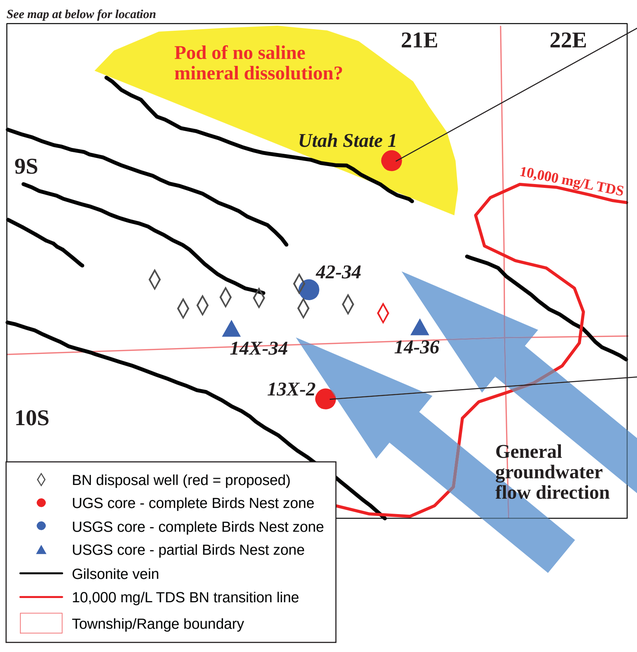
RESULTS: INFLUENCE OF GILSONITE VEINS

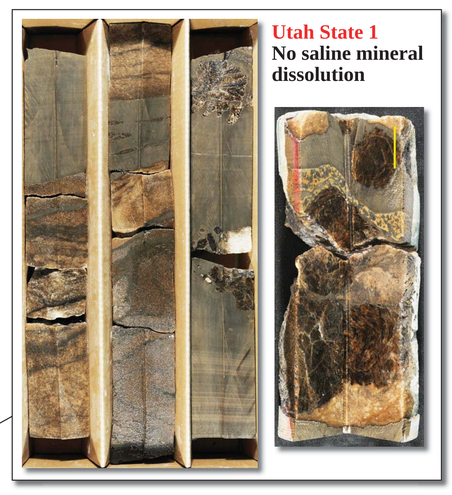
Gilsonite (a solid hydrocarbon) occurs in veins ranging in thickness from a couple inches to tens of feet and originates in the rich oil shale beds of the upper Green River Formation, continuing up to the surface, cross-cutting the Birds Nest aquifer. Questions remain as to how these veins might affect groundwater movement through the Birds Nest aquifer; whether they act as barriers to flow or whether they create vertical and/or horizontal pathways for water transmission.

Core evaluation, evidence for barrier:

Near the basin's depocenter, several cores exist that recovered the entire Saline zone. Most of these cores (e.g., 13X-2) show significant saline mineral dissolution, in fact, Anadarko has begun disposing saline water into the Birds Nest in this area. However, there is one well (Utah State 1) with core slightly to the north, which shows no signs of saline mineral dissolution. This core is separated from the others by a gilsonite vein. With the beds dipping to the northwest, water generally travels from southeast to northwest. Water within the Birds Nest has dissolved the saline minerals to the south of the vein, but the gilsonite vein seems to stop water from reaching the area on its northern side, creating a zone of no dissolution. It is assumed that similar areas of no saline mineral dissolution exist throughout the Birds Nest aquifer, but it is difficult to quantify these areas without core.

See map at below for location





Utah State 1
No saline mineral dissolution

13X-2
Significant saline mineral dissolution

Within the mined out Cowboy vein which cross cuts the Birds Nest aquifer (red circles indicate saline nodules)

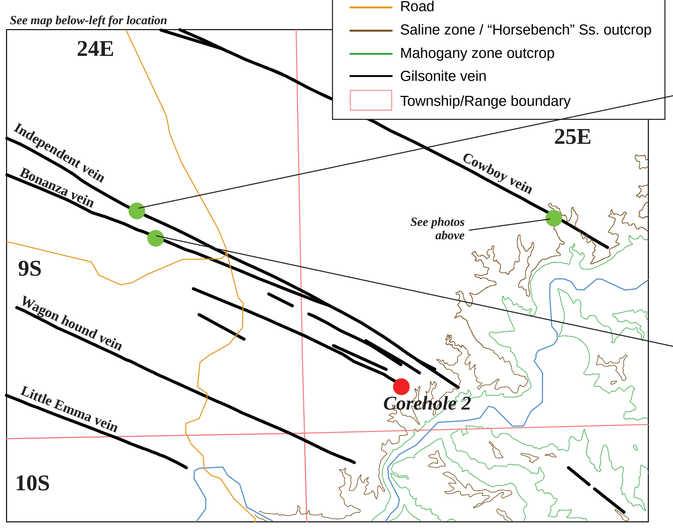
Nahcolite nodules replaced with gilsonite within wall of mined out vein

Cowboy vein

Gilsonite mine tour, evidence for both transmission and barrier:

UGS geologists toured two mines in different gilsonite veins to assess how groudwater interacts with the veins. The first mine contained a highly fractured type of gilsonite which easily transmitted water through the vein. The second mine contained a type of gilsonite that was very solid and transmitted no water. These observations suggest that gilsonite veins could act as both barriers or conduits for water depending on the type of gilsonite in the vein. However, gilsonite type at depth is nearly impossible to identify in the absence of an actual mine.

See map below-left for location

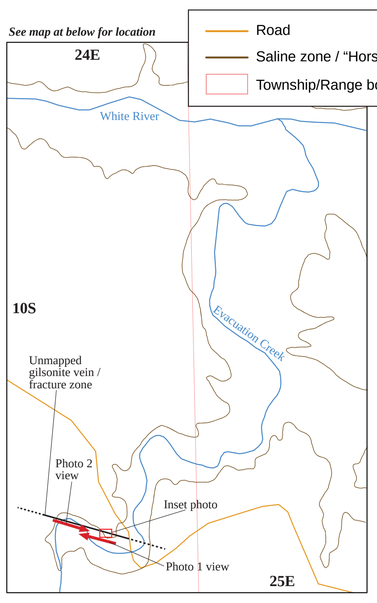


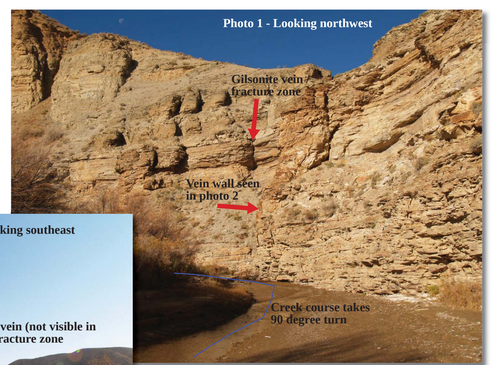
Independent vein mine
- "Solid" gilsonite
- 230 ft depth (Uinta Fm.)
- Minor water inflitration from wall rock

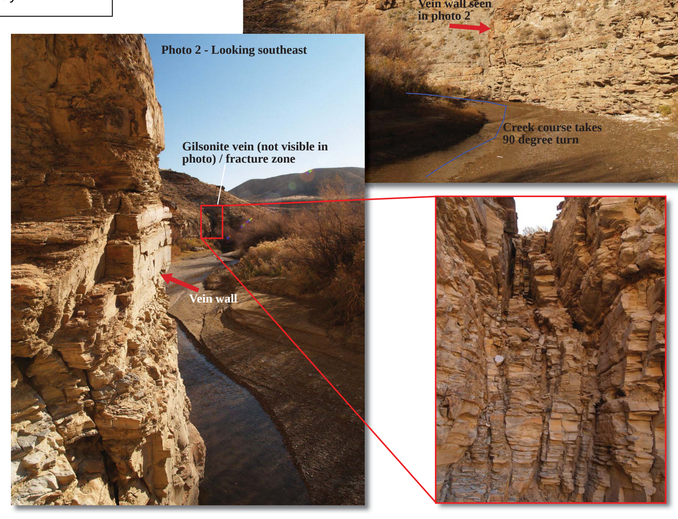
Bonanza vein mine
- Highly fractured gilsonite
- 630 ft depth (Uinta Fm.)
- Lots of water inflitration from wall rock and vein

Gilsonite vein and associated fractures influencing course of Evacuation Creek:

See map at below for location

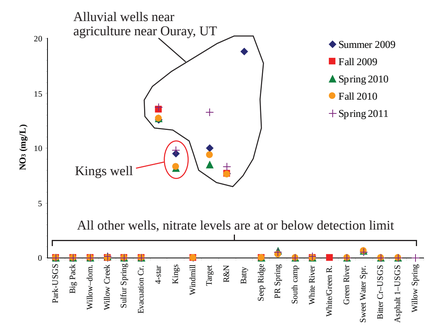




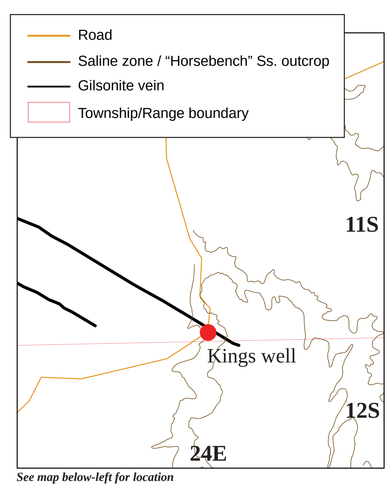


Possible transmission of contaminated surface water into the groundwater aquifer via a gilsonite vein:

Water from the Kings well, which is completed in a shallow bedrock aquifer, has elevated nitrate levels. This might be expected from alluvial aquifers in an area with significant agriculture, but not in a bedrock aquifer from an area with no farmland. The Kings well does supply water to grazing stock - waste water from the stock might be traveling down the gilsonite vein and into the bedrock aquifer.



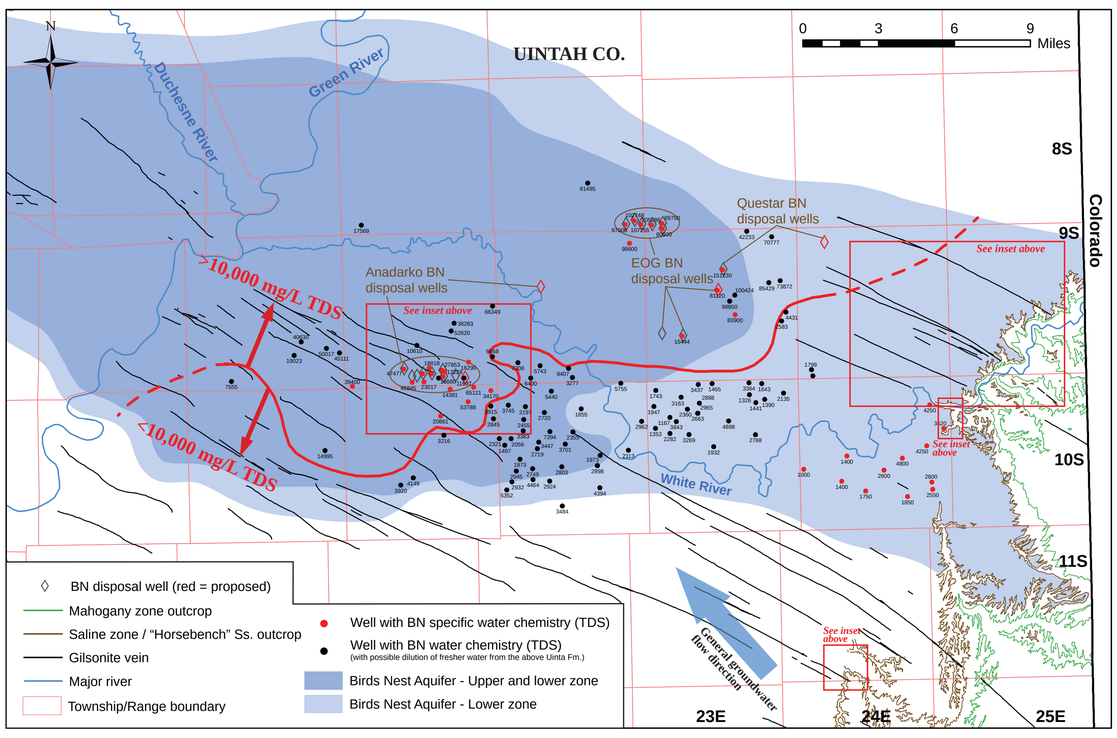
Seasonal nitrate concentrations from select wells in Uintah County



See map below-left for location

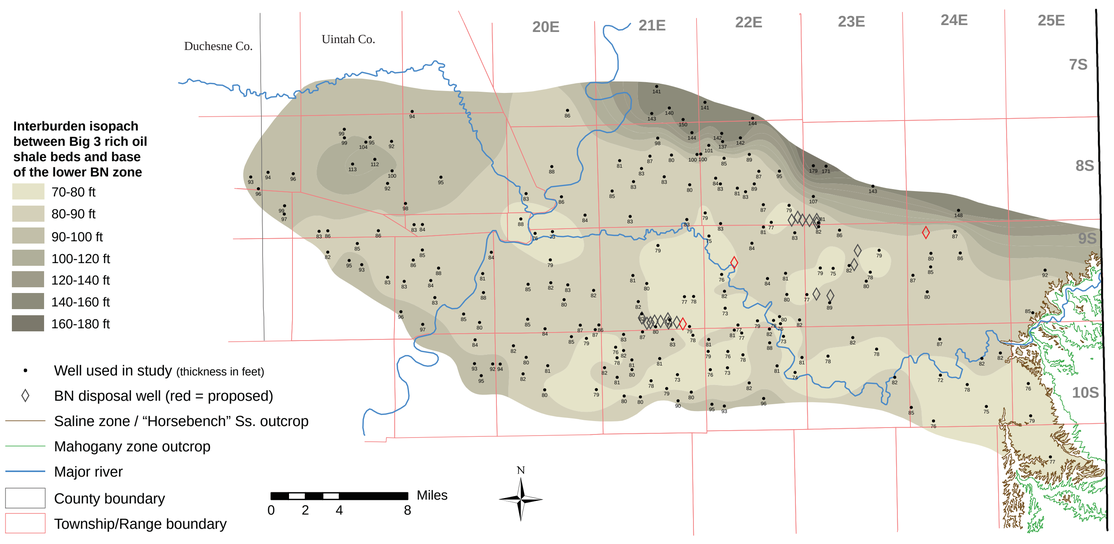
RESULTS: WATER CHEMISTRY

Chemistry of Birds Nest water (mostly acquired by Anadarko) in the north (averaging >10,000 mg/L TDS and as high as 100,000 mg/L TDS) is distinct from that in the south (averaging <10,000 mg/L TDS and down to near 1000 mg/L TDS). This abrupt change in water chemistry is most likely due to the differing amounts of saline mineral dissolution in the two areas; the southern area may have been flushed clean, whereas saline minerals in the northern area are still actively dissolving. This transition is important because produced saline water can only be disposed into the aquifer where the water is currently 10,000 mg/L TDS and above (only north of the red line). In some areas, like near Anadarko's disposal wells, it seems that the presence of gilsonite veins has had an influence on the shape of the 10,000 mg/L TDS line. The gilsonite veins could be acting as barriers, creating underground channels of groundwater flow (see discussion above).



RESULTS: INTERBURDEN - BIRDS NEST TO ECONOMIC OIL SHALE

The base of the lower Birds Nest aquifer is mostly between 70 and 100 ft (except in the north) above the top of economic oil shale, picked at the top of the Big 3 oil shale beds (see panel 3). Saline water disposal could impact development of the underlying oil shale if vertical migration of water occurs via fractures or joints.



RESULTS: STORAGE VOLUME ESTIMATION

Evacuation Creek outcrop

Red circles = open saline nodule cavity

Macro-porosity estimations based on outcrop

Approximate space for saline water - north of 10,000 mg/L TDS line

Upper Birds Nest aquifer:

Area = 360 miles^2 (930 km^2)
Mean thickness = 81.7 ft (24.9 m)
Total volume = 8.2x10^{11} ft^3 (2.3x10^{10} m^3)
Macro pore volume (at 2.5%) = 2.0x10^{10} ft^3 (5.8x10^8 m^3)
= 469,000 acre feet

Lower Birds Nest aquifer:

Area = 499 miles^2 (1290 km^2)
Mean thickness = 85.2 ft (26.0 m)
Total volume = 1.2x10^{12} ft^3 (3.4x10^{10} m^3)
Macro pore volume (at 2.5%) = 3.0x10^{10} ft^3 (8.5x10^8 m^3)
= 680,000 acre feet

Complications:

- Calculations do not take into account fracture porosity and micro porosity
  - Highly varible and hard to quantify
- Calculations do not take into account the large areas with no saline mineral dissolution
  - These areas are very difficult to quantify

CONCLUSIONS / SUGGESTIONS

The Birds Nest aquifer has significant potential as a saline water disposal zone...

- The aquifer currently contains highly saline water in areas generally north of T. 10 S.
- There is a large amount of potential storage space (on a vacuum) due to the dissolution of saline minerals and natural fracturing.
- The aquifer is relatively shallow (could be good or bad?).
- The aquifer is located close to significant natural gas drilling activity.
- Disposal will be associated with leaner oil shale deposits with marginal economic potential.

However, disposal into the Birds Nest poses unique challenges and risks...

- There are potentially large areas with no saline mineral dissolution, thus reducing potential.
- Cross-cutting gilsonite veins and associated fractures could transmit water vertically through the section, posing risks to "fresh" water aquifers and future oil shale operations.
- Monitoring wells will be key, but add expense.

Additional Conclusions:

- The maps of the Birds Nest aquifer can guide where saline water disposal might be possible. Additional drilling should be performed to confirm the presence of a suitable disposal zone (e.g., it is currently unclear where all large zones of no saline mineral dissolution exist).
- Wells for saline water disposal into the Birds Nest aquifer should be accompanied by down-dip water monitoring wells in aquifers both above and below the disposal unit.
- The effect of saline water disposal into the Birds Nest aquifer on oil shale development depends on the value of leaner deposits.
  - The Saline zone in general will likely be bypassed by both mining and in-situ processes.
  - Mining will most likely focus on outcrop sections of the organic-rich Mahogany zone, ~300 ft below the Saline zone.
  - In-situ extraction will likely target deposits below the Big 3 oil shale beds, ~80 ft below the Saline zone.
  - However, it is still unclear if water can travel vertically through the section via fractures or gilsonite veins, adversely affecting future development.
- Gilsonite veins may act as barriers to flow in some areas and pathways for vertical movement of water in others, depending on the type of gilsonite (i.e., solid or fractured) and vein thickness.
  - Little information is available on the gilsonite veins at depth near the center of the basin where active saline water disposal is taking place.
- Flow tests should be conducted in wells near gilsonite veins to test for linear movement of water.
- Tracer tests should be conducted to determine the flow path(s) and destination of the water injected in the Birds Nest aquifer.