The 1B Hydraulic System

Presented at

MEND Manitoba Workshop
Changes in Acidic Drainage for Operating,
Closed or Abandoned Mines

Winnipeg, Manitoba
June 5, 2008

Joe Shea
Cape Breton Development Corporation

Abstract

Coal was first mined in Cape Breton, Nova Scotia in 1685, by the French military authorities, from the exposed coal seam outcrops. By 2001 the last remaining underground coal mine in the Sydney Coalfield had ceased operation and so began the legacy of mine water in Cape Breton. More than fifty underground coal mines have worked the three major coal seams in the Sydney Coalfield, producing an estimated 500 million tons of coal and waste rock, thus leaving enough void space for more than 50 billion gallons of ARD producing mine water. At present there are several large groups of interconnected and abandoned coal mines or "hydraulic systems" within the Sydney Coalfield that are flooded to equilibrium, and there are several other hydraulic systems that are in the process of flooding. One such group of ten interconnected mines that is partially flooded is referred to locally as the 1B Hydraulic System. This paper addresses the mine water management techniques that were developed to prevent a discharge of deleterious mine water to the environment from the 1B Hydraulic System and outlines the plans for the future.

The 1B Hydraulic System

The Sydney Coalfield is located on the east coast of Cape Breton Island (Figure 1). The regional setting for this paper is found in the southern and eastern portion of the Sydney Coalfield (Figure 2). The 1B Hydraulic System is comprised of ten abandoned, underground coal mines spanning three coal seams (Figure 3). The 1B System is made up of both land and submarine workings, originating beneath the communities of Glace Bay, Dominion and Reserve Mines and extending seaward beneath the Atlantic Ocean. The mining history of the coal mines in the 1B System spans 127 years, beginning with the opening of No.5 Colliery in 1872 and ending with the closure of Phalen Colliery in 1999. The majority of the mines that make up the 1B System were owned and operated by the Dominion Coal Company, a British owned company that was facing closure in 1967. The Government of Canada took control and assumed full ownership of all Dominion Coal Company properties and assets in Cape Breton and formed the Cape Breton Development Corporation (CBDC), a Federal Crown Corporation, to manage the coal mines on it's behalf. The CBDC operated only the No.26, Lingan and Phalen mines in the 1B System. A summary of the individual mines in the 1B System is listed in Table 1.

Geological Setting and Geographic Location

The mines in the 1B System operated within a gently folded structure known as the Glace Bay Syncline and along the northward flanks of the Bridgeport Anticline (Figure 4). Three major coal seams (in order from the deepest to shallowest were : the Emery, Phalen, Harbour) were mined. The coal seams outcrop on land and dip northward at 3 to 14 degrees and are known to extend seaward under the Atlantic Ocean for at least 25 miles. The coal measures strata are of Carboniferous age, with the seams separated by sequences of sedimentary rock ranging from 130 ft (Emery to Phalen), to 425 ft (Phalen to Harbour). The inter seam strata generally consists of mudstone, shale, siltstone, sandstone, and minor carbonaceous limestone, which are indicative of deposition in fluvial & lacustrine environments (Figure 5). Faulting did not impact the operations of these mines.

The working areas of No.1A, No.5, and No.10 originated at the seam outcrops and were entirely under land. The working areas of No.1B, No.20, No.26, Lingan and Phalen were entirely submarine but all were connected directly or indirectly to land through slopes or interconnected tunnels from other 1B System mines. The workings of No.2 and No.9 straddle both land and the submarine environment. The working depths of the mines ranged from 125 ft above sea level at the southern outcrop, to 2700 ft below sea level at the northern most extent. Accessibility is no longer possible for the mine workings beyond the coast. There has never been a reported inflow of seawater recorded in the Sydney Coalfield.

Mining Methods and Mine Connections

The earliest and shallowest mines in the 1B System were located under land and used the room and pillar method of extraction. This resulted in the extraction of 40 to 50% of the coal with the remainder left as pillars to support the mine roof. However in many cases, the remnant pillars were removed by over zealous mine managers which led to widespread collapse of roof strata and ground subsidence at surface. In No.5 Colliery, extensive areas of de-pillaring took place, with almost 100% of the coal removed over large portions of the mine with some areas having less than 100 ft of vertical cover. In No.1A Colliery, room and pillar mining with very little pillar extraction was practiced, probably because this mine was located directly below the more heavily populated community of Dominion. As the mines proceeded under the sea, very regimented room and pillar mining was employed, with pillar sizes always erring on the side of safety. Full extraction longwall mining was practiced when vertical, solid rock cover to the seabed exceeded 900 ft..

The mines within the 1B System are connected to one another by one or more openings consisting of shafts, tunnels, drifts, boreholes, and mining induced fractures through longwall gobs or de-pillared zones. For example, direct connectivity exists between many mines that worked in the same coal seam, such as No.1A, No.5, and No.1B by virtue of dozens of mutually used roadways. Likewise, other mines that operated in different seams such as No.1B and No.26, were directly connected by cross measure stone tunnels and/or inter seam boreholes. The picture is further complicated by the fact that available records leave considerable doubt about the extent and adequacy of many of the mine seals, especially in the older mines, and it is practically impossible to obtain confirmatory information regarding their current condition.

Flooding of the 1B Hydraulic System

The flooding process for many of the mines in the 1B System began when individual mines ceased operation due to poor economics and the mine pumps were simply shut down. This was the case for No.9 and No.10. However, a key group of other mines in the 1B System including No.1A, No.1B and No.5 (all in the Phalen Seam), were intentionally kept dry, as they were directly connected, via several inter seam cross measures tunnels, to No.26 Colliery which was extracting coal further offshore in the Harbour seam. A large mine water collection lodgment and pumping station had been constructed near the 1B Shaft during the development of No.1B. It was designed to intercept and collect all mine water that was draining down dip through the older mine workings in No.1A and No.5. The pumping operation from this lodgment kept No.1B, No.2 and eventually the No.26 workings dry. Mine water was pumped to the surface at a rate of 1750 US gpm, and discharged to an ocean outfall without any noticeable discoloration to the ocean.

The No.26 Colliery was lost to a mine fire in 1984 and a decision was made in 1985 to shut off the 1B Shaft pumps. This decision set in motion an accelerated rate of flooding for the entire 1B Hydraulic System. The ensuing history of flooding in the 1B System has been recorded by water level measurements taken in the 1B Shaft. These measurements were used to construct the hydrograph shown in Figure 6. The hydrograph portrays the typical mine water rebound curve, however it also identifies several occasions where the rising mine water reverses direction due to underground dam failures and inrushes at operating mines. One such incident occurred in 1992 when 5 East longwall at Phalen Colliery, located in the Phalen seam, retreated below the flooded No.26 workings in the Harbour seam, continued below an 1100 ft barrier pillar of coal, and then retreated below the Lingan workings. The result was a sustained, major inrush of water (up to 7000 US gpm) through the compromised barrier pillar that had been designed to separate the workings of Lingan and No.26 (Figure 7). Pumping was immediately re-established to lower the level of water in the 1B Shaft. The objective was to reduce the pressure head acting on No.26 Colliery (300 psi) and stop the inrush of mine water into Lingan. However, the quality of the discharged mine water at the 1B Shaft proved to be unacceptable (very high iron and TDS) and the pumping operation was stopped (Figure 8). The compromised barrier pillar and the inability to pump from the 1B Shaft led to the closure of Lingan Colliery. It was determined that it was no longer safe to work the mine with the high risk of catastrophic mine water inrushes.

Phalen Colliery now had the distinction of being the last operating mine in the 1B System. It continued to mine directly below (425 ft vertical separation) the flooded workings of Lingan and No.26 Colliery until 1999. During this seven year mining period, there were several large flushes of mine water into the longwall gobs at Phalen Colliery from the overlying workings of Lingan and No.26 colliery. However, the Phalen pumping system was upgraded to handle increased water makes. The Phalen Colliery closed in 1999 due to severe longwall weighting problems associated with massive overlying sandstone beds. At closure the Phalen Colliery was making approximately 1200 US gpm of mine water from indirect connections to the overlying, flooded workings. Surprisingly, the mine water being pumped from Phalen was of sufficient quality that it did not require treatment. The highly acidic mine water located in Lingan and No.26 was being filtered and buffered as it percolated down through 425 ft of gob induced subsidence fractures to the underlying Phalen workings.

Where do we go from here ?

With the closure of the Phalen Colliery, the company focus had shifted to the operation of it's remaining coal mine, (Prince Colliery at Point Aconi) and the shutdown of the remaining infrastructure associated with the coal industry. Prince Colliery closed due to economic reasons in late 2001.
Meanwhile, monitoring of the rising mine water level in the 1B Hydraulic System continued at many locations. In the summer of 2001, the Corporation drilled a series of boreholes into the No 1A workings and found that they were dry. By mid year 2002, the mine water had reached the boreholes that were drilled in 2001, and the chemistry of the mine water samples collected from the boreholes indicated that the quality was very similar to the mine water that had been pumped from the 1B Shaft in 1992. The realization set in that detailed plans were required to deal with an impending discharge of mine water. The following engineering stepped approach was taken to address the rising mine water problem.

Step 1 – Calculation of Overflow Date

Mine plans were scrutinized for remaining void spaces left to fill. Data loggers located at various mine shafts and boreholes were checked for rates of fill. It was determined that the point of mine water overflow from the 1B Hydraulic System, would be at the No.1A Colliery water level tunnel which exits the mine just above sea level at the shore in the Town of Dominion. It was projected that overflow would begin in April 2003 (Figure 9).

Step 2 - Identify and block surface water entrance points into the mines

Mine plans for No.1A and No.5 were overlaid with topographic plans to identify areas where shallow workings from these mines and illegal "bootleg workings" were in the shadow of any wetlands or watercourses. An area know as Mac Kays Corner, which lies directly above the shallow and de-pillared workings of No.5 Colliery, was identified as being a major surface water infiltration point. The MacKay's Corner area is a lowland drainage feature and natural wetland that forms the headwaters for Cadegan Brook.
In addition, several areas to the west of Mac Kays corner, above both No.1A and No.5, along the Phalen seam outcrop were also identified as inflow areas. All surface water infiltration points that could be identified, were backfilled and sealed with clay (Figure 10). An average infiltration rate in the order of 2.9 US gpm per acre has been calculated for workings up to 200 ft deep from the Phalen seam outcrop. However, the Mac Kays Corner wetland is still considered as the main infiltration point to the 1B System. There is no surface water infiltration to the 1B system suspected from the land based No.9 Harbour Seam workings as they are over 250 ft. deep.

Step 3 – Establish expert groups to give advice in mine water treatment and mine water management

A Technical Advisory Committee (TAC) was set up with individuals who had a high level of expertise and a strong historical understanding of the issue of rising mine water in abandoned coal mines. Subcommittees for Hydrogeology and Water Treatment were established, and various consultants studied the mine water issues and recommended both short term and long term solutions.

Step 4 – Sample rising mine water chemistry

TAC recommended that additional land based boreholes be drilled near the shoreline into the No.1A workings to intercept the rising front of mine water, and to sample and assess the mine water quality. The chemistry of the mine water in these boreholes was found to be similar to those drilled in 2001.

Step 5 – Construct an emergency water treatment plant at the 1B Shaft

TAC recommended to the Corporation that an emergency water treatment plant would have to be constructed and operating by March 2003 to avoid an overflow of deleterious mine water to the marine environment. A conventional, hydrated lime, 1500 US gpm emergency water treatment plant and settling pond was hastily constructed and operating at the 1B Shaft location by the end of February 2003 (Figure 11). Plans were made to increase the capacity to 4000 US gpm if required.

Step 6 – Establish sampling boreholes in the upper areas of No.5 Colliery

TAC recommended that additional land based boreholes be drilled into the shallower, updip workings of No.1A and No.5 Colliery to sample the chemistry of the rising mine waters. The mine water chemistry in the adjacent and flooded workings of No.3 Colliery (not connected to the 1B System), had been sampled on previous occasions and was known to be net alkaline. The new boreholes drilled into No.1A and No.5 were carefully logged to identify the presence of any buffering material (limestone beds) in the roof strata. The boreholes were successful in proving the presence of limestone beds in the strata above both mines. However, the strata above No.1A, was found to be mostly intact with very few pathways for surface water percolation and limestone buffering (Figure 12). The strata above the shallow workings in No.5, were found to be highly fractured, due to widespread pillar extraction being the preferred mining practice for this mine (Figure 13). In conjunction with the borehole campaign, the mine plans of No.5 and No.1A were studied to identify the underground pathways that surface infiltration waters had been following for the previous 75 years. It was believed that the flushing action along these pathways should have helped to remove many of the products of pyritic oxidation (Figure 14). As the mine water reached the upper workings of No. 5 Colliery, it was sampled and the results indicated that a much better quality of mine water was present. In fact, the mine water chemistry was extremely similar in quality to the surface water in the Mac Kay’s Corner wetland area.

Step 7 – Establish an untreated discharge

TAC recommended that a pilot pumping test program be implemented to determine if a high volume pumping operation could be sustained with an acceptable discharge to the environment. A site at Neville Street in Reserve Mines, which was located 175 ft above the No.5 Colliery workings, was selected for the test. Mine water was pumped from two wells at a rate of 200 US gpm, for a one week period, into Cadegan’s Brook. The water chemistry was monitored, fish mortality tests were performed, and the mine water discharge quality remained constant. In March 2003, these results were presented to the Federal and Provincial regulators who accepted the findings. Subsequently, additional wells and pumps were installed at the Neville Street location to increase the pumping capacity to 3500 US gpm. The chemistry of the mine water discharge remained stable and it was further determined that the removal of water from the No.5 Colliery workings resulted in the ability to control the mine water elevation in the 1B Hydraulic System. The flooding of the 1B System had been halted, albeit, with less than 5% of the workings in the 1B System remaining unflooded (Figure 15).The ability to be able to control the mine water level in the 1B Hydraulic System from Neville Street, eliminated the need to operate the emergency water treatment plant at the 1B Shaft site. The WTP was mothballed in June 2003 and has been maintained in a state of emergency preparedness ever since.

Pumping Strategy and Mine Water Quality Trends

From 2003 to 2008, the pumping strategy has been prioritized to pump from the best quality wells, and to pump from the lesser quality wells only during large and extended precipitation events. In 2003, the Neville Street Wellfield was a fairly crude setup with individual wells, supplied with a 7.5, 20, or 30 HP submersible pump, powered by a portable diesel generator. In late 2003, the individual generators were replaced by a more reliable, 350 KVA diesel generator. In 2004, the site infrastructure was upgraded by adding a 12.4KV electrical service, telephone lines, and electrical switchrooms. In January 2005, the pumping infrastructure was upgraded with an 18” common pipeline installed to collect individual well flows and direct the mine water by gravity flow to an equalization pond. As well, below ground pump chambers were installed and the well pumps were standardized to 20 and 30HP Berkely submersibles.

Since 2005, the Neville Street Wellfield has been further upgraded to a fully automated, 5700 US gpm capacity facility, consisting of twelve x 30 HP submersible pumps and related infrastructure (Figure 16). The extra capacity and full reliability was required to deal with major rain/snow melts that occur in the late Fall and early Spring. Inflows into the 1B System from large precipitation events are time dependent, normally showing up 24 hours after the event has started. Large event, peak inflows into the 1B System have been calculated at up to 8000 US gpm. The current operating plan is to maintain the mine water level in the 1B System within a stable maintenance zone, at the top of the mine pool between –17 and –19 ft below sea level (Figures 17,18,19,20).

Due to the fairly crude setup at the Neville Street Wellfield during the first two years of operation, the accuracy of the pumping data that was recorded is considered suspect, and has been discounted for calculating yearly averages (Table 2). However the mine water chemistry data is considered valid for these two years because the standard for collection and analysis is the same as it is today.

The pumping data for 2005 – 2007 shows a strong correlation between pumping rates and precipitation. This is good news for the CBDC, as it indicates that no new inflows are entering the 1B System through surface sinkholes, mining induced fractures, or from adjacent coal mines. However we have all heard about Murphy’s Law and know that conditions can change. Therefore the Corporation has recently commissioned three initiatives to “stay ahead” of the mine water. A consultant has been hired to assess the risk of a pillar breach or mine seal failure in an adjacent mine that could cause a new inflow of mine water to the 1B System. Secondly, an extensive drilling campaign is underway to collect additional information on mine water quality and roof/floor strata within the coal mines of the 1B System and adjacent coal mines. Lastly, an aerial survey using LIDAR technology is planned for early May 2008. It will involve aerial flyovers along the outcrops of the coal seams to identity any new surface water infiltration points.

During the same 2003 to 2008 time period, the mine water quality trends have been slowly deteriorating. The reason for this has not been fully determined, but it is suspected that more frequent large rain events, which create extended periods of full pumping capacity, is drawing poorer quality mine water southward from No.1A Colliery (Table 3). It is planned to begin detailed mine water tracer tests during 2008 to try and understand the underground flow paths of mine water in the 1B System. The mine water discharge continues to be sampled bi-weekly and there has never been a fish mortality recorded to date. An Environmental Risk Assessment (ERA) was conducted on the mine water discharge into Cadegan’s Brook, in October 2007. The conclusion of the ERA was that it could find no measurable impacts to the waterway or wildlife as a direct result of the Neville Street discharge. However, it was noted that iron precipitate is accumulating in several locations along Cadegan Brook, creating aesthetic conditions that need to be addressed.

The Future – Near Term and Long Term

The untreated mine water discharge at the Neville Street Wellfield is predicted to remain in a net alkaline position for several more years. Mine water discharge chemistry data from the previous five years has been trended for increased metal loadings and total acidity. All indications are that the mine water quality will continue to deteriorate.
To deal with the deteriorating mine water quality in the near term, the decision has been made to install a passive treatment system with provision for an alkalinity dosing chamber at the Neville Street Wellfield location. The design and construction of a large settling pond and aerobic wetland scheme, will be completed by July 2008, with full functionality expected by the end of the second growing season.

For the long term, the solution is not totally clear, however it is suspected that there will be some form of active treatment required to fully flush the acidic mine water located beneath the landward portion of the 1B Hydraulic System, The volume of mine water in this pool is estimated at 2 billion gallons. To lead us to the final solution, the CBDC is co-sponsoring the establishment of an Industrial Research Chair at Cape Breton University in the area of Mine Water Management. This Chair will be tasked with undertaking the research and testing necessary to develop the science to create a compliant, passive discharge of mine water from the 1B System to the marine environment.

TABLE 1
Mines Within the 1B Hydraulic System

Mine Name	Year Opened	Year Closed	Seam Mined	Seam Thickness (m)	Workings Elevation Range (m)*	Location	Primary Mining Methods	Primary Mode of Access	Estimated Inflow Rate During Operations (GPM)	Estimated Volume of Water In Workings (US gallons)
No. 5 Colliery	1872	1938	Phalen	2.3	+35 to -168	Under land	R & P** & R & P with Pillar Extraction	Slopes from Outcrop & Shaft	400 (?)	803,000,000
No. 1A Colliery	1893	1927	Phalen	2.1	+9 to -187	Under land	R & P** & R & P with Pillar Extraction	Shafts	550	863,000,000
No. 2 Colliery	1899	1949	Phalen	2.2	-160 to -613	Submarine & Under Land	R & P** & R & P with Pillar Extraction	Shafts	12	4,559,000,000
No. 9 Colliery	1899	1924	Harbour	1.9	-61 to -213	Submarine & Under Land	R & P** & R & P with Pillar Extraction	Shaft	900	1,315,800,000
No. 10 Colliery	1905	1942	Emery	1.1	+38 to -140	Under land	R & P** & Longwall	Slopes from Outcrop & Shaft	1750	748,770,000
No. 1B Colliery	1924	1952	Phalen	2.1	-187 to -716	Submarine	R & P** & Longwall	Shafts	50	4,348,500,000
No. 20 Colliery	1939	1971	Harbour	1.6	-89 to -426	Submarine	R & P** & Longwall	Shaft & Cross Measure Tunnel	135	2,634,000,000
No. 26 Colliery	1943	1984	Harbour	1.8	-103 to -822	Submarine	R & P** & Longwall	Shaft & Cross Measure Tunnel	15	1,872,000,000
Lingan Colliery	1978	1993	Harbour	2.0	+26 to -817	Submarine	R & P** & Longwall	Slopes from Outcrop	+/-50 (prior to flooding event)	1,562,000,000
Phalen Colliery	1985	1999	Phalen	2.1	+27 to -750	Submarine	Longwall	Slopes from Outcrop	+/-50 (prior to flooding event)	1,573,500,000
							Estimated Total Water Volume In 1B Hydraulic System			20,279,570,000

*Elevations are relative to sea level
**Room and Pillar

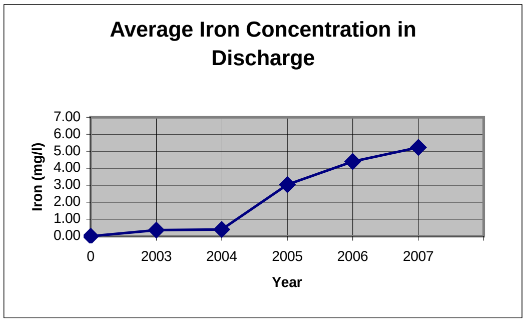
TABLE 2 - Pumping at Neville Street vs Total Annual Precipitation

Pumping Periods	Average Pumping Rate (US gpm)	Total Precipitation (mm)	Ratio Pumping/Precip
March 1, 2003 to Feb.29, 2004 *	1472	1528	0.96
March 1, 2004 to Feb.28, 2005 *	1619	1250	1.30
March 1, 2005 to Feb.28, 2006	2444	1430	1.71
March 1, 2006 to Feb.28, 2007	2054	1247	1.65
March 1, 2007 to Feb.29, 2008	2214	1397	1.58
Averages	2237	1358	1.65

* Pumping data for first two years considered unreliable and not used in average.

TABLE 3 - Iron and Aluminum Concentration in the Neville Street Discharge

		2003	**2004**	**2005**	**2006**	**2007**
Fe	Minimum	0.10	0.14	0.43	0.87	0.20
	Maximum	0.50	16.00	12.00	12.00	9.60
	Mean	0.36	0.40	3.03	4.40	5.06
Al	Minimum	0.02	0.01	0.05	0.13	0.05
	Maximum	0.40	0.83	2.10	2.50	1.80
	Mean	0.09	0.15	0.71	0.79	0.61



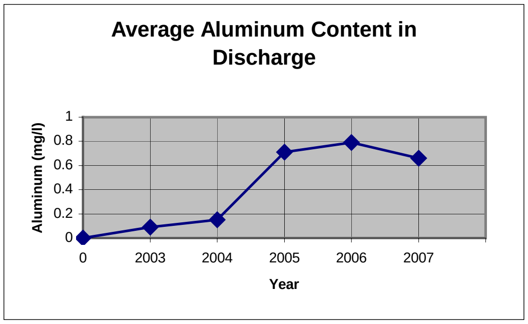


Figure 1 - Location Plan Cape Breton, Nova Scotia

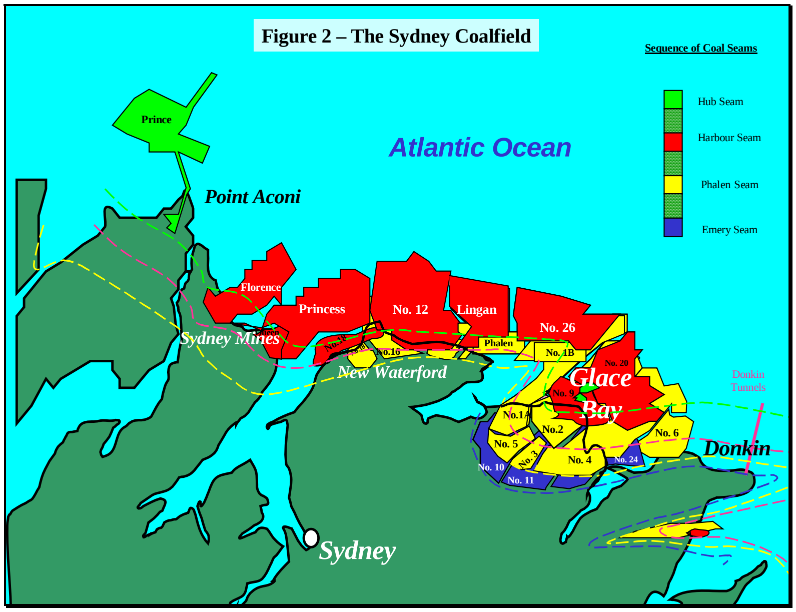


Figure 2 – The Sydney Coalfield

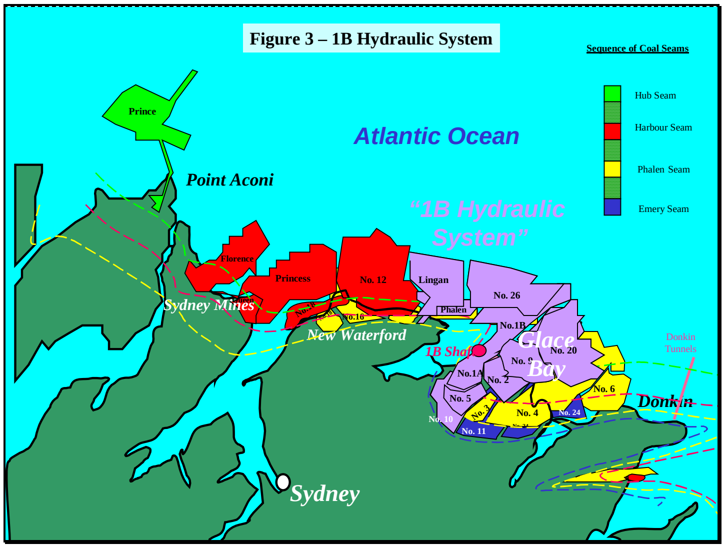


Figure 3 – 1B Hydraulic System

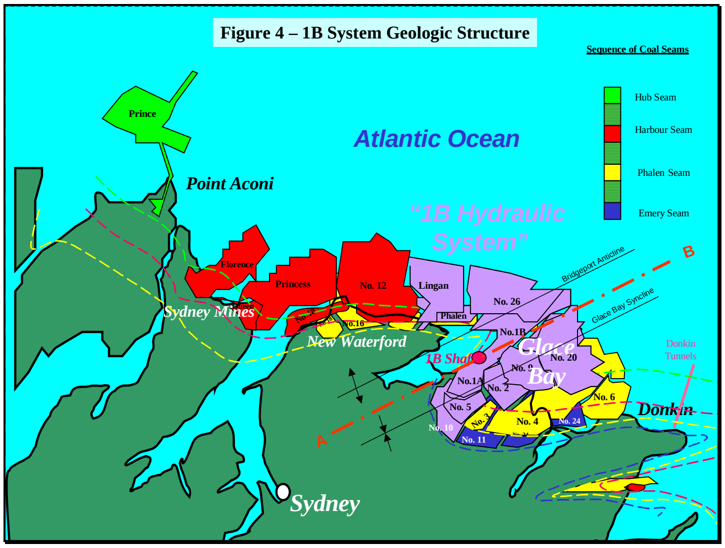
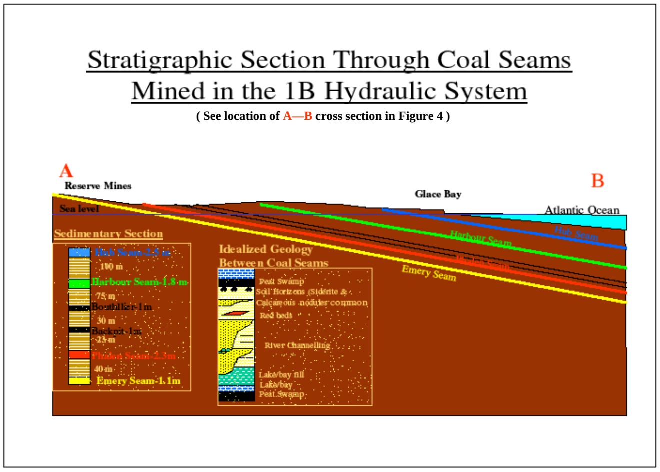


Figure 4 – 1B System Geologic Structure

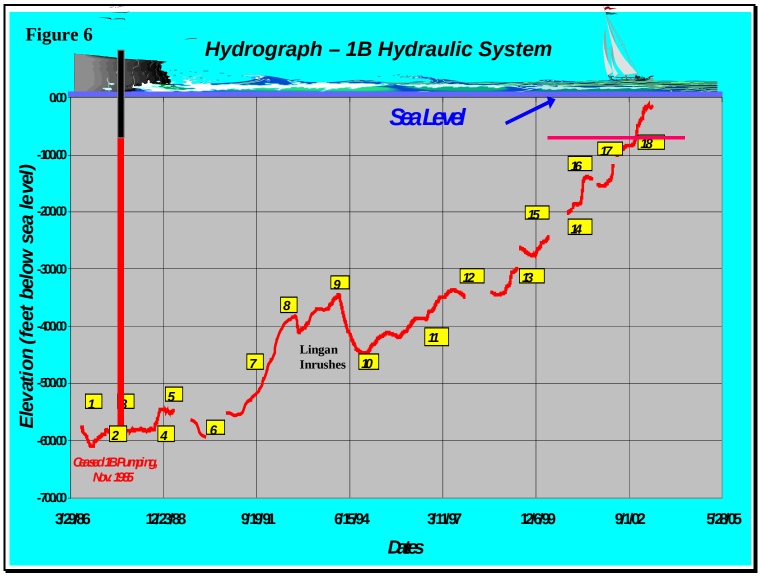
Figure 5 – Stratigraphic Section



Stratigraphic Section Through Coal Seams Mined in the 1B Hydraulic System

(See location of A—B cross section in Figure 4)

Figure 6



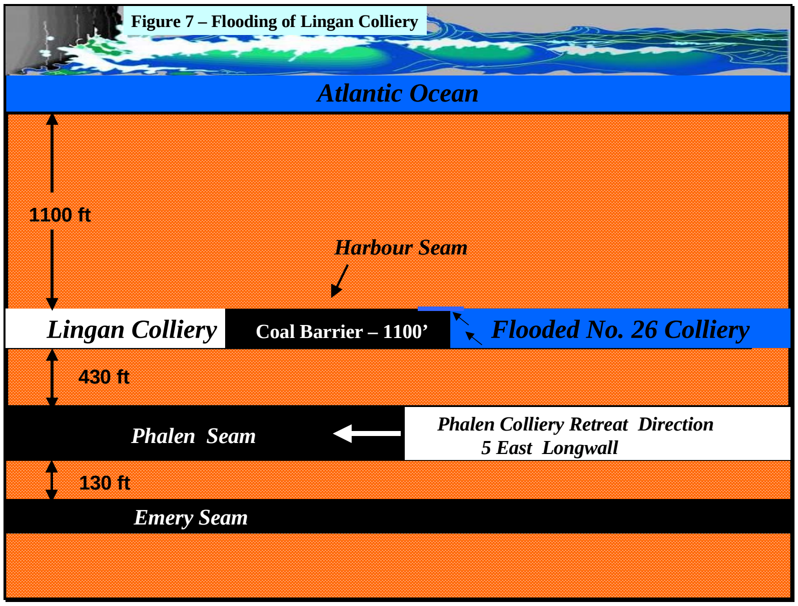


Figure 7 – Flooding of Lingan Colliery

Figure 8 – 1B Discharge Nov. 1994

Figure 9 – 1A Outfall

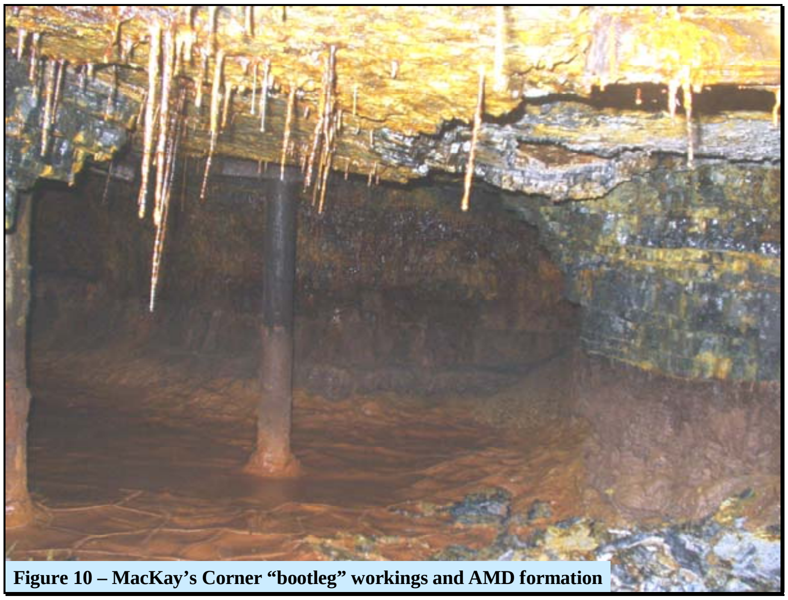


Figure 10 – MacKay's Corner "bootleg" workings and AMD formation

Figure 11 – 1B Treatment Plant and Settling Pond

Figure 12 – No.1A Room and Pillar workings

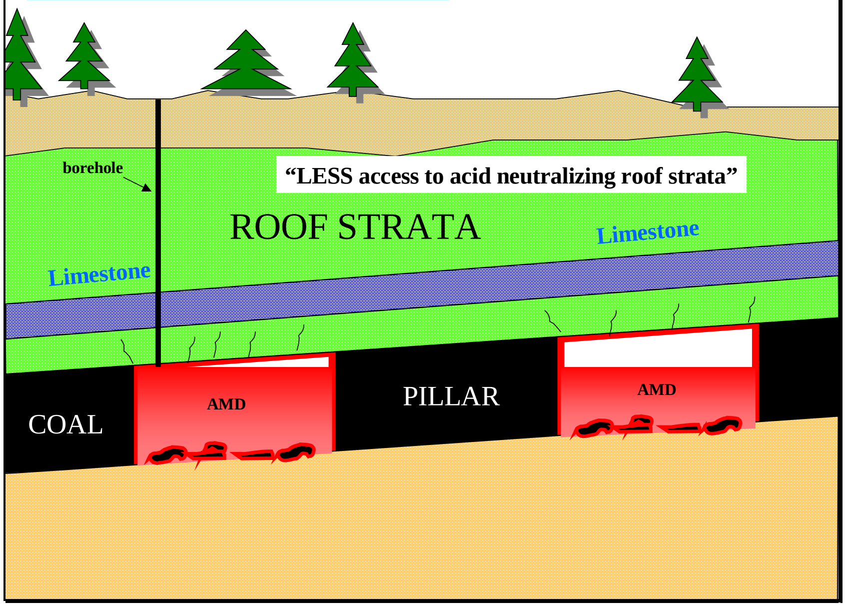


Figure 13 – No.5 Pillar Extraction

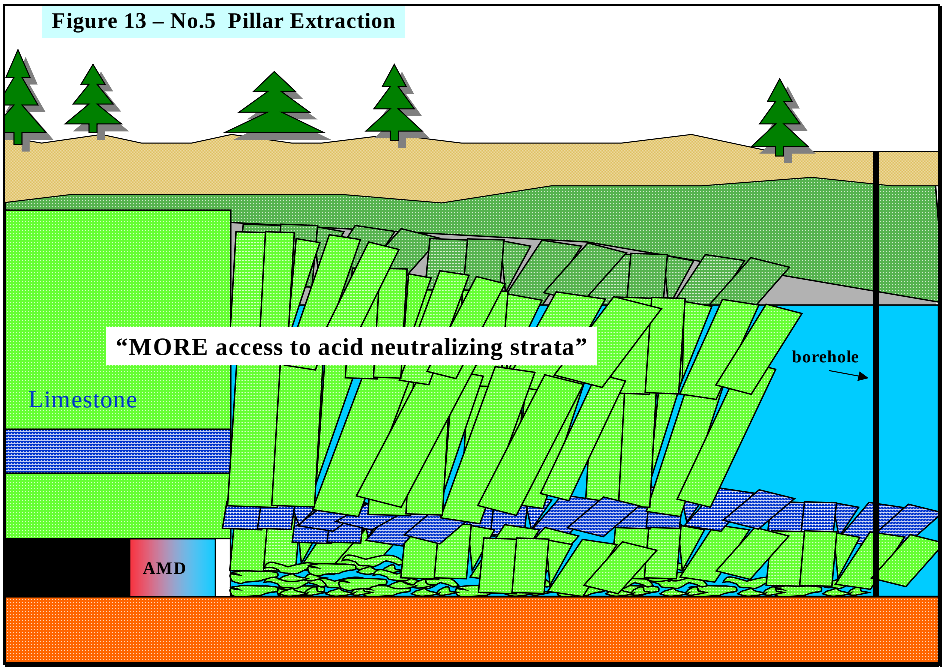
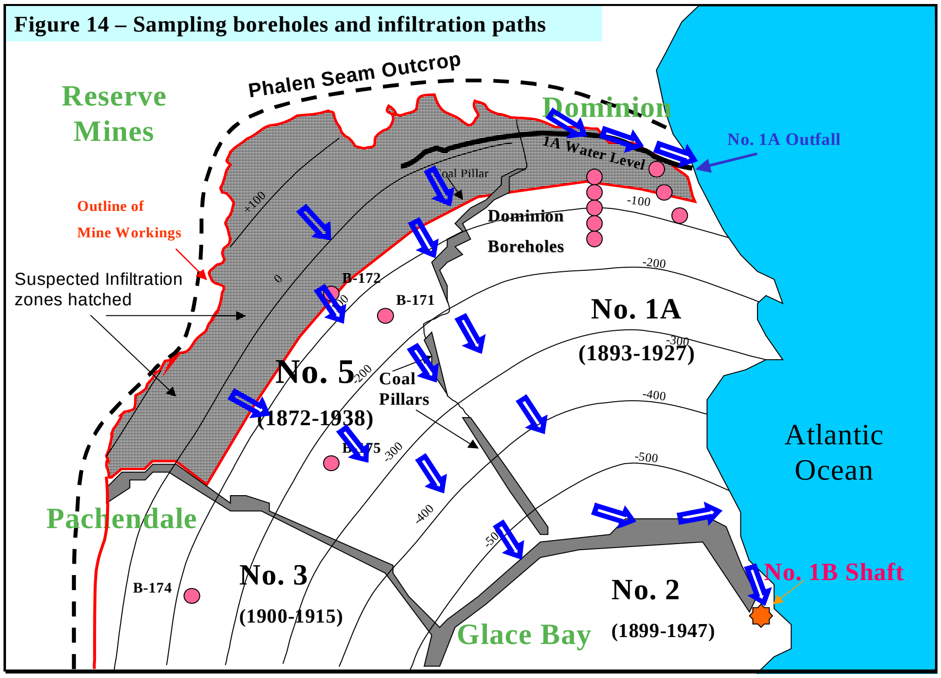


Figure 14 – Sampling boreholes and infiltration paths



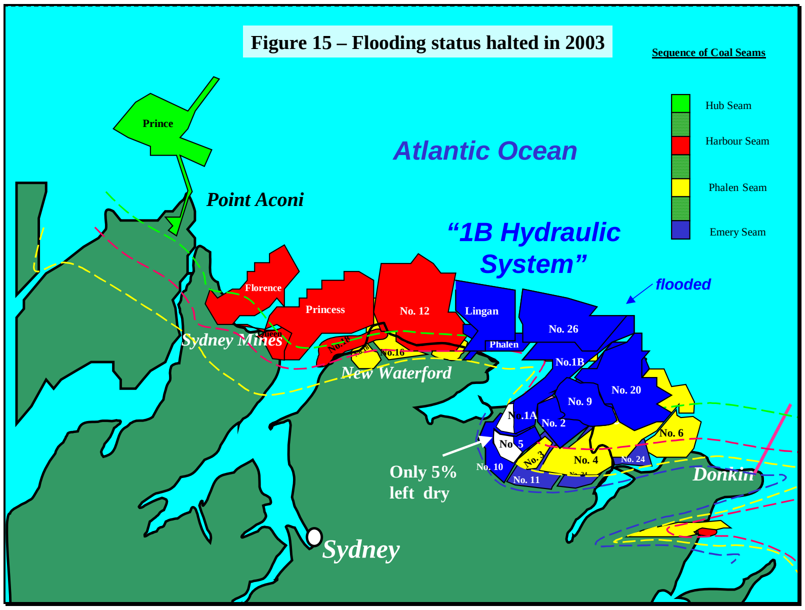


Figure 15 – Flooding status halted in 2003

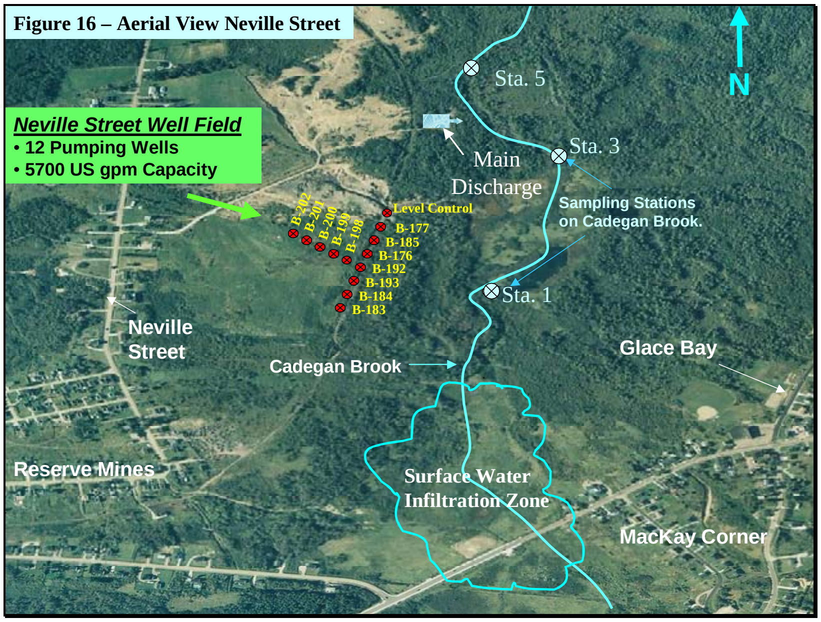


Figure 16 – Aerial View Neville Street

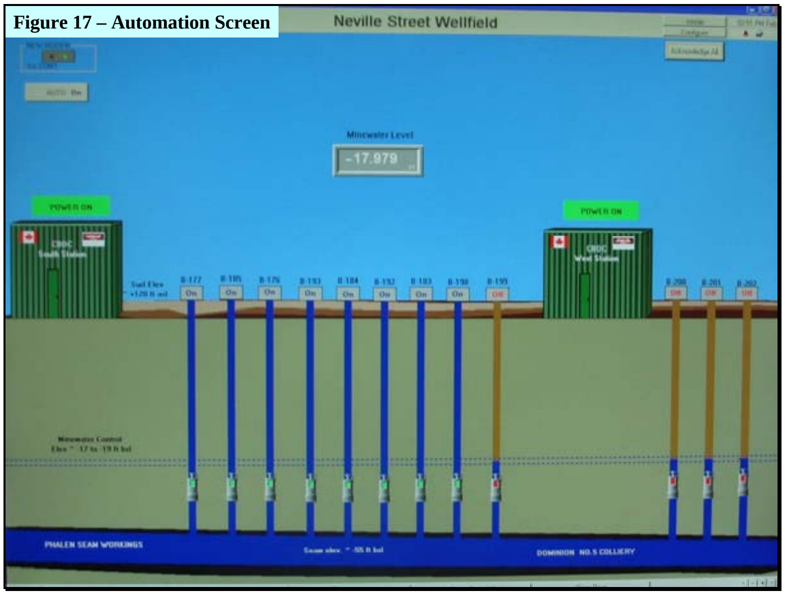


Figure 17 – Automation Screen

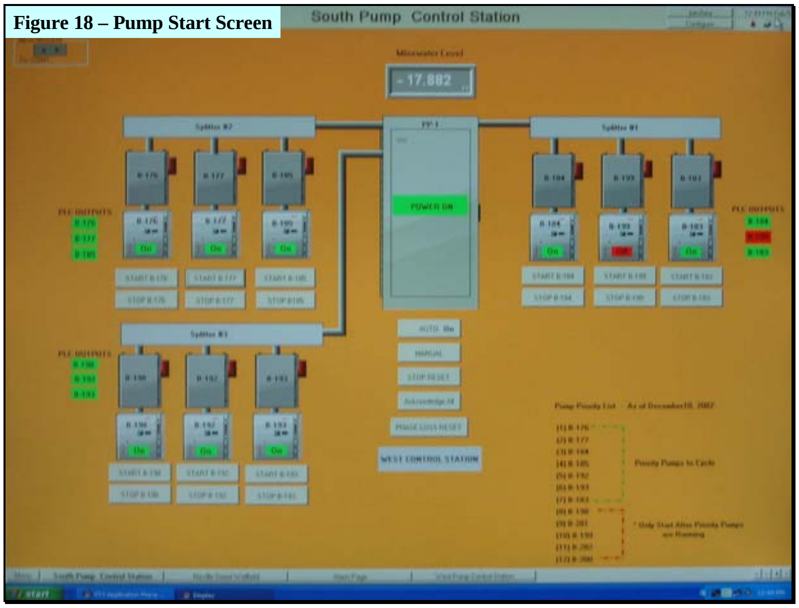


Figure 18 – Pump Start Screen

Figure 19 - Neville Street at full capacity – 5700 US gpm Feb. 2008

Figure 20 - Neville Street at Full Capacity Feb. 2008