TRACKING THE SOURCE: BACKFILL AND BACKFILL WATER QUALITY AT A LARGE POWDER RIVER BASIN COAL MINE[1]

Philip A. Murphree[2]

Abstract. Due to poor water quality in the initial backfill well constructed in 1981 at the Caballo Mine, the Wyoming Department of Environmental Quality, Land Quality Division required that the mine drill more backfill wells in the small area surrounding the initial well. The water quality results from these wells led to a number of landmark studies on backfill water quality and the behavior of selenium, nitrogen, and organic carbon in backfill waters. Although it was thought at the time that these water quality results would be typical for the Powder River Basin (PRB), the benefit of experience with other backfill wells in the PRB and a review of the history of the backfill surrounding these original backfill wells, indicates that the high total dissolved solids (TDS), selenium, and nitrogen concentrations observed in the early backfill area are not typical of backfill wells at Caballo. These high concentrations are a product of the backfill material used near the wells and their location. Selenium and nitrogen concentrations in the backfill waters are now very low in the initial backfill area. Moreover, the water quality in the initial backfill area and other resaturated or partially-resaturated backfill areas at Caballo is also similar to or better than premining water quality in the area surrounding these wells. Moderate amounts of selenium have been detected in more recently constructed wells at Caballo, but selenium concentrations have decreased to below the detection limit or are expected to rapidly decline as more saturated and reducing conditions develop.

Additional Key Words: Backfill, Alluvium, Geochemistry, Selenium, Nitrogen, Wetlands

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Introduction

The Caballo Mine is located approximately 20 km south of Gillette, Wyoming (Fig. 1). Mining began at Caballo in 1978. The mine, which produced 24.0 million metric tons of coal in 2003, was owned by The Carter Mining Company until 1994 when Powder River Coal Company acquired the mine. The mine is among those in the Powder River Basin with the highest percentage of disturbed land reclaimed with 49.5 percent reclaimed and total reclaimed area of 1,120 hectares. The Caballo Mine is located within the Belle Fourche River drainage system. Caballo Creek, a tributary to the Belle Fourche, drains the region in and around the Caballo Mine with the exception of a small part of the eastern permit area. Most of the area that will be disturbed by mining is within three drainage basins: Tisdale Creek and Gold Mine Draw are intermittent in their lower reaches and drain the western and eastern portions of the permit area respectively. North Tisdale Creek, which drains the central portion of the permit area, is ephemeral. North Tisdale Creek and Gold Mine Draw flow into Tisdale Creek near the southeast corner of the Caballo Mine permit area. Tisdale Creek joins Caballo Creek about one mile south of the Caballo permit area. Caballo Creek flows into the Belle Fourche River about 6.5 km below the Tisdale-Caballo confluence.

Topography at Caballo is characterized by gently rolling terrain. Sparse sagebrush dominates the uplands, while mixed grasses or alfalfa cover the lowland areas. Stream channels within and near the Caballo permit area are generally poorly defined and well vegetated. Streamflow within the Caballo permit area is infrequent and occurs at low flow rates due to several factors. The Caballo Mine occupies the headwaters of the streams crossing the permit area, thus, there is minimal surface area from which to collect runoff. In addition, there are many topographic depressions (playas) within the permit area. These internally drained areas do not contribute stream flow to the regional system. Aeolian sand deposits that cover a significant amount of surface area within the permit area also limit surface water runoff because precipitation readily infiltrates into these areas. Additional surface water retention occurs due to the numerous small stock reservoirs present within the drainage basins intersected by the Caballo permit area.

The climate at the Caballo Mine is semi-arid, characterized by dry, cold winters and short, warm summers. Annual precipitation at the Caballo Mine is high for Campbell County at over 42 cm per year. Factors controlling the regional climate include elevation, abundant sunshine, and mountainous moisture barriers to the west and south. The generally open terrain of the region permits free movement of wind and weather systems through the area, allowing rapid and extreme weather changes. The elevation of the permit area ranges from 1,350 to 1,470 m above mean sea level.

Eighteen backfill wells have been constructed at the Caballo Mine as of 2004. The current density standard for construction of backfill wells at the Caballo Mine is approximately one well per square mile. The first backfill well, CA-649-B, was constructed at Caballo in 1981. Due to high TDS, selenium, and nitrogen concentrations in water recovered from this well, the Wyoming Department of Environmental Quality, Land Quality Division (WDEQ/LQD) required that nine additional wells be drilled in the backfill surrounding this well. Caballo then drilled four wells, CA-824-B, CA-967-B, CA-968-B, and CA-969-B in 1989, using the then standard of four wells per section. Four additional wells, CA-1449-B, CA-1538-B, CA-1539-B, and CA-1540-B, were drilled in 1997 and 1998 using the current one well per section density. One backfill well, CA-1696-B was added in 2003. Presently, water levels are being measured at ten wells on a quarterly basis, however, wells CA-1538-B and CA-1696-B are currently dry. Figure 2 shows the backfill wells and the other wells discussed in this paper. Water quality sampling is currently being conducted at six backfill wells, including the two dry wells, on a quarterly basis, one well on a semi-annual basis, and one well on an annual basis. All water samples are analyzed using methods approved by the WDEQ/LQD.

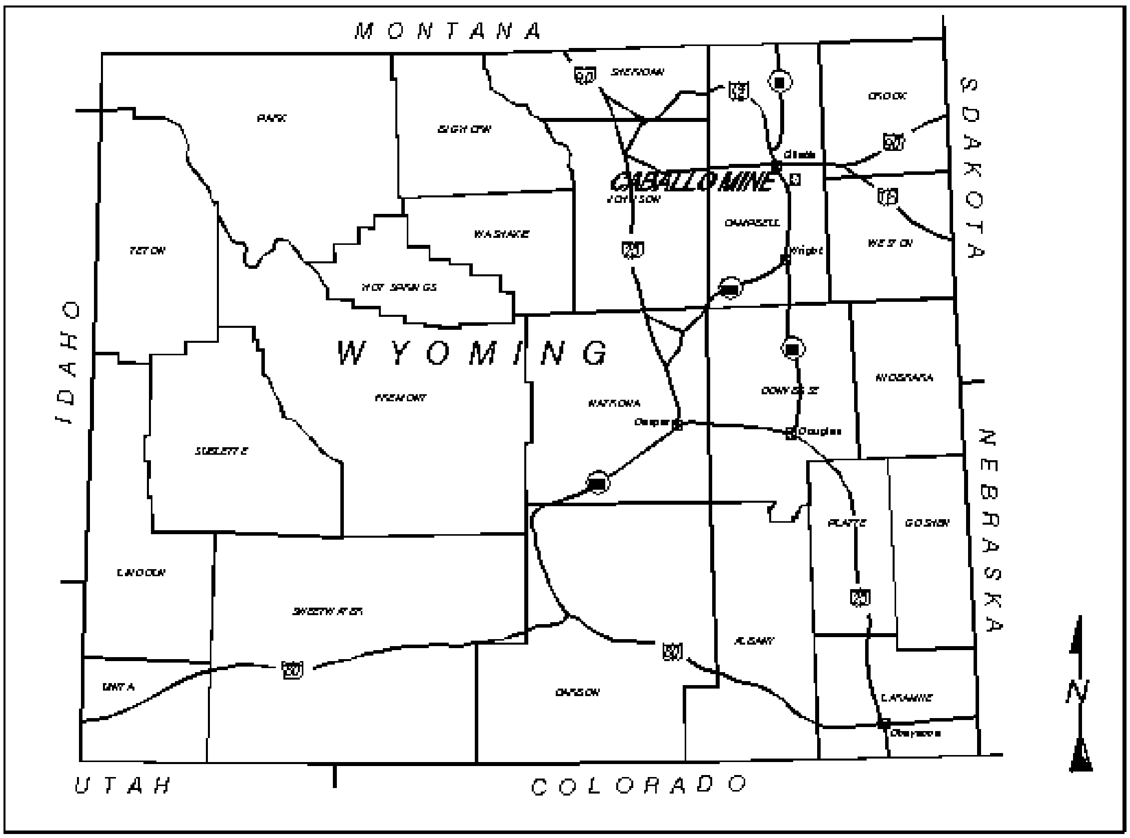

Figure 1: Location of the Caballo Mine: Campbell County, Wyoming.

The ground water flow gradient generally follows the direction of the stream channels and is approximately from northeast to southeast. Caballo Creek controls both the surface and ground water flow for the mine. Recharge to the overburden is from clinker (baked overburden technically referred to as porcelainite) deposits north, west, and east of the permit area; and surface runoff from overland flow, stream channels, and playas. Recharge to the coal is from the overburden, underburden, and from clinker units along the outcrop. There are also distinctly separate water tables in the mainly fine-grained alluvial deposits along the main stream channels where recharge is primarily from surface runoff.

During mining and backfilling and until sufficient resaturation of the backfill, the ground water gradient is reversed towards the pits and backfill areas. At Caballo, the earliest backfill areas have resaturated to near the predicted postmining potentiometric surface due to adjacent clinker units. The newer backfilled areas at Caballo have varying degrees of resaturation depending on their contact with surrounding saturated areas. Those contacting clinker or having an underlying underburden with a confining head have resaturated quickly. Where backfill only contacts overburden and where there is no confining head in the underburden, recharge has occurred much more slowly.

This study discusses the water level and quality results from sixteen of the eighteen backfill wells constructed at the Caballo Mine. In addition, a discussion of the backfill material and premining overburden and alluvial water quality has been included to explain the water quality observed in particular backfill wells. For purposes of comparison, the reclamation area has been divided into three parts, Areas A, B, and C as shown on Fig. 2.

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Discussion of Water Quality in Areas A, B, and C

Area A

Well CA-649-B, the first backfill well drilled at the Caballo Mine, was constructed in 1981 near reclaimed North Tisdale Creek. The well was monitored for water levels and sampled for water quality quarterly until 2002, when monitoring was ceased due to construction of the North Tisdale Wetlands Reservoir, which occupies seven cells over a 300 m portion of the reclaimed

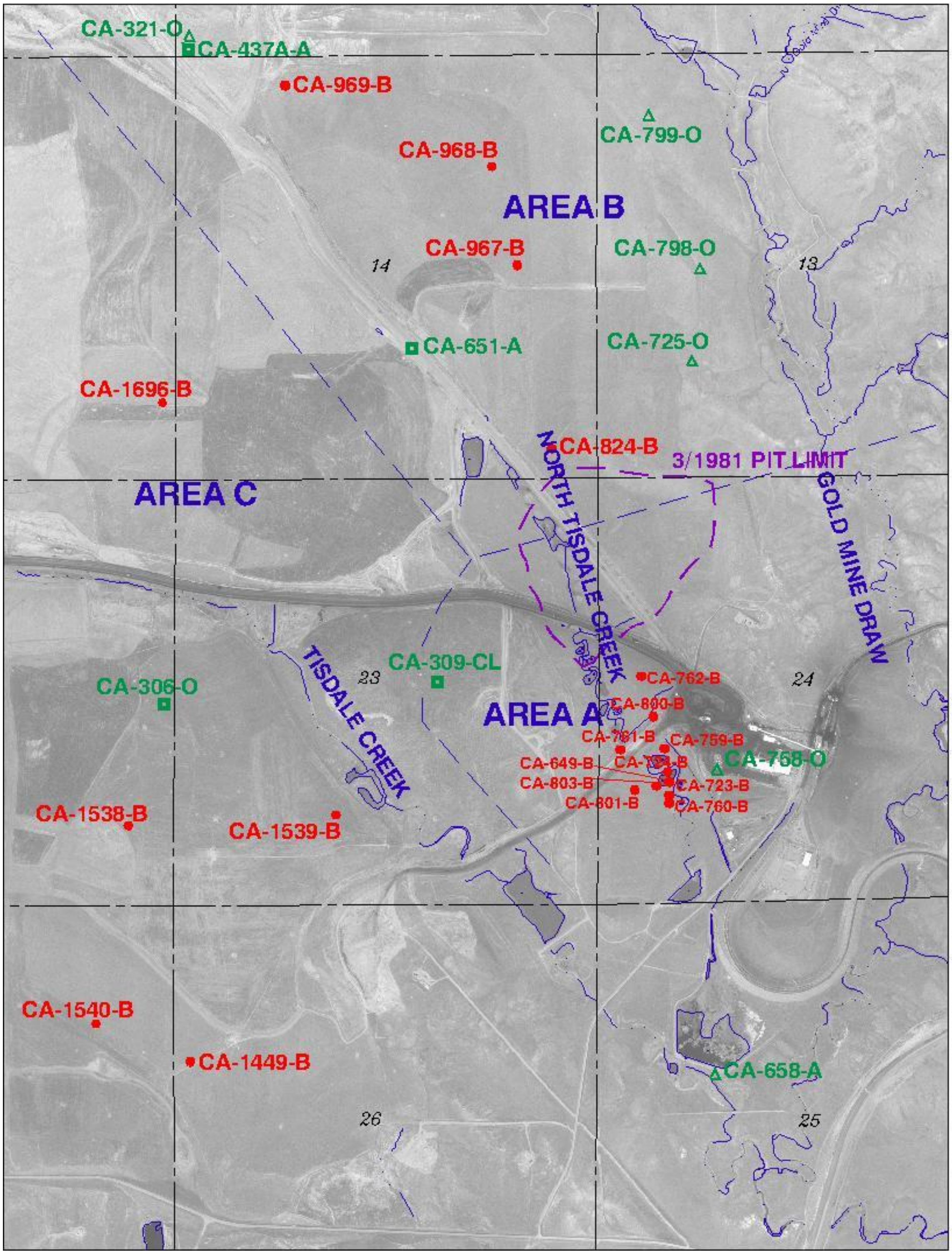


Figure 2: Location of the backfill and other wells at Caballo Mine (backfill wells are shown in red and premining wells are shown in green; Wells CA-1538-B and CA-1696-B are currently dry). Section lines provide scale (a section is approximately one square mile).

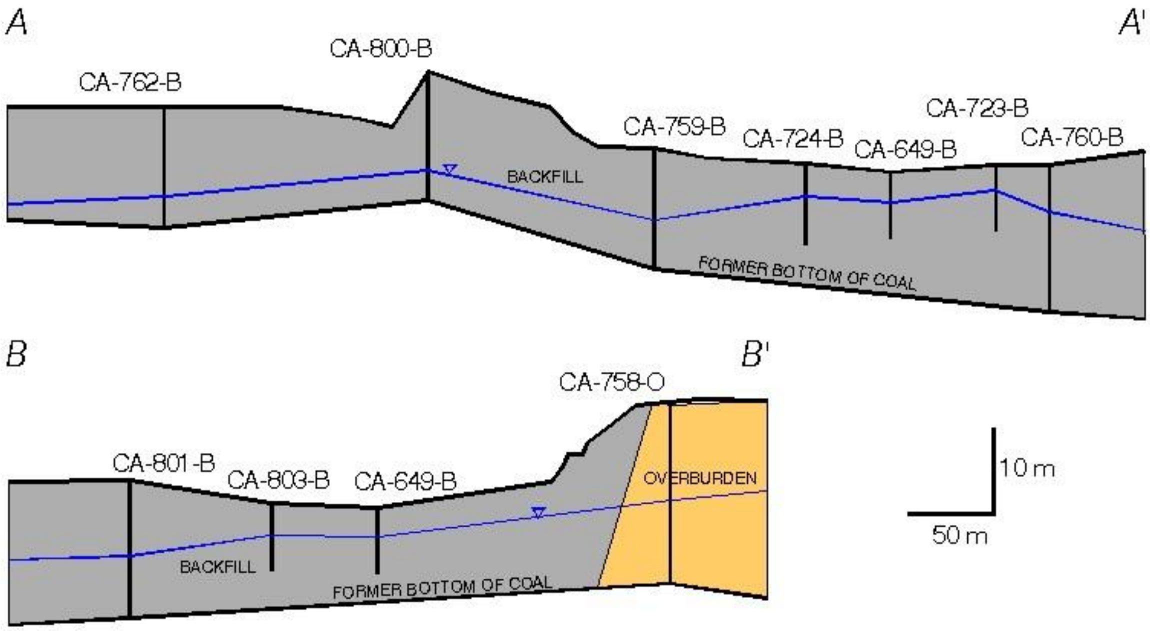
stream channel. In 2002, monitoring and sampling were moved to the adjacent well CA-724-B. Water levels at CA-649-B rose consistently to the water level measured in 2002, except for an upward spike in water level measured in 1995-1996. In 2002, there was about 4.0 m of water in the 7.6 m deep well and the water level at CA-724-B is currently about 3.4 m below the predicted postmining steady-state surface. Fig. 3 shows simple cross sections of the Area A wells and a demonstration of the relative water levels in the wells.

The water quality at CA-649-B was poor. Total dissolved solids (TDS) concentrations declined from approximately 7,000 mg/l to approximately 5,000 mg/l in 2002. The water is of a calcium-magnesium-sulfate type, which is typical of downgradient overburden, alluvium, and backfill not receiving recharge from deeper coal units. Table 1 shows the water quality of the wells discussed in this paper. As in many backfill wells in the Powder River Basin, high TDS and selenium concentrations have been of greatest concern at CA-649-B. Selenium concentrations at CA-649-B were as high as 759 μg/l, but between 1998 and 2002, have been fluctuating between the detection limit and 100 μg/l. Since 2002, the selenium concentration at CA-724-B has been below the detection limit. Selenite (SeO_3^{-2}) and selenate (SeO_4^{-3}) measurements taken at CA-649-B and other nearby wells indicated fluctuating redox conditions. The 2002 sampling at CA-649-B was taken following the construction of the North Tisdale Wetlands Reservoir and conditions in the well were probably much more reducing than prior to reservoir construction.

As shown on Table 1, the three native wells in Area A were located in the clinker, alluvium, and overburden. Coal wells are excluded for comparison from this study, although water flowing from adjacent coal may influence backfill water quality near the limits of mining

The TDS in clinker well CA-309-CL, which was mined through in 1985, ranged from 2,140 to 2,370 mg/l. Some selenium was detected in the water with concentrations ranging from 25-45 μg/l. In the overburden east of North Tisdale Creek near Area A, TDS concentrations at well CA-758-O, which is still actively monitored, have ranged from 1,142 to 1,450 mg/l, which is low in comparison to other overburden wells at Caballo; and only a small amount of selenium has been detected in this well. In the alluvium of North Tisdale Creek, water quality is very poor. TDS concentrations at CA-658-A, near the confluence of North Tisdale and Tisdale Creeks, have ranged from 4,184 to 9,160 mg/l and from 23,302 to 47,700 mg/l at well CA-651-A. Dissolved selenium concentrations at CA-651-A, which was mined through in 1982, were as high as 45 μg/l, but most selenium, which can be very concentrated in the alluvium, was probably fixed in insoluble forms. The recent improvement in water quality at CA-658-A shown on Table 1 has probably occurred due to mine discharges, which are dominated by water from the coal and deep wells.

The other backfill wells in Area A have exhibited water quality similar to CA-649-B. TDS concentrations in these wells have ranged from 888 to 7,380 mg/l. The shallow wells have higher TDS concentrations with the 7.7 m deep CA-723-B having TDS of 3,903 to 7,380 mg/l. The TDS at the 14.2 m deep CA-759-B has ranged from 888 to 4,690 mg/l. And, the TDS at shallow backfill well CA-724-B has ranged from 6,010 to 6,283 mg/l since 2002. Selenium concentrations have generally been highest in the shallow backfill wells of Area A. The selenium



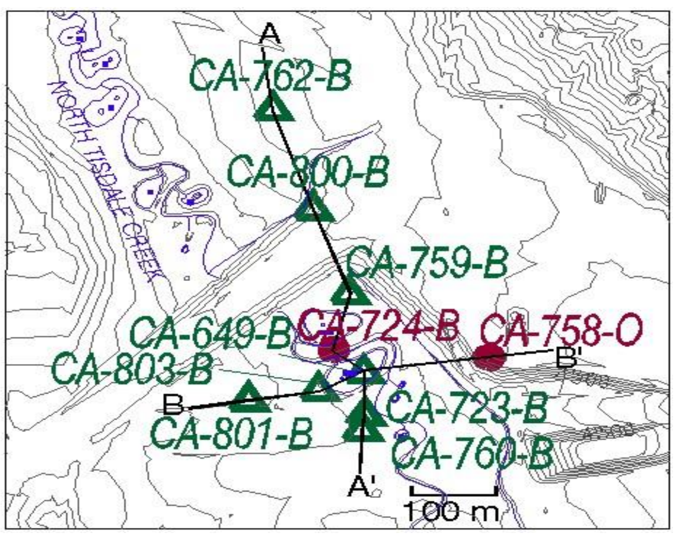


Figure 3: Cross sections of Area A wells. Burgundy wells are actively monitored for water quality. Green wells are inactive. Water levels are based on 2003 and 2004 monitoring. Contour intervals are 5 feet (1.5 m).

concentration in the ten backfill wells in Area A has ranged from below detection to 878 μg/l, but recent measurements have been at or below the detection limit. Fig. 4 shows the historical selenium concentrations from the four shallow backfill wells in Area A. Selenium concentrations in all of the shallow Area A wells dropped until 1990, when drying of the channel caused a sharp rise in concentrations recorded at CA-649-B and CA-803-B. The increase in selenium concentrations during drying events indicates that movement of selenium downgradient is not the primary cause of the change in selenium concentrations. In addition, TDS concentrations would probably fluctuate or rapidly increase or decrease if dispersion were dominant since the surrounding water quality is very different. Construction of the North Tisdale Creek Wetlands Reservoir in 1999 has probably caused a more geochemically reducing environment than might otherwise have developed and selenium concentrations in the shallow wells are now below or

Table 1: Summary of Water Quality Results from Selected Wells at the Caballo Mine - 2004								
Well	**Depth (m)**	**Water Type**	**TDS Range (mg/l)**	**TDS (2002-2004) (mg/l)**	**NO_3- NO_2 (mg/l) Range**	**NO_3- NO_2 (mg/l) (2002-2004)**	**Se Range (μg/l)**	**Se – (2002-2004) (μg/l)**
Area A Wells								
CA-309-CL*	27.4	Ca- SO_4	2,140-2,370	N/A	0.25-1.16	N/A	25-45	N/A
CA-658-A	2.7	(Ca-Mg)-SO_4	4,184-9,160	4,942-4,976	0.03-6.02	0.03-6.02	<2-9	5-7
CA-758-O	20.7	Ca- SO_4	1,142-1,450	1,224-1,290	0.01-2.67	0-1.21	2-11	<5
CA-649-B*	7.6	(Ca-Mg)-SO_4	5,060	5,060	0-111	15.73	<5-759	<5
CA-723-B*	7.6	(Ca-Mg)-SO_4	3,903-7,380	N/A	0-300	N/A	2-600	N/A
CA-724-B	9.5	Ca-SO_4	2,690-7,000	6,010-6,283	0.03-228	0.03-4.11	2-878	<5-6
CA-759-B*	14.2	(Ca-Mg-Na)- SO_4	888-4,690	N/A	0-171	N/A	9-558	N/A
CA-760-B*	17.1	Ca-SO_4	1,900-3,840	N/A	0.01-1.45	N/A	<5-110	N/A
CA-761-B*	13.4	Ca-SO_4	3,360-4,466	N/A	0.01-0.12	N/A	2-27	N/A
CA-762-B*	14.2	Ca-SO_4	3,050-4,000	N/A	0.01-0.02	N/A	2-14	N/A
CA-800-B*	14.9	(Na-Ca)-SO_4	2,416-4,160	N/A	0.01-3.43	N/A	2-12	N/A
CA-801-B*	15.9	Ca-SO_4	3,000-5,226	N/A	0.01-1.34	N/A	<1-11	N/A
CA-803-B*	7.9	(Ca-Mg)-SO_4	4,305-5,880	N/A	0-138	N/A	25-822	N/A
Area B Wells								
CA-321-O*	25.9	(Ca-Mg)- SO_4	2,000-9,510	N/A	0.02-9.35	N/A	1-10	N/A
CA-437A-A*	3.1	Ca- SO_4	60,500-105,770	N/A	0.03-1.19	N/A	3-13	N/A
CA-651-A*	3.7	(Na-Mg)- SO_4	23,302-47,700	N/A	0.87-41.5	N/A	2-45	N/A
CA-725-0*	22.5	(Mg-Ca)-SO_4	24,800-31,414	N/A	0.03-0.45	N/A	2-55	N/A
CA-798-O	34.1	Ca- SO_4	2,535-3,360	N/A	0.01-0.12	N/A	2-10	N/A
CA-799-O	36.9	Ca- SO_4	1,450-1,920	1,766-1,810	0.03-1.89	N/A	6.6-7.9	N/A
CA-824-B	33.8	(Ca-Mg-Na)- (SO_4-HCO_3)	944-2,440	796-1265	0.01-14.24	0-11.87	3-69	<5-6
CA-967-B*	40.5	(Na-Ca)-HCO_3	638-1,994	N/A	0.01-8.51	N/A	1.2-<5	N/A
CA-968-B	44.2	Ca-SO_4	765-25,730	N/A	0.01-5.56	N/A	<5	N/A
CA-969-B	43.9	(Na-Mg)- SO_4/Na-HCO_3	1,080-5,360	2,344-2,537	0.01-23.2	0-6.34	1-<5	<5
Area C Wells								
CA-306-O*	15.2	(Ca-Mg)-SO_4	2,600-6,680	N/A	0-0.65	N/A	<5-30	N/A
CA-1449-B	41.2	Na-HCO_3	611-848	590-750	0.03-5.22	0.03-5.22	<5-52	<5-52
CA-1539-B	33.8	Na-HCO_3	1,035-1,400	1,048-1,190	0.03-6.66	0.15-6.66	<5-55	<5-55
CA-1540-B	36.9	Na-(HCO_3- SO_4)	2,211-2,640	2,174-2,308	0.03-2.61	0.24-2.61	<5-8	<5-8
Footnotes								

*- Inactive or Destroyed Well (1)- Insufficient Water to Sample Note: All monitoring wells screened through entire saturated interval of lithologic unit	Well Suffix Explanation A- Alluvium B-Backfill Cl- Clinker O- Overburden

near the detection limit. It has been observed that wetland construction at the North Antelope Rochelle Mine caused a sharp and rapid lowering of selenium concentrations in reclaimed alluvium (Murphree, 2003).

Nitrogen (NO_3-NO_2) concentrations have also generally been highest in the shallow backfill wells of Area A. Nitrogen concentrations have reached as high as 305 mg/l in Area A, but as with selenium concentrations, declined significantly until 1993, when drying of the reclaimed stream channel caused an increase in nitrogen concentrations to near 100 mg/l. Nitrogen concentrations have since declined significantly. Fig. 5 shows the historical nitrogen concentrations from the four shallow backfill wells in Area A.

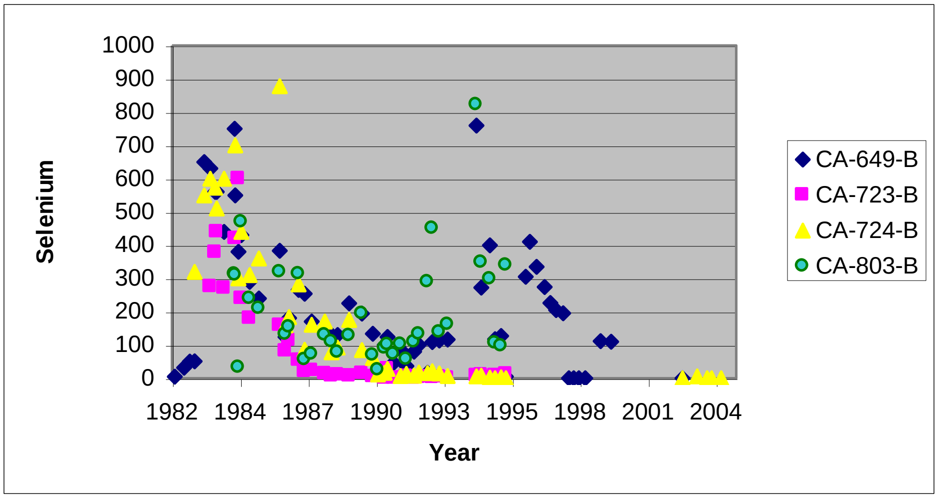


Figure 4: Selenium concentrations (μg/l) from four shallow Area A wells.

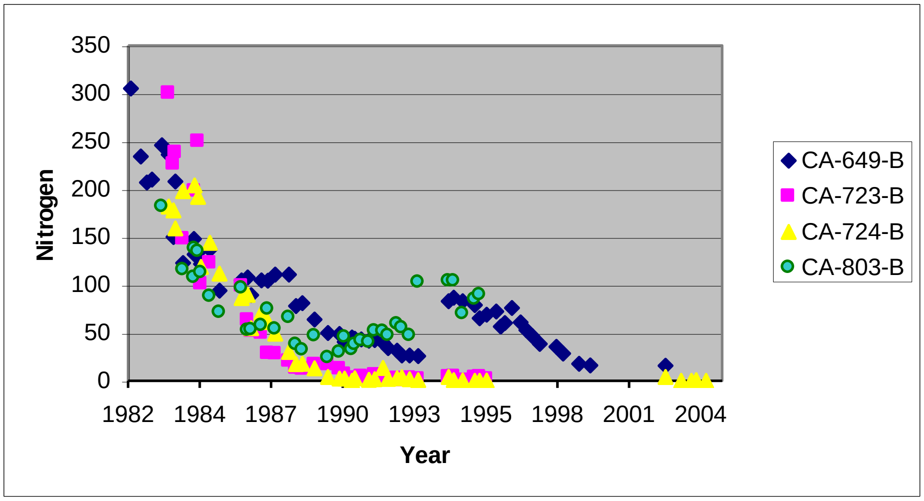


Figure 5: Nitrogen (NO_3-NO_2) concentrations (mg/l) from four shallow Area A wells.

Following the installation of the new wells, a number of important studies, (Dreher and Finkelman, 1986; Klein, 1986; Naftz and Rice, 1989; Dreher and Finkelman, 1992; See, et al, 1995), were undertaken in the late-1980's and early-1990's with the cooperation of The Carter Mining Company to study the problem of poor water quality in the Area A wells. Naftz and Rice (1989) studied the processes controlling selenium at selected coal and in-situ uranium mines in the Powder River Basin. These authors found that, in similar shallow backfill wells at Caballo, dissolved selenium concentrations in backfill wells may be related to dissolved organic carbon (DOC) in coal and carbonaceous shales, and conversion of organic selenides to selenite (SeO_3^{-2}) and selenate (SeO_4^{-3}). Highly mobile selenate was the major constituent in the wells at that time. Selenite is less mobile and adsorption of selenite, and to a lesser extent selenate, on clays and iron oxides is a possible sink for selenium following mining (Caballo Coal Company, 1985). High concentrations of dissolved organic carbon may saturate adsorption sites on goethite and similar materials (Balistrieri and Chao, 1987; Naftz and Rice, 1989).

See, et al (1995) included one of the Area A wells as part of a study of the role of natural organic solutes in the mobility of selenium in coal mine backfill ground water. They found that at wells where there was little selenium in the ground water, the dissolved organic carbon level was very low. In a number of wells, dissolved organic carbon and selenium concentrations were both very high. Dreher and Finkelman (1992), studied backfill wells at Caballo, including some of the wells discussed in Naftz and Rice (1989), and stated that because the selenium concentrations were decreasing, competition of organic acids for sorption sites is not a strong factor in the Area A wells.

In an internal study for The Carter Mining Company, Dreher and Finkelman (1986) speculated on sources of the high selenium and nitrogen concentrations in the Area A wells. A number of causes were investigated including placement of top of coal cleanings or unexploded ammonium-nitrate in the backfill, and dumping of oxidized backfill material in a water-filled pit. While the latter cause was thought probable by Dreher and Finkelman, it is unlikely that in the oxic environment of the shallow backfill of North Tisdale Creek, it would have mattered whether the water was in the pit prior to backfilling or the backfill saturated following placement. The primary source of the high amounts of selenium observed in the Area A wells was believed by Dreher and Finkelman (1986) to be dissolution of selenium-bearing salts from the unsaturated overburden in saturated backfill. The primary source of the high nitrogen concentrations was believed by the authors to be oxidation of ammonium-bearing minerals in the unsaturated zone. However, a review of Fig. 6, which is a photo of the Caballo pit in June 1981, shows mining progressing up North Tisdale Creek and backfilling in the area of the reclaimed channel. Much of the backfill below the reclaimed North Tisdale Creek originated as highly organic and mineralized alluvium from the native North Tisdale channel. While some of the selenium in the reclaimed North Tisdale Creek probably occurred due to dissolution of soluble selenium-bearing salts as speculated by Dreher and Finkelman, the primary source of the selenium and nitrogen observed in the Area A wells may have been oxidation of organic matter in the native alluvium. Dreher and Finkelman (1986) found that the modes of occurrence for selenium at Caballo were 10-15% pyrite, 5-10% sulfides and selenides, and 20-40% organic association.

Figure 6: Caballo pit in June 1981. Photo is looking north. (Area A wells are located where backfilling is taking place north of meandering reclaimed North Tisdale Creek). Native North Tisdale Creek trends to northwest in photo.

Factor analysis results presented in Naftz and Rice (1989) showed that selenium at Caballo was closely associated with constituents common to detrital grains. These authors believed that the water transporting the detrital grains also contained dissolved selenium. Therefore, selenium and organic carbon concentrations would be expected to be greatest in the alluvium where evapo-concentration of ground water and carbon cycling processes were also most pronounced. High nitrogen concentrations in the overburden are often associated with oxidized organic matter such as the shallow coal rider seams in the overburden, which have a similar formation as the organic matter in the alluvium.

It does not appear that the North Tisdale Creek alluvium was investigated as a source of the high selenium and nitrogen concentrations in the Area A backfill during previous investigations, but a search of premining records may have been outside of the researchers' scopes. A review of correspondence between the WDEQ/LQD and The Carter Mining Company concerning reclamation of North Tisdale Creek showed that the discussion was limited to geomorphology and surfacing of the reclaimed channel. Carter also lacked a hydrology database such as the one used by Powder River Coal Company that would enable a rapid search of old records. However, the data would have been available in mine annual reports. No overburden geochemistry drill holes that could be used to better explain the source of the high selenium and nitrogen concentrations penetrated the North Tisdale Creek alluvium.

Because of the poor water quality at CA-649-B, the location and depth of the well, and the premining alluvial water quality in Tisdale and North Tisdale Creeks, it is probable that CA-649-B was constructed primarily in reclaimed alluvial material. Aquifer test results from CA-649-B are more similar to premining alluvial wells than those from most other backfill wells. Indeed, given the selenium and nitrogen results from the shallow backfill wells in the area and the adjacent well CA-759-B, it is probable that all of these wells were constructed in reclaimed alluvium. The other deep Area A wells are also constructed in material that formerly adjoined the North Tisdale Creek alluvium. Based on previous research (Casagrande et al, 1985), Dreher and Finkelman (1986) did not believe that organically bound selenium would be released during mining and backfilling operations. However, decomposition of organic material from the alluvium in the backfill would not only explain the high selenium and nitrogen concentrations observed in the wells, but also the association of the selenium and dissolved organic carbon observed by Naftz and Rice (1989) and See et al (1995) and the small areal extent of the high selenium and nitrogen concentrations since the alluvium composed a small percentage of the overburden.

At the North Antelope Rochelle Mine (NARM), 100 km south of Gillette, where native alluvium was required by the WDEQ/LQD for reconstruction of the first replacement segment of the Porcupine Creek Alluvial Valley Floor (AVF), high TDS, selenium, and nitrogen concentrations were initially observed. Nitrogen concentrations soon decreased. High concentrations of dissolved organic carbon were associated with high selenium concentrations in See et al (1995), but the association was not as distinct with much lower selenium concentrations in 2003 (Murphree, 2003). As reported in Murphree (2003), wetland construction has significantly reduced the selenium concentrations in the reclaimed Porcupine Creek. Due to the high TDS and selenium concentrations in the original AVF segment at Porcupine Creek, selected sandy overburden is now used at NARM for alluvial replacement and postmining water quality in newer replacement units is similar to premining water quality in the overburden.

Although the water quality currently observed in the Area A wells is poor, it is similar to the water quality observed in the downstream premining alluvial wells on North Tisdale Creek and much better than the water quality observed in the upstream alluvial wells. Water quality results from well CA-725-O show that the high TDS water observed along North Tisdale Creek has not migrated into the adjacent overburden and the downstream alluvial water quality has actually improved following mining. Surface water quality in North Tisdale Creek is also good. Despite the number of studies conducted on the Area A wells, following the initial period of resaturation, water quality in backfill wells in the Powder River Basin is generally similar to premining water quality in the overburden. as shown in reports produced by the Gillette Area Groundwater Monitoring Organization and a number of studies.

Partly, due to the problems in Area A, in 1990, Caballo and the WDEQ/LQD agreed on standards for handling seleniferous material in the shallow backfill. Similar statewide standards were later implemented.

<u>Area B</u>

Four monitoring wells have been constructed at Caballo in the backfill east of North Tisdale Creek north of the Area A wells. Native water quality in the alluvium of North Tisdale Creek in Area B was extremely poor. TDS at well CA-651-A ranged from 23,300 to 47,700 mg/l and from 60,500 to 105,770 mg/l at CA-437A-A. Selenium has also been measured in the alluvial waters in Area B with measured concentrations as high as 45 μg/l. The overburden water quality is generally much better. TDS concentrations in wells CA-798-O, and CA-799-O have ranged from 1,450 to 3,360 mg/l with very little selenium measured. At well CA-321-O, TDS concentrations generally ranged from 2,000 to 4,000 mg/l, but one sample of 9,510 mg/l was measured in 1983. However, water quality at well CA-725-O has been poor with a TDS range of 24,800 to 31,414 mg/l and moderate amounts of selenium. It is unknown why the TDS at this well was so high. Gold Mine Draw, located east of CA-725-O has alluvial water quality with a TDS concentration near 4,000 mg/l. But it is possible that one of the sand bodies common in the area is connected to the North Tisdale Creek alluvium and has caused the high TDS measurements at CA-725-O.

Backfill water quality in Area B is comparable to that observed in the better quality overburden waters. TDS has ranged from 944-2,440 mg/l at CA-824-B and 638-1,994 mg/l at CA967-B. Recent samples at CA-824-B show a TDS range of 796 to 1,265 mg/l. At well CA-969-B, TDS concentrations have ranged from 1,080 to 5,360 mg/l, but recent samples have TDS near 2,400 mg/l. The change in water quality at well CA-968-B is interesting. TDS at this well was between 17,700 and 25,730 mg/l between 1990 and early-1995, but declined to between 765 and 3,396 mg/l in later 1995 samples when monitoring was discontinued in favor of well CA-969-B. The possible cause of the change is early recharge from the surface and later recharge from the higher quality overburden and coal aquifers adjoining the backfill of Area B. Selenium concentrations as high as 69 μg/l have been observed in the Area B backfill, but recent measurements are below or near the detection limit.

<u>Area C</u>

Area C contains the most recently backfilled areas at the Caballo Mine. Tisdale Creek, the largest drainage in the Caballo permit area, has been mined and reclaimed within Area C. Premining alluvial water quality in lower Tisdale Creek is generally good upstream of North Tisdale Creek with TDS concentrations ranging from 1,000 to 4,000 mg/l. Overburden well CA-306-O, which was near the native Tisdale Creek, had a range of TDS concentrations from 2,600 to 6,680 mg/l with small amounts of selenium detected. The higher TDS samples occurred in the middle sampling periods.

Water levels in the backfill of Area C are still rising, but it should be pointed out that initial resaturation was rapid due to the large amount of sand in the backfill and the nearby clinker and resaturated backfill of the Belle Ayr Mine to the south. Recharge may also take place from below the former bottom of coal. The potentiometric surface was over 6 m above the base of the backfill approximately eight months following backfilling. TDS concentrations have ranged from 611-848 mg/l at well CA-1449-B, 1,035-1,400 mg/l at well CA-1539-B, and 2,211-2,640 mg/l at well CA-1540-B. Recent samples from these wells exhibit similar water quality. Moderate selenium concentrations of up to 55 μg/l have been observed in the Area C backfill wells, but periodic samples with selenium concentrations below the detection limit have also been measured recently. Although the good backfill water quality observed in Area C may simply be due to the material that the wells are placed in, it may also reflect selective overburden placement by Caballo using the mine's overburden tracking program.

Conclusion

Due to poor water quality in the initial backfill well constructed in 1981 at the Caballo Mine, the Wyoming Department of Environmental Quality, Land Quality Division (WDEQ/LQD) requested that the mine drill more backfill wells in the small area surrounding the well. Water quality results from these Area A wells formed the basis for a number of studies on backfill water quality and the behavior of selenium, nitrogen, and organic carbon in backfill waters. Although it was thought at the time that the water quality results would be typical for the Powder River Basin (PRB), the benefit of experience with other backfill wells in the PRB and a review of the history of the backfill surrounding these wells, indicates that the high TDS, selenium, and nitrogen concentrations observed in the early backfill area are not typical of backfill wells at Caballo and are a product of the alluvial material from native North Tisdale Creek used near the wells and their location along the reclaimed North Tisdale Creek. High selenium concentrations in Area A are probably partly due to dissolution of soluble salts as suggested by Dreher and Finkleman (1992), but the primary source of high selenium and nitrogen concentrations in some of the Area A wells is probably oxidation of organic matter and sulfides from the North Tisdale Creek alluvium. Water quality in the Area A wells is actually similar to, or better than, premining alluvial water quality. Selenium concentrations are now near or below the detection limit.

The relatively poor water quality observed in early backfill areas may have been typical for the PRB since most mines began mining in or adjacent to stream channels where overburden is thinnest and alluvial water quality is poor. But, as mining moved into deeper areas where overburden quality is generally better and knowledge of overburden suitability improved, water quality in the newer backfill areas is better than in the earlier backfilled areas.

The water quality in other resaturated or partially-resaturated backfill areas at Caballo is also similar to or better than premining overburden water quality. Moderate amounts of selenium have been detected in more recently constructed wells at Caballo, but selenium concentrations have decreased to below the detection limit or are expected to rapidly decline as more saturated and reducing conditions develop. It is unfortunate, but understandable, that most published studies on backfill water quality have focused on areas where water quality appears poor, rather than backfill water quality on aggregate. This gives the implication that water quality problems are to be expected in the backfill.

Studies such as this one may have regulatory implications as the WDEQ/LQD has at times discussed setting standards for postmining water quality based on Wyoming Class III water quality standards for livestock consumption (e.g. TDS< 5,000 mg/l). Such standards assume that premining water quality met Class III standards. But in the case of many alluvial and overburden monitoring wells in the Powder River Basin, native water quality may be much worse than Class III standards. Backfill water quality should not be expected to be a problem, but it should also not be expected to be better than premining water quality.

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