Evaluating Underground Mine Reclamation Projects in North Dakota[1]

Presented by
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ABSTRACT

Lignite coal mining has been an important part of North Dakota's history and economy for over a century. The Abandoned Mine Lands (AML) Division of the North Dakota Public Service Commission has been charged with eliminating hazards and otherwise reclaiming abandoned coal mine sites in North Dakota since 1981. Abandoned underground mine subsidence has caused significant danger and problems for landowners and the public; especially when sinkholes caused by mine collapse have occurred at or near homes, buildings and public roads. The North Dakota AML Division has taken a two-pronged approach to eliminating hazards associated with abandoned underground mines. Sinkhole filling projects have been conducted annually since the early days of the AML program. In these projects, sinkholes caused by mine collapse have been filled with earthen materials. More than 2,000 sinkholes have been filled in North Dakota at a cost of approximately $1 million. Remote backfilling projects are conducted in North Dakota to prevent underground mine subsidence in residential and commercial areas and public roads. In 1982 the AML Division began conducting remote backfilling projects by drilling holes into underground mines and filling open mine voids with sand and water slurry. In 1991, the AML Division began pumping cementitious grout under pressure into open and rubble-filled underground mine voids. Since 1982, about 50 remote backfilling projects have been conducted in North Dakota at an approximate cost of $20 million.

Key Words: underground mines, underground mine voids, underground mine collapse, subsidence, sinkholes, remote backfilling, drilling, grouting,

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Introduction

Lignite coal mining has been an important part of the history and economy of North Dakota since the first commercial coal mine opened in 1873. Mineable lignite reserves in North Dakota are estimated at approximately 25.1 billion tons, which is enough to last over 800 years at the current rate of mining (Murphy 2001). Presently, approximately 28 million tons of lignite are mined in North Dakota annually. About 79% of North Dakota's lignite is used to generate electricity, 13.5% is used to generate synthetic natural gas and about 7.5% is used to produce fertilizer products like anhydrous ammonia. The North Dakota lignite industry directly employs about 4,000 people and indirectly employs another 13,000 people (Lignite Energy Council 2012).

There are over 600 documented abandoned mines in North Dakota and most of these are abandoned underground room and pillar mines. As these abandoned underground mines have deteriorated with time deep collapse features, or sinkholes, have surfaced in many areas. These features are very dangerous, especially when they occur at or near residential and commercial areas and public roads. The Abandoned Mine Lands (AML) Division of the North Dakota Public Service Commission (PSC) has been conducting reclamation projects to eliminate mine related hazards since 1981. Of the approximately $43 million spent on AML reclamation projects in North Dakota, more than half has been used to eliminate public hazards caused by underground mines.

The AML Division has used two general strategies to eliminate underground mine hazards. The first is filling sinkholes and other subsidence features that have already collapsed to the surface. The second strategy is to prevent subsidence by remotely filling underground mine voids with slurry or cementitious grout. The remainder of this paper will discuss the history of underground coal mine reclamation in North Dakota, assess its effectiveness and also to suggest ways in which it could possibly be improved.

Earliest Underground Mine Reclamation Projects, 1980-1987

The very first AML reclamation projects conducted in North Dakota under the Surface Coal Mining and Reclamation Act (SMCRA) were a 40 acre surface mine reclamation project at the Old Pittsburgh site near Dickinson; a uraniferous coal reclamation project at the Howie site near Belfield; and a small OSM emergency coal refuse fire project near Wilton. These projects were conducted in the period from 1980-1981.

The first AML underground mine reclamation projects were conducted under a cooperative agreement with Dickinson State College. These were research and development projects evaluating the effectiveness of alternative techniques. A 72 acre project near Scranton, ND, conducted from 1982 to 1987, utilized daylighting, blasting, dynamic consolidation, hydraulic jetting (supersaturation), and sinkhole grading in an attempt to collapse and reclaim a large underground mine. The cost of this project was approximately $1.7 million.

Photo of Scranton, ND, circa 1981. Note the surface mine and sinkholes directly across the highway from the Scranton public school.

Daylighting was conducted on the west side of this site. Large equipment removed all the soils down to the original mine level, approximately 60-70 feet, and replaced it. This technique was effective but was also very expensive. Techniques like blasting, dynamic compaction, and supersaturation were less effective and also had potential for adverse effects to wells, foundations and groundwater. Sinkhole grading was cost effective and eliminated the immediate hazard but didn't prevent subsequent subsidence.

Similar research and development projects were conducted at undermined sites at the Lehigh Site near Dickinson in 1982-83, the Urlacher site near New England in 1983 and near New Leipzig in 1983. These projects mainly included daylighting, blasting, surface grading and closing mine entries. All were conducted through cooperative agreements with Dickinson State except for the New Leipzig project which was conducted by a private contractor, Weisz & Sons Construction. These early R&D projects encompassed about 110 acres of underground mine subsidence and the total cost was approximately $2.2 million.

Early Underground Mine R&D Projects 1982-87

Year	**Site**	**Contractor**	**Acres**	**Approx. Cost**
1982-87	Scranton	Dickinson State	72	$1,7000,000
1982-83	Lehigh-Dickinson	Dickinson State	10	$167,000
1983	Urlacher-New England	Dickinson State	7	$52,000
1983	New Leipzig	Weisz & Sons	20	$269,000
		Total	**109**	**$2,188,000**

Daylighting underground mine at Scranton in 1983

Blasting underground mine at New Leipzig in 1983

Early Sinkhole Grading Projects, 1982-1988

The early R&D projects indicated that area-wide grading was an effective and relatively cheap way to eliminate hazards in large areas with many sinkholes. In this technique, topsoil was stripped from the entire site and saved and the sinkholes were graded with heavy equipment like bulldozers, scrapers and payloaders. After grading, topsoil was replaced and the sites were seeded with locally adapted grass species.

Eleven sinkhole grading projects were conducted in North Dakota between 1982 and 1988. These projects encompassed about 390 acres of subsidence at an approximate cost of $915,000. Three of those projects were conducted near Beulah. These projects were relatively inexpensive and effective in eliminating the immediate hazard of the dangerous sinkholes but did not prevent subsequent subsidence.

Early Sinkhole Grading Projects 1982-88

Year	Site	Contractor	Acres	Approx. Cost
1983	Beulah	Kjelbertson Const.	12	$177,200
1983	Garrison	Kjelbertson Const.	13	$16,240
1984-85	Hanson-Reeder	Dickinson State	30	$60,400
1984	Wilton	Kjelbertson Const.	60	$178,400
1985	Beulah	Lindeman Const.	80	$126,000
1986	Beulah	Holen Const.	45	$102,000
1986	Lehigh-Dickinson	Kindt Earth Moving	45	$72,000
1986	South Scranton	Morlock Const.	15	$41,000
1987	Andrews Lake-Bowman	Schwartz Const.	12	$26,000
1987	Zenith-South Heart	L.P. Anderson	52	$68,000
1988	West Williston	Morlock Const	23	$46,000
		Total	**387**	**$913,240**

Sinkhole Grading Sites at Beulah (1983) and Wilton (1984)

Remote Backfilling Projects – Slurry-Fill Drilling & Grouting, 1982-89

The major disadvantages of sinkhole grading were that it only addressed sinkholes after they had occurred and didn't prevent subsequent sinkholes from developing. Remote backfilling methods were used in order to prevent dangerous sinkholes before they occurred in high use areas such as residential and commercial areas and public roads.

Nine slurry-fill projects at a total cost of approximately $2.85 million were conducted in North Dakota between 1982 and 1989. In this technique, slurry, usually consisting of sand, water and sometimes flyash, was "poured" from cement trucks down drilled holes into the mine workings. This technique was adequate when the mine was relatively open; but when the mine had begun to collapse and was rubblized, it was not very effective. Serious subsidence events subsequent to the gravity fill projects indicated that the mined voids were not completely filled. This technique was discontinued in 1989 and later replaced by pressurized grouting.

The earliest remote backfilling projects were conducted by OSM as emergency projects along public roads and residential areas. A 1982 OSM emergency drilling & grouting project along McLean County Highway 20 near Sawyer, ND, was conducted in an area where sinkholes had already occurred on the road surface and other near-surface mine voids were suspected. Two other OSM emergency projects were conducted in 1982 at Mercer County Highway 21 and Sun Valley Trailer Court, near Beulah.

Three large drilling and grouting slurry projects were conducted between 1983 and 1987 in an attempt to stabilize collapsing underground mine workings beneath a complex of commercial

buildings and several highways near Beulah between 1983 and 1987. Other slurry-fill projects were conducted beneath a highway near Sawyer, beneath a Catholic abbey near Richardton and beneath a highway near Wilton.

Remote Backfilling (Slurry) Projects 1982-89

Year	Site	Contractor	Approx. Cost
1982	Ward Co. Hwy 20, Sawyer	OSM Emergency	$800
1983	Mercer Co. Hwy 21, Beulah	OSM Emergency	$97,000
1983	Sun Valley Court, Beulah	OSM Emergency	$117,000
1983	Manny's (Boat Dealer & Bar), Beulah	Kjelbertson Const.	$578,000
1983	Ward Co. Hwy 20, Sawyer	Kjelbertson Const.	$147,000
1984-86	Highways 200 & 49, Beulah	Gravel Products, et. al.	$1,154,000
1987	Highway 200, Beulah	R& D Const.	$84,000
1989	Assumption Abbey, Richardton	Rolac Contracting	$71,000
1989	Highway 36, Wilton	Hulstrand Const.	$609,000
		Total	**$2,857,800**

A 1985 slurry-fill drilling and grouting project near Beulah

Remote Backfilling Projects – Pressurized Grout Drilling & Grouting, 1993-Present

Pressurized grout remote backfilling is a proven technique for subsurface stabilization of undermined areas (Beechie 1993). In this technique, a cementitious grout is pumped through cased drill holes directly into the mined cavities in order to prevent collapse of mined workings. Since 1991, this has been the exclusive method for drilling and grouting to prevent subsidence in North Dakota.

Remote Backfilling (Pressurized Grout) Projects 1991-present

Year	Site	Contractor	Approx. Cost
1991	Scenic East Subdivision, Williston	Thiem Drilling	$1,084,400
1992	Eagles Club /SunValley Court, Beulah	Northern Improvement	$629,260
1992	Highway 36, Wilton	Northern Improvement	$179,200
1993	Roughrider RV, Beulah	Thiem Drilling	$493,335
1994	Highway 2/52 Bypass, Burlington,	Thiem Drilling	$1,102,750
1994	Highway 20, Sawyer	Thiem Drilling	$293,000
1994	26th St & 318th Ave, Wilton	Northern Improvement	$313,350
1995	Hwy 2/52 & Sub, Burlington Phase 2	Thiem Drilling	$401,900
1996	Lehigh Road, Dickinson	Northern Improvement	$445,650
1996	Ruud Farmstead & Hwy 23, Parshall	The Concrete Doctor	$161,550
1997	Bar & Boat Dealership, Beulah	The Concrete Doctor	$469,150
1997	Lehigh Road Phase 2, Dickinson	Northern Improvement	$231,950
1998	Bar & Mobile Homes, Beulah Phase 2	Thiem Drilling	$311,800
1998	Lehigh Road Phase 3, Dickinson	Northern Improvement	$265,000
1999	KHOL Radio & Co. 21, Beulah Ph. 3	Earth, Energy & Water	$307,350
1999	Lehigh Road Phase 3, Dickinson	Earth, Energy & Water	$215,000
2000	City Residential & Co. 21, Beulah Ph 4	Earth, Energy & Water	$350,000
2000	Lehigh Road Phase 4, Dickinson	Thiem Drilling	$221,275
2001	Co. 21 & Hwy 200, Beulah Phase 5	Thiem Drilling	$314,840
2001	Lehigh Road Phase 6, Dickinson	Thiem Drilling	$275,400
2002	Highways 37 & 15, Garrison	Thiem Drilling	$138,250
2002	Highway 200, Beulah Phase 6	Thiem Drilling	$251,860
2002	Lehigh Road Phase 7, Dickinson	Thiem Drilling	$278,800
2003	Highway 200, Beulah Phase 7	Thiem Drilling	$262,100
2003	Lehigh Road Phase 7, Dickinson	Thiem Drilling	$211,615
2003	Buechler/Garrison, Hwy 23, 37, 13	Thiem Drilling	$220,000
2004	Snake Road, Burlington	Thiem Drilling	$231,750
2004	Co. Rd. 13 Zap, Beulah/Zap Phase 8	Thiem Drilling	$236,500
2004	South Garrison Addition, Garrison 3	Thiem Drilling	$208,000
2005	Co. Rd. 13 Zap, Beulah/Zap Phase 9	Thiem Drilling	$267,600
2005	Residential Areas, Garrison Phase 4	Thiem Drilling	$270,000
2006	Co. Rd. 13 Zap, Beulah/Zap Phase 10	Thiem Drilling	$285,000
2006	Williams Co. Rd 9, Williston	Thiem Drilling	$355,000
2007	Williams Co Rd 9 Ph 2, Williston	Thiem Drilling	$637,600
2008	Williams Co Rd 9 Ph 3 (Res), Williston	B&C Concrete Pumping	$628,500
2009	Williams Co Rd 9 Ph 4 (Res), Williston	Agri Industries	$992,200
2010	Co. 13 & Hwy 200, Beulah/Zap Ph 11	B&C Concrete Pumping	$669,000
2010	Williams Co Rd 9 Ph 5 (Res), Williston	B&C Concrete Pumping	$230,800
2011	Co. 21N & 60th Ave, Beulah/Zap Ph 12	B&C Concrete Pumping	$1,087,500
2012	60th Ave, Beulah/Zap Ph 13	B&C Concrete Pumping	$730,000
2013	SEE Road, Scranton/Bowman Ph 1	B&C Concrete Pumping	$883,000*
2013	60th Ave, Beulah/Zap Ph 14	B&C Concrete Pumping	$951,500*
	*Pending Projects	**Total**	**$18,092,735**

The grout is composed of (per cubic yard): 100 lbs. Portland Cement, 600 lbs. Flyash, 70 ounces Superplasticizer, approximately 2200 lbs. fine aggregate (sand) as required to meet yield requirements, and approximately 50 gallons of water as required to achieve the desired slump. Each component of the grout mix has its specific requirements. This grout mix formulation has been approved by the North Dakota State Department of Health and is classified as a beneficial use for flyash. This formulation has been used for all AML drilling and grouting projects in North Dakota since 1991.

A separate contract for material testing is a part of each drilling and grouting project in order to ensure the grout performance and components meet specifications. The grout is required to achieve an uncompressed compressive strength of 150 psi after 28 days of curing.

A relatively flowable grout (10-11 inch slump) is used for most projects. This seems to be effective for filling voids and also capable of penetrating cementing and densifying collapsed and rubblized mine workings, especially when the grout is pumped to refusal. A stiffer (6-8 inch slump) grout may be used when voids are open or as a barrier to impede grout from flowing away from the desired area.

Approximately 43 drilling and grouting projects utilizing pressurized grout remote backfilling, at a cost of more than $18 million, have been conducted in North Dakota since 1991. This has proven to be a relatively effective technique for stabilizing collapsing underground mines before they collapse to the surface and cause sinkholes.

One of the major disadvantages of pressurized drilling and grouting is the cost. It is an expensive technique and only used in "high-use" areas such as residential and commercial properties and public roads. A second disadvantage is that it is a remote technique and it is difficult to contain the grout within a specific area. It's also difficult to know whether mine voids and rubbilized areas are completely filled. Confirmation drilling has been conducted at most sites to check whether the mine voids were completely filled. A third disadvantage of pressurized drilling and grouting is that it can potentially cause surface lifting that can damage structures such as basements, foundations and roads. Pre- and post-construction surveys and ongoing monitoring techniques have been used in North Dakota to prevent damage associated with this technique (Dodd 2001).

Drilling and grouting projects at Beulah (2000) and Williston (2009)

Sinkhole Filling Projects 1993-Present

The pressurized drilling and grouting projects have been effective in preventing subsidence in high-use areas in cities, residential and commercial areas and roads. However, dangerous sinkholes occur frequently on cropland, grazing land and public properties. These sinkholes have resulted in damage to farm equipment, loss of livestock and serious danger to landowners and the public. Sinkhole filling projects have been conducted annually since at least 1993 in order to address these immediate hazards.

In these projects, topsoil is removed within and around the sinkholes and borrow area(s), the sinkholes are excavated and filled with dirt, topsoil is replaced and the area is seeded. These projects eliminate the immediate hazard of sinkholes while limiting the area of disturbance as much as possible. Almost all these sinkhole filling projects are conducted at sites where previous reclamation work has been conducted and are considered construction maintenance.

Sinkhole filling projects have varied in scope and size. In the early years, projects were often conducted locally. The AML Division would often execute "quickie" one page contracts with local contractors and fill a few dangerous sinkholes as they were reported. In recent years, these contracts have become larger, of longer duration, and have covered multiple sites.

Recent sinkhole filling projects have usually been conducted post-harvest in late fall, addressing all sinkhole reports received for the year. In the relatively wet years of 2008-2011, over 800 dangerous sinkholes were filled at sites all over the western half of North Dakota. After completion, project summary reports were sent to all affected property owners with data and pictures about the work conducted.

Sinkhole filling projects are a relatively low cost means of eliminating immediate hazards of abandoned underground mines that directly affect the public. These projects are a great help to farmers, ranchers and other rural property owners in western North Dakota; but, again, they only address existing sinkholes and do not prevent subsequent occurrences.

Before and after photos of sinkhole filling at Dave & Cathy Zimmmerman property, Richardton, ND

Sinkhole Filling Projects 2000-2013

Year	Sites	Sinkholes	Contractor	Approx. Cost
2000	Turtle Lake, Wilton, Scranton, Haynes, Havelock, Zap, Beulah	120	Holen Construction	$49,750
2001	New Salem, Wilton, Burlington, Tioga, Zap, Beulah	200	Basaraba's Excavating	$80,400
2002	Noonan, Wilton, New Salem, Dickinson, Beulah and Haynes	100	Onsite Improvements	$33,250
2003	Scranton, Washburn, Wilton, and Beulah	150	Basaraba's Excavating	$20,030
2004	Beulah, Dickinson, Havelock, Haynes, New Salem, Parshall, Wilton and Zap	80	Quality Construction	$24,630
2005	Baldwin, Beulah, Dickinson and Wilton	80	C&L Backhoe Services	$18,330
2006	Hanks, Noonan, Sawyer, Wilton, Haynes, Regent, and Beulah	115	Hanson's Excavating	$20,000
2007	Hanks, Noonan, Sawyer,	215	Hanson's Excavating	$21,190
2008	Noonan, Scranton, New Leipzig, Leith, Beulah, Williston Dickinson, New Salem, Wilton, Sawyer, Washburn, Garrison	350	Hanson's Excavating	$134,075
2009-2010	Beulah, Bowman, Dickinson, Hanks, Cartwright, New Salem, Noonan, Wilton	360	Basaraba's Excavating	$127,600
2011	Burlington, Noonan, Hanks, Beach, Haynes, Dickinson, Richardton, NewSalem, Parshall, Garrison, Wilton, Washburn	172	Basaraba's Excavating	$153,250
2012	Haynes, Dickinson, Wilton, Velva, Baldwin	45	Earthworm Excavating	$61,775
2013	Beulah, Richardton, Dickinson, Williston, Hanks, Noonan, Haynes, Washburn, Wilton	100*	Pleasant & Sons Const.	$100,000*
	Totals	**2087**		**$884,280**

*Pending Project

Emergency Underground Mine Reclamation Projects

Emergency reclamation projects, under the North Dakota Emergency Program, have been conducted when the AML hazard constituted an immediate and extreme hazard to the public. Approximately 20 emergency sinkhole filling projects and one emergency drilling and grouting project have been conducted in North Dakota since 1994 at a cost of approximately $225,000. These have generally been conducted in residential and commercial areas and on public roads.

2001 Lehigh Emergency, sinkhole beneath commercial building.

2001 Beulah (Garner Sailer) Emergency, sinkhole inside a machine shed.

2008 Williston (David Njos) Emergency, drilling & grouting underneath a commercial building with voids directly underneath the floor.

2010 Beulah (KDKT) Emergency, sinkhole near KDKT Radio Tower, Beulah, ND.

Potential Improvements to Underground Mine Reclamation

Improvements to each of these underground mine reclamation methods to improve efficiency and reduce cost will continue to be considered in the future. Geophysical methods have been used in North Dakota and other states in an attempt to locate and characterize subsurface mine voids. Some of these techniques including near-surface seismic reflection, reverse vertical seismic profiling (RVSP) and cross-hole tomography appear promising and could reduce the cost and impacts of exploratory drilling (MSHA 2007).

The Colorado AML program has experimented with the use of engineered foam to transport sand and other materials into mine voids. In a 2009 AML project conducted on Country Club Circle, a residential area in Colorado Springs, foamed sand was used to fill an open underground mine entry. The sand was allowed to settle for several weeks and then grouted using low mobility grout in order to completely fill the void (Amundson 2012). This hybridized approach, utilizing

a combination of foamed sand and pressurized grout has the potential to reduce the high cost of drilling and grouting.

Improvements to sinkhole filling and sinkhole grading projects may include methods to improve the compaction of fill materials placed in the sinkholes. This could reduce settling of repaired sinkhole sites. Some methods to accomplish this may be requiring a physical compaction standard in specifications or requiring that engineering fabric and/or rock, or even a layer of flowable-fill grout, be placed in the bottom of the sinkhole prior to filling it with dirt.

Conclusion

Several techniques have been used in North Dakota to address the hazards posed by abandoned underground mines. Pressurized grout drilling and grouting has proven most effective for stabilizing underground mine voids and preventing subsidence. This method can permanently fill mine voids and rubblized areas and densify loose soil materials before sinkholes collapse to the surface. This is an expensive technique and is only used in "high-use" areas like homes, commercial buildings and roads. Sinkhole grading and sinkhole filling is an inexpensive and effective method for filling sinkholes after they have occurred, especially in rural areas. This eliminates the immediate hazard of dangerous sinkholes but does not prevent subsequent sinkholes. The North Dakota AML Division intends to continue this two-pronged approach to eliminating hazards associated with abandoned underground mines.

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