Aquifer Storage Options

Montana

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Aquifer Storage Options (by any other name)

Artificial Recharge (**AR**): intentional banking and treatment of water in aquifers.

Artificial Recharge and Recovery (**ARR**): recharge to and recovery of water from an aquifer, that is, both artificial recharge of the aquifer and recovery of the water for subsequent use.

Managed (or Management of) Aquifer Recharge (**MAR**): intentional banking and treatment of water in aquifers (synonymous with AR).

Dry/vadose/drainage well: a well constructed in the interval between the land surface and the top of the static water level and designed to optimize infiltration of water

Underground Storage and Recovery (**USR**) or Managed Underground Storage (**MUS**): any type of project whose purpose is the artificial recharge, underground storage, and recovery of project water.

Aquifer Storage Recovery (**ASR**): injection of water into a well for storage and recovery from the same well.

Aquifer Storage Transfer and Recovery (**ASTR**): injection of water into a well for storage and recovery from a different well, generally to provide additional water treatment.

Sustainable Underground Storage (**SUS**): often used as a catch all term in place of ASR

For this discussion…

ASR injection or infiltration of surface water into an aquifer for later withdrawal by pumping.

ASR Operating Ranges (other states):

Well depths:	30 to 2,700 feet
Aquifer thickness:	20 to 400 feet
Storage Volumes:	100 to 270,000 acre-feet
Footprint:	~1000 feet, but can be much larger
Well capacity:	up to 25 acre-feet/day or 8 mgd
Well field capacity:	up to 490 acre-ft/day or 160 mgd

1 acre-foot = 325851 gallons

Assessment methods – some examples

Comparative Assessment of many sites (e.g. Brown's Rating System)

1.Pass Fail criteria:

Less than 3 miles to source water
Land use is not lakes, landfill, wetland, protected habitat

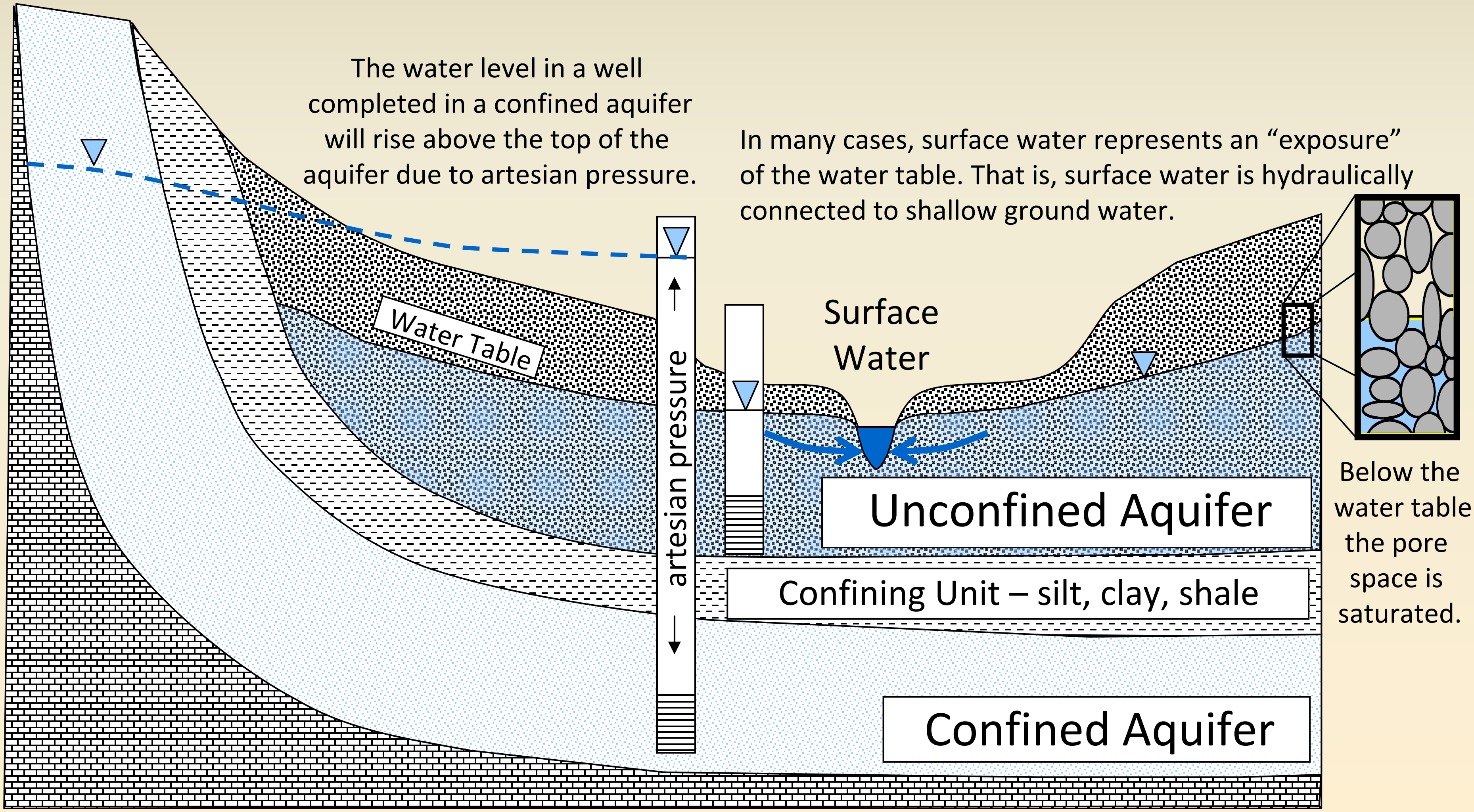
2.Rate parameters from 0 to 2, find percentage of ideal conditions for ASR:

Ecological Suitability	Transmissivity
Well Density	Aquifer Thickness
Source Water Quality	Ground Water Quality
Distance to Source Water	Hydraulic Gradient

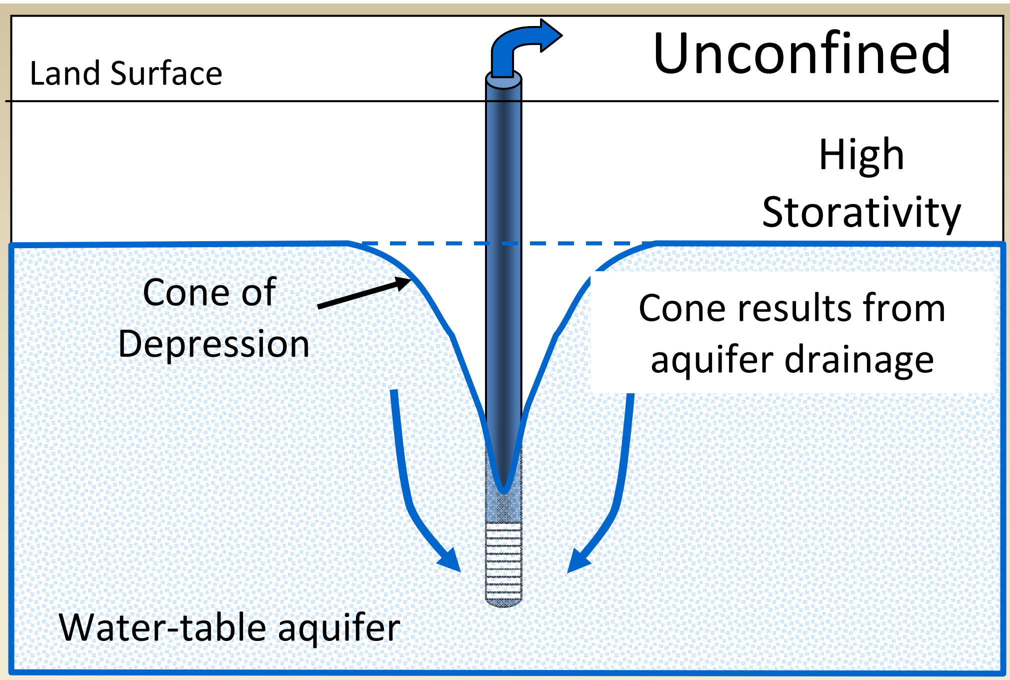
ASR Metric (site specific)

- aquifer properties (transmissivity, aquifer thickness, depth to water…)
- economic/engineering (transportation/injection, distribution, market price)

Confined versus Unconfined Aquifers

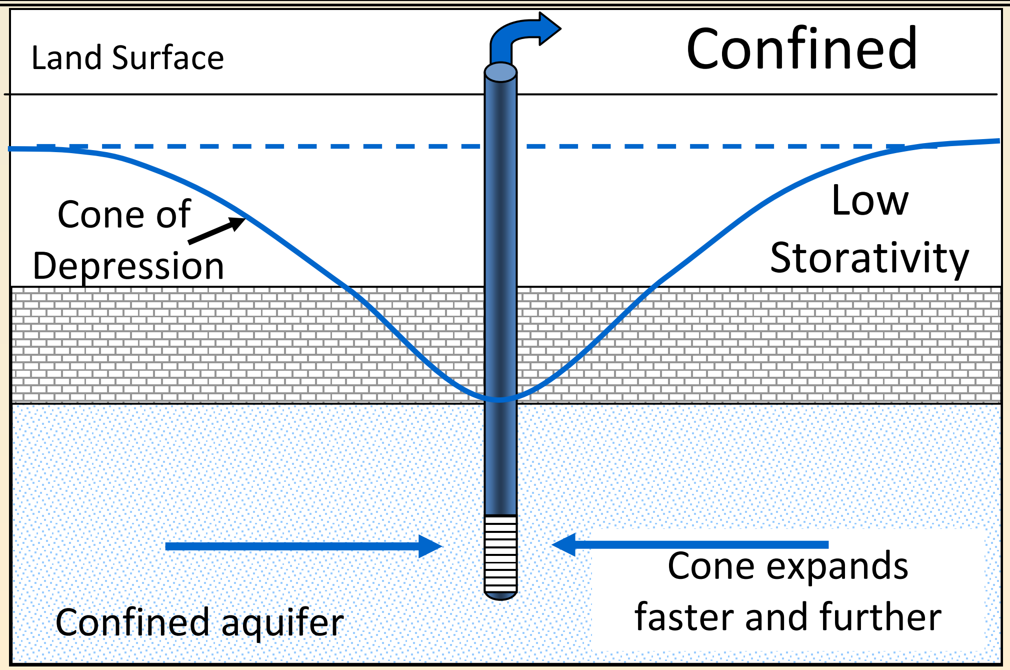


Aquifer Storage **PUMPING**



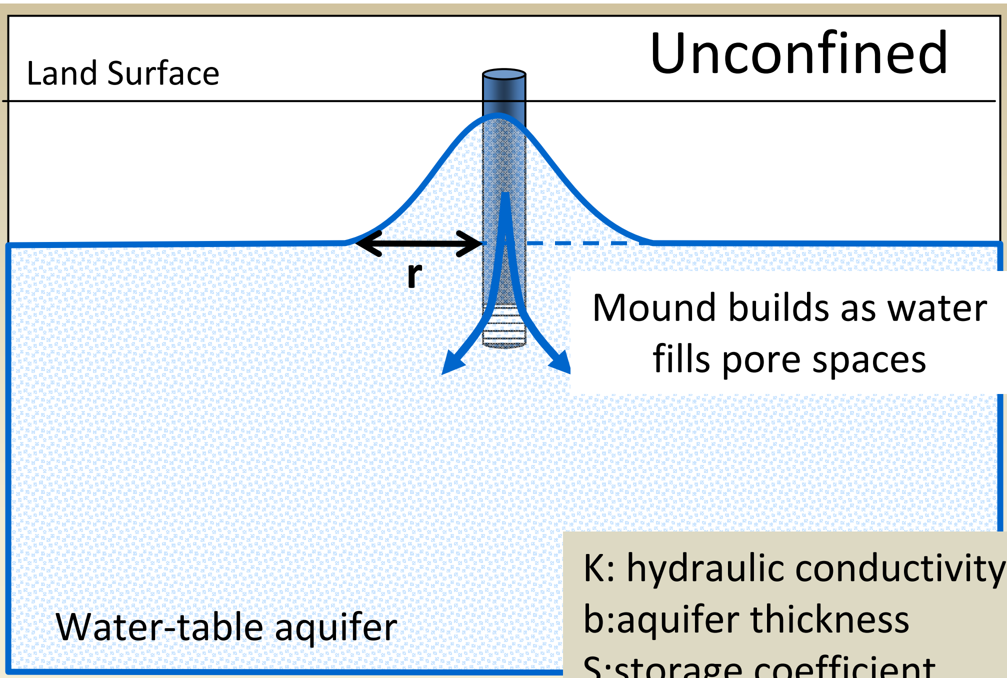
<u>Storage coefficient</u> determines the size and rate of cone development.

- In unconfined aquifers storage is large
- water comes directly from pore spaces
- expansion of the cone of depression is relatively slow and the cone is relatively small.



- In confined aquifers, storage is very small
- water is released by aquifer compaction due to the release of pressure
- expansion of the cone is relatively fast, and the cone may expand over large areas.

Aquifer Storage **INJECTION**

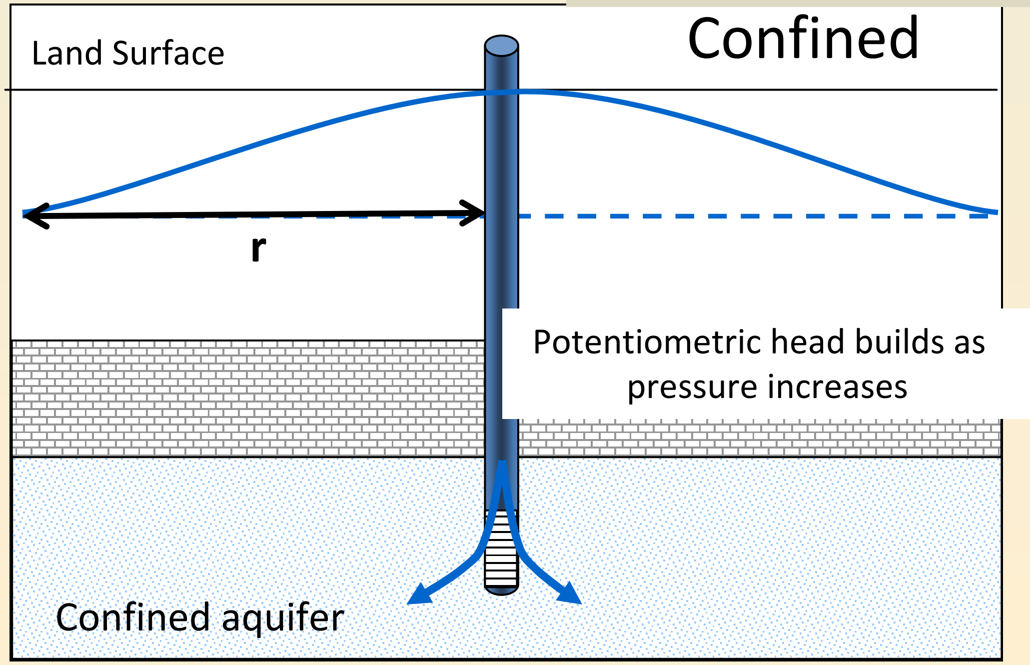


K: hydraulic conductivity
b:aquifer thickness
S:storage coefficient
Q: discharge/injection rate

<u>Storage coefficient</u> ALSO determines the size and rate of mound development. The solution is simply **inverted**.

Example (<u>unconfined</u>):
K=100 feet per day
b=100 feet
Q=96,250 cubic feet/day (500gpm)
t= 30 days
S=0.20

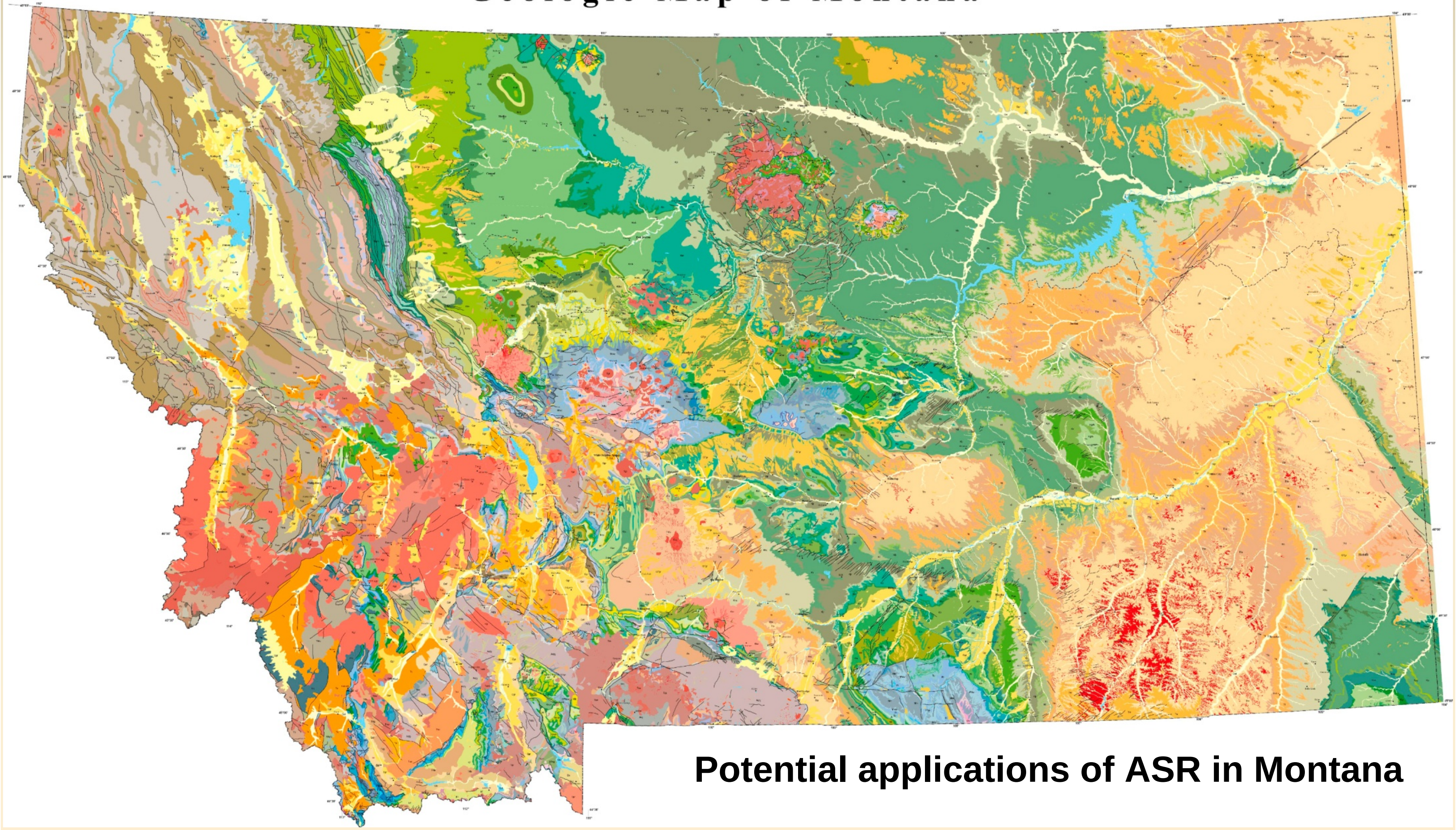
At r=2,640 feet, increase = 0.1 feet



Example (<u>confined</u>):
K=100 feet per day
b=100 feet
Q=96,250 cubic feet/day (500gpm)
t= 30 days
S=0.0002

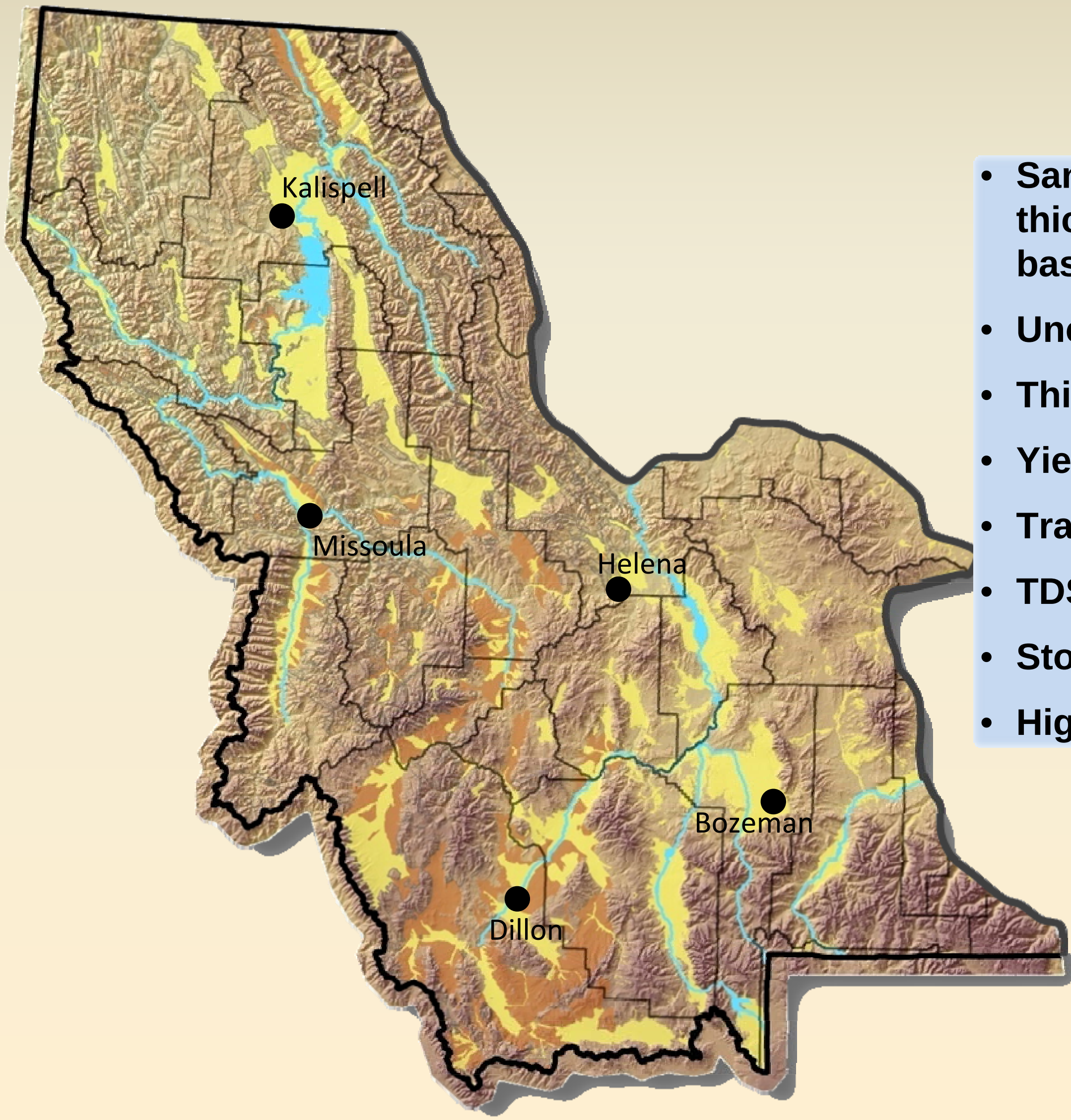
At r=52,800 feet, increase = 0.4 feet

Geologic Map of Montana



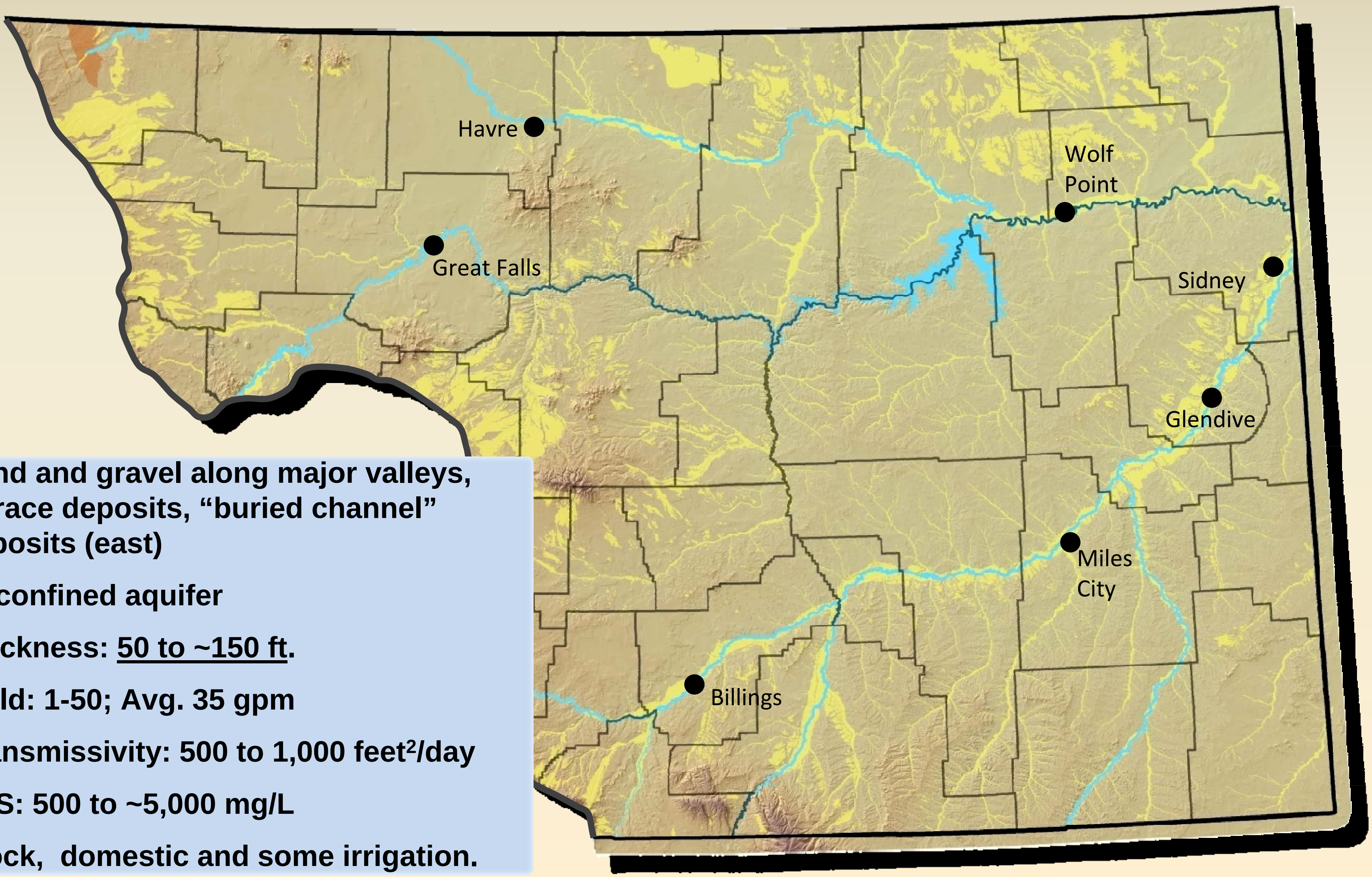
Potential applications of ASR in Montana

Basin fill/alluvial aquifers west



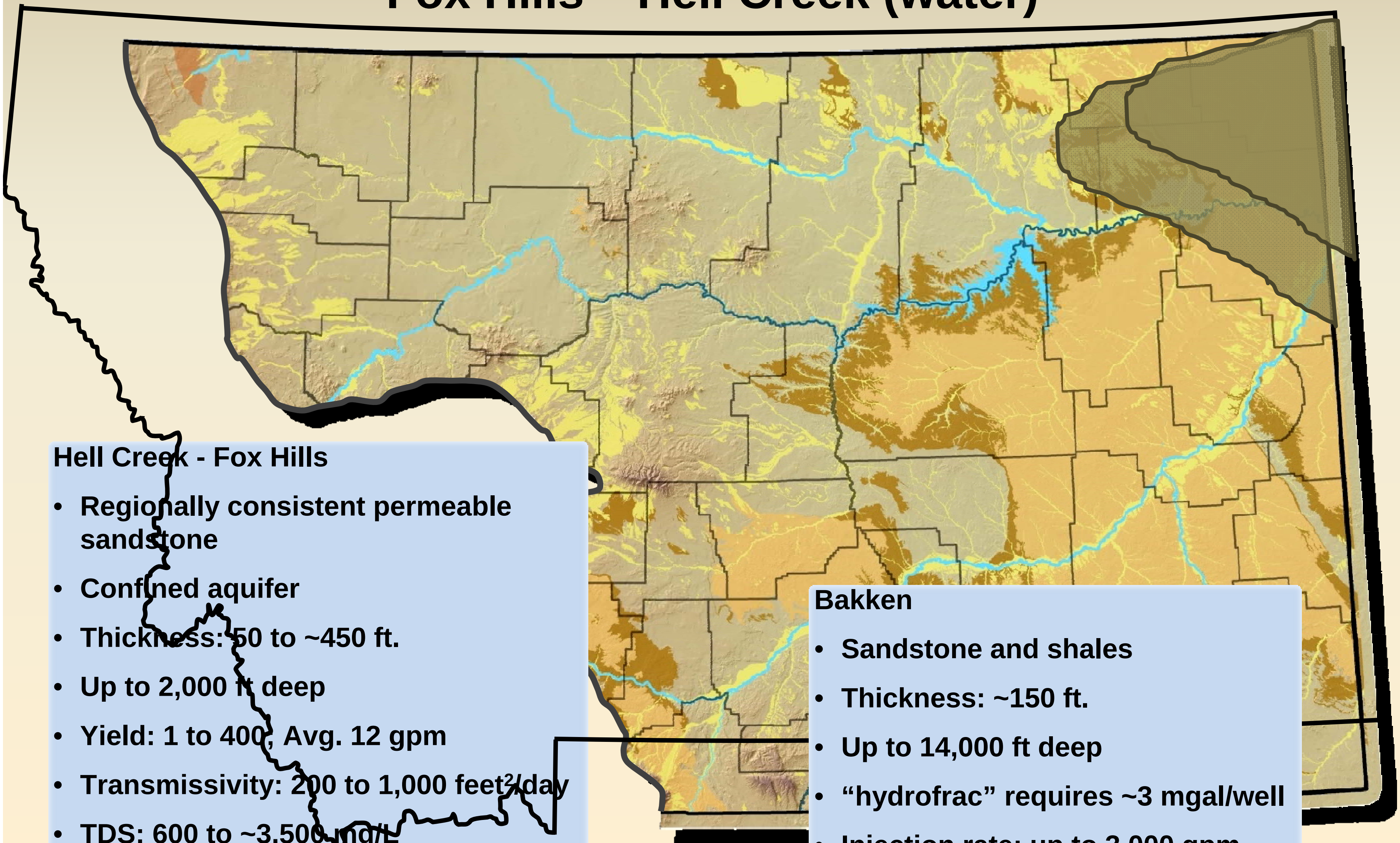
- Sand and gravel along major valleys, thick basin-fill deposits in intermontane basins
- Unconfined aquifers
- Thickness: 30 to >1,000 ft
- Yield: 1 to 3500; Avg. 35 gpm
- Transmissivity: 500 to 200,000 feet^2/day
- TDS: < 500 mg/L
- Stock, domestic and some irrigation
- High demand in small areas

Alluvial aquifers: east



- **Sand and gravel along major valleys, terrace deposits, "buried channel" deposits (east)**
- **Unconfined aquifer**
- **Thickness: 50 to ~150 ft.**
- **Yield: 1-50; Avg. 35 gpm**
- **Transmissivity: 500 to 1,000 $feet^2$/day**
- **TDS: 500 to ~5,000 mg/L**
- **Stock, domestic and some irrigation.**

Bakken Formation (oil)
Fox Hills – Hell Creek (water)



Hell Creek - Fox Hills

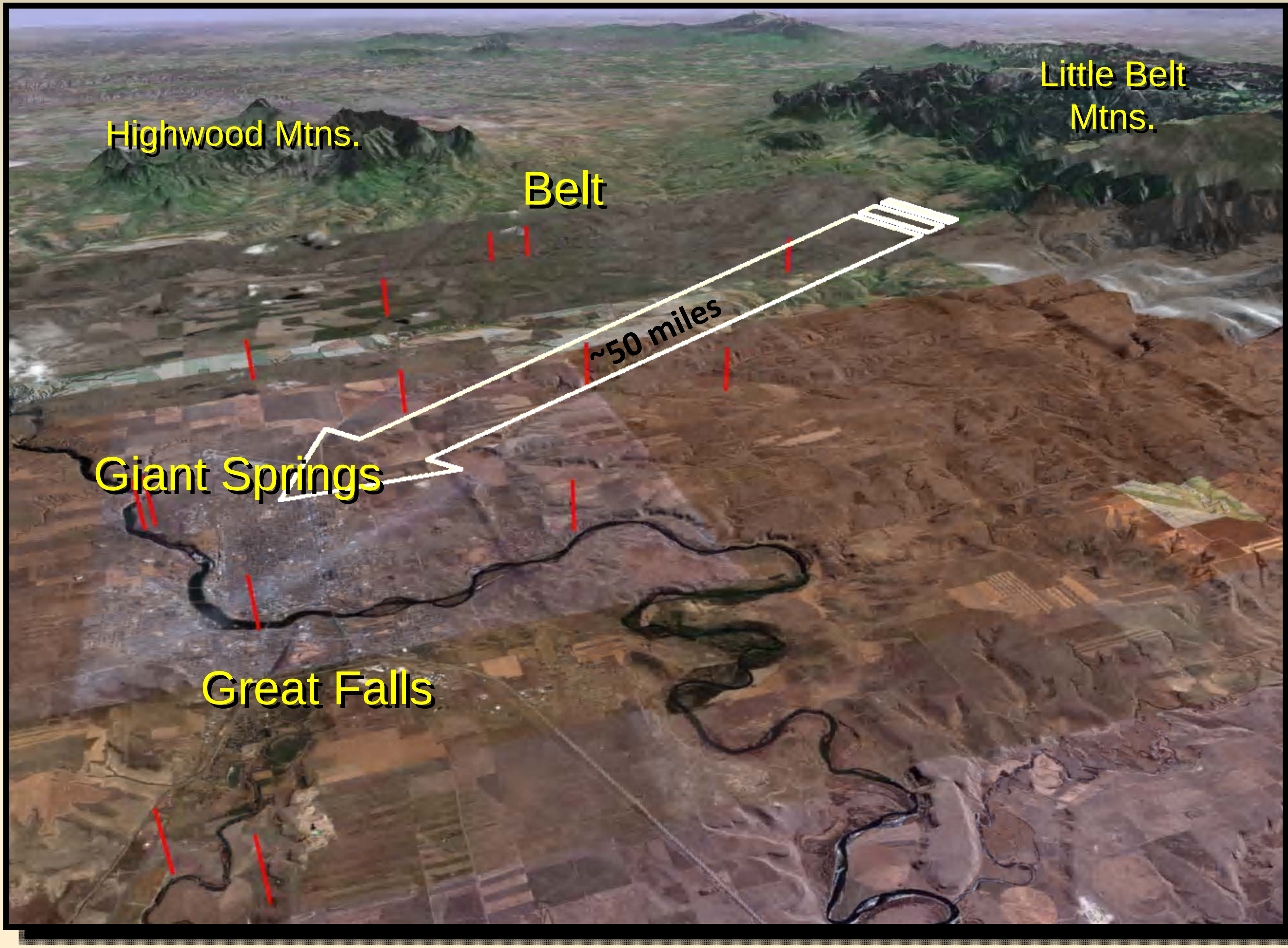
- Regionally consistent permeable sandstone
- Confined aquifer
- Thickness: 50 to ~450 ft.
- Up to 2,000 ft deep
- Yield: 1 to 400, Avg. 12 gpm
- Transmissivity: 200 to 1,000 feet^2/day
- TDS: 600 to ~3,500 mg/L
- Stock, domestic

Bakken

- Sandstone and shales
- Thickness: ~150 ft.
- Up to 14,000 ft deep
- "hydrofrac" requires ~3 mgal/well
- Injection rate: up to 3,000 gpm

Kootenai and Madison Formations

- Kootenai: sandstone and shale
- Madison: massive and bedded limestone
- Unconfined in Little Belt Mtns, confined at Great Falls
- Thickness: up to 1,500 feet; 270 feet deep at Giant Springs
- Yield: up to 5,000 gpm; Average = 35 gpm
- Transmissivity: 500 to 20,000 feet^2/day
- TDS: ~400 mg/L
- Domestic, municipal, and irrigation

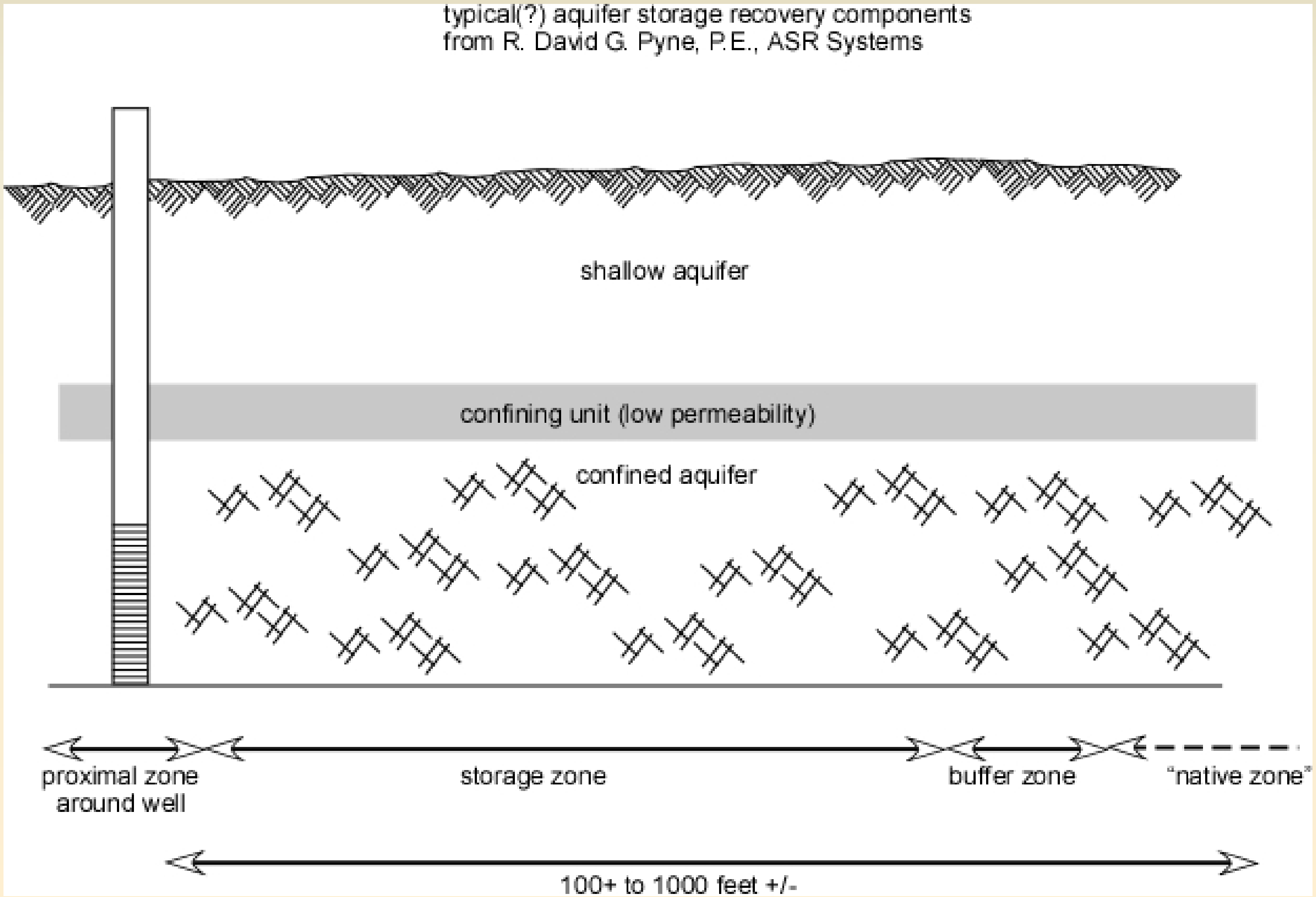

Highwood Mtns.
Little Belt
Mtns.
Belt
~50 miles
Giant Springs
Great Falls

Management Considerations (other states, grossly simplified):

- considered a beneficial use; no change in priority date; no increase in volume or rate of use (injection)
- pre-application conference is required for all applications
- existing water rights are used for the source water (artificial recharge requires a new permit)
- use of stored water MUST be same as that for the existing right?
- period of use does not change (for injection or both injection and withdrawal?)
- well injection only (no gallery)
- drinking water standard must be met; background concentrations of COCs must be established
- recovery can be 100%, but is often less; 2 to 5% is "taxed" to allow for water lost
- a ground-water level and water-quality monitoring plan (aka work plan) is required
- testing (demonstration?) is required; a limited license is issued (5 years is common)

Management Considerations (other states):

- minimum performance requirements for footprint / storage zone, buffer zones, etc.



Management Considerations (continued):

Geochemistry

- Chemical reaction in the mixed solution of two (or more) waters
  - Background or baseline conditions must be known
- Rock (aquifer matrix) – (mixed)water interaction
- Ion exchange with clays/minerals
- Dissolution/Precipitation of aquifer minerals – may produce physical changes to aquifer properties
- Pathogens / Pharmaceuticals

Management Considerations (tools):

Monitor…Model…Manage…Monitor…

- Physical system
    - Ground water flow modeling (MODFLOW)
- Geochemical System
    - reaction and mixing models
- Combinations
    - Flow path modeling, “contaminant” transport