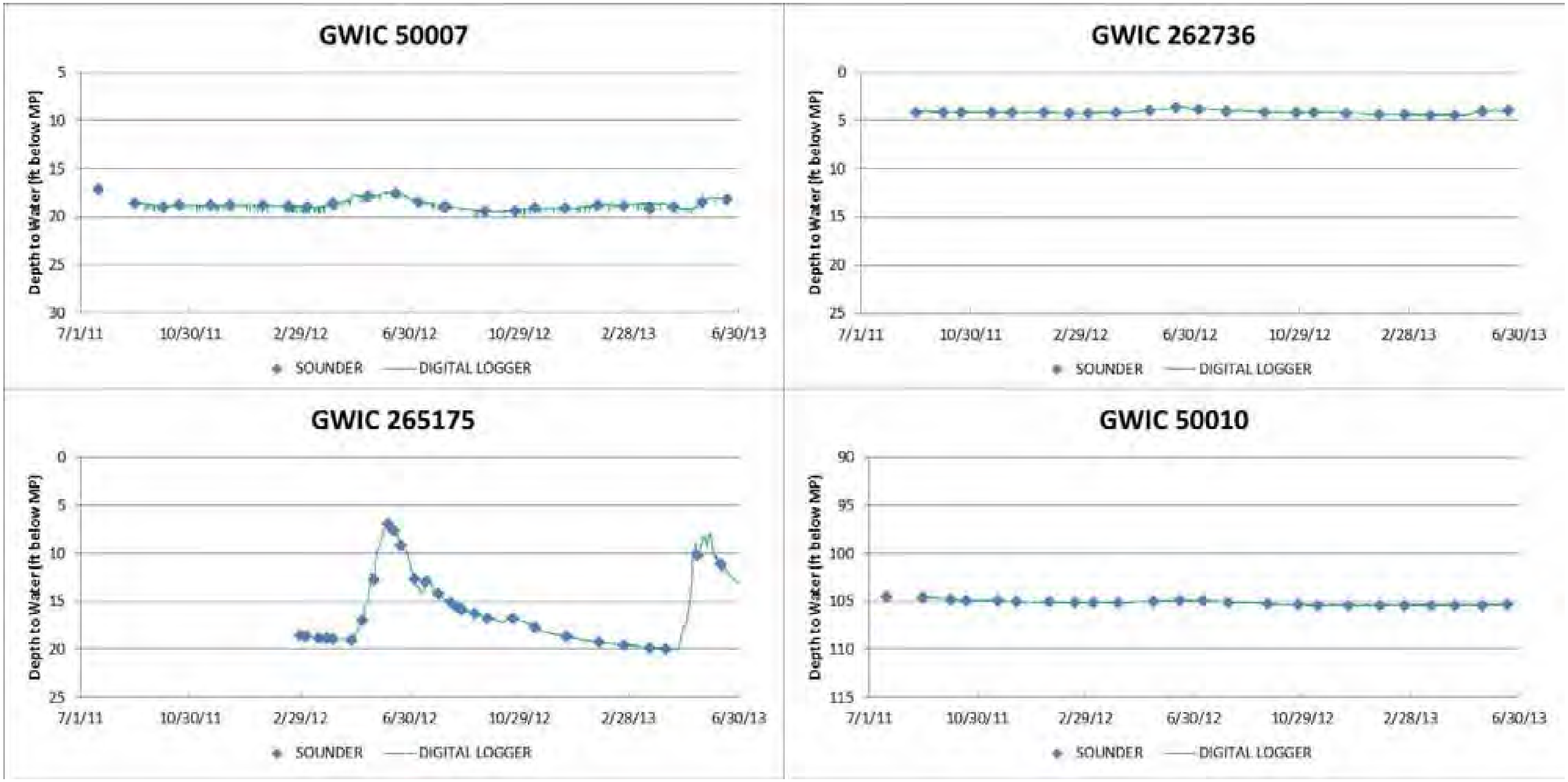
Field Observations Monitored Wells

79 wells

Geology
Irrigation
Canals
Streams



Field Observations – Hydrographs (one location over time)

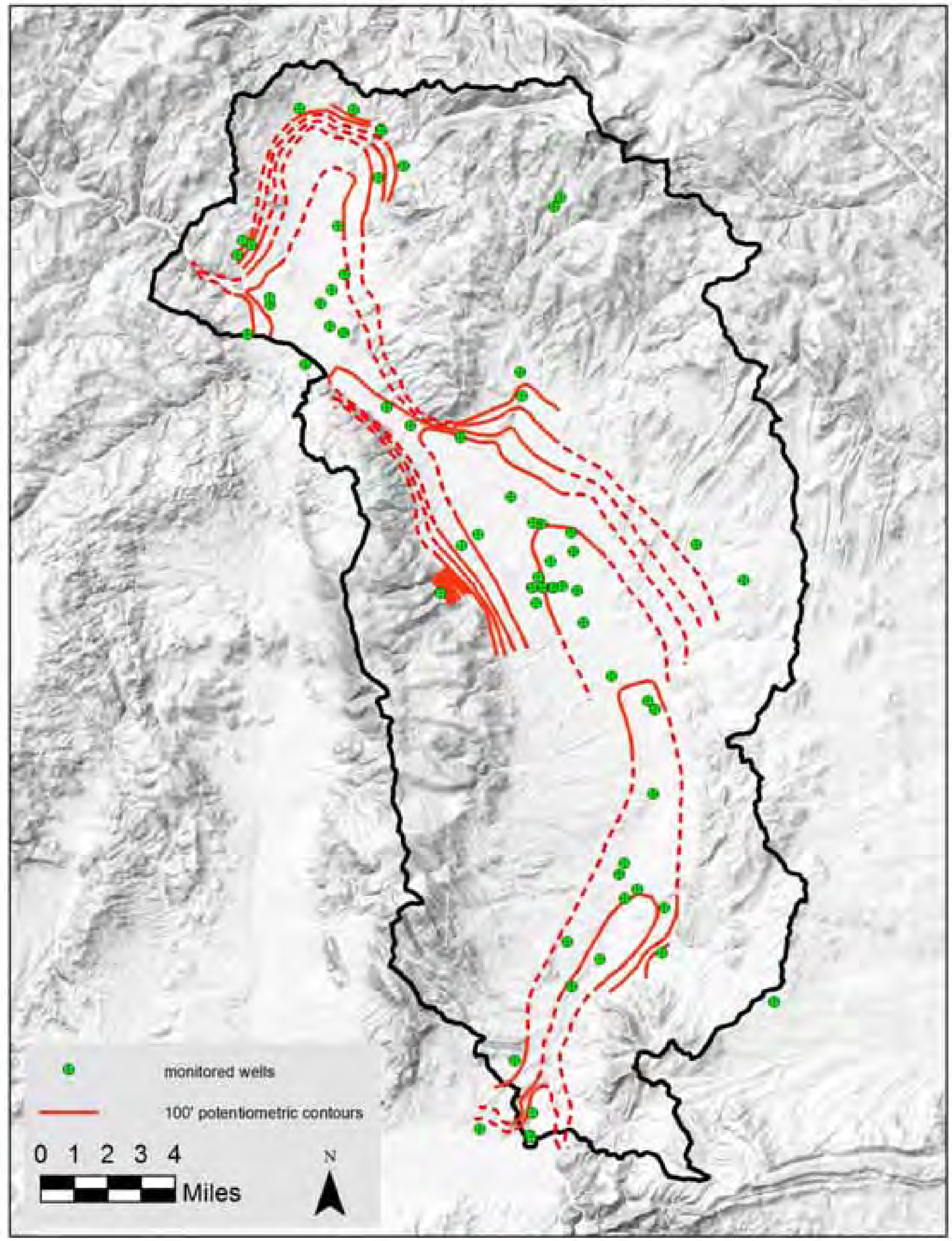


Field Observations Potentiometric Surface

Many points at the same time (November, 2012)

Groundwater flow is perpendicular to contours

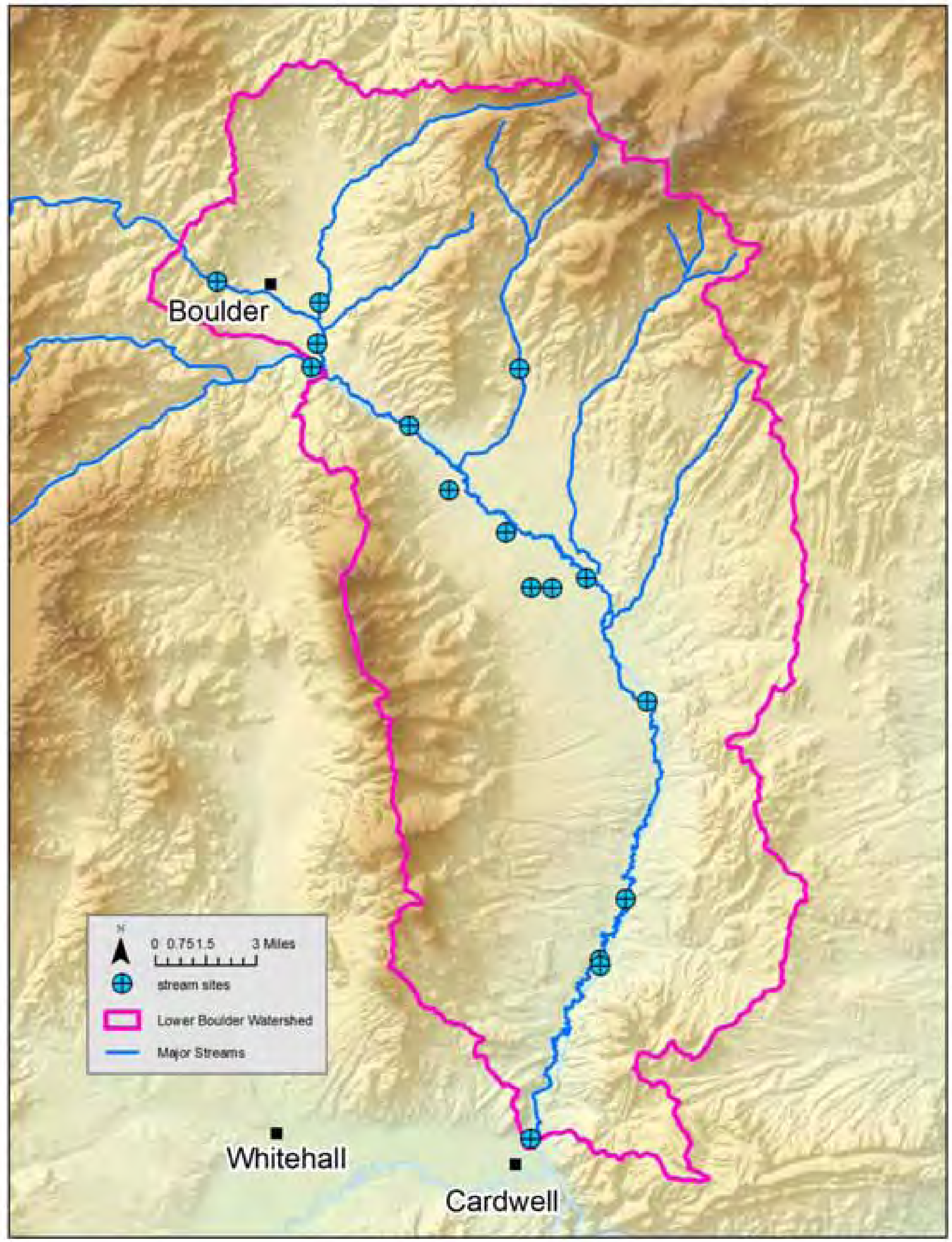
Contour spacing is indicative of transmissivity



Field Observations
Surface Water

16 sites

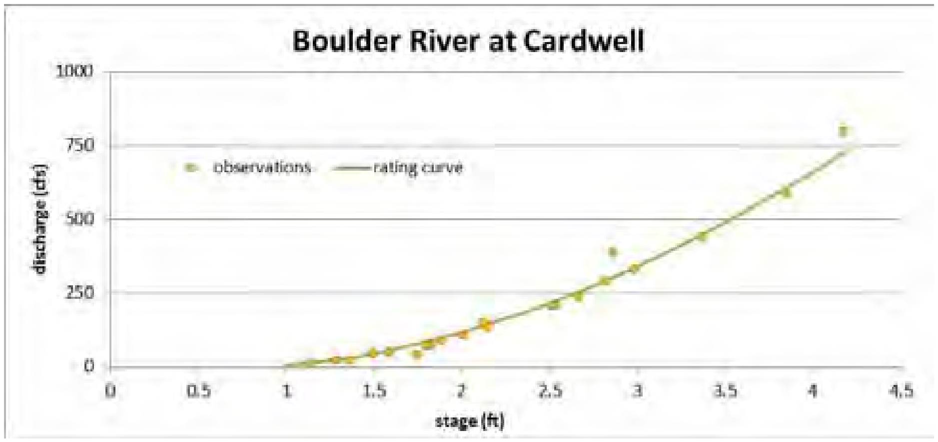
Boulder River (8)
Major Tributaries (3)
Canals (4)
Cold Spring

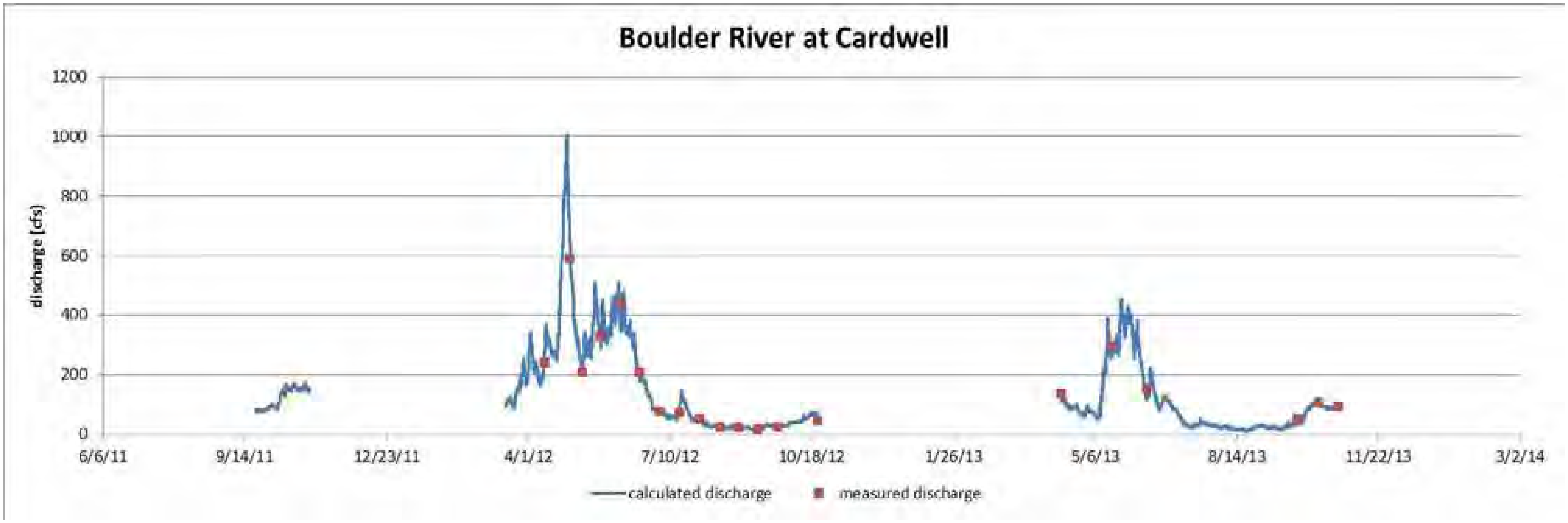


Field Observations – Staff Gage/Stilling Wells

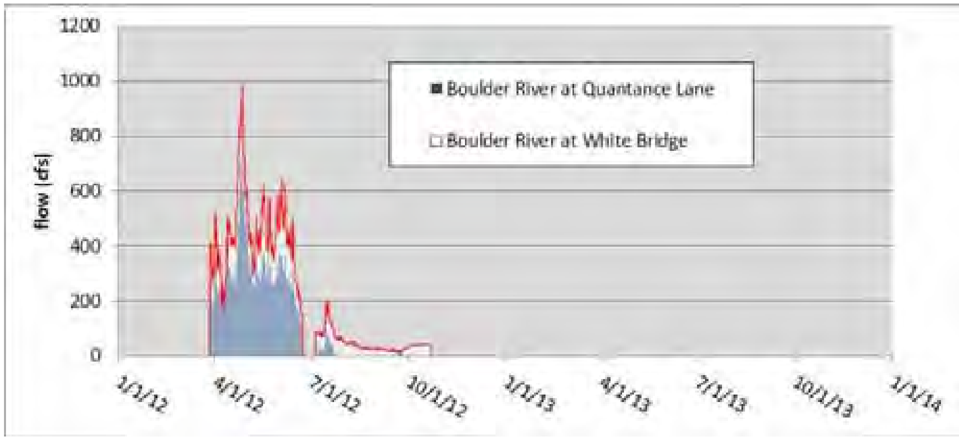
Field Observations – Measuring Discharge

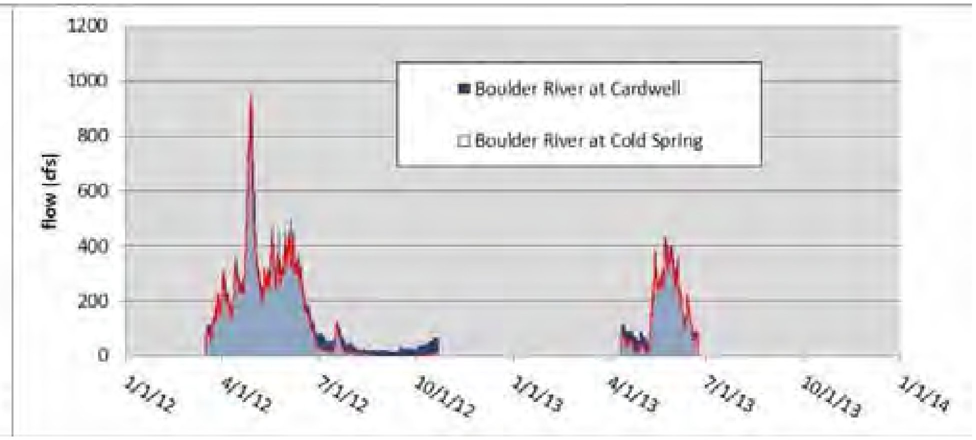
Rating Curves and Surface Water Hydrographs

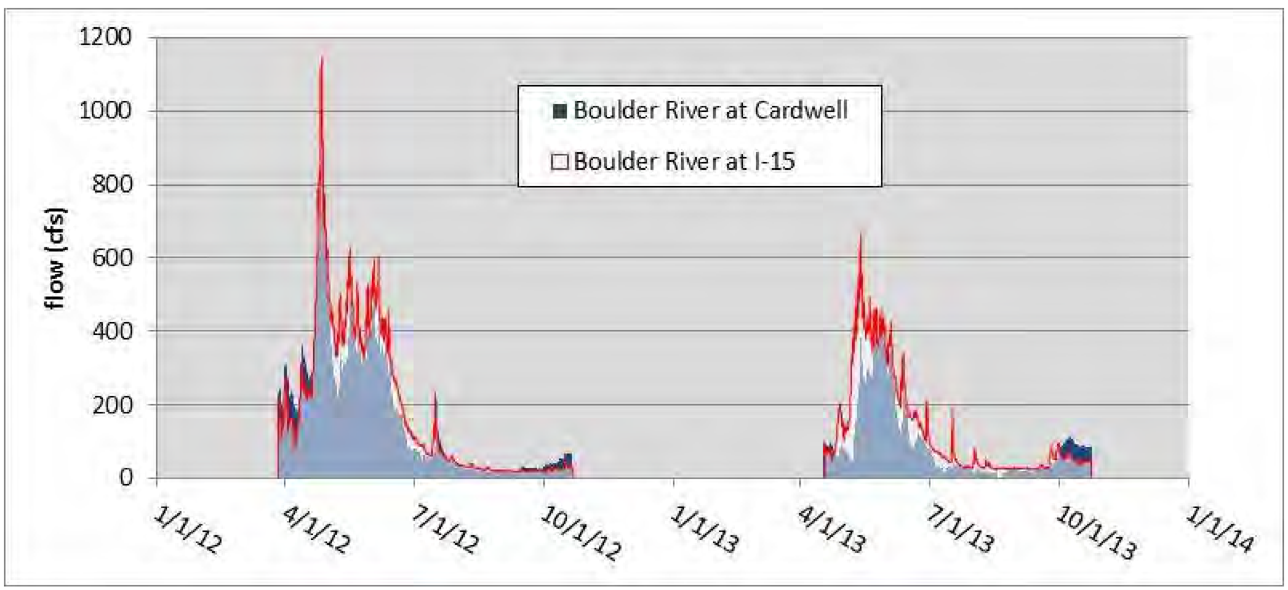




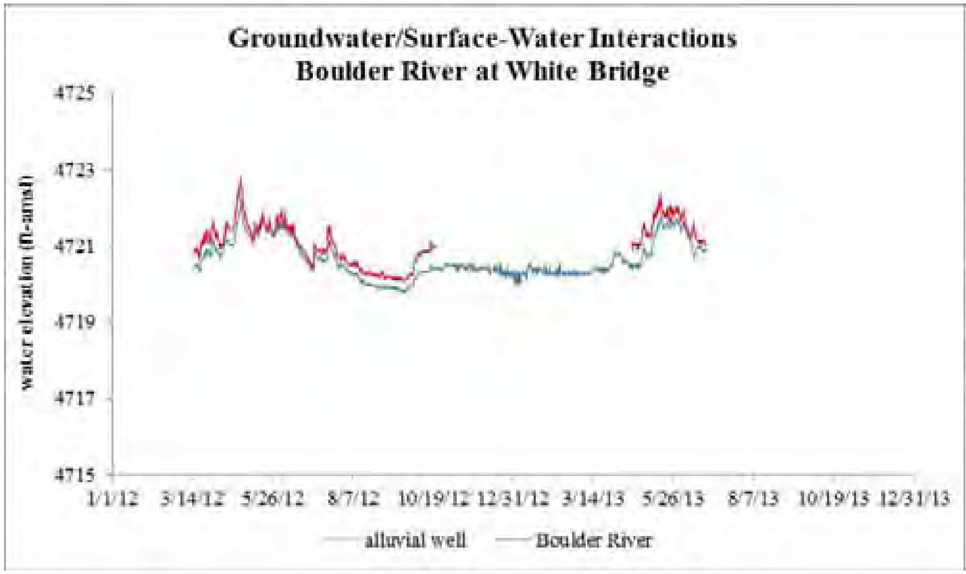
Hydrographs Comparisons

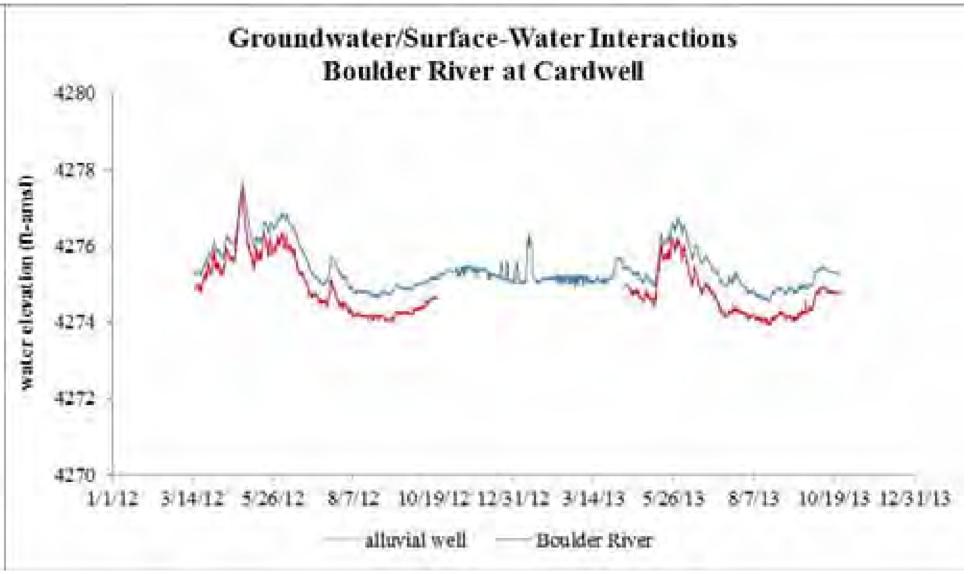


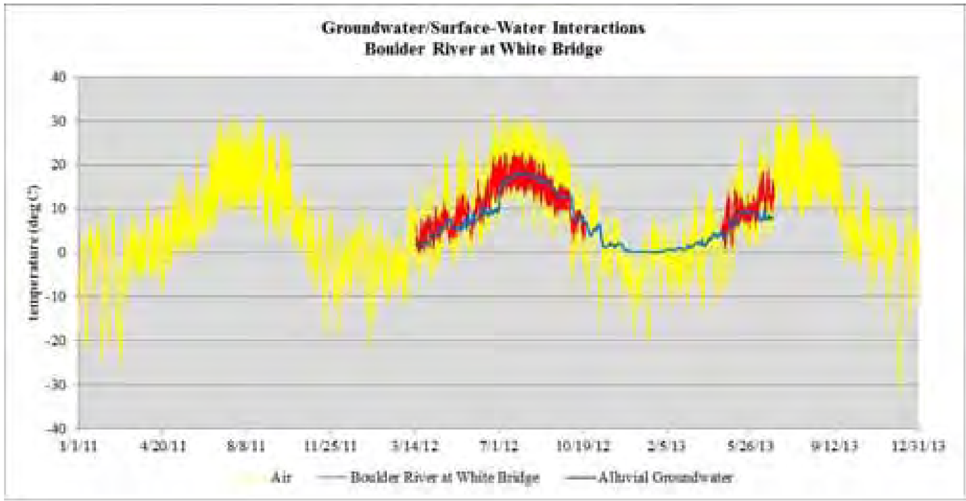


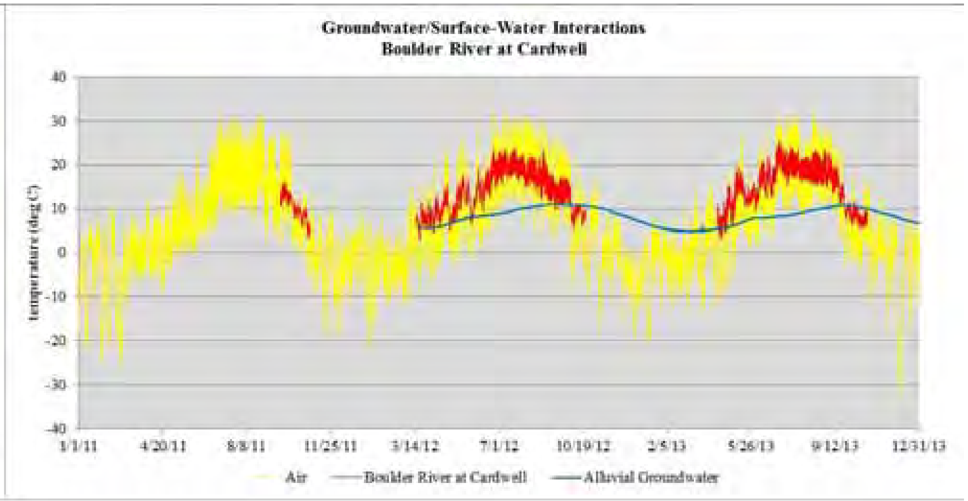


Groundwater/Surface-water Interactions

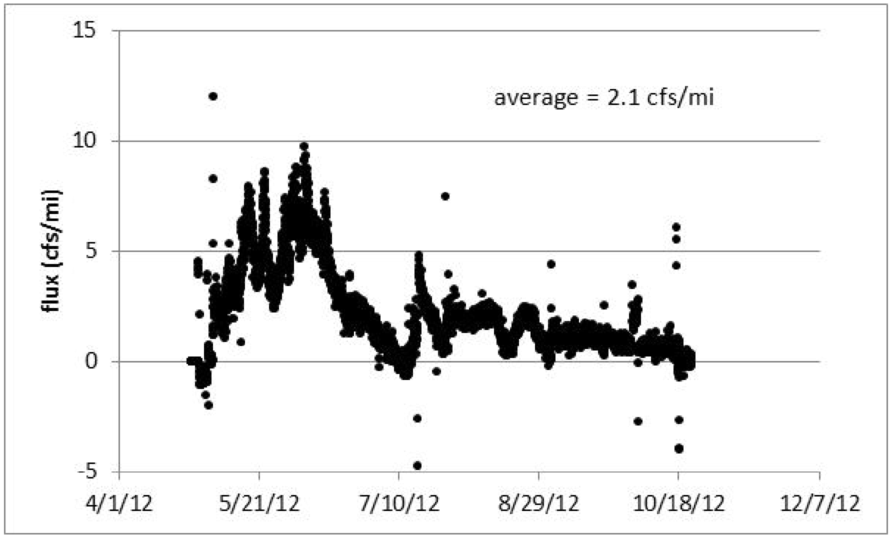


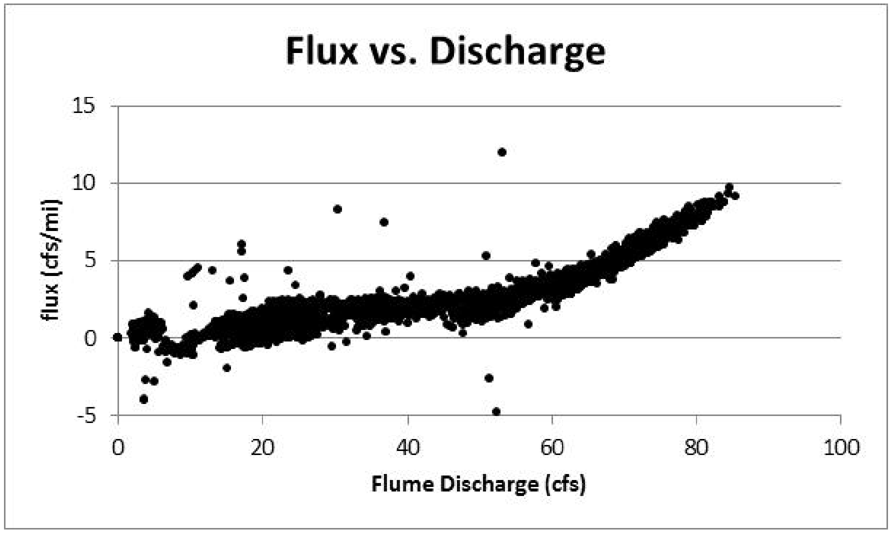






Canal Leakage
Carey Canal





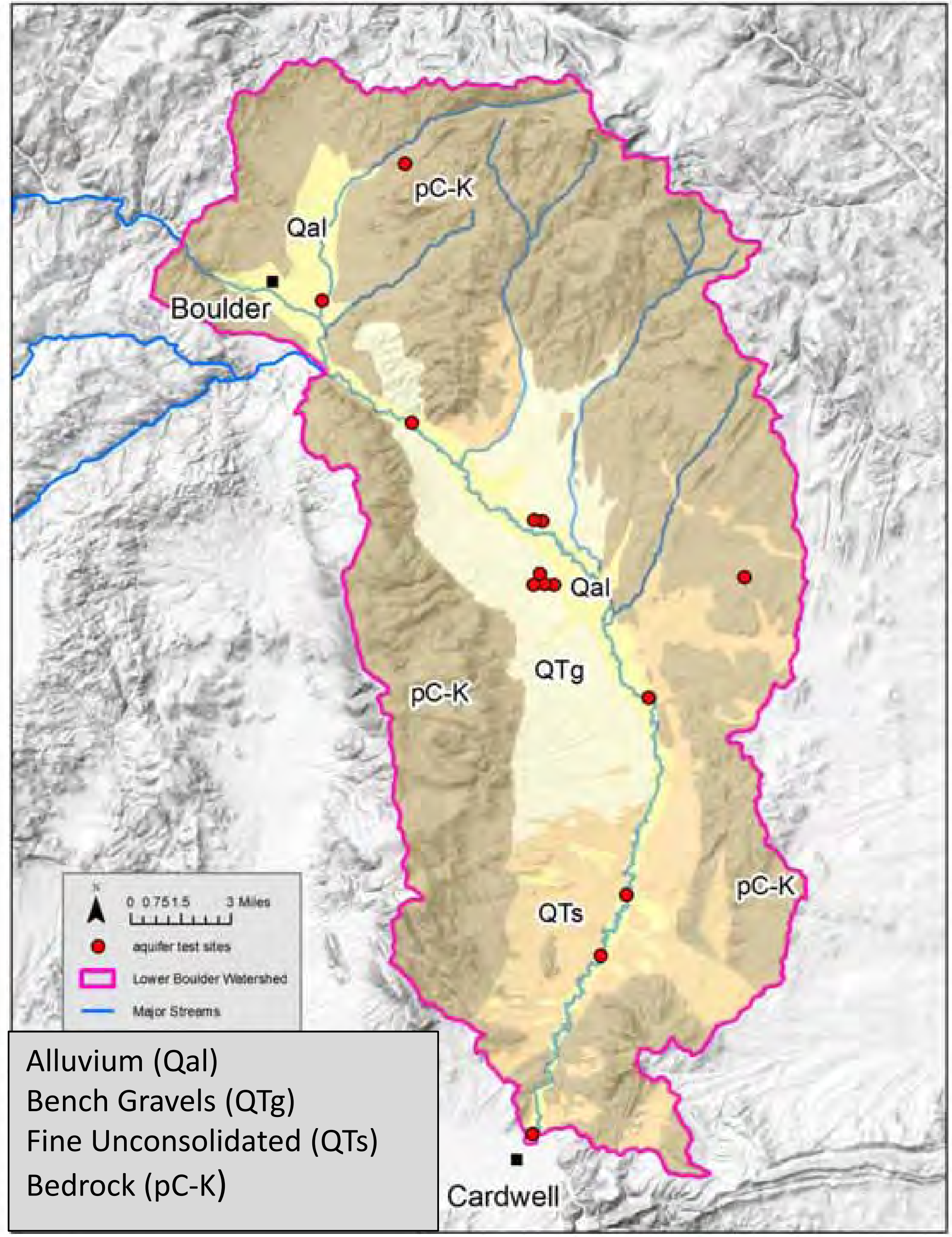
Transect is 2.47 miles from flume

Leaked water recharges groundwater & supplements stream flow.

Field Observations
Aquifer Tests

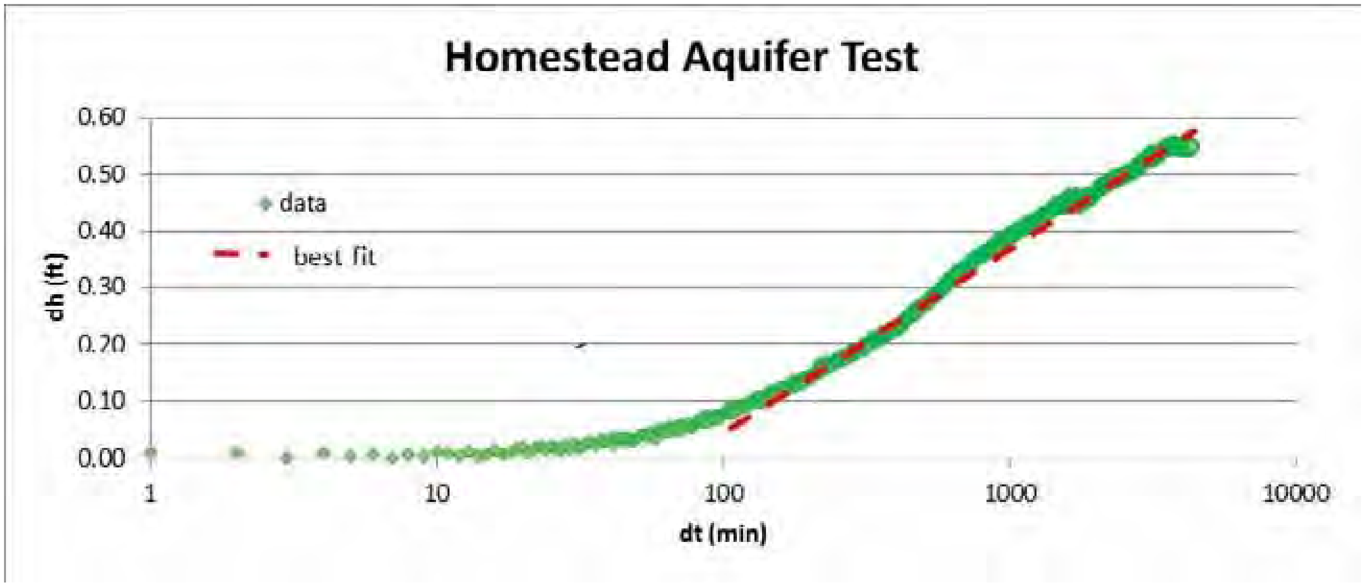
13 sites

- 8 Qal
- 3 QTg
- 2 pC-K



Field Observations – Aquifer Tests

Field Observations – Aquifer Tests



dh = change in water level (ft)
dt = change in time (min)

Knowing the pumping rate, and the distance between the pumping well and the observation well we can calculate:

- Transmissivity (T)– how easily water moves through the unit (ft^2/d)
  - inversely proportional to the slope of the best fit line
  - Hydraulic Conductivity (K) is T divided by aquifer thickness (ft/d)
- Storativity (S) – how much water the aquifer releases per unit change in head over a unit area (ft^3/ft^3; unitless)
  - Proportional to the intercept of the best fit line with the x-axis

Conceptual Model

To answer the questions quantitatively we need to develop a good conceptual model of the groundwater system.

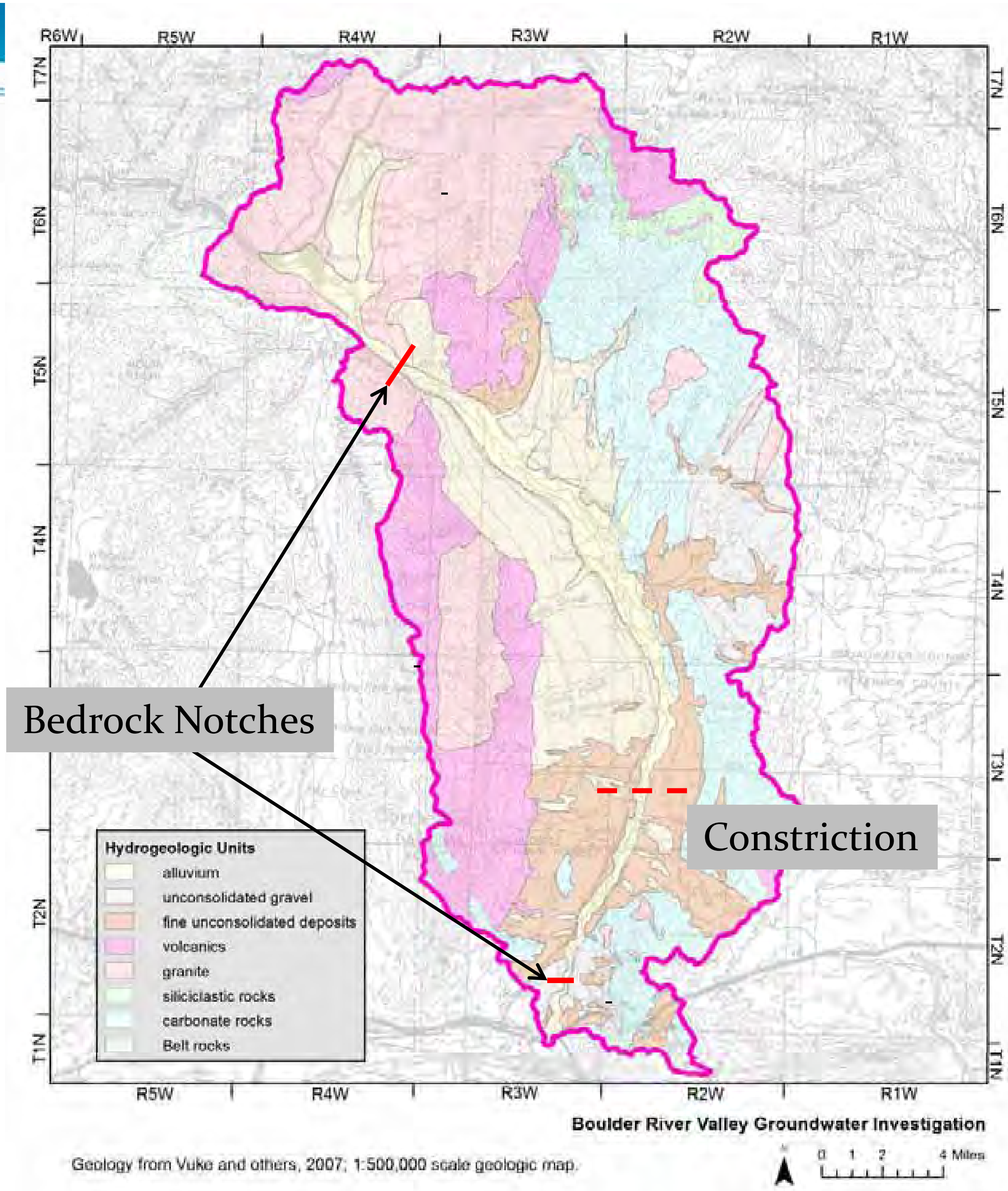
- Groundwater levels over space and time
  - Potentiometric Surface and Hydrographs
- Hydrogeologic Framework – The distribution of geologic units and their aquifer properties
- Water Budget
  - Diffuse infiltration
  - Irrigation recharge
  - Canal seepage
  - Groundwater inflow
  - River gains/loses
  - Riparian transpiration
  - Well withdrawals
  - Groundwater outflow

Hydrogeologic Units

Alluvium and gravel are most permeable

Fine unconsolidated less permeable

Bedrock has low permeability



Water Budget - Diffuse Infiltration

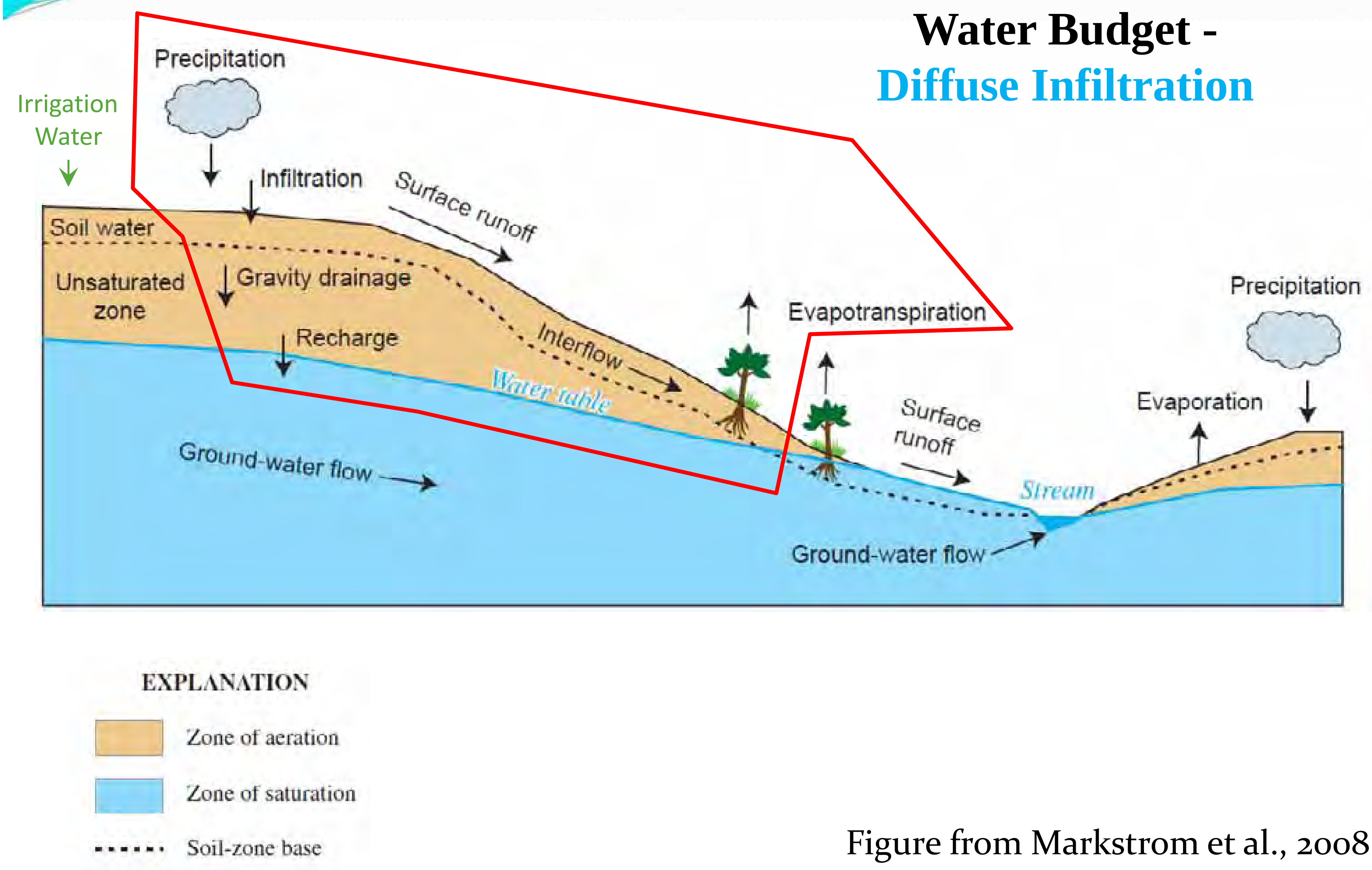
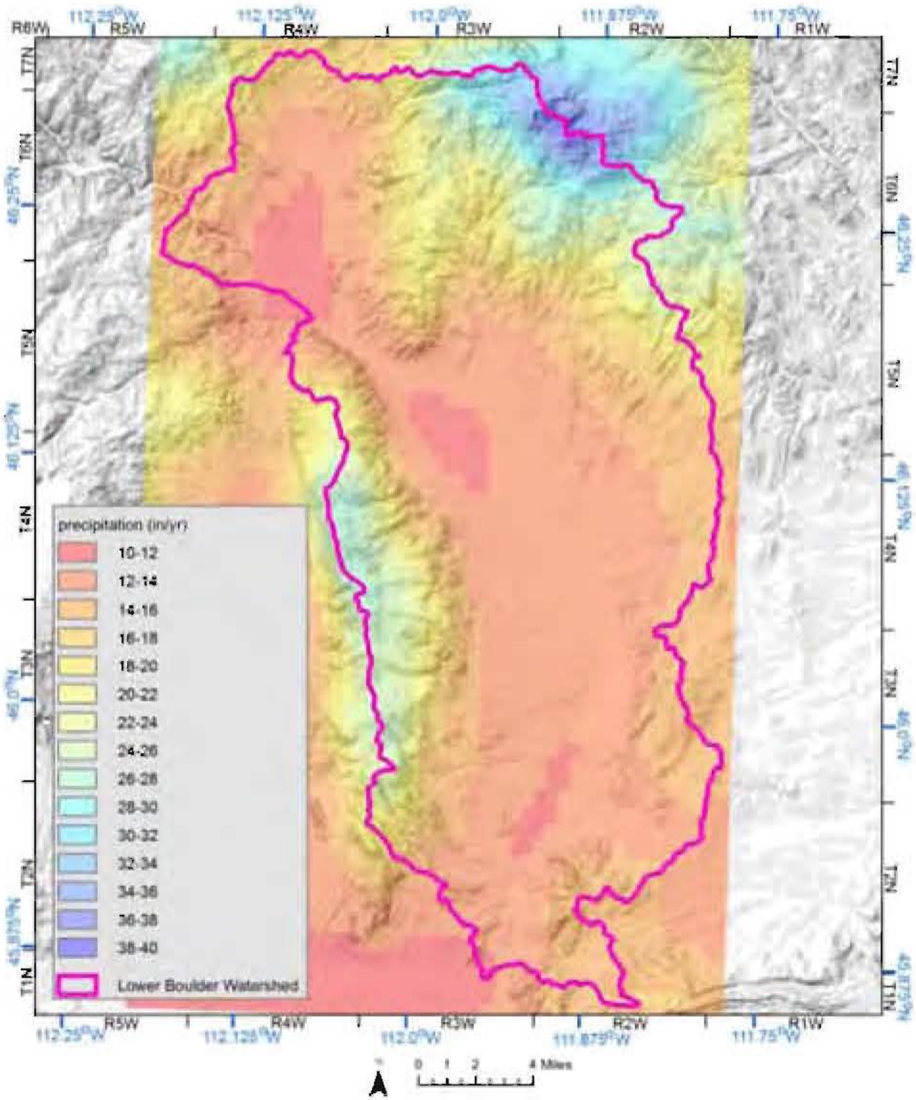
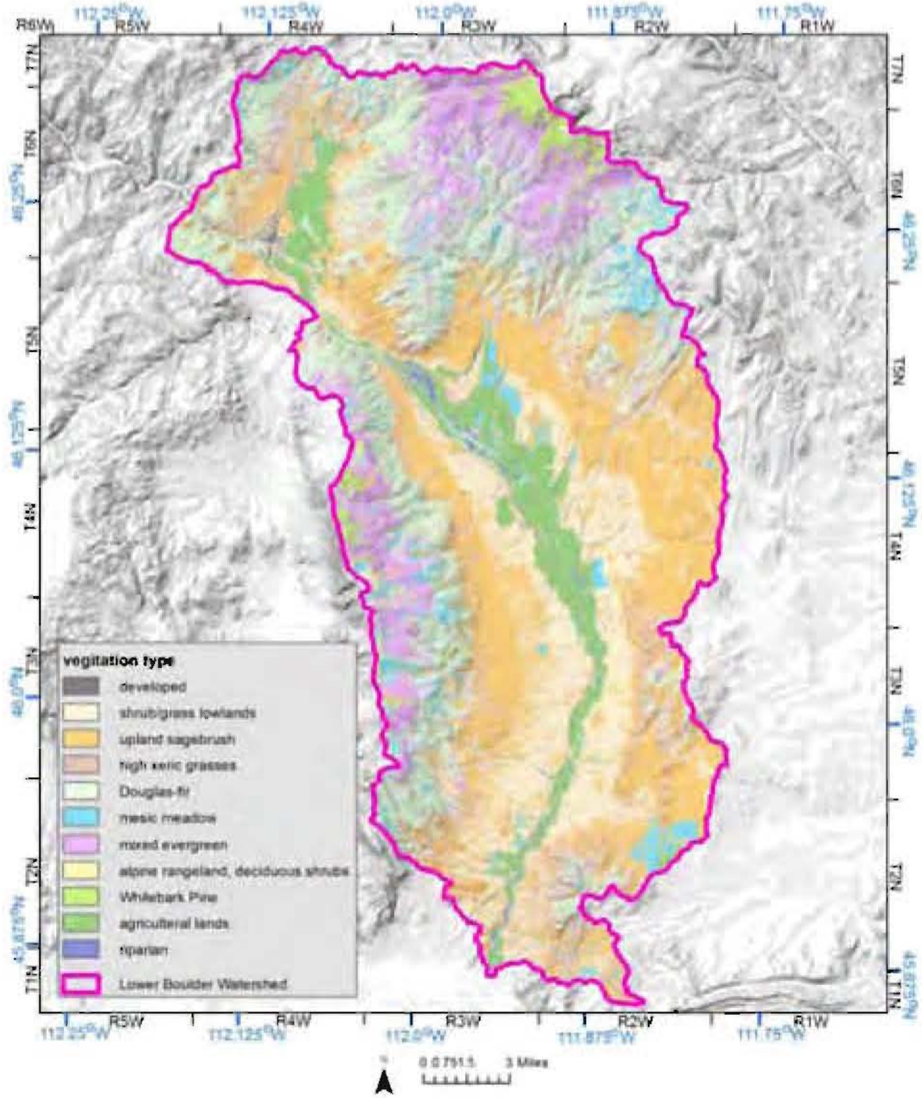


Figure from Markstrom et al., 2008
Not to scale


precipitation (in/yr)
10-12
12-14
14-16
16-18
18-20
20-22
22-24
24-26
26-28
28-30
30-32
32-34
34-36
36-38
38-40
Lower Boulder Watershed
R6W
R5W
R4W
R3W
R2W
R1W
112.25°W
112.125°W
112.0°W
111.875°W
111.75°W
T7N
T6N
T5N
T4N
T3N
T2N
T1N
46.25°N
46.125°N
46.0°N
45.875°N
0 1 2 4 Miles


vegitation type
developed
shrub/grass lowlands
upland sagebrush
high xeric grasses
Douglas-fir
mesic meadow
mixed evergreen
alpine rangeland, deciduous shrubs
Whitebark Pine
agriculteral lands
riparian
Lower Boulder Watershed
R6W
R5W
R4W
R3W
R2W
R1W
112.25°W
112.125°W
112.0°W
111.875°W
111.75°W
T7N
T6N
T5N
T4N
T3N
T2N
T1N
46.25°N
46.125°N
46.0°N
45.875°N
0 0.75 1.5 3 Miles

Upper Bound Estimate:

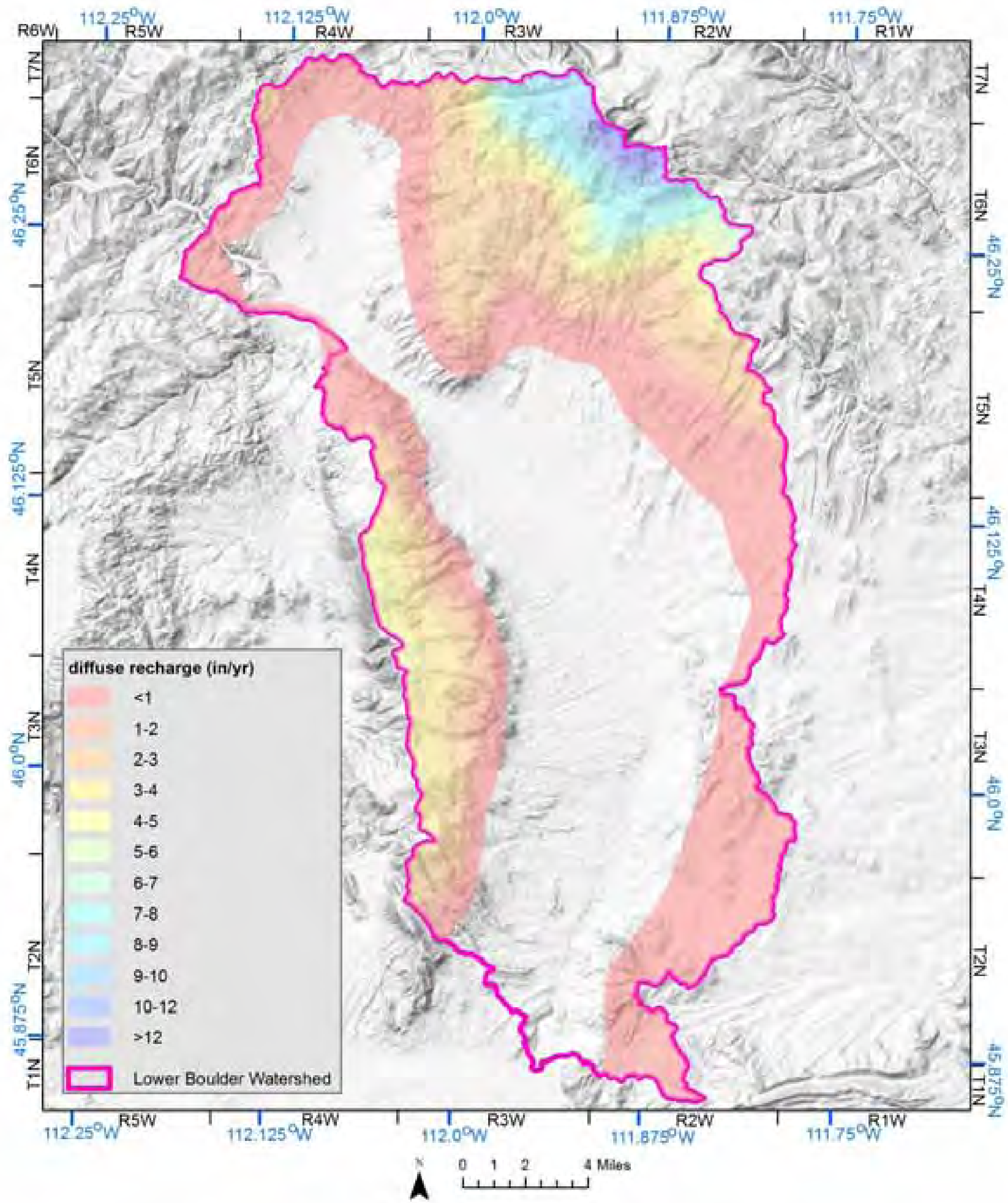
Use literature values for transpiration rates of different vegetation types

Precip – ET = Potential Recharge

Runoff is not accounted for.

Most streams infiltrate when they hit the bench, but during snow melt and intense summer storms all water does not infiltrate (irrigation canals and river).

Use with the numerical model and reasonable estimates of K to dial it back.



Water Budget – Irrigation Recharge

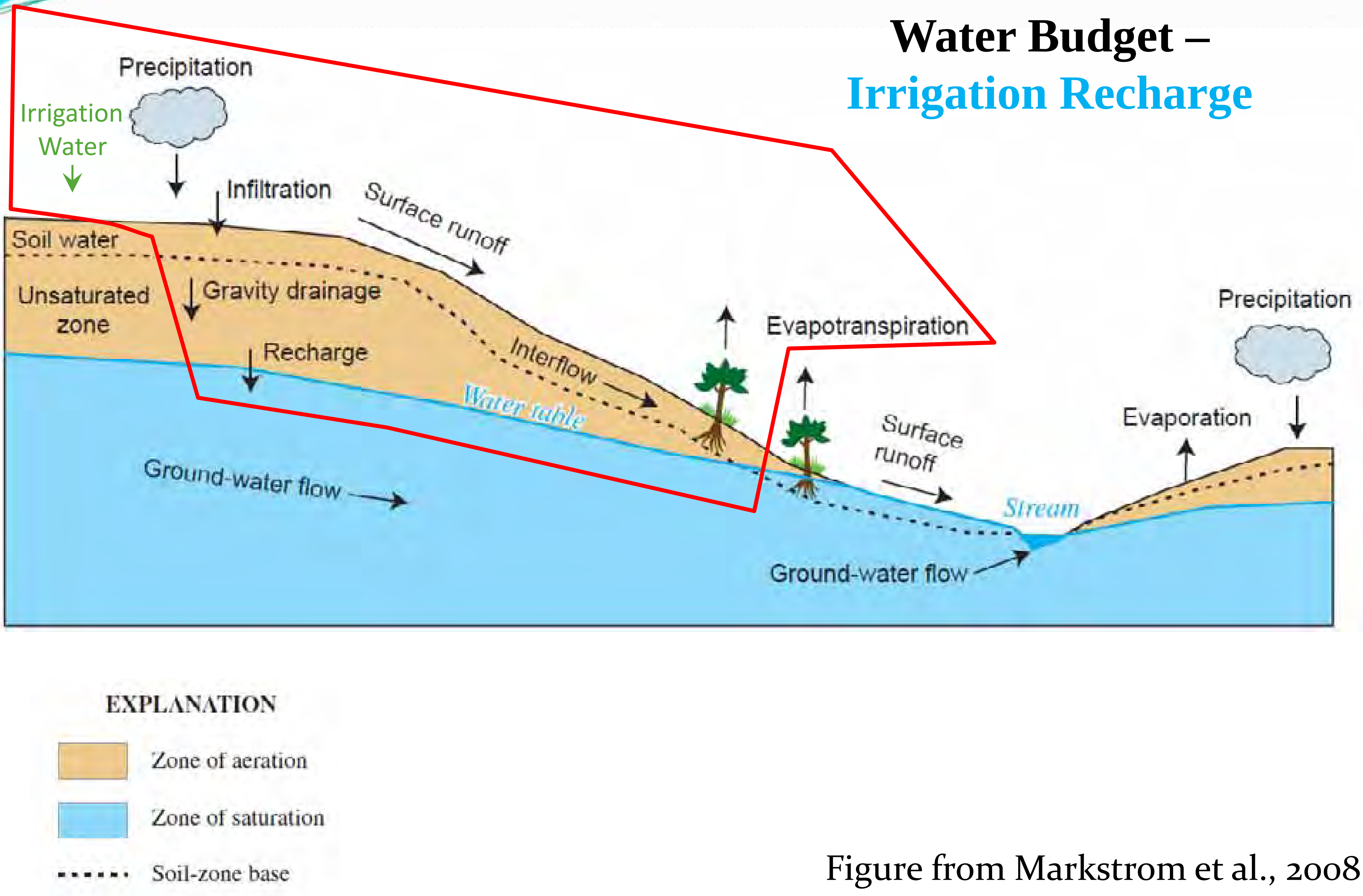
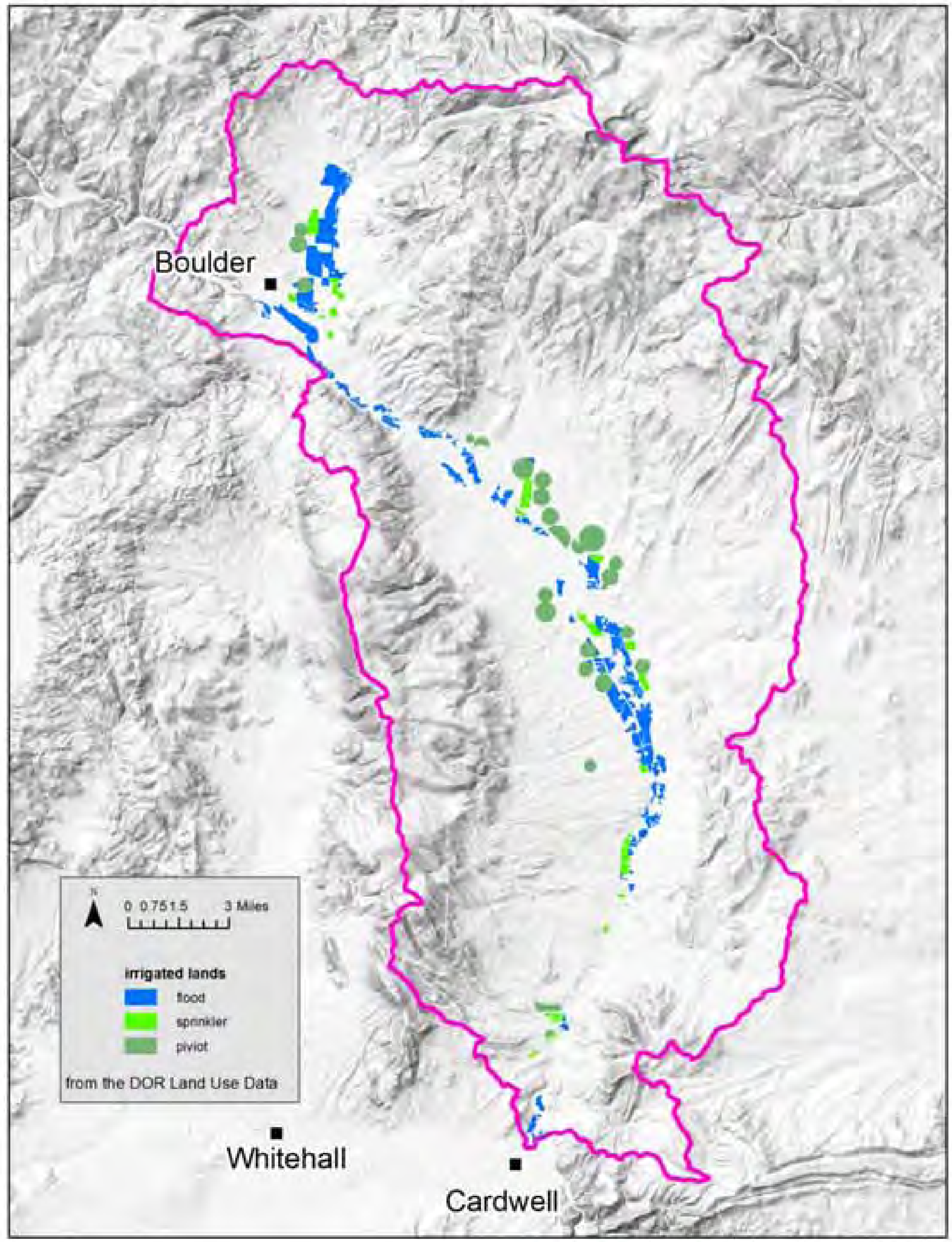


Figure from Markstrom et al., 2008
Not to scale

Use the Natural Resources Conservation Service's (NRCS's) Irrigation Water Requirements (IWR) program to calculate annual irrigation recharge based on the type of irrigation (efficiency) and crop.

Distributed the timing of this recharge based on the canal being used to irrigate, and when water was available for it.

April – July – All canals
July – October – Some canals off line



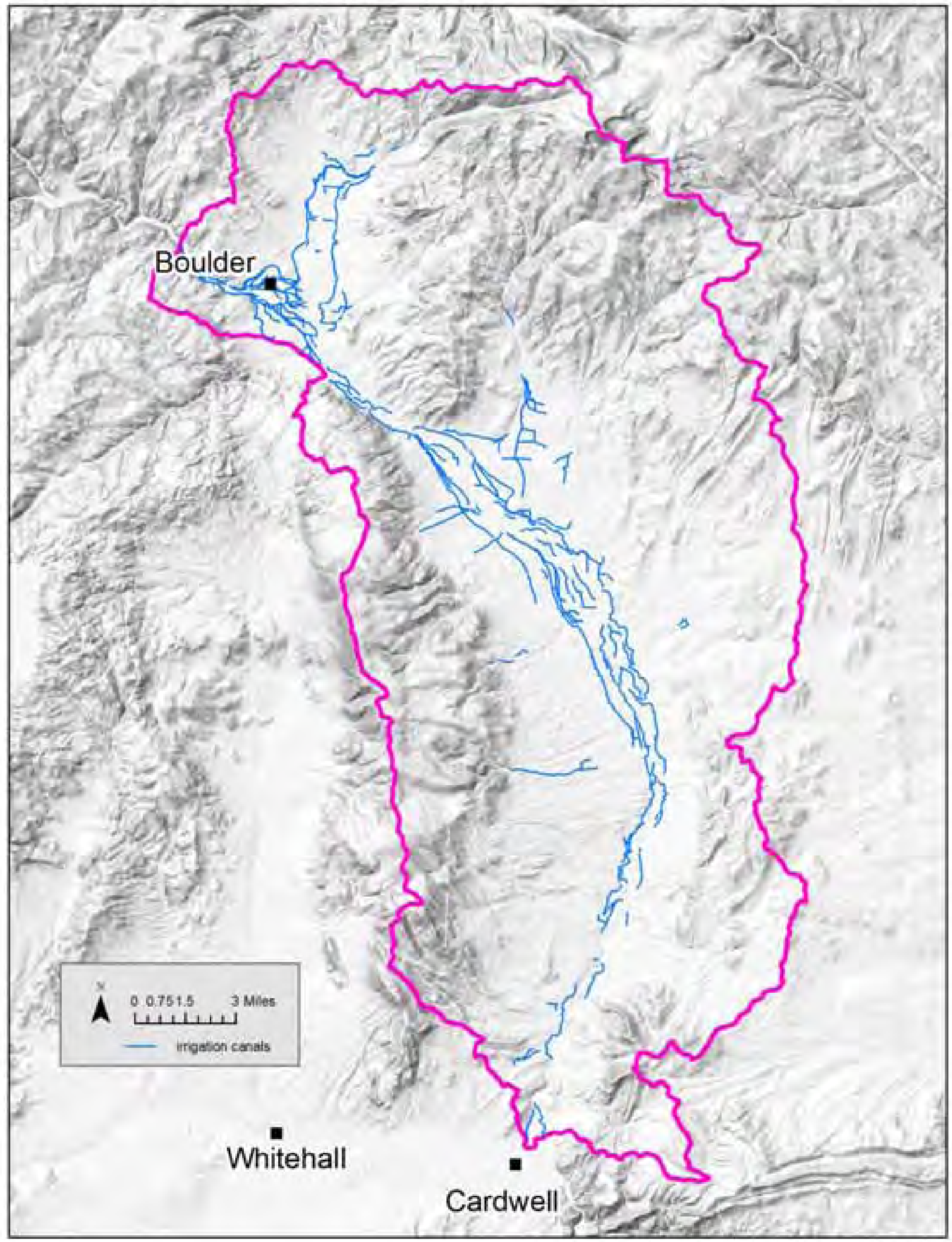
Water Budget – Canal Leakage

2 canals monitored for leakage
Carey – Large
Murphy – Small

Canals assigned based on size to:

- Similar to Carey
- Similar to Murphy
- Between them

Similar to irrigation recharge, leakage was distributed based on when the canal had water in it.



Groundwater In/Out

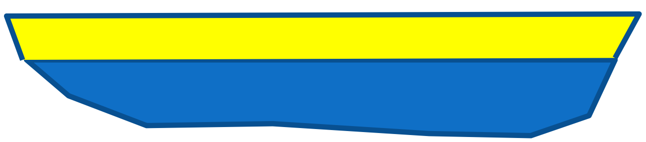
Potentiometric surface and geology show

- 2 inflow locations
  - Boulder River – Upstream
  - Little Boulder River

- 1 outflow location
  - Boulder River - Downstream

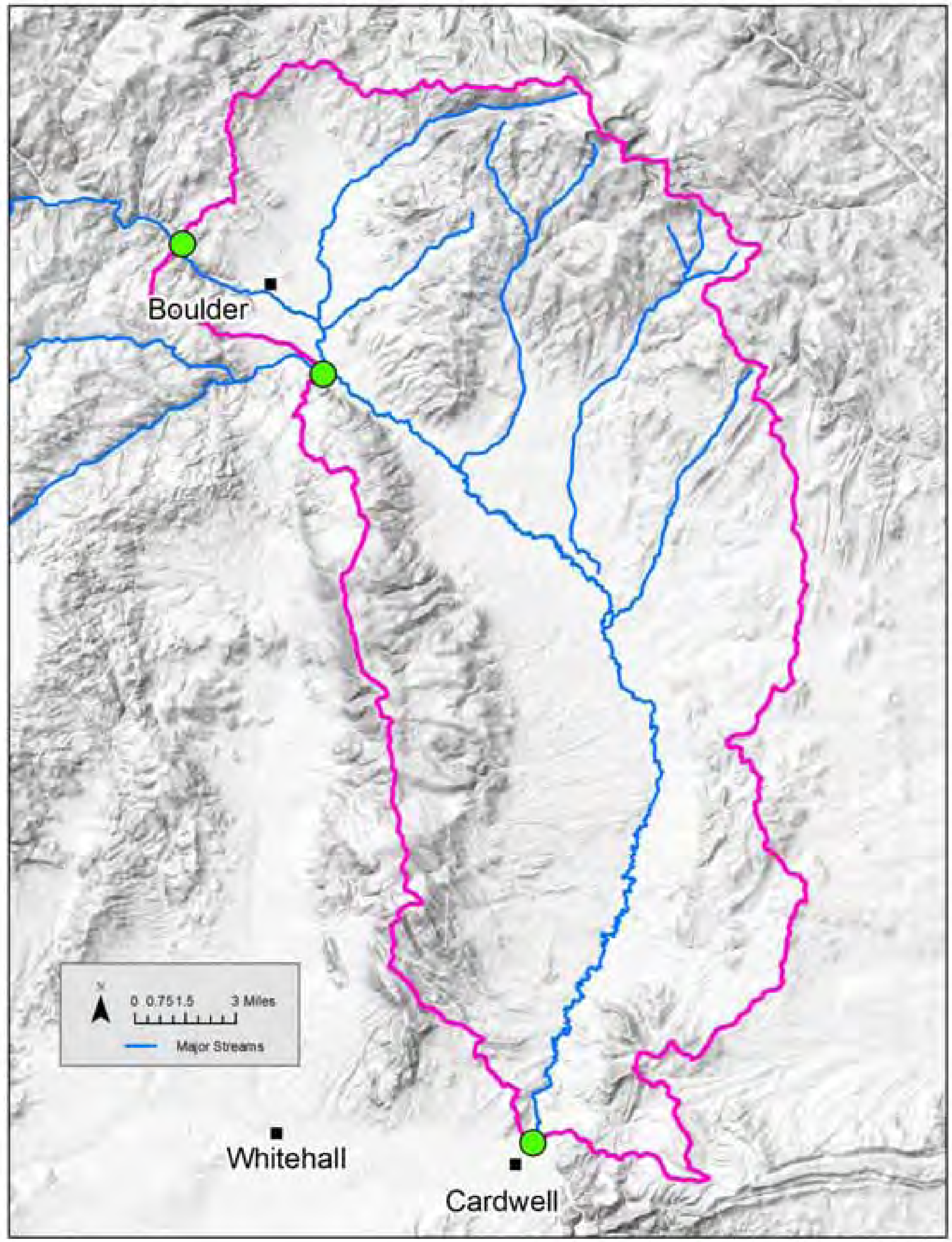
Little groundwater flux due to thin alluvium

Q = KA(*dh/dl*)



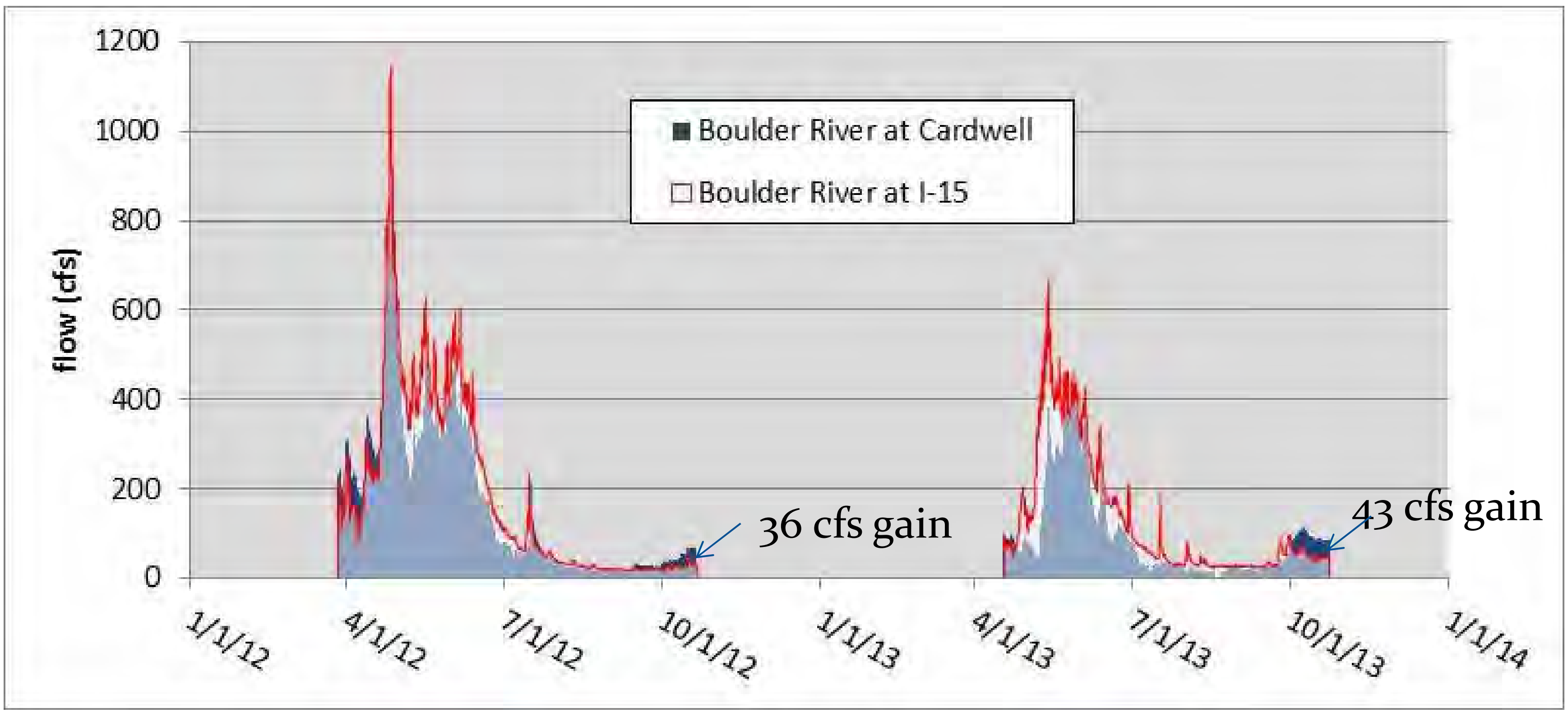
Totals:

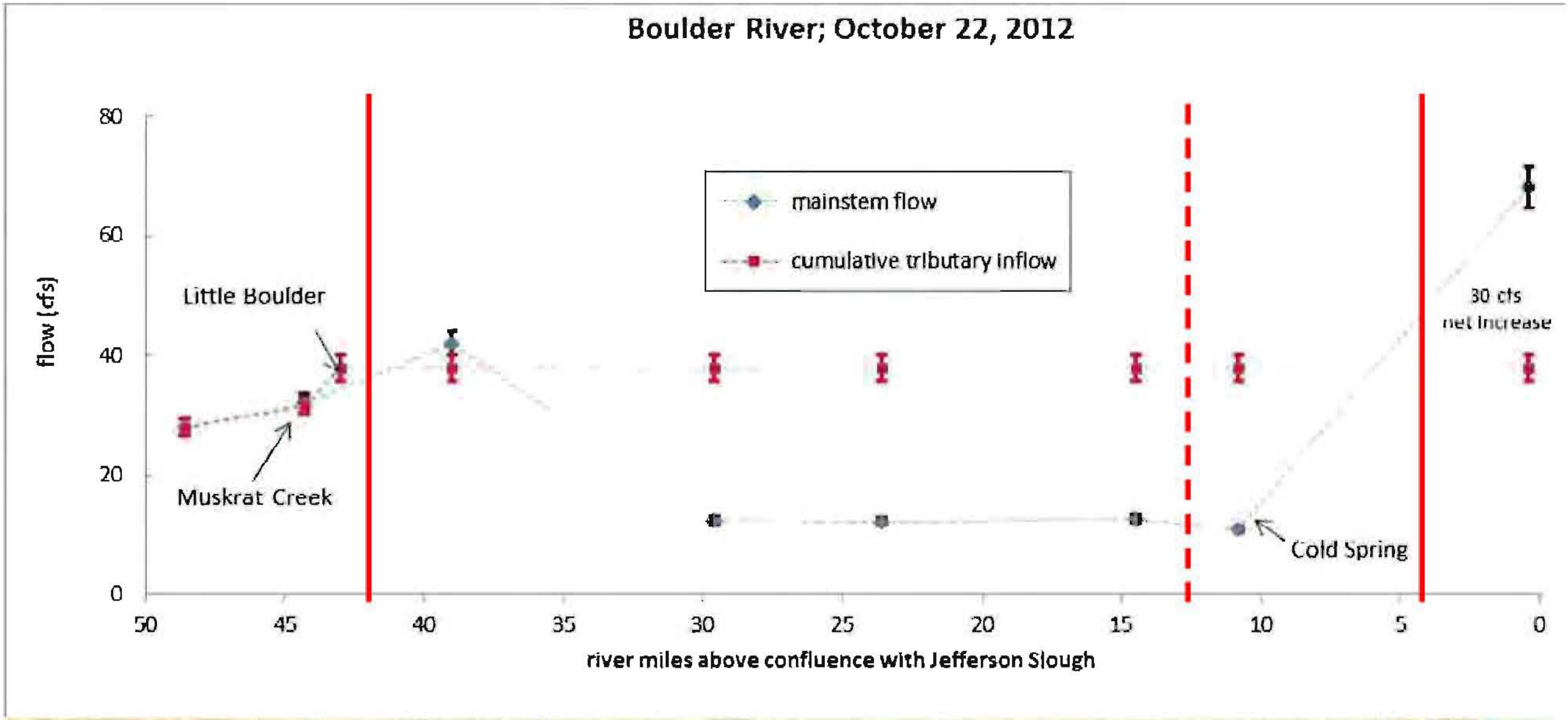
- In 148 ac-ft/yr
- Out 150 ac-ft/yr



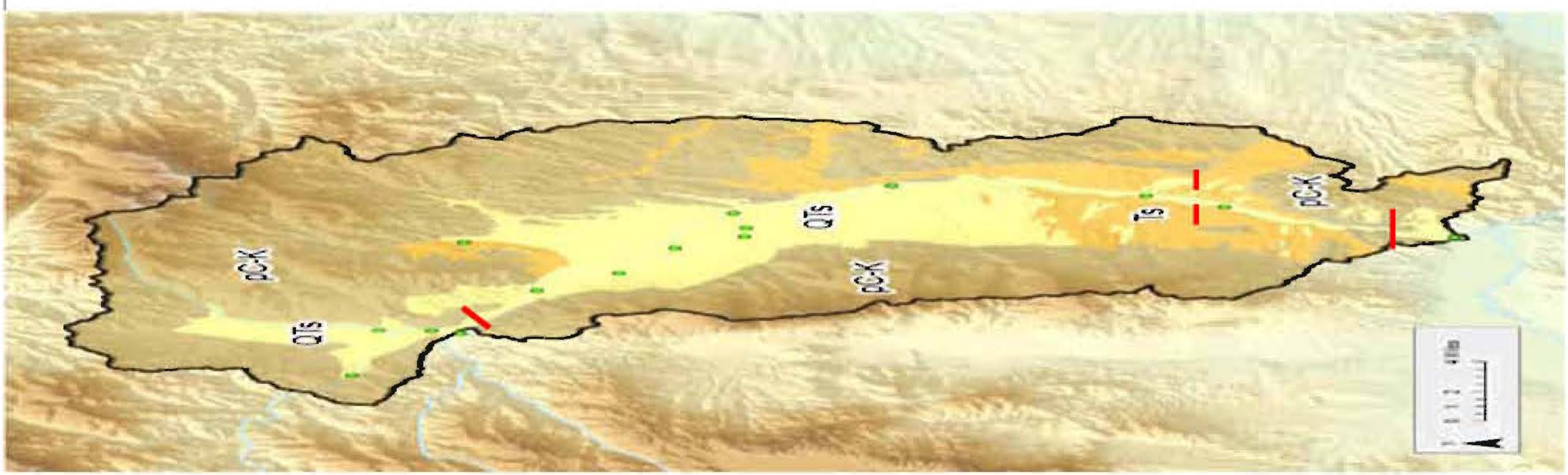
River Gains/Loses

- Net Gain of about 35 – 40 cfs
  - 36 to 43 cfs gain observed during late October
  - 37 cfs in model
  - 35 cfs by water budget difference
- Net Loss during the irrigation season due to diversions





Boulder River; October 22, 2012
mainstem flow
cumulative tributary inflow
Little Boulder
Muskrat Creek
Cold Spring
30 cfs
net increase
flow (cfs)
river miles above confluence with Jefferson Slough
80
60
40
20
0
50
45
40
35
30
25
20
15
10
5
0



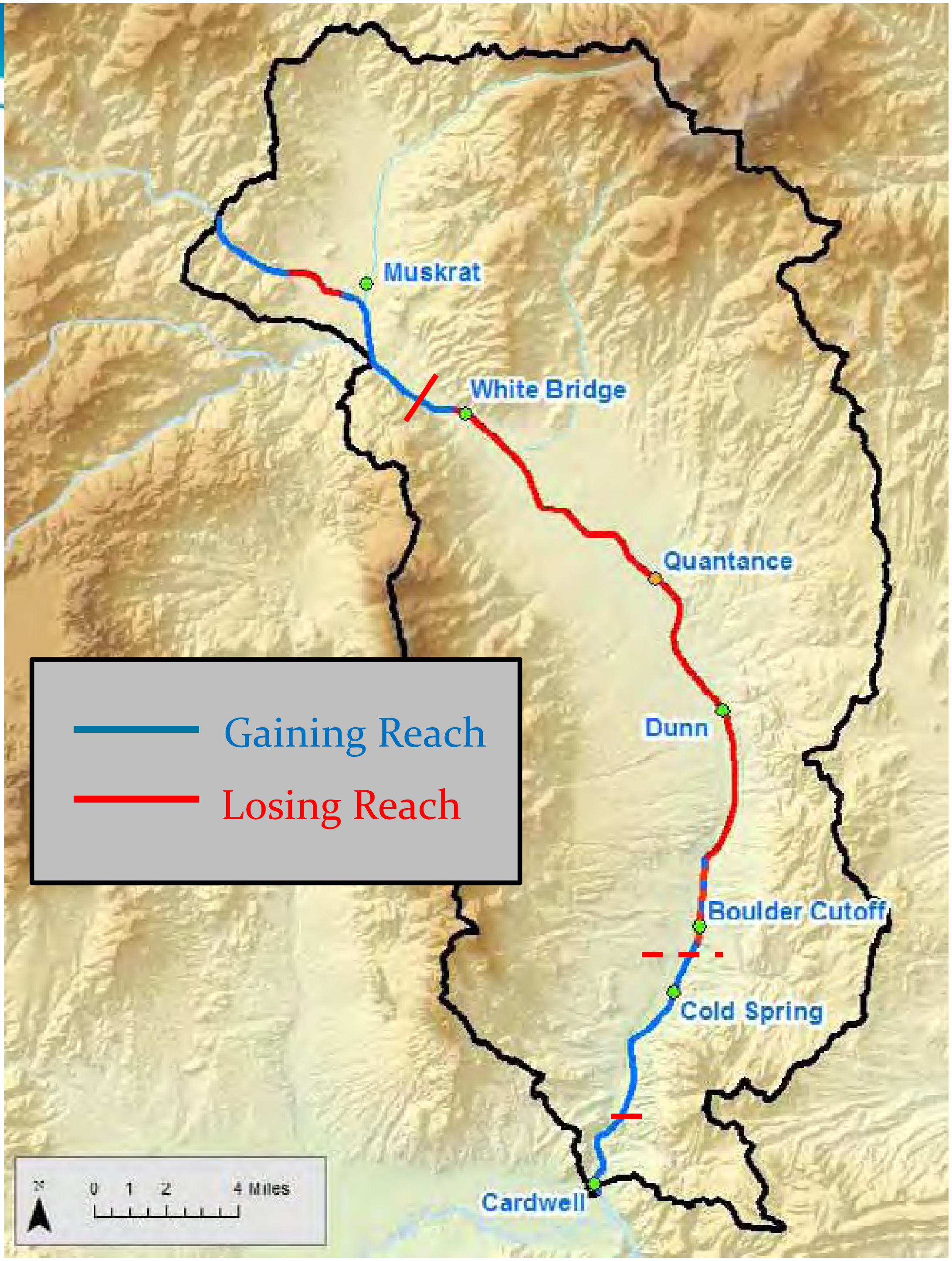
pC-K
QTs
pC-K
Ts
pC-K
QTs

River Gains/Loses

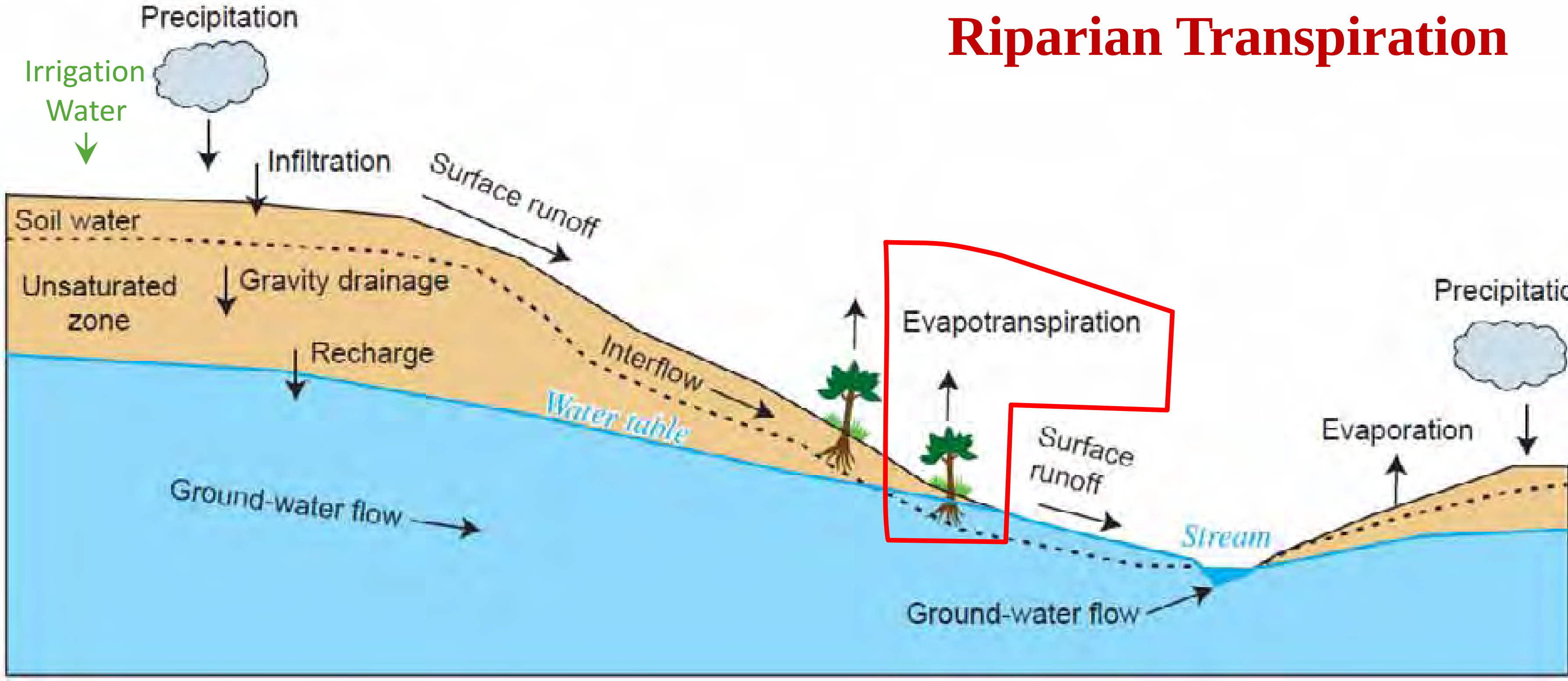
Particular reaches of the Boulder River gain or lose water consistently.

Overall Gain is 35-40 cfs

Observed difference during the irrigation season is affected by irrigation diversions



Conceptual Model – Riparian Transpiration



EXPLANATION

Zone of aeration

Zone of saturation

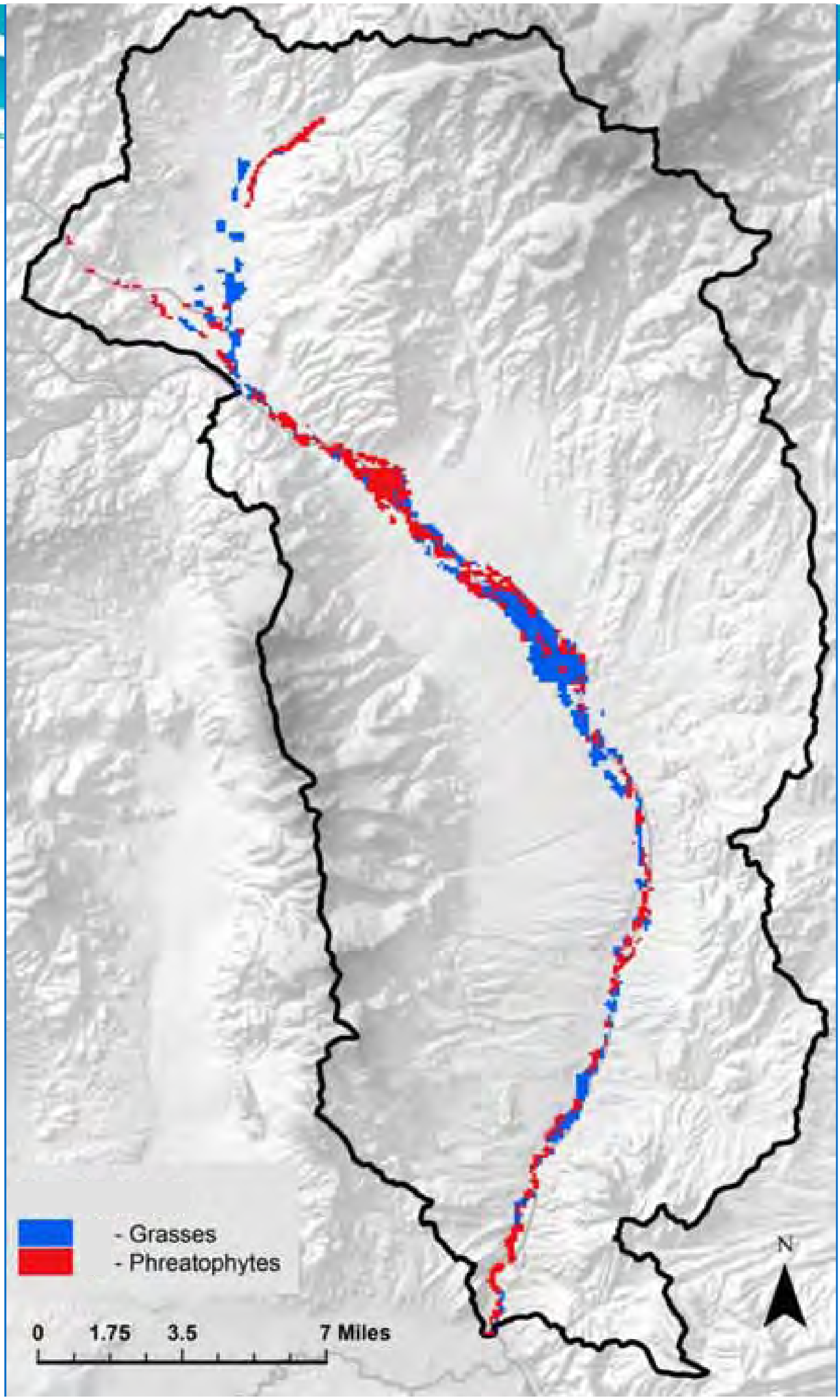
Soil-zone base

Figure from Markstrom et al., 2008
Not to scale

Riparian Transpiration

Some plants pull water directly from the aquifer (willow, Cottenwood, and wetland grasses).

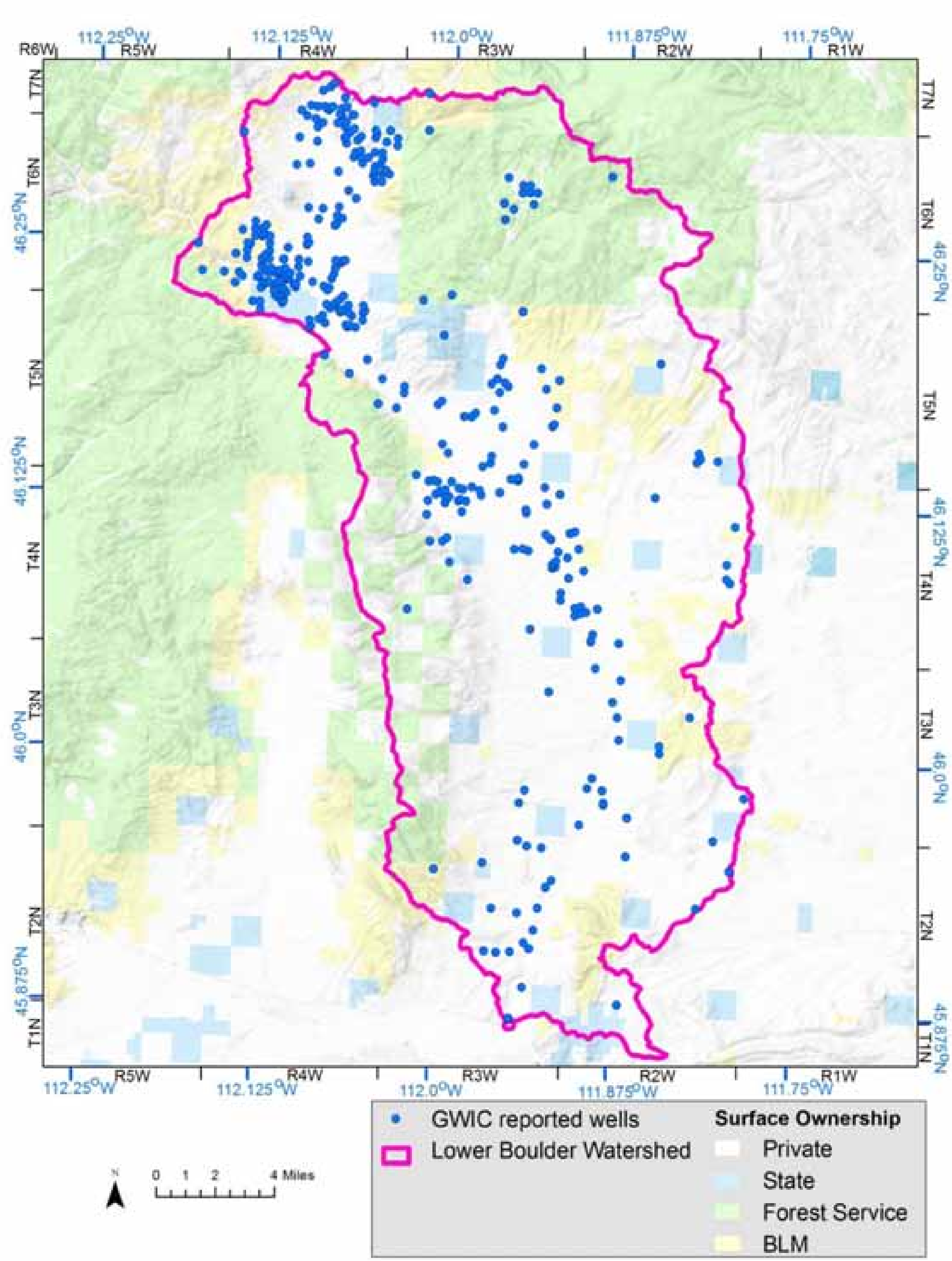
Model calculates based on depth to groundwater, root extinction depth, and maximum rates



Well Withdrawals

Divided by reported types

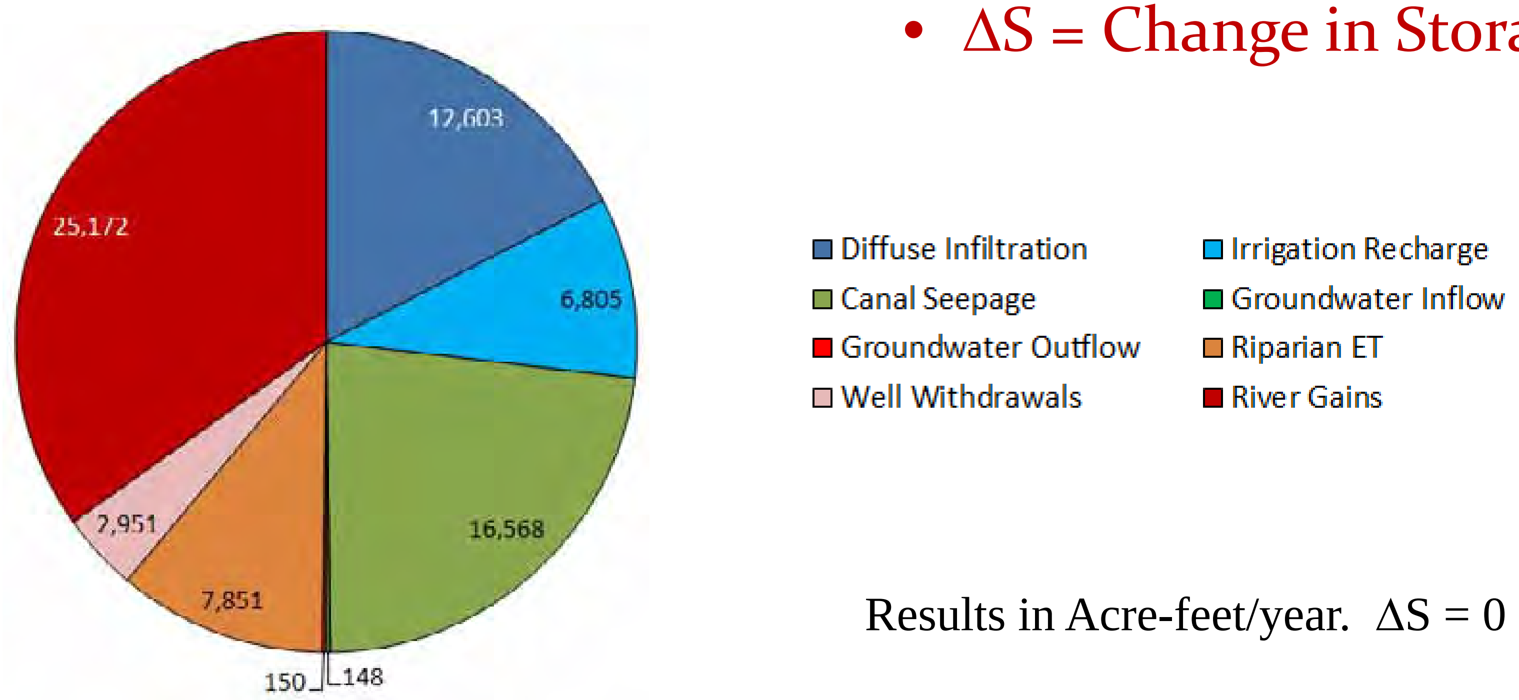
- Livestock – 23 ac-ft/yr
- Domestic – 112 ac-ft/yr
- Public water supply - 688 ac-ft/yr
- Irrigation – 2,120 ac-ft/yr



Groundwater Budget

$$DI + IR + CS + GW_{in} = RG + ET_r + WL + GW_{out} + \Delta S$$

- DI = Diffuse infiltration
- IR = Irrigation recharge
- CS = Canal seepage
- GW_{in} = Groundwater inflow
- RG = River gains/loses
- ET_r = Riparian evapotranspiration
- WL = Well withdrawals
- GW_{out} = Groundwater outflow
- ΔS = Change in Storage



Results in Acre-feet/year. $\Delta S = 0$

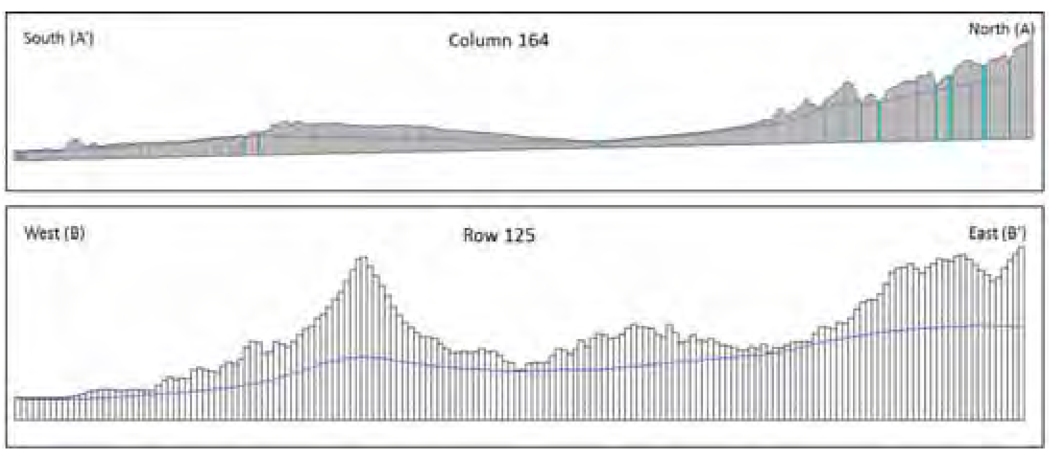
Numerical Modeling MODFLOW

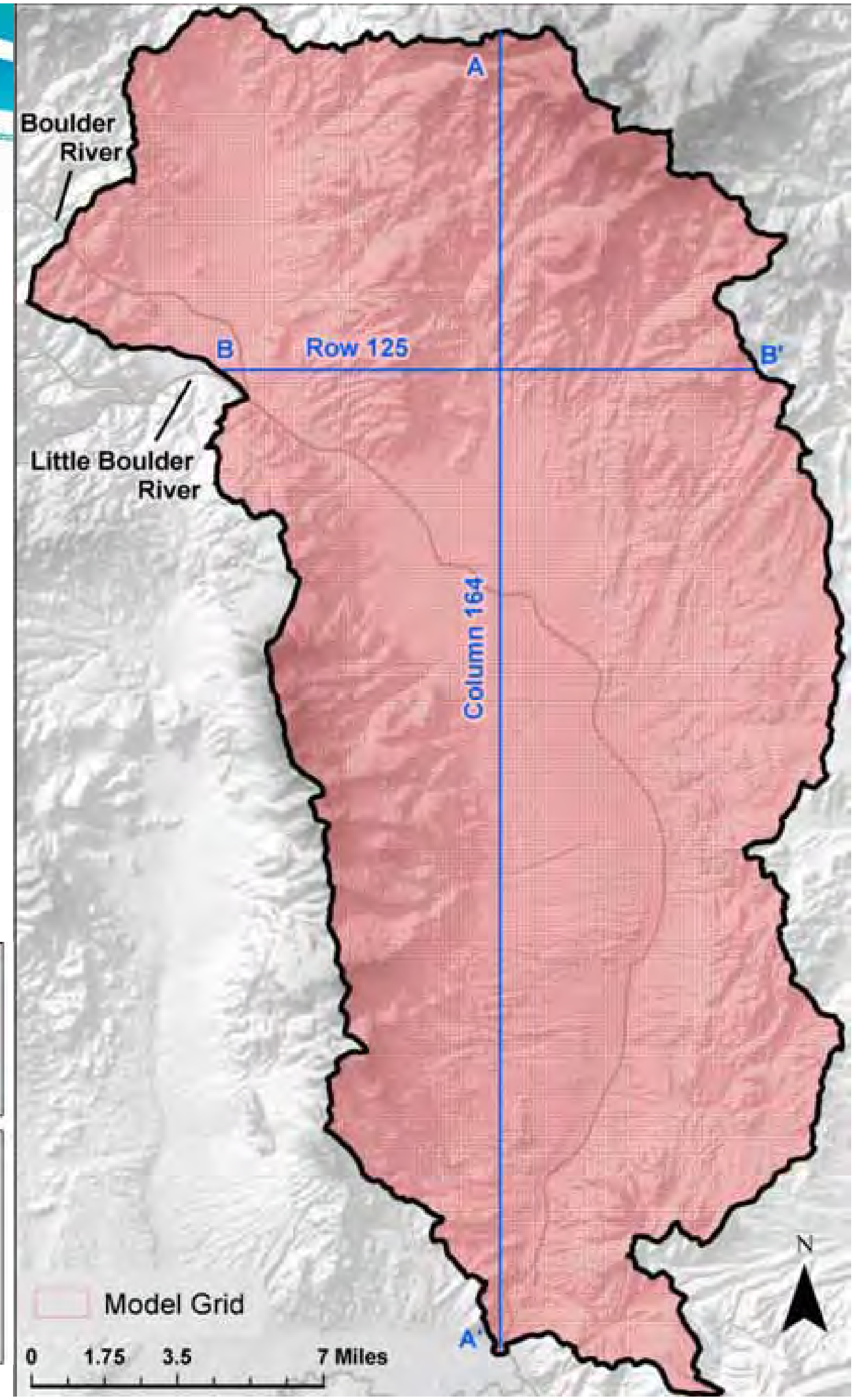
Break the area up into a network of cells

- rectangular prisms
- 400’ x 400’
- 1 Layer
- Top = land surface (DEM)
- Bottom = a sloping plane to keep the saturated thickness below the river at ~250’

Assign Boundaries, Sources and Sinks

- Add or remove water
- Recharge, rivers, canals, wells, etc.

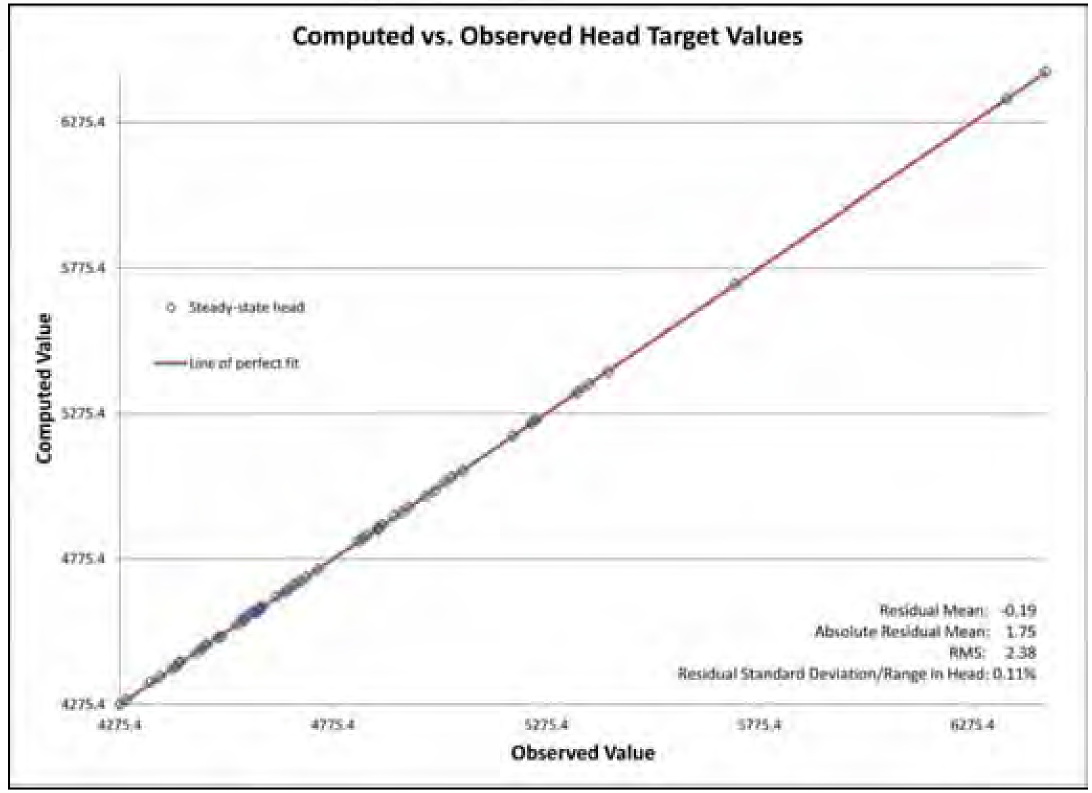




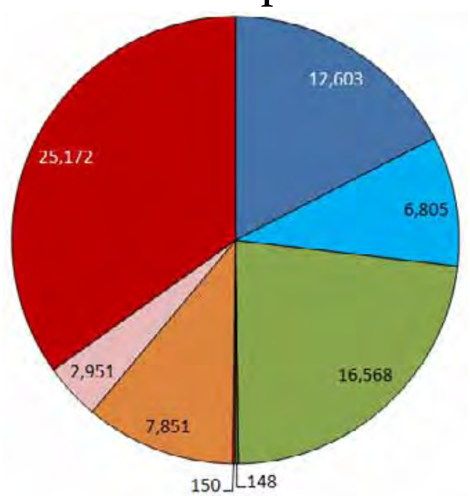
Numerical Modeling Calibration

Calibration

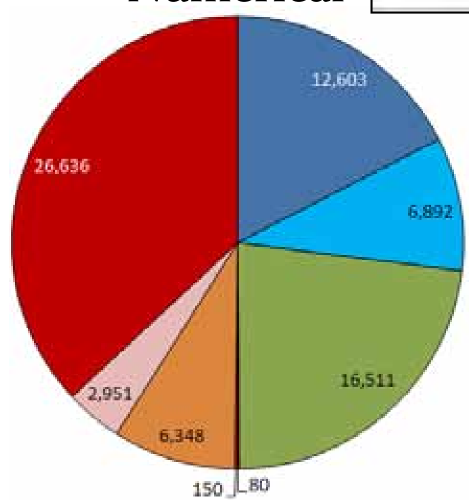
- Adjust model parameters within specified ranges until the model reasonably replicates observations
  - Groundwater elevations
  - Water Budget
  - Geology



Conceptual



Numerical

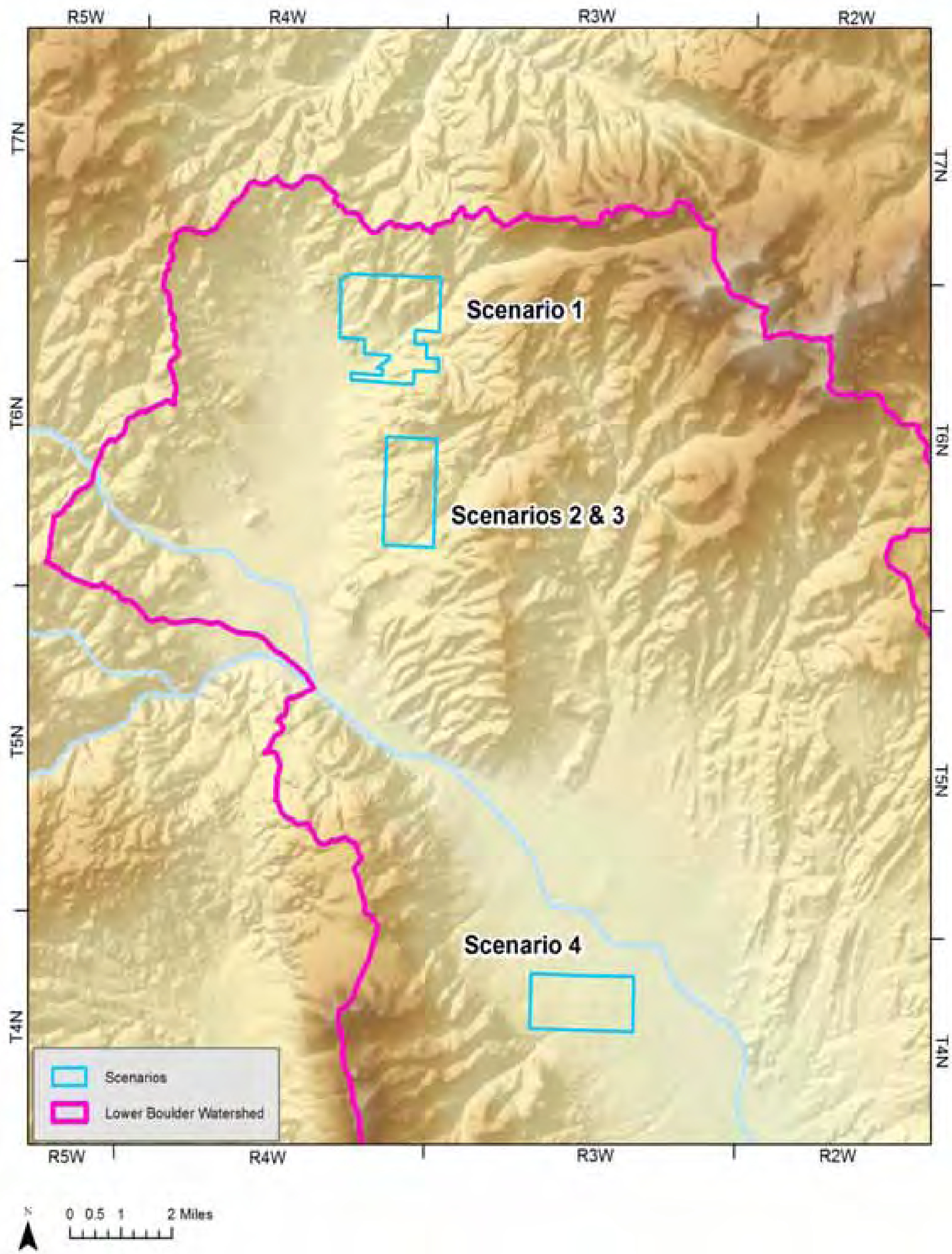


Numerical Modeling Area-Wide Scenarios

- Scenario 1 – Build out empty lots in Aspen Valley Ranch
- Scenario 2 – New sub-division
  - 64 residences on 20 acre lots
- Scenario 3 – New sub-division
  - Same area as 2
  - 128 residences on 10 acre lots
- Scenario 4 – New sub-division
  - South of Jack Creek
  - 64 residences on 20 acre lots

Note: 64 residences at 435 gpd/residence = 19 gpm

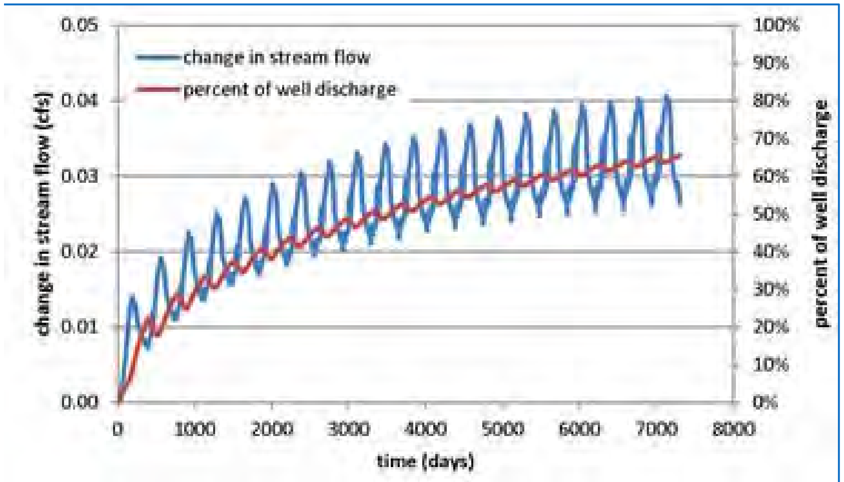
- average annual



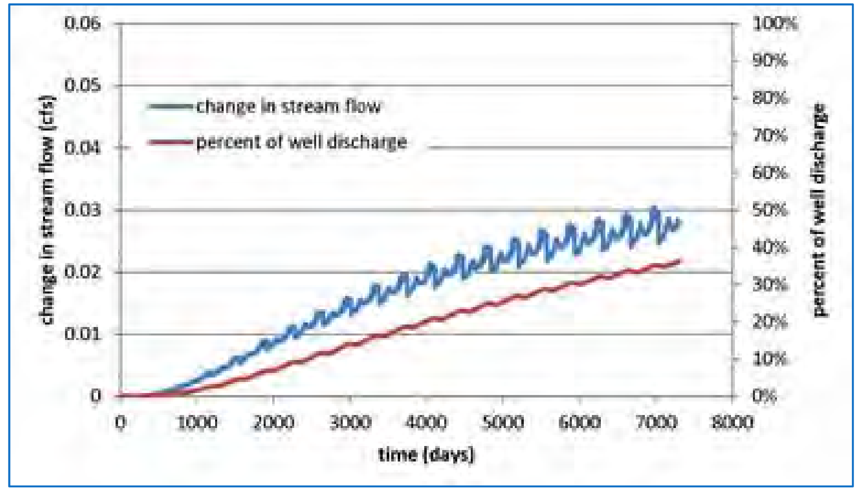
Numerical Modeling - Area-Wide Scenarios

Each Scenario is compared to the baseline model (current conditions) run over 20 years

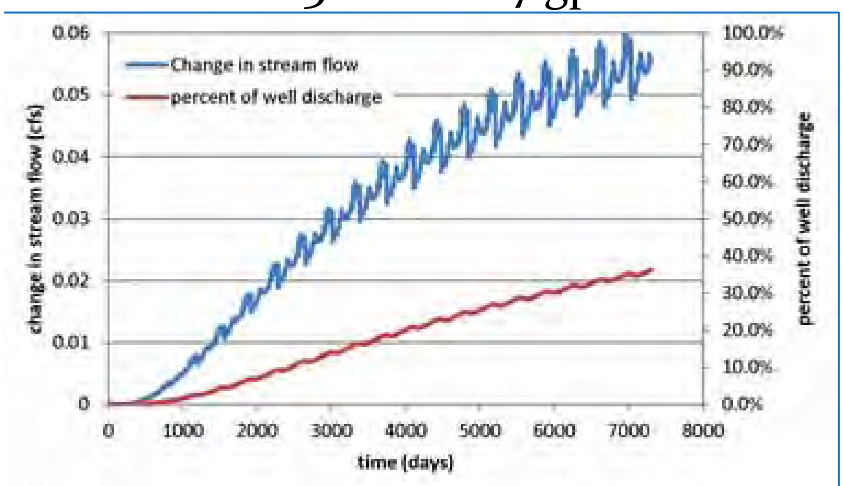
- Scenario 1: max ~ 18 gpm



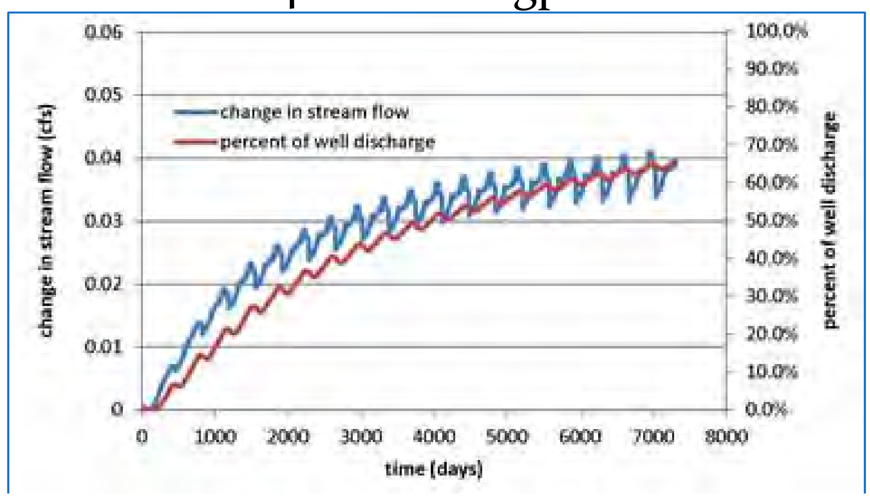
- Scenario 2: max ~ 13 gpm



- Scenario 3: max ~ 27 gpm

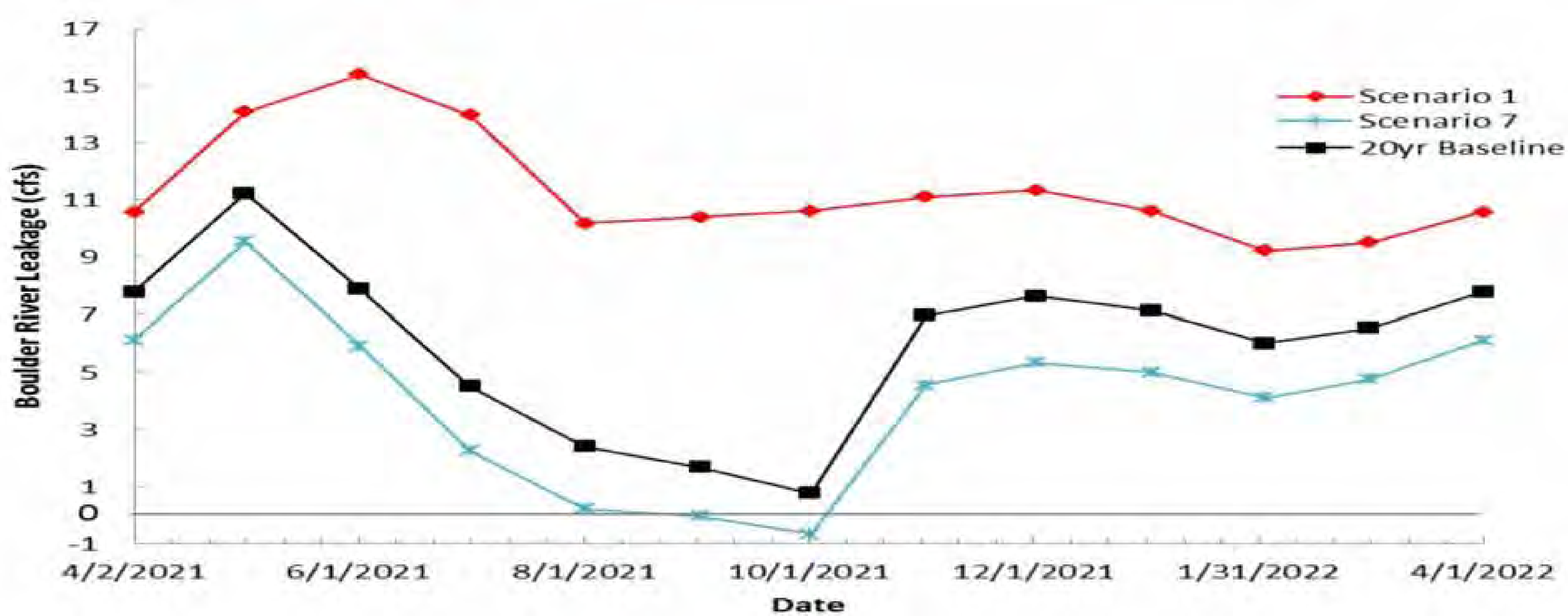


- Scenario 4: max ~ 18 gpm



Numerical Modeling Managed Recharge Grid

- Scenario 1 – Stop canal leakage
  - Canals provide a pre-existing proxy for infiltration basins.
  - Average decrease of 5.3 cfs in the Boulder River.
- Scenario 7 – Optimal Recharge
  - Murphy Canal used as source. Uses all water that can physically be diverted, and canal is lined.
  - 30 acre-ft/day
  - March 15 – May 9
  - Average increase of 1.9 cfs in the Boulder River



Major Questions

- How would increased groundwater development affect stream flows?
  - Pumping from housing developments maximum of 13-27 gpm (0.03-0.06 cfs)
    - Calculable, but too small to measure
  - The timing would be different if in the alluvium, but eventual maximum the same.
    - Closer
    - Higher T and S
  - Land uses changes may also affect stream flow
    - Reduced recharge

Major Questions

- Can managed recharge be used to enhance late-summer stream flows?
  - Yes – The physical setting appears workable
  - Unsaturated flow lag times
  - Dissolution of salts
  - Water Rights
  - Arsenic
  - Ice (March – May)
  - Cost

Draft Recommendations

- Depend on the objective for keeping more water in the Boulder River in the late-summer
  - Availability of Irrigation Water
    - Storage appears to be the most feasible way to increase irrigation water availability in the late-summer.
    - Difficult to permit large surface reservoirs
    - Groundwater Reservoirs
      - Managed recharge via infiltration basins or injection wells
      - Allow for natural flow to surface water, or extract with wells
      - Water Rights
        - Increased consumptive use
      - Water quality issues
        - Arsenic
        - Dissolution of salts

Draft Recommendations

- Depend on the objective for keeping more water in the Boulder River in the late-summer
  - Aquatic Life and Recreation
    - Changes in flow from housing developments are small compared to irrigation diversions
    - Voluntary reductions in irrigation diversions during low flows
      - Coordination among irrigators
        - If a senior water right holder voluntarily leaves some water in the river, they need to be confident that it will not just be diverted
      - Avoid un-needed diversions
      - Investments in canal operating and measuring structures
        - Structures that are easy to modify and read are more likely to be used.
      - Upper Jefferson and Big Hole Drought Management Plans

Questions?