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POLICY MEMO: DUAL WELL COMPLETIONS IN THE HIGH PLAINS AQUIFER AND LANCE FORMATION, SOUTHEAST WYOMING

TO: State Engineer's Office

FROM: Patrick T. Tyrrell, State Engineer

EFFECTIVE DATE: June 27, 2006

SUBJECT: Dual well completions in the High Plains Aquifer and Lance Formation, Southeast Wyoming

Summary:

The State Engineer's Office will not approve applications or statements of completion for wells that are open to both the High Plains Aquifer and the Lance Formation in southeastern Wyoming.

Authority:

Wyoming Statute 41-3-909 (State Engineer; powers generally) gives the State Engineer the authority to regulate well construction:

> a) In the administration and enforcement of this act [W.S. 41-3-901 through W.S. 41-3-938] and in the effectuation of the policy of the state to conserve its underground water resources, the state engineer is authorized and empowered on advice and consent of the board of control:
>
> i) To prescribe such rules and regulations as may be necessary or desirable to enable him to effectively administer this act. . .
>
> vi) To establish standards for the construction of wells . . .

Regulatory Justification:

It has been the practice of the State Engineer to not allow wells to be completed in more than one aquifer. The reasons for this have not been well documented or publicized but agree with practices in many other states and countries. Some states, such as Colorado, have explicit rules prohibiting production from more than one aquifer by the same well.

If there are large head (water level) differences between aquifers, the aquifer with the higher head will drain into the aquifer with the lower head, to the detriment of any users of the higher-head aquifer. Correcting such a situation could require drastic measures, such as plugging the connecting well. Completions in multiple aquifers would greatly complicate the regulation and management of water supplies should the need for regulation or management ever arise.

Water quality and pollution are probably greater concerns in the minds of the public. An aquifer with good quality water could be degraded over time if it is connected with an aquifer of poorer quality water by a well or borehole. If a well becomes contaminated for any reason, it is easier to control and clean up the pollutants if they are restricted to only one aquifer. These concerns may also be the major justification for the Wyoming Department of Environmental Quality's rule for the design and construction of public water supplies that prohibits multiple completions (see Chapter 12, Section 9).

In most of southeastern Wyoming, the Lance Formation is not targeted for water wells because more productive zones at shallower depths in the High Plains aquifer are present. However, rural growth in Laramie County has increased use of the High Plains aquifer and extended use to areas where the High Plains aquifer is not very productive. For whatever reasons, wells are commonly being drilled to depths of 500 to 600 feet around Cheyenne and could penetrate the top of the Lance Formation. Some applicants are intentionally targeting the Lance Formation but a larger number may end up with a dual completion inadvertently. This policy has been adopted to prevent or minimize damage to aquifers caused by manmade hydraulic connections. Although the impetus for this policy has come from activities in Laramie County, the policy is more generally applicable to other parts of southeastern Wyoming with similar hydrogeologic conditions.

Stratigraphy:

The Lance Formation consists of interbedded shale, siltstone, sandstone, carbonaceous shale, and coal which was deposited over most of southeastern Wyoming during the Upper Cretaceous epoch, between 96 million and 66 million years ago[1]. The Lance Formation conformably or disconformably overlies the Upper Cretaceous Fox Hills Sandstone of well-sorted, fine- to medium-grained, quartz-rich sandstone and minor silty sandstone and sandy shale. The Lance Formation represents the beginning of continental deposition following the retreat of the Late Cretaceous western interior seaway and the commencement of Laramide tectonism.

The Lance Formation is named for Lance Creek, Wyoming, and crops out around the margins of the Powder River structural basin. It is exposed at the surface in Goshen Hole between Hawk Springs Reservoir and Yoder and on both sides of highway 85[2]. It is also exposed in Weld County, Colorado, east of highway I-25[3]. It does not occur at the surface in Laramie County but the Fox Hills Sandstone crops out north of the Happy Jack Road and west of the Federal Road, northwest of the Bunkhouse Bar and Gilchrist School, in western Laramie County[4].

Sediments deposited on the Lance Formation were removed by erosion over most of southeastern Wyoming prior to extensive deposition of the White River Group. The White River Group consists of siltstone, claystone, sandstone, conglomerate (rock composed of gravel-size

clasts), and limestone which was deposited during the latest Eocene and early Oligocene epochs, between 38 million and 28 million years ago[5,6]. Sediments of the White River Group contain abundant volcanic ash derived from explosive eruptions in present-day Nevada[6]. In some areas, the White River Group is divided into an upper Brule Formation and a lower Chadron Formation but this distinction is often unreliable in Wyoming.

The White River Group is exposed north of Hat Creek Breaks in Niobrara County, near the North Platte River in Converse County, at scattered locations in Platte County, and locally east and south of Fort Laramie in Goshen County[3]. In Laramie County, it is at the surface in a 2- to 8-mile wide band from the northern boundary near Farthing south to highway I-80 (and possibly to the state line) in the west, from Pine Bluffs to Carpenter and south to the state line in the east, and along Horse Creek in the northeast[4].

After a period of erosion, the Arikaree Formation was deposited over parts of southeastern Wyoming in the late Oligocene and early Miocene epochs, between 28 million and 20 million years ago[5,6]. The Arikaree Formation consists of sandstone, siltstone, claystone, and conglomerate deposited in fluvial, floodplain, and eolian environments. Volcanic ash is less abundant than in the White River Group.

The Arikaree Formation is the surface formation over much of Platte and Goshen Counties. It is exposed across northern Laramie County from highway I-25 to the Nebraska border but may wedge out between the Ogallala Formation and White River Group to the southwest near Cheyenne[7].

After a period of erosion, the Ogallala Formation was deposited over much of Laramie County and in some other areas of southeastern Wyoming during the late Miocene epoch, between 15 million and 5 million years ago[5]. It consists of variably clayey and silty sandstone, conglomerate, siltstone, and limestone deposited in alluvial fan, fluvial, and floodplain environments.

The principal exposure of the Ogallala Formation in southeastern Wyoming is in Laramie County from the Horse Creek escarpment in the west to the Carpenter – Pine Bluffs lowlands in the east and south to the state line[4].

Hydrogeologic Units:

In the Powder River Basin, the Lance Formation is split between two hydrogeologic units: the Upper Lance confining unit (also referred to as the Upper Hell Creek confining unit after the Hell Creek Formation, which is the temporal equivalent of the Lance Formation in Montana) and the Lower Lance (or Hell Creek) – Fox Hills aquifer[8]. The Upper Lance confining unit has a mean sand content of 35% whereas the Lower Lance – Fox Hills aquifer has a mean sand content of 50%[9]. Resistivity and spontaneous potential logs show a clear change in character from fewer and thinner high-resistivity beds in the Upper Lance confining unit to generally higher resistivity and fewer low-resistivity beds in the Lower Lance – Fox Hills aquifer[9].

In the Denver ground water basin of Colorado, the temporal equivalent of the Lance Formation, the Laramie Formation, is also divided into an Upper Laramie confining unit, predominantly of shale, and a Laramie – Fox Hills aquifer of sandstone, siltstone, and shale[10].

Due to deeper erosion in southeastern Wyoming following deposition of the Lance Formation than in the Powder River or Denver basins (where the Fort Union Formation or equivalents are preserved above the Lance), much of the Upper Lance confining unit may not be present. The paucity of wells with geophysical logs or detailed lithologic logs makes it impossible to map out the distribution of the upper and lower Lance Formation below younger Tertiary rocks in southeastern Wyoming. Folding of the Denver – Julesburg Basin syncline followed by erosion would have removed all or parts of the upper Lance Formation on the eastern and western limbs of the syncline, possibly east of Egbert and west of the Cheyenne municipal landfill, respectively, and erosion may have been greater in paleo-river valleys. The Borie and Horse Creek anticlines in western Laramie County complicate this simple structural picture[11,12]. Consequently, the thickness and extent of the Upper Lance confining unit are not known even if the Lance Formation in southeastern Wyoming is similar to that in the Powder River Basin and to the Laramie Formation in Colorado. Because the hydrogeologic properties of the Lance Formation in southeastern Wyoming are poorly understood, only the formation will be referred to here rather than a specific hydrogeologic unit.

The High Plains aquifer (or aquifer system) occurs at the surface in eight states between the Rocky Mountains and the Mississippi River, including in the southeastern corner of Wyoming. In Wyoming, it consists of various water-bearing zones in the Tertiary White River Group, Arikaree Formation, and Ogallala Formation and of locally connected Quaternary alluvium and dune sand[13,14]. Lowry and Crist (1967) stated, "Hydraulic connection between the Tertiary formations is sufficient to permit contouring a common water table."[4] However, Cooley and Crist (1991) found perched water-bearing zones and discontinuities in potentiometric surfaces (water levels) for shallow versus deep wells and from one area to the next in the vicinity of Cheyenne[14]. Lowry and Crist (1967) characterized the "water-bearing beds in the Ogallala" Formation as "lenses, stringers, and irregular masses of sand and gravel which are interbedded with silt and clay", identified fractures and piping as the principal cause of permeability in the White River Group, and found it difficult to distinguish between the Arikaree and Ogallala formations[4]. These features indicate that while the High Plains aquifer may be difficult to subdivide and is hydraulically connected internally, it is not analogous to a sand box.

Lithologic similarities make it difficult to consistently distinguish the White River Group, Arikaree Formation, and Ogallala Formation in drill cuttings. Geophysical logs are run in few wells and may also be ambiguous. Drillers' logs reported on statements of well completion almost never identify the formation and when they do formation names are often misused. Water levels are not routinely measured in most wells to ascertain the continuity of the potentiometric surface(s) and wells in most areas are too widely spaced for the unambiguous recognition of discontinuities. Due to the extensive use of filter pack (gravel or sand placed in the well annulus) and lack of use of grout seals, many wells are open to more than one water-bearing zone or formation so differences in heads and water chemistry may gradually diminish from their original state. Water quality analyses are available for only a small percentage of wells and the repeat analyses necessary to determine sample variance are almost unheard of in any case.

Consequently, as there are no reliable criteria for consistently distinguishing between the White River Group, Arikaree Formation, and Ogallala Formation, splitting the High Plains aquifer into smaller hydrogeologic units is not currently feasible.

General Considerations:

Head differences between the High Plains aquifer and the Lance Formation have not been determined. The best way to measure any head differences would be contemporaneous measurements in adjacent shallow and deep wells completed in one or the other unit. Alternatively, one could monitor water levels as a well is drilled from one formation into another or conduct packer tests while the well is open to both formations. The State Engineer's Office does not have such data.

There is some evidence for water quality differences between the High Plains aquifer and the Lance Formation in Laramie County. Eight water quality analyses in SEO records indicate that relatively deep wells in the High Plains aquifer, which are screened below 440 feet, have hardness (as calcium carbonate, $CaCO_3$) greater than 70 mg/l, 25-60 mg/l calcium, 5-40 mg/l sodium, 10-35 mg/l sulfate, and 180-270 mg/l total dissolved solids. The few wells known to be completed in the Lance Formation have overlapping ranges for sulfate and total dissolved solids but generally lower hardness and calcium and higher sodium.

Four samples apparently collected during a pumping test of the Wycon #15 well (Permit No. U.W. 36518), which is also open to the High Plains aquifer, had 65-70 mg/l hardness, 18.3-19.1 mg/l calcium, 48.5-49.0 mg/l sodium, and 25.3-37.4 mg/l sulfate. The first sample in the series had 45.8 mg/l calcium and 83 mg/l sodium. A sample from the Koppes No. 3 Test well (Permit No. U.W. 108831), which may also be open to the High Plains aquifer, had 17.1 mg/l calcium, 66.1 mg/l sodium, 30 mg/l sulfate, and 264 mg/l total dissolved solids. Five samples collected after 1 to 72 hours of pumping the Fox Hills Observation Well No. 1 (Permit No. U.W. 34606) had 11-22 mg/l hardness, 3.1-6.1 mg/l calcium, 110-150 mg/l sodium, 20-35 mg/l sulfate, and 316-478 mg/l total dissolved solids. An analysis from the Pine Bluffs Lance Fox/Hills Test Site #1 well (Permit No. U.W. 160731) had 8.2 mg/l hardness, 2 mg/l calcium, 180 mg/l sodium, 5 mg/l sulfate, and 423 mg/l total dissolved solids. It is not known how representative these analyses are or how much concentrations change laterally and with depth within the High Plains aquifer and Lance Formation.

The most convincing evidence for a difference in water chemistry between the High Plains aquifer and the Lance Formation is the results of samples collected from the same well. During the drilling of a well for the Veterans Administration Hospital in Cheyenne (before permitting was required), a water sample collected after drilling had reached a depth of 442 feet had 75 mg/l hardness, 24 mg/l calcium, 33 mg/l sodium, 29 mg/l sulfate, and 230 mg/l total dissolved solids. A sample collected after the drilling had reached 1,070 feet had 49 mg/l hardness, 14 mg/l calcium, 75 mg/l sodium, 31 mg/l sulfate, and 246 mg/l total dissolved solids[15]. During testing of the Holman No. 1 replacement well (Statement of Claim No. U.W. 265), a sample from the upper portion of the well screened between 110 and 335 feet had 55 mg/l calcium, 6.3 mg/l sodium, 18.1 mg/l sulfate, and 206 mg/l total dissolved solids. A sample from the lower portion

of the well screened between 378 and 1,020 feet had 13.4 mg/l calcium, 84 mg/l sodium, 37.3 mg/l sulfate, and 312 mg/l total dissolved solids[16].

Lowry and Crist (1967) reported two analyses from wells completed in both the Lance Formation and High Plains aquifer in section 3, Township 18 North, Range 62 West: 10-12 mg/l hardness, 3.2-3.2 mg/l calcium, 247-270 mg/l sodium + potassium (potassium concentrations are generally less than 10 mg/l in other samples), 28-32 mg/l sulfate and 625-688 mg/l total dissolved solids. Six samples from wells completed only in the White River Group had 98-187 mg/l hardness, 24-50 mg/l calcium, 12-47 mg/l sodium, 12-17 mg/l sulfate, and 232-274 mg/l total dissolved solids[4].

Although water from the Lance Formation appears to be suitable for drinking water and does not appear to be much worse than that of the High Plains aquifer, it does appear to be chemically distinct.

Statement of Decision:

Allowing wells to connect two aquifers can have serious negative consequences. Available evidence does not show that hydraulic connection of the High Plains aquifer and Lance Formation would impair either but it does suggest the two are not currently connected or are only weakly connected. When the data are inconclusive, the consequences are poorly understood, and the decision is irrevocable, it makes sense to err on the side of protection. Dual completions in the Lance Formation and the High Plains aquifer will not be allowed and filter (gravel or sand) pack must not extend across the formation boundary. If a well penetrates both units, the borehole must be filled with bentonite or completed with blank casing and a grout seal (10 feet of cement at the formation contact and bentonite elsewhere) in the annulus where it traverses the unit which is not intended to supply water to the well. Due to the lack of information on the lower White River Group and Lance Formation in Laramie County, the formation contact between the White River Group and Lance Formation will be considered the aquifer boundary for well construction purposes.

Some wells in Laramie County are presently open to both the Lance Formation and the High Plains aquifer. However, the fact that the State Engineer's Office has not been sufficiently vigilant and drillers have not been sufficiently diligent in the past does not justify continuing to put both aquifers' integrity at risk. The State Engineer's Office will notify applicants who propose drilling deeper than 400 feet that dual completions are not allowed. The State Engineer trusts that drillers will also inform their clients of proper well construction designs.

Tips for Identifying Lance Formation - White River Group Contact:

Lithologic characteristics of the Lance Formation –

In Goshen County, the Lance Formation consists of "two distinct units: a lower unit that consists predominantly of dark materials, and an upper unit that consists of a sequence of light, variegated beds. . . The lower unit consists of a thick sequence of beds of carbonaceous shale, gray siltstone, and dark- to light-gray sandstone, and thin beds of coal throughout the sequence.

"The upper unit consists of a colorful sequence of beds of sandstone and soft shale. The extreme upper part of the unit consists mainly of platy clay that is red, blue, green, brown, and brownish yellow, with no restriction of color to individual beds. Contained in this clay zone are a few thin dark-gray beds of carbonaceous soft shale, and lenses of dark- to very-light-gray loosely to well-cemented sandstone, some of which contain moderately hard yellowish-brown sandstone concretions. These lenses of sandstone are somewhat similar to the channel deposits of sandstone in the upper unit of the overlying Chadron formation [White River Group], but they are lacking in the many very small flakes of biotite that are contained in the Chadron. Below the predominantly shaly unit is a relatively thick sequence of beds that is mostly sandstone and partly soft shale. The beds of sandstone range from yellow to white, are very fine to fine grained, and for the most part are loosely cemented. These beds contain very hard dark-brown sandstone and ironstone concretions, which are as much as 2 feet in diameter and weather into typical concave-convex fragments.

"The [upper] unit contains a few thin beds of coal, a few thin beds of impure limestone that contain oyster shells, and brown pebbles, cobbles, and boulders of chert."[2]

"In test well 11, drilled in Goshen Hole, 1,390 feet of Lance strata was penetrated. The lower 1,100 feet consists of carbonaceous shale, siltstone, and sandstone and the upper 290 feet is a yellow soft crossbedded sandstone containing partings and beds of bentonite, carbonaceous shale, and variegated shale."[17]

In Weld County, Colorado, the Laramie [Lance] Formation "consists mainly of yellow-brown and gray to blue-gray soft carbonaceous shale and clay interbedded with light-gray to yellow-brown sand and shaly sand. It contains some cross-bedded gray to buff sandstone, which is slightly to well cemented, and coal, especially in the lower part. Calcareous limonite concretions occur throughout the formation, and clam shells may be found in the lower part."[3]

The log for the Koppes No. 3 Test well (Permit No. U.W. 108831), east of the Cheyenne municipal landfill, includes the following description of the Lance Formation in the 940-950 feet interval:

> "Silty, sandy claystone: Dusky yellowish brown to light gray claystone and dark yellowish orange siltstone, very sticky, dark material appears to be carbonaceous and weakly fizzes in acid, light gray claystone is greasy, siltstone appears rusty (limonite), with moderate brown, well cemented (with carbonate), subrounded to subangular, well sorted, fine to very fine grained sand."

Lithologic Characteristics of the White River Group –

Typical outcrops in Laramie County consist "predominantly of massive brittle argillaceous siltstone containing a few beds of sandstone, conglomerate, and volcanic ash. The siltstone is pinkish gray on fresh exposures. Near the base of the formation, red and green shale and coarse channel deposits are present."[4]

In Goshen County, the White River Group has been divided into the lower Chadron Formation and upper Brule Formation. Rapp and others (1957) also identified a unique unit in the lower part of the Chadron: "The lower unit is of fluviatile origin and consists of a series of lenses and beds of deposits that range in grain size from clay through coarse to very coarse gravel; the coarsest materials represent channel deposits. The overall color is red; the beds of clay and silt are brick red, dark red, green to blue green, and buff; and the beds of sandstone and conglomerate are brick red, maroon, purple, and green."[2]

"The upper unit [of the Chadron Formation] consists mainly of green, brown, red, or buff bentonitic loosely to moderately cemented clay and silt. The upper unit is sandy in places . . . In addition, the upper unit contains a few lenticular beds of limestone and volcanic ash."[2]

"The Brule formation . . . consists of buff, moderately hard, brittle argillaceous siltstone that is sandy at the top and in places at the base. It contains moderately thick channel deposits of sand and sandstone, localized beds of limestone, moderately thick beds of clay, and a few beds of volcanic ash."[2]

Distinguishing Features of the Lance Formation and High Plains Aquifer –

The presence of coal or thick sections of dark gray to blue-gray shale or silty shale or sandstone are indicative of the Lance Formation. Hard, dark brown limonitic concretions may be restricted to the Lance. The presence of coarse-grained sand, conglomerate, or gravel is indicative of the High Plains aquifer although fine to medium sand can occur in both units.

Yellow to brown clay or shale and sandstone occur in both units.

Depth to top of Lance –

The fence diagram of Cooley and Crist (1981)[7] shows the base of the White River Group at depths of 440 to 800 feet in the vicinity of Cheyenne. This would also be the depth to the top of the Lance Formation if the Lance Formation is present. A cursory review of logs for some deep water wells suggests the top of the Lance Formation may be as shallow as 400 feet near Cheyenne.

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