Saga of the Dakota Sandstone

History

1. Lewis and Clark 1804-1806 described Dakota sandstone near Omaha in bluffs on west side of Missouri R. - "yellow, soft sandstone".

2. In 1853 Meek and Hayden described 400' type section —sandstone alternating with shales and lignite in western Nebraska.

3. Homestead Act (1862) opened up western frontier for farming. High rainfall in 1870's led to general belief that "rain follows the plow" (Cyrus Thomas).

4. USGS founded in 1879 under Clarence King and John Wesley Powell became next director in 1881.

5. Wounded Knee Dec. 1890.

6. Drought from 1886 - 1889 and into 90's led to 10,000 wells in S. Dakota and 8,000 wells in N. Dakota by 1923. Question before Congress in 1891 was whether or not this artesian water of the Dakota sandstone was adequate to develop the whole west. Powell's concluding testimony includes the following:

> It has been shown that the supply of water to be obtained through artesian wells is narrowly limited, the limitation arising from natural conditions of reception by reservoirs [water-bearing formations], transmission through them, and leakage from them and being expressed practically through the interference of wells one with another. The permanent flow is in some cases much less than the initial flow. * * * While the Dakota sandstone is one of the most important of the known artesian reservoirs, the amount of land wich can be redeemed to agriculture through its aid is yet so small that disastrous results might follow if great expectations were aroused in regard to it.
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> It is estimated that if all the water received by the Dakota sandstone could be brought to the surface by artesian wells, it would cover to the depth of 1 foot an area of land equivalent, at the utmost, to a belt one-fifth of a mile wide and extending from the Canadian boundary to the Mexican.
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> This is the outside limit for permanent flow. The temporary flow may be large but can not be estimated from existing data. Such is the complexity of conditions and so great is the danger of disaster through expensive exploitation in ignorance of the true conditions that the subject demands the most skillful investigation which can be bestowed.

Hydrogeology

1. Darton (1897) "Preliminary Rept. on Artesian Waters of a Portion of the Dakotas."

2. Dakota s.s. somewhat over 100' thick throughout S. Dakota. Outcrops near Black Hills. At n = 15%, water in storage is 1.1 billion A.F. = 20' water over all of S. Dakota.

3. Oscar E. Meinzer (1928), Compressibility and elasticity of artesian aquifers, *Econ. Geology, v. 23*, 263-291. — Water balance study of east-west line of 18 townships (T. 129. N., Rs. 48–65 W.) at N/S Dakota border. Average withdrawal of 3000 gal/min for 38 years between 1886 and 1923. But discharge declined with time:

   Q = 10,000 gpm in 1910
   Q = 5,000 gpm in 1915
   Q = 2,000 gpm in 1920
   Q = 1,000 gpm in 1923

4. Is it from recharge where the Dakota s.s. crops out in the Black Hills?

   Estimate using Darcy's law: Q=KIA

   K = 10^{-4} m/s

   I = 10 ft/mile

   A = 6 miles (10,000 m) by 60 ft (20 m)

   Q = 600 gal/min

   Meinzer calculated 500 gal/min at most.

   From where does the other 2500 gal/min come?

5. Answer is that aquifer is compressible, e.g., F. H. King's observation that "in one of his observation wells situated near a railroad the water level rose whenever a train went by but fell again as soon as the train had passed . . . a heavy freight train produced a greater rise than a lighter and swifter passenger train and . . . a locomotive alone did not produce any noticeable effect." Quantitatively, equate volume of water

$$2500\text{gal/min} \times 38\text{years} = 1.9 \times 10^8 \text{m}^3$$

   to volume of aquifer that must be reduced over the area of 18 townships (648 square miles) times the amount of vertical compression, *Deltab*. The answer is *Deltab* = 10cm, which is a vertical strain of

$$\epsilon_z = \frac{0.1\text{m}}{20\text{m}} = 0.5\%.$$

   The vertical compressibility $\beta_p = \epsilon_z / \Delta\sigma_v^{\text{eff}}$, where by the law of effective stress the increase in vertical stress is the decrease in fluid pressure $\sigma_v^{\text{eff}} =$

$-\Delta p$. The fluid pressure declined by about 150 psi or 1 MPa over the 38 years. Therefore, $\beta_p = 5 \times 10^{-9}\text{m}^2/\text{N}$. The compressibility of water $\beta_w = 4.6 \times 10^{-10}\text{m}^2/\text{N}$ and because water occupies only 15% of the bulk volume, the amount of water produced from expansion of the water is $n\beta_w = 0.7 \times 10^{-10}\text{m}^2/\text{N}$, about 70 times less than the compressibility of the aquifer itself.