CAPE BRETON DEVELOPMENT CORPORATION
COLLIERY WATER STUDY
SYDNEY COAL FIELDS, CAPE BRETON
NOVA SCOTIA

PROJECT NO. 8728

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REPORT TO

CAPE BRETON DEVELOPMENT CORPORATION

ON

COLLIERY WATER STUDY
SYDNEY COAL FIELDS, CAPE BRETON, NOVA SCOTIA

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1.0 INTRODUCTION

1.1 Purpose and Scope

The purpose of this report is to evaluate the current status of the ground water contained within coal mine workings located between Donkin and New Victoria, Nova Scotia and to predict the future discharge locations, quantity and quality of ground water which may drain from these workings.

The work consisted of a review of available mine records, water level information, water pressure monitoring and chemical analyses. The hydraulic interconnections between the abandoned mines and the surface, through shafts, slopes, service and development openings and tunnels, boreholes, and other man-made and natural features were also assessed. The hydrogeological interactions between the mine workings, host aquifers and surface water regime was evaluated.

1.1.1 Conduct of Study

The work reported herein represents the efforts of a number of professional staff employed by Jacques, Whitford and Associates (JWA).

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1.1.2 Acknowledgements

We gratefully acknowledge the willing co-operation and assistance of Cape Breton Development Corporation (CBDC) personnel to provide the information upon which the study was based.

R. Cooper, P.Eng. - V.P. Engineering & Safety
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The staff at the Beaton Institute was helpful in locating archival information and records. The late Mr. Louis Frost is recognized for his efforts in compiling and recording the events at the collieries in his work "A Review of the Coal Properties Operated by Dominion Steel and Coal Corporation Ltd.".

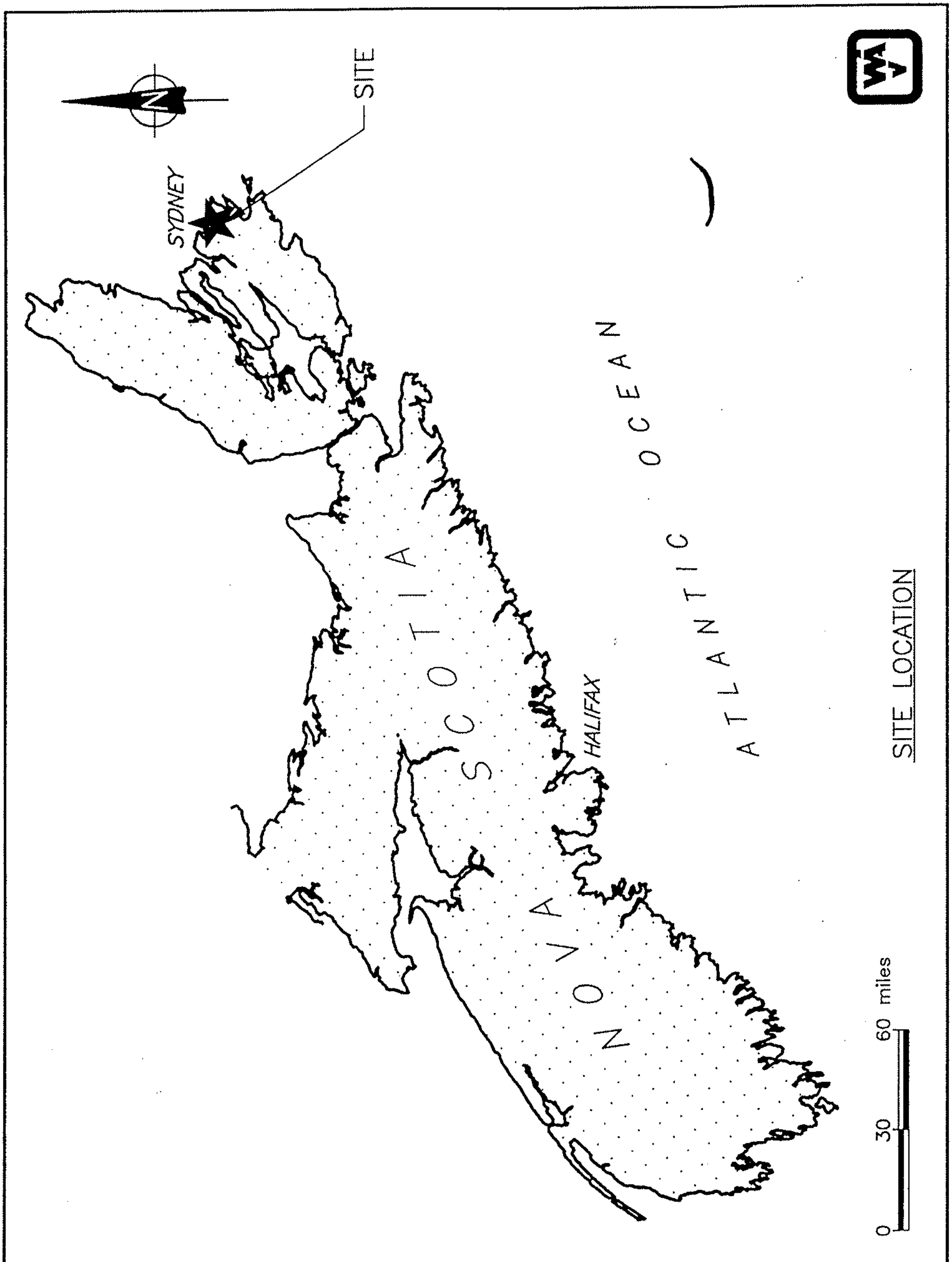
1.2 Historical Background

1.2.1 Coal Mining History

The Sydney Coal Field, which is the largest in Atlantic Canada, is located on the northeastern coast of Cape Breton Island (Figure 1.1). Coal from outcrops was first mined in the Sydney Coalfield by the French military in 1685; however, organized commercial mining of outcrops did not commence until around 1720. Mining continued on various seams until 1825 when the General Mining Association (GMA) was formed. Mining continued under the operations of several mining companies until 1893 when the mines, with the exception of the Sydney Mines lease area held by the General Mining Association, consolidated under a new Company known as the Dominion Coal Company. Operations continued under both the Dominion Coal Company and the General Mining Association until 1901, when GMA's operating interests in the Sydney Mines area were acquired by the Nova Scotia Steel and Coal Company.

In 1967, the operations of the Dominion Coal Company Limited (DOSCO) were acquired by the Cape Breton Development Corporation (CBDC). At the time of acquisition, there remained four collieries in operation within the study area; the Dominion Nos. 12, 16, 20 and 26. A number of colleries Lingan (1968), Prince (1974) and Phalen (1985) were subsequently opened by CBDC. By 1993, however, only the Phalen mine remained in production within the study area. The Lingan colliery suspended mining operations in November, 1992 following an inrush of water, and is being abandoned.

At least 27 known collieries were developed on five main coal seams within the study area, which extends between Donkin and New Victoria. These seams, listed in order of increasing depth, are the Hub, Harbour, Phalen, Emery and Gardiner. The location of the respective surface outcrops and geological orientation are illustrated on Drawing 8728-1 (Base Plan). The coal seams within the Sydney Basin extend north and northeast of the shoreline on two main anticlinal folds, which create three main basins. The folds vary the direction and dip of the strata within the Sydney Basin. The strata dips north at an average rate of 6% along the axis of the basins, while on the flanks of the basins, the dip varies from 7% to greater than 40%. Average dip in the workings varies from 7% to 25%. The



SITE LOCATION

FIGURE 1.1

majority of the workings in the Sydney Basin extend under the Atlantic Ocean. Mining reserves extend 5 miles from shore, however, the coal seams are known to extend much further off-shore.

1.2.2 Mining Methods

The mining and development methods utilized at the various collieries play a significant role in the nature and current condition of the interconnections. The age of the mine workings also reflects on the mining methods utilized. Manual mining methods were utilized exclusively until 1932 when mechanization was first introduced. By the later 1940's gradual acceptance of mechanical cutting, loading and mining systems led to complete mechanization over the next number of years.

Early mining operations within the Sydney Coal Field were conducted to shallow depths within the land portions of the coal reserves. Typically, the mining utilized room and pillar methods. The size of the pillars were generally 32 by 48 to 47 by 63 feet and yielded extraction ratios of 50 and 40 % respectively. In many cases, to maximize coal production of the room and pillared areas, the support pillars were often drawn over large areas. This practise subsequently left minimal to no ground support within the seam for these areas. Examples of these mines that practiced pillar removal include the Sterling Mine and Dominion Nos. 3, 4, 5, 7 and 8. This mining practice often led to surface subsidence over these mining areas that at an early date in the history of the mining operations resulted in water infiltration into the mine workings. The known shallow workings and crushed zones are shown on Drawing 8728-6. Although some longwall mining was carried out in the shallow zones, it was typically conducted in the deeper mining areas that had a minimum of 1,000 feet of cover.

At deeper mining depths, pillars were generally left in place to provide roof support. However, pillar drawing at the close of mining operations within a mining section would result in unstable ground conditions. Similar events would also occur in longwall mining areas, where caving of the workings behind the longwall face would disturb the overlying rock mass. This rock mass disturbance could lead to destabilization of the overlying rock and openings could develop leading to interconnections between seams or across barrier pillars separating two mines on the same seam. This type of mechanism may have been responsible for the inflow of water at the Lingan Mine in November 1992.

Mine openings developed for production, development, ventilation and services as well as cross-measure tunnels, that formed interconnections between the various collieries, were widely distributed throughout the Sydney Coal Field. Since these openings were typically developed for long term use, the openings would have been supported with steel arches or timber. Over time many of these openings would have collapsed. For the purposes of this study, it has been assumed these openings, other than those that had bulkheads installed, still form interconnections between the various colliery workings.

During mining operations, strict control was maintained over the size and requirement for barrier pillars between the collieries on the same seam. The barrier pillars separated the colliery workings, although in numerous locations, mine openings were developed between collieries through these southeast barrier pillars.

Typically, the minimum width of the barrier pillars was 300 feet; however, in many cases the width was variable. In assessing the barrier pillar widths, the accuracy and completeness of the early surveys must be considered. In one case, the Old Gardiner Mine that operated between 1870 and 1893, an unexpected breakthrough occurred into these old workings by development headings from Dominion No. 25. The resulting water inflow into Dominion No. 25 resulted in two fatalities. Later investigations showed that the Old Gardiner Workings had extended 325 feet past the locations shown on the available mine plans.

1.2.3 Bootleg Mine Operations

Concurrent with licensed coal mining activities within the Sydney Basin, unauthorized coal mining (i.e., bootleg mining) has been historically conducted along the surface outcrops of the coal seams. Due to the covert nature of these mining operations, the location and extent of bootleg workings were unreported and rarely documented. As a result, plans for only a small percentage of these bootleg workings that were discovered and surveyed are available. It has been assumed that the bootleg workings can occur anywhere along strike within 100 feet of the surface outcrop of the respective coal seams, as shown on Drawing 8728-6. Although these bootleg workings are considered shallow, in some cases they may have connected directly to underground workings. These areas provide potential sources of water inflow into the colliery workings as well as a near surface connection between workings, if bootleg operations extended across the surface portion of the barrier pillars.

1.2.4 Recent Mine Water Events

The most recent mine water event in the study area occurred in November 1992. At that time an inflow of water was detected from behind the sump bulkhead on the 2 East Bottom Level, near the main slopes of the Lingan colliery. From observations of water levels in adjacent abandoned mines and water chemistry analyses, it was determined that the most likely source of this water was the flooded No. 26 colliery. The No. 26 mine is adjacent to and in the same seam (Harbour Seam) as the Lingan colliery and separated at that location by a 1,100 foot barrier pillar. Peak recorded flows reached 4,000 igpm (imperial gallons per minute). Based on chemical analyses, the inflow water was considered a typical coal mine water; and was characterized by both low pH and elevated dissolved metals (Table D-2).

Two other recent water inflows have also been recorded. On November 7, 1988 an inflow of water occurred into the Phalen 2E workings. Initially the inflow was in excess of 1,000 igpm; however, the flow decreased to 6 to 7 igpm within a month. A second inflow in late 1990, occurred in the Phalen 5E working area. This 400 igpm inflow decreased to 76 igpm within a few weeks. It was felt this second inflow originated from the roof behind the gob of a production face. The sources of these 1988 and 1990 inflows were determined to be formation waters, that entered the workings as a result of fracturing in surrounding bedrock aquifers as longwall mining proceeded (JWEL, 1988 and 1992). Additional information on the water quality from each of these three inflows is provided in Section 5 and summarized in Appendix D. (Note: All flows reported as gpm were assumed to be igpm).

Much earlier inflows had occurred at other collieries, Dominion Nos. 4 and 25. Typically, these inflows resulted from surface infiltration through near surface workings where drawn or crushed pillars had initiated surface subsidence, or from unintentional connections made with abandoned, flooded workings of adjacent collieries. Excessive water flow in some of these collieries, particularly those situated in the Lower Morien bedrock aquifer, resulted in operational closure.

1.2.5 Land Subsidence

In addition to the obvious hazards of a collapse zone, subsidence areas provide a potential infiltration pathway directly into the mine workings. Subsidence of land over near-surface workings has occurred since early in the mining history of the Sydney Basin. Specific examples can be drawn from subsidence over the early workings of the Dominion Nos. 4, 7, 8 and the Sterling Mine. Because of the shallow mining depths, the early near-surface workings were mined using high extraction ratios to maximize coal production. These high extraction mining practices, which often included pillar drawing, often resulted in large zones of crushed voids, in turn leading to extensive areas of surface subsidence. In the case of Dominion No. 4, surface subsidence from these conditions permitted substantial flows of surface water into the colliery workings. Surface subsidence over large areas of the land-based mine workings has been a continual concern during the mining history.

1.2.6 Mine Drainage Cases

The drainage of colliery workings that had been flooded to extinguish mine fires, or allowed to naturally flood following abandonment, has occurred a number of times in the Sydney Basin in order to re-start mining operations. Two examples include the Dominion Nos. 1A and 7, both of which were intentionally flooded through tunnels driven to the shoreline to extinguish mine fires in 1903 and 1906 respectively.

Historically, natural water drainage into the operating collieries has been controlled by pumping water collected in sumps within the mine to surface through pipelines in the shafts or slopes, or through boreholes drilled from surface. Water inflow has varied from 12 igpm for the Dominion No. 2 to 1,750 igpm for the Dominion No. 10 (Frost, 1964). Mine water was at times drained through other interconnected colliery workings prior to being pumped to surface; this occasionally required the development of drainage tunnels. In one specific case, a drainage tunnel was developed from the lower workings of the Dominion No. 4, through the barrier pillar with the Dominion No. 3, to improve the quality of the mine water in the Dominion No. 4. Mine water from Dominion No. 4, which had a pH of 2.1 was mixed with mine water from the abandoned Dominion No. 3 to increase the pH levels prior to being pumped to surface. The low pH levels in Dominion No. 4 were partially attributed to the acidification of recharging water which drained into the colliery through the area of surface subsidence in the upper crushed zones of the mine.

Late in 1992 pumping was initiated at No. 1B Shaft to relieve water pressure accumulating within Lingan 2E colliery via No 26 workings. The quality of the water was unacceptable for discharge into the marine environment due to unacceptable TDS and metal content, and the discharge had to be terminated.

Mine drainage was also facilitated through the use of sea drains which helped reduce pumping costs. Four known sea drains that were used during mine operations still continuously drain mine water from the Dominion Nos. 1A, 7, 8, 4 and any interconnected land workings above sea level. Additional sea drains may also exist from other collieries, although none were identified from examination of available information during the course of the study.

1.3 Environmental Concerns

Mine water can be released to the groundwater and surface water environment both during active mining operations and after abandonment of operations, as discussed in the following sections.

1.3.1 Active Mine Pumping

Active mine pumping involves the continuous or intermittent discharge of water collected in sumps at the bottom of the mine.. This water is a combination of waters used to operate mining equipment, seepage from surrounding bedrock and infiltration from higher areas of the mine. Specific concerns include:

i) Highly acidic water is often discharged. The acidity levels are elevated because of the large amount of sulphide-rich rock (coal shale) exposed to a constant source of oxygen-rich water percolating throughout the mines.

ii) ~~Heavy~~ High metals load ~~is high~~. The acidity allows high concentrations of metals, including ferrous iron, aluminum, copper, chromium, nickel and others ~~in solution~~. The surface waters receiving the discharge invariably have a higher pH and this causes precipitation or adsorption of these metals.

iii) High total dissolved solids (TDS) load. The concentration of sulphate, as a result of sulphide oxidation, chloride and major cations, as a result of infiltration of hyperfiltrated brines, can often be elevated in mine waters along with their associated cations. Such waters can be a hazard to aquatic life when discharged in low TDS freshwater ecosystems.

iv) High suspended solids load. Suspended solids, including iron sludge or floc, can be a hazard to aquatic life; in addition suspended solids also carry adsorbed metals that can precipitate from solution.

v) Strongly reducing electrochemical conditions. Lack of dissolved oxygen, elevated ammonia-nitrogen as well as dissolved iron, manganese and organic carbon can place a high chemical oxygen demand on receiving waters.

vi) High pumping rates required to discharge the large volume of mine workings can easily overwhelm surface water ecosystems.

Based on a review of the existing CBDC chemistry data, all of the above factors are, or have been, of concern at pumping discharge points within the study area.

It is our understanding that the Phalen colliery is the only mine currently being pumped in the study area. In late 1992, No. 1B and the Lingan collieries have also been pumped for short periods. JWA understands the pumping rates have varied but are in the order of hundreds to thousands of gallons per minute.

1.3.2 Mine Closure and Passive Mine Drainage

A number of passive outfalls draining old workings presently occur within the study area. One of the primary concerns initiating this study was the potential for more mine water outfalls to develop after closure that would discharge to surface unknown quantities of poor quality water.

Passive discharge and active mine pumping present similar water quality concerns. However, turbidity and suspended solids are less likely to be a problem under passive discharge conditions. Passive discharge is of greater interest to this study than active mine pumping because it represents a longer term environmental problem.

Conceptually, the quality of water is directly related to the degree of oxidation of sulfides such as pyrite which can produce sulfuric acid and consequently lower the pH of the groundwater. The degree of oxidation will depend upon the following factors which are listed in decreasing order of significance:

i) the volume of the unsaturated mine workings that remain above the water level;

ii) the length of time the mine has been inundated to its equilibrium water level;

iii) the chemical quality of water recharging the workings (eg: rainwater, groundwater, seawater); and

iv) the amount of flow-through.

1.3.3 Land Subsidence and Flooding

Subsidence is an environmental concern because it can provide hydraulic connection between the surface and shallow mine workings. This connection can be a pathway for:

i) upward seepage of acid-impacted water and inundation of low lying areas, including newly subsided lands; and

ii) downward infiltration and recharge into the underground complex, causing passive discharge of acidic drainage at some lower elevation where a connection to surface exists.

2.0 STUDY APPROACH AND METHODOLOGY

To undertake this study a conceptual mine water flow model was first developed. This required that a vast amount of existing information be compiled, synthesised and grouped within the context of the entire Sydney Coal Basin. Based on this existing information, a conceptual model of mine water flow interconnections was developed. Using this model and data (e.g., water levels in abandoned workings, discharge rates, topographic data), predictions were made regarding future mine water discharge rates and locations. In conjunction with this conceptual mine water flow model, available water chemistry data was reviewed and potential relationships were identified. Estimates of future water quality at the discharge locations and within the abandoned interconnected mine systems were based on these relationships.

This investigation involved a number of tasks, namely: compilation of information, identification of mine interconnections, assessment of mine water infiltration and migration pathways, the assessment of mine water chemistry, and interpretation and reporting. Each of these tasks are briefly discussed in the following sections.

2.1 Information Compilation

Information utilized in this study was obtained from the following sources.

- Copies of mine plans for all of the underground operations in the defined study area, at a scale of 1 inch = 400 feet, or as necessary, 1 inch = 200 feet, were obtained from CBDC.
- Reports detailing the history of mining operations in the Sydney Basin, particularly the summary report prepared by Mr. Louis Frost.
- Compilation drawing (No. 1116-H) of mine interconnections developed by CBDC.
- Borehole logs, mine pumping data and water chemistry information, company correspondence, memos and reports, and other relevant information on the mine operations from CBDC, the Beaton Institute, Nova Scotia Department of Natural Resources and other sources.
- Field visit and interviews with key personnel.
- Topographic, geological and surficial geology maps and air photographs.
- Personal communications.

A listing of all reference drawings and sources of information is provided in Appendix A. Numerous references on acid mine drainage are generally available. A cursory literature search identified only a limited number of references relevant to groundwater infiltration control in the abandonment of shallow coal mines, and the control and mitigation of mine water drainage from abandoned coal workings. Two references with abstracts are provided in Appendix B.

2.2 Identification of Mine Interconnections

The methodology used to identify the various types and locations of mine interconnections of the collieries within the study area was as follows:

- The mine plans of the underground workings of the collieries were assembled based on CBDC's currently mining grid. In some cases (e.g., the older plans) the mining grid had to be established based upon available general features. The map sheets generated were then joined to show the total extent of mine workings for each of the five separate coal seams (Hub, Harbour, Phalen, Emery and Gardiner).

- The extent of colliery workings and their corresponding barrier pillars, were identified for each seam.

- The access slopes and/or shafts, and all other identified service raises, shafts and other openings, including boreholes shown on the mine workings plan, were noted and recorded for each colliery. Locations of cross-measure connections by these features were also documented.

- Interconnections between adjacent collieries across the in-seam barrier pillars identified on the mine plans were noted and recorded.

Subsequent to the identification of all known interconnections, plans for each of the coal seams were superimposed to identify the locations and elevations of the interconnections between the various collieries and coal seams.

Associated information from the sources identified in Section 2.1 was also utilized to assemble the various mine plans, and to identify the interconnections between the various mines and ground surface.

A series of plans and a cross-referenced spread sheet tabulation were prepared to document the results of the study. These plans and spreadsheets represent an easy to understand compilation of data that was previously not available in either the public or private sector. In addition to supporting the objectives of this study, these plans and tabulations may prove useful for other applications.

Reference Tabulation Spread Sheet

A spread sheet was prepared to organize and cross-reference the data obtained during the investigation process (Table 2.1). This tabulation provides a complete listing of all the collieries in the study area and summarizes key information for each colliery. This information included: operating period; top and bottom elevations of the workings; average seam thickness; coal production; lateral extent of workings; a listing of all identified access openings and interconnections; including the known status; coordinates; elevations; length and dimensions; documented water make and quality; and specific comments and details relating to each identified access and interconnection type.

Base Plan

A base plan was developed using the information obtained from the mine plans and other reference material as listed above. This plan (Drawing 8728-1) shows the outcrop location of the major coal seams; location of all the collieries; bedrock and surficial geology; and land features, including major roadways; as well as community and location names.

Colliery, Access and Interconnection Plans

Four plans were prepared for the workings on the Hub and Gardiner, Phalen, Harbour and Emery seams. Each shows the extent of mine workings for each of the collieries developed on that particular seam. Major development headings for each colliery, access and service openings, and all known interconnections both in-seam and between seams are also shown. Each of the known interconnection locations were also cross-referenced to Table 2.1. All plans were prepared to the same scale as the Base Plan to facilitate correlation of features between the various plans. Specific plans prepared were summarized as follows;

Drawing 8728-2:	Hub and Gardiner Seams
Drawing 8728-3:	Harbour Seam
Drawing 8728-4:	Phalen Seam
Drawing 8728-5:	Emery Seam

Topography, Drainage and Recharge Risk Areas

Drawing 8728-6 provides the topography and watershed drainage characteristics of the study area. The drawing further details the recharge risk areas, namely the projections of all mine workings within 100 feet of ground surface and known crushed zones and subsidence within 200 feet of surface. The areas of bootleg mining activity assumed to exist along the respective coal seam outcrop locations were also outlined.

2.3 Mine Water Infiltration and Migration Pathways

Potential sources of mine water infiltration were assessed. Municipal, provincial, and CBDC officials were contacted regarding the existence of relevant publications or reports, and were interviewed for anecdotal information on possible sewer discharge into workings, existing mine drainage outfalls, subsidence and sinkhole reports, and other information. Published geological, hydrogeological, hydrological, and topographic sources were acquired, compiled and reviewed to determine background hydrogeological setting. JWA geotechnical and hydrogeological reports on nearby areas were also reviewed to provide baseline information. Although some information was available in specific areas, detailed published information on subsidence incidents has not been documented for the entire study area.

The background information was assessed, in conjunction with the compilation of the workings and interconnections, to develop conceptual models for the recharge of mine hydraulic systems. Each potential infiltration source was reviewed and considered with respect to potential pathways into the mines. This assessment technique focused on possible pathways for each source and either eliminated or identified potential sources.

Quantitative assessment of discharge from abandoned outfalls was attempted with some success. Equilibrium effluent flow rates were estimated by assessing historical mine discharge rates and infiltration rates calculated using hydrogeological principles.

2.4 Assessment of Mine Water Geochemistry

Available historical information on the geochemistry of mine waters during operation of the collieries was obtained through research at the Beaton Institute and from CBDC files. Upon review of this information and after assessment of the conditions existing within the study area, it became apparent that the chemistry of mine water in operating mines in this area will have little resemblance to the long term chemistry of waters discharging from outfalls after closure. The chemistry of mine waters at the outfalls is more likely to be affected by the nature of the workings from which they are discharging, the amount of recharge water and, most important, the area of the workings which remain above water after equilibrium water levels have been established. The area of the workings above equilibrium water levels will determine the surface area available for sulphide oxidation and this subsequently affects the water quality. Because of this, the initial work to determine effluent water quality involved predicting the state in which the workings would remain after equilibrium water levels have been established.

Once it was determined what factors will affect the mine water level and their relationship to each other, these factors were used in a ranking system to rate each of the identified mine hydraulic systems. The systems were ranked according to its relative risk for discharging a high quantity of acidic water from outfalls.

Final pH ranges were estimated using the results of the limited fieldwork conducted to date, literature information, and JWA's past experience in dealing with the processes involved.

The location of mine discharge outfalls were determined from field observations, known existing outfalls and the mine interconnection assessment. A description of the known and suspected outfalls is provided in Section 4.7.1.

2.5 Interpretation and Reporting

The results of the mine interconnection work, as well as the hydrogeological and the hydrogeochemical assessments, were combined to assess the overall hydraulic interaction between the on-land shallow workings, the sub-sea workings and mine-surface water interactions. Emphasis was placed on identification of possible water infiltration pathways to the mines, flow between the mines, and prediction of likely mine water discharge areas after hydraulic equilibrium has been reached in the abandoned mines. The existing mine water chemistry data was interpreted, and predictions were made on the likely mine water quality after mine abandonment. What are considered to be a series of distinct mine hydraulic "systems," have been identified based on this existing information.

Recommendations are provided for follow-up location and monitoring of potential mine water discharge pathways. The study output provides CBDC with a series of plans and tables that illustrate the extent and interconnections of the various mine systems. These plans and tables can be readily up-dated as new information is obtained and they can provide a baseline for any future investigations.

3.0 ASSESSMENT OF MINE INTERCONNECTION

3.1 Potential Interconnections

The location of the known interconnections between the various collieries was critical to the assessment phase of the project. Once the interconnections were identified, they were categorized with respect to potential for the transmission of water, as follows:

i) Without specific available information, openings due to shafts, slopes, cross-measure tunnels, water diversion/drainage tunnels, ventilation, travel or haulage drifts and colliery workings across barrier pillars, ~~available~~ were assumed to be supported using arches or timber. Although these openings may have collapsed, it was assumed they can still transmit significant volumes of water.

ii) Service boreholes were drilled for the installation of electrical cables, water lines or drainage between collieries, within the same seam or between different seams. These boreholes, typically reported to be between 10 inches and 12 inches in diameter, may or may not have been cased, or had a pipe installed within them. Cased holes, or boreholes drilled through rock between coal seams would have a higher probability of remaining open and could transport water.

iii) Fracturing or destabilization of barrier pillars, between mines on the same seam or pillars between overlying mines on different seams, would enhance the movement of water. If barrier pillars in adjacent seams are not superimposed over each other, the possibility exists that undermining pillars could result in fracturing and parting of the pillars permitting the flow of water between mine workings.

Potential bootleg mining operations that extend across barrier pillars could potentially act as a hydraulic interconnection between two adjacent workings, as water levels rise in one or both of the workings.

iv) Exploration boreholes that were drilled from surface to obtain geological and coal reserve quality information often extended through various coal seams. These boreholes were typically 2¾ inches in diameter (i.e., diamond drill holes) or 8 ~~inches~~ to 12 inch in diameter, (i.e., "Keystone Drill") ~~boreholes~~ and may or may not have been grouted upon completion. Holes that were not sealed to their full depth could potentially act as channels for water flow between seams if mine workings intersect the borehole. The most significant would be the 8 inch to 12 inch diameter boreholes, since they have the potential to transport large quantities of water.

v) Crushed and de-pillared workings over which surface subsidence has occurred. Although ~~these areas~~ they may not act as direct interconnections between collieries, ~~crushed zones that have resulted in surface subsidence~~ they are known to be sources of significant water inflow into the mine workings and can also be potential outflow areas. These shallow mine workings may in turn be hydraulically connected to deeper mines. Crushed zones typically occurred in areas of near surface workings where high extraction mining practices (i.e., pillar drawing or total extraction mining using long wall methods) were carried out.

Without the ability to inspect and evaluate the current condition of the identified interconnections, a number of assumptions and evaluation parameters have been established, that are supported with available information. Assumptions used in the study to categorize the various types of colliery interconnections were as follows:

i) In some instances, shafts, slopes and other access service raises or openings in abandoned collieries were assumed to have been backfilled, based on data reviewed during this study. Typically, the vertical shafts and raises were filled with a layered combination of rock fill and cement, that was assumed to effectively seal them to any vertical water flow.

ii) In most cases documentation could not be found to support recommended backfilling and sealing of shafts, slopes and other access service raises or opening.

iii) References to tunnels that had been dammed, implied only a partial obstruction and not a complete blockage of the opening that would seal off water.

iv) Where conditions permitted and data was available, CBDC water level measurements were used to indicate the existence of open or sealed interconnections between colliery workings.

3.2 Hydraulic Interconnections and Hydraulic "Systems"

Section 1.2 (3.1?) discussed the interconnection of collieries through workings, tunnels and boreholes. Section 3.2 discusses the grouping of collieries into hydraulic systems that are likely to behave independently.

As previously discussed, it is not always apparent whether tunnels and/or borehole connections between collieries are still open and capable of hydraulic connection. In many cases, tunnels have been sealed or partially sealed. Hydraulic evidence suggests some boreholes were either sealed or were otherwise left in a state that does not provide a good hydraulic connection. The hydraulic systems and the evidence used to define them are discussed below. Some of the interconnections were inferred from assumptions needed for estimating final water levels and flow rates; these assumptions should be confirmed. The identified interconnection systems are described in the following sections.

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Table 2.1
CBDC Colliery Water Study
Compilation of Colliery Data

July 1993

Colliery No.	Service Dates	Seam	Colliery Workings Elevation Ranges Top(ft)	Bottom (ft)	Avg Seam Thickness (ft)	Coal Production (Long Tons)	Worked Area (Acres)	Access and Interconnection Type	Reference Number I.D.	Access Status	Access Coordinates (Dominion Grid) Northing (ft)	Southing (ft)	Easting (ft)	Westing (ft)	Access or Interconnection Details Top Elev. (ft@sea L)	Bottom El. (ft@sea L)	Length (ft)	Opening Dimensions (ft H)	(ft V)	(ft dia.)	Water Make (GPM)	Water Quality	Comments or Other Details
Dominion 20	**1939-1971**	**Harbour**	**-293**	**-1400**	**5.2**	**17,155,142.0**	**-**	**X-Measure Tun.**													**135.0**	**Acidic**	**Includes Dom.2, De-watering effects**
-Workings	1939	Phalen to Harbour						X-Measure Tun.	2C	Existing connection.		8,000.0 8,550.0	39,900.0 34,825.0		-1021	-1086	5,500	13.0	6.0				Overlies Dom.2 & 4 of Phalen seam. Dom.20 Harbour seam entrance. Dom.2 Phalen seam exit.
	1939	Phalen to Harbour						Air Shaft Connect.	2D	Assumed existing connection.		10,220.0 10,230.0	37,800.0 37,820.0		-836	-1263	427						Interconnection between Dom.2 Phalen and Dom.20 in Harbour seam.
Dominion 23	**1926-1927**	**Gardiner**	**-604**	**-609**	**5.0**	**No Product'n**	**-**	**Shaft**														**N/A**	
-Workings	1893 1926	Phalen to Gardiner						Material Shaft	1A	Assumed filled		14,200.0	16,700.0		90.5	-63.5 -603.5	154 694	22.0	16.0	13.5			Dom.1A Material Shaft deepened to 694' level to open Dom.23 in Gardiner seam.
Dominion 24	**1919-1953**	**Emery**	**5**	**-800**	**4.0**	**5,578,793.0**	**3,616.0**	**Slope Mine**														**N/A**	
-Workings	1919	Emery						Slope entrance	24A	Assumed filled		27,650.0	34,110.0										Originally planned to bridge to Donkin area; aborted due to thinning seam.
	After 1919	Emery to Phalen						De-watering Borehole (Shaft)	4E	Assumed existing connections.		25,350.0	34,600.0		-20	-170	150						Seam interconnection between Dom.24 of of Emery and Dom.4 of Phalen.
	After 1919	Emery						Potential Bootleg Connections	10C	Assumed existing connections.		-	-										Dom.24 potentially connected to Dom.11 within Barrier Pillars by bootleg workings mined to @ water table.
Dominion 25	**1941-1959**	**Gardiner**	**57**	**310**	**4.0**	**2,071,639.0**	**128.0**	**Slope Mine**													**100.0**	**N/A**	**No connections to other Collieries.**
-Workings	1941	Gardiner						Slope Entrance	25A	Assumed filled		18,600.0	5,700.0		97.4	290							Closed due to uncontrilable flooding in the area of water bearing minor fault zone. Pumping had increased to 1954 IGPM.
	After 1941	Gardiner						Air Shaft	25B	Assumed filled		19,000.0	6,600.0		79.4	14.6	65						
	After 1941	Gardiner						Water Shaft	25C	Assumed filled		23,650.0	10,000.0		130	-115	245						
	After 1941	Gardiner						Coal Shaft	25D	Assumed filled		18,400.0	7,660.0		118	-55	173						
	1954	Gardiner						Water Zone Break	25E	Assumed existing connection.													
Dominion 26	**1943-1983**	**Harbour**	**-340**	**-2700**	**6.0**	**7,268,093.0**	**1,574.4**	**X-Measure Tun.**													**15.0**	**N/A**	
-Workings	1923 1946	Phalen and Harbour				-	-	Air and Man Shaft Aux. Air Shaft	1D	Concrete capped with 8" dia. pipe vent.		10,620.0 10,620.0	26,480.0 26,480.0		-170 55	-615 -170	445 225 Total 670			12.0 16.0			-Both shafts are connected and intersect Dom.26 Harbour and Phalen Dom.1B seams.
	1942	Phalen to Harbour						X-Measure Tunnel 1	1E	Existing connection.	350.0 2,250.0		29,000.0 28,700.0		-547	-565	2,180						Driven to Dom.26 of Harbour Seam 428' overhead, @ 2.6 miles from Dom.1B shaft.
	After 1942	Phalen to Harbour						X-Measure Tunnel 2	1F	Existing connection.	2,400.0	150.0	30,200.0 29,800.0		-558	-572	2,700						Driven to Dom.26 of Harbour Seam 428' overhead, @ 2.6 miles from Dom.1B shaft.
	After 1942	Phalen to Harbour						Air Intake Tunnel	1G	Existing connection.	2,000.0 2,350.0		29,000.0 28,750.0		-550	-910	480						Interconnection between Dom.1B & 26, @45 Degree grade.

Conversions: 1 Acre = 4046.86 square metres
1 Long Ton = 1.016 tonne

Table 2.1 continued

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Table 2.1
CBDC Colliery Water Study
Compilation of Colliery Data

July 1993

Colliery No.	Service Dates	Seam	Colliery Workings Elevation Ranges Top(ft)	Colliery Workings Elevation Ranges Bottom(ft)	Avg Seam Thickness (ft)	Coal Production (Long Tons)	Worked Area (Acres)	Access and Interconnection Type	Reference Number I.D.	Access Status	Access Coordinates (Dominion Grid) Northing (ft)	Southing (ft)	Easting (ft)	Westing (ft)	Access or Interconnection Details Top Elev. (ft@sea L.)	Bottom El. (ft@sea L.)	Length (ft)	Opening Dimensions (ft H)	(ft W)	(ft dia.)	Water Make (GPM)	Water Quality	Comments or Other Details
Dominion 1A	**1893–1927**	**Phalen**	**15**	**–615**	**7.0**	**13,202,419.0**	**2,415.0**	**Shaft Mine**													**550.0**	**Acidic**	**Dom.1A was replaced by 1B**
–Workings	1893	Phalen						Coal Shaft	1A	Assumed filled		14,200.0	16,700.0		86.08	–67.8	154	24.0	10.5				Sunk to work the Phalen seam.
	1893 1925	Phalen to Gardiner						Material Shaft	1A	Assumed filled		14,200.0	16,700.0		86.08	–67.8 –603.5	154 694 Total 694	22.0	16.0	13.5			Dom.1A Material Shaft deepened 694' total to open Dom.23 in Gardiner seam.
	1893	Phalen						Air Shaft	1A	Assumed filled		14,200.0	16,700.0		88.5	–62.1	154			11.0			
		Phalen						Colliery Intersect.	1B	Known direct connection.		16,500.0 15,300.0	15,200.0 24,800.0		15	–560							Dom.1A is virtually connected to adjacent Dom.5 to a depth of –560'.
	1903	Phalen						Tunnel	1C	Presently sealed		12,400.0	16,300.0		5		119	6	6				Fire in 1903; Tunneling 119' long, 6x6' driven to +5' on shoreline to quench fire
	Unknown	Phalen						Sea Level Drain	1C	Known Discharge		12,400.0	16,300.0		5								Discharge along the shoreline of Indian Bay
inion 1B	**1924–1955**	**Phalen**	**–615**	**–2350**	**7.0**	**17,022,961.0**	**–**	**Shaft Mine**													**50.0**	**N/A**	**Shafts within 55 yards of shoreline.**
–Workings	1923	Phalen						Hoisting Shaft	1D	Concrete capped with 8" dia. pipe vent.		10,700.0	26,340.0		55	–615	670	31.1	13.3				Connected to Dom.2 at shaft bottom in the Phelan seam @ –615'
	1922	Phalen						Air and Man Shaft	1D	Sealed in 1929 with concrete		10,620.0	26,480.0		55	–615	670			12.0			Driven to Phelan Dom.1B seam, however connected to Dom.26 in Harbour seam.
	1946	Harbour						Aux. Air Shaft	1D	Assumed filled		10,620.0	26,480.0		55	–170	225			16.0			Connected to above shaft however driven only 225' to Dom.26 of Harbour seam.
	1942	Phalen to Harbour						X–Measure Tunnel 1	1E	Assumed existing connection.	350.0 2,250.0		29,000.0 28,700.0		–547	–565	2,180						Driven to Dom.26 of Harbour Seam 428' overhead, @ 2.6 miles from Dom.1B shaft.
	After 1942	Phalen to Harbour						X–Measure Tunnel 2	1F	Assumed existing connection.	2,400.0	150.0	30,200.0 29,800.0		–558	–572	2,700						Driven to Dom.26 of Harbour Seam 428' overhead, @ 2.6 miles from Dom.1B shaft.
	After 1942	Phalen to Harbour						Air Intake Tunnel	1G	Assumed existing connection.	2,000.0 2,350.0		29,000.0 28,750.0		–550	–910	480						Interconnection between Dom.1B & 26, @45 Degree grade.
	Unknown	Phalen						Colliery Intersect.	1H	Dammed travel way.		10,400.0	27,150.0		–650		–		12				Interconnection between Dom.1B & 2, dammed to half the opening height.
		Phalen						Colliery Intersects.	1I	Direct Barrier breakthrough		9,700.0 8,800.0	27,300.0 28,050.0		–645 –645		200 200						Interconnections within Pillar Barrier of Dom.1B and Dom.2

Conversions: 1 Acre = 4046.86 square metres
1 Long Ton = 1.016 tonne

Table 2.1 continued

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Table 2.1
CBDC Colliery Water Study
Compilation of Colliery Data

Colliery No.	Service Dates	Seam	Colliery Workings Elevation Ranges Top(ft)	Colliery Workings Elevation Ranges Bottom (ft)	Avg Seam Thickness (ft)	Coal Production (Long Tons)	Worked Area (Acres)	Access and Interconnection Type	Reference Number I.D.	Access Status	Access Coordinates (Dominion Grid) Northing (ft)	Southing (ft)	Easting (ft)	Westing (ft)	Access or Interconnection Details Top Elev. (ft@sea L)	Bottom El. (ft@sea L)	Length (ft)	Opening Dimensions (ft H)	(ft W)	(ft dia.)	Water Make (GPM)	Water Quality	Comments or Other Details
Dominion 2	1899–1949	Phalen	−525	−2010	7.2	26,571,920.0	5,184.0	Shaft Mine													12.8	N/A	
–Workings	1899	Phalen and Harbour						Coal Shaft	2A	Backfilled to shaft bottom & Concrete capped 1973–74.		15,050.0	30,560.0		93	−749 −302	440 395 Total 835	18.5 38	10.0 12				Originally sunk to work Phelan seam, later used to haul Harbour seam coal from Dom.20.
	1899	Phalen and Harbour						Material Shaft	2A	Backfilled to shaft bottom & Concrete capped 1973–74.		14,840.0 14,840.0	30,510.0 30,510.0		91	−762 −308.6	453 402 Total 855	17.0 17.0	10.0 10.0				Shaft connects both Dom.2 Phelan and Dom.9 Harbour seams.
	1946 1899	Phalen and Harbour						Intake Air Shaft	2A	Backfilled to shaft bottom & Concrete capped 1973–74.		14,710.0 14,710.0	30,720.0 30,720.0		98.8	−764.2 −328.1	448 419 Total 863	20.0 38.0	12.0 12.0				Deepened the Dom.9 Air shaft by 445', 1946 to Dom.2 Phelan seam.
	1899 1939	Phalen and Harbour						Water Hole and Wire Hole	2B	Existing Monitoring Hole		11,955.0	32,660.0		48 48	−942 −500	548 438 Total 986			1.0 1.0			Borehole connects both Dom.2 Phelan and Dom.9 Harbour seams.
	1939	Phalen to Harbour						X–Measure Tunnel	2C	Assumed existing connection.		8,550.0 8,000.0	34,825.0 39,900.0		−1021	−1086	4,800		13.0 13.0				Dom.2 Phalen seam entrance Dom.20 Harbour seam exit
	1939	Phalen to Harbour						Air Shaft Connection	2D	Assumed existing connection.		10,220.0 10,230.0	37,800.0 37,820.0		−836	−1263	427		20.0				Interconnection between Dom.2 Phelan and Dom.20 in Harbour seam.
	Unknown	Phalen to Harbour						Borehole	2E	Assumed plugged		11,370.0	32,880.0		−539.5	−966.5	427		1				Interconnections between Dom.2 Phelan and Dom.9 in Harbour seam.
	Unknown	Phalen						Colliery Intersect.	1H	Dammed travel way.		10,400.0	27,150.0		−650		–		12				Interconnection between Dom.2 & 1B, assumed dammed to half the opening height
		Phalen						Colliery Intersects.	1I	Existing connections.		9,700.0 8,800.0	27,300.0 28,050.0		−645 −645	−645 −645	200 200						Interconnections within Barrier Pillar of Dom.2 and Dom.1B
Dominion 3	1900–1915	Phalen	30	−530	7.5	3,976,690.0	492.8	Slope Mine														N/A	
–Workings		Phalen						Slope Entrance	3A	Assumed filled		25,450.0	25,330.0										
		Phalen						Colliery Intersect.	3B	Existing connections.		21,800.0 23,600.0	24,000.0 23,200.0			−155 −45	10 100		12 12				Interconnections within Barrier Pillar of Dom.3 and Dom.5
		Phalen						Colliery Intersect.	3C	Existing connections.		18,500.0 19,200.0 21,800.0 22,500.0 24,000.0	29,200.0 28,800.0 26,800.0 26,400.0 25,200.0			−520 −475 −225 −170 −70	200 100 200 200 100		12 12 12 12 12				Interconnections within Barrier Pillar of Dom.3 and Dom.4
	After 1900	Phalen						Potential Bootleg Connections	3D	Assumed existing connections		–	–										Dom.3 potentially connected to Dom.5 & Dom.4 within Barrier Pillars by bootleg workings mined to @ water table.

Co... sions: 1 Acre = 4046.86 square metres
1 Long Ton = 1.016 tonne

Table 2.1 continued

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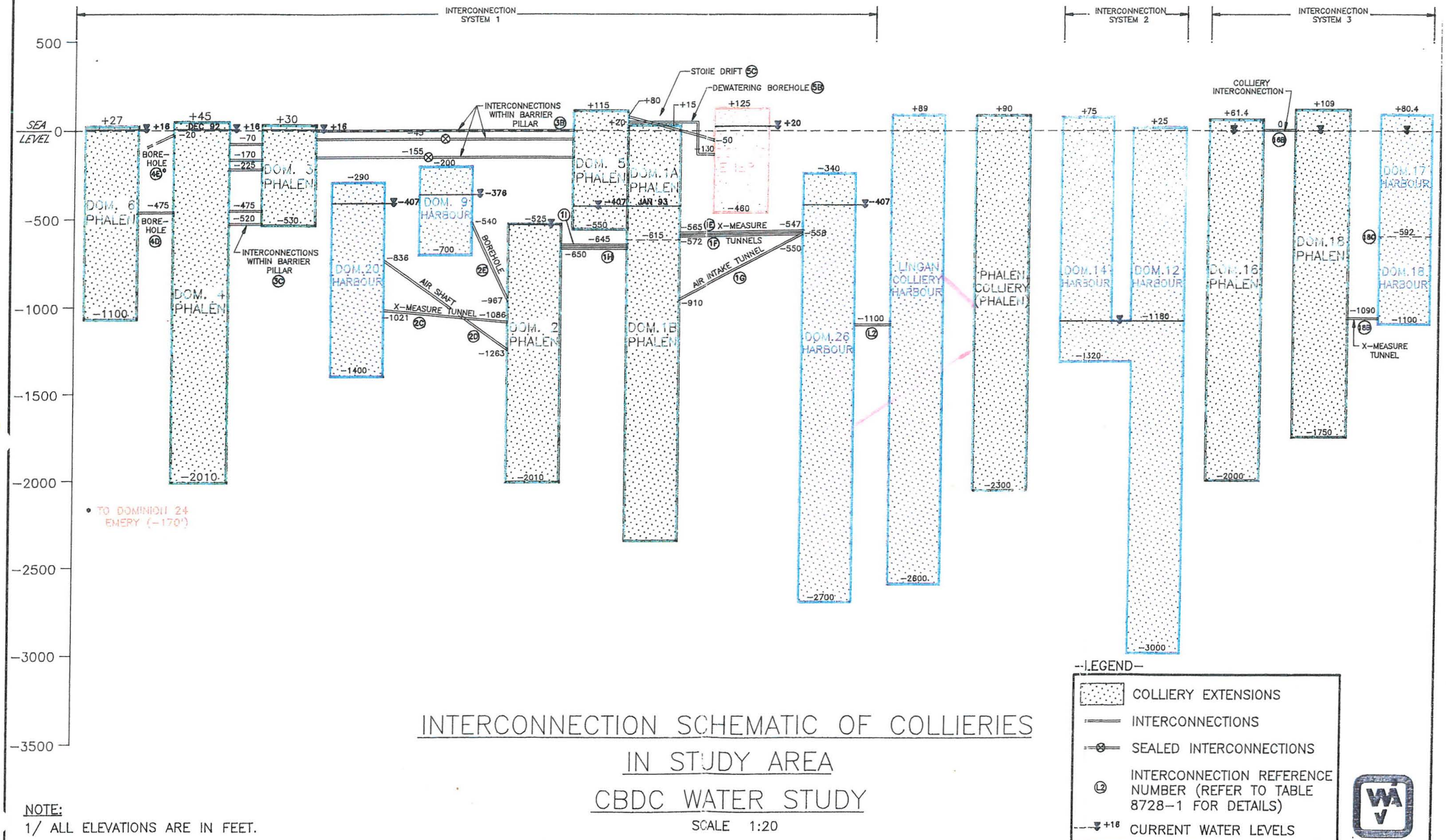
Table 2.1
CBDC Colliery Water Study
Compilation of Colliery Data

July 1993

Colliery No.	Service Dates	Seam	Colliery Workings Elevation Ranges		Avg Seam Thickness (ft)	Coal Production (Long Tons)	Worked Area (Acres)	Access and Interconnection Type	Reference Number I.D.	Access Status	Access Coordinates (Dominion Grid)				Access or Interconnection Details						Water Make (GPM)	Water Quality	Comments or Other Details
			Top(ft)	Bottom(ft)							Northing (ft)	Southing (ft)	Easting (ft)	Westing (ft)	Top Elev. (ft@sea L)	Bottom El. (ft@sea L)	Length (ft)	Opening Dimensions (ft H)	(ft W)	(ft dia.)			
Lingan	**1978–1993**	**Harbour**	**86.9**	**–2680**	**6.5**	**24,591,307.0**		**Slope Mine**														**Alkaline**	
–Workings	1973	Harbour						Slope Entrance	L1	Existing; recently closed		340.0	5,400.0		86.9								
	Nov 1992	Harbour						Water Break	L2	Currently Flowing	4,000.0		13,000.0										Inferred water break in Level 2E; chemistry indicates Dom.26 likely source.
	1973	Harbour						De–watering Hole	L3	Existing; recently closed	410.0		6,290.0		67.2								Bore Hole Discharge
Phalen	**1985 to date**	**Phalen**	**90**	**–3000**				**Slope Mine**														**Alkaline**	
–Workings	1985	Phalen						Slope Entrance	P1	Currently Operating					90								
	1985	Phalen						De–watering Hole	P2	Currently Discharging		311.6	3821.2		62.6								Bore Hole Discharge

Conversions: 1 Acre = 4046.86 square metres
1 Long Ton = 1.016 tonne



INTERCONNECTION SCHEMATIC OF COLLIERIES IN STUDY AREA

CBDC WATER STUDY

SCALE 1:20

NOTE:
1/ ALL ELEVATIONS ARE IN FEET.

8728

FIGURE 3.1

3.2.1 The No. 1B Hydraulic System (Interconnection System 1)

Interconnection System 1 on Figure 3.1 shows colliery Nos. 1A, 1B, 2, 5, 9, 10, 20, and 26 to be connected by workings, tunnels and/or boreholes. It has been assumed that Lingan 2E is connected to No. 26 by a break in a barrier pillar zone that was assumed to have developed prior to November, 1992. The known connections are described below:

i) Nos. 1B, 1A, and 5 are connected by workings.

ii) No. 2 is connected to No. 1B by at least two tunnels.

iii) No. 9 is connected with No. 2 by a borehole. Water level changes in both have not been observed to respond identically. The borehole pathway is assumed to be partially restricted, but does allow water to flow between both collieries.

iv) No. 26 is connected with No. 1B by at least five tunnels. Monitoring of water level changes by CBDC between 1987 and 1989, as well as water level changes in response to the 1992 Lingan 2E break event, indicate response in Nos. 26 and 1B, and direct hydraulic connection between these workings.

v) Lingan colliery at the bottom of 2E wall, has a hydraulic connection with No. 26 due to a break in the pillar between them; this break is now suspected to have partially sealed itself. Water level responses during the recent Lingan 2E break event in November, 1992 indicated a direct hydraulic connection between No. 1B and Lingan 2E.

vi) No. 10 is connected to No. 5 by at least one tunnel and one borehole. The water inflow to No. 10 mine was such that it ought to have filled within several years of its closing in 1942. If the aforementioned connections have not been sealed, they are likely to be contributing water to both the Nos. 5 and 1B workings. It was assumed this hydraulic connection exists and that No. 10 was filled to the spillway.

vii) No. 20 was connected to No. 2 by several air shafts and tunnels and their condition is unknown. Since they were used to haul coal until both No. 20 and No. 2 were abandoned in the early 1970's, it is likely they were sealed. The depth of the tunnels are great enough that high water pressures would have developed, between the inundated side of the seal and the dry side, to sufficiently rupture any seals that did exist. It was therefore assumed that a hydraulic connection exists between Nos. 2 and 20.

viii) A borehole potentially exists between the No. 4 and No. 24 collieries. Available mine plans suggest a de-watering borehole may exist that would permit water to flow between both collieries.

These aforementioned connections comprise the "1B Hydraulic System", and includes colliery Nos. 1A, 1B, 2, 5, 9, 10, 20, 24, 26 and Lingan 2E.

3.2.2 The No. 4 Hydraulic System (Interconnection System 1)

The Nos. 3 and 4 collieries are shown on Figure 3.1 as being connected to Interconnection System 1. Colliery Nos. 3, 4, and 6 were originally connected to No. 5; however current monitoring indicates they are separate from the No. 1B Hydraulic System. Recent water levels taken in the No. 4 Shaft are approximately 500 feet higher than those in the No. 1B Shaft. This indicates that the connections between them are sealed. Because there are many connections between Nos. 3 and 5, and not all are sealed, the water level differential could only be maintained if functioning seals exist between these collieries. colliery Nos. 3, 4 and 6 comprise the "No 4. Hydraulic System.".

An additional interconnection to the adjacent No. 6 colliery was investigated. A borehole connection between Nos. 6 and 4 collieries is shown on Figure 3.1 and Drawing 8728-4. It was suspected that a borehole was drilled to investigate pillar thickness between the two mines. While it was likely this borehole was sealed after drilling, this has not been confirmed. Therefore colliery No. 6 was included with the No. 4 Hydraulic System.

The water level in Hydraulic System No. 4 fluctuates from +13 to +19 feet ASL (above sea level). Investigations and fact finding discussions among CBDC and JWA officials concluded Nos. 3 and 5 are likely interconnected at the +16 foot ASL elevation. Accordingly, the No. 4 Hydraulic System was included with Interconnection System 1.

3.2.3 The No. 12 / 14 Hydraulic System (Interconnection System 2)

Colliery Nos. 12 and 14 are completely connected below approximately 1,200 feet BSL (below sea level) and will behave as one hydraulic system. These workings are not known to be hydraulically connected with the other systems.

3.2.4 The No. 18 Hydraulic System (Interconnection System 3)

Colliery Nos. 17 and 18 in the Harbour seam are completely connected via workings. No. 18 colliery in the Harbour seam is connected to No. 18 in the Phalen seam with a tunnel at 1,090 feet BSL. It was assumed that this tunnel still provides a hydraulic connection, although no documented evidence has been found. No. 18 in the Phalen seam is connected to No. 16 via a cross-cut tunnel at sea level. This tunnel will likely provide a hydraulic connection once the water levels reach equilibrium, but not before.

3.2.5 The No. 8 Hydraulic System (Interconnection System 4)

The Old Harbour and Sterling Mine, and No. 8 colliery are connected through mine workings.

3.2.6 Hydraulic Systems Consisting of Individual Collieries

All the remaining collieries are either known or strongly suspected to be separate hydraulic systems. These include Nos. 7, 11, 15, 23, 25, Phalen and Old Victoria collieries.

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4.0 GROUNDWATER INFILTRATION POTENTIAL

4.1 Meteorology

Nearly all terrestrial groundwater has precipitation as its source. Precipitation becomes groundwater through infiltration and the percentage of precipitation that infiltrates varies according to location. The factors that affect infiltration include temperature, slope of land, climate, geologic nature and thickness of overburden, and vegetation. Estimates of infiltration have been made by JWA in areas proximal to the study area such as Point Aconi, and range between 15% and 18% with a geometric mean of 15% (JWEL, 1990).

There are limitations to using surface infiltration as a measure of total infiltration into a mine. The proportion of infiltrated precipitation a deep mine receives depends more on fracture spacing and width than on the total area of the mine. Unless there is primary porosity in the rock or uniform fracture spacing, there is not likely to be a recognizable relationship between the amount of subsurface infiltration into the mine. In general, the degree of groundwater infiltration into a mine system will be a function of the water transmitting properties of the bedrock aquifers surrounding the mined areas.

4.2 Surficial Hydrogeology

The surficial geology in the study area is shown on Drawing 8728-1. The surficial deposits in this part of Cape Breton are classified into various major units: till; terminal moraine complex; outwash sand and gravel; ice contact stratified drift; and recent deposits such as colluvium, organic deposits, stream alluvium, etc. The predominant units in the study area are glacial till and organic deposits. Of these only the basal till and the outwash sand and gravel were classified as important hydrostratigraphic units (Baechler, 1986).

Overburden hydrostratigraphic units are of secondary importance to this study because they enhance infiltration and provide storage that can later infiltrate bedrock if pathways exist. Through the bedrock, there is a potential for infiltration into the underground workings. This potential is increased if thick, permeable overburden units (e.g., outwash sand and gravel) overlie subsidence areas associated with shallow mine workings. Potential exists for this to occur within the study area, but there are no documented cases. Most of the glacial till exhibits a low hydraulic conductivity and would promote overland flow rather than direct vertical recharge.

Direct infiltration through the overburden is possible only where poor mining practices have allowed workings to extend very close to surface, or where abandoned mine entrances are flooded by ground surface runoff. Drawing 8728-6 shows areas where workings have extended to within 100 feet of ground surface. Other implications of overburden recharge are subsequently discussed in Section 4.5.2.

4.3 Bedrock Hydrogeology

All the bedrock that outcrops within the study area belongs to the Morien Group. It consists of a thick sequence of non-marine, transgressive clastic sedimentary rocks within which are found the economic coal seams. The lithotypes within the Group include conglomerate, arkosic grit, sandstone, siltstone and shale. These units show rapid lateral and vertical variations and are often lenticular in nature. The permeability is largely secondary and is derived from open, interconnecting joints sets, fractures and faults.

The regional strike of beds within the study area is northwest-southeast, with a dip to the northeast. Gentle folding has produced an orthogonal joint pattern with the strike of one joint set approximately parallel to that of bedding while the other two joint sets occur at right angles to it. Fractures generally occur in the more competent sandstone, grit and conglomeratic units, and disappear in the shales that are more ductile. The joints are "open" near surface where they have been observed or, based on permeability testing, are known to transmit significant quantities of groundwater. These joints can be expected to close with depth, as the influence of erosional unloading becomes less significant.

Very little faulting occurs within the study area. The Cape Perce Thrust Fault occurs just off-shore but shows little displacement. Faults in the Precambrian basement rocks may be more common but are of little interest to this study.

Baechler (1986) described the hydrostratigraphy in the area and recognized two hydrostratigraphic units (i.e., the lower and upper hydrostratigraphic units) within the Morien Group. The two zones have recognizable hydrostratigraphic distinctions as described below.

The lower zone encompasses strata from the base of Morien Group to approximately 20 feet above the Emery coal seam, with a total thickness of in excess of 6,500 feet. The Lower Morien consists mostly of arkosic grit, sandstone, shale and minor siltstone and includes the Gardiner and Emery coal seams. Hydrostratigraphically, it is described as having relatively open and interconnected discontinuities capable of transmitting water. Packer tests in the sandstone units (Baechler, 1986) indicate a mean hydraulic conductivity of 0.28 to 1.4 ft/d - feet per day-(1.0×10^{-6} to 5.0×10^{-6} m/s). An exception to this is the stratigraphic zone immediately adjacent to the Gardiner seam that typically has a lower hydraulic conductivity (i.e., range of 2.0 to 0.02 ft/d or 7.2×10^{-6} to 7.1×10^{-8} m/s) wider

The upper zone contains most of the economic coal in the Sydney Coalfield and includes the Phalen, Backpit, Bouthillier, Harbour and Hub seams. Baechler (1986) does not provide a thickness for this zone. The upper zone contains greater amounts of finer-grained shale and siltstone, and consequently exhibits a lower hydraulic conductivity than the lower unit. Packer tests indicate hydraulic conductivity in the range of 0.01 to 0.001 ft/d (3.4×10^{-8} to 4.2×10^{-9} m/s) in the siltstones and shales, 0.05 to 0.001 ft/d (1.6×10^{-7} to 4.1×10^{-9} m/s) in the coal seams and 2.8 to 0.03 ft/d (1.0×10^{-5} to 1.0×10^{-7}

m/s) in the sandstone/grit units. The lower overall hydraulic conductivity of the unit is a result of shale strata that have caused discontinuities to be relatively tight and poorly connected.

The Lower Morien bedrock unit is known to be a good water supply aquifer in the Sydney Coalfield area. Most of the high capacity industrial well water supplies are completed in this unit. The most notable examples are the Nova Scotia Power production wells at Point Aconi that have confirmed sustainable yields in excess of 260 Igpm (Imperial gallons per minute). The Upper Morien generally provides lower yields to drilled wells. The hydrostratigraphy in the Sydney Coalfield was derived from surface-based hydrogeological studies on wells reaching a maximum depth of approximately 300 feet. Conditions deeper than this are likely to result in lower permeabilities because of increased lithostatic loading. In addition there is always an upper fracture network present in Canadian bedrock, regardless of lithology, that has resulted from weathering and glacial pressure unloading. This is usually characterized by high horizontal hydraulic conductivities that decrease rapidly with depth. Baechler (1986) describes such a zone as being about 15 feet or less where the Lower Morien hydrostratigraphic unit subcrops.

These combined factors will produce lower hydraulic conductivities with increasing depth until, at some unspecified depth, they are low enough to result in the "relatively dry" mines that are characteristic of the Sydney Coalfield. This decreasing hydraulic conductivity with increasing depth was not noted by Baechler (1986) because the depth of his investigation was limited to about 300 feet. Typically increased hydrostatic loading will reduce the permeability at some depth. The second factor contributing to the relative lack of groundwater infiltration problems in these mines is that they are each located within a single stratigraphic unit (i.e., the Upper Morien Group). Since vertical cross connection is limited by shale and mudstone, there are usually few fractures encountered that have sufficient interconnection or storage potential to result in long-term continuous discharges into the mine.

Upon review of the historical records, it was apparent that the earlier mines had considerably more problems with water inrushes than the current mines. This may be partly due to a bias based on the poorer dewatering technology causing greater awareness of water problems, and improved surveying and record keeping. However, the historical records do indicate water inflow events occurred more frequently and with greater severity than at present. This may attributable to several factors such as:

i) Some of the earlier mines, including Nos. 25, 10, 11 are located in the more permeable Lower Hydrostratigraphic unit of the Morien Group.

ii) Many of the earlier mines are shallower and have workings closer to surface, thus promoting direct infiltration of shallow groundwater into the mine. Historic mining practices near surface would also likely result in increased subsidence and induced infiltration from the surface.

4.4 Hydrogeological Budget and Infiltration Potential

Conceptually, water flow in a given hydraulic system of collieries would consist of:

i) recharge throughout the whole complex from a variety of different sources and through a variety of different pathways,

ii) movement of water through the interconnections between collieries (cross measure tunnels, boreholes, etc.) following hydraulic gradients,

iii) discharge from the outfall with the lowest above-sea elevation, and

iv) discharge from sumps by active pumping in deep sub-sea mines.

This conceptual model is illustrated in Figure 4.1. In general, mine water in each hydraulic system is expected to rise to a point that is equal to the lowest major outfall or cross-connection between mines unless the following conditions occur:

i) recharge in one or more collieries is significantly greater than the outfall rate and results in water back-up,

ii) discharge points are partially blocked, or

iii) cross-connections are partially or completely sealed.

What's the difference between blocked & sealed? Sealed deliberate?

The potential sources of recharge and discharge that may affect the equilibrium water levels and control the total flow-through in the abandoned collieries are shown schematically on Figure 4.2. This figure is divided into sources of recharge, pathways into the mine workings, and pathways for discharge from the workings.

With the exception of any input from sewers, all the post-closure inputs are from natural sources. While the pathways can be both natural and man-made, the latter potentially transmit far larger quantities of water. In cases where open discharge pathways exist, such as mines with open dewatering audits, the total quantity of flow-through in the mine will depend upon recharge pathways. Section 4.5 deals with the potential sources and their associated pathways.

Mine interconnection is also important in determining flow-through. In mines where the interconnections are known to exist, it has been assumed that the system acts as one hydraulic unit. This is considered a valid assumption; for example if a connection as small as an 8 inch borehole is left open, under high gradients, it could transmit over 1000 igpm. While mine interconnections will help

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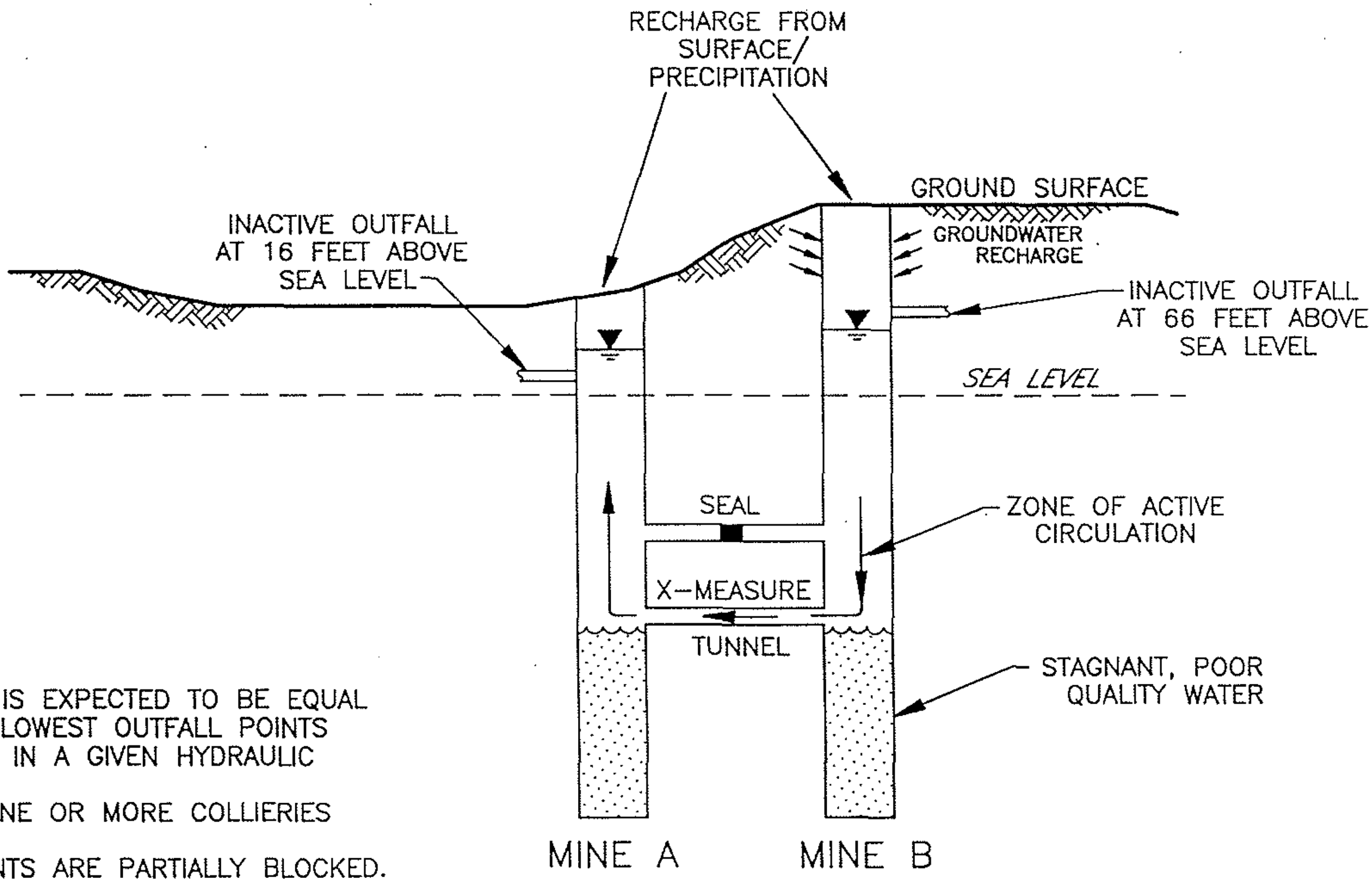

MINE WATER LEVEL IS EXPECTED TO BE EQUAL OR CLOSE TO THE LOWEST OUTFALL POINTS (ABOVE SEA LEVEL) IN A GIVEN HYDRAULIC SYSTEM UNLESS:

1/ RECHARGE IN ONE OR MORE COLLIERIES IS VERY GREAT.
2/ DISCHARGE POINTS ARE PARTIALLY BLOCKED.
3/ CROSS CONNECTIONS ARE PARTIALLY OR COMPLETELY SEALED.

CONCEPTUAL MODEL OF MINE WATER FLOW

NOT TO SCALE

FIGURE 4.1

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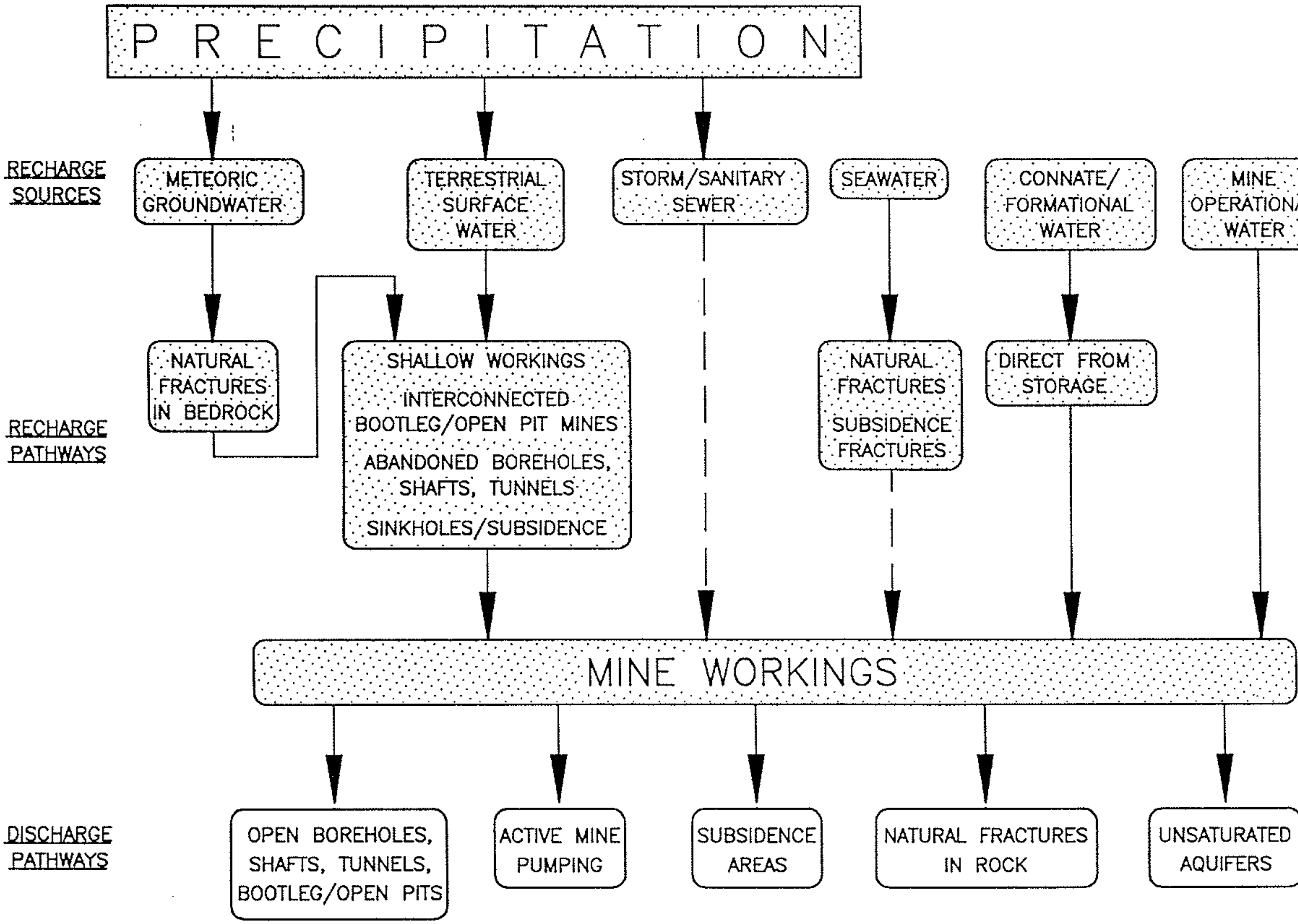

POTENTIAL SOURCES OF RECHARGE, DISCHARGE AND ASSOCIATED PATHWAYS

FIGURE 4.2

to reduce the total number of mine outfalls, they may also result in higher quantities of water being discharged from those that do flow.

Of the potential discharge pathways, all are man-made with the possible exception of exfiltration through bedrock. In cases where open roadways or tunnels exist, exfiltration from bedrock would represent such small volumes of water that they would have a minor effect on water levels. While bedrock exfiltration is not considered a significant flow pathway, these flows do have environmental implications that are discussed in Section 4.7.

4.5 Sources and Pathways of Mine Water Infiltration

4.5.1 Meteoric Groundwater

Meteoric groundwater is defined as groundwater recharged, usually recently, by precipitation that is present within an active flow system. Meteoric groundwater can infiltrate through either bedrock into workings or surficial deposits where workings, tunnels, shafts or boreholes breach the bedrock surface. Historical records show that problems with groundwater have occurred since the mines opened in the 19th century. The earlier mines, particularly those in the Gardiner and Emery seams had serious problems with infiltrating groundwaters. Colliery No. 25 had to be abandoned after a water bearing fault was encountered that produced in excess of 1900 igpm.

The high hydraulic conductivities described by Baechler (1986) for the lower hydrostratigraphic unit of the Morien Group do not extend into the Upper Morien coal seams, or the immediately adjacent strata, but are limited to the sandstone and grit units. If these conductivities did extended into the sandstone and grit units, mining would likely be very difficult due to high infiltration rates. Accordingly, the more significant groundwater flows are probably limited to the Lower Morien unit due to its higher hydraulic conductivity. The Lower Morien would be recharged from infiltration in the area where the unit outcrops. Unless confined by overlying units, it is expected that most groundwater flow within the Lower Morien would migrate down-dip, from the recharge area, and discharge into the ocean. This conceptual flow model suggests that meteoric groundwater should not be encountered naturally at elevations much lower than sea level.

A simple order of magnitude estimate of the post-closure flow-through was made using Darcy's Law:

$$Q = KiA$$

where: Q - was inflow, in igpm

K - was the a geometric average of reported hydraulic conductivities for coal seams and mudstone/siltstone layers, about 0.007 ft/d (2.6×10^{-8} m/s);

i - an assumed moderate hydraulic gradient of 10 %; and

A - was the surface area, in square feet, for each mine that was doubled to account for both the roof and floor areas of the workings.

For each mine, only the mine area above elevation -100 feet BSL was estimated (i.e., only shallow workings were considered). The calculated inflow for each mine is presented in Table 4.1. The mine infiltration calculations resulted in water volumes that are generally within the same order of magnitude as the known "water make" of the mines.

A second method, using a hydrologic budget approach, was used to estimate the potential infiltration volumes (i.e., Q) into the shallow mine workings. Assumptions included: a mean annual precipitation of about 55 inches, a groundwater recharge coefficient of 16 % (JWEL, 1990), and the previously estimated mine surface areas of above elevation -100 feet BSL. The calculated volumes are presented in Table 4.1.

Review of Table 4.1 indicates that the potential recharge generally exceeds the estimated inflow rate for mines completed in the Upper Morien bedrock (e.g., Nos. 1B, 6, 8, 18). Conversely, the estimated inflow rate exceeds the potential recharge in the more permeable Lower Morien mines (e.g., Nos. 10, 11, 24, and 25, Emery, Gardener). Actual inflow is likely to be within these two calculated estimates, since total inflow is limited by both the hydraulic conductivity and available meteoric infiltration. The calculated estimates compare reasonably well with known historical flow rates. Based on the aforementioned calculated methods, as well as the historical data, the most likely inflow rate was estimated for each mine (Table 4.1).

The estimated and historical mine water flow rates in Table 4.1 show that the greater proportion of mine water within a given system originates either from the older, shallow workings (Nos. 10, 3, 4, and 8) or those completed in the Lower Morien bedrock (Nos. 10, 11, 24, and 25). CBDC has estimated a 1,600 igpm inflow rate for the No. 1B workings that is lower than the predicted rates. This may be a consequence of the partial saturation of the current workings and interconnections, and loss of some flow to Lingan 2E. The 300 igpm CBDC estimate for Interconnection System 2 (i.e., No. 12/14 Hydraulic System) compares well to the historical values. The high inflow values inferred for the Lower Morien Group are not comparable to historical records, and may suggest that the bedrock permeability of these mines was decreasing with depth, as would be expected.

TABLE 4.1 ESTIMATED MINE INFILTRATION RATES BASED ON AREA OF INFLUENCE

Hydraulic System	Colliery	Seam	Estimated Area Above −100 feet BSL (ft^2)	Hydraulic Conductivity (ft/d)[1]	Assumed Hydraulic Gradient	Calculated Inflow[2] (igpm)	Potential Recharge[3] (igpm)	Historical[4] Flow Rates (igpm)	Most Likely Total Q[5] (igpm)
Phalen									
	Phalen	Phalen	45,646	$7.4x10^{-2}$	0.1	<1	<1	100−200	10−200
No.1B									
	No. 5	Phalen	26,027,805	$7.4x10^{-2}$	0.1	166	230	?	
	No. 26	Harbour		$7.4x10^{-2}$	0.1		0	15	
	No. 20	Harbour		$7.4x10^{-2}$	0.1		0	135	
	No. 2	Phalen		$7.4x10^{-2}$	0.1		0	12	
	No. 1A&B	Phalen	6,498,998	$7.4x10^{-2}$	0.1	41	56	600	
	No. 9	Harbour	0	$7.4x10^{-2}$	0.1	<1	0	900	<1
	No. 10	Emery	23,230,073	0.20	0.1	4104	200	1750	1500−3000
	No. 24	Emery	4,396,924	0.20	0.1	777	38	?	30−100
	Lingan	Harbour	89,367	$7.4x10^{-2}$	0.1	1	1	200	100−200
No. 4									
	No. 4	Phalen	11,484,406	$7.4x10^{-2}$	0.1	73	100	940	
	No. 3	Phalen	3,961,157	$7.4x10^{-2}$	0.1	25	35	?	100
	No. 6	Phalen	3,691,139	$7.4x10^{-2}$	0.1	24	33	240	30
No.7									
	No. 7	Hub	5,303,929	$7.4x10^{-2}$	0.1	34	46	?	30−40
No. 8									
	Sterling	Harbour	4,097,980	$7.4x10^{-2}$	0.1	26	35	?	
	No. 8	Harbour	22,260,932	$7.4x10^{-2}$	0.1	142	190	?	150−200
No. 11									
	No. 11	Emery	12,257,748	0.20	0.1	2165	107	420	100−500
No. 12/14									
	No. 14	Harbour	2,074,398	$7.4x10^{-2}$	0.1	13	18	90	
	No. 12	Harbour	2,581,472	$7.4x10^{-2}$	0.1	16	22	175	30
No. 15									
	No. 15	Phalen	1,502,473	$7.4x10^{-2}$	0.1	10	13	?	10
No. 18									
	No. 18	Phalen	582,552	$7.4x10^{-2}$	0.1	4	5	260	
	No. 17	Harbour	1,354,090	$7.4x10^{-2}$	0.1	9	12	?	
	No. 16	Phalen	1,618,616	$7.4x10^{-2}$	0.1	10	14	80	20−30
No. 25									
	No. 25	Gardiner	16,762,627	0.20	0.1	2961	146	?	150−1000

Notes:

1) Geometric Mean Hydraulic Conductivity; Lower Morien = 0.20 ft/d (i.e. $7.2x10^{-7}$ m/sec); Upper Morien = 7.4 x 10^{-2} ft/d (i.e. $2.6x10^{-8}$ m/sec).
2) Inflow assumes flow through floor and roof over area of workings to −100 feet BSL, assumed gradient 10 %, mean K of host bedrock.
3) Predicted groundwater infiltration rate assuming 16 % of mean annual rainfall over same area as calculated inflow.
4) Information from historical records, (see Table 2.1)
5) Subjective assesment of likely infiltration rate to mine based on calculated inflow, potential recharge and historical flow rates.
?) Denotes unavailable information.

The values for inflow calculated in Table 4.1 only consider an average hydraulic conductivity within the units and do not consider lateral or vertical variation in bedrock hydraulic conductivity. These estimates do not include potential groundwater input from surficial deposits into buried shafts, boreholes, and subsidence sinkholes. These estimates do not account for the increased permeability that is likely to have occurred due to subsidence fracturing.

Effect of Mine - Induced Subsidence

If a mined-out coal seam was narrow or the depth of the seam was great, the fractures that develop as a result of collapse can be expected to dissipate upwards and may not result in connection with aquifers or with the bedrock surface. However, in the cases of shallow workings, there is a danger of subsidence fractures propagating upward to surface and/or promoting the development of sinkholes. When this happens beneath surface waters, or groundwater bearing zones, direct hydraulic connection can occur.

It is difficult to quantify the extent of subsidence-induced permeability and the effect it will have on total water flows. If the areal extent of subsidence overlying a given colliery was known, estimates of the degree of hydraulic connection could be made along with estimates of infiltration. Apparently this type of information is not known for any single collieries in the area.

Subsidence in the Emery and Gardiner seams is likely to result in greater infiltration rates than subsidence in the Harbour and Phalen Seams. This is because a greater proportion of the workings in the Emery and Gardiner seams are shallow and located in the Lower Morien hydrostratigraphic unit where subsidence induced fractures can intercept high transmissivity aquifers.

Subsidence will have less effect in deeper portions of mines. This is because overlying strata will have intrinsically less permeability, since subsidence fractures will be more likely to be "tight" and such fractures are more likely to heal themselves due to increased lithostatic loading. The inflows in Phalen, 1E and 5E are examples. Roof collapse behind long-wall mining operations resulted in fracturing of deep confined sandstone aquifers and resulted in the sudden inflow of highly saline connate groundwaters under high pressure. Although initial inflows were substantial, flow rates rapidly dissipated as the water bearing bedrock was depressurized. In a shallow or near surface situation, the inflow would probably have been more continuous.

Strip Mines

Where strip mines have breached old underground workings, there will be a high potential for recharge through the strip mine spoil. Strip mine spoil in the U.S. is known to have hydraulic conductivities that are very high. This would cause a water table drawdown in surficial deposits adjacent to the spoil thus generating a significant capture area, within which all infiltrated precipitation could end up in the workings. There is no evidence this phenomena is occurring within the study area. This conclusion is based on two factors: 1) historically there have been no reports of strip mines intersecting significant underground workings, and 2) there are no known reports of increased mine seepages in former surface mining areas. Currently there is no surface mining within the study area, although an open cast coal mining operation that was working the Gardiner seam in the Reserve Mines area recently closed.

4.5.2 Terrestrial Surface Waters

Many of the pathways noted above could also potentially transmit surface water into mine workings. Subsidence under moderate to large streams or lakes was not known to be a major problem because the potential for infiltration from these sources was well known and mining practices reflected this concern. Subsidence under small wetlands or creeks, like those outside the town of Glace Bay east of Highway 4, is more likely to be a problem. Several sinkholes have developed adjacent to this wetland area and municipal officials have indicated that surface waters flowing into them during rain events drain within hours into the subsurface. These inflows are probably recharging workings in the No. 10 colliery. This phenomenon may be occurring elsewhere within the study area.

Bootleg operations also have the potential to enhance drainage recharge into colliery workings through the capture of surface water. For this to occur, the bootleg workings would have to breach the colliery workings and be opened to surface in a way that would allow capture of surface water. It is also possible that limited amounts of surface water could enter the mines through abandoned shafts, service boreholes or tunnels.

4.5.3 Seawater

The potential for input from seawater exists while the mines are in operation or after they have been abandoned but before they have reached their equilibrium water levels. The final equilibrium water levels are assumed to be at sea level or higher. Therefore there can be no hydraulic gradients that would induce the long term movement of post-closure seawater into the mines.

Contributions from seawater during filling of the mines can result from subsidence over shallow workings; from natural fractures connected through strata to the ocean; or through boreholes, shafts or tunnels that have been exposed to the ocean by shoreline erosion. The latter pathway is not known to exist within the study area. Two historical cases of seawater inflow were identified: 1) the inclined shaft into No. 1A that was used seawater to quench a fire; and 2) seawater inflow into one of the No. 1B Shafts at the shoreline at a rate of 20 igpm during low tide and at an increased rate when the tide was high.

4.5.4 Connate and Formational Water

Connate and formational waters may also flow into active mine workings under high hydraulic gradients. Such inflows will be largely eliminated once mine operations have ceased and the mine has flooded to equilibrium (i.e., sea level). Historical records (Section 5) suggest that formation waters have been a significant proportion of the water infiltrating the collieries in the past. During the progressive flooding of the mines after closure, the formational and/or connate waters should contribute diminishing volumes of inflow, as the hydraulic gradients decrease due to mine water level increases.

4.5.5 Mine Operational Water

Mine operational water contributes a large proportion of water in the operating Phalen Mine but this source will obviously contribute nothing to the mines after closure. Fire fighting water that may have to be used to quench underground fire, during operations, could also contribute significant volumes of water but will not be a factor after closure.

4.5.6 Storm/Sanitary Sewer Input

Much anecdotal evidence exists for the existence of sewer connections to old mine workings. This pathway was investigated using the Nova Scotia Water and Sewer Inventory, as well as through conversations with municipal officials and local residents. Apparently there are no official direct connections between mines and municipally-owned storm or sanitary sewers. However, one case exists where a storm/sanitary outfall discharges into a creek, that subsequently may discharge into a sinkhole during high flow periods.

There is anecdotal evidence that domestic sanitary sewage and possibly foundation drainage, may be directed into shallow workings through boreholes specifically drilled for drainage purposes. It does not appear that this practice is widespread, nor is it likely to contribute much volume to the total water budget of the collieries.

4.6 Present Water Levels, Rates of Inflow and Storage Volumes

4.6.1 Present Water Levels

Present water levels are known for some of the collieries where measurements can be taken directly. Other water levels can be inferred from known or likely connections. The known water levels are shown on Figure 3.1. In several colliery systems, water levels are not known, and have been assumed. The rationale used to determine the water levels presented in Figure 3.1 is provided in the following sections.

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Table 2.1
CBDC Colliery Water Study
Compilation of Colliery Data

July 1993

Colliery No.	Service Dates	Seam	Colliery Workings Elevation Ranges Top(ft)	Colliery Workings Elevation Ranges Bottom(ft)	Avg Seam Thickness (ft)	Coal Production (Long Tons)	Worked Area (Acres)	Access and Interconnection Type	Reference Number I.D.	Access Status	Access Coordinates (Dominion Grid) Northing (ft)	Southing (ft)	Easting (ft)	Westing (ft)	Access or Interconnection Details Top Elev. (ft @sea L)	Bottom El. (ft @sea L)	Length (ft)	Opening Dimensions (ft H)	(ft W)	(ft dia.)	Water Make (GPM)	Water Quality	Comments or Other Details
Dominion 12	**1906–1979**	**Harbour**	**25**	**–3000**	**6.5**	**35,422,880.0**		**Slope Mine**													**175.0**	**Acidic**	
–Workings	1905	Harbour						Slope Entrance	12A	Assumed filled	100.0			3,835.0	25	–3000							
		Harbour						Colliery Intersect.	12B	Existing connection.	8,200.0		200.0			–1180	300						Main pillar (300')between Dom.12 & 14 extends only to –1180' level.
Dominion 14	**1906–1952**	**Harbour**	**75**	**–1320**	**6.5**	**5,878,001.0**	**1,427.0**	**Slope Mine**													**90.0**	**Acidic**	
–Workings	1906	Harbour						Slope Entrance	14A	Assumed filled		100.0	1,650.0		75	–1320	300						Water pumped to surface through Dom.12
		Harbour						Colliery Intersect.	12B	Existing connection.	8,200.0		200.0			–1180	300						Main pillar (300')between Dom.12 & 14 extends only to –1180' level connecting both.
Dominion 15	**1910–1925**	**Phalen**	**75**	**–900**	**5.5**	**1,838,535.0**	**376.0**	**Slope Mine**														**N/A**	**No connections to other Collieries.**
–Workings	1910	Phalen						Slope Entrance	15A	Assumed filled		1,600.0	1,800.0		85	–900							Developed to work the Phalen (Lingan) seam. Submarine reserves allocated to Dom.16.
Dominion 16	**1911–1962**	**Phalen**	**61.36**	**–2000**	**5.2**	**18,050,900.0**	**3,840.0**	**Slope Mine**													**80.0**	**Non Acid**	
–Workings	1910	Phalen						Slope Entrance	16A	Assumed filled		850.0		3,700.0	61.36	–2000							Developed in the Phalen (Lingan) seam including the submarine res. of Dom.15.
	After 1938	Phalen						Colliery Intersect.	16B	Existing connection.					0	0	250						Dom.16 to 18 workings connection.
Old Victoria	**1865–1878**	**Harbour**	**80**	**N/A**	**6.6**	**820,411.0**	**64.0**	**Slope Mine**														**N/A**	**Located on SE side of Dom.17**
–Workings	1865	Harbour						Slope entrance	O1	Assumed filled													
Dominion 17	**1883–1921**	**Harbour**	**80.4**	**–592**	**6.5**	**5,185,000.0**	**422.4**	**Slope Mine**														**N/A**	
–Workings	1883	Harbour						Slope entrance	17A	Assumed filled		200.0		14400									
	After 1946	Harbour						Colliery Intersect.	18C	Existing connection.					–591.8	–591.8							Dom.17's lower workings connect onto Dom.18's in the Harbour seam @591.8'
Dominion 18	**1938–1946** **1946–1966**	**Phalen** **Harbour**	**109**	**–1750**	**5.2** **6.2**	**1,551,320.0** **5,752,379.0**	**422.4** **—**	**Slope Mine** **X–Measure Tun.**													**260.0**	**Acidic**	**Includes Dom.17, De–watering efforts**
–Workings	1938	Phelan						Slope entrance	18A	Assumed filled		400.0		9500									
	1946	Phalen to Harbour						X–Measure Tuns.	18B	Assumed existing connection.	4710 4650	----		10950 12200	–1090	–1090		1760					Two horz. X–Measure Tunnels driven within Dom.18 Phelan to Harbour seam.
	1946	Phalen to Harbour						Inclined Tunnel.	18B	Assumed existing connection.						–1090	(610)	670					Inclined tunnel @45 deg. Return Airway from the Phelan to Harbour seam.
	After 1946	Harbour						Colliery Intersect.	18C	Existing connection.						–591.8							Dom.18's workings connect onto Dom.17
	After 1938	Phalen						Colliery Intersect.	16B	Existing connection.					0	0	250						Dom.18 to 16 workings connection.

Conversions: 1 Acre = 4046.86 square metres
1 Long Ton = 1.016 tonne

Table 2.1 continued

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July 1993

Table 2.1
CBDC Colliery Water Study
Compilation of Colliery Data

Colliery No.	Service Dates	Seam	Colliery Workings Elevation Ranges Top(ft)	Colliery Workings Elevation Ranges Bottom(ft)	Avg Seam Thickness (ft)	Coal Production (Long Tons)	Worked Area (Acres)	Access and Interconnection Type	Reference Number I.D.	Access Status	Access Coordinates (Dominion Grid) Northing (ft)	Southing (ft)	Easting (ft)	Westing (ft)	Access or Interconnection Details Top Elev. (ft@sea L)	Bottom El. (ft@sea L)	Length (ft)	Opening Dimensions (ft H)	Opening Dimensions (ft W)	Opening Dimensions (ft dia.)	Water Make (GPM)	Water Quality	Comments or Other Details
Dominion 9	1899–1924	Harbour	-200	-700	6.5	6,413,916.0	1,734.0	Shaft Mine													900.0	Acidic	42% Room & Pillar extraction
–Workings	1899	Harbour and Phalen						Coal Shaft	2A	Backfilled to shaft bottom & Concrete capped 1973–74.		15,050.0	30,560.0		93 93	–302 –749	395 440 Total 835	38 18.5	12 10.0				Same as Dom.2, shafts are connected to Dom.9 Harbour and Dom.2 Phelan seams.
	1899	Harbour and Phalen						Material Shaft	2A	Backfilled to shaft bottom & Concrete capped 1973–74.		14,840.0 14,840.0	30,510.0 30,510.0		91 91	–308.6 –762	402 453 Total 855	33.5 17.0	10.0 10.0				Same as Dom.2, shafts are connected to Dom.9 Harbour and Dom.2 Phelan seams.
	1899 1946	Harbour and Phalen						Intake Air Shaft	2A	Backfilled to shaft bottom & Concrete capped 1973–74.		14,710.0 14,710.0	30,720.0 30,720.0		98.8 98.8	–328.1 –764.2	419 448 Total 863	16.0 20.0	12.0 12.0				Same as Dom.2, shafts are connected to Dom.9 Harbour and Dom.2 Phelan seams.
	1899	Harbour and Phalen						Water Hole	2B	Existing monitoring hole		11,955.0	32,660.0		48 48	–500 –942	548 986 Total 986			1.0 1.0			? Same as Dom.2, shafts are connected to Dom.9 Harbour and Dom.2 Phelan seams.
	Unknown	Harbour and Phalen						Borehole	2E	Restricted Flow		11,370.0	32,880.0		–539.5	–966.5	427			1.0			Interconnections between Dom.9 Phelan and Dom.2 in Harbour seam.
Dominion 10	1905–1942	Emery	125	-460	3.5	6,726,390.0	2,432.0	Slope and Shaft													1,750.0	Acidic	42% Room & Pillar extraction
orkings	1905	Emery						Slope Entrance	10A	Assumed filled		25,330.0	17,200.0										
	After 1905	Emery						Shaft	10B	Assumed filled		23,150.0	16,300.0		185.5	37.5	148	21.2	16.5				Water was pumped on South side through a 12" B.H. directly to surface @235' higher
	After 1905	Emery						Potential Bootleg Connections	10C	Assumed existing connections.		–	–										Dom.10 potentially connected to Dom.11 within Barrier Pillars by bootleg workings mined to @ water table.
		Phalen						Dewatering B.H.	5B	Assumed existing connection.		20,300.0	16,450.0		20	–130	150			1			Water was pumped on North side through 12"dia B.H. to Dom.5 Main slope @ 150'.
	1905	Emery to Phalen						Stone Drift	5C	Assumed existing connection.		21,200.0 21,850.0	16,450.0 16,400.0		–80	–50		600		12			Dom.10 Emery seam entrance, Dom.5 Phalen seam exit.
Dominion 11	1899–1949	Emery	20	-950	3.5	7,543,358.0	1,920.0	Slope Mine													420.0	Non Acid	No connections to other Collieries.
–Workings	1899	Emery						Slope Entrance	11A	Assumed filled		27,440.0	28,740.0										
	After 1899	Emery						Air Shaft	11B	Assumed filled		27,090.0	23,600.0		57								
	1921	Emery						De–watering B.H.	11C	Assumed filled		24,200.0	28,350.0		91	–230	321						Water was discharged to surface through 12" dia B.H.@ 320' to surface.
	After 1899	Emery						Potential Bootleg Connections	10C	Assumed existing connections.		–	–										Dom.11 potentially connected to Dom.10 & Dom.24 within Barrier Pillar by bootleg workings mined to water table depth.

Conversions: 1 Acre = 4046.86 square metres
1 Long Ton = 1.016 tonne

Table 2.1 continued

Interconnection System 1 - The No. 1B Hydraulic System

The water level for this system varies across numerous workings. For Nos. 1A, 1B, and 5, an elevation of 407 feet BSL was assumed based on CBDC measurements (Figure 3.1). Levels in associated workings were based on either measurements or elevations of known interconnections.

Water levels were measured during the Lingan inflow (November, 1992) in 2E, and are constantly measured with a transducer in No. 1B. The water levels in the other connected collieries, except No. 10, are assumed because of the connections with Nos. 1B and 2. No. 10 was a small mine with a very high infiltration rate (i.e., 1,750 igpm - Table 2.1) and should have filled to an elevation of + 20 feet ASL. This elevation also represents the elevation of a connection with No. 5 that existed shortly after the closure of No. 10 in 1942. No. 5 closed in 1938

Prior to the water problem in Lingan 2E during November 1992, the water level in the Lingan mine complex was at the bottom sump approximately 2,600 feet BSL. After the decision to abandon the Lingan in early 1993, water from 2E was allowed to flow into the deeper portions of the mine at an estimated rate of 1,500 igpm. A June 2, 1993 measurement indicated the water level in the Lingan mine was 1,985 feet BSL. The Lingan A workings are flooded behind seals and were flowing at a rate of about 200 igpm in 1989 (JWEL, 1990). More than 50% of these workings are assumed to be flooded.

The water level in No. 9 colliery can be measured directly. It was measured during the Lingan break (i.e., November 1992) and water was at 376 feet BSL. A water elevation of 376 feet BSL was therefore assigned to No. 9.

The water level in No. 23 colliery was assumed to have reached equilibrium based on the length of time since its 1927 abandonment (Table 2.1). No direct measurements are available.

Interconnection System 1 - The No. 4 Hydraulic System

The water level for this system was assumed to be at elevation +16 feet ASL based on the water level in Dominion No. 4 (Figure 3.1).

The water level can be measured directly in Dominion No. 4 and has remained at elevation +16 feet ASL for several years.

The water level in No. 6 colliery is assumed to have reached equilibrium with Nos. 3 and 4 (i.e., about +16 feet ASL). This assumption is based on the estimated 240 igpm inflow rate (Table 2.1) and the length of time since its abandonment in 1933.

Interconnection System 2 - The No. 12/14 Hydraulic System

The water level for this system was assumed to be at an elevation of -1,180 feet BSL based on CBDC work (Figure 3.1).

An extensive study by CBDC indicates that the water level in this system is just above the -1,200 foot BSL connection between the two mines.

Interconnection System 3 - The No. 18 Hydraulic System

The water level for this system was assumed to be at sea level (Figure 3.1).

Water levels in colliery Nos. 16, 17, and 18 were assumed to have reached equilibrium based both on their inflow rates and the time since their abandonment (Tables 2.1 and 4.1). These workings are assumed to be flooded at least to sea level. If possible, this should be confirmed because the rate of filling may not have been constant, and the system was only abandoned in 1966.

Interconnection System 4 - The No. 8 Hydraulic System

The water level for this system was assumed to be at an elevation of +5 feet ASL based on known interconnections.

An outfall is known to exist at approximately 5 feet ASL. This outfall is currently discharging mine water. This mine has a large volume of workings within the Lower Morien Group, and was assumed to capable of yielding large volumes of poor quality water (Table 4.1).

Hydraulic Systems Consisting of Individual Collieries

No. 7 colliery: Water level is assumed to be at elevation +5 feet ASL based on a known discharge point. An outfall is known to exist at approximately 5 feet ASL and is currently discharging mine water. Flow rates were assumed to range from 10's to several 100's igpm.

No. 11 colliery: The water level was assumed to range from 0 to +20 feet ASL. This assumes an equilibrium condition has been reached based on inflow rate (i.e., 420 igpm - Table 2.1), and length of time since its abandonment in 1949 (Table 2.1). No direct measurements were available for this mine.

24?

Colliery Nos. 15, 23 and Old Victoria: Water levels for these collieries were assumed to have reached equilibrium based on length of time since abandonment in 1925 (Table 4.1). No measurements were available.

No. 25 colliery: At least one borehole was reported to be flowing near the location of the old shaft; therefore it was assumed the water level has reached an equilibrium. No measurements were available. The colliery was reported to yield 100 igpm (Table 4.1).

Phalen colliery: The water level is at elevation -2,000 feet BSL based on the current sump location in this operating mine.

For those workings assumed to be at equilibrium, water levels should be at, or slightly above, mean sea level. If no outfalls are present, the hydraulic head would be expected to mirror topography, and based on observation at other mines, water levels should be approximately 20 to 30 feet below ground surface. However, recent measurements of water level data are needed to confirm these assumptions.

4.6.2 Mine Storage Volumes

Mine water storage volumes were required to estimate the amount of time it would take for infiltrating waters to fill a mine to its assumed equilibrium water level. The available void volume above the present water level was required in addition to the inflow rates in the colliery/hydraulic system. Table 4.2 summarizes volumes for each of the collieries while Appendix C - summarizes mine volumes for 100 vertical foot increments. The volumes in these tables were subsequently used in Sections 4.6.3 and 4.7 to estimate the flooding time for various colliery systems.

The volume of workings above sea level, or above the lowest potential passive discharge point in the mine/system, was also important in estimating the final quality of the discharge water at outfalls. It was assumed that the larger the volume of mine workings remaining above the water level at equilibrium, the greater the acidity of discharge waters (Section 5). This assumption was based on the volume of workings available for oxidization, hence acid generation potential, above the equilibrium water level.

The mine volume above the highest cross connection between various workings and below the final equilibrium water level was also important. As the mine fills, the infiltrating water will be heavily impacted by sulphide oxidation and the resulting water in storage will be acidic. If the workings are completely inundated and major sulphide oxidation ends, low pH water will still exist until flushed out over a period of time. Flushing times are discussed further in Section 5.

4.6.3 Rates of Inflow

Rates of flow into the collieries during filling were assumed to be the sum total of all the rates from the sources described above in Section 4.5. Historically, only the total inflow is known for the mines and not the individual inputs from each source. In most cases, these rates have been determined through research at the Beaton Institute or through other sources. The infiltration rates used for calculations to determine filling times of the collieries are provided in Table 4.1. For the Nos. 12/14 and 1B Hydraulic Systems, infiltration rates of 300 and 1,600 igpm respectively were used; these flow rates were estimated by CBDC.

It is important to distinguish between inflow rates during filling and those that will occur after the mine has filled to its equilibrium level. Depending upon the location of the infiltration sources within the mine, an increasing water level can result in a decreasing infiltration rate. In most cases, the infiltration points are located in the upper portions of the mines and therefore the rates will be unaffected by the mine flooding. As the water level passes infiltration points, increasing hydrostatic head will probably reduce the inflow rates at those points. Thus as the water level approaches an equilibrium point, inflow rates should be reduced. Because of the multiple infiltration points and discharge rates, there is no easily established relationship between the flooding rate and the final discharge rate. It is assumed that the flooding rate can only be equal to or lower than the final discharge rate, given no changes in the sources with time. A program of mine flooding monitoring would provide a better estimate of likely discharge rates at equilibrium.

Two Hydraulic Systems (Nos. 1B and 12/14) have not yet reached equilibrium water levels. Using historical flow rates (Table 4.1), measured water levels (Figure 8728-2), and approximate mine volumes (Table 4.2), estimated times for flooding the unsaturated collieries to sea level have been calculated.

<u>The No. 1B Hydraulic System</u>

The current water level for this system is assumed to be approximately 407 feet BSL, excluding the Lingan workings. The estimated void volume between this elevation and sea level is 4.45×10^8 ft^3 (cubic feet). This value represents the volume of mine workings, within a particular seam, between the assumed/measured water levels (i.e., base level) and sea level. The estimated filling time for this system, assuming an inflow rate of 1,600 igpm and no further pumping was about 5 years (i.e., by year 1998). This does not include the Lingan mine whose current water level elevation is about -2,000 feet BSL.

The mine volumes are documented in Appendix C and summarized in Table 4.2. The CBDC 1,600 igpm inflow rate, for No. 1B, came from calculations on No. 26's flooding rate after cessation of pumping operations in the spring of 1993. This calculated inflow rate is within the same order of magnitude as the sum of the historical flow rates for the 1B system (i.e., about 3,000 igpm - Table 4.1), excluding the anomalous No. 10 mine inflow rate.

The No. 12/14 Hydraulic System

As previously indicated, the current water level is assumed to be at approximately elevation -1,200 feet BSL. The mine volume to sea level from this elevation is in the order of 1.6 x 10^8 ft^3. CBDC estimated the current inflow rate into this system to be approximately 300 igpm. Accordingly, the time expected to flood the system should be about 7.3 more years (i.e., by year 2000).

Lingan colliery

As discussed before, the Lingan colliery is known to be in hydraulic connection with the No. 1B Hydraulic System. Assuming the current inflow rate of 1,500 igpm, from the No. 1B System at level 2E, and a total mine volume of 1.4 x 10^8 ft^3, the Lingan mine should be flooded in about 2 to 4 years (i.e., by years 1995 to 1997).

4.7 Identification of Potential Mine Water Discharge Pathways

4.7.1 Approach

The conceptual model for flow-through in a given hydraulic system involves mine water reaching an equilibrium flow rate with both recharge and discharge balanced. Water levels will also reach an equilibrium, but in many cases, this will depend more on the elevation of the lowest major outfall rather than the flow-through rates. Since this will result in relatively large quantities of impacted water discharging from a few points, it is important to know the nature of these points and their locations.

Potential discharge points have been compiled from mine plans and are shown on Drawing 8728-7. Table 4.3 presents a summary of outfall details for the various colliery hydraulic systems while Drawing 8728-7 presents the known and expected outfall locations. A limited field reconnaissance was conducted as part of this study, and local residents were interviewed in an attempt to locate existing outfalls. Three outfalls discharging from Nos. 7, 4 and 1A were inspected. Four more outfalls discharging from Nos. 8, 11, 25 and the Old Harbour Mine were reported to exist, but were not inspected.

Based on the above information and the discussion in Section 4.6, the following eight hydraulic systems are believed to have reached their respective equilibrium water levels, and are now capable of passive discharge. These systems and their likely discharge points are summarized as following:

i) No. 4 Hydraulic System (colliery Nos. 3, 4 and 6);

ii) No. 18 Hydraulic System (colliery Nos. 16, 17, and 18);

iii) No. 8 Hydraulic System; (colliery No. 8 and Sterling and Old Harbour mines)

iv) No. 11;

v) No. 7;

vi) No. 15;

vii) No. 25; and

viii) Old Victoria colliery.

Of the systems that have not yet filled, the No. 1B Hydraulic System is of primary concern with respect to quantity of effluent. It is the largest of the hydraulic systems and could discharge 1,800 to 3,600 igpm, based on Table 4.1 estimates once the equilibrium water level has reached an outfall point. The most likely outfall would be from the Dominion Nos. 1A/1B or 5.

The flooded mines in the Emery and Gardiner seams and others that are located inland, are likely to have a greater proportion of their workings filled than those near the shoreline. This is because the outfalls are at higher elevation and dewatering tunnels to sea level were never constructed. As earlier indicated, mines in the Lower Morien bedrock can produce high quantities of groundwater.

4.7.2 Outfalls from Open Shafts, Service Boreholes and Dewatering Tunnels

The mines close to the shoreline that had dewatering tunnels driven to just above sea level include Nos. 1B, 8, 4 and 7. All four of these mines are known to, or believed to be, currently discharging water. The No. 1B discharge is suspected to represent groundwater that has infiltrated into the tunnel and redirected to the outfall. The water level in the No. 1B Hydraulic System is still more than 400 feet BSL therefore it is unlikely this discharge is mine water. ?

The two of the outfalls inspected during the fieldwork were both tunnels driven to approximately 5 feet above the high water mark. The first outfall was located at Table Head near Glace Bay, and is suspected to drain the No. 7 colliery in the Hub seam. The tunnel to the outfall could not be located on available mine plans. The discharge rate was estimated to be approximately 100 igpm, while the measured pH of the water was 4.0. The second outfall was in the Dominion area, and is believed to be the sea drain tunnel driven to discharge water from the No. 1A colliery. The shoreline No. 1A outfall was buried however visible ground seepage of 5 - 10 igpm was estimated, and the measured pH was 5.1. Reportedly this outfall is a full flowing 4 inch diameter pipe that has been buried by shoreline tidal processes.

The No. 25 outfall was visited during this study to investigate a reported flowing borehole but it was not located. It was reported to be impacting a nearby stream and causing precipitation of iron

Project 8728			Table 4.3 CBDC Colliery Water Study – Outfall Details				July 1993
HYDRAULIC SYSTEM			OUTFALL TYPE and LOCATION [1]	MINE WATER DISCHARGE [2]			
				Existing (Jan 93)	Projected at Lowest Outfall Elevation		
No.	Collieries	Seam		Mine Water Level (feet)	Mine Water Level (feet)	Quantity (igpm)	Quality
1B	1A,1B 2 5 10 20 26	Phalen Phalen Phalen Emery Harbour Harbour	1C – Sea Drain at Indian Bay, north of Dominion 1D – 1B Shaft at Wallaces Cove (O'Neil's Point) 2B – No.2 & No.9 Dewatering Boreholes	–407	+15	1500–2900	Rank 10 pH 3.5 – 4.5 Rank 9 pH 3.5 – 4.5
	24	Emery	24 – Dewatering borehole at Morien Hill	+ 90[3]		seep	pH 7.01
4	3 4	Phalen Phalen	4C – Sea Drain at Big Glace Bay Lake, south of Glace Bay Hospital	+16		200	Rank 9 pH 3.5 – 4.5
	6	Phalen	6 – Dewatering borehole at MacRae Pt.	+15[3]		50[4]	Rank <5[6]
8	8	Harbour	8E – Sea Drain at Bridgeport Cove, shoreline near Shore Road	+16		455 (no change expected)	Rank 9 pH 3.5 – 4.5
	Sterling	Harbour	H1 – Shaft at Glace Bay Hbr., upstream, on west side of South St. Bridge	+15		455[5]	Rank 9 pH 3.5 – 4.5
Individual Hydraulic Systems							
7	7	Hub	7C – Sea Drain at Table Head	+15[3]		177	Rank 5[6]
11	11	Emery	11C – Dewatering borehole at Renwick Brk.	+ 91		525	Rank 6[6]
25	25	Gardiner	25D – Water Shaft at Gardiner Mines	+79		350	Rank 8[6]

Notes:

1) See Drawing 8728–7 for complete Outfall locations and descriptions. Locations on 8728–7 are identified by values such as – 4C, 24, 7C, etc.
No outfalls have been identified for any other systems (e.g. No. 12/14, No. 18)
2) Water level and discharge rates provided by CBDC during Summer 1993.
3) Water level at time of dewatering.
4) Flow based on Donkin mine records.
5) Flow based on colliery No. 8 flow rate.
6) pH values for individual Hydraulic Systems 6, 7, 11 and 25, ranged between 5.0 – 5.5.

hydroxides all the way to the ocean. This was confirmed later by a JWEL employee who is familiar with this outfall and who had previously estimated its discharge rate to be more than 100 igpm.

The status of outfall points (Drawing 8728-7) associated with the other flooded colliery systems is not known and will require fieldwork to determine. It is possible that some of these collieries may have no obvious surface discharge points. This would happen if: 1) the shafts, borehole or tunnels were all properly sealed, which is unlikely to have happened in all cases; or 2) if the potential discharge points would all be above the elevation of the regional aquifer piezometric surface. This latter situation presents potential for groundwater impacts as discussed in Section 4.7.3.

In extreme cases, water from mines may begin to discharge on surface as springs from either subsidence areas or areas where workings have extended to the surface. Sealing outfall points could potentially be considered as a remediation strategy, but would require further hydrogeological assessment before such a strategy could be implemented.

4.7.3 Exfiltration Through Bedrock

As with infiltration, exfiltration from inundated workings can occur through fractures in bedrock. If pathways exist, exfiltration will tend to occur in lower topographic areas where the piezometric surface within the mine workings rises above the adjacent strata and/or ground surface. Exfiltration should not occur until the mine has filled above sea level and would only occur where hydraulic pathways (e.g., fractures) occur. If outfalls such as tunnels exist, particularly near sea level, hydraulic gradients above sea level should direct flow toward these drains and exfiltration would be unlikely to occur.

If no lower elevation outfall exists in a given hydraulic system, then exfiltration to an adjacent aquifer may take place once equilibrium water levels have been reached. Flow to an adjacent aquifer may also occur if the outfalls were deliberately blocked to eliminate flow of acidic water. Increasing the water level in workings above sea level may result in flow from the workings into adjacent aquifers and create a potential impact to groundwater quality.

There are no localities in the study area where mine water is known to be discharging by exfiltration through bedrock. While such instances are difficult to document without specific work, exfiltration may be occurring. Mines that do not have outfall points and are receiving enhanced recharge, may be discharging water through exfiltration into permeable bedrock units. To determine if exfiltration is occurring, a specific program, including monitoring well installation, water quality sampling and water level monitoring, would likely be required in the vicinity of flooded workings.

4.7.4 Other Discharge Pathways

Other discharge pathways potentially exist. As with infiltration, discharge can occur through bootleg mines or through surface mines spoil if there is a hydraulic connection and if the bootleg or surface mines are at a lower elevation than the mine piezometric surface, discharge can also occur.

Abandoned exploratory boreholes are another potential discharge pathway. Hundreds of exploratory boreholes were drilled across the study area and many of these are may have been improperly abandoned. Improperly sealed boreholes could become flowing artesian wells, if the top of the well is lower than the piezometric surface of an intercepted mine working. Similarly, water wells drilled into old workings by accident, or to utilize the geothermal potential of the water, may ultimately become artesian.

5.0 MINE WATER GEOCHEMISTRY

5.1 General

Originally the focus of this study was the estimation of the quality of the effluent from various mine drains after all mining operations cease at some undetermined future date. During this study, continued operation of the Phalen mine, through pumping of the No. 1B Hydraulic System became a concern. Pumping of No. 1B was required to relieve hydraulic pressures on the No. 26 Lingan mine that overlie the Phalen mine. Subsequently, CBDC became concerned over the quality of mine water effluent generated during proposed depressurization (i.e., pumping) of the No. 1B Hydraulic System and how to handle this effluent. Thus an additional focus of this study became the quality of mine waters discharged from Nos. 1B and 4 mines while mining proceeded at the Phalen Mine.

The factors that influence water quality of abandoned mines were discussed conceptually in Section 1.3. These factors included: 1) the size of the workings exposed above the water level; 2) the length of time the mine has been inundated to its equilibrium water level; 3) the quality of water recharging the workings; and 4) the amount of flow-through.

Considerably more hydrogeochemical information exists for the Phalen and the recently closed Lingan mines than is available for any of the earlier mines. This is primarily a result of increased awareness of the capabilities of hydrogeochemistry as an interpretive tool, and of increasing environmental concerns. The chemical analysis of earlier mine waters focused on the parameters that indicated the potential for corrosion and/or scaling (e.g., pH, hardness and electrical conductance). The water chemistry concerns at that time typically were: 1) whether the water could be used for cooling of machinery, and 2) whether special fittings were required on dewatering equipment due to excessively high corrosion potential. As a result, the list of parameters that are historically available to describe early mine water quality is limited.

Table 5.1 summarizes typical water qualities for the various mines. These values and additional analyses are presented in Appendix D and are excerpts from historical files stored in the Beaton Institute. Summaries of the range and mean of recent (1988 to present) mine water chemistry monitoring are presented in Appendix D for the Lingan "A", Lingan 2E break, Phalen 1E and 5E breaks, and the No. 1B Shaft dewatering monitoring program.

A preliminary discussion of mine water quality concerns is presented, for existing mines, abandoned mines, and the No. 1B Shaft dewatering program, based on the historical data and known hydrogeochemical principles. The monitoring of the recent in-rush at Lingan 2E and pumping of the No. 1B Shaft provides the best source of information on the likely effluent quality during the next few years. The quality of historical mine water chemistry data was insufficient to provide a reliable estimation of long term mine water quality, however the intended No. 1B dewatering work offers an

Table 2.1
CBDC Colliery Water Study
Compilation of Colliery Data

Colliery No.	Service Dates	Seam	Colliery Workings Elevation Ranges Top(ft)	Colliery Workings Elevation Ranges Bottom (ft)	Avg Seam Thickness (ft)	Coal Production (Long Tons)	Worked Area (Acres)	Access and Interconnection Type	Reference Number I.D.	Access Status	Access Coordinates (Dominion Grid) Northing (ft)	Southing (ft)	Easting (ft)	Westing (ft)	Access or Interconnection Details Top Elev. (ft@sea L.)	Bottom El. (ft@sea L.)	Length (ft)	Opening Dimensions (ft H)	(ft W)	(ft dia.)	Water Make (GPM)	Water Quality	Comments or Other Details
Dominion 6	**1904–1933**	**Phalen**	**27.4**	**–1100**	**6.5**	**4,238,311.0**	**1,792.0**	**Slope Mine**													**240.0**	**Acidic**	**Connected to old Clyde mine workings.**
–Workings	1904	Phalen						Slope Entrances	6A	Unknown		24,050.0	53,150.0										Two slopes; one later abandoned due to poor quality, other devel. in NE direction.
	1924	Phalen to Harbour						X–Measure Tun.	6B	Assumed existing connection.		17,850.0	52,000.0			–770.3							Two parallel Tunnelsdriven from Dom.6 Phalen to Harbour seam, however not used to develope the Harbour seam.
		Phalen						Borehole	4D	Assumed existing connection.		20,400.0	44,500.0			–475	350						BH interconnection within Barrier Pillar of Dom.6 and Dom.4
Dominion 7	**1861–1918**	**Hub**	**15**	**–581**	**8.0**	**2,174,839.0**		**Slope and Shaft**														**N/A**	**No connections to other Collieries.**
–Workings	1861	Hub						Slope Entrances	7A	Various slopes along seam outcrop; presummed filled.													Seaward extension of the Hub mine; four parallel slopes between shoreline and easward extension(1905).
	1903	Hub						Shaft	7B	Assumed filled		13,130.0	32,260.0		53	–67	120						Dom.7 shaft referred as the "table head" area.
								Sea Level Drain	7C	Existing connection.						5							
Dominion 8	**1858–1914**	**Harbour**	**159**	**–275**	**5.3**	**5,259,118.0**		**Slope and Shaft**														**N/A**	
–Workings	1858	Harbour						Slope Entrance	8A	Assumed filled		17,050.0	22,780.0										–Limited information from available maps No connections to other coll'ys other than Sterling Mine.
	1863	Harbour						Shaft	8B	Assumed filled		14,790.0	22,725.0		73.54	6.46	80	6.0	14.0				Located 200 yards from shoreline.
	1906	Harbour						Pumping Shaft	8C	Assumed filled		13,415.0	27,550.0				373	6.0	12.0				Sunk on barrier between Dom.8 & Dom.9
		Harbour						Colliery Intersects.	8D	Assumed existing connections		19,830.0 19,335.0 18,380.0	29,730.0 29,040.0 27,790.0			–15 –45 –60							Interconnections between Dom.8 and adjacent Sterling Mine in Harbour seam.
		Harbour						Sea Drain	8E	Assumed existing connection.		22,415.0	12,200.0		5								
Sterling	**1872–1896**	**Harbour**	**Unavail.**	**–215**	**5.3**	**1,151,199.0**		**Shaft**														**N/A**	
–Workings	1872	Harbour						Shaft	S1	Assumed filled		17,240.0	31,320.0										Open to work extension of the old Harbour mine. Room and Pillar operation; extensive subsidence occured within area due to poor pillar mining practice.
		Harbour						Colliery Intersects.	8D	Assumed existing connection.		19,830.0 19,335.0 18,380.0	29,730.0 29,040.0 27,790.0			–15 –45 –60							Interconnections between Sterling Mine & adjacent Dom.8 in Harbour seam.
								Harb. Mine Shaft	H1	Assumed existing connection.		19,775.0	32,900.0		15								Potential Mine water discharge into Glace Bay Harbour.

Conversions: 1 Acre = 4046.86 square metres
1 Long Ton = 1.016 tonne

Table 2.1 continued

Table 2.1
CBDC Colliery Water Study
Compilation of Colliery Data

Colliery No.	Service Dates	Seam	Colliery Workings Elevation Ranges Top(ft)	Colliery Workings Elevation Ranges Bottom(ft)	Avg. Seam Thickness (ft)	Coal Production (Long Tons)	Worked Area (Acres)	Access and Interconnection Type	Reference Number I.D.	Access Status	Access Coordinates (Dominion Grid) Northing (ft)	Southing (ft)	Easting (ft)	Westing (ft)	Access or Interconnection Details Top Elev. (ft@sea L)	Bottom El. (ft@sea L)	Length (ft)	Opening Dimensions (ft H)	(ft W)	(ft dia.)	Water Make (GPM)	Water Quality	Comments or Other Details
Dominion 4	**1866–1961**	**Phalen**	**45**	**–2010**	**6.6**	**28,627,961.0**	**6,188.8**	**Shaft Mine**													**940.0**	**Acidic**	**Bulk of underground water from surface** cave–ins due to poor mining practices in early stages. Water from aband'ed Dom.3 was allowed to flow into Dom.4 to offset low pH's.
–Workings	1866	Phalen						Two Compart. Shaft	4A	Filled and capped 1963.		24,400.0	32,390.0		79.95	–95.5	176	19.0	11.0				
	1866	Phalen						1st Intake Shaft	4A	Filled and capped 1963.		24,400.0	32,390.0		78.5	–98.3	177			10.0			–1st Intake Shaft abandoned 1947
	1908	Phalen						Exhaust Shaft	4A	Assumed filled		23,850.0	37,600.0		10	–139	149			–			
	1947	Phalen						2nd Intake Shaft	4B	Capped, not filled		19,700.0	35,990.0		36	–510	546			18.0			Quarry Point
	After 1866	Phalen						Sea Level Drain	4C	Assumed filled		25,650.0	35,750.0			5							Sea Drain.
	1933	Phalen						Borehole	4D	Existing connections.		20,400.0	44,500.0			–475		350					Interconnections within Barrier Pillar of of Dom.4 and Dom.6
	After 1866	Phalen to Emery						De–watering Borehloe	4E	Assumed existing connections.		25,250.0	34,750.0		–20	–170	150						Seam interconnection between Dom.4 of Phalen and Dom. 24 of Emery seam.
	After 1866	Phalen						Colliery Intersect.	3C	Assumed existing connections.		18,500.0 19,200.0 21,800.0 22,500.0 24,000.0	29,200.0 28,800.0 26,800.0 26,400.0 25,200.0			–520 –475 –225 –170 –70		200 100 200 200 100		12 12 12 12 12			Interconnections within Barrier Pillar of Dom.4 and Dom.3
	After 1866	Phalen						Potential Bootleg Connections	3D	Assumed existing connections.		–	–										Dom.4 potentially connected to Dom.3 within Barrier Pillars by bootleg workings mined to @ water table.
Dominion 5	**1872–1938**	**Phalen**	**115**	**–550**	**7.7**	**12,898,468.0**	**1,312.0**	**Slope Mine**														**N/A**	
–Workings	1872	Phalen						Slope Entrances	5A	Assumed filled		23,830.0	20,790.0										
	After 1872	Phalen to Emery						Dewatering B.H.	5B	Assumed existing connection.		20,300.0	16,450.0		20	–130	150			1			Water pumped up on N. side Dom.10 via 12"dia B.H. to Dom.5 Main slope up 150'.
	1905	Phalen to Emery						Stone Drift	5C	Assumed existing connection.		21,850.0 21,200.0	16,400.0 16,450.0		80	–50		600		12			Dom.5 Phalen seam entrance. Dom.10 Emery seam exit.
		Phalen						Colliery Intersect.	1B	Known direct connection.		16,500.0 15,300.0	15,200.0 24,800.0		15	–560							Dom.1A is virtually connected to adjacent Dom.5 to a depth of –560'.
	After 1872	Phalen						Colliery Intersect.	3B	Existing connections.		21,800.0 23,600.0	24,000.0 23,200.0			–155 –45		10 100		12 12			Interconnections within Barrier Pillar of Dom.5 and Dom.3
	After 1872	Phalen						Potential Bootleg Connections	3C	Assumed existing connections.		–	–										Dom.5 potentially connected to Dom.3 & Dom.1A within Barrier Pillars by bootleg workings mined to @ water table.

Conversions: 1 Acre = 4046.86 square metres
1 Long Ton = 1.016 tonne

Table 2.1 continued

TABLE 5.1 REPRESENTATIVE WATER QUALITY ANALYSES FOR VARIOUS COLLIERIES DURING OPERATION

Colliery	Location	Date	pH	Hardness (mg/L $CaCO_3$)	SO_4 (mg/L)	Cl (mg/L NaCl)	Fe (mg/L)	Al (mg/L)	TDS (mg/L)
1B	pit bottom	Oct 20/70	6.4	294					
2	13 Lodgement	Nov/32	2.28		1441	103700			
4	weir at Quarry Point	June 14/74	6.25						30
6	6E Large Lodgement	Nov/32	2.29		1961	450			
9	Deeps	April 17/40	2.5		4042	16845	v. high	v. high	
10		April 17/40	3.1		3325	2960	high	high	
11	7.5 Lodgement	May 16/38	3.3		1008	2196	3.5	34	
12	11 Lodgement	July 27/38	2.6		3115	5020	175	172	
14	10 Lodgement	July 27/38	3.0		2841	10620	75	118	
15		1920	~7.0						27877
16	8.5 Lodgement	June 6/34	7.2		2484	5460			
21		1920	<2						20000
22		1920	<2						19450
25	Main Deep	June 18/54	6.0						60
26	3 S. arch deep	July 5/68	6.02	17450		47090			
Lingan	Mine discharge	Dec 1/93	5.5	6494	3551	23864	800		27690
Phalen	4E Bottom	Nov 28/92	6.3	38335	750	76655	6.8		117858

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excellent opportunity to obtain the necessary information. A program of on-going chemical and hydraulic monitoring for the various outfalls identified in this report, is needed to provide more reliable estimations of future effluent quality (Section 7).

5.2 Mine Water Quality During Mining Operations

The present operating collieries in Cape Breton generally exhibit a very hard, high TDS, alkaline mine water with a pH in the order of 7 to 8. The effects of acid drainage within the workings appear to be neutralized by the more alkaline connate formation waters that resemble sea water (Tables D-3, D-4 and D-5 - Appendix D).

High TDS saline formational waters result in poor water quality in the Sydney Coalfield operational mines. These waters may have been naturally hyperfiltered through the process of naturally occurring reverse osmosis within the sandstone and shale bedrock. These waters typically have a chemistry resembling a saline brine, with a salinity and TDS about three times higher than sea water. The historical record suggests such water quality was encountered in all the mines, even in the land-based mines. The recent in-rushes at Phalen 1E, in November 1988, and Phalen 5E, in November 1990, illustrate this chemistry (Tables D-3 and D-5 - Appendix D). Although non-acidic, these saline mine waters are of concern if discharged to a fresh water receiving stream because of high TDS, metals and reducing conditions. In comparison to the No. 1B Shaft waters (Table D-1), the Lingan and Phalen mine waters are considerably lower in sulfate, iron and metals but higher in sodium, chloride and TDS.

There is no significant active pumping of mine water to the surface. The abandoned Lingan mine is currently flooding at an estimated rate of 1,500 igpm from a break at Lingan 2E. The source of this water is believed to be the No. 26 colliery and No. 1B Hydraulic System. The pumping of the No. 1B Shaft in recent months has been discontinued due to concerns about effluent quality and its impact on the near-shore marine environment.

The Phalen mine is the only underground mine currently operating in the study area. This mine is considered relatively "dry." Regular water samples are now taken at several points in the mine, as well as the Lingan mine. Several studies of the mine water source and chemical trends, including isotopic analysis, have been performed by JWEL and CBDC (JWEL 1989, 1991, and 1992). This work has generally indicated several things: 1) the water associated with the November 1992 Lingan mine in-flow probably originated in No. 26 mine; 2) the 1988 and 1990 waters that in-flowed to the Phalen mine, were probably hyperfiltration formation brines; 3) 1993 data suggests roof inflow water quality may be increasingly influenced by Lingan mine water rather than hyperfiltration brines; and 4) water within the No. 1B workings originates from infiltration of meteoric groundwater.

5.3 Abandoned Mines: Water Quality at Outfalls

Another focus of this study was the future water quality at on-shore and near-shore outfalls from abandoned flooded workings. Drawing 8728-7 identified a number of potential outfall locations from these flooded workings. Many of these outfalls are not producing water at this time because the mine water levels are currently far below sea level. It is expected that mine water will discharge through these identified outfalls after cessation of all mining activity in the area. Historical records indicated that these mines typically produced an acidic water quality with a pH < 4.0 (Table 5.1).

Once active mining ceases and workings begin to flood, the mine water chemistry should gradually evolve from its operational chemistry, to a chemistry that is dominated by the source waters. These source waters are likely to be meteoric groundwaters infiltrating from the upper landward portions of the respective mines. The chemistry of the effluent will likely be dependent on the volume of workings remaining exposed to the atmosphere at equilibrium. For example, those outfalls in hydraulic interaction with large volume abandoned mines, located above both sea level and the equilibrium water level, will probably exhibit the greatest degree of acidic impact.

The nature of the outfall should have an effect on the equilibrium water chemistry. Relatively large outfalls such as audits and tunnels will effectively drain the entire mine to the level of the outfall, and could exhibit acidic water chemistry. Smaller outfalls and seeps on the other hand may allow the water level to rise significantly above the outfall point. These waters may be less acidic but exhibit higher TDS values due to less contact between the mine water and the atmosphere near the outfall.

? The final mine water is expected to exhibit a distinct chemical stratification with depth. It should range from a high TDS saline, or brackish, water with near neutral pH (i.e., about 6.5) at depth, to a more dilute and acidic pH (i.e., range 4.5 to 5.5) water at the surface of the water column. At depth mine water chemistry is expected to resemble that of the Lingan and Phalen mines (Appendix D) and the chemistry of water in the upper portions of the mine should resemble that of the Old Harbour Seam, Table D-1. In both cases, the water chemistry will be characterized by elevated concentrations of dissolved solids, sulfate, iron, manganese, ammonia, and salinity. ?

Once the mine complex floods to its equilibrium level, several water movement/discharge scenarios are possible. These include: 1) the poor quality water in the mine workings may begin to be flushed out within the area of active mine water circulation; 2) infiltrating meteoric groundwaters will exfiltrate through the bedrock essentially having little impact on the deeper stratified poor quality mine water; or 3) these meteoric groundwaters will improve the upper-most stratified water quality that will then be discharged to surface by outfalls, subsidence zones, etc. It is unlikely that infiltrating meteoric groundwater will significantly influence the deeper mine water quality. Significant hydrostatic pressures would need to be overcome for the meteoric water to move into the deeper workings. In addition, the greater density associated with this poorer quality water will inhibit downward migration of the meteoric water.

The length of time required for on-set of these scenarios will depend upon the inflow rates, the degree of mixing, and the volume of water in storage within the zone of active circulation as discussed in Section 4.6. The zone of active circulation within a connected system should extend down to at least the uppermost connection (Figure 4.1). In a hydraulic system consisting of either a single mine, or a larger hydraulic system, the zone of active circulation may be the shortest interconnected mine route between the recharge and discharge areas. Alternatively, and depending upon the hydrogeologic conditions present in the zone of the equilibrium water level, a circulation path through mine workings may be short-circuited by water exfiltration through fractured bedrock. For the mine circulation pathway, it is estimated that circulation times would be similar to the mine filling times. Generally this might range from several months, in a single mine system, to more than 5 years, for larger hydraulic systems such as the No. 1B and No. 12/14 Systems. In the case of exfiltrated water, the time to reach a receptor (e.g., surface depression, adjacent well) will vary and depend upon the hydraulic conductivity of the bedrock, hydraulic gradients involved, and distance to the receptor. Circulation times could range from less that a year to 10's of years, depending upon the distance to a receptor and the averaged hydraulic conductivity of the bedrock. Whether any water quality improvement is achieved with time in either pathway will depend upon a variety of factors as discussed below.

At equilibrium, the actual water quality, in terms of pH, sulphate and metals content will probably fall between two end points. The poorest quality to be expected should be that of the storage water in the collieries. Based on the recent No. 1B pumping, this water is likely to be in the 4.0 to 4.5 pH range, and have iron and sulfate concentrations of 100's to 1000's of mg/L (milligrams per litre) respectively. The best quality water that can be expected, in the short term, will have a pH of around 5.0. This pH is slightly above the minimum pH (i.e., about 4.5) that can result from oxidation of sulfides by oxygen saturated groundwater without an external input of oxygen. The expected concentration of sulfate for these better quality waters is around 30 mg/L.

The two outfalls that were inspected, during JWA's field reconnaissance, drain the Nos. 1A and 7 collieries and had pH values of 5.1 and 4.0 respectively (Section 4.7.2). The relatively high pH and low flow rate at the No. 1A outfall may result from the fact that the outfall is draining a short portion of the tunnel and not the entire workings.

The mines located in the Gardiner and Emery seams (i.e., Lower Morien Group) are expected to produce a greater quantity of flow-through than those collieries in the upper seams. Increased flow-through may result in improved water quality near the upper stratified mine water column but its impact on deeper mine waters in storage may be limited. In addition, oxidation of sulfides which is a surface phenomenon and increased flow-through, may cause faster oxidation. With time there may also be a loss of oxidizable sulfides along a given pathway. If exfiltration through the bedrock predominates, the water quality at discharge points may not improve significantly with time.

The groundwater recharging the interconnected collieries is not expected to add contaminants to the mine-water discharge. The very small potential input from domestic sewage is also unlikely to cause a significant degradation of water quality. Sewage may marginally improve the water quality because the associated organic matter is likely to increase the biological oxygen demand and result in less oxidation of sulfides.

Water recharging through surface mine spoil could have a major impact on the quality of underlying mine water. Bottom coal and other wastes left on the pavement or pyritiferous rock in the re-graded overburden, would present potential for generating acid rock drainage that could be intercepted by the underground workings. This could potentially contribute to the acidic potential of the underground mine effluent water quality. Such potential should be considered in any future surface mining operations.

5.4 Active Pumping of the 1B Shaft

Active pumping or dewatering of existing coal mines will probably result in an "evolution" of the mine water quality from one of relatively neutral pH to a lower pH (e.g., 3.5 to 4.5) as the water level is drawn down. An example of this was observed during the recent (October to December 1992) dewatering of the No. 1B Shaft in an effort to depressurize the inflow at Lingan 2E. Vertical profiling of the shaft water pH, prior to the dewatering operation, indicated a relatively constant pH of 6.5 from the top to bottom of the shaft. With pumping, the pH gradually decreased from pH 6.5 to 4.3, from the top to the bottom of the shaft, respectively. The pumped water represented a poor quality mine water, with a steady decrease in pH from 6.4 to 3.9, and increasing concentrations of iron (e.g., typically a maximum of 2,000 mg/L total iron), sulfate (5,500 mg/L), manganese (66 mg/L), ammonia (22 mg/L) and aluminum (Appendix D). As pumping progressed, there was a concurrent decline in the concentrations of sodium, chloride and alkalinity. This decline probably indicated a greater proportion of shallow mine water in the pumped water.

Tables D-1 and D-6 (Appendix D) illustrate the difference between a sample bailed from the shaft in 1991, and active pumping of the shaft in late 1992 that resulted in a dramatic increase in iron and sulfate concentrations and a decrease in pH. Discharge of this water to the surface environment (e.g., ocean) results in oxidation of the effluent, with consequent precipitation of significant amounts of iron oxyhydroxide and sulfate minerals.

The change in effluent water quality observed during the No. 1B Shaft dewatering is attributed to mixing with acidic mine waters from shallow workings in hydraulic connection to the Nos. 1B and 26 collieries (or possibly the Nos. 4 or 20 collieries). Exposure of the shaft walls to atmospheric oxygen and inflow from adjacent groundwaters may have also contributed to the acid generation. Historical records indicate a very poor water chemistry from the No. 4 mine during past dewatering (Table D-1). In one instance, a pH of approximately 2.3 was reported, and water from the No. 3 mine had to be pumped in to improve the No. 4 effluent quality. As the deep saline high TDS waters are removed from the No. 1B system, the majority of recharge should be from above, and a poor quality acidic mine water is expected. The No. 1B water chemistry shown on Table D-6 (Appendix D) likely represents a "worst case" water chemistry.

5.5 Mine Outfall Points

5.5.1 Ranking Outfall Quality

Five multiple-colliery hydraulic systems consisting of two or more collieries, and seven individual collieries that are not interconnected hydraulically have been identified. This potentially amounts to twelve, or more, outfalls that could develop (Section 4.7). Drawing 8728-7 shows the location of these potential discharge points. Many of these points were verified by CBDC personnel in the field, while some still need field verification. A description of the known and suspected outfalls are provided in Section 4.7. Table 4.3 summarizes the known details of these outfalls.

In order to assess the relative risk of poor quality, high quantity passive discharge at outfalls, an empirical semi-quantitative ranking system was employed. The ranking assigned a number from one to ten to each system, with one representing the lowest level of risk and ten representing the highest. The ranking system was based on our experience with the hydrogeochemical processes involved, a review of available literature and the current understanding of the conditions existing on site as previously discussed. While the system is qualitative and subjective, it does provide a basis to identify the areas of relatively high and low risk within the study area. Without additional supporting information, including monitoring data, it is not directly applicable to the design of treatment systems. This ranking system, together with the outfall locations shown on Drawing 8728-7, are intended to provide a focus for future monitoring and remediation work.

The procedure used for assigning ranks is summarized as follows:

i) The volume of the workings above sea level were considered. If the volume was less than 1,000,000 ft^3, a number of 1 was assigned; between 1,000,000 and 5,000,000 ft^3, a number of 2 was assigned; between 5,000,000 and 10,000,000 ft^3, a number of 3 was assigned; and if greater than 10,000,000, ft^3, a number of 4 was assigned.

ii) The elevation of the lowest major outfall was taken into consideration, to include the degree of inundation of the above-sea workings in the ranking. If the hydraulic system does not have a sea-level drain, a multiplication factor of 1 was applied to the volume related number established in Item i. If a sea level drain exists, a multiplication factor of 2 was applied.

iii) The third criteria used in the ranking system was the anticipated outfall flow rate. For a rate <100 igpm, a number of 1 was added to the ranking total; between 101 and 200 igpm, a number of 2 was added; between 201 and 500 a number of 3 was added; and for a discharge greater than 500 igpm, a number of 4 was added.

The estimation of mine volumes was previously discussed (Section 4.6). Mine volume estimates, based on detailed calculations documented in Appendix C, are summarized in Table 5.2. The estimated discharge rates were established based on a review of calculated rates shown in Table 4.1, the reported historical pumping rates during operation (Table 2.1), and rates calculated by CBDC. Table 5.2 also contains estimated pH ranges based on historical records. These pH values likely represent worst case scenarios and were included to provide a connection between the rating system and historical analytical results. These pH estimates should be verified by field observations. Recent pH measurements for some of these outfalls, indicated in pH values of approximately 7 for all outfalls measured. Based on JWA's experience, such pH values are not considered representative of anticipated mine water discharge quality and should be carefully re-checked.

The maximum number that can be obtained from this ranking system is twelve. The maximum number calculated and reported was ten. The various rankings and the criteria used to establish them are provided in Table 5.2. Although flow rate was considered, the potential reduction in acidity by increased flow-through was not included in the ranking.

Based on the ranking, the No. 1B Hydraulic System has the highest risk of discharging large quantities of acid-impacted water from potential outfalls. The No. 1B System was followed, in decreasing order, by the No. 4 Hydraulic System, the No. 8 Hydraulic System, and the individual hydraulic systems associated with Nos. 25, 11 and 7 mines (Table 5.2). All the other hydraulic systems and/or mines have a rating less than five, however some of these would still be capable of discharging mine water to the environment.

5.5.2 No. 1B Shaft Dewatering

The significance of the proposed No. 1B System dewatering, to elevation -565 feet BSL, is likely to result in movement of stored mine waters over a wide area of workings. This movement may include removal of mine water from the No. 4 Hydraulic System, if it is confirmed to be in hydraulic connection with the No. 1B System.

The No. 1B water chemistry is expected to resemble an acidic (pH 4.0) and corrosive high TDS calcium sulfate mine water. Elevated concentrations of iron (i.e., up to 2,000 mg/L), hardness (3,500 mg/L), sulfate (5,500 mg/L), manganese (50 mg/L) and ammonia (20 mg/L), are likely based on existing data (Table D-6, Appendix D). This evolution in chemistry is likely to occur within a period of days for the No. 1B water, based on earlier No. 1B pumping data, assuming similar pumping rates. The influence

TABLE 5.2 ESTIMATED DISCHARGE RATES, WATER QUALITY AND RANKING OF ENVIRONMENTAL RISK ASSOCIATED WITH COLLIERY SYSTEMS

Hydraulic System	Colliery	Flood Status (feet)	Seam	Volume Above MSL (ft³)	Estimated Flow Range (igpm)	Reported Flow Rates (Table 2.1) (igpm)	Estimated pH Range	Ranking
Phalen	Phalen	empty	Phalen	54,000	<100		5.0–6.0	2
1B	No. 5	−400	Phalen	33,850,000				
	No. 26	−400	Harbour	0				
	No. 20	−400	Harbour	0		135	< 4	
	No. 2	−400	Phalen	0		12		
	No. 1A&B	−400	Phalen	1,113,000		600	< 4	
	No. 9	−400	Harbour	0	200–500	900	5.0–6.0	4
	No. 10	−400	Emery	25,169,000		1750	< 4	
	Lingan	−400	Harbour	162,000	>500		3.5–4.5	10
	Sub–Total 1B			60,294,000				
1B	No. 4	Full	Phalen	4,240,000		940	< 4	
1B	No. 3	Full	Phalen	1,422,000	200–500		3.5–4.5	9
	Sub–Total Nos. 3 & 4			5,662,000				
1B	No. 6	Full	Phalen	1,604,000	100–200	240	4.5–6.0	4
1B	No. 24	Full	Emery	1,979,000	100–200		4.5–6.0	4
No. 7	No. 7	Full	Hub	2,830,000	<100		3.5–4.5	5
No. 8	Sterling/Old Harbour	Full	Harbour	0				
No. 8	No. 8	Full	Harbour	12,035,000	<100		3.5–4.5	9
No. 11	No. 11	Full	Emery	8,247,000	200–500	420	4.5–6.0	6
No. 12&14	No. 14	−1200	Harbour	0		90	< 4	
No. 12&14	No. 12	−1200	Harbour	0	<100	175	5.0–6.0	2
No. 15	No. 15	Full	Phalen	189,000	<100		5.0–6.0	2
No. 18	No. 18	Full	Phalen	848,000		260	< 4	
	No. 17	Full	Harbour	1,368,000				
	No. 16	Full	Phalen	120,000	100–200	80	4.5–6.0	4
	Sub–Total Nos. 18–16			2,336,000				
No. 25	No. 25	Full	Gardiner	14,020,000	200–500	100	3.5–6.0	7

Note: Numbers rounded to nearest 100 feet of elevation.

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of the No. 4 System, if hydraulically connected, should be evident in a relatively short period of time (i.e., days to weeks).

6.0 SUMMARY OF CONCLUSIONS

6.1 General

This study involved review and synthesis of a very large amount of historical and current data on mine workings and practices, hydrogeology, geology, as well as historical and recent records pertaining to mine water pumping and water quality. This work provides CBDC with summary information that, has not been previously available in some cases.

The study focus primarily centered on future mine outfalls. However, in response to current CBDC concerns, active pumping of the Nos. 1B and 4 Hydraulic Systems has been considered and discussed as a component of this study.

This section summarizes and presents the main project results and practical achievements. These include the following:

i) the assessment of hydraulic interconnections among the collieries within the study area;

ii) the prediction and location of probable mine water outfall points from each hydraulic system or colliery;

iii) estimates of the quality and quantity of passive mine water at these outfalls;

iv) assessment of the implications of pumping the No. 1B Shaft, especially with repect to anticipated discharge water quality; and

v) ranking of the mine water hydraulic systems, according to their relative degree of environmental risk.

6.2 Mine Interconnections

Many of the 27 collieries in the study area are interconnected by workings, tunnels, service boreholes or, in one case, a known subsidence-related break. Based on a synthesis of all available information, a total of twelve hydraulic systems were defined. This included five multiple-colliery hydraulic systems, with at least one connection, and seven single collieries with no interconnections. Upon reaching equilibrium water levels, the inter-connected mine systems are expected to act as one hydraulic unit. This assumption was based on the presence of interconnections at, or below, the anticipated elevation of both the equilibrium water level and potential outfalls.

The nature of the connections between mines is shown schematically on Figures 8728-2 through 5. The five multiple-colliery hydraulic systems and their components are conceptually presented on Figure 3.1. These multiple systems include:

i) the No. 1B Hydraulic System, consisting of colliery Nos. 1A, 1B, 2, 5, 9, 10, 20, 24, 26 and the Lingan mine;

ii) the No. 4 Hydraulic System, consisting of colliery Nos. 3, 4 (Caledonia) and 6;

iii) the No. 12 & 14 Hydraulic System, consisting of colliery Nos. 12 and 14

iv) the No. 18 Hydraulic System, consisting of Nos. 16, 17 and 18; and

v) the No. 8 Hydraulic System, consisting of the No. 8, and the Sterling and Old Harbour mines.

vi) the seven individual collieries that are not hydraulically connected to others (Nos. 7, 11, 15, 23, 25, as well as the Phalen and Old Victoria mines).

No 24 -> Shaft - Above water level

Of the twelve hydraulic systems identified, eight are believed to be flooded to equilibrium level, and four others (i.e., Nos. 1B, 12/14, 23 and the active Phalen mine) are currently below predicted equilibrium levels.

6.3 Present Water Levels and Predicted Time to Equilibrium After Decommissioning

The final equilibrium water levels will probably be controlled largely by the elevation of the lowest major outfall for each system. Eight hydraulic systems are believed to have reached their respective equilibrium water levels at or above mean sea level. These hydraulic systems include the Nos. 4, 7, 8, 11, 15, 18, 25 and the Old Victoria mine.

The Nos. 4, 7, 8, and 25 Hydraulic Systems are either known, or strongly suspected, to be currently discharging mine water from land based outfalls. The remaining hydraulic systems, listed above, have the potential to develop outfalls.

For some hydraulic systems (e.g., No. 18), little or no data (e.g., water level, chemical) was available since the workings were not accessible. Such data gaps effect the ability to make future predictions on the quantity and quality of mine water at the outfalls. In some cases, water levels were inferred from reported operational inflow rates, mine void volumes, and/or the time interval since mining ceased.

Assuming no pumping, it was estimated that the No. 1B Hydraulic System would refill to equilibrium in approximately 5 years, after cessation of pumping; this did not consider loss of water to the Lingan mine. Passive discharge from the No. 1B System would likely begin at three identified discharge points: the sea drain at Indian Bay, No. 1B Shaft at Wallaces Cove, and Nos. 2 and 9 dewatering borehole (Table 4.3). Assuming that the majority of recharge (i.e., 1,500 igpm) to the Lingan Mine is from the break at 2E, it was estimated that 2 to 4 years would be required to flood the Lingan colliery. In total, Interconnection System 1 (i.e., Hydraulic Systems Nos. 1B and 4) would probably require 7 to 9 years to flood completely. The No. 12/14 Hydraulic System was estimated to begin discharging about the year 2000.

The time required for flooding of the Lingan mine is uncertain because of the rate of flow into the Lingan mine from the No. 1B System. Since active pumping at the No. 1B Shaft was discontinued, inflow to the Lingan 2E has been estimated to be about 1500 igpm (S. Forgeron, Chief Geologist CBDC, personal communication).

6.4 Potential For Recharge and Groundwater-Mine Interaction

During mining operations, most water recharging the mines originates either from process water pumped into the mine for equipment operation, or seepage of water between flooded and active mine workings. Specific collieries, notably Lingan, receive a significant portion of the recharge from adjacent flooded collieries, as previously discussed. However in most other cases and after mine decommissioning, groundwater infiltration into mine workings above sea level should be the primary mode of mine water recharge. This assumes these workings above sea level are hydraulically connected to the lower workings.

The potential for groundwater recharge of mine workings is related to the hydraulic properties of the host bedrock. Collieries situated within the more permeable Lower Morien hydrostratigraphic unit are likely to have a greater potential infiltration rate than collieries situated in the less permeable Upper Morien unit. Colliery Nos. 10, 11, 24 and 25 located within the Emery and Gardiner coal seams, are located within the Lower Morien unit, and the other mines are developed within the Upper Morien strata. This accounts for the generally "dry" conditions reported in the seaward mines such as the Lingan and Phalen, and historical flooding problems associated with the Emery and Gardiner workings.

Natural groundwater infiltration (i.e., about 16 % of mean annual precipitation) is enhanced through subsidence-induced fracturing that typically occurs over relatively shallow mine workings. This fracturing potentially allows recharge from shallow bedrock aquifers and permeable surficial deposits. Little specific information was identified regarding subsidence related recharge problems within the study area. This pathway is probably most applicable to the older, land based mines. Within the deeper mines, subsidence fractures may intersect water bearing zones above the coal seam. Flows associated with such fracturing are typically temporary in nature and these flows will decrease rapidly as the intercepted aquifers are depressurized.

Other potentially significant sources of mine water recharge include: surface water flows through open boreholes, tunnels, shafts or sinkholes; seawater inflow; formational or connate water inflow; and operational water input. With the exception of possible surface water flows through sinkholes over shallow workings, these potential sources should provide a relatively small component of the total mine water flow budgets.

6.5 Mine Water Discharge Pathways

Two modes of future mine water discharge were identified: passive discharge from the discharge points identified in this study, and active pumping of the Nos. 1B and 4 Hydraulic Systems during current mine operations.

6.5.1 Passive Mine Water Discharge Pathways

Once the mines have saturated to sea level, the majority of mine recharge will originate above sea level. The workings will continue to fill up to the level of an outfall, or to static groundwater conditions (i.e., typically 10 to 30 feet below grade) if no outfall exists.

The principle discharge pathways will be open tunnels, shafts and boreholes exhibiting hydraulic connection with the workings. The outfalls considered to pose the greatest environmental concern are those that were originally designed to passively dewater workings above sea level. Such dewatering outfalls were identified for portions of the No. 1B Hydraulic System, the No. 4 System, the No. 8 System and the No. 7 System. Twelve potential major mine discharge outfall locations have been identified (Drawing 8728-7) and are summarized in Table 4.3. It is possible that other potential discharge points may also exist.

Another discharge pathway of potential concern is exfiltration through bedrock above sea level. This pathway would probably only be important if there were no direct sea level outfalls and if hydraulic gradients were outward with respect to the workings. Such a situation may be occurring now in a number of the abandoned mines. Workings within the more permeable Lower Morien bedrock (e.g., Emery mine, Gardiner mine) would most likely be effected by bedrock exfiltration pathway, rather than seaward mines within the less permeable Upper Morien bedrock. Domestic and industrial water wells completed in bedrock adjacent to flooded workings between the coal seam outcrop and the coast would be most affected.

6.5.2 Active Discharge Pathways

While the Phalen mine continues to operate, CBDC proposes to discharge water from the Nos. 1B and 4 Hydraulic Systems. This would reduce hydraulic pressure on the No. 26 and Lingan mines that stratigraphically overlies the active Phalen workings. The No. 1B System would be dewatered to an elevation of -565 feet BSL. The water level in the No. 4 System may be lowered to an elevation below +16 feet ASL, the assumed connection with the No. 1B System, in an effort to improve the No. 1B water quality.

6.6 Predicted Mine Water Discharge Rates

Order of magnitude outfall discharge rates were estimated for the various workings. These estimates used the area of abandoned workings above sea level, an average precipitation infiltration rate (i.e., 16% of mean annual precipitation - 55 inches), and considered the limiting hydraulic conductivity of the Upper Morien bedrock. Subsequent to predicting these values, CBDC personnel inspected the various outfall locations. Based on this site reconnaissance, field estimates of flow were made and provided to JWA. The estimated future outfall discharge values (i.e., calculated and field estimated) are presented in Table 4.3 and summarized as follows:

Colliery	Outfall (igpm)
No. 1B	1,500-2,900
No. 4	200
No. 8	455
No. 6	50
No. 7	180
No. 11	525
No. 24	<10
No. 25	350
Lingan	10
Phalen	<10

Typically, steady state flow rates in the order of 10 to 1,000 igpm were anticipated based on the calculated estimates. For those outfalls subsequently inspected by CBDC, the calculated values and field estimates were within half an order of magnitude. For this type of calculation, such an estimate should be considered quite good. The highest flows were expected from the No. 1B system that covers a large portion of the study area. Higher inflows were expected from those mines in the more permeable

Lower Morien bedrock (i.e., Nos. 10, 11, 24 and 25) on the Emery and Gardiner seams. The No. 1B discharges are expected to be distributed over several outfall locations. Field monitoring of existing outfalls should be undertaken.

Steady state pumping rates in the order of 1,500 and 200 igpm were predicted for the Nos. 1B and 4 Shafts respectively.

6.7 Predicted Water Quality and Ranking of Risk Areas

6.7.1 General

Undiluted mine water discharge quality is expected to range between two extremes. The worst quality mine water is expected to discharge from mines that have a large volume of unsaturated workings exposed above the water level. Under this type of condition, the oxidation of pyrite associated with acid generation can readily occur. The pH of these mine waters can be expected to range between 3.5 and 4.5, based upon historical water quality data and from field measurements. The mine water chemistry should generally exhibit high TDS, hardness, and elevated concentrations of sulfate, ammonia, iron, manganese, and soluble metals (e.g., aluminium and zinc). The discharge from the No. 1B colliery and Lingan 2E exemplify this type of discharge (Appendix D).

In cases where most or all of the workings are flooded, the pH will probably not drop below 5.0 because acid production should be limited by oxygen solubility. Dilution, from flow-through of high quantities of better quality meteoric groundwater, may result in pH values of 6.0 or more in cases where workings are fully flooded. In addition, meteoric groundwater flow-through may, with time, consume a portion of the oxidizable pyrite along a given groundwater pathway.

Some flushing of poor quality deeper mine water might occur, where hydraulic conditions permit. In these cases, quality problems could include high salinity, suspended solids, iron, ammonia, sodium, chloride and TDS, if deep saline waters were displaced from the workings. These waters are not expected to be acidic, with pH's in the 7 - 8 range. The Lingan and Phalen mine waters are examples of this type of water quality (i.e., Tables D-3, D-4, and D-5).

not latterly

6.7.2 Pumping from the Nos. 1B and 4 Shafts

Both the Nos. 1B and 4 workings are expected to yield significant volumes of poor quality mine water if pumping is conducted to relieve hydraulic pressures on the Lingan 2E mine and the underlying active Phalen mine. Because of its large volume of unsaturated workings above sea level, the poorest quality water (i.e., low pH water) is expected to be associated with the No. 4 mine. No chemistry data was available for the No. 4. However, chemical analyses of recent discharge waters from pumping of the

No. 1B Shaft (i.e., November 1992 to March 1993) illustrates the mine water chemistry anticipated (Table D-6).

6.7.3 Passive Discharge at Outfalls

The quality of historical data on mine water flow rates, past water levels and water chemistry was generally limited, and analytical quality was uncertain. As a result, much of the hydrogeological evaluation for this study relied upon a good understanding of physical and chemical hydrogeologic processes and previous experience; therefore, to a degree, this study necessitated subjective interpretation. Based on the value of recent monitoring data (i.e., water quality and water levels) from the Lingan 2E break and past Phalen inflows, additional monitoring work will be necessary to enhance our current understanding of the mine water problem.

Tables 4.3 and 5.2 summarize the probable water chemistry, based on pH, of the various workings at equilibrium. The environmental risks associated with outfalls was considered to be a function of both the quality and quantity of water discharging from a given system. In order of priority and on a scale of 1 to 12 (i.e., lowest to highest risk), the environmental risk associated with passive discharge from collieries was ranked as follows:

Systems	Rank
No. 1B	10
No. 4	9
No. 8	9
No. 25	8
No. 11	6
No. 7	5
All others	<5

Hydraulic systems ranked above five were considered likely to produce some acidic mine water. This empirical ranking scale was largely derived from anticipated flow rates, the expected water quality and volumes of workings remaining above sea level at equilibrium. Additional field work is necessary to provide data that would refine the above rankings.

In summary, as the mines flood to equilibrium, it is anticipated there will be an evolution in water chemistry at the various outfalls. Typical mine water will range from the present low to moderate pH meteoric water chemistry, to a low pH high TDS mine water chemistry in the short term (i.e., several years). A higher pH, high TDS mine water is anticipated over the longer term. Depending on hydraulic head distributions at equilibrium, and anticipated chemical stratification due to fluid density within the mines, the quantity of deeper poorer quality saline mine water discharged through the outfalls may not be significant. The existing flooded systems should continue to exhibit a similar discharge water chemistry as present. Monitoring of effluent flow rate at the identified outfalls and quality should be undertaken to confirm these assumptions.

7.0 RECOMMENDATIONS

7.1 Confirmatory Fieldwork and Monitoring

The scope of this study was quite broad, encompassing several issues important to CBDC. However, much of this study has relied on narrow or poorly documented historical information and/or limited recent monitoring data. Considering the long coal mining history in this area and the poorly documented nature of some activities (e.g., water inflows, inflow quality), further work is needed to support and refine the conclusions presented. Accordingly, the following recommendations are made for additional fieldwork and monitoring:

i) The status of the interconnections between some workings should be confirmed, if possible. The status of interconnections between collieries Nos. 9 and 2, Nos. 6 and 4, Nos. 3 and 5, Nos. 10 and 5, and Nos. 4 and 24, are considered most important. The interconnection between the No. 4 workings, that are suspected of containing low pH mine water, and the No. 1B Hydraulic System should also be addressed. Such work should assess the impact of No. 4's water quality on the quality of the discharge water from No. 1B; this is particularly important in light of the need in treatment of effluents prior to release to the surface. Review of historical information not available for this study, if such information exists, and interviews with long-time employees, may provide additional and useful anecdotal evidence on the status of these connections.

ii) Based on this study, CBDC has already conducted a field reconnaissance of suspected outfall locations. Additional field reconnaissance is needed to identify and document other outfall locations.

iii) An outfall monitoring program should be established to document flow rates, water quality and temperature variations due to precipitation events and seasonal factors. Based on this information, the flow rate and mine water quality estimates made during this study should re-assessed and adjusted, if necessary. This monitoring program will provide a better basis for assessing the degree of through-flow, pyrite oxidation, and meteoric water impact.

iv) Conduct a detailed assessment of the No. 1B and Lingan mine water level and quality monitoring data, to both confirm the estimated inflow rates from No. 1B to Lingan 2E and to assess whether there is a seasonal component.

v) To enhance predictions of chemical trends and future mine water discharge quality, a thorough hydrochemical assessment of recent mine discharge water chemistry (i.e., No. 1B, Lingan, Phalen) should be conducted. This assessment should include both the available inorganic and isotopic data. This work would augment the outfall monitoring program and provide a better basis on which to predict future water quality data. Such an assessment could also enhance existing mine operations (e.g., mine safety), by providing a better characterization for any future potential mine inflows.

vi) The existing mine water level monitoring program should be modified to include dedicated water level recorders. Use of such equipment will be more cost-effective in the long-term, and will provide more continuous and consistent data for both operational and environmental monitoring. In addition, CBDC should: 1) modify existing methane monitoring wells to allow water level monitoring, this would involve installation of 1.5 or 2.0 inch inside diameter standpipes for water level measurement; and 2) obtain at least one 1000 foot electric water level tape to facilitate manual monitoring of rising mine water levels.

vii) An important component of any monitoring program is storage, access and use of the data gathered. To be most useful, data should be stored in a computer database. A database is much more than electronic storage of data on disk. Generally, it consists of a computer program that allows the user to quickly retrieve stored data in a formate (e.g., graphs, by data type - pH, etc.) that can be used to answer time-sensitive questions. Depending upon how the database is structured, it can allow a user to undertake the following: 1) long-term trend analyses, 2) automatic flagging of action levels (e.g., instances where regulatory criteria have been exceeded), 3) determine the statistical significance of an event, 4) check the laboratory quality control of samples analyzed, 5) produce data plots specific to the user's needs, 6) provide summary reports of data by event, location, time, etc., 7) export data to other software applications for additional analyses (e.g., water level data for groundwater modelling), etc.

It is recommended that CBDC consider developing a database for the water level and water quality data that both currently exists and will be collected in the future. Such a database would expedite review and assessment of data, especially in respect to operational needs (e.g., new inflows). It could provide a single, current source of data that would meet CBDC's operational and environmental needs for the workings and outfalls. Some of the more recent data for Lingan and Phalen mine water quality monitoring has been compiled by JWEL and CBDC and should be incorporated into the database.

7.2 Suggested Alternatives to Mine Water Quality Treatment

Given the number and widely distributed location of the outfalls, careful consideration should be given to the treatment approach used in dealing with these outfalls. Conventional treatment of mine waters usually involves alkali treatment that precipitates associated metals and typically generates considerable quantities of sludge. Because of high metal concentration, these sludges will probably require careful waste management. Conventional treatment at each outfall may not be practical, due to their scattered distribution and the poor quality of discharge water.

To augment CBDC's waste water management program, a number of suggestions are offered to assist CBDC in minimizing potential treatment costs associated with these mine waters. CBDC's current management program might be expanded to include: 1) identifying alternatives to conventional treatment of mine water discharges, 2) providing a screening for such potential alternatives, 3) assessing the role of conventional treatment technologies within the context of these alternatives, 4) developing a specific program(s) to further assess those alternatives that are considered to be most practical, and 5) consideration of remedial options that could eliminate and/or minimize both existing (e.g., sinkholes, foundation drainage, sewage discharge) and future (e.g., surface mining) infiltration pathways.

CBDC's management program could consider a broad range of possible alternatives to conventional water treatment, including:

i) Blockage of the outfalls. It may be feasible to plug some of the outfalls, to provide better control of mine discharge rate, quality, and location. In some cases, this could either improve the discharge water quality or possibly eliminate such discharge.

ii) Enhancing discharge through bedrock exfiltration. Inducing mine waters to migrate from the workings through adjacent bedrock units may be an option in some mine areas. This should improve the quality of mine water by forced mixing with better quality meteoric groundwater. However, this option should recognize the potential to impact groundwater quality in these aquifers.

iii) A program of selective mine dewatering by gravity drainage to other workings could eliminate some outfalls. Such an approach might serve to minimize the number of outfall locations, making centralized mine water treatment more practical.

iv) In-situ mine water mixing might improve the quality of mine water discharge. Such an approach might minimize surface treatment requirements and/or sludge management.

v) Artificial flooding of mine workings, to control development of acidic drainage through partially flooded workings should be considered.

vi) The potential for deep well injection of mine water should be considered.

A knowledge of existing mine conditions and an appreciation for the hydrogeological implications of potential alternatives, will be critical to considering such alternatives.

7.3 Assessment of Proposed No. 1B and No. 4 Dewatering

CBDC has proposed to depressurize Interconnection System 1, by pumping from the Nos. 1B and 4 Shafts. This pumping would reduce the hydraulic pressure and thereby reduce potential inflows into the No. 26 and Lingan mines. Such pumping would involve the discharge of large volumes of potentially poor quality mine water to the surface environment. Currently, these flows are estimated by CBDC to be in the order of 1,500 igpm from the No. 1B Shaft and 200 igpm from the No. 4 Shaft.

Concern has been raised about the quantity and quality of this effluent, and possible requirements for effluent treatment prior to surface discharge (e.g., the ocean). Recent pumping has demonstrated that the No. 1B Shaft waters would be low in pH (4.5), and exhibit elevated concentrations of sulfate (5,500 mg/L), iron (2,000 mg/L), manganese (66 mg/L), TDS, and COD (i.e., ammonia in the order of 22 mg/L). This experience has clearly demonstrated that discharge of such mine waters to either fresh water or sea water should result in considerable precipitation of iron, and sulfate minerals, that would be visibly evident as colour and turbidity changes. In addition, it is likely that dissolved oxygen concentrations in small streams would be significantly impacted, if they received such discharge.

The role of CBDC's mine water management program, including alternatives to conventional treatment, should be carefully considered within the context of any future dewatering. Any No. 1B Shaft pumping program should be designed to maximize the amount of data that could be used in expanding CBDC's strategy. For example, depending upon the role of conventional treatment, there may be the need for design-based information; some of this data could potentially be provided by the pumping program. Without a good design basis, a conventional treatment system also could be either inefficient or ineffective. CBDC's water management program might benefit from pilot testing of potential mine water disposal options during any future pumping of the shaft. Disposal of such discharge may provide an opportunity to assess alternative treatment options.

Because several mines contribute flow to the No. 1B Hydraulic System, it is important to determine which mines are contributing the most water and their water quality. An opportunity exists to address this issue early in any future dewatering of the Nos. 4 and 1B Shafts. A controlled pumping program would improve CBDC's current understanding of both mine connectivity and the quality of mine waters contributing to this discharge. This type of information would provide CBDC with valuable information for any expansion of their mine water management strategy.

Approval for temporary discharge of mine water may be needed prior to any future dewatering. Mitigation of discharge impacts to the near shore environment may be possible through use of options such as: 1) distribution of effluent over a larger area via flow diffusers; 2) pumping water to another unconnected mine; 3) mixing the effluent with sea water in sedimentation ponds prior to discharge; or 4) deep well injection of mine waters. Once the problem of dealing with the discharge water is solved, the following suggested actions during the initial stages of mine dewatering are recommended to focus the proposed dewatering program. These recommendations are presented to CBDC to provide a basis on which a specific dewatering program might be developed. The program should include involvement of an experienced hydrogeologist who can facilitate modifications to such testing while in progress and based on field results. General recommendations include:

i) Any dewatering done on the Nos. 1B and 4 Shafts might consist of the following program components: 1) pumping the water level in these shafts down in a series of steps (e.g., about 50 feet per step), after which the steady state flow rate and chemistry of the effluent would be determined; 2) monitoring the other mines, particularly No. 4, to determine hydraulic continuity with No. 1B; 3) while the No. 1B water level was held at steady state, the No. 4 Shaft would be pumped to below elevation +16 feet ASL (i.e., the assumed interconnection elevation) and the No. 1B flow rates and water chemistry would then be monitored to assess if either there is an improvement in water quality (e.g., pH increases), or a reduction in the discharge rate.

Similar work could be done on other workings. Consideration should be given to installation of groundwater monitoring wells in the area of the Nos. 1B and 4 Shafts. Water level data obtained from these monitoring wells during the testing would provide important information on meteoric groundwater response, bedrock during such pumping.

ii) Slow dewatering of the No. 1B Hydraulic System, by reducing the water level in distinct and controlled steps, is recommended to minimize the mixing of poor quality mine waters at depth.

iii) During dewatering, the mine water level and water levels at various depths should be closely monitored. This should provide the most reliable basis for estimating volume and inflow rate at various water levels. Monitoring of the other workings during such pumping, should provide an indication of the most likely inflow source.

iv) The water chemistry should be monitored during the dewatering work. It is expected that the water chemistry will change as the mine water level approaches the level of the No. 1B workings. Past monitoring, during the dewatering of the No. 1B Shaft, indicated pHs in the 6.2 to 6.5 range until the water level reached the bottom of the Shaft. This may have resulted from: 1) the more acidic waters associated with the unsaturated portions of the mine workings, particularly those portions above mean sea level; and/or 2) convection and mixing by high pumping rates that resulted in mixing of poor quality waters from the workings with better quality waters within the Shaft by high pumping rates.

v) Careful water level and quality monitoring of the No. 4 mine should be done during the pumping of this system. Because a large volume of workings are exposed above sea level, it is possible this mine will yield the poorest quality groundwater. Historical records suggest a flow rate of approximately 200 igpm; that can be assessed by the proposed testing.

vi) By carefully reducing the No. 1B Shaft water level in stages, this should help to minimize the volume of acidic drainage generated. However, this will not reduce the volume of high TDS, anoxic calcium sulfate water. By staging the dewatering process, it may be possible to generate a better overall effluent quality.

vii) An assessment of water quality in individual workings associated with the No. 1B Hydraulic System may lead to better control of effluent quantity and quality. For example, if the No 4. System is discharging poor quality water to the No. 1B System, as suspected by CBDC, pumping No. 4 below elevation +16 feet ASL may improve the water quality entering the No. 1B Shaft. A similar approach might be needed for other interconnection systems where surface discharge of poor quality mine waters is an issue. Effluent quality could be determined through a program similar to that proposed for No. 1B.

viii) A detailed dewatering pumping strategy should be developed based upon discussions with CBDC and a thorough understanding of CBDC's needs and objectives. A typical pumping strategy might generally include the following components:

1. Prior to pumping, measure static water levels on all workings of concern by establishing water level monitoring points on as many associated workings as possible. Analysis of the relative rates of drawdown and time lags between mine responses can provide additional insight on mine interactions.

   Prior to pumping, profile the mine shaft to be pumped for pH, temperature, dissolved oxygen and general water chemistry. Subsequent profiles of the shaft during pumping may provide an indication of chemical stratification, mixing and water source.

2. Initiate pumping at a rate that results in a moderate rate of drawdown (i.e., a 5 to 10 feet per day). Maintain a continuous record of water level and flow rates.

   Periodically monitor the in-situ dissolved oxygen, pH, temperature, redox potential and electrical conductance. This will provide additional data for interpretation of the mine water quality and possible design of water treatment options.

3. Pump the shaft down in discrete increments (e.g., 50 feet) and hold the water level constant for a few days. The resulting steady state flow rate should be representative of the mine water inflow for that increment.

4. After the No. 1B Shaft water level has stabilized, consider pumping in the No. 4 Shaft in a similar manner, and reduce the water level to below elevation +16 feet ASL. It is suggested that this be done after the first drawdown step in the dewatering of No. 1B.

5. If undertaken, monitor the effect of Item 4 on the flow rate and chemistry of the No. 1B discharge. This may require adjustment of the discharge rate to hold the water level in No. 1B constant, and several days of pumping lag time, to detect possible modifications in discharge water chemistry.

6. Pump the water down an additional increment and repeat the above process.

7. Reduce the rate of drawdown as the water level approaches the top of the No. 1B workings (i.e., elevation - 565 BSL). Profile pH, temperature, etc. in the shaft, and closely monitor pH at this point to determine the presence of acidic water.

#26 "break-point"?

8. Monitor both the flow rate at the Lingan 2E break and the water levels on the other workings associated with the No. 1B System during the testing. The flow rate should decline as head in the No. 1B Shaft decreases and may cease when the No. 1B drawdown reaches the level of the assumed interconnection.

9. Adjust the water level in the No. 1B Shaft to the desired elevation or to an elevation that optimizes the discharge water pH. This should be representative of the No. 1B System's flow rate and quality at that level.

10. Collect discharge water samples on a regular basis, based on field indicators, during the dewatering period. Consider analyzing these samples for major ions, field filtered metals, and other necessary parameters baseline sample from the No. 4 for example should be collected. The initial monitoring frequency may be adjusted based on field indicator parameters (e.g., pH, conductivity, temperature).

    Sampling for environmental isotopes may help assess the degree of interaction between various mines and meteoric groundwater infiltration.

11. Monitoring discharge water temperature can provide an indication of mine water sources, and their possible interaction with either the shallow groundwater or surface waters.

8.0 REFERENCES

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9.0 CONCLUDING STATEMENT

We respectfully submit this report of our findings.

Yours very truly,

JACQUES WHITFORD ENVIRONMENT LIMITED

John A. Amirault, M.Eng., P.Eng.
Vice-President Mining

JAA/kw

APPENDIX A

CBDC Water Study
Map Inventory

CBDC Drawing #	JWA Assigned Drawing Number	Seam	Contents	Scale	Reference To Drawing 8728
Unknown	1	Phalen	Dom. 1A, 1B, 2 & Lower Portion of 4	1" = 400'	4
Unknown	2	Phalen	Dom. 2 & 1B Bottom Portions, 15, 16, 18	1" = 400'	4
Unknown	3	Harbour	Dom. 12 & 14, Partial 17	1" = 400'	3
Unknown	4	Harbour	Dom. 17 & Dom 18	1" = 400'	3
Unknown	5	Harbour	Princess Mine	1" = 400'	-
328-T	6	Harbour	Dom. 9 & 20	1" = 400'	3
Unknown	7	Harbour	Lower Portions of Dom. 12 & 14	1" = 400'	3
177-T, Cab. 42, 1925	8	Emery	Plan of Emery Seam Workings Dom. 10, 11 & 24	1" = 400'	5
-	9	Phalen	Dom. 3, 4, 5, 6 Top 1A, 1B, 2	1" = 400' (2 copies)	4
Jan. 1919	10	Hub	Underground Workings Hub Seam/Dom. 7	1" = 400'	2
21-T, Cab. 38	11	Gardner	Dom. 25	1" = 400'	2
-	12	Harbour	Lingan	1" = 600'	3
93.04.03	13	Harbour	Lingan Colliery/Quarterly Update	1" = 500'	3
-	14	Harbour	Dom. 26	1" = 400'	3
65-7, 1978	15	Harbour	Harbour Seam Workings	1" = 1000'	3
-	16	Harbour	Dom. 8 (eight map mosaic)	1" = 100'	3
1977	17	All	Cape Breton Coal Field Map	1" = 1/2 mile (2 copies)	1,2,3,4,5,6

CBDC Drawing #	JWA Assigned Drawing Number	Seam	Contents	Scale	Reference To Drawing 8728
-	18	Phalen	Dom. 4 subsidence & crushed zones	1" = 200'	4
-	19	Harbour	Lingan "A" Section	1" = 100'	3
249-R, Cab. 75, 1946	20	Phalen	Dom. #3 Bootlegs	1" = 50'	4
-	21	Harbour	Lingan (1983)	1" = 200'	4
-	22	Harbour	Dom. 26	1" = 200'	4
-	23	All	Sydney Coal Field Plan - 1954	1" = 1/2 mile	4
-	24	Phalen	Dom. 4	1" = 1000'	3
-	25	Harbour	Plan of Dom. 26	1" = 400'	4
93.01.04	26	Phalen	Phalen Colliery/Quarterly Update	1:5000	4

APPENDIX B

Title: Hydrologic Characterization and In-situ Neutralization of Acidic Mine Pools in Abandoned Underground Coal Mines

Author: Aljoe, W.W, Mining Engineer, U.S. Bureau of Mines, Pittsburgh, PA
Hawkins, J.W., Hydrologist, U.S. Bureau of Mines, Pittsburgh, PA

Abstract: The feasibility of abating acidic discharges from an abandoned underground coal mine by in-situ neutralization within the mine pool has been investigated by the U.S. Bureau of Mines. In order to develop and implement an alkaline injection plan, a hydrologic study of an acid mine pool was performed at a site within the Keystone State Park, near Latrobe, PA. Maps of the mine entries and mine floor elevations, mine discharge flow rates, precipitation records, monitoring well water levels and water quality analyses were used to characterize the mine pool flow system. The mine pool flow is believed to occur mainly through the open entries, with negligible lateral flow through the overlying strata and coal pillars. Chemical tracer tests indicated that flow through mine entries is probably not uniform through all sections of the mine and that preferred flow paths exist.

Title: Determining the Capacity for Metal Retention in Man-Made Wetlands Constructed for Treatment of Coal Mine Drainage

Author: Weider, R.K., Villanova University, PA

Abstract: Within the past several years, there has been a tremendous increase in the use of man-made wetland systems for the treatment of acid coal mine drainage. However, quantitative estimates of the long-term capacity of a wetland for metal retention are lacking. Although it has been suggested that man-made wetlands may offer a low-cost approach to mine drainage treatment, cost/benefit analyses cannot be carried out without being able to reliably estimate long-term capacity for metal retention in a man-made wetland system given a particular volume and chemistry of mine drainage water. Until long-term capacity for metal retention in man-made wetlands can be reliably predicted, the environmental and economic potential of wetland treatment of coal mine drainage remains difficult to assess.

APPENDIX C

Methodology for Calculating the Estimated Void Volumes for each Colliery within the study area (Refer to following tables).

1. Using available CBDC colliery maps (scale 1" = 400' and 1" = 200') outlining the collieries, the areas within the 100 foot coal seam contour intervals and the corresponding colliery outlines were planimetered. The **Measured Areas** for all collieries were determined to a depth of 1000 feet with the exception of the Emery seam collieries which were limited to 500 feet.

2. The **Average Dip** was calculated as a percent ratio of the 100 foot contour intervals over the horizontal **Lateral Distance** perpendicular to the seam contours (as averaged over the length of the colliery outline within each contour interval).

3. The average dip was applied against the planimetered area to provide a **Corrected Area.**

4. The corrected area was multiplied by the reported **Average Coal Thickness** for the given colliery.

5. Finally the **Average Void Ratio** which includes the anticipated convergence depending upon mining method used was applied to produce the **Estimated Void Volume.** These ratios were as follows:

   › Room And Pillar (R&P): 42-47% Extraction x 90% Convergence; **42% used**

   › Pillar Drawing (R&P Draw.): 100% Extraction x 30% Convergence; **30% used**

   › Longwall: 100% Extraction x 30% Convergence; **30% used**

COLLIERY: Dominion No. 1A and 1B (Phalen Seam)

Elevation Interval (ft)	Lateral Distance (ft)	Measured Area (ft2)	Average Dip (%)	Corrected Area (ft2)	Ave. Coal Thickness (ft)	Mining Method			Average Void Ratio (%)	Estimated Void Vol. (ft3)
						R & P (%)	R & P Draw (%)	Longwall (%)		
15										
0	270	355,000	5.6	378,566	7.0	100			42.0	1,112,985
-100	1,800	6,300,000	5.6	6,309,715	7.0	98	2		41.8	18,444,558
-200	1,400	8,486,000	7.1	8,507,620	7.0	90	10		40.8	24,297,764
-300	1,100	18,381,000	9.1	18,456,798	7.0	90	10		40.8	52,712,616
-400	900	33,576,000	11.1	33,782,623	7.0	95	5		41.4	97,902,043
-500	900	31,320,000	11.1	31,512,740	7.0	95	5		41.4	91,323,921
-600	900	28,305,000	11.1	28,479,186	7.0	100			42.0	83,728,808
-700	800	15,427,000	12.5	15,547,056	7.0	100			42.0	45,708,345
-800	600	13,512,000	16.7	13,698,381	7.0	100			42.0	40,273,241
-900	600	10,217,000	16.7	10,357,931	7.0	100			42.0	30,452,317
-1000	500	9,104,000	20.0	9,284,295	7.0	100			42.0	27,295,827
TOTAL:										513,252,424

COLLIERY: Dominion No. 2 (Phalen Seam)

Elevation Interval (ft)	Lateral Distance (ft)	Measured Area (ft2)	Average Dip (%)	Corrected Area (ft2)	Ave. Coal Thickness (ft)	Mining Method			Average Void Ratio (%)	Estimated Void Vol. (ft3)
						R & P (%)	R & P Draw (%)	Longwall (%)		
-500										
-600	1,500	8,145,000	6.7	8,163,080	7.2	70	30		38.4	22,569,283
-700	1,550	25,917,000	6.5	25,970,882	7.2	85	15		40.2	75,170,120
-800	1,900	26,810,000	5.3	26,847,107	7.2	98	2		41.8	80,721,734
-900	1,525	24,540,000	6.6	24,592,703	7.2	96	4		41.5	73,518,411
-1000	1,450	20,990,000	6.9	21,039,858	7.2	100			42.0	63,624,529
TOTAL:										315,604,078

COLLIERY: Dominion No. 3 (Phalen Seam)

Elevation Interval (ft)	Lateral Distance (ft)	Measured Area (ft2)	Average Dip (%)	Corrected Area (ft2)	Ave. Coal Thickness (ft)	Mining Method			Average Void Ratio (%)	Estimated Void Vol. (ft3)
						R & P (%)	R & P Draw (%)	Longwall (%)		
30										
0	510	500,000	5.9	509,521	7.5	60	40		37.2	1,421,564
-100	1,700	3,700,000	5.9	3,706,396	7.5	40	60		34.8	9,673,693
-200	1,450	3,600,000	6.9	3,608,551	7.5	40	60		34.8	9,418,318
-300	1,350	3,300,000	7.4	3,309,041	7.5	20	80		32.4	8,040,970
-400	1,300	3,200,000	7.7	3,209,453	7.5	15	85		31.8	7,654,547
-500	1,450	3,800,000	6.9	3,809,026	7.5	40	60		34.8	9,941,558
-600	1,500	1,000,000	6.7	1,002,220	7.5	45	55		35.4	2,660,893
TOTAL:										48,811,543

COLLIERY: **Dominion No. 4** (Phalen Seam)

Elevation Interval (ft)	Lateral Distance (ft)	Measured Area (ft2)	Average Dip (%)	Corrected Area (ft2)	Ave. Coal Thickness (ft)	Mining Method			Average Void Ratio (%)	Estimated Void Vol. (ft3)
						R & P (%)	R & P Draw (%)	Longwall (%)		
45										
0	475	1,637,000	9.5	1,672,884	6.6	70	30		38.4	4,239,756
−100	1,050	10,600,000	9.5	10,647,964	6.6	55	45		36.6	25,721,222
−200	1,150	12,500,000	8.7	12,547,170	6.6	60	40		37.2	30,805,812
−300	1,150	15,500,000	8.7	15,558,491	6.6	45	55		35.4	36,350,858
−400	1,150	16,800,000	8.7	16,863,396	6.6	50	50		36.0	40,067,430
−500	1,150	18,500,000	8.7	18,569,812	6.6	85	15		40.2	49,269,424
−600	1,200	13,660,000	8.3	13,707,348	6.6	98	2		41.8	37,779,646
−700	1,150	10,500,000	8.7	10,539,623	6.6	100			42.0	29,215,834
−800	1,050	10,200,000	9.5	10,246,154	6.6	100			42.0	28,402,339
−900	1,100	10,900,000	9.1	10,944,949	6.6	100			42.0	30,339,398
−1000	1,000	10,400,000	10.0	10,451,871	6.6	100			42.0	28,972,585
TOTAL:										341,164,304

COLLIERY: **Dominion No. 5** (Phalen Seam)

Elevation Interval (ft)	Lateral Distance (ft)	Measured Area (ft2)	Average Dip (%)	Corrected Area (ft2)	Ave. Coal Thickness (ft)	Mining Method			Average Void Ratio (%)	Estimated Void Vol. (ft3)
						R & P (%)	R & P Draw (%)	Longwall (%)		
115										
0	2415	12,000,000	4.8	12,010,283	7.7	55	45		36.6	33,847,380
−100	2,100	20,000,000	4.8	20,022,663	7.7	50	50		36.0	55,502,822
−200	1,700	10,600,000	5.9	10,618,323	7.7	20	80		32.4	26,490,593
−300	1,550	6,700,000	6.5	6,713,929	7.7		100		30.0	15,509,177
−400	1,500	5,600,000	6.7	5,612,431	7.7		100		30.0	12,964,715
−500	1,450	4,800,000	6.9	4,811,401	7.7	10	90		31.2	11,558,911
−600	1,350	1,600,000	7.4	1,604,384	7.7	15	85		31.8	3,928,494
TOTAL:										159,802,091

COLLIERY: **Dominion No. 6** (Phalen Seam)

Elevation Interval (ft)	Lateral Distance (ft)	Measured Area (ft2)	Average Dip (%)	Corrected Area (ft2)	Ave. Coal Thickness (ft)	Mining Method			Average Void Ratio (%)	Estimated Void Vol. (ft3)
						R & P (%)	R & P Draw (%)	Longwall (%)		
30										
0	220	535,000	13.6	587,675	6.5	100			42.0	1,604,354
−100	720	3,365,000	13.9	3,397,301	6.5	95	5		41.4	9,142,136
−200	750	4,600,000	13.3	4,640,709	6.5	98	2		41.8	12,596,740
−300	820	5,600,000	12.2	5,641,488	6.5	100			42.0	15,401,263
−400	820	7,200,000	12.2	7,253,342	6.5	100			42.0	19,801,624
−500	800	6,300,000	12.5	6,349,028	6.5	100			42.0	17,332,846
−600	800	6,500,000	12.5	6,550,584	6.5	100			42.0	17,883,095
−700	800	3,400,000	12.5	3,426,460	6.5	100			42.0	9,354,235
−800	750	1,900,000	13.3	1,916,814	6.5	100			42.0	5,232,904
−900	800	262,000	12.5	264,039	6.5	100			42.0	720,826
−1000	700	172,000	14.3	173,746	6.5	100			42.0	474,327
TOTAL:										109,544,349

COLLIERY: **Dominion No. 7** (Hub Seam)

Elevation Interval (ft)	Lateral Distance (ft)	Measured Area (ft2)	Average Dip (%)	Corrected Area (ft2)	Ave. Coal Thickness (ft)	Mining Method R & P (%)	R & P Draw (%)	Longwall (%)	Average Void Ratio (%)	Estimated Void Vol. (ft3)
15										
0	290	980,000	5.2	1,036,628	6.5	100			42.0	2,829,994
−100	1,900	4,779,000	5.3	4,785,615	6.5	70	30		38.4	11,944,894
−200	1,800	491,000	5.6	491,757	6.5	100			42.0	1,342,497
−300	1,400	5,362,000	7.1	5,375,661	6.5	100			42.0	14,675,555
−400	1,800	6,036,000	5.6	6,045,308	6.5	100			42.0	16,503,690
−500	1,800	5,711,000	5.6	5,719,806	6.5	100			42.0	15,615,072
−600	1,800	1,788,000	5.6	1,790,757	6.5	100			42.0	4,888,767
TOTAL:										67,800,469

COLLIERY: **Dominion No. 8** (Harbour Seam)

Elevation Interval (ft)	Lateral Distance (ft)	Measured Area (ft2)	Average Dip (%)	Corrected Area (ft2)	Ave. Coal Thickness (ft)	Mining Method R & P (%)	R & P Draw (%)	Longwall (%)	Average Void Ratio (%)	Estimated Void Vol. (ft3)
70										
0	2,100	5,907,000	3.3	5,913,693	5.3	70	30		38.4	12,035,549
−100	2,000	19,280,000	5.0	19,304,085	5.3	70	30		38.4	39,287,674
−200	2,000	11,421,000	5.0	11,435,267	5.3	70	30		38.4	23,273,056
−300	1,900	5,175,000	5.3	5,182,163	5.3	70	30		38.4	10,546,737
TOTAL:										85,143,016

COLLIERY: **Dominion No. 9** (Harbour Seam)

Elevation Interval (ft)	Lateral Distance (ft)	Measured Area (ft2)	Average Dip (%)	Corrected Area (ft2)	Ave. Coal Thickness (ft)	Mining Method R & P (%)	R & P Draw (%)	Longwall (%)	Average Void Ratio (%)	Estimated Void Vol. (ft3)
−200										
−300	2,200	16,935,000	4.5	16,952,486	6.5	70	30		38.4	42,313,405
−400	1,600	25,311,000	6.3	25,360,387	6.5	75	25		39.0	64,288,582
−500	1,600	13,646,000	6.3	13,672,626	6.5	95	5		41.4	36,793,038
−600	1,500	9,340,000	6.7	9,360,733	6.5	100			42.0	25,554,800
−700	1,400	2,540,000	7.1	2,546,471	6.5	100			42.0	6,951,867
TOTAL:										175,901,691

COLLIERY: **Dominion No. 10** (Emery Seam)

Elevation Interval (ft)	Lateral Distance (ft)	Measured Area (ft2)	Average Dip (%)	Corrected Area (ft2)	Ave. Coal Thickness (ft)	Mining Method			Average Void Ratio (%)	Estimated Void Vol. (ft3)
						R & P (%)	R & P Draw (%)	Longwall (%)		
125										
0	1,870	18,700,000	6.7	18,726,719	3.5	70	30		38.4	25,168,710
−100	1,500	13,836,000	6.7	13,866,713	3.5	65	35		37.8	18,345,661
−200	1,500	13,351,000	6.7	13,380,636	3.5	55	45		36.6	17,140,595
−300	1,600	15,182,000	6.3	15,211,623	3.5	60	40		37.2	19,805,534
−400	1,600	11,657,000	6.3	11,679,745	3.5	65	35		37.8	15,452,303
−500	1,600	2,998,000	6.3	3,003,850	3.5	80	20		39.6	4,163,336
TOTAL:										100,076,138

COLLIERY: **Dominion No. 11** (Emery Seam)

Elevation Interval (ft)	Lateral Distance (ft)	Measured Area (ft2)	Average Dip (%)	Corrected Area (ft2)	Ave. Coal Thickness (ft)	Mining Method			Average Void Ratio (%)	Estimated Void Vol. (ft3)
						R & P (%)	R & P Draw (%)	Longwall (%)		
80										
0	960	5,580,000	8.3	5,610,192	3.5	100			42.0	8,246,982
−100	1,200	9,420,000	8.3	9,452,652	3.5	95	5		41.4	13,696,892
−200	1,100	9,022,000	9.1	9,059,204	3.5	90	10		40.8	12,936,544
−300	1,200	9,582,000	8.3	9,615,213	3.5	90	10		40.8	13,730,525
−400	1,200	9,912,000	8.3	9,946,357	3.5	80	20		39.6	13,785,651
−500	1,200	9,257,000	8.3	9,289,087	3.5	85	15		40.2	13,069,745
TOTAL:										75,466,339

COLLIERY: **Dominion No. 12** (Harbour Seam)

Elevation Interval (ft)	Lateral Distance (ft)	Measured Area (ft2)	Average Dip (%)	Corrected Area (ft2)	Ave. Coal Thickness (ft)	Mining Method			Average Void Ratio (%)	Estimated Void Vol. (ft3)
						R & P (%)	R & P Draw (%)	Longwall (%)		
0										
−100	450	2,520,000	22.2	2,581,472	5.0	100			42.0	5,421,092
−200	475	3,050,000	21.1	3,116,857	5.0	80	20		39.6	6,171,377
−300	475	3,100,000	21.1	3,167,953	5.0	65	35		37.8	5,987,432
−400	525	3,540,000	19.0	3,603,646	5.0	60	40		37.2	6,702,781
−500	550	3,760,000	18.2	3,821,643	5.0	70	30		38.4	7,337,555
−600	600	4,220,000	16.7	4,278,210	5.0	100			42.0	8,984,240
−700	625	4,525,000	16.0	4,582,554	5.0	100			42.0	9,623,363
−800	550	3,965,000	18.2	4,030,004	5.0	85	15		40.2	8,100,309
−900	575	4,135,000	17.4	4,197,067	5.0	85	15		40.2	8,436,105
−1000	475	5,320,000	21.1	5,436,617	5.0	85	15		40.2	10,927,599
TOTAL:										77,691,854

COLLIERY: Dominion No. 14 (Harbour Seam)

Elevation Interval (ft)	Lateral Distance (ft)	Measured Area (ft2)	Average Dip (%)	Corrected Area (ft2)	Ave. Coal Thickness (ft)	Mining Method			Average Void Ratio (%)	Estimated Void Vol. (ft3)
						R & P (%)	R & P Draw (%)	Longwall (%)		
0										
-100	450	2,025,000	22.2	2,074,398	5.0	100			42.0	4,356,235
-200	450	2,500,000	22.2	2,560,985	5.0	100			42.0	5,378,068
-300	450	2,660,000	22.2	2,724,888	5.0	100			42.0	5,722,264
-400	550	3,310,000	18.2	3,364,266	5.0	100			42.0	7,064,958
-500	575	3,690,000	17.4	3,745,388	5.0	100			42.0	7,865,314
-600	650	4,580,000	15.4	4,633,884	5.0	100			42.0	9,731,157
-700	700	5,145,000	14.3	5,197,235	5.0	100			42.0	10,914,193
-800	800	6,160,000	12.5	6,207,938	5.0	30	70		33.6	10,429,337
-900	700	5,320,000	14.3	5,374,012	5.0	45	55		35.4	9,512,000
-1000	700	3,850,000	14.3	3,889,087	5.0	50	50		36.0	7,000,357
TOTAL:										77,973,883

COLLIERY: Dominion No. 15 (Phalen Seam)

Elevation Interval (ft)	Lateral Distance (ft)	Measured Area (ft2)	Average Dip (%)	Corrected Area (ft2)	Ave. Coal Thickness (ft)	Mining Method			Average Void Ratio (%)	Estimated Void Vol. (ft3)
						R & P (%)	R & P Draw (%)	Longwall (%)		
75										
0	230	75,000	32.6	81,782	5.5	100			42.0	188,917
-100	310	1,391,000	32.3	1,461,582	5.5	100			42.0	3,376,254
-200	280	1,719,000	35.7	1,825,341	5.5	50	50		36.0	3,614,175
-300	300	1,964,000	33.3	2,070,238	5.5	80	20		39.6	4,508,978
-400	300	1,977,000	33.3	2,083,941	5.5	70	30		38.4	4,401,283
-500	300	2,001,000	33.3	2,109,239	5.5	90	10		40.8	4,733,133
-600	340	2,509,000	29.4	2,615,270	5.5	70	30		38.4	5,523,451
-700	420	2,772,000	23.8	2,849,488	5.5	90	10		40.8	6,394,252
-800	500	2,872,000	20.0	2,928,877	5.5	85	15		40.2	6,475,747
-900	560	2,594,000	17.9	2,635,034	5.5	95	5		41.4	5,999,972
-1000	600	104,200	16.7	105,637	5.5	100			42.0	244,022
TOTAL:										45,460,183

COLLIERY: **Dominion No. 16** (Phalen Seam)

Elevation Interval (ft)	Lateral Distance (ft)	Measured Area (ft2)	Average Dip (%)	Corrected Area (ft2)	Ave. Coal Thickness (ft)	Mining Method			Average Void Ratio (%)	Estimated Void Vol. (ft3)
						R & P (%)	R & P Draw (%)	Longwall (%)		
60										
0	215	50,000	27.9	55,144	5.2	100			42.0	120,434
−100	360	1,533,000	27.8	1,591,045	5.2	100			42.0	3,474,841
−200	380	2,787,500	26.3	2,882,405	5.2	50	50		36.0	5,395,861
−300	380	2,993,000	26.3	3,094,901	5.2	50	50		36.0	5,793,655
−400	360	3,100,000	27.8	3,217,377	5.2	70	30		38.4	6,424,458
−500	420	3,464,600	23.8	3,561,449	5.2	50	50		36.0	6,667,033
−600	400	3,501,000	25.0	3,608,748	5.2	40	60		34.8	6,530,391
−700	440	3,732,000	22.7	3,827,171	5.2	50	50		36.0	7,164,464
−800	500	4,124,000	20.0	4,205,671	5.2	50	50		36.0	7,873,017
−900	560	4,466,000	17.9	4,536,647	5.2	40	60		34.8	8,209,516
−1000	600	5,183,000	16.7	5,254,493	5.2	50	50		36.0	9,836,411
TOTAL:										67,490,080

COLLIERY: **Dominion No. 17** (Harbour Seam)

Elevation Interval (ft)	Lateral Distance (ft)	Measured Area (ft2)	Average Dip (%)	Corrected Area (ft2)	Ave. Coal Thickness (ft)	Mining Method			Average Void Ratio (%)	Estimated Void Vol. (ft3)
						R & P (%)	R & P Draw (%)	Longwall (%)		
80										
0	160	425,000	50.0	501,180	6.5	100			42.0	1,368,222
−100	200	987,000	50.0	1,103,500	6.5	100			42.0	3,012,554
−200	230	1,126,000	43.5	1,227,823	6.5	100			42.0	3,351,958
−300	200	2,254,000	50.0	2,520,049	6.5	100			42.0	6,879,733
−400	200	2,405,000	50.0	2,688,872	6.5	100			42.0	7,340,620
−500	200	1,118,000	50.0	1,249,962	6.5	100			42.0	3,412,396
−600	175	727,000	57.1	837,323	6.5	100			42.0	2,285,892
TOTAL:										27,651,374

COLLIERY: **Dominion No. 18** (Phalen Seam)

Elevation Interval (ft)	Lateral Distance (ft)	Measured Area (ft2)	Average Dip (%)	Corrected Area (ft2)	Ave. Coal Thickness (ft)	Mining Method			Average Void Ratio (%)	Estimated Void Vol. (ft3)
						R & P (%)	R & P Draw (%)	Longwall (%)		
100										
0	360	374,200	27.8	388,368	5.2	100			42.0	848,197
−100	360	374,200	27.8	388,368	5.2	100			42.0	848,197
−200	380	603,000	26.3	623,530	5.2	100			42.0	1,361,790
−300	340	1,012,000	29.4	1,054,864	5.2	100			42.0	2,303,823
−400	300	1,656,000	33.3	1,745,577	5.2	100			42.0	3,812,341
−500	310	1,433,900	32.3	1,506,659	5.2	100			42.0	3,290,542
−600	310	1,431,000	32.3	1,503,611	5.2	100			42.0	3,283,887
−700	300	1,391,000	33.3	1,466,243	5.2	100			42.0	3,202,274
−800	300	1,348,900	33.3	1,421,865	5.2	100			42.0	3,105,354
−900	300	1,280,000	33.3	1,349,238	5.2	100			42.0	2,946,737
−1000	300	1,071,000	33.3	1,128,933	5.2	100			42.0	2,465,590
TOTAL:										27,468,732

COLLIERY: **Dominion No. 18** (Harbour Seam)

Elevation Interval (ft)	Lateral Distance (ft)	Measured Area (ft2)	Average Dip (%)	Corrected Area (ft2)	Ave. Coal Thickness (ft)	Mining Method			Average Void Ratio (%)	Estimated Void Vol. (ft3)
						R & P (%)	R & P Draw (%)	Longwall (%)		
-600										
-700	200	1,302,000	50.0	1,455,680	6.2			100	30.0	2,707,565
-800	200	3,271,000	50.0	3,657,089	6.2			100	30.0	6,802,186
-900	400	7,109,000	25.0	7,327,789	6.2			100	30.0	13,629,688
-1000	700	8,776,000	14.3	8,865,099	6.2			100	30.0	16,489,084
TOTAL:										39,628,523

COLLIERY: **Dominion No. 20** (Harbour Seam)

Elevation Interval (ft)	Lateral Distance (ft)	Measured Area (ft2)	Average Dip (%)	Corrected Area (ft2)	Ave. Coal Thickness (ft)	Mining Method			Average Void Ratio (%)	Estimated Void Vol. (ft3)
						R & P (%)	R & P Draw (%)	Longwall (%)		
0										
-100										
-200	500	305,000	20.0	311,040	5.2	100			42.0	679,312
-300	700	3,293,000	14.3	3,326,432	5.2	100			42.0	7,264,928
-400	750	7,235,000	13.3	7,299,028	5.2	100			42.0	15,941,077
-500	750	11,149,000	13.3	11,247,666	5.2	100			42.0	24,564,902
-600	900	13,543,000	11.1	13,626,342	5.2	100			42.0	29,759,932
-700	925	17,433,000	10.8	17,534,577	5.2	100			42.0	38,295,516
-800	1,050	22,804,000	9.5	22,907,186	5.2	100			42.0	50,029,294
-900	1,050	19,426,000	9.5	19,513,901	5.2	100			42.0	42,618,360
-1000	1,100	15,138,000	9.1	15,200,425	5.2	100			42.0	33,197,728
TOTAL:										242,351,048

COLLIERY: **Dominion No. 24** (Emery Seam)

Elevation Interval (ft)	Lateral Distance (ft)	Measured Area (ft2)	Average Dip (%)	Corrected Area (ft2)	Ave. Coal Thickness (ft)	Mining Method			Average Void Ratio (%)	Estimated Void Vol. (ft3)
						R & P (%)	R & P Draw (%)	Longwall (%)		
45										
0	450	1,150,000	10.0	1,178,053	4.0	100			42.0	1,979,129
-100	1,000	3,789,000	10.0	3,807,898	4.0	100			42.0	6,397,268
-200	1,000	4,675,000	10.0	4,698,317	4.0	100			42.0	7,893,172
-300	1,000	17,104,000	10.0	17,189,307	4.0	100			42.0	28,878,036
-400	1,200	13,833,000	8.3	13,880,948	4.0	100			42.0	23,319,993
-500	1,200	13,332,000	8.3	13,378,212	4.0	100			42.0	22,475,395
TOTAL:										90,942,994

COLLIERY: **Dominion No. 25** (Gardiner Seam)

Elevation Interval (ft)	Lateral Distance (ft)	Measured Area (ft2)	Average Dip (%)	Corrected Area (ft2)	Ave. Coal Thickness (ft)	Mining Method R & P (%)	R & P Draw (%)	Longwall (%)	Average Void Ratio (%)	Estimated Void Vol. (ft3)
100										
0	1,500	8,327,000	6.7	8,345,484	4.0	100			42.0	14,020,413
−100	1,500	12,562,000	6.7	12,589,885	4.0	100			42.0	21,151,006
−200	1,600	6,914,000	6.3	6,927,491	4.0	100			42.0	11,638,184
−300	1,700	998,000	5.9	999,725	4.0	100			42.0	1,679,538
TOTAL:										48,489,142

COLLIERY: **Dominion No. 26** (Harbour Seam)

Elevation Interval (ft)	Lateral Distance (ft)	Measured Area (ft2)	Average Dip (%)	Corrected Area (ft2)	Ave. Coal Thickness (ft)	Mining Method R & P (%)	R & P Draw (%)	Longwall (%)	Average Void Ratio (%)	Estimated Void Vol. (ft3)
−300										
−400	400	4,293,000	25.0	4,425,123	6.0	100			42.0	11,151,310
−500	400	7,862,000	25.0	8,103,964	6.0	100			42.0	20,421,990
−600	400	6,024,000	25.0	6,209,397	6.0	100			42.0	15,647,681
−700	400	7,186,000	25.0	7,407,159	6.0	100			42.0	18,666,041
−800	380	7,049,500	26.3	7,289,511	6.0	100			42.0	18,369,566
−900	380	6,417,000	26.3	6,635,476	6.0	100			42.0	16,721,400
−1000	380	4,368,000	26.3	4,516,715	6.0	100			42.0	11,382,122
TOTAL:										112,360,110

COLLIERY: **Sterling and Old Harbour** (Harbour Seam)

Elevation Interval (ft)	Lateral Distance (ft)	Measured Area (ft2)	Average Dip (%)	Corrected Area (ft2)	Ave. Coal Thickness (ft)	Mining Method R & P (%)	R & P Draw (%)	Longwall (%)	Average Void Ratio (%)	Estimated Void Vol. (ft3)
0										
−100	1,600	4,090,000	6.3	4,097,980	5.3	50	50		36.0	7,818,947
−200	1,500	6,013,000	6.7	6,026,347	5.3	50	50		36.0	11,498,271
−300	1,400	606,000	7.1	607,544	5.3	50	50		36.0	1,159,194
TOTAL:										20,476,411

COLLIERY: **Lingan** (Harbour Seam)

Elevation Interval (ft)	Lateral Distance (ft)	Measured Area (ft2)	Average Dip (%)	Corrected Area (ft2)	Ave. Coal Thickness (ft)	Mining Method			Average Void Ratio (%)	Estimated Void Vol. (ft3)
						R & P (%)	Arched Tun. (%)	Longwall (%)		
100										
0	450	81,100	22.2	83,078	6.5		100		30.0	162,003
-100	400	46,400	25.0	47,828	6.5		100		30.0	93,265
-200	375	52,300	26.7	54,128	6.5		100		30.0	105,549
-300	375	65,400	26.7	67,685	6.5		100		30.0	131,987
-400	460	1,247,000	21.7	1,276,126	6.5	80	20		39.6	3,284,748
-500	475	2,380,000	21.1	2,432,171	6.5	90	10		40.8	6,450,116
-600	450	1,683,000	22.2	1,724,055	6.5	90	10		40.8	4,572,193
-700	530	2,350,000	18.9	2,391,464	6.5	90	10		40.8	6,342,163
-800	530	1,203,000	18.9	1,224,226	6.5	90	10		40.8	3,246,647
-900	500	2,625,000	20.0	2,676,985	6.5			100	30.0	5,220,121
-1000	600	1,972,000	16.7	1,999,201	6.5			100	30.0	3,898,443
-1100	600	3,342,000	16.7	3,388,099	6.5			100	30.0	6,606,793
-1200	750	2,463,000	13.3	2,484,797	6.5			100	30.0	4,845,354
-1300	780	2,738,000	12.8	2,760,410	6.5			100	30.0	5,382,799
-1400	700	6,358,000	14.3	6,422,550	6.5			100	30.0	12,523,972
-1500	780	7,621,000	12.8	7,683,376	6.5			100	30.0	14,982,584
-1600	900	6,741,000	11.1	6,782,483	6.5			100	30.0	13,225,843
-1700	850	7,209,000	11.8	7,258,718	6.5			100	30.0	14,154,500
-1800	900	7,942,000	11.1	7,990,874	6.5			100	30.0	15,582,205
-1900	850	7,063,200	11.8	7,111,912	6.5			100	30.0	13,868,229
-2000	750	6,293,000	13.3	6,348,691	6.5			100	30.0	12,379,948
-2100	700	5,573,000	14.3	5,629,580	6.5			100	30.0	10,977,681
-2200	600	3,385,000	16.7	3,431,692	6.5			100	30.0	6,691,799
-2300	550	4,945,000	18.2	5,026,071	6.5			100	30.0	9,800,838
-2400	500	1,692,000	20.0	1,725,508	6.5			100	30.0	3,364,741
-2500	500	35,000	20.0	35,693	6.5			100	30.0	69,602
TOTAL:										177,964,122

COLLIERY: **Phalen** (Phalen Seam)

Elevation Interval (ft)	Lateral Distance (ft)	Measured Area (ft2)	Average Dip (%)	Corrected Area (ft2)	Ave. Coal Thickness (ft)	Mining Method			Average Void Ratio (%)	Estimated Void Vol. (ft3)
						R & P (%)	Arched Tun. (%)	Longwall (%)		
100										
0	375	24,210	26.7	25,056	7.2		100		30.0	54,121
-100	375	32,000	26.7	33,118	7.2		100		30.0	71,535
-200	375	32,000	26.7	33,118	7.2		100		30.0	71,535
-300	375	32,000	26.7	33,118	7.2		100		30.0	71,535
-400	375	53,800	26.7	55,680	7.2		100		30.0	120,269
-500	375	53,800	26.7	55,680	7.2		100		30.0	120,269
-600	375	53,800	26.7	55,680	7.2		100		30.0	120,269
-700	375	53,800	26.7	55,680	7.2		100		30.0	120,269
-800	375	53,800	26.7	55,680	7.2		100		30.0	120,269
-900	375	53,800	26.7	55,680	7.2			100	30.0	120,269
-1000	375	4,334,000	26.7	4,485,452	7.2			100	30.0	9,688,575
-1970	5,250	85,423,000	18.5	85,438,495	7.2			100	30.0	184,547,149
TOTAL:										195,226,065

APPENDIX D

TABLE D-1 WATER QUALITY DATA FOR VARIOUS MINE WATERS – CAPE BRETON, NOVA SCOTIA

LOCATION / DATE / TIME / SAMPLE NUMBER	1-B Discharge Nov 30/92 0954 hrs WP-51	1-B Shaft Jun 14/91 1-B	No. 26 Colliery Nov 6/90	No. 4 QUARRY PT. Jun 14/91 SHAFT	PHALEN 4E BOT Nov 28/92 0825 hrs WP-44	PHALEN 5E BOT Nov 28/92 0915 hrs WP-45	PHALEN Portal Nov 16/88 Groundwater CBDC-02	NSPC ASH LAGOON Nov 16/88 NSPC-02	SEA WATER Nov 16/88 NSPC-03	OLD HARBOUR SEAM Nov 17/88 CBDC-05	OLD HARBOUR SEAM Nov 17/88 CBDC-07
PARAMETER											
Sodium (mg/L)	900.00	1020	870	70.6	20700.00	20800.00	165.00	2200.00	8500.00	24.00	2180
Potassium (mg/L)	24.00	44.3	40	13.5	95.00	135.00	5.80	91.00	350.00	2.40	56
Calcium (mg/L)	225.00	421	308	218	10900.00	9750.00	130.00	230.00	365.00	47.20	290
Magnesium (mg/L)	700.00	132	99	18.8	2700.00	2400.00	42.00	330.00	1310.00	19.30	375
Hardness (mg/L)	3444.43	1590	1180	621	38335.90	34228.95	498.00	1931.00	6297.00	197.00	2266
Alkalinity (mg/L)	570.00	230	233	160	30.90	17.60	191.60	5.80	107.00		
Sulfate (mg/L)	5519.90	951	593	352	749.90	1410.50	350.00	919.00	2180.00		
Chloride (mg/L)	1283.00	1850	1410	142	46178.00	48356.00	190.00	3840.00	16100.00		
Silica (mg/L)		8.6		8.5			9.70	4.90	0.50		
NO2 + NO3 (mg/L)	<0.01	<0.05		0.86	<0.01	<0.01	<0.05	<0.05	<0.05	0.23	<0.05
Ammonia (mg/L)	13.14	<0.05		<0.05	20.75	34.91	0.66	<0.05	<0.05	<0.05	1.3
Color (TCU)	0.00	3		<3	5.00	5.00	3.50	2.50	5.30		
Turbidity (JTU)	1.10	40.4		0.19	24.00	31.00				1.70	140
Conductivity (uS)	14300	8760	7390	1730	123900	130500	1790.00	16000.00	57400.00		
pH (units)	4.40	7.4	7.6	7.6	6.30	6.30	7.70	5.20	7.90	4.10	6.5
T.O.C. (mg/L)		1.8		1.5			1.00	0.40	0.80	1.60	1.9
Iron (mg/L)	2000.00	4.1	5.75	0.07	6.80	9.20	2.68	2.2	0.35	1.80	430
Manganese (mg/L)		1.01	0.85	<0.01			5.14	<0.01	0.12	1.50	6.5
Copper (mg/L)		<0.01		<0.01			<0.01	<0.01	<0.01	<0.01	<0.01
Zinc (mg/L)		3		0.02			<0.01	<0.01	<0.01	0.05	0.08
Lead (mg/L)		<0.05		<0.05			<0.01	0.04	<0.01	<0.05	<0.05
Aluminum (mg/L)		<0.1	0.11	<0.1			<0.05	1.10	0.18	1.30	0.33
Barium (mg/L)		0.05		0.031			0.05	0.06	0.01	0.02	0.2
Boron (mg/L)		0.2		<0.1			0.06	1.10	3.20	<0.02	0.38
Beryllium (mg/L)		<0.005		<0.005			<0.005	<0.005	<0.005	<0.005	<0.005
Chromium (mg/L)		<0.02		<0.02			<0.01	0.01	0.04		
Cadmium (mg/L)		<0.05		<0.05			<0.01	<0.01	<0.01	<0.01	<0.01
Cobalt (mg/L)		<0.01		<0.01			<0.01	0.04	0.05	0.03	
Nickel (mg/L)		<0.05		<0.05			<0.02	0.03	<0.02	0.03	0.03
Antimony (mg/L)		<0.02		<0.02			<0.05	<0.05	<0.05	<0.05	<0.05
Selenium (mg/L)		<0.1		<0.1			<0.10	<0.10	<0.10	<0.10	<0.10
Strontium (mg/L)	2.50				1200.00	1350.00	2.00	1.20	4.40	0.35	6.30
Tin (mg/L)		<0.01		<0.01			<0.03	<0.03	<0.03	<0.03	<0.03
Vanadium (mg/L)		<0.01		<0.01			<0.01	<0.01	<0.01	<0.01	0.02
TDS (Theor)	13862	4570	3650	923	117858	115660					
SUSPENDED SOLIDS (mg/L)											

TABLE D-2
STATISTICAL SUMMARY OF WATER CHEMISTRY MONITORING
AT LINGAN 2E (NOV. 20/92 - DEC. 04.92)

PARAMETER	LINGAN 2E BOTTOM LEVEL					LINGAN 2E TOP LEVEL				
	MEAN	MAX	MIN	STD	N	MEAN	MAX	MIN	STD	N
Sodium (mg/L)	7839	8500	7200	412.56	12	6053	7310	4700	799	11
Potassium (mg/L)	50	90	37	14.73	12	48	78	25	19	11
Calcium (mg/L)	1070	1700	800	248.38	12	808	1200	600	180	11
Magnesium (mg/L)	1060	1400	831	209.67	12	773	1400	500	244	11
Hardness (mg/L)	7036	8775	5910	871.90	12	5200	8762	3557	1348	11
Alkalinity (mg/L)	123	235	40	70.89	12	77	167	8	54	11
Sulfate (mg/L)	5586	7100	1539	1406.27	12	6229	7950	1435	1941	11
Chloride (mg/L)	11569	15040	114	3768.39	12	8704	11899	6233	1780	11
Silica (mg/L)	<0.5				2	<0.5				1
O-Phosphorus (mg/L)	<0.01				2	<0.01				2
NO2 + NO3 (mg/L)	<0.05				12	<0.05				11
Ammonia (mg/L)	16	26	5	6.72	12	15.6	27.5	2.5	8.1	11
Color (TCU)	32	210	<3	65.56	12	5	29	0	8	11
Turbidity (JTU)	102	341	12	93.80	12	167	637	27	227	10
Conductivity (uS)	51842	70000	44800	6849.63	12	39991	59400	33800	7207	11
pH (units)	6	6	6	0.12	12	5.9	6.3	5.4	0.2	11
T.O.C. (mg/L)	1	1	1	0.00	1	0.9	0.9	0.9	0.0	1
Iron (mg/L)	1188	1450	832	192.72	8	1590	1790	1160	200	7
Manganese (mg/L)	53	53	52	0.45	2	50	54	46	4	2
Copper (mg/L)	0.03	0.04	0.03	0.01	2	0.010	0.020	0.000	0.010	2
Lead (mg/L)	0.07	0.14	0.00	0.07	2	0.138	0.260	0.015	0.123	2
Zinc (mg/L)	0.22	0.38	0.07	0.16	2	0.99	1.92	0.06	0.93	2
Aluminum (mg/L)	0.50	0.94	0.06	0.44	2	0.24	0.35	0.12	0.12	2
Arsenic (mg/L)	0.05	0.05	0.05	0.00	1	0.04	0.04	0.04	0.00	1
Barium (mg/L)	0.03	0.03	0.03	0.00	2	0.03	0.03	0.02	0.00	2
Boron (mg/L)	0.10	0.20	0.00	0.10	2	0.10	0.20	0.00	0.10	2
Beryllium (mg/L)	<0.005				2	<0.005				2
Cadmium (mg/L)	<0.005				2	<0.005				2
Chromium (mg/L)	0.003	0.01	0.00	0.00	2	0.005				2
Cobalt (mg/L)	0.20	0.39	0.00	0.20	2	0.25	0.49	0.00	0.25	2
Nickel (mg/L)	0.33	0.38	0.28	0.05	2	0.53	0.54	0.51	0.02	2
Antimony (mg/L)	0.04	0.07	0.00	0.03	2	0.07	0.13	0.00	0.07	2
Selenium (mg/L)	0.05	0.10	0.00	0.05	2	0.07	0.14	0.00	0.07	2
Strontium (mg/L)	101.57	450.00	36.00	142.36	7	20.92	40.10	11.80	10.31	5
Tin (mg/L)				0.00	2	<0.002				2
Vanadium (mg/L)	0.25	0.31	0.19	0.06	2	0.24	0.30	0.18	0.06	2
Cation Sum	483	506	437	22.20	12	369	494	290	57	11
Anion Sum	471	538	407	32.80	12	374	486	311	51	11
TDS (ION SUM)	36820	62900	27163	9177.35	12	30507	53300	18928	9387	11

TABLE D-3
MEAN CHEMISTRY DATA - PHELAN 1E (NOV. 16/88 - APR 19/90)

PARAMETER	Mean	Maximum	Minimum	STD DEV	Number
Sodium (mg/L)	12636	17200	10600	1850.0	65
Potassium (mg/L)	59	78	50	7.2	65
Calcium (mg/L)	2936	5870	1226	1009.9	66
Magnesium (mg/L)	1248	2560	882	332.3	66
Hardness (mg/L)	12464	24539	7846	3806.1	66
Alkalinity (mg/L)	75	110	26.2	26.0	65
Sulfate (mg/L)	1065	1480	285	317.8	65
Chloride (mg/L)	27635	43700	21800	5566.6	65
Silica (mg/L)	6	24	2	4.19	65
O-Phosphorus (mg/L)	<0.01	0.13	<0.01	0.02	65
NO2 + NO3 (mg/L)	<0.05	1.4	<0.05	0.25	65
Ammonia (mg/L)	19	27	15	2.71	65
Color (TCU)	7	210	<3.0	26.10	64
Turbidity (JTU)	2	63	<1.0	8.27	64
Conductivity (uS)	97832	159000	79500	17938.74	65
pH (units)	8	8.5	6.9	0.33	64
T.O.C. (mg/L)	<1.0	2.6	<1.0	0.63	65
Iron (mg/L)	<0.5	3.1	<0.5	0.44	66
Manganese (mg/L)	3.26	5.94	<3	1.21	66
Copper (mg/L)	<0.01	0.07	<0.01	0.02	66
Lead (mg/L)	<0.05	1	<0.05	0.25	66
Zinc (mg/L)	<0.05	0.44	<0.05	0.12	66
Aluminum (mg/L)	0.10	0.79	<0.05	0.20	66
Barium (mg/L)	0.36	1	0.18	0.21	66
Boron (mg/L)	0.11	2	<0.01	0.24	66
Beryllium (mg/L)	<0.005	0.009	<0.005	0.00	66
Cadmium (mg/L)	0.01	0.08	<0.01	0.02	66
Chromium (mg/L)	0.17	1.7	<0.01	0.43	66
Cobalt (mg/L)	0.10	0.26	<0.05	0.05	66
Nickel (mg/L)	0.08	2.9	<0.02	0.36	66
Antimony (mg/L)	0.00	0.1	<0.05	0.01	66
Selenium (mg/L)	0.00	0.13	<0.10	0.02	66
Strontium (mg/L)	277.11	650	122.00	160.53	64
Tin (mg/L)	<0.03	<0.03	<0.03	0.00	66
Vanadium (mg/L)	0.02	0.2	0.00	0.05	66
Cation Sum	791.43	1227	646.00	138.28	63
Anion Sum	785.42	1152	646.00	134.13	63
TDS (Theor)	45586.46	69390	37100.00	8505.21	65
Flow Rate (igpm)	235.29	650	7.00	235.72	7

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TABLE D–4
LINGAN "A" STATISTICS (NOV 18/88 – APR 10/90)

PARAMETER	Average	Maximum	Minimum	STD	N
Sodium (mg/L)	7940.4	8700	6900	354.45	71
Potassium (mg/L)	93.1	150	60	20.81	71
Calcium (mg/L)	1062.6	1282	900	245.60	72
Magnesium (mg/L)	985.9	1264	840	82.12	72
Hardness (mg/L)	6819.9	8286	6020	503.89	72
Alkalinity (mg/L)	61.8	120	21	24.12	72
Sulfate (mg/L)	1741.7	1910	1500	80.67	71
Chloride (mg/L)	15679.4	16455	14700	316.85	71
Silica (mg/L)	5.6	11	0.5	1.16	71
O–Phosphorus (mg/L)	<0.01	0.12	<0.01	0.02	71
NO2 + NO3 (mg/L)	0.2	3.7	<0.05	0.55	70
Ammonia (mg/L)	6.8	8.8	0.18	1.74	71
Color (TCU)	12.0	120	<3.0	20.88	71
Turbidity (JTU)	21.1	100	0.4	20.09	71
Conductivity (uS)	58935.1	65300	55500	2110.36	71
pH (units)	7.6	8.3	6	0.50	71
T.O.C. (mg/L)	0.7	9	0.00	1.34	71
Iron (mg/L)	5.1	43	0.00	6.61	72
Manganese (mg/L)	3.5	6.57	0.00	1.19	72
Copper (mg/L)	<0.01	0.08	<0.01	0.02	72
Lead (mg/L)	0.10	0.73	<0.01	0.17	71
Zinc (mg/L)	0.07	0.47	<0.05	0.11	72
Aluminum (mg/L)	0.13	0.80	<0.05	0.18	69
Barium (mg/L)	0.09	0.59	<0.05	0.06	69
Boron (mg/L)	0.69	1.65	<0.1	0.32	69
Beryllium (mg/L)	<0.005	0.01	<0.005	0.00	67
Cadmium (mg/L)	0.01	0.06	<0.01	0.02	67
Chromium (mg/L)	0.15	1.60	<0.01	0.38	69
Cobalt (mg/L)	0.12	0.28	<0.05	0.07	69
Nickel (mg/L)	0.11	2.80	<0.05	0.34	68
Antimony (mg/L)	0.00	0.00	<0.05	0.00	67
Selenium (mg/L)	<0.10	<0.10	<0.10	0.00	67
Strontium (mg/L)	70.71	95.00	49.00	11.69	67
Tin (mg/L)	<0.03	<0.03	<0.03	0.00	67
Vanadium (mg/L)	0.02	0.16	<0.01	0.05	67
Temperature (C)	11.2	12.5	9.44	1.12	4
Cation Sum	484.8	524	449.00	15.60	71
Anion Sum	479.1	499	451.00	9.22	71
TDS (Theor)	27556.8	28700	25767.00	543.66	71

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TABLE D-5
PHELAN 5E BREAK (OCTOBER-NOVEMBER 1992)

LOCATION	5 EAST	5 EAST
DATE	OCT 9/92	NOV 5/92
SAMPLE NUMBER		CBDC-634
PARAMETER	(200 igpm)	(10 igpm)
Sodium (mg/L)	30000	22600
Potassium (mg/L)	270	81
Calcium (mg/L)	850	5100
Magnesium (mg/L)	175	1540
Hardness (mg/L)	2843	19100
Alkalinity (mg/L)	15.6	<1.0
Sulfate (mg/L)	1270	2130
Chloride (mg/L)	68040	45200
Silica (mg/L)		28
O-Phosphorus (mg/L)	0.17	<0.01
NO2 + NO3 (mg/L)	<0.01	<0.05
Ammonia (mg/L)	43	30.5
Color (TCU)	0	7
Turbidity (JTU)	34	18.6
Conductivity (uS)	159100	168000
pH (units)	6.8	5.4
T.O.C. (mg/L)		<0.5
Iron (mg/L)	1.8	42.5
Manganese (mg/L)	8.5	13.6
Copper (mg/L)	0.32	0.01
Lead (mg/L)		0.2
Zinc (mg/L)	0.4	0.02
Aluminum (mg/L)		0.21
Barium (mg/L)		0.11
Boron (mg/L)		0.12
Beryllium (mg/L)		0.006
Cadmium (mg/L)		<0.01
Chromium (mg/L)		0.11
Cobalt (mg/L)		<0.05
Nickel (mg/L)		0.04
Antimony (mg/L)		<0.05
Selenium (mg/L)		<0.10
Strontium (mg/L)		
Tin (mg/L)		<0.03
Vanadium (mg/L)		<0.01
Cation Sum	1371	
Anion Sum	1946	
TDS (Theor)	100620	
FLOW RATE (igpm)	170	

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TABLE D-6
WATER QUALITY MONITORING DATA FOR THE 1B SHAFT DEWATERING – NOVEMBER 1992

LOCATION / DATE / TIME / SAMPLE NUMBER	1–B Shaft Jun 14/91 1–B	No. 26 Colliery Nov 6/90	1–B Discharge Nov 24/92 0954 hrs WP–22	1–B Nov 25/92	1–B Nov 26/92	1–B Discharge Nov 28/92 0954 hrs WP–38	1–B Discharge Nov 29/92 0926 hrs WP–47	1–B Discharge Nov 30/92 0954 hrs WP–51	AVERAGE	MAX	MIN	N
PARAMETER												
Sodium (mg/L)	1020	870	1100	7700	200	920	900	900.00	1701.25	7700	200	8
Potassium (mg/L)	44.3	40	68	45	23	15	22	24.00	35.1625	68	15	8
Calcium (mg/L)	421	308	250	1100	420	250	225	225.00	399.875	1100	225	8
Magnesium (mg/L)	132	99	155	910	510	500	700	700.00	463.25	910	99	8
Hardness (mg/L)	1590	1180	1263	6494	3148	2808	3444	3444.43	2921.425	6494	1180	8
Alkalinity (mg/L)	230	233	79	8.2	4.7	5.9	5	570.00	141.9625	570	4.7	8
Sulfate (mg/L)	951	593	602	3552	4823	5551	5721	5519.90	3414.1375	5721.2	593	8
Chloride (mg/L)	1850	1410	2068	14376	2030	1080	1281	1283.00	3172.25	14376	1080	8
Silica (mg/L)	8.6								8.6	8.6	8.6	1
NO2 + NO3 (mg/L)	<0.05		<0.01	0.01	<0.01	<0.01	<0.01	<0.01	0.00142857	0.01	<0.01	7
Ammonia (mg/L)	<0.05		<0.01	22.04	15.14	14.17	11.63	13.14	10.8742857	22.04	<0.01	7
Color (TCU)	3		0	0	0	0		0.00	0.5	3	0	6
Turbidity (JTU)	40.4		8.00	75	3.1	1	4.30	1.10	18.9857142	75	1	7
Conductivity (uS)	8760	7390	9100.00	48400	13800	12800	14100	14300	16081.25	48400	7390	8
pH (units)	7.4	7.6	7.20	5.5	3.9	4.3	4.50	4.40	5.6	7.6	3.9	8
T.O.C. (mg/L)	1.8								1.8	1.8	1.8	1
Iron (mg/L)	4.1	5.75		800	1600	1800	1810.00	2000.00	1145.69285	2000	4.1	7
Manganese (mg/L)	1.01	0.85		46	66				28.465	66	0.85	4
Copper (mg/L)	<0.01			1.32	2				1.11	2	0	3
Zinc (mg/L)	3			0.16	4.6				2.59	4.6	0.16	3
Lead (mg/L)	<0.05				0.07				0.04	0.07	<0.02	2
Aluminum (mg/L)	<0.1	0.11		0.09	120				30.05	120	<0.02	4
Barium (mg/L)	0.05			0.16	<0.02				0.07	0.16	<0.02	3
Boron (mg/L)	0.2			3.6	8				3.93	8	0.2	3
Beryllium (mg/L)	<0.005			<0.02	<0.02				<0.02	<0.02	<0.02	3
Chromium (mg/L)	<0.02			<0.02	0.04				0.01	0.04	<0.02	3
Cadmium (mg/L)	<0.05			0.4	0.1				0.17	0.4	<0.02	3
Cobalt (mg/L)	<0.01			0.4	2				0.80	2	<0.02	3
Nickel (mg/L)	<0.05			<0.02	3.6				1.20	3.6	<0.02	3
Antimony (mg/L)	<0.02			<0.02	0.02				0.01	0.02	<0.02	3
Selenium (mg/L)	<0.1								0.00	0	<0.02	1
Strontium (mg/L)						1.9	2.30	2.50	2.23	2.5	1.9	3
Tin (mg/L)	<0.01			<0.02	0.02				0.01	0.02	<0.02	3
Vanadium (mg/L)	<0.01			<0.02	0.02				0.01	0.02	<0.02	3
TDS (Theor)	4570	3650	4321.98	27692	8726		14120	13862	10991.71	27692	3650	7