WATER BALANCE ASSESSMENT
CAPE BRETON DEVELOPMENT CORPORATION
NO. 1B HYDRAULIC SYSTEM
GLACE BAY, RESERVE AND DOMINION
CAPE BRETON, NOVA SCOTIA

JANUARY 31, 2003

Looking east from Lingan-Phalen Collieries toward the Glace Bay mining district in the background.

PREPARED BY:

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MR. STEVE FORGERON, CONSULTING GEOLOGIST

2.0 DATA COLLECTION PROGRAMS

2.1 Bedrock and Surficial Geology

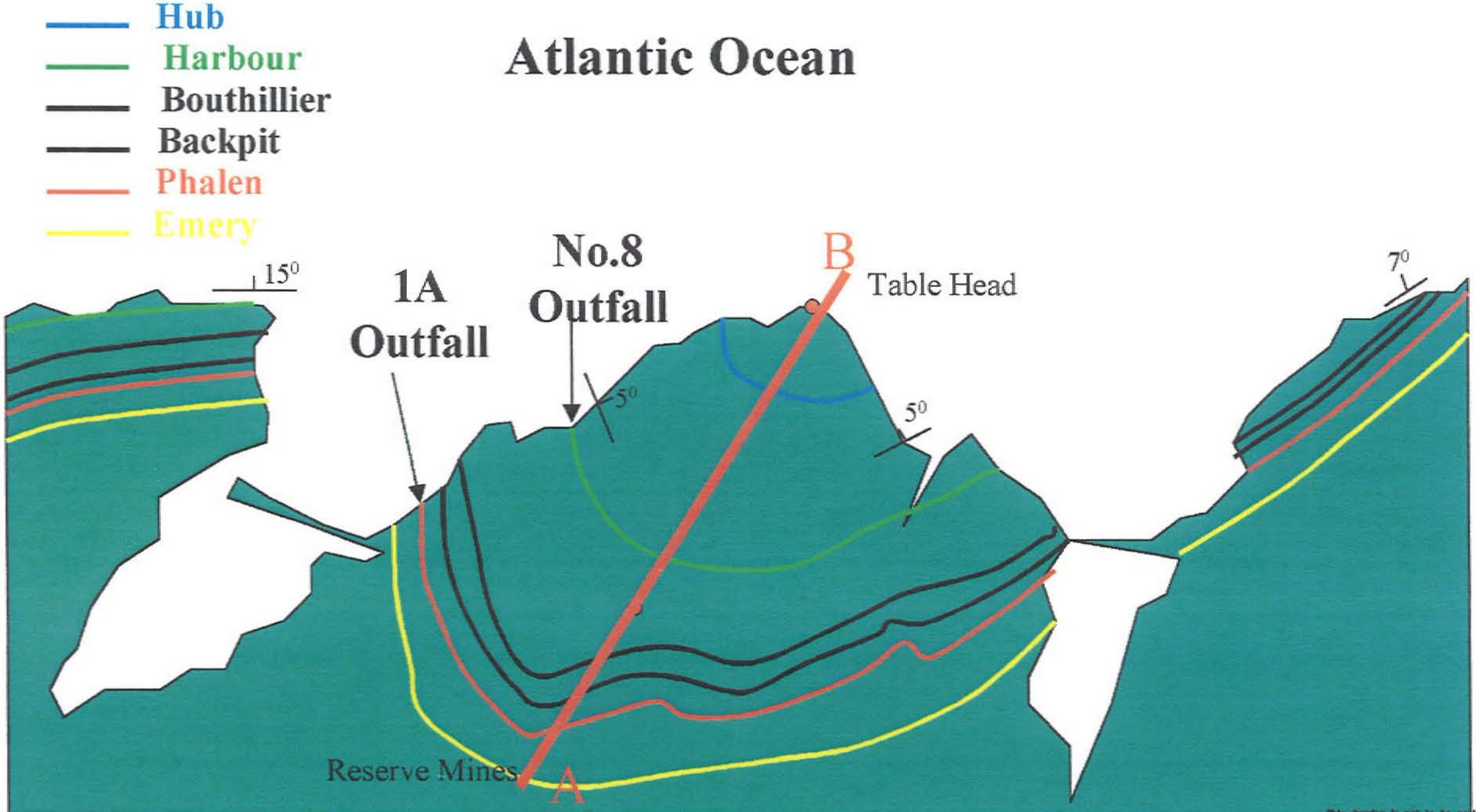
2.1.1 Bedrock Geology

The study area is located in the Sydney Coalfield. The Coalfield constitutes the on-land and near-shore portion of a much larger Carboniferous sedimentary basin (Sydney Basin), which extends northeastward under the Atlantic Ocean. Glace Bay is situated in the eastern part of the Coalfield and is underlain by strata belonging to the Morien Group which has been divided into (ascending order) the South Bar, Waddens Cove and Sydney Mines Formations. These strata comprise an 1800-metre thick succession of upward fining sediments. The basal South Bar Formation is composed primarily of braid-stream deposited sandstone and fines upwards into the argillaceous coal-rich sediments of the Sydney Mines Formation. The Waddens Cove Formation is equivalent to the South Bar, but contains appreciable duricrusts and red beds.

The Sydney Mines Formation hosts most of the major coal seams, which have been exploited during the 250-year mining history in the area. This formation is composed of sandstone, siltstone, mudrocks, shale, fresh water carbonaceous limestone and coal. They bear the characteristics of deposition in a fluvial environment on a slowly subsiding coastal plain. Marine sediments do not exist, but evidence of agglutinated Foraminifera suggests that minor incursions of the sea may have occurred and established brackish conditions locally.

Six major coal seams are present in the project area. The sequence of these seams is shown in plan and sectional view in Figures 2.1 and 2.2. Deposition of the coal seams and the enclosing sediments was cyclical with a roughly similar sequence of strata developed between each of the seams. These repetitive sequences are often referred to as cyclothems and reflect depositional changes associated with the rising and falling of sea level. A typical cyclothem sequence is shown in Figure 2.3.

Sequence of Coal Seams



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Proj.	WATER BALANCE ASSESSMENT No.1B HYDRAULIC SYSTEM	Proj. No.5285-001.1 Drawn By: NEB Dwg. Standards Chk. By:
Dwg.	FIGURE 2.1 PLAN VIEW OF COAL SEAMS	Designed By: SF Dwg. Design Chk. By: SF Date: 02.10.28 Rev.

Stratigraphic Section at Glace Bay

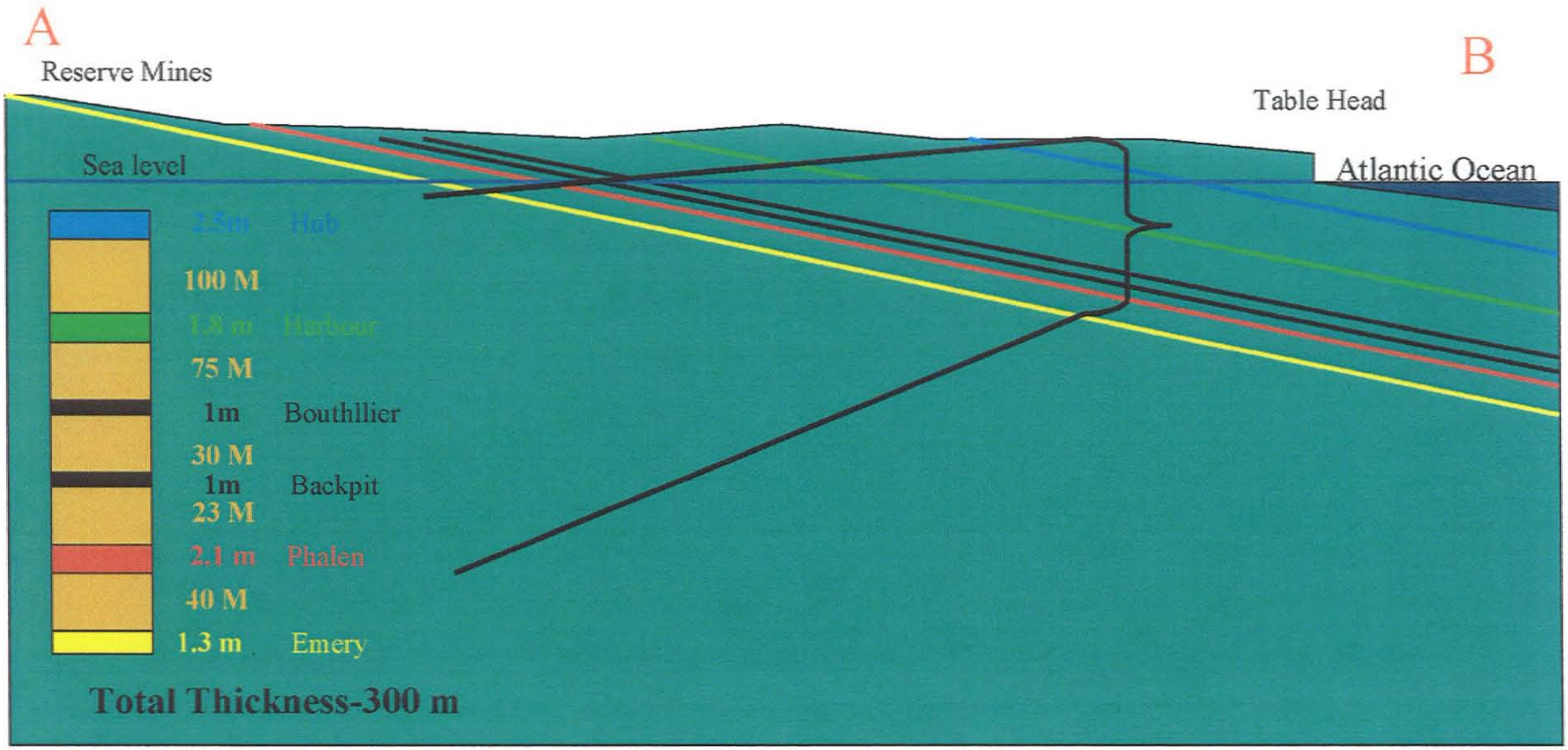

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FIGURE 2.2
CROSS SECTIONAL VIEW
OF COAL SEAMS

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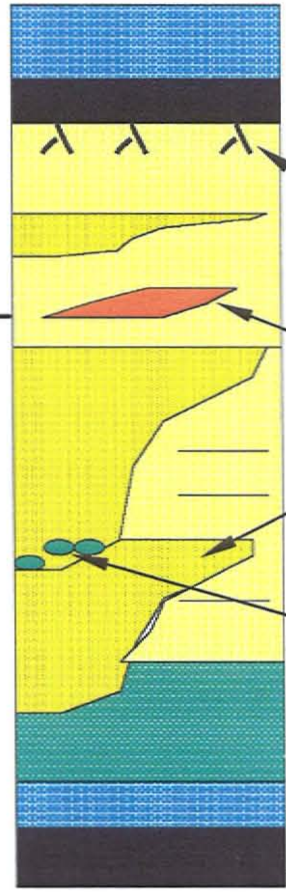
Typical Cyclothem

LEGEND:

(blue)	LAKE/bay SEDIMENT COMPOSED OF FRESH/BRACKISH WATER LIMESTONES AND BLACK CARBONACEOUS MUDROCKS
(green)	LAKE/bay FILL SEDIMENT COMPOSED OF SEQUENCES OF COARSENING UPWARDS SEDIMENT- SHALES, SILTSTONES AND SANDSTONES. SIDERITE COMMON
(yellow)	OVERBANK LEVEE DEPOSITS OF SANDSTONE, SILTSTONE AND MUDROCKS. SIDERITE COMMON
(yellow channel)	CHANNEL FILL SANDSTONE. CALCITE CEMENT COMMON
(black)	COAL



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MGI — A member of the Family of Companies; Jacques Whitford	ADI Limited, Sydney, Nova Scotia. Engineering, Consulting, Procurement and Project Management. ADI GROUP. Charlottetown, Moncton, Saint John, Ottawa, Vancouver, Sydney, St.John's, Halifax, Fredericton and Salem, NH. Steve Forgeron Consulting Geologist	Proj. WATER BALANCE ASSESSMENT No.1B HYDRAULIC SYSTEM Dwg. FIGURE 2.3 TYPICAL CYCLOTHEM SEQUENCE

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An examination of borehole data and coastline mapping in the area reveals a predominantly argillaceous sedimentary package with lesser amounts of sandstone, mudrocks, coal, limestone and mixed sediments (siltstones, shales). The approximate proportion of each lithology within the study area is summarized in Table 2.1.

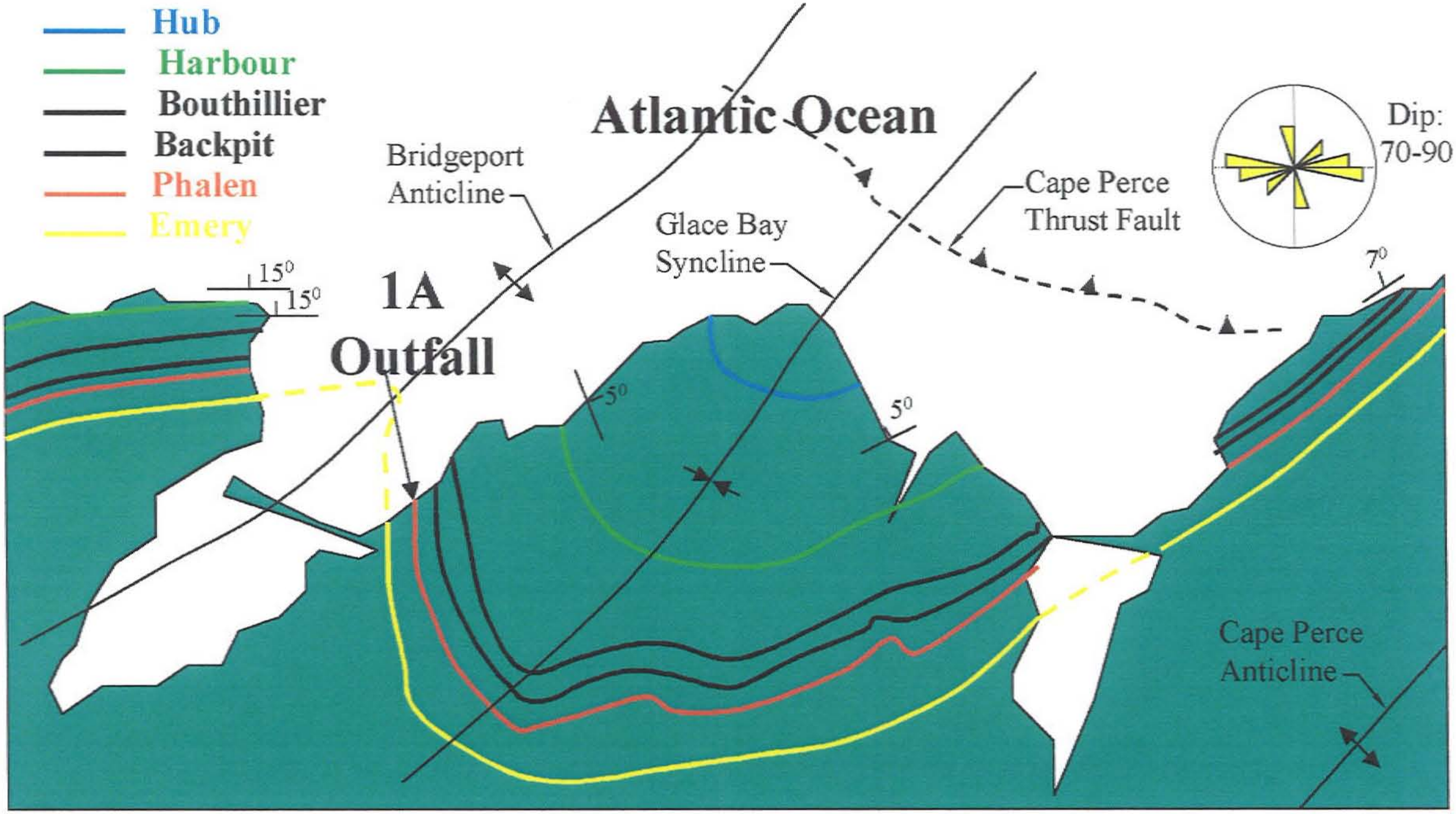
TABLE 2.1: STUDY AREA PROPORTIONAL LITHOLOGY (%)

	Mudrocks	Sandstone	Coal	Mixed	Limestone
Above Hub	83	17	?	?	?
Hub-Harbour	70	23	2	12	1
Harbour-Phalen	65	22	4	4	9
Phalen-Emery	58	25	3	2	11
Average	**66**	**20**	**3**	**4**	**7**

Structurally, the study area lies within the Glace Bay Syncline (Figure 2.4). The Bridgeport Anticline and Cap Perce Anticline lie immediately to the west and east, respectively. The syncline is believed to have formed in a half-graben structure that was in the process of down warping at the time of deposition. The strata on the flanks of the fold dip to the north and east at an average dip of about 5 degrees. The primary set of jointing is east-northeast with a dip of 70 to 90 degrees. Secondary joints occur at various angles to this primary set. The sandstone beds exhibit clean, smooth fracture surfaces that can be traced for tens of metres in outcrop. Jointing in the argillaceous rocks tends to be discontinuous and end abruptly. For the most part, mining in this area has been spared the effects of major faulting. The only major fault is the Cap Perce Thrust. It was encountered in several of the submarine mines where measured displacements of less than 5 metres were reported.

The rank of the coal seams is high volatile A bituminous. The seams are generally considered to be low in ash, but high in sulfur. Since sulphur is instrumental in the formation of acid mine drainage, Table 2.2 has been constructed to show its variability within the seams in the study area. The sulphur content of the major seams (Hub, Harbour, Phalen and Emery) range from 2 to 5%, while the minor seams (Bouthillier and Back Pit) average about 7%. The table also shows the distribution of sulphur forms. Due to the fact that the sulphur content of the coals is quite high and pyritic sulphur is the predominant form of sulphur, these coals can be expected to yield copious amounts of acid mine water.

Structural Geology



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Proj.	WATER BALANCE ASSESSMENT No.1B HYDRAULIC SYSTEM
Dwg.	FIGURE 2.4 STUDY AREA STRUCTURAL GEOLOGY

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TABLE 2.2: COAL SEAM SULPHUR CONTENT VARIABILITY %

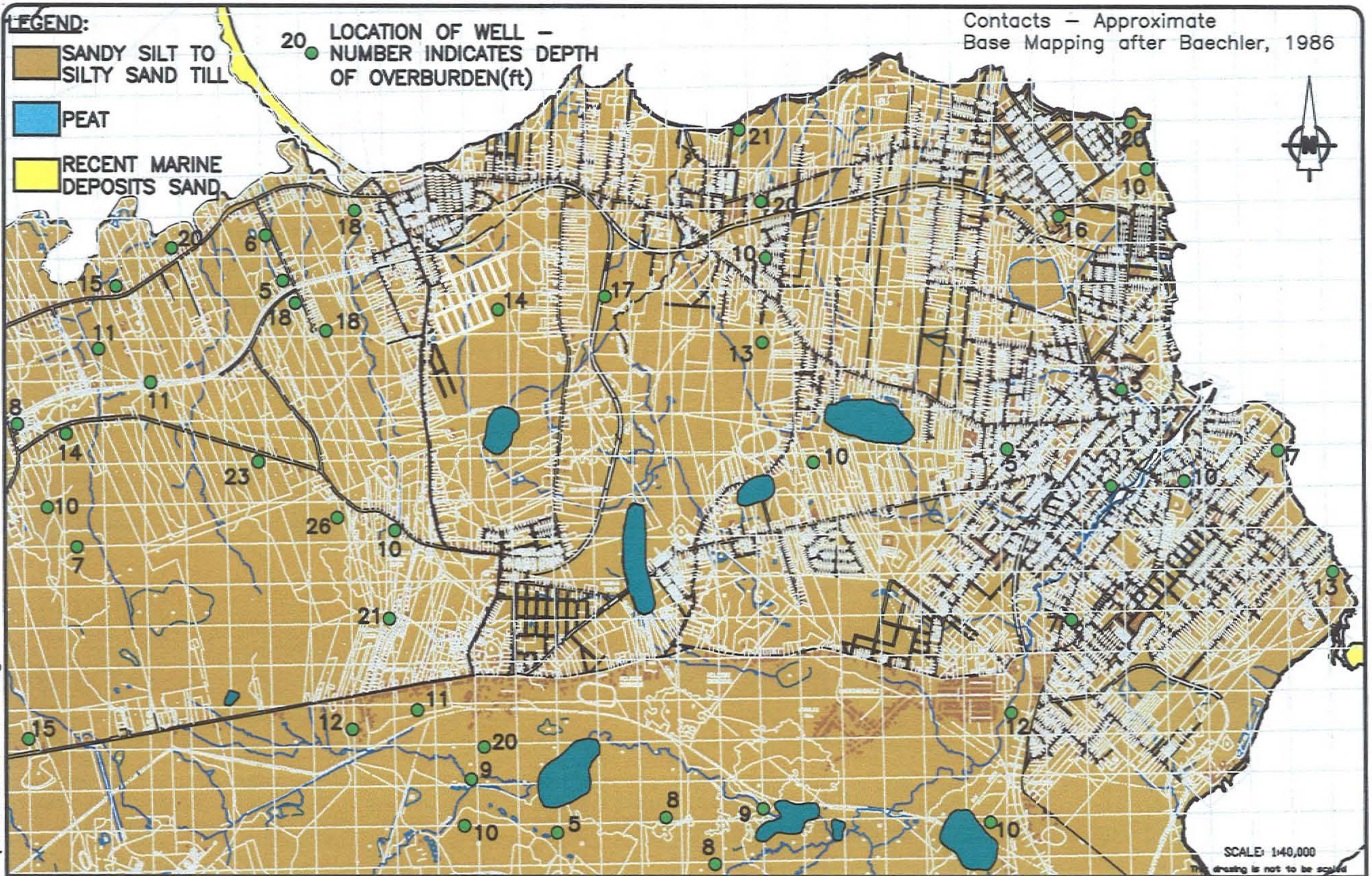
	Total Sulphur	Sulphur Forms		
		Sulphate	Pyritic	Organic
Hub	3 – 5			
Harbour	2 – 4	2	62	35
Bouthillier	7.0			
Back Pit	6.9			
Phalen	2.5 – 4	1	63	34
Emery	2.5 – 5			

In addition to the presence of acid generating agents, acid neutralization sediments and minerals are also present. Carbonates are probably the most effective substances for neutralizing acid mine waters. The mineral siderite is the most common carbonate found in the Sydney Coalfield, however, the most effective acid neutralizing carbonates are calcite, dolomite and to a lesser extent, ankerite. Both dolomite and ankerite are present in the Glace Bay area, but only in minor amounts. Calcite, however, is relatively abundant. It occurs as the primary constituent of thin (20 to 30 centimetres) beds of fresh water limestone immediately overlying the coal seams, as layers and nodules of calcrete in both the roof and floor of the seams and as the cementing agent within channel sandstones. Fresh water limestones have been observed above all the coal seams except the Hub Seam in the Glace Bay area.

2.1.2 Surficial Geology

In the study area, bedrock has a widespread covering of a stoney silty sand to sandy silt basal till (Baechler, 1986). Based on information obtained from boreholes drilled by the coal companies in the area, it ranges from 2 to 16 metres in thickness with an average depth of about 5 metres. It is generally dense and compact where moisture and clay content is high, but may be loose to very loose in areas that are well drained and sandy. Colour ranges from brown to gray.

The study area is characterized by low relief with many swamps and bogs that may lie immediately on bedrock or glacial till. A thin (<1 metre) veneer of peat is common in most swampy areas, but thicknesses in excess of 7 metres are not uncommon near the central areas of bogs. The surficial geology of the study area is depicted in Figure 2.5.



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Dwg. FIGURE 2.5 SURFICIAL GEOLOGY	Designed By: FEB
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2.2 Study Area Surface Watershed Delineation

The study area can be divided into three major surface watersheds and several minor watersheds, as depicted on Map 1, located in the pouch at the conclusion of this report. The first of the three major watersheds is the Dominion Brook Watershed, located in the western portion of the study area. This watershed encompasses 352 hectares and drains Centreville, Reserve Mines and a portion of the Town of Dominion and discharges into Indian Bay to the west of Dominion Beach. The second major watershed is the Cadegan Brook Watershed, located in the central portion of the study area. This watershed encompasses 864 hectares and drains into Indian Bay, near Bridgeport. The third major watershed is the Renwick Brook Watershed, located in the eastern portion of the study area. This watershed encompasses 2,819 hectares and drains into Glace Bay, just west of Quarry Point.

There are also several minor watersheds within the study area, which all drain overland or through small brooks directly to the marine coastal waters. The first of these minor watersheds is the Indian Bay Watershed (128 hectares), located in the eastern portion of the study area, immediately north of the Dominion Brook Watershed and west of the Cadegan Brook Watershed. The second, third and fourth minor watersheds are located east of the Cadegan Brook Watershed and north of the Renwick Brook Watershed. These watersheds are referred to from west to east, as Bridgeport, New Aberdeen and the Sterling watersheds and encompass 215, 123 and 273 hectares, respectively. The fifth and final minor watershed is located to the east of the Renwick Brook Watershed and drains a 225-hectare coastal area that feeds into, for the most part, Big Glace Bay Lake.

In developing the conceptual model for mine inflow mechanisms (Section 4.0), ground and surface water watersheds were assumed to coincide, as discussed above. The watersheds provide a basis upon which to develop the local surface sub-watersheds that drain into the active No. 1B Hydraulic System recharge area.

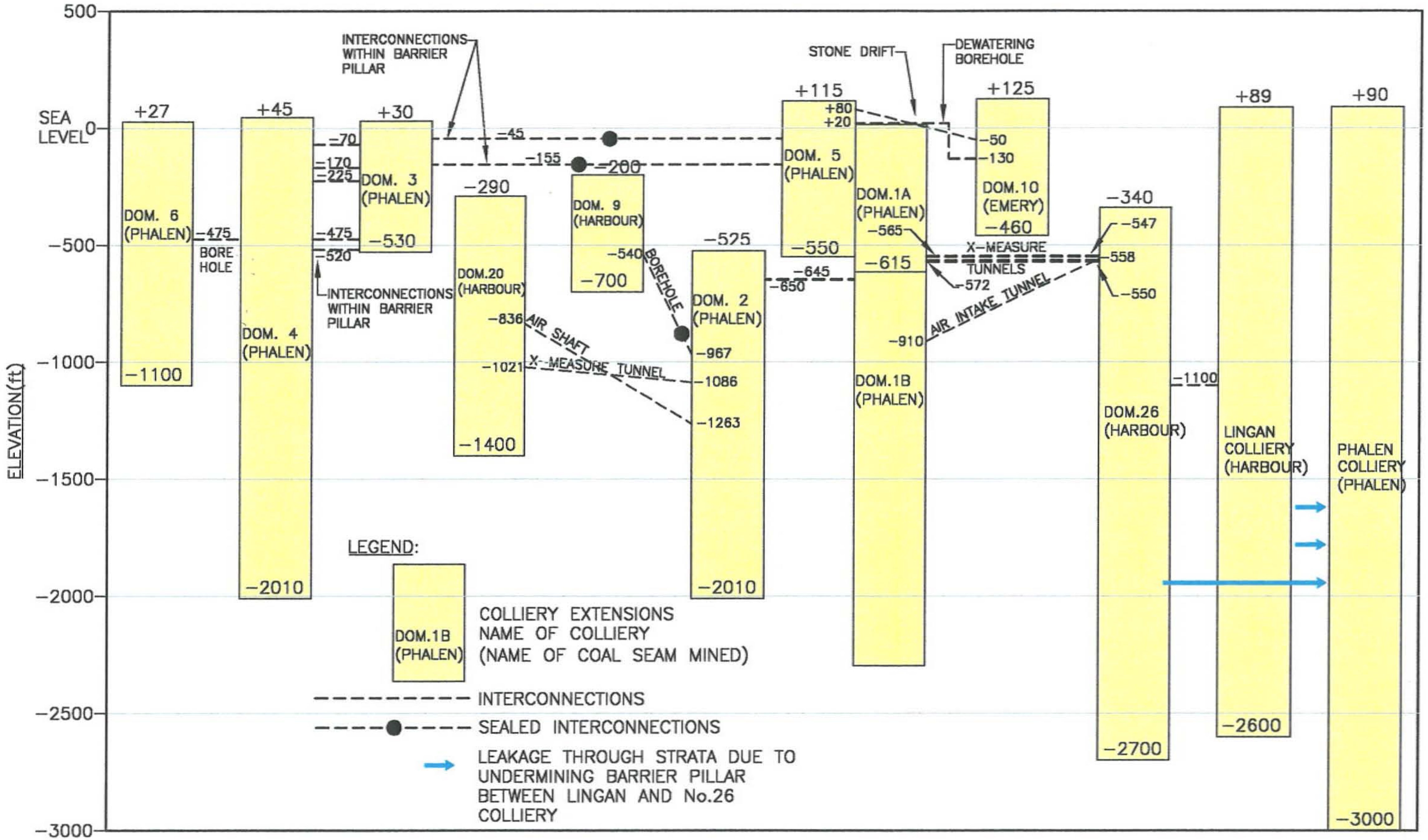
2.3 Municipal Storm/Sanitary Sewer Definition

Mapping of the extent of Reserve Mines Sewage Disposal System discharging into the MacKay's Corner Lift Station was provided in hard copy by CBRM. The drawing was by C. A. Campbell and Associates, dated September 1974. It notes approximately 5.4 km (3.3 miles) of piping covering portions of Rte. 4, Tompkinsville Road, Main Street, Chant Street, Haulage Road, Summerville Street and Wilson Road. All these discharge into the MacKay's Corner Sewage Lift Station just west of Fraser Street along Rte. 4. From there it is pumped over the topographic high at the corner of Rte. 4 and Phalen Road and then drains by gravity into the Glace Bay sewer system. However, it is known that the system upstream, in Glace Bay, has insufficient capacity to handle the flow during significant storm/runoff events and/or during electrical power outages. To avoid a surcharge situation at the MacKay's Corner Lift Station, a 12-inch diameter overflow pipe was installed, which gravity drains directly into the No. 1B System via the No. 5 Colliery. This pipe has the potential of contributing approximately 1700 USgpm to the mine during the above noted situations, assuming a pipe grade of 1%. Monitoring of the sewage lift station through September and October 2002 has not witnessed this overflow, and, therefore, the total volume of water potentially being contributed to the mine has not been confirmed to date.

2.4 Location of Underground Mine Workings and Mine Watersheds

2.4.1 Location of Underground Workings

The study area lies in a district that has been subject to continuous coal mining for over 250 years. During this time, all economic reserves of coal underlying the land and adjacent submarine area have been removed. The coal seams of primary interest were the Hub, Harbour, Phalen and Emery. These seams were exploited by 16 major collieries that removed approximately 170,000,000 tonnes of coal. The largest mine was No. 2 Colliery; it extracted about 29,000,000 tonnes. The locations of the collieries comprising the 1B Colliery Hydraulic System underlying the study area are depicted in Figure 2.6.



No.	Issue	Date

No.	Revision	Ckd. By	Date

Subconsultant

Project No.

Const. North

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Designed By:	FB
Date Printed: OCT. 28, 2002	Design Ckd. By:
Date Last Modified: OCT. 28, 2002	Last Modified By: NB

Project Title

WATER BALANCE ASSESSMENT
1B COLLIERY HYDRAULIC SYSTEM

Dwg. Title

INTERCONNECTION SCHEMATIC
OF COLLIERIES IN
1B MINE HYDRAULIC SYSTEM
(modified after Jacques Whitford, 1993)

Project No. 5285-001.1

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Vertical shafts, cross measure tunnels and slopes driven along the seam from portals at the surface provided access to the coal. The surface expression of many of these access ways is still evident throughout the study area. Mining was conducted to allow maximum recovery of the coal reserve. Extraction methods included room-and-pillar, room-and-pillar with pillar drawing, longwall and full extraction longwall. Organized underground mining operations did not extend to the surface outcrop, but usually stopped when 40 to 50 ft of solid cover was attained. Extensive illegal bootleg mining of this remaining shallow coal is evident wherever it could be effectively exploited. The location of these bootleg operations, and cave-ins (subsidence areas) associated with the organized underground mines, are shown on Map 2, included in the pouch at the conclusion of this report.

2.5 Climatic Data

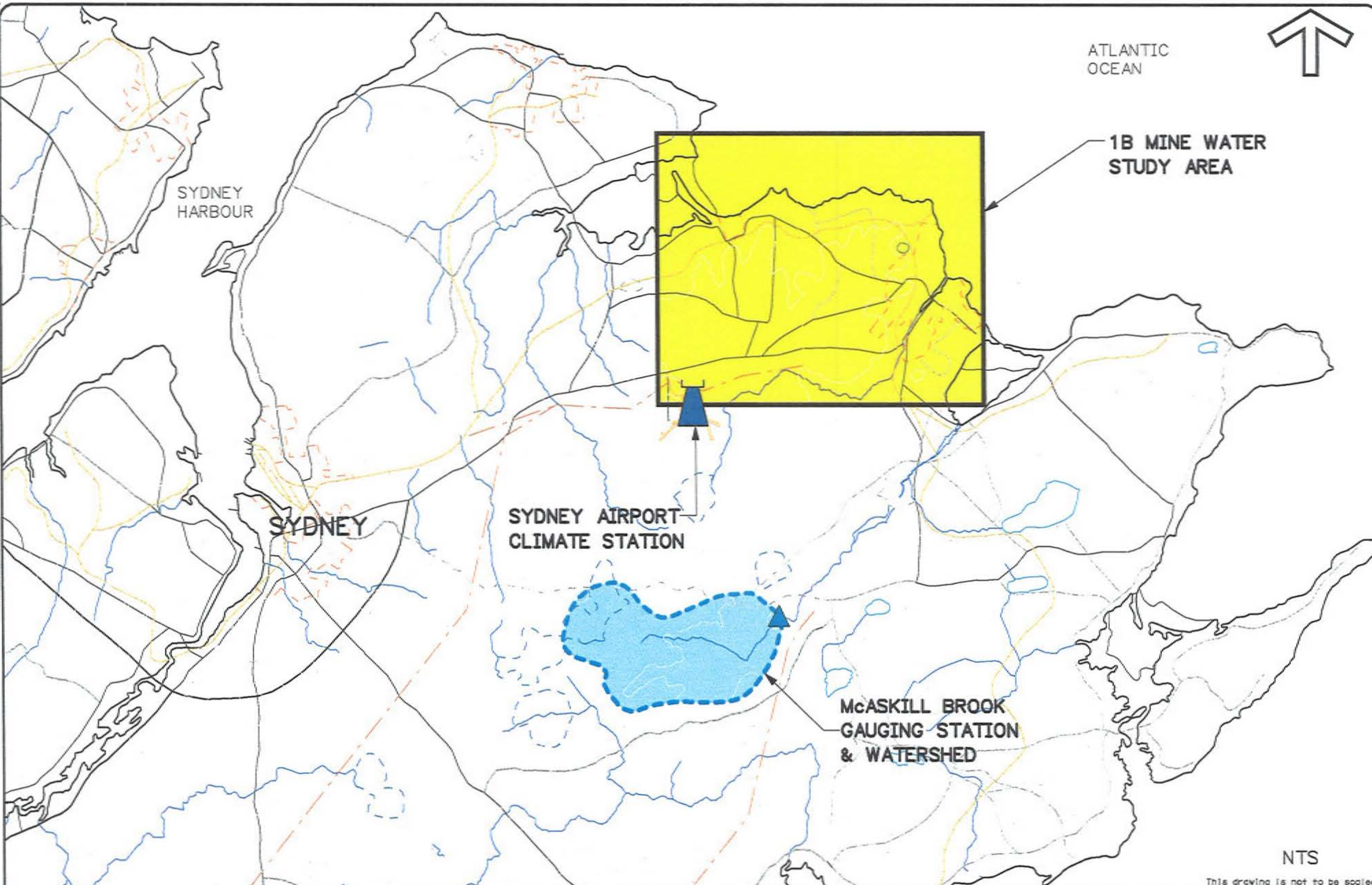
A long term (>100 years of records) Environment Canada climate station, identified as Sydney A, is positioned in the southwestern corner of the study area at the Sydney Airport (Figure 2.7). It forms part of the national program for monitoring long term changes, with records dating back to 1895.

Climatic and weather data for the mine water ingress evaluation (Section 3.0) and the water balance (Section 4.0) has been abstracted from the station files. Where pertinent, the data is presented in figure format; raw data is not appended.

2.6 Stream Flow Data

An intermediate term (>20 years of records) Environment Canada streamflow station, identified as McAskill Brook, was established by Baechler (1986) to form a background index station for the Sydney Coalfield. The gauge is positioned some 6 km south of the study area with continuous recording commencing in 1978 (Figure 2.7).

Relevant data has been abstracted from the station files for the water balance assessment (Section 4.0). Where pertinent, the data is presented in figure format; raw data has not been appended.



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	Dwg. Standards Chk. By:
Dwg. FIGURE 2.7 LOCATION OF CLIMATE AND STREAM GAUGING STATIONS	Designed By: FEB
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2.7 Estimates of Evapotranspiration

Theoretical evapotranspiration losses calculated using the Thornthwaite Method provide an annual value of 535 mm (21 inches) (Baechler, 1986). However, the accuracy is suspect for areas exhibiting a humid maritime climate, possibly overestimating the loss. Further discussion is provided in Appendix B.

2.8 Mine Water Level Data

2.8.1 Water Level Monitoring Methods

CBDC has been monitoring water levels at several locations throughout the Coalfield since 1984. The objectives of the mine water level assessment were to:

- Validate CBDC Water Level Rise Time Lines to 2002
- Determine Seasonal Influence on Mine Flooding Rates
- Assess Storage Volume of No. 12/14 Mine System
- Predict Time to Fill Remaining Voids
- Predict Fill Rate for a Variety of Above-Sea Storage Options
- Provide Information for Hydrology Study

Monitoring at Dominion No. 2 and 9 was discontinued in December 1993 and January 1996, respectively. Monitoring at Dominion No. 4 at Quarry Point was recently discontinued in March 2002. Available mine water level records are presented in Table 2.3. Only three mine locations are presently being monitored, in addition to the four Dominion boreholes that are used to monitor water level and "first flush" water quality as the water levels rise up the No. 1A and No. 5 slopes.

The assessment of mine water levels presented in this report focus on the No. 1B Hydraulic System using the more or less continuous records from the No. 1B Shaft (1986 through October 2002). Water levels in the Lingan and Phalen Collieries are also addressed in light of the outflow of waters from the No. 1B System while these mines were in operation. The No. 4 water levels are assessed to show the effects of seasonal recharge on a "mature" or fully flooded mine pool. The No. 4 situation provides insight into possible water level responses after the No. 1B System has reached equilibrium.

Water levels in the various mines are measured by CBDC with Campbell Scientific CX10X Data Loggers. Water levels are downloaded monthly for the Lingan and Phalen mines and weekly for the No. 1B Shaft. Bi-weekly manual measurements were made during some periods of the record. Two data loggers are set in the No. 1B Shaft. Two loggers are set in the Phalen Mine at depths of -1,760 ft (No. 1 Centre Top Level) and -969 ft (No. 1 East Bottom Level). One data logger is set in the Lingan Mine.

Water level data for the No. 1B Shaft is available since July 1986. Monitoring at the Lingan Colliery began in November 11, 1992, after the first inrush occurred. Monitoring in the Phalen Colliery began in June 2000 after closure of that mine. This study uses the "new" monitoring data collected since October 1993 in the inflow assessment and all of the data in the water level assessment.

TABLE 2.3: SUMMARY OF AVAILABLE MINE WATER LEVEL MONITORING DATA FOR THE SYDNEY COALFIELD

Colliery	Location	Type	Period of Record	Notes
No. 1A/1B	No. 1B Shaft	Data Logger	Jul 18/86 to Apr 6/89 Apr 6/89 to Oct 17/93 Oct 17/93 to Mar 15/90 Mar 15/90 to Dec 28/90 Dec 28/90 to Nov 27/92 Nov 27-92 to Jul 29/97 Aug 28/97 to Oct 27/97 Aug 16/98 to May 20/99 Jun 23/99 to Apr 18/00 Nov 17/00 to Mar 1/01 Mar 18/01 to Jul 28/01 Oct 5/01 to Mar 11/02 Apr 23/02 to Present	Intermittent Instrument Failure Intermittent Instrument Failure Intermittent (weekly) Daily Daily Daily Daily Daily Daily Daily Daily
Lingan		Data Logger	Nov 11/92 to 8 Sep/94 Nov 7/94 to Jan 18/95 Mar 30/95 to 7 Sep/97 16-Jul/98 to Aug 18/91 Feb 17/02 to Present	Daily
Phalen		Data Logger	Jun 11/00 to Dec 21/00 Jan 16/00 to Mar 17/02 Apr 19/02 to Present	Daily
Dominion No. 4	Quarry Point	Data Logger	Sep 8/86 to May 13/93 Jun 21/93 to Jan 28/94 Apr 4/95 to Jan 19/97 Aug 20/98 to Jun 21/99 Feb 24/00 to Mar 7/02	Weekly Daily Daily Daily Daily
Dominion No. 1A	BH1 BH2 BH3 BH4 BH5		Mar 12/02 to present Apr 26/02 to present Jun/02 to Present	Water Level and Quality Water Level and Quality Water Level & Quality Water Level and Quality Water Level and Quality
Dominion No. 2		Data Logger	Mar 9/95 to Jan 7/96	Continuous, hourly
Dominion No. 9		Data Logger	Mar 9/95 to Jan 4/96	Continuous, hourly

2.8.2 Determination of Mine Volumes

A number of basic assumptions were made in order to estimate the residual mine void volumes. The work done in 1993 (JWEL, 1993) involved the following steps:

- The plan view area (square feet) lying within each 100-ft structure contour interval was measured using a planimeter.
- The average dip between each 100-ft structure contour was calculated.
- The plan view area was adjusted for dip to reflect the increase in area produced by a dipping surface.
- The adjusted area was multiplied by the average coal thickness to determine extracted volume of coal.
- The extracted volume of coal was multiplied by the following **Estimates of Residual Void Space** to obtain the mine void volumes (ft^3) in place:
  - For Room and Pillar Mining with 42 to 47% coal extraction - **42%.**
  - For Room and Pillar Mining (Pillar Drawing) with 100% coal extraction - **30%.**
  - For Longwall Mining with 100% coal extraction - **30%.**
  - For Main HaulageTunnels with 100% coal and rock extraction **-100%.**

The term "Estimate of Residual Void Space" is used to indicate the amount of space remaining after the coal has been removed, the roof has collapsed into the mining-induced void and loading by superincumbent strata has compressed the collapsed rubble. It is an estimate of the void space available for filling with water as the mine waterfront advances. It has not been quantitatively derived. It is based on the judgment of experienced mining people using basic mining assumptions. The value of "Estimated Residual Void Space" is site-specific because local geology, mining depth, time and a number of other factors control it. In general, residual void space will be at a minimum in old mining areas that are deep and overlain by roof strata with good bulking characteristics (example: weak mudstone). It will reach a maximum in the youngest mining areas that are shallow and overlain by strata with poor bulking characteristics (example: laminated sandstone). In room-and-pillar mining areas, the Residual Void Space is essentially the same as the percentage of coal extraction. In Main Haulage Tunnels supported by steel arches, the roadways are assumed to be intact (not necessarily the case in all areas) and the Residual Void Space calculation is based on the area of the arch opening. The revised mine void calculations are presented in Appendix A.

2.8.3 Prepare Water Level Hydrographs

Water level monitoring records for the No. 1B Shaft, No. 4 Colliery, Lingan and Phalen mines, maintained by CBDC were compiled and presented as a series of annual water level hydrographs. A composite hydrograph covering all of the available period of record and annual hydrographs are presented in Appendix A (Figures A1 through A11) for the four mines with continuous records extending into 2002. All hydrographs include meteorological data from 1990. Other water level monitoring data for Dominion No. 2 and Dominion No. 9 mines was terminated prior to 1997, and were addressed in JWEL (1993) and JWEL (1997).

2.8.4 Review Mine Flooding History

An interpretation of the likely influences of active mining on the No. 1B water level rise was made for the period 1986 through present, using the revised mine water level data for the No. 1B Shaft, No. 4 Colliery, Lingan and Phalen mines, and through review of available historical records such as Frost (1964), JWEL (1993) and other information compiled on the CBDC web site.

2.8.5 Prepare Daily Flood Rate Hydrographs for Each Mine

In an effort to assess probable recharge rates to the mine complex, the water level data was converted to volumetric flow rate data and plotted on annual hydrographs (Appendix A). The estimated volume per 100 ft of mine void was divided by 100 and multiplied by the incremental daily water level rise in each mine to produce a hydrograph of "apparent" daily mine inflow. Because of the "noise" inherent in the daily values, a seven-day running mean (e.g., average of preceding three days and following three days plotted for a specific day) was utilized to provide a smoother hydrograph. All assessments are based on seven day running means.

"Apparent inflow rate" is defined as the likely rate of flow into the mine over a specified period. It should be noted that inflow rate on a daily basis will vary over time due to time lag between precipitation events, loss of water from the No. 1B - 26 Collieries to the Lingan and Phalen mine between 1993 and 2001, until those mines were almost fully flooded, and undetectable variations in mine volumes on a one foot basis as water level rise through collapsed workings, open or sealed workings, barrier pillars and haulage ways, etc.

The method clearly illustrates seasonal recharge variation to the No. 1B Hydraulic System, as measured at the No. 1B Shaft. The older data (1992 through 1999) clearly shows the effects of barrier pillar breaks on the Lingan and Phalen mines and consequent outfall of No. 1B mine water to those mines. A discussion of mine recharge is presented in Section 3.0.

2.8.6 Compare Flooding Rate With Precipitation

Early in the assessment, it became apparent that seasonal precipitation was the main driving force behind the observed rate of mine recharge and water level rise. Daily precipitation records were obtained from Sydney Airport for the period January 1990 through October 2002. These records were plotted as bar hydrographs against the annual recharge hydrographs to visually assess the effect and lag times of individual rainfall events on mine water level responses.

2.8.7 Estimate Current Rate of Water Level Rise and Recharge Rates

Trend analysis was performed on the last five years of data for a dry year, a wet year and average conditions to determine the annual recharge rate and water level rise rate that could be expected under current conditions. Where possible, bias introduced by missing hydrographic data was considered.

2.8.8 Predict Mine Water Discharge Times

Three time lines were generated using seasonal recharge assumptions for a dry, wet and average year. Predicted outfall times to sea level at the No. 1A sea drain were made for the three time lines. Time to fill remaining void above mean sea level on a 5-metre basis was also generated using the assumed void volumes above mean sea level.

2.8.9 Predict Mine Water Discharge Rates

A key component of the assessment is to predict probable effluent rates once the mine system has flooded to sea level, or to some above sea level equilibrium. An initial assessment of probable outfall rate is provided through a comparison of the inferred mine recharge rates and the hydrology studies of the landward recharge areas (Section 4.0).

2.8.10 Assessment of Mine Water Storage Options

The mine void assessment, review of historical water levels and water makes and on-going drilling exploration work was employed to assess various mine water storage options in other workings. The objective was to store water pumped from the No. 1B System in other non-flooded workings, thereby extending the time before sea level outfall occurs from the No. 1B System. Options under assessment included the No. 12/14 mines and the feasibility of pumping relatively non-aciduous waters from the No. 8 Mine.

3.0 MINE WATER INGRESS EVALUATION

This section presents an overview and summary of historical water level rise within the No. 1B Hydraulic System, based on measurements made in the No. 1B Shaft. A review of the water level and recharge responses at the Lingan and Phalen Collieries is also performed, since these collieries are now considered to be in direct hydraulic interaction with the No. 1B System through various strata breaks and seepage pathways. Hydrographs and detailed data tables are presented in Appendix A, which provide a more detailed assessment of the mine water levels and apparent recharge rates to the No. 1B Colliery.

3.1 No. 1B Hydraulic System

The Cape Breton Coalfield consists of 25 separate collieries organized into four Hydraulic Interconnection Systems and eight individual collieries (JWEL, 1993). These collieries contain 46 billion US gallons of mine water with static water levels being between -75 ft (No. 1B System) to +16 ft above sea level. Water levels in the No. 1B System were prevented from flooding to equilibrium due to exfiltration from the No. 1B and No. 26 Collieries into Lingan and Phalen mines over the past two decades. Since the Lingan and Phalen mines were closed in February 1993 and July 2000, respectively, water levels in the No. 1B System, as measured in the No. 1B access shaft, have been steadily rising towards sea level and as of October 30, 2002, were at -75 ft below sea level.

The No. 1B Hydraulic System consists of several abandoned collieries: No. 1A, No. 1B, No. 5, No. 9, No. 10, No. 20, No. 24, No. 26 and the most recent collieries of the Lingan and Phalen mines. Several other collieries (No. 3, 4, 6 and 11) are suspected to be indirectly interconnected to the No. 1B System via subsidence fracturing, bootleg workings or pillar retrieval operations. Table A1 (Appendix A) summarizes details for the collieries in the No. 1B Hydraulic System, as well as collieries in other Hydraulic Systems and their respective flooded and non-flooded volumes. Figure 2.6 (after, JWEL 1993) illustrates the assumed hydraulic interconnections between the collieries.

3.1.1 Current Flooding Status

Table 3.1 summarizes the flooding history for the No. 1B System. Six of the 24 collieries (Nos. 1A, No. 5, No. 12, No. 14, Lingan and Phalen) are currently flooding towards equilibrium between mean sea level and some elevation above sea level between 16 ft and 30 ft. The No. 1B System is presently (October 30, 2002) 96% flooded to an elevation of -75 ft below mean sea level. The Lingan Colliery is almost full and is flooded to -200 ft in main haulage ways. The Phalen Colliery is also almost full and is flooded to -557 ft in main haulage ways. Of mine void remaining to sea level, the No. 5 mine represents 66% of available No. 1B System storage.

TABLE 3.1: SUMMARY OF MINE FLOODING STATUS – NO. 1B HYDRAULIC SYSTEM (OCTOBER 30, 2002)

Mine	Static Water Level (ft)	Remaining to Sea Level		% Flooded	Total Volume Above Sea Level (ft^3)	Flooded Above Sea Level (ft^3)	Non-Flooded Above Sea Level (ft^3)
		(ft)	(ft^3)				
No. 1B Hydraulic System							
Dominion 1A/1B	-75.8	75.8	12,040,049	97.3%	1,984,957	0	1,984,957
Dominion No. 2	full	0.0	0		0	0	0
Dominion No. 5	-75.8	75.8	27,985,396	66.0%	12,852,894	0	12,852,894
Dominion No. 9	full	0.0	0	100.0%	0	0	0
Dominion No. 10	full	0.0	0	79.9%	25,168,710	5,033,742	20,134,968
Dominion No. 20	full	0.0	0	100.0%	0	0	0
Dominion No. 24	90	0.0	0	99.8%	1,979,129	98,956	1,880,173
Dominion No. 26	full	0.0	0	100.0%	0	0	0
Lingan	-198	198.0	662,713	99.0%	540,007	0	540,007
Phalen	-557	557.0	1,745,655	99.3%	180,403	0	180,403
Total (ft^3)			**42,433,813**		**42,706,100**	**5,132,698**	**37,573,402**
Total (m^3)			**1,201,793**		**1,209,504**	**145,366**	**1,064,138**

3.1.2 Water Level Responses

Annual water level hydrographs for the No. 1B Hydraulic System data logger records for the No. 1B Shaft are presented in Appendix A (Figures A2 through A10). Figure A11 illustrates the relative water levels for the Lingan, Phalen and No. 1B System from November 1992 to present.

The annual hydrographs generally show a relatively rapid rate of water level rise in the spring and late fall and a general decrease in water levels over the summer period (June through October). The rate of water level rise in the No. 1B System is related to precipitation, outfall to other mines and uneven filling rates within the workings, which are constantly changing in area as the water level rises. For example, a relatively quick rise would be expected where limited lateral workings or predominantly haulage water are present, as opposed to elevations with large areas of interconnected workings.

Figure A1 in Appendix A illustrates the flooding history in the No. 1B Shaft between February 1984 and present. The No. 26 Colliery closed in 1984, No. 1B pumps were stopped November 1985 and the No. 4 pumps stopped in September 1986. The numbers indicate significant events occurring during the period of monitoring and are summarized below:

1. No. 1B losing water to No. 2 prior to February 1986
2. No. 1B and No. 2 mines reach equilibrium (about November 7, 1986)
3. No. 1B level reaches No. 5 deep barrier spill point to inside region of No. 1B (elev. -580 ft)
4. Inside region of No. 1B reaches equilibrium with rest of No. 1B by September 19, 1988
5. Water level reaches No. 26 seals mid-December 1988; began to spill to No. 26 Colliery
6. 45 ft water level decline October 1989 to March 1990 (unknown cause; possible void filling)
7. No. 1B and No. 26 reach equilibrium at -554 ft level mid March 1991
8. First break between No. 26 and Lingan 2E November 29, 1992 (2,000 USgpm outfall to Lingan)
9. Second break between No. 26 and Lingan February 17 to 25, 1994 (7,000 USgpm outfall to Lingan)
10. Lingan and No. 1B water levels approach hydraulic pressure equilibrium at break elevations
11. Seasonal declines in summer due to continuing outfall to Lingan (and/or Phalen)
12. Water level reaches top of Dominion No. 26 (-340 ft)
13. Water level reaches top of Dominion No. 20 (-290 ft)
14. Water level reaches top of Dominion No. 9 (-200 ft)
15. Recovery trend over past three years due to reduction in outfall to Lingan-Phalen
16. Major spring recharge events control annual rate of water level rise

17. Spring recharge 2002

18. Beginning of fall recharge 2002

Figure A11 (Appendix A) illustrates the relative water levels in the Lingan, Phalen and No. 1B System between 1992 and 2002. By the end of 1997, the Lingan and No. 1B mines were near hydraulic equilibrium and rates of water level rise were similar thereafter, suggesting that the majority of inflow originated from the No. 1B System. The Lingan water level was at -198 ft (October 30, 2002) and was rising in the main haulage ways at an average rate of 0.35 ft per day.

The water level in the Phalen mine recovered quickly over the past two years and correlates with the estimated average pumping rate of about 1,000 USgpm prior to the closure of the Phalen mine. The water levels in the Phalen mine are currently at -557 ft elevation and are rising in the main haulage ways at an average rate of 1.6 ft per day.

3.1.3 Estimated Inflow Rates

The historical water make of the No. 1B Hydraulic System and other mines in the Cape Breton Coalfield, determined from historical records summarized in Frost (1964) and JWEL (1993), are shown on Table 3.2. Additional details are shown on Table A.2 in Appendix A. Historical records suggest a maximum recharge potential of up to 3,400 USgpm if all workings were still in operation, with the greatest potential for recharge to occur in the vicinity of the No. 10 (50%), No. 9 (26%) and combined No. 1A and No. 5 (16%) Collieries. With the exception of the No. 9, which was entirely sub-sea, the higher contributor comes from above-sea workings. It is noted, that there was no inflow data for the No. 5 Colliery, which is suspected to be a major contributor to current inflows. Other possible connected contributors could include the No. 4, which provided a 940 gpm inflow rate. If collieries Nos. 3, 4, 6 and 11 were contributing the No. 1B Hydraulic System, total operational inflows could be as great as 5,000 USgpm when all mines were in operation or non-flooded.

TABLE 3.2: SUMMARY OF NO. 1B HYDRAULIC SYSTEM MINE DATA

Colliery	Seam	Elevation Top (ft)	Elevation Bottom (ft)	Water Make (USgpm)	Water Quality Type	Water Quality pH
No. 1A	Phalen	15	-615	550	acid	-
No. 1B	Phalen	-615	-2,350	50	acid	-
No. 2	Phalen	-525	-2,010	12	acid	2.28
No. 5	Phalen	115	-550	?	?	-
No. 9	Harbor	-200	-700	900	acid	2.5
No. 10	Emery	125	-460	1,750	acid	3.1
No. 20	Harbor	-293	-1,400	135	acid	-
No. 24	Emery	5	-800	?	?	-
No. 26	Harbor	-340	-2,700	15	alkaline	6.02
Lingan	Harbor	87	-2,680	<50	alkaline	5.5
Phalen	Phalen	90	-3,000	<50	alkaline	6.3
Total No. 1B System				**3,412**		
Other Mines Possibly in Hydraulic Connection:						
No. 3	Phalen	30	-530	?	alkaline	6.0
No. 4	Phalen	45	-2,010	940	acid	2.1
No. 6	Phalen/ Harbor	27	-1,300	248	acid	2.29
No. 11	Emery	20	-950	420	acid	3.3
Total No. 1B System With Other Interconnections:				**5,020**		

Figures A12 through A21 (Appendix A) illustrate the combined (Figure A12) and annual (Figures A13 to A21) recharge hydrographs for the No. 1B Hydraulic System based on the observed water levels and known void volumes per foot of water level rise. All values are presented as seven day running mean USgpm.

Several approaches were taken to estimate a reasonable average annual recharge rate to the No. 1B Hydraulic System. In selecting appropriate recharge rates for a given year, consideration was given to degree of outfall to the underlying Lingan Colliery, seasonal considerations and missing data. Calculations of annual recharge involved estimation of apparent recharge rates over periods with missing data.

Table 3.3 summarizes the range and mean apparent annual recharge rates for the No. 1B Hydraulic System based on seven day running means. Missing data in the record is compensated for by adding the average daily recharge rate (USgpm per foot of mine volume rise) for each missing day.

TABLE 3.3: MEAN ANNUAL APPARENT DAILY RECHARGE RATES FOR NO. 1B HYDRAULIC SYSTEM

Year	Minimum (USgpm)	Maximum (USgpm)	Annual Mean (USgpm)	Summer Mean (USgpm)
2002	-110	5,039	**847**	654
2001	-331	5,386	**342**	-149
2000	-281	3,988	1,217	-
1999	-1,266	10,381	1,580	-611
1998	-1,665	2,361	174	-1,061
1997	-1,459	5,496	592	-143
1996	-651	6,836	1,545	551
1995	-1,375	4,342	834	151
1994	-14,032	5,876	2,471	-2,885
1993	2,451	5,876	n/a	-
1995-2001	**-14,032**	**10,381**	**891**	-

Note: Minima and Maxima are absolute daily values; annual and summer mean values corrected for missing data

Based on the annual inflow rate hydrographs presented in Appendix A and Table A.3, the 10 year long term average annual recharge rate at the No. 1B System appears to be approximately 890 USgpm, ranging from a maximum inflow of up to 10,381 USgpm during and shortly after peak storm events, to a maximum outfall of -14,032 USgpm during the Lingan Break (Appendix A). This is consistent with the 834 USgpm flow rate for 1995, which is selected as a representative mean year. This long-term value may be low because of the large volumes of water lost to the Lingan and Phalen Collieries since the first Lingan break in November 1992. Outflows to Lingan and Phalen are negligible over the past year (< 100 USgpm).

Since water level response and rates of recharge are strongly related to seasonal precipitation and runoff distribution, three mean annual recharge rates are considered for further assessment:

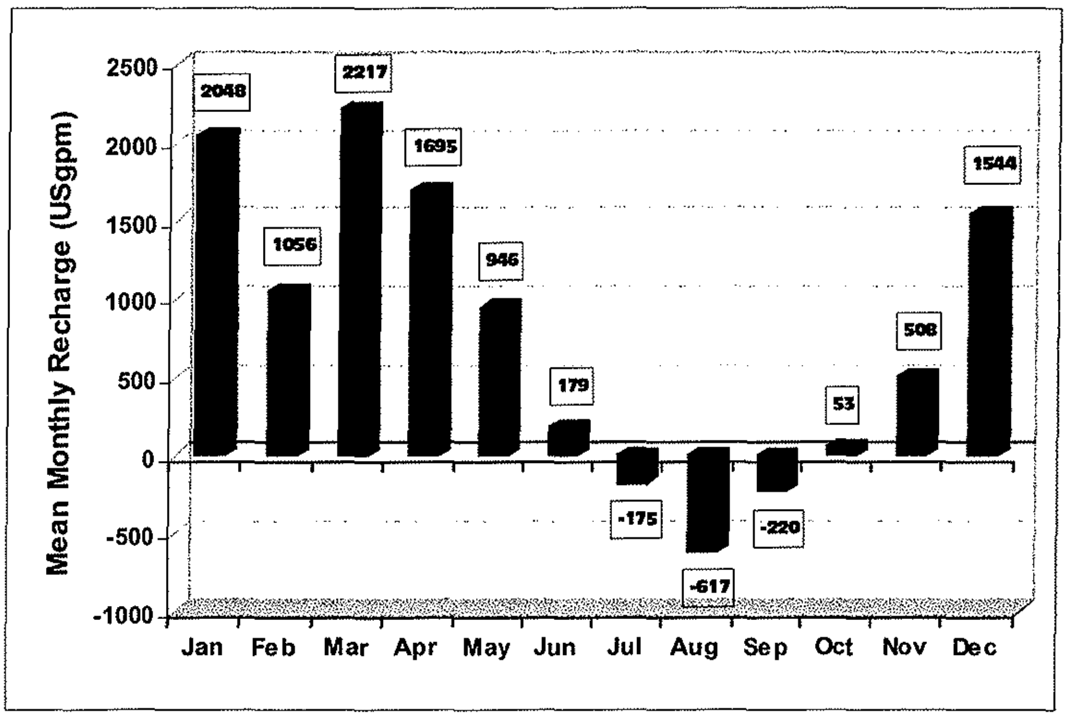
- Dry Year (1995): 370 to 439 USgpm
- Average Year: 812 USgpm
- Wet Year (1996): 1,545 USgpm

In consideration that no data was available for the summer period, August through October in 2001, and assuming that outfall in the order of -350 USgpm occurred over the period, actual dry year annual recharge may be as low as 370 USgpm.

3.1.4 Seasonal Relationships

The water level and recharge rates are controlled by seasonal variation in precipitation with declining degree of loss to Lingan-Phalen Collieries over the past two to seven years (Figure A22 (Appendix A) and Figure 3.1). While individual annual hydrographs (Figures A13 to A21) typically exhibit a bimodal hydrograph coincident with Nova Scotia stream and groundwater hydrographs and climate normals, the composite hydrograph shown on Figure A22 shows that the majority of mine recharge occurs between November and April. The 1996 year is anomalous due to the intense rainfalls associated with Hurricane Hortense in September 1996. Water level declines are observed during the summer due to net loss of water to the Lingan and Phalen Collieries and to redistribution throughout other areas of the No. 1B complex. The spring recharge events tend to be larger than the fall events, likely due to the time lag required for the hydrogeological system to become saturated after a long period of drought. In the past two years, the rate of discharge has diminished from a maximum of over 2,800 USgpm in 1994 as Lingan filled, to less than 200 USgpm in 2001 and 2002.

Figure 3.1 Distribution of Mine Recharge Using Monthly Means No. 1B System



3.2 Lingan and Phalen Collieries

An evaluation of the water level rise and apparent recharge rates to the Lingan and Phalen Collieries was completed to provide further insight into the possible inter-relationships between the two mines, especially in earlier years when the No. 1B System was contributing water to the flooding Lingan Colliery. A more detailed explanation of interconnection mechanisms was presented in JWEL (1997). The relative water levels for the three collieries are shown on Figure A11 (Appendix A). Figures A24 to A34 (Appendix A) and Figures A35 to A38 (Appendix A) illustrate the estimated mine water recharge rates for the Lingan mine and the Phalen mine, respectively.

As shown in Figures A24 to A34, the rate of recharge to Lingan has declined from over 2,000 USgpm in 1992 and 1993 to less than 10 USgpm over 10 years. The Lingan water levels also appear to respond to major precipitation events, possibly a pressure response from the overlying No. 1B System, with rates of apparent inflow reaching 100 USgpm in spring and fall.

Apparent recharge to the Phalen mine was very rapid (up to 7,000 USgpm) in September and October of 2000 after pumping was terminated, declining rapidly to a steady recharge rate of about 1,000 to 1,200 USgpm which is consistent with final mine pumping rates prior to closure, with fluctuations of 200 to 400 USgpm until about mid June 2002, when the water level filled the main workings and reached the haulage ways. Current flooding rate is in the order of 35 USgpm.

3.3 Effect of MacKay's Corner Remediation

The MacKay's Corner wetland was partially remediated in late 1996 after a major inflow of water into the No. 1B System. After repeated sinkhole formation in this area, further remediation continued until August 2001 by placing a layer of low permeability glacial till over the subsided areas. A comparison of the rate of water level rise in the spring of 2000 and 2001 with the spring of 2002 indicates negligible change that cannot be accounted for by seasonal effects. For example, the 48 ft of water level rise in 2001 (a dry year) was very similar to the 53 ft of rise in 2002 (also after a dry period).

3.4 Predicted Fill Times

Tables 3.4 and A.4 in Appendix A summarize the estimated time lines for mine water levels to reach mean sea level for a dry, average and wet year, respectively. Fill predictions are made for Lingan and Phalen assuming the average of the last year of recharge of 10 USgpm and 45 Usgpm, respectively.

TABLE 3.4: SUMMARY OF PREDICTED MINE FILLING DATES

	No. 1B		Lingan		Phalen	
	Months	Date	Months	Date	Months	Date
Dry Year	18.5	April 2004	-	-	-	-
Average Year	8.4	July2003	12.5	November 2003	6.6	April 2003
Wet Year	4.4	March 2003	-	-	-	-

3.4.1 No. 1B Hydraulic System

Water levels in the No. 1B System (No. 1A and No. 5 Collieries) are predicted to reach sea level within 4.4 to 18.5 months for a wet or dry year, respectively (mean 8.2 months for an average year of rainfall). Assuming the trends observed over the past few months continue, outfall could occur by June 2003, a wet fall could result in outfall by spring 2003. Each 5 ft increment above sea level represents an additional time delay or storage of 1 month (wet year) to 4.5 months (dry year), mean 2 months is estimated. Allowing the mine to flood to +30 ft is, therefore, not considered to be viable due to numerous possible outfalls near or slightly above sea level, including the No. 1A outfall at about +5 ft elevation.

In consideration of the recharge distribution (e.g., Figure A23), about 75% of this recharge is expected to occur over the winter and spring of 2002 - 2003. Therefore, the mine could be full or approaching sea level (± 20 ft) by the end of the 2003 spring recharge event.

3.4.2 Lingan Mine

Based on the current water level of -200 ft (October 2002), an assumed volume of 662,713 ft^3 remaining to sea level and a calculated recharge rate of 9 USgpm, the Lingan mine should be filled to sea level within about one year. Time to fill to the expected static water level at 20 ft above sea level could add approximately 30 months. Since water levels are rising in the main haulage ways, the Lingan can be assumed to be essentially flooded now. No outfall from the Lingan is anticipated.

3.4.3 Phalen Mine

Based on the current water level of -557 ft (October 30, 2002), an assumed volume of 1,745,655ft^3 remaining to sea level and a calculated recharge rate of 45 USgpm, the Phalen mine should be filled to sea level within about 6.6 months. Negligible additional storage is present above sea level and about 3.8 years would be required to fill the remaining voids to +40 ft. Since water levels are rising in the main haulage ways, the Phalen can be assumed to be essentially flooded now. No outfall from the Phalen is anticipated.

3.4.4 Summary

In summary, apparent recharge predictions suggest that the three remaining flooding collieries could be filled to sea level in less than 1.2 years (December 2003). In the event of a wet year, recharge could be complete by the spring of 2003. If dry conditions continue, filling could be delayed to late 2003 or early 2004. Allowing the workings to flood above sea level is not expected to increase these projections by more than a few months. The main uncertainty is the potential for recharge rates to continue to decline as the mines fill, thereby extending the discharge time by several months or years. Continuing monitoring of water level rise is needed to detect this trend.

4.0 WATER BALANCE DEVELOPMENT

4.1 Background and Approach

Section 3.0 defined "*how much*" water was getting into the 1B System, as well as "*when*" and "*how fast*", based upon analysis of mine water levels.

This section summarizes a water balance investigation designed not only to determine "*how*" and "*where*" the water identified in Section 3.0 is infiltrating into the workings, but also to define "*how much*". Support documentation for this section is provided in Appendix B and Map 4 (included in the pouch at the conclusion of this report). A summary of the approach and findings is provided below.

4.2 Conceptual Flow Model - "How is the Water Moving?"

Climatic and geological conditions within the Sydney Coalfield have created conditions which maximize infiltration and, therefore, inflow to the mine workings. High rainfall from low intensity storms creates a large water surplus that recharges groundwater during at least two periods every year (fall and spring) and possibly a third during mild winters.

This recharge maximizes the extent of saturation of the geological materials providing high water tables to drive the flow system. Stream drainage densities are low, with high width/depth ratio channels, thereby enhancing recharge and providing direct drainage control for only interflow and shallow water table saturated groundwater flow – the remainder is available for deeper recharge.

Urban landuse within the study area should generally act to minimize recharge. Historical mining activities near the outcrop of the Phalen Coal Seam creates subsidence and increased permeability, further enhancing recharge directly into the mines. This is exacerbated by one of the longest on-land extent of cropline in the study area, some 9.4 km (5.7 miles) long.

4.3 Watershed Areas – "Where is the Water Getting In?"

By understanding the flow systems (Section 4.2), it was then possible to delineate watershed areas contributing flow by these processes to the mine workings. This included not only natural "watersheds" (drainage controlled by ground surface topography), but also "Minesheds" (drainage controlled by extent of mine workings) and "Sewersheds" (drainage controlled by storm/sanitary sewers). The aerial extent of these "sheds" as they relate to the Phalen Coal Seam are delineated on Map 4.

These "sheds" were further subdivided into drainage types that corresponded with different flow systems defined in Section 4.2, including: Sinkholes and their Drainage Area, Bootleg Workings, Watersheds for Bootleg Workings, Groundwater Flow Field, Ground-Surface Water Interaction, Sewersheds and Minesheds.

These seven drainage types were combined into three Watershed Scenarios for determining contribution to the No. 1B Mine Hydraulic System, namely:

Scenario A – No. 5 Colliery Mineshed, with a watershed area of 87 hectares (214 acres) along 3.6 km (2.3 miles) of cropline.

Scenario B – Scenario A plus No. 1A Outfall extension, with a watershed area of 109 hectares (286 acres) along 4.5 km (2.8 miles) of cropline.

Scenario C – Scenario B plus No. 3 and 4 Colliery Minesheds, with a watershed area of 269 hectares (664 acres) along 8.0 km (5.0 miles) of cropline.

Three major streams cross the watershed areas allowing potential for additional inflow. Groundwater-stream interaction where Cadegan Brook crosses the bootleg workings at MacKay's Corner (Map 2) is of paramount importance since it is positioned over the No. 5 Colliery Mineshed, which is in direct link to the No. 1B System. In addition, the reach is relatively long, occurs within a large wetland with a lake and includes two dense areas of sinkholes. Finally, of the three crossings, it is positioned at the highest topographic elevation (30 m) and is known to have a higher hydraulic head in the surface water system than in the underlying unsaturated mine workings; thereby creating a downward driving head and confirmed influent conditions. Three localized sinkholes have already been infilled by CBDC where surface water within the wetland was noted flowing directly into the mine workings. This is augmented by direct discharge into the workings from the MacKay's Corner Sewershed through the lift station. If fully inundated, the overflow pipe could, theoretically, discharge some 1,700 USgpm into the No. 5 Colliery.

4.4 Contribution from Contributing Areas – "How Much?"

Having defined *"how"* the water could infiltrate into the mines (Section 4.2) and *"where"* (Section 4.3), the next step was to quantify the flows using a water balance approach.

The simplified water balance equation for a watershed of known size without man-made diversions to investigate groundwater inflow is:

$$\mathbf{Rgw = P - (ET + Rsw \pm S)}$$

Where:

Rgw = groundwater runoff
P = precipitation
ET = evapotranspiration
Rsw = surface water runoff
S = change in storage

The last decade has shown an overall decline in total annual precipitation (Baechler, 1999). To best reflect existing conditions, the last 10 years was assessed for high, low and normal precipitation years. The selection was also based on having adequate No. 1B System hydrograph records to allow for calibration of the analysis. This resulted in the year 1995 taken as a normal year (54.27 inches of precipitation), 1996 as the wet year (69.01 inches) and 2001 as the dry year (46.09 inches).

The lack of reliable information on evapotranspiration loss was resolved by undertaking a baseflow recession analysis of the McAskill Brook streamflow data to determine the groundwater runoff component of streamflow. The streamflow hydrographs, developed from mean daily flow data for the three selected years, are provided in Figures B.2 to B.4 at the end of

Appendix B. A modified Kunkle (1962) method of baseflow analysis was undertaken on each annual hydrograph to develop minimum and maximum groundwater flow components, as outlined in Figures B.2 to B.7 (Appendix B).

Given consideration to the conceptual flow model and watershed areas, the following recharge values were utilized to quantify groundwater inflow to the mines.

A. Sinkholes and their drainage areas (all precipitation)
B. Bootleg workings (maximum groundwater inflow)
C. Bootleg working drainage area (minimum groundwater inflow)
D. Inflow leakage from the Groundwater Flow Field (GW-FF) was calculated using the equation: **Q=KIA**

The maximum groundwater flow component resulted in 28.9 to 29.4 inches of annual groundwater recharge over the three years. The minimum groundwater flow ranged from 14.5 to 15.5 inches. This is far in excess of values used within the Sydney Coalfield in the past of 152 mm (6 in.) (Brown, 1967) and in numerical computer models of 380 mm (15 in.) (JDAC, 2001). This further supports the maximizing of mine water inflow by the climatic and geological setting.

In summary, the model predicts average annual inflow rates to range between 450 (dry year) and 1070 (wet year) USgpm, with an average of approximately 1000 USgpm. The resulting calculations are summarized in tabular format on Map 4 and re-defined in terms of USgpm and percentage of total in Table 4-1.

TABEL 4-1: SUMMARY OF AVERAGE ANNUAL INFLOW RATES FROM VARIOUS SOURCES

	Sinkholes and Drainage Area	Bootleg Workings	Bootleg Working Drainage Area	Groundwater Flowfield	Total Inflow
DRY 2001					
Scenario A	83 (22%)	175 (46%)	47 (13%)	71 (19%)	376 (100%)
Scenario B	146 (32%)	175 (38%)	67 (15%)	71 (15%)	459 (100%)
Scenario C	231 (25%)	317 (34%)	266 (28%)	121 (13%)	936 (100%)
NORMAL 1995					
Scenario A	98 (25%)	176 (44%)	50 (13%)	71 (18%)	395 (100%)
Scenario B	172 (35%)	176 (35%)	72 (15%)	71 (15%)	490 (100%)
Scenario C	272 (28%)	320 (32%)	283 (28%)	121 (12%)	997 (100%)
WET 1996					
Scenario A	124 (29%)	177 (42%)	50 (12%)	71 (17%)	422 (100%)
Scenario B	218 (41%)	177 (33%)	71 (13%)	71 (13%)	538 (100%)
Scenario C	346 (32%)	322 (30%)	281 (26%)	121 (12%)	1072 (100%)

Note: Values are in USgpm (% of total for specified scenario)

In summary, the information indicates:

DRY YEAR (2001): In a dry year, the average annual flows theoretically range from 376 to 936 USgpm, depending upon which Watershed Scenario is selected. When compared with the average annual inflow from the mine water hydrograph analysis of 342 (corrected) to 472 (uncorrected) USgpm, the closest approximation is Scenario B (459 USgpm). This underestimates inflow at 85% of calibrated value. Given consideration of the errors involved in deriving the water balance and calibration values, this suggests that when rainfall isn't high, direct inflow through the No. 5 Colliery, including the No. 1A Outfall extension (Scenario B), dominates. Most of the water enters through the bootleg workings (38%) followed by the sinkholes (31%).

NORMAL YEAR (1995): In a normal year, the average annual flows theoretically range from 395 to 997 USgpm. When compared with the mine water hydrograph analysis of 834 USgpm, the most representative value is Scenario C of 997 USgpm. This overestimates inflow at 120%

of calibrated value. This suggests that as conditions become wetter the No. 3 and No.4 Colliery Minesheds become hydraulically active and direct inflow to the No. 1B System. Most of the water continues to enter through the bootleg workings (32%), followed by the drainage area to the bootleg workings (28%) and the sinkholes (27%).

WET YEAR (1996): In a wet year, the average annual flows theoretically range from 422 to 1072 USgpm. When calibrated against the hydrograph analysis of 1545 USgpm, the most representative value is again Scenario C of 1072 USgpm. This underestimates inflow at 67% of calibrated value. This confirms what was noted above, that as conditions become wetter the No. 3 and 4 Colliery Mineshed become more important in directing flow into the workings. Since the percent error of calibration is larger and becomes an underestimation compared to a normal year, it also suggests that other factor(s) also become active as conditions become wetter, including, but not limited to:

- Enhanced leakage from storm/sanitary sewers (i.e., MacKay's Corner Lift Station); and
- Enhanced leakage from streamflow crossing the bootleg workings, combined with expansion of the sinkhole and bootleg working watershed areas due to extension of storm saturated overland flow, particularly in the MacKay's Corner wetland area. Most of the inflow now appears to originate from the sinkholes (32%), followed by the bootleg workings and their drainage area at 30% and 26%, respectively. This increased importance of the sinkhole system further supports the above contention.

Additional investigations into No. 3 Colliery since October 31, 2002, suggest there is no strong direct hydraulic link between No. 3 and No. 5 Collieries. However, indirect hydraulic connection through low permeable collapsed zones is still possible. These would be expected to provide enhanced leakage during periods of higher head in No. 3 Colliery.

On a maximum one-day duration peak storm event, inflow rates are expected to range from 2,000 to 2,500 USgpm for the Scenario A Watershed, 3,100 to 3,900 USgpm for Scenario B and 5,400 to 6,400 USgpm for Scenario C. The close resemblance of flows between all three years for each Watershed Scenario suggests that regardless of the annual climatic conditions there will be at least one such event of this magnitude. Regardless of year, or Watershed Scenario, most of the inflow occurs from the sinkholes and their drainage area, ranging from 47 to 89%, with higher values associated with wetter conditions. There is, therefore, a high probability that a "large" portion of peak storm inflow is from the MacKay's Corner wetland area.

The water balance model provides mine water inflow rates approximately similar to that provided by the mine hydrograph model at both average annual and maximum peak daily inflows. Therefore, the water balance model appears to provide an acceptable description of *"how"* and *"where"* water is entering the mine workings. The degree of error between the two models increases as wetter and wetter conditions prevail, with the former providing underestimates. This discrepancy is believed due to other processes becoming more dominant, such as sewer inflows and storm saturated overland flow within the MacKay's Corner wetland.

5.0 CONCLUSIONS

The terms of reference for the Water Balance Assessment fundamentally involved answering, to the best extent possible, a series of questions posed by the Hydrogeological Working Group. These questions, and the associated answers, form the basis of the following report conclusions and any data gaps or suggestions for on-going work are outlined in the following Recommendations (Section 6.0).

(a) Can the rate of mine water rise in the 1B System be slowed by controlling input?

(b) Can the rate of mine water rise in the 1B System be slowed through diversion to available storage?

(a) Yes, based on the information available, it appears that the rate of mine water ingress can be slowed by mitigating input through subsidence areas and direct sewage discharge (i.e., MacKay's Corner). The elimination of this input, estimated at up to 6,000 USgpm, would extend the flooding to sea level time frame to between approximately 21 and 33 months from the current estimate of three to six months. It is noted that although this solution would significantly reduce the rate of inflow, it would not eliminate the eventual flooding and overflow of the system and, therefore, treatment may be required. It is further noted that the cost of eliminating the subsidence areas via infilling is significant (estimated at between 2.5 and 3 million dollars) and there are numerous timing and logistical problems associated with this potential undertaking, including the fact that many of these areas are located on private property. In addition, the cost associated with the redirection of the MacKay's Corner overflow is again not a simple or inexpensive proposition (estimated at between 1.5 and 2 million dollars) and extensive discussions with the CBRM and the NSDEL will have to occur prior to rerouting this flow.

(b) No, it appears from the available data that there is no available storage in adjacent hydraulic systems to temporarily divert water from the No. 1B Hydraulic System. However, it may be possible to remove and directly discharge (to the marine environment) water from the No. 8 Hydraulic System and, therefore, create storage for water from the No. 1B System. Thereby, extend the flooding time line for an additional estimated 12 to 16 months and not eliminate the eventual need for treatment. This time frame is based on a total available empty storage volume in the No. 8 Hydraulic System of 73,000,000 ft^3 (546,040,000 US gallons) not taking into consideration the variation in vertical storage volumes and assuming an average flow rate from the No. 1B System of 800 USgpm. It is noted that the total removal of water from the No. 8 Hydraulic System may raise subsidence concerns and, therefore, this requires investigation prior to pursuing this option. In addition, there is also a concern that the pumping of water into the No. 8 System may re-dissolve the iron precipitate (i.e., ochre) and create eventual additional treatment and/or discharge problems.

What is the maximum flow rate that may enter the mine through the 12-inch overflow pipe located in the MacKay's Corner Sewage Lift Station?

Based on hydraulic principles of a 12-inch diameter pipe and a grade of 1%, it is estimated that the sewage overflow at MacKay's Corner could theoretically contribute 1700 USgpm when running at full volume. To date, no information is available that would enable a calculation of how much water, as a peak flow or in total, is being contributed to the No. 1B Hydraulic System from this source. This is due to the fact that overflow conditions have not occurred during current monitoring efforts and that it is probable that the significant flow occurs during spring runoff conditions, which have not been monitored to date.

Can discharge be controlled by plugging existing/potential outfalls and allowing the water to rise above sea level?

Yes, by allowing the No. 1B System to flood to sea level or above, the overall flow rate at the point of discharge will be reduced based on a reduction of groundwater input via infiltration and leakage due to reduced groundwater head differentials. Furthermore, allowing the No. 1B System to rise to an elevation of +20 ft above sea level should not affect basements or groundwater well supplies, as to the best information available, there are no basements located below this elevation or any existing wells in the area to be potentially affected. A 20 ft additional head would extend the outfall time at No. 1A by 8.5 months for an average water year, but only by about 1 month during a wet year.

When will the water level in No. 1B reach sea level?

Given the present level of information, it is estimated that the No. 1B Hydraulic System will flood to sea level within 4 to 12 months (i.e., April to December 2003). The variability of this estimate is due to a lack of predictive capability with respect to precipitation over this period going forward and not on mine storage volume estimates, which are believed to be relatively accurate. Planning should anticipate a spring 2003 discharge date.

What maintenance water level should be maintained in the No. 1B System?

The maintenance water level in the No. 1B Hydraulic System can be maintained at a variety of different levels, depending upon the amount of water removed via pumping. Alternatively, the mine water discharge can be controlled via a variable pumping rate and maintaining a constant water level in the mine, which would, in all probability, provide a more consistent flow and water quality. It is noted, however, that the pumping rate would be extremely variable and is estimated to range from a minimum of a few hundreds of USgpm, up to 6,500 USgpm, under spring flood conditions. Assuming maximum spring recharge event of 10 days at 6,500 USgpm, a freeboard of about 25 ft is recommended.

What will be the pumping rate necessary to establish the above-noted maintenance water level?

Based on the results obtained from the water ingress evaluation and conceptual water balance study, it is estimated that a pumping rate of between 800 and 1,000 USgpm will be required on a constant annual basis to eliminate natural discharge. This estimate could be reduced by an estimated 20 to 25% as the mine pool hydrogelogical conditions stabilize.

What is the seasonal variation in the expected flow rate at the outfall?

Without water elevation control via pumping, it is estimated that the seasonal variation in the rate of expected flow from the outfall will range from a minimum of 400 to 600 USgpm to a maximum of 6,500 USgpm.

Where is the best location to pump (or extract) the mine water?

Based on the available information, the optimum location to extract mine water from the No. 1B Hydraulic System is via a series of pumping wells into the No. 5 Colliery, assuming that constant pumping and the maintenance of a stable water level is the chosen long term option.

What will be the chemical, bacteriological and physical quality of the mine water and will it require treatment prior to discharge?

This issue is to be addressed in greater detail in the "Water Quality Report" for the No. 1B Hydraulic System, which will be provided under separate cover.

If the No. 1A Outfall is plugged, determine where the next seeps or outfalls will occur?

If the No. 1A Outfall is plugged, it is estimated that the mine water in the No. 1B Hydraulic System will rise above sea level. Based on this supposition, water may discharge via a water level drift from the No. 1B coal shaft to the coast at approximately the 5 ft elevation. Based on the configuration of the No. 1A water level, mine water levels are likely to rise to between 8 and 13 ft before exiting via the No. 1A sea drain. Discharge may also occur through known bootleg workings at the coast near the 1A Outfall (per. comm., Don Peckham, CBDC).

6.0 RECOMMENDATIONS

1) Continue investigations into mine pool water quality to address the potential of the discharge of untreated mine water from the No. 1B System into wetlands or the coastal marine environment.

2) Continue monitoring the MacKay's Corner Lift Station through to the summer of 2003 to determine an estimate of the total and peak volumes of water being contributed from this source.

3) Install additional boreholes into mine hydraulic systems including No. 4 and No. 8 to gain an understanding of the various mine pool water quality and/or elevations.

4) Initiate stream flow monitoring upstream and downstream of the three major stream crossings, which transverse the designated No. 1B Hydraulic System inflow areas to determine any potential losses of surface water to the mine system in these areas. Monitoring should be conducted during both non-rainfall and storm flow conditions.

7.0 LIST OF REFERENCES

ADI Nolan Davis, 1993, *Origin of Saline Groundwater Entering the Phalen 6E Panel*, September 1993, Submitted to CBDC, 44 pg's.

Baechler, F. and L. Baechler, 2002, *The Water Resources of Cape Breton Island* – in progress.

Baechler, F., 1999, *Cape Breton Island – Climatic Change Since the 1940's and Its Hydrologic Implications*, CWRA 52nd Annual Conference, June 1999, pp 1-14.

Baechler, F., 1986, *Regional Water Resources Sydney Coalfield, Nova Scotia*, Nova Scotia Department of Environment, 111 pg's.

Brown, I.C., 1967, *Groundwater in Canada*, Geological Survey of Canada, Economic Geology, Report No. 24, Ottawa.

Dunne., T. and I. Leopold, 1978, *Water in Environmental Planning*, W. H. Freeman and Co., San Francisco, 818 pg's.

Frost, L., 1964, *A Review of the Coal Properties Operated by Dominion Steel and Coal Corporation Limited,* 172 pp., Additional Notations dated 1977.

Grant, D. R., 1994, *Quaternary Geology, Cape Breton Island, Nova Scotia*, Geological Survey of Canada Bulletin 482, 159 pg's.

Heath, R. C., 1988, *Hydrogeological Setting of Regions, in Hydrogeology, the Geology of North America*, edited by Baeck, W., J. Rowenshein and P. Seaber, Geological Society of America, 524 pg's.

JDAC Environment 2001, *Phase II Environmental Site Assessment Report – Muggah Creek Watershed*, Vols 1 – 4, submitted to Nova Scotia Department of Transportation and Public Works.

Jacques Whitford and Associates Limited, 1993, *Colliery Water Study, Sydney Coal Fields, Cape Breton, Nova Scotia*, Report to Cape Breton Development Corporation, Project No. 8728, September 16, 1993.

Jacques Whitford Environment Limited, 1997, *Environmental Engineering Study - Update Status of Flooding Mines,* Report to Cape Breton Development Corporation, Project No. 11545, February 25, 1997.

Kunkle, G. R., 1962, *The Baseflow-Duration Curve, a Technique for the Study of Groundwater Discharge from a Drainage Basin*, Journal of Geophysical Research, Vol. 67, No.4 pgs 1543 – 1554.

Randall, A. D., R. M. Francis, M. H. Frimpter and J. M. Emery, 1988 Region 19, Northeastern Appalachians, in Back, W., J.S. Rosenshein, P.R. and Seaber, eds Hydrogeology: Boulder, Colorado, Geological Society of America, The Geology of North America, V.-2.

Thornthwaite, C., 1948, *An Approach Towards a Rational Classification of Climate*, Geog. Rev., Vol. 38, pp 55-94.

Toth, J., 1962, *A Theoretical Analysis of Groundwater Flow in Small Drainage Basins*, in Proceedings of Hydrogeology Symposium N.3 – Groundwater National Research Council of Canada, Assoc. Committee Geodesy and Geophysics, pp 81-90.

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APPENDIX A

MINE WATER INGRESS EVALUATION

A.0 MINE WATER INGRESS EVALUATION

The Cape Breton Coalfield consists of 25 separate collieries organized into four Hydraulic Interconnection Systems and eight individual collieries (JWEL, 1993). These collieries contain 17.5 billion US gallons of mine water with static water levels being between -75 ft (No. 1B System) to +16 ft above sea level.

A.1 No. 1B Hydraulic System

Water levels in the No. 1A/1B System were prevented from flooding to equilibrium due to exfiltration from the No. 1B and No. 26 Collieries into Lingan and Phalen mines over the past two decades. Since the Lingan and Phalen mines were closed in February 1993 and July 2000 respectively; water levels in the No. 1B System, as measured in the No. 1B access shaft, have been steadily rising towards sea level and as of October 30, 2002, were at approximately 75 ft below sea level.

A.1.1 Description

The No. 1B Hydraulic System consists of several abandoned collieries: No. 1A, No. 1B, No. 5, No. 9, No. 10, No. 20, No. 24, No. 26 and the most recent collieries of the Lingan and Phalen mines. Several other collieries (No. 3, 4, 6 and 11) are suspected to be indirectly interconnected to the No. 1B System via subsidence fracturing, bootleg workings or pillar retrieval operations. Table A.1 summarizes the collieries in the No. 1B Hydraulic System, as well as collieries in other Hydraulic Systems and their respective flooded and non-flooded volumes. Figure 2.6 in the text (JWEL, 1993) illustrates the assumed hydraulic interconnections between the collieries.

TABLE A.1: SUMMARY OF MINE FLOODING VOLUMES - CAPE BRETON COALFIELDS

158840ft³/Ft
369200
TOTAL = 528040ft³/ft

Mine	Seam	Status (Oct. 30/02)	Static Water Level (ft)	Total Void Volume (ft^3)	Flooded Volume (Oct. 2002) (ft^3)	Remaining to Sea Level			Total Volume Above Sea Level (ft^3)	Flooded Above Sea Level (ft^3)	Non-Flooded Above Sea Level (ft^3)
						Elevation (ft)	Volume (ft^3)	% Flooded to MSL			
No. 1B Hydraulic System											
Dominion 1A/1B	Phalen	Flooding	-75.8	511,563,809	497,538,803	75.8	12,040,049	97.6%	1,984,957	0	1,984,957
Dominion No. 2	Phalen	Full (bsl)	-	315,604,078	315,604,078	0.0	0	100.0%	0	0	0
Dominion No. 5	Phalen	Flooding	-75.8	120,224,831	79,386,541	75.8	27,985,396	73.9%	12,852,894	0	12,852,894
Dominion No. 9	Harbour	Full (bsl)	-	175,901,691	175,901,691	0.0	0	100.0%	0	0	0
Dominion No. 10	Emery	Flooded	20	100,076,138	79,941,170	0.0	0	79.9%	25,168,710	5,033,742	20,134,968
Dominion No. 20	Harbour	Full (bsl)	-	242,351,048	242,351,048	0.0	0	100.0%	0	0	0
Dominion No. 24	Emery	Full	5	90,942,994	89,062,821	0.0	0	100.0%	1,979,129	98,956	1,880,173
Dominion No. 26	Harbour	Full (bsl)	-	112,360,110	112,360,110	0.0	0	100.0%	0	0	0
Lingan	Harbour	Flooding	-200	179,113,995	177,911,275	200.0	662,713	96.6%	540,007	0	540,007
Phalen	Phalen	Flooding	-557	197,570,560	195,644,502	557.0	1,745,655	99.1%	180,403	0	180,403
Total (ft^3)				**2,045,709,254**	**1,965,702,039**		**42,433,813**		**42,706,100**	**5,132,698**	**37,573,402**
Total (m^3)				**57,937,718**	**55,671,788**		**1,201,793**		**1,209,504**	**145,366**	**1,064,138**
No. 4 Hydraulic System											
Dominion No. 3	Phalen	Full	16	48,811,543	48,148,146	0.0	0	98.6%	1,421,564	227,450	1,194,114
Dominion No. 4	Phalen	Full	16	341,164,304	338,432,018	0.0	0	99.2%	4,239,756	678,361	3,561,395
Dominion No. 6	Phalen	Full	15	109,544,349	108,795,650	0.0	0	99.3%	1,604,354	240,653	1,363,701
Total (ft^3)				**499,520,196**	**495,375,814**		**0**		**7,265,674**	**1,146,464**	**6,119,210**
Total (m^3)				**14,147,201**	**14,029,826**		**0**		**205,775**	**32,470**	**173,306**
No. 8 Hydraulic System											
Dominion No. 8	Harbour	Full	5	85,143,016	73,709,244	0.0	0	86.6%	12,035,549	601,777	11,433,772
Sterling/Old Harbour	Harbour	Full	15	20,476,411	13,830,307	0.0	0	67.5%	848,197	127,230	720,967
Total (ft^3)				105,619,427	87,539,552		0		12,883,746	729,007	12,154,739
Total (m^3)				2,991,309	2,479,258		0	82.9%	364,888	20,647	344,241
No. 12/14 Hydraulic System											
Dominion No. 12	Harbour	Flooding	-84	77,691,854	73,138,137	84.0	4,553,717	94.1%	0	0	0
Dominion No. 14	Phalen	Flooding	-84	77,973,883	74,314,646	84.0	3,659,237	95.3%	0	0	0
Total (ft^3)				**155,665,737**	**147,452,782**		**8,212,955**		**0**	**0**	**0**
Total (m^3)				**4,408,700**	**4,176,096**		**232,604**	**94.7%**	**0**	**0**	**0**
Total Coalfields											
Total (ft^3)				**2,806,514,614**	**2,696,070,187**		**50,646,768**		**62,855,520**	**7,008,170**	**55,847,350**
Total (m^3)				**79,484,928**	**76,356,967**		**1,434,396**	**96.1%**	**1,780,168**	**198,482**	**1,581,685**

The No. 1B Hydraulic System as of October 30, 2002, contained 57.5 million m^3 (15.3 billion US gallons) of mine water. There is approximately 1.2 million m^3 (316.9 million US gallons) of storage remaining to sea level in the No. 1A and No. 5 Collieries. Approximately 145,400 m^3 (38.4 million US gallons) of mine is flooded above sea level to a maximum known elevation of 17 ft. An additional approximate 1 million m^3 (264 million US gallons) of storage is available above sea level in the No. 1B Hydraulic System. Table A.2 summarizes the mining history for the No. 1B System (after Frost, 1964, 1977).

A.1.2 No. 1B Hydraulic System Flooding Status (October 2002)

As of the end of October 2002, the following summary of flooding status is presented. Table A.1 summarizes the current water levels and flooding status for the No. 1B mines and other collieries within the Cape Breton Coalfield.

- Six collieries (Nos. 1A, No. 5, No. 12, No. 14, Lingan and Phalen) are not flooded to mean sea level;
- 76.4 million m^3 of mine water (96.1% flooded) in Sydney Coalfield; (73% of this in 1B System);
- 1.2 million m^3 remaining in No. 1B System to mean sea level (including Lingan and Phalen);
- 1 million m^3 potential storage remaining in No. 1B above mean sea level;
- No. 1B system 96.1% flooded to elevation -75.8 ft;
- Lingan Colliery flooded to -200 ft in main haulage ways (96.6% flooded);
- Phalen Colliery flooded to -557 ft in main haulage ways (99.1% flooded); and
- No. 5 Mine represents 66% of available 1B storage (73.9% flooded).

A.1.3 Historical Inflow Potential

The historical water make of the No. 1B Hydraulic System and other mines in the Cape Breton Coalfield were determined from review of historical records summarized in Frost (1964) and JWEL (1993). Table A.2 summarizes known information.

Based on the historical records and assuming that the majority of flows into the Lingan and Phalen Collieries were from the older collieries, total inflow potential to the No. 1B mines would be expected to be in the order of 3,400 USgpm if all workings were still in operation (Table A.2). Based on historical inflow records, the greatest inflows would be expected to occur from the vicinity of the No. 10 (50%), No. 9 (26%) and No. 1A and No. 5 (16%) Collieries. With the exception of the No. 9, which was entirely sub-sea, the higher contribution comes from above-sea level workings. It is noted, that there was no inflow data for the No. 5 Colliery. Historical records (Frost, 1964) suggest that the No. 5 and No. 1A flows were combined. Since the No. 1A and the No. 5 were in operation at the same time between 1893 and 1927 and no reports of pumping were given in Frost (1964) for No. 5 alone, it is possible that the reported 550 USgpm flows from No. 1A may have included flows from both No. 1A and from No. 5 Collieries. During operation of No. B Colliery between 1924 and its' closure (about 1965), water collected from collieries No.1B and No. 5 was impounded in an abandoned portion of No. 1A, then transferred via a 14" diameter cast iron pipeline to the No. 1B sump that was located 74 ft below the lodgement (assumed to be 74 ft below bottom of No. 1B Shaft).

Other possible connected contributors could include the No. 4, which provided a 940 USgpm inflow rate. If collieries Nos. 3, 4, 6 and 11 were contributing, total operational inflows could be as great as 5,000 USgpm. There is uncertainty on how much flow could occur from the Nos. 3, 4, 6 and 11 Collieries, as these are assumed to be isolated from the No. 1B System with seals. However, it is noted that the No. 3 was constructed to recover the barrier pillar between the No. 4 and No. 5 Collieries and assessment of long term water levels at the Quarry Point borehole suggests possible movement of recharge water into other areas of the mined complex.

A.1.4 Water Levels

Figure A1 shows water level response over the time period 1986 through October 2002. Daily precipitation is also shown. Note that all figures, which support Appendix A (i.e., A1 to A38), are provided at the end of this appendix. Figures A2 through A10 illustrate the water level trends on an annual basis between 1994 and 2002 for the No. 1B System. Detailed discussion of water level trends prior to 1994 were discussed in JWEL, 1993 and 1997.

TABLE A.2: SUMMARY OF NO. 1B HYDRAULIC SYSTEM MINE DATA (AFTER FROST, 1964, JWEL 1993)

Colliery	Locations	Seam	From	To	Elev (ft)	Elev (ft)	Thickness (ft)	Area (acres)	Production (Long Tons)	Make (USgpm)	Water Quality		Notes
											type	pH	
No. 1A	Dominion	Phalen	1895	1927	15	-615	7.0	2,415	13,202,419	550	acid	-	
No. 1B	Dominion	Phalen	1924	1955	-615	-2,350	7.0	-	17,822,961	50	acid	-	
No. 2	Glace Bay	Phalen	1899	1949	-525	-2,010	7.2	5,184	26,571,920	12	acid	2.28	
No. 5	Reserve Mines	Phalen	1872	1938	115	-550	7.7	1,312	12,898,468	?	?	-	
No. 9	Glace Bay	Harbour	1899	1924	-200	-700	6.5	1,734	6,413,916	900	acid	2.5	
No. 10	Reserve Mines	Emery	1905	1942	125	-460	2.67 to 1.33 ft	2,432	6,726,390	1,750	acid	3.1	
No. 20		Harbour	1939	1971	-293	-1,400	5.3	6,077	17,155,142	135	acid	-	1
No. 24	Glace Bay	Emery	1919	1953	5	-800	31" to 4'	3,616	5,578,793	?	?	-	
No. 26		Harbour	1943	1983	-340	-2,700	7.17 to 6	1,574	7,268,093	15	alkaline	6.02	2
Lingan		Harbour	1978	1993	87	-2,680	6.5	-	24,593,308	<50	alkaline	5.5	
Phalen		Phalen	1985	1999	90	-3,000	-	-	-	<50	alkaline	6.3	
Total No. 1B System								**24,344**	**138,231,410**	**3,412**			
Other Mines Possibly in Hydraulic Connection:													
No. 3	Glace Bay	Phalen	1900	1915	30	-530	7.5	493	3,976,690	?	alkaline	6.0	3
No. 4	Glace Bay	Phalen	1866	1961	45	-2,010	6.6	6,189	28,627,961	940	acid	2.1	4
No. 6		Phalen/Harbour	1904	1933	27	-1,300	6.5	1,792	4,288,312	248	acid	2.29	5
No. 11	Glace Bay	Emery	1899	1949	20	-950	3.5	1,920	7,543,358	420	acid	3.3	6
Total No. 1B System								**34,738**	**182,667,731**	**5,020**			

Notes:
1. Connected to No. 5, No. 2 and No. 4
2. Connected to No. 1B
3. Recover coal between No. 4 & No. 5 Collieries; attached to No. 11
4. Potential connection to No. 3, 6, 24
5. Connection to Old Clyde; potential connecting to No. 4
6. Potential connection to No. 10 & No. 4 via bootleg workings.

The annual hydrographs generally show a relatively rapid rate in water level rise in the spring and late fall and a general decrease in water levels over the summer period (June through October). The rate of water level rise in the No. 1B System is related to precipitation, outfall to other mines and uneven filling rates within the workings, which are constantly changing in area as the water level rises. For example, a relatively quick rise would be expected where limited lateral workings or predominantly haulage ways are present, as opposed to elevations with large areas of interconnected workings.

A.1.5 No. 1B Flooding History

Figure A1 illustrates the water level rise in the No. 1B Shaft between February 1984 and present. The No. 26 Colliery closed in 1964. No. 1A pumps were stopped November 1985 and the No. 4 pumps stopped in September 1986. The numbers indicate significant events occurring during the period of monitoring and are summarized below:

1. 1B losing water to No. 2 prior to February 1986
2. No. 1B and No. 2 mines reach equilibrium (about November 7, 1986)
3. No. 1B level reaches No. 5 deep barrier spill point to inside region of 1B (elevation -580 ft)
4. Inside region of No. 1B reaches equilibrium with rest of No. 1B by September 19, 1988
5. Water level reaches No. 26 seals mid-December 1988; begin to spill to No. 26 Colliery
6. 45 ft water level decline October 1989 to March 1990 (unknown cause; possible void filling)
7. No. 1B and No. 26 reach equilibrium at -554 ft level mid March 1991
8. First break between No. 26 and Lingan 2E November 29, 1992 (2,000 USgpm outfall to Lingan)
9. Second break between No. 26 and Lingan February 17 to 25, 1994 (7,000 USgpm outfall to Lingan)
10. Lingan and No. 1B water levels approach hydraulic pressure equilibrium at break elevations

11. Seasonal declines in summer due to continuing outfall to Lingan (and/or Phalen)
12. Water level reaches top of Dominion No. 26 (-340 ft)
13. Water level reaches top of Dominion No. 20 (-290 ft)
14. Water level reaches top of Dominion No. 9 (-200 ft)
15. Recovery trend over past three years due to reduction in outfall to Lingan-Phalen
16. Major spring recharge events control annual rate of water level rise
17. Spring recharge 2002
18. Beginning of fall recharge 2002

Figure A11 illustrates the relative water levels in the Lingan, Phalen and No. 1B System between 1992 and 2002. Water levels in the No. 1B Shaft were recovering slowly before the first break into the Lingan mine through the No. 26 barrier pillar in November 1992. After the second break through Lingan 5E in February 1994, the Lingan mine was abandoned and allowed to flood to equilibrium. When the Lingan water levels passed the elevation of the barrier breaks, the rate of outfall from the No. 1B System began to slow. By the end of 1997, the Lingan and No. 1B mines were near hydraulic equilibrium and rates of water level rise were similar, thereafter, confirming that the majority of inflow originated from the No. 1B System.

Based on the 2002 period of record, the Lingan water levels are currently at -200 ft and are rising in the main haulage ways at an average rate of 0.35 ft per day.

The water level in the Phalen mine recovered quickly over the past two years and correlates with the estimated average pumping rate of about 1,000 USgpm prior to the closure of the Phalen mine. Based on the 2002 period of record, the water levels in the Phalen mine are currently at -557 ft elevation and are rising in the main haulage ways at an average rate of 1.6 ft per day. Since September, water levels have been rising at about 25 ft per day after the fall rains. Because of the hydraulic head difference between the Lingan and Phalen Collieries (350 ft), and the strong inflow from the No. 1B, it is anticipated that the rate of water level rise will increase as the spatial dimensions of the Phalen complex diminish with elevation and that the Phalen Colliery will be filled to sea level within a year.

A.1.6 Estimated Inflow Rates

Several approaches have been taken to estimate a reasonable average annual recharge rate to this colliery. Several possible influences on observed recharge rates, shown in Table A3, had to be addressed. The annual recharges are often biased by missing data that can increase or decrease apparent recharge, depending on what data is missing. Also, the loss of water to the Lingan mine from No. 1B System also decreases the apparent annual recharge rate. The time period selected for statistical analysis also affects the estimation, since the effect of the apparent recharge rate is dependent on the degree of exfiltration to Lingan and/or Phalen and seasonal precipitation.

Figures A12 through A21 illustrate the combined (Figure A12) and annual (Figures A13 to A21) recharge hydrographs for the No. 1B Hydraulic System based on the observed water levels and known void volumes per foot of water level rise. All values are presented as seven day running mean in USgpm.

Table A.3 summarizes the range and mean apparent recharge rates for the No. 1B Hydraulic System. The annual maximum values are representative of peak inflows during winter, spring or fall recharge events. The minimum values (which are usually negative values) are representative of late summer outflow rates to the other mines (Lingan, Phalen, other parts of No. 1 B System, etc.).

Based on the hydrographs, some observations are as follows:

- The average for 2002 may be biased low since some spring recharge data was missing.
- The 2001 summer data is missing and outfall rate may be higher than estimated.
- The 2000 data is unreliable, as data from April through October was missing.
- The 1999 data is reliable; all data is present.
- The 1998 data is biased, as no data is available from January through mid August.

- The 1997 average may be slightly low as the fall recharge period was not available.
- The 1996 year is complete and provides a representative annual and summer flow rate for a wet year.
- The 1995 year is complete and provides a representative annual and summer flow rate. The annual and summer means are dominated by outflow to Lingan Colliery.
- The 1993-1994 data is dominated by outflow to Lingan Mine after November 1993.

TABLE A3. SUMMARY OF APPARENT ANNUAL RECHARGE RATES - NO. 1B HYDRAULIC SYSTEM

		USgpm			USgpm Corrected		
Year		Daily	Weekly	Monthly	Daily	Weekly	Monthly
2002	min	-701	-110	-24	-701	-110	-24
	max	7,510	5,039	3,868	7,510	5,039	3,868
	mean	777	**778**	876	846	**847**	880
	summer	656	654	698	656	654	698
2001	min	-879	-331	-340	-879	-331	-340
	max	7,032	5,386	3,223	7,032	5,386	3,223
	mean	472	472	428	343	**342**	333
	summer	-155	-149	-201	-155	-149	-201
2000	min	-2239	-281	202	-2239	-281	202
	max	4996	3988	2148	4996	3988	2148
	mean	1037	**1036**	1059	1219	**1217**	1208
	summer	-	-	-	-	-	-
1999	min	-6257	-1266	-936	-6257	-1266	-936
	max	19242	10381	5630	19242	10381	8011
	mean	974	**961**	949	1598	**1580**	1540
	summer	-728	-730	-727	-599	-611	-518
1998	min	-4130	-1655	-1242	-4130	-1655	-1242
	max	8439	2361	4257	8439	2361	4257
	mean	-124	**-135**	434	180	**174**	321
	summer	-1067	-1078	-798	-1067	-1061	-798
1997	min	-2099	-1626	-1684	-2099	-1459	-1380
	max	6983	5496	2948	6983	5496	2948
	mean	645	**643**	529	592	**592**	549
	summer	-410	-409	-579	-146	-143	-348
1996	min	-1611	-651	-385	-1611	-651	-385
	max	8530	6836	4381	8530	6836	4381
	mean	1546	**1545**	1557	1546	**1545**	1557
	summer	543	551	895	543	551	895
1995	min	-4227	-1375	-895	-4227	-1375	-895
	max	7465	4342	3128	7465	4342	3128
	mean	834	**834**	769	834	**834**	769
	summer	151	161	-41	151	161	-41
1994	min	-15048	-14032	-8954	-15048	-14032	-8954
	max	6004	4236	2984	6004	4236	2984
	mean	-2473	**-2471**	-2420	-2473	**-2471**	-2420
	summer	-2887	-2885	-2587	-2887	-2885	-2587
1993	min	-1377	-393	1467	-1377	-393	1467
	max	6936	5876	2960	6936	5876	2960
	mean	2386	2461	2247	2386	2461	2247
	summer	-					
1995 to 2002	min	-15048	-14032	-8954	-15048	-14032	-8954
	max	19242	10381	5630	19242	10381	8011
	mean	768	765	823	895	891	895
	N	2609	2609	2608	3284	3286	3274

Note: Minima and Maxima are absolute daily values; annual and summer mean values corrected for missing data

Based on the annual inflow rate hydrographs presented in Table A.3, the 10 year long term average annual recharge rate of the No. 1B System appears to be approximately 890 USgpm, ranging from a maximum inflow of up to 10,381 USgpm, to a maximum outfall of -14,032 USgpm during the Lingan Break. This is consistent with the 834 USgpm flow rate for 1995, which is selected as a representative mean year. This long-term value may be low because of the large volumes of water lost to the Lingan and Phalen Collieries since the first Lingan break in November 1992.

A maximum potential recharge rate can be estimated by adding the rate of apparent recharge in the Lingan and Phalen mines over the past 10 years and 2 years, respectively, and assuming that all of this water originated from the No. 1B System. Historical records indicate that the Phalen effluent pumping rate rose from 200 USgpm in 1993 to about 1,200 USgpm by late 1996 (JWEL, 1997) and was reported to remain at this level for the remainder of the life of the mine (S. Forgeron, pers. comm.). While much of this highly saline mine water originates from formation sources, some of it (perhaps 50%) is suspected to have originated from overlying flooded workings. Inflows to the Lingan Colliery declined from over 7,000 USgpm in 1992 to negligible flows after 2001. The rates of outfall to the Lingan and Phalen Collieries declines over the years, as water levels equilibrate between the mine pools and flows consequently decline as head pressure declines.

Assuming all of the 1,200 USgpm pumping rate and fill rate at Phalen over the past few years originates from the No. 1B System and the average flow rate needed to recharge Lingan since 1992 averaged 250 USgpm, a mean annual maximum inflow rate in the order of 834 + 250 + 1200 = 2,284 USgpm is suggested. Since hydraulic head pressures have equilibrated over the years as water levels rose in the Lingan and Phalen Collieries, it is expected that the actual recharge rate should be considerably lower than this theoretical maximum value.

Taking the mean monthly recharge values and excluding the 1994 data, which was biased by outfall to Lingan Colliery, a long term mean average recharge rate of 812 USgpm is indicated. This correlates well with the estimated long-term mean of 834 USgpm (Table A3) and the mean annual recharge rate for 1995, which is considered to be an average water year.

A range of recharge scenarios is selected for further evaluation. A recharge of 370 to 439 USgpm* is used for a wet year (1996), a recharge of 812 USgpm is used for an average year based on several methods of estimation, and a maximum recharge rate of 1,545 USgpm is used for a wet year (1996). In consideration that no data was available for the summer period August through October in 2001 and assuming that outfall in the order of -350 USgpm occurred over the period, actual dry year annual recharge may be as low as 370 USgpm.

A.1.7 Relationships To Precipitation Events

The water level and recharge rates are controlled by seasonal variation in precipitation with declining degree of loss to Lingan-Phalen Collieries over past two to seven years. The majority of recharge occurs in spring and late fall recharge (100% between November and April). The summer water level decline and negative recharge rates are controlled by exfiltration into Lingan and Phalen and possibly to other mine interconnections and No. 5 filling.

Figure A22 superimposes seven hydrographs between 1996 and 2001. Figure A23 shows the monthly distribution of recharge between 1995 and 2002. It can be seen that most recharge occurs in the spring and winter months. While individual annual hydrographs (Figures A13 to A21) typically exhibit a bimodal hydrograph coincident with Nova Scotia stream and groundwater hydrographs and climate normals, the composite hydrograph shown on Figure A22 shows that the majority of mine recharge occurs between November and April. The 1996 year is anomalous due to the intense rainfalls associated with Hurricane Hortense in September 1996. Spring recharge events tend to be larger than the fall events, likely due to the time lag required for the hydrogeological system to become saturated after a long period of drought. The lowest recharge potential occurs in the summer between June and October. July, August and September generally exhibited a net loss of water to the Lingan and Phalen Collieries and to other areas of the No. 1B complex.

A comparison of monthly mean data indicates that the rate of recharge in the fall (November and December) has generally declined since 1997. The spring data does not exhibit much change, although a smaller volume of recharge is indicated since 2000.

Additional recharge events can occur during open warm winters, such as in 1994, 1995, 1997, 1999, 2000 and 2001 (Figures A10, A11, A12, A14).

While the mine water levels often begin to rise after a major storm event, there is typically a three week delay between the major storm event and peak inflow in the mine system (see Figure A14 for 1996).

During the summer months, little or no recharge is occurring to the No. 1B System (Figure A17, Appendix A) and net recharge rate is essentially negative, as water is lost to the Lingan and Phalen System. In the past two years, the rate of outfall has diminished from a maximum of over 2,800 USgpm in 1994 as Lingan filled, to less than 200 USgpm in 2001 and 2002.

A.1.8 Hydraulic Relationship Between Lingan and Phalen Collieries

An attempt was made to estimate the outfall rates from the No. 1B System to the Lingan and/or Phalen. The relative water levels for the three collieries are shown on Figure A11. Figures A24 to A34 and Figures A35 to A38 illustrate the estimated mine water recharge rates for the Lingan mine and the Phalen mine, respectively.

It is assumed that most of the Lingan and Phalen water originated from the No. 1B System (specifically the No. 26 Colliery) then maximum outfalls were in the order of several hundred to up to 7,000 USgpm (Lingan in February 1994). These outfalls occurred prior to the Lingan and Phalen mines reaching hydraulic equilibrium with the No. 1B.

A.1.8.1 Lingan

The Lingan is now flooded to the -200 ft level within the haulage ways and is essentially full. The rate of recharge to Lingan has declined from over 2,000 USgpm in 1992 and 1993 to less than 50 USgpm over 10 years. In summary, since the end of 1997, recharge rates to the Lingan colliery have slowed to an average of 8 to 10 USgpm. The Lingan water levels also appear to respond to major precipitation events. Apparent recharge increased from a summer flow rate of 10 USgpm to about 100 USgpm after the spring and fall recharge events (Figures A25 and A26 for 2000 and 2001, respectively) before the water level reached the haulage ways (-300 ft elevation). Since late 2001, seasonal fluctuations have been limited to about 10 to 20 USgpm (Figure A25).

A.1.8.2 Phalen

The Phalen Colliery is flooded to the -557 ft level in the main haulage ways and is also nearly full. The current recharge rate in the Phalen Colliery is estimated to be in the order of 45 USgpm, with some seasonal variation. Apparent recharge to the Phalen mine was very rapid (up to 700 USgpm) in September and October of 2000, declining rapidly to a steady recharge rate of about 1,000 to 1,200 USgpm, with fluctuations of 200 to 400 USgpm until about mid June 2002, when the water level is interpreted to have filled the main workings and reached the haulage ways. It should be noted that there is some uncertainty regarding actual mine volume and area above the -850 ft elevation.

A.1.9 Effect of MacKay's Corner Remediation

The MacKay's Corner wetland was partially remediated in late 1996 after a major inflow of water into the No. 1B System. After repeated sink hole formation in this area, further remediation continued until August 2001 by placing a layer of low permeability glacial till over the subsided areas. A comparison of the rate of water level rise in the spring of 2000 and 2001 with the spring of 2002 indicates negligible change that cannot be accounted for by seasonal effect. The 48 ft of water level rise in 2001 was very similar to the 53 ft of rise in 2002. This suggests negligible affect from the remediation. It is suspected that the un-remediated portion of the site in the sewer overflow may be continuing to contribute to the recharge.

A.2 Predicted Fill Times

A range of apparent mine recharge rates and the remaining estimated void volumes remaining to sea level and above sea levels, were utilized to estimate probable fill times for the No. 1B Hydraulic System for an average, dry and wet year. A similar approach was used to predict the Lingan and Phalen recovery using the observed recovery rates over the past year.

Table A.4 summarizes the estimated time lines for mine water levels to reach mean sea level and 5 ft increments above sea level.

Predictions are made for an average year flow rate of 812 USgpm (1995), a dry year of 370 USgpm (2001) and a wet year of 1,545 USgpm (1996). These years were analyzed in detail for three potential mine recharge scenarios outlined in the Water Balance Assessment. Fill predictions are made for Lingan and Phalen assuming the average of the last year of recharge of 10 USgpm and 45 Usgpm, respectively.

No. 1B Hydraulic System

Water levels in the No. 1B System (No. 1A and No. 5 Collieries) are predicted to reach sea level within 4.4 to 18.5 months for a wet or dry year, respectively (mean 8.2 months for an average year of rainfall). Assuming an average trend will continue, outfall could occur in June 2003.

Each 5 ft increment above sea level represents about 73 million US gallons of storage and an additional time delay or storage of 1 month (wet year) to 4.5 months (dry year), mean two months is estimated. Allowing the mine to flood to +30 ft is, therefore, not considered to be viable due to numerous possible outfalls near or slightly above sea level, including the No. 1A outfall at about +5 ft elevation.

In consideration of the recharge distribution (e.g., Figure A23), about 75% of this recharge is expected to occur over the winter and spring of 2002-2003. Therefore, the mine could be full by the end of the spring recharge event.

TABLE A.4: PREDICTED FILL TIME FOR NO. 1B, LINGAN AND PHALEN WORKINGS

Colliery		to Sea Level	to +5 ft	to +10 ft	to +15 ft	to +20 ft	to +25 ft	to +30 ft	to +35 ft	to +40 ft
	Volume (US gal)	299,390,329	372,424,007	445,457,685	518,491,363	591,525,041	664,558,719	737,592,397	810,626,075	883,659,753
No. 1A/No. 5	**Recharge Rate**	**Time to Fill in Months at Indicated Annual Recharge Rate**								
Dry Year (2001)	370 USgpm	18.5	23	27	32	36	41	45	50	54
Average Year (1995)	812 USgpm	8.4	10	13	15	17	19	21	23	25
Wet Year (1996)	1,545 USgpm	4.4	5	7	8	9	10	11	12	13
	Volume (US gal)	4,957,093	8,064,210	11,171,327	14,278,444	17,385,561	20,492,678	23,599,795	26,706,912	29,814,029
Lingan	Recharge Rate	**Time to Fill in Months at Indicated Annual Recharge Rate**								
	9 USgpm	1.0	1.7	2.4	3.0	3.7	4.3	5.0	5.6	6.3
	Volume (US gal)	13,057,502	13,994,596	14,931,690	15,868,784	16,805,878	17,742,972	18,680,066	19,617,160	20,554,254
Phalen	**Recharge Rate**	**Time to Fill in Months at Indicated Annual Recharge Rate**								
	45 USgpm	0.6	0.6	0.6	0.7	0.7	0.8	0.8	0.8	0.9

Lingan Mine

Based on the current water level of -200 ft (October 2002), an assumed volume of 662,713 ft^3 remaining to sea level and a calculated recharge rate of 9 USgpm, the Lingan mine should be filled to sea level within about one year. An additional seven to eight months can be achieved for each 5 ft increment above sea level. Since water levels are rising in the main haulage ways, the Lingan can be assumed to be essentially flooded now. No outfall from the Lingan is anticipated.

Phalen Mine

Based on the current water level of -557 ft (October 2002), an assumed volume of 1,745,655 ft^3 remaining to sea level and a calculated recharge rate of 45 USgpm, the Phalen mine should be filled to sea level within about 200 days (6.6 months). An additional two months can be achieved for each 5 ft increment above sea level. Since water levels are rising in the main haulage ways, the Phalen can be assumed to be essentially flooded now. No outfall from the Phalen is anticipated.

Figure A1. No. 1B Hydraulic System Water Level Hydrograph (1984 to 2002)

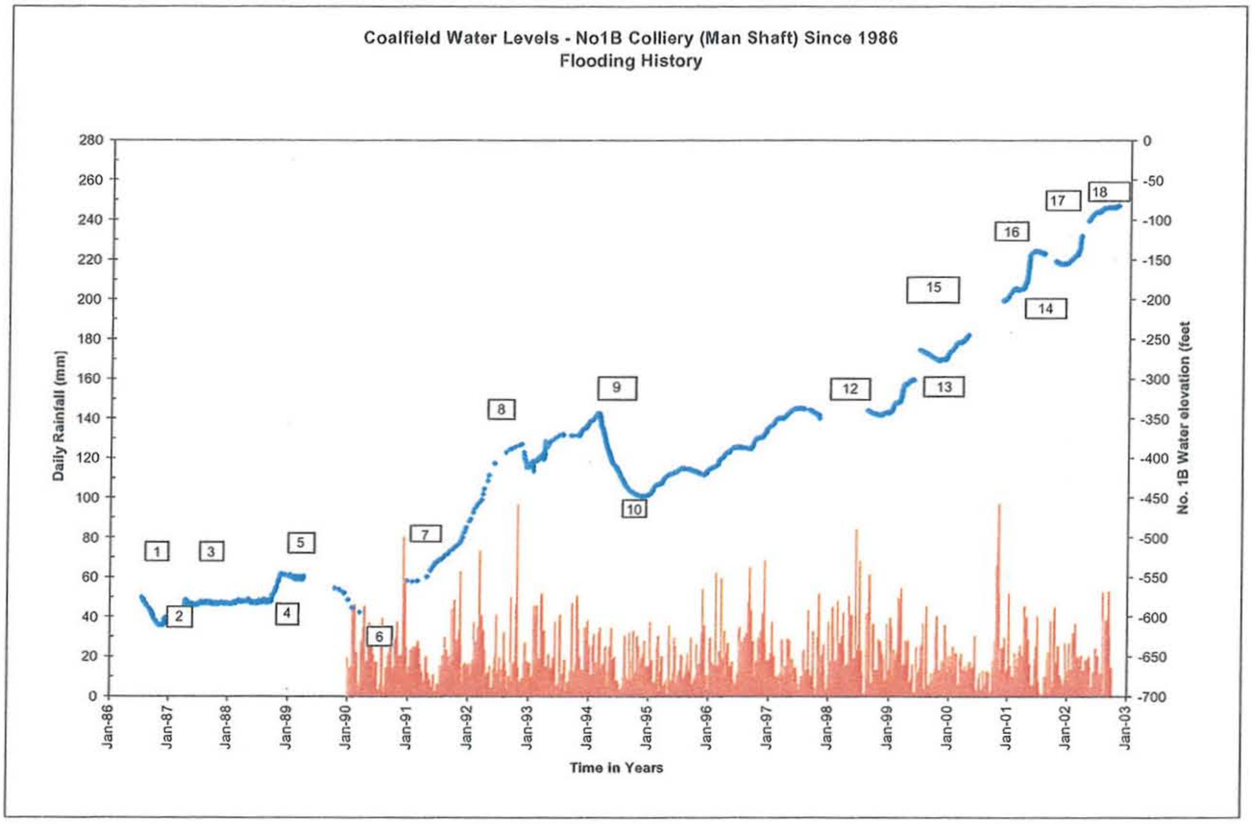


Figure A2. No. 1B Hydraulic System Water Level Hydrograph (2002)

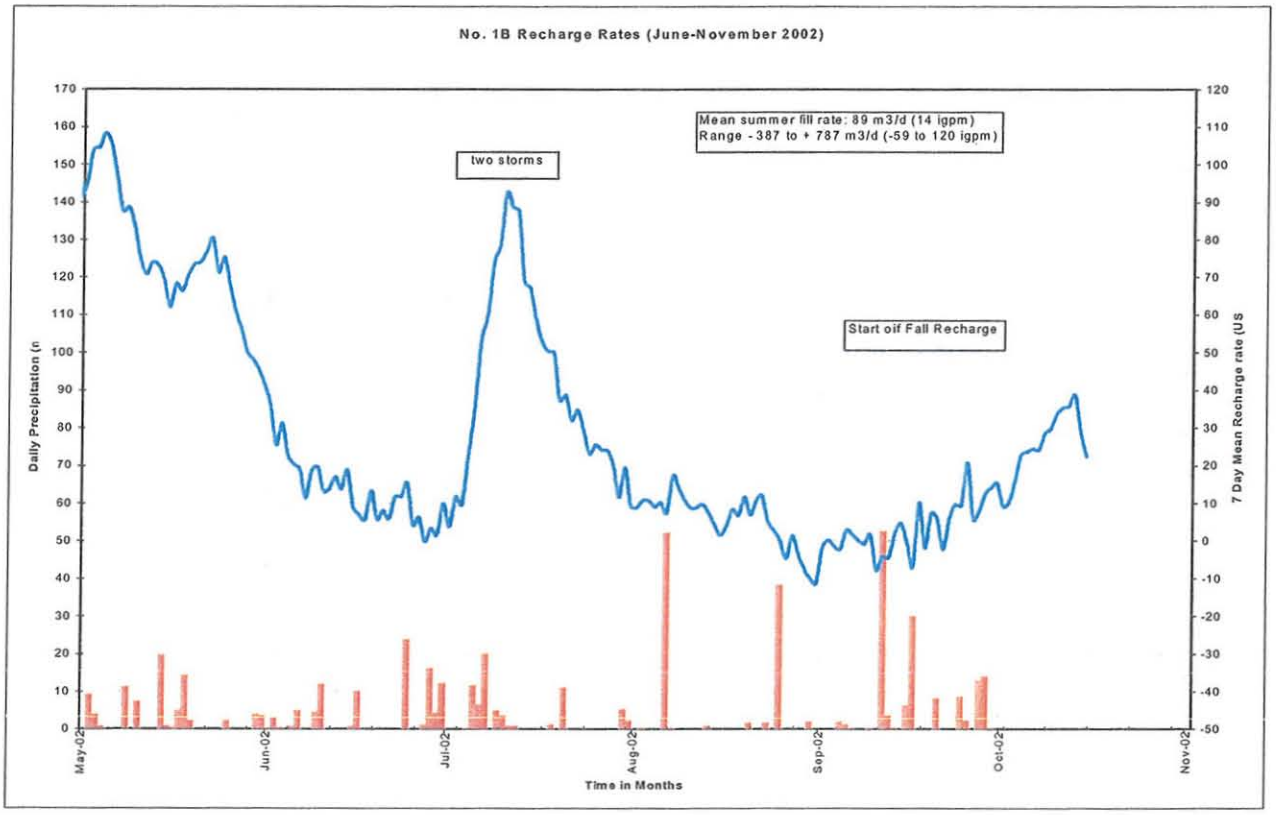


Figure A3. No. 1B Hydraulic System Water Level Hydrograph (2001)

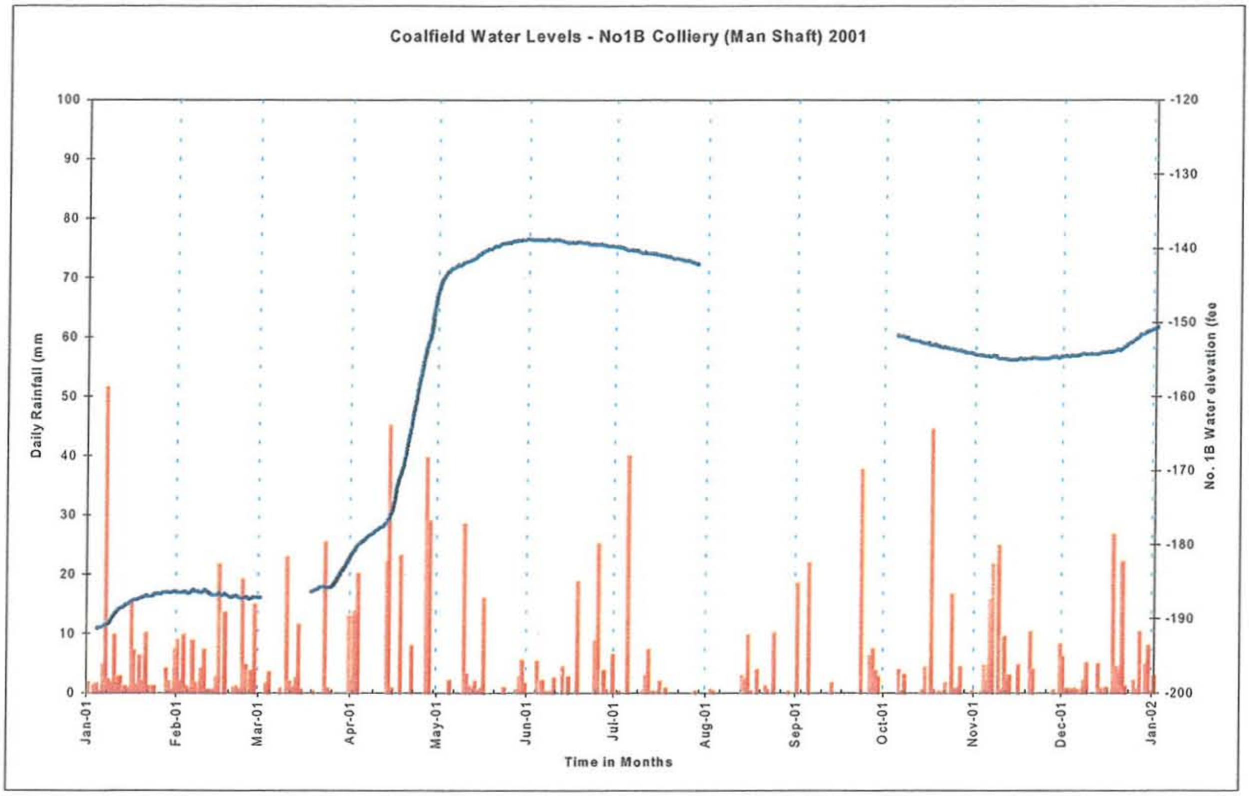


Figure A4 No. 1B Hydraulic System Water Level Hydrograph (2000)

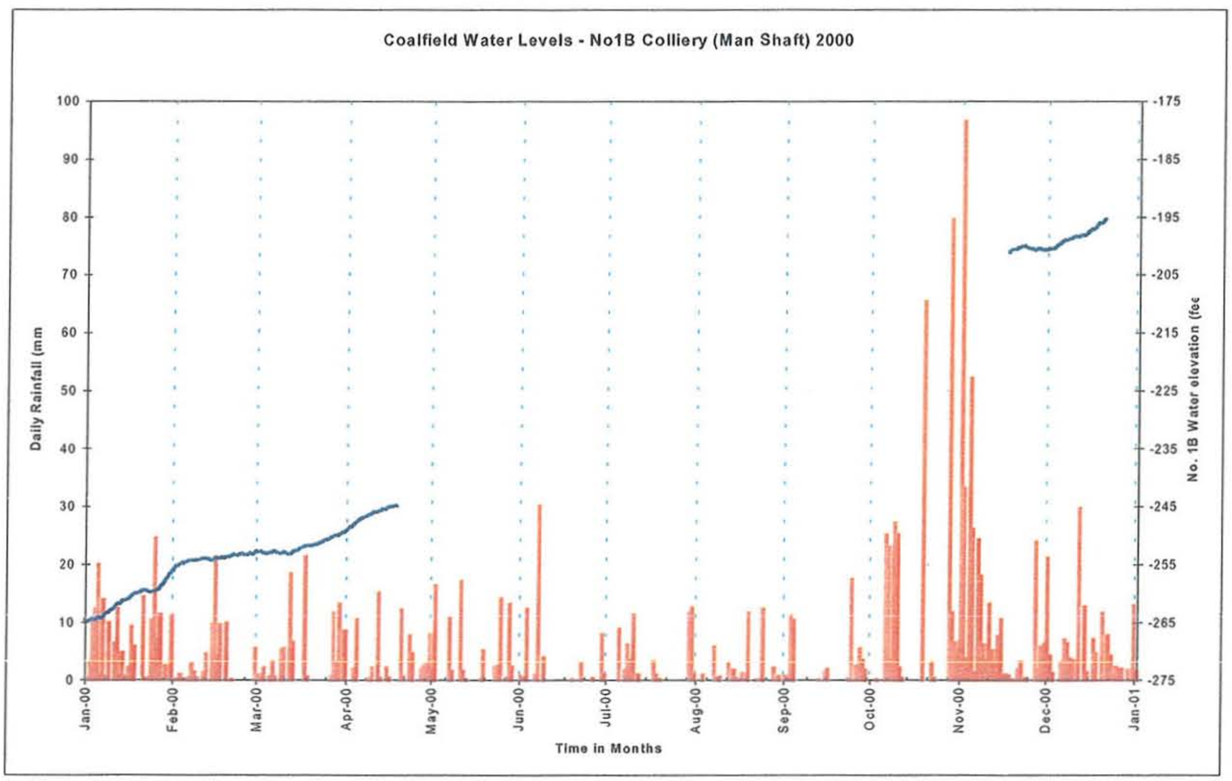


Figure A5. No. 1B Hydraulic System Water Level Hydrograph (1999)

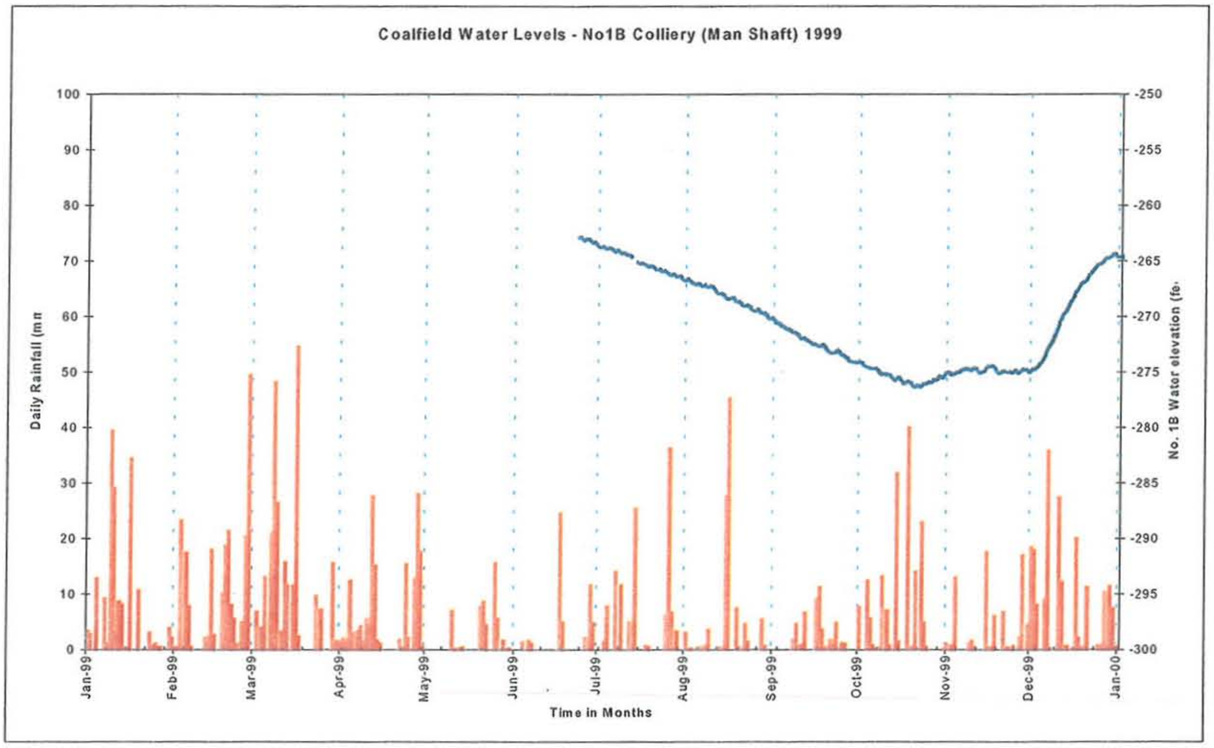


Figure A6. No. 1B Hydraulic System Water Level Hydrograph (1998)

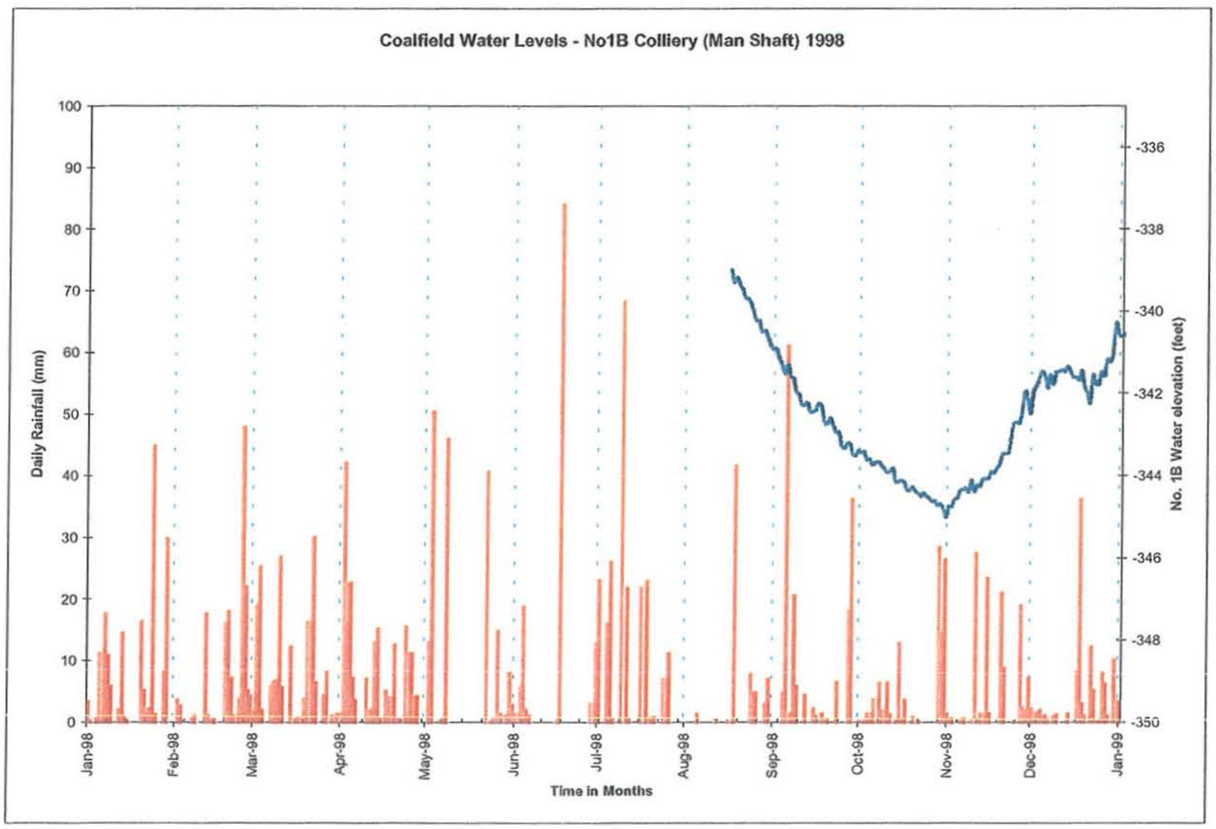


Figure A7. No. 1B Hydraulic System Water Level Hydrograph (1997)

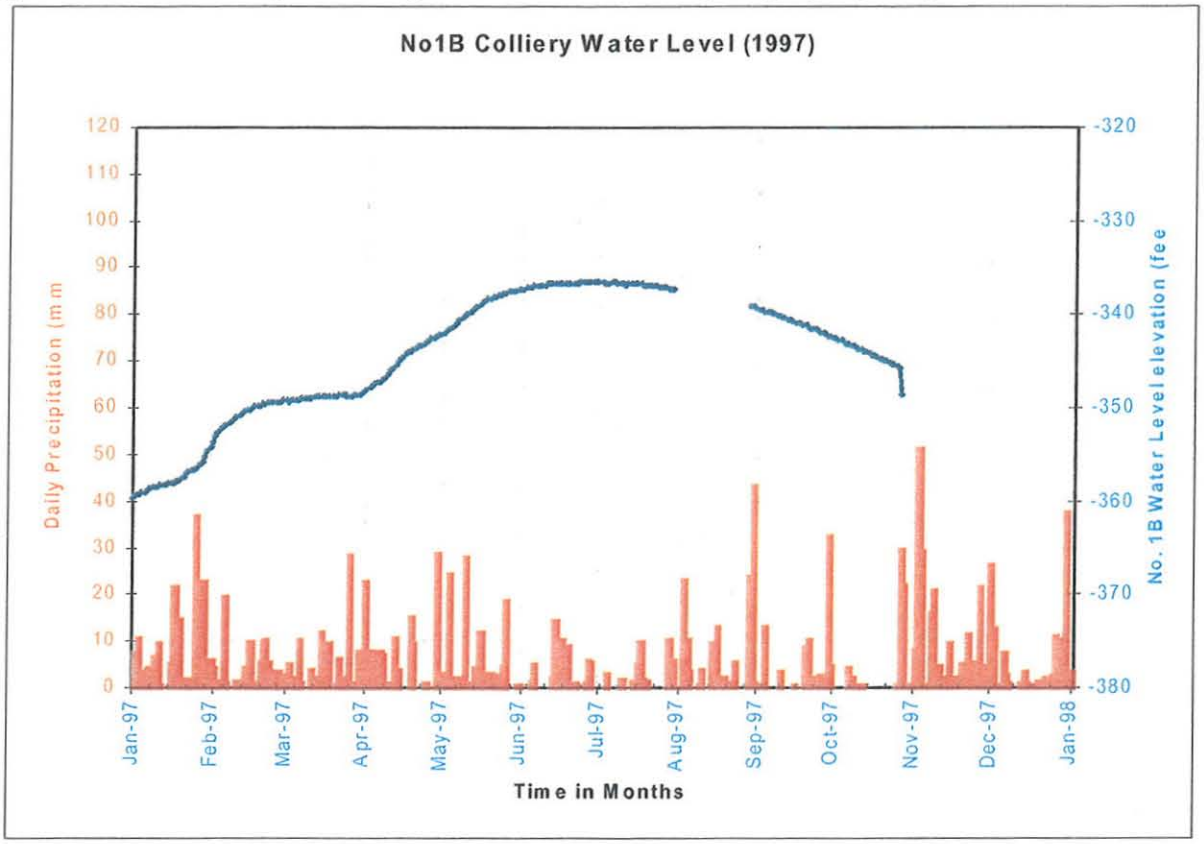


Figure A8. No. 1B Hydraulic System Water Level Hydrograph (1996)

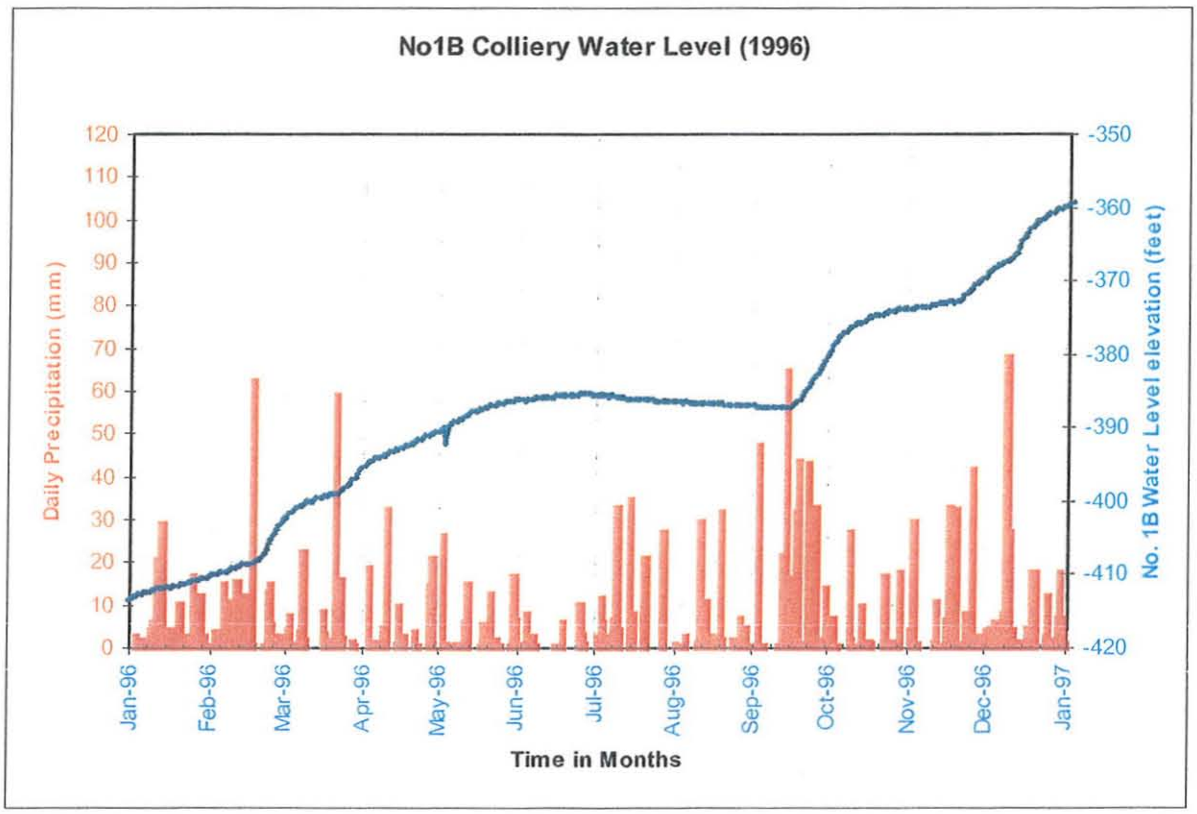


Figure A9. No. 1B Hydraulic System Water Level Hydrograph (1995)

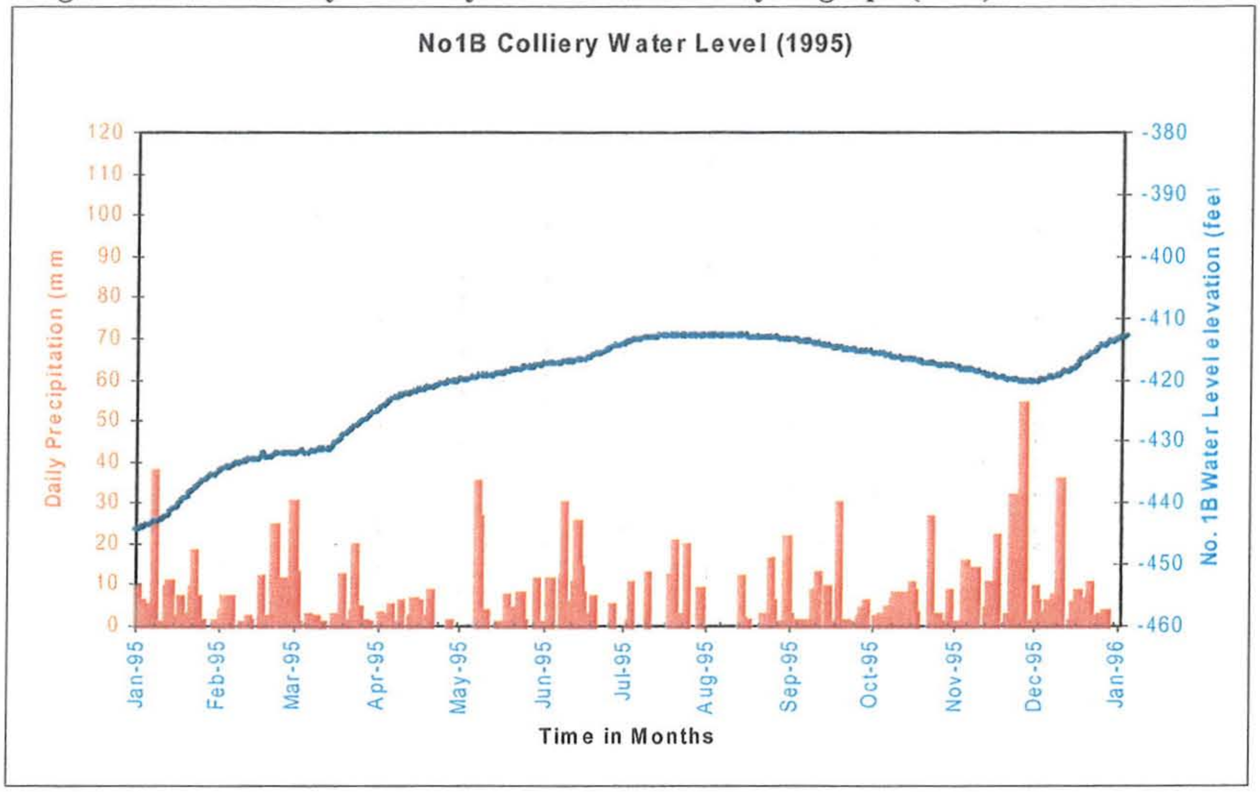


Figure A10. No. 1B Hydraulic System Water Level Hydrograph (1994)

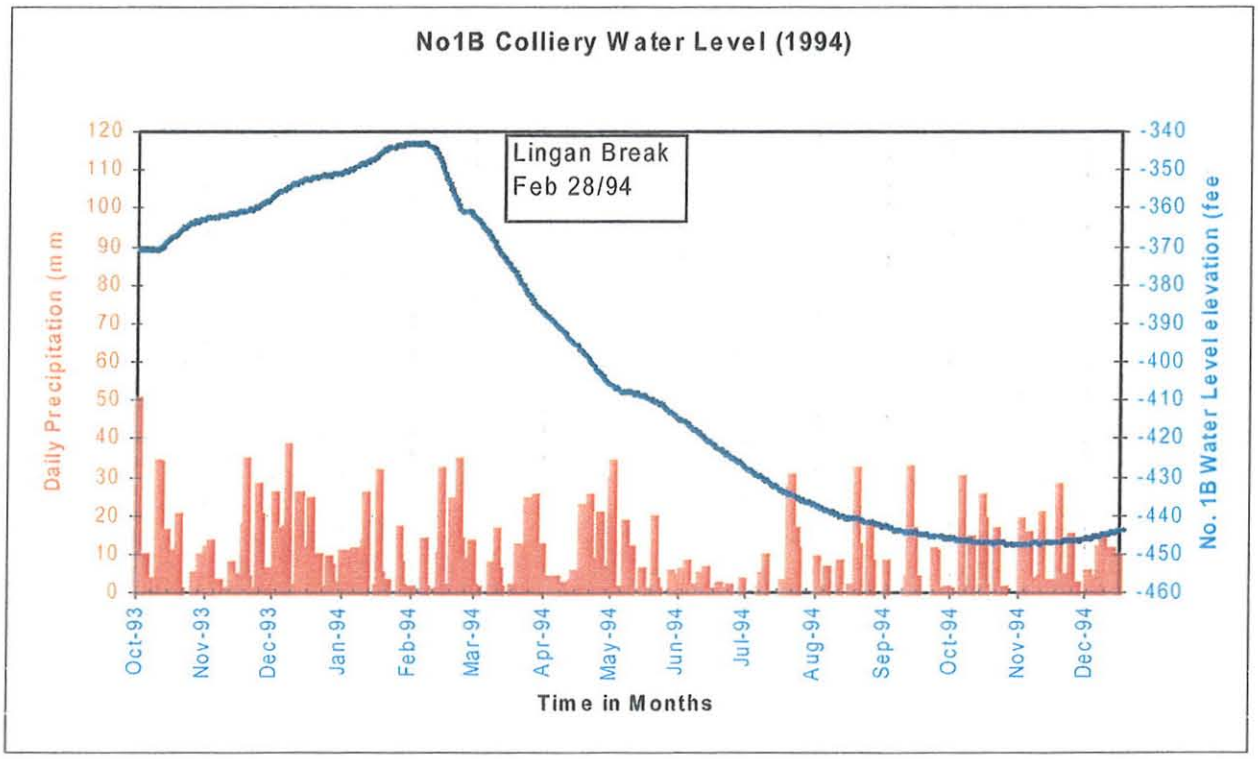


Figure A11. Water Levels for No. 1B, Lingan and Phalen Collieries (1992 to 2002)

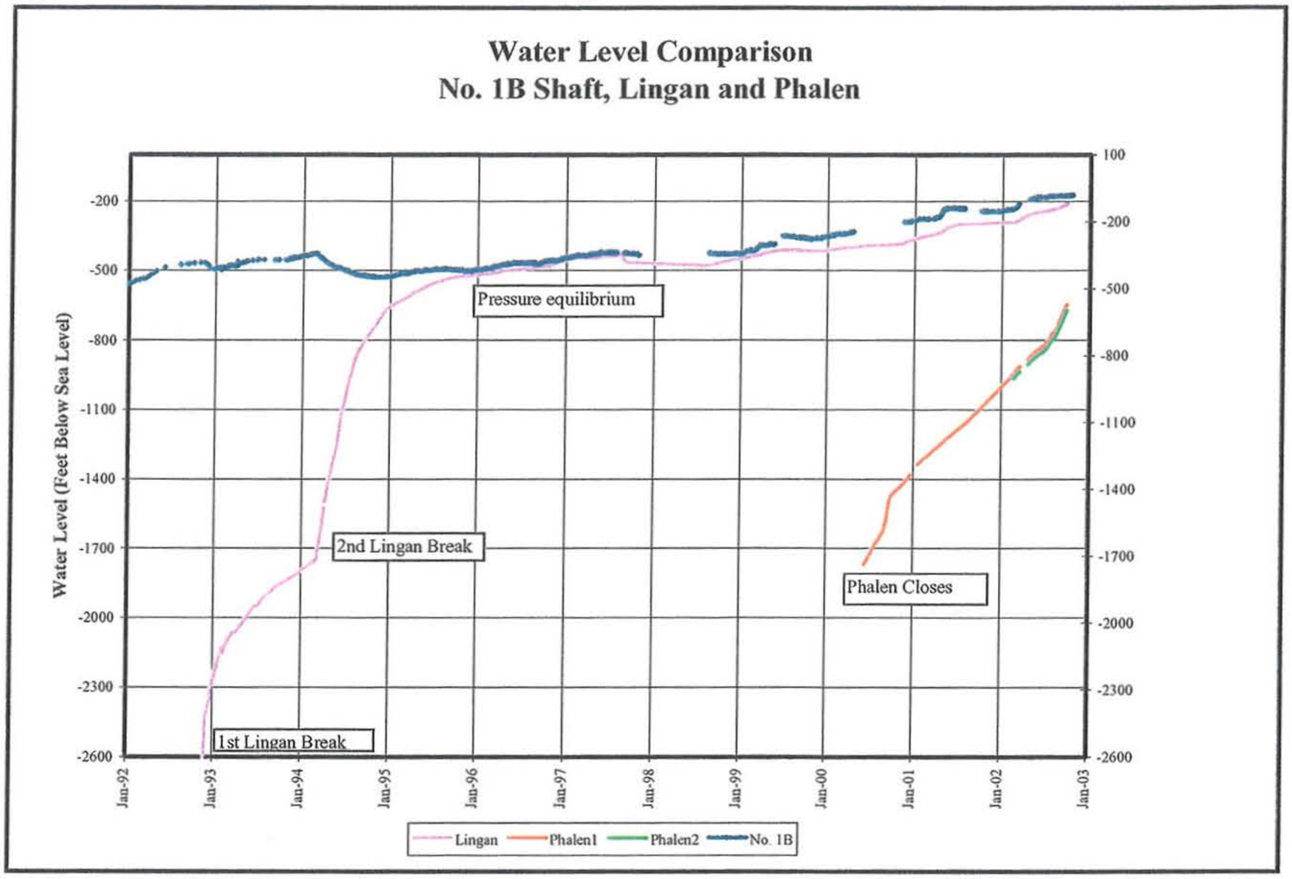


Figure A12. No. 1B Hydraulic System Annual Recharge Distribution (1994 to 2002)

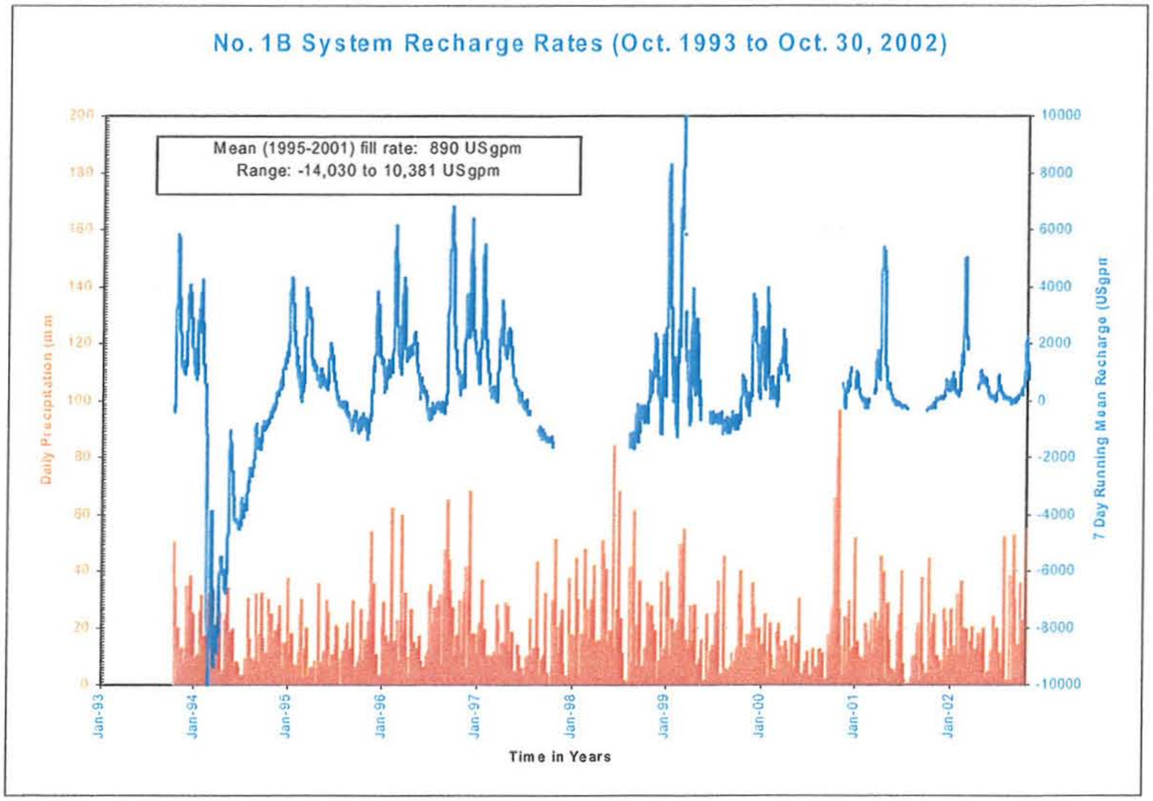


Figure A13. No. 1B Hydraulic System Annual Recharge Distribution (2002)

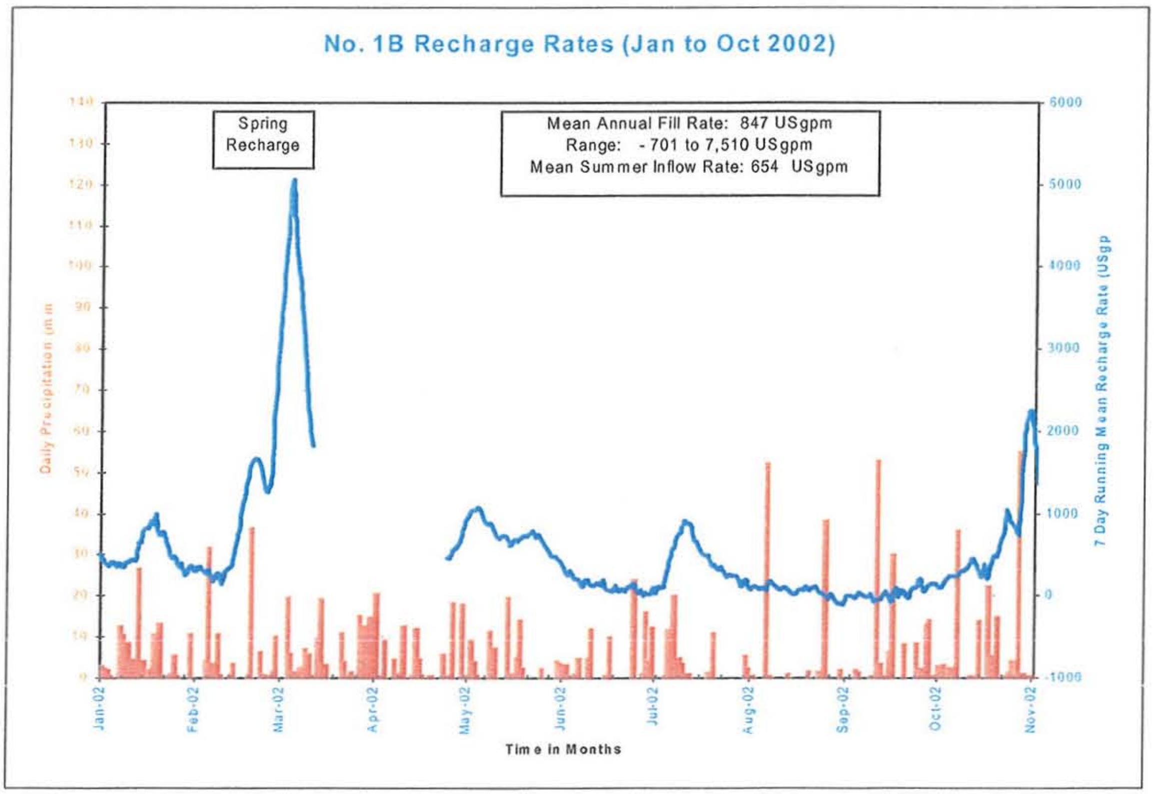


Figure A14. No. 1B Hydraulic System Annual Recharge Distribution (2001)

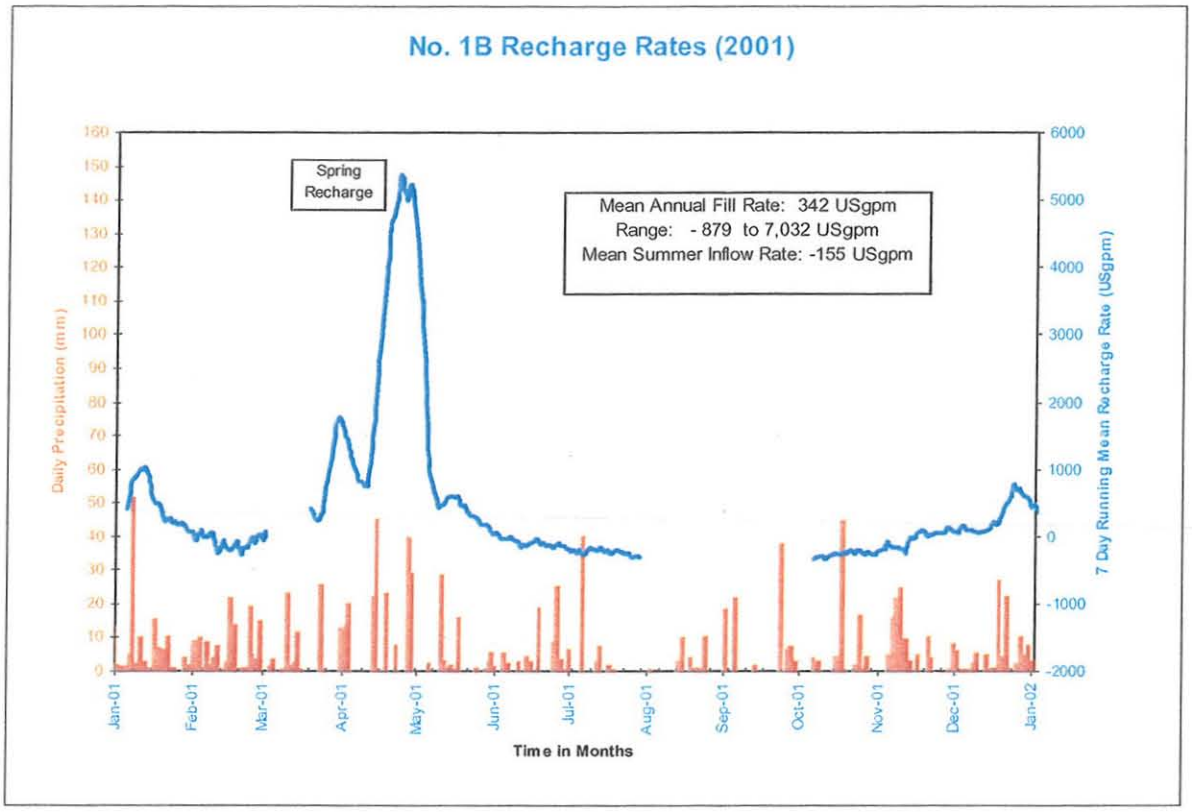


Figure A15. No. 1B Hydraulic System Annual Recharge Distribution (2000)

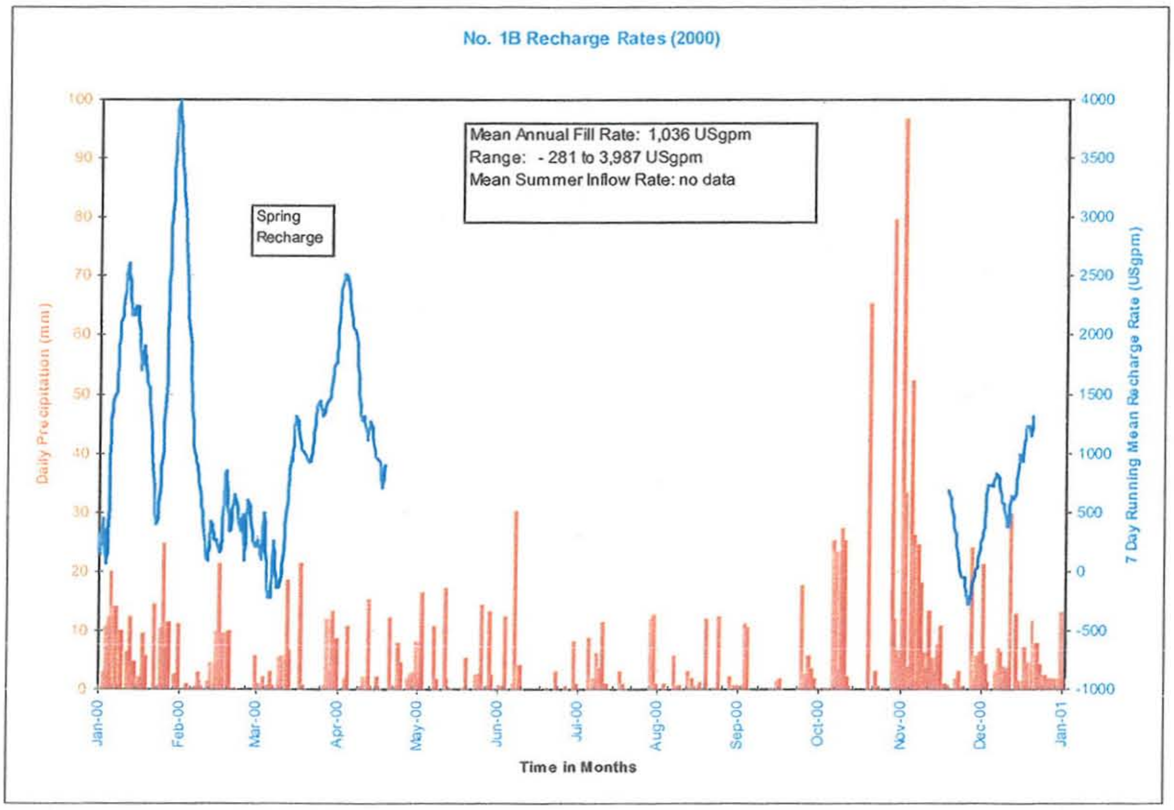


Figure A16. No. 1B Hydraulic System Annual Recharge Distribution (1999)

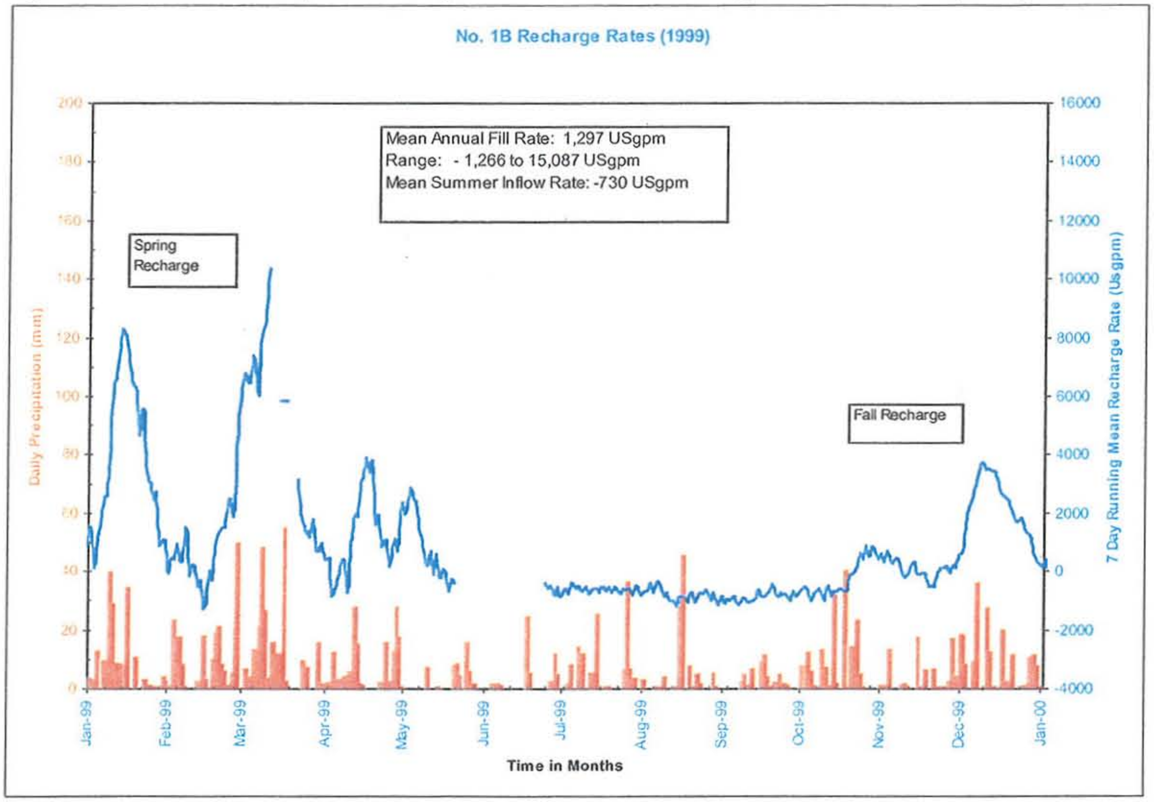


Figure A17. No. 1B Hydraulic System Annual Recharge Distribution (1998)

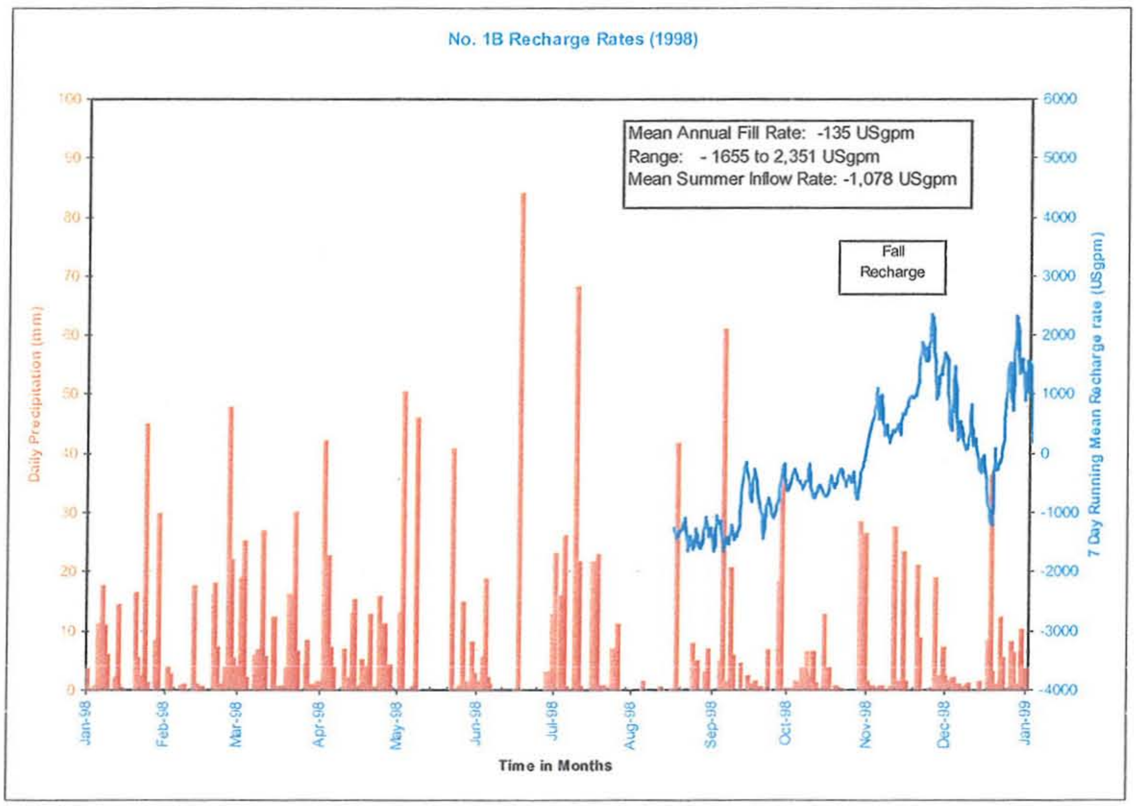


Figure A18. No. 1B Hydraulic System Annual Recharge Distribution (1997)

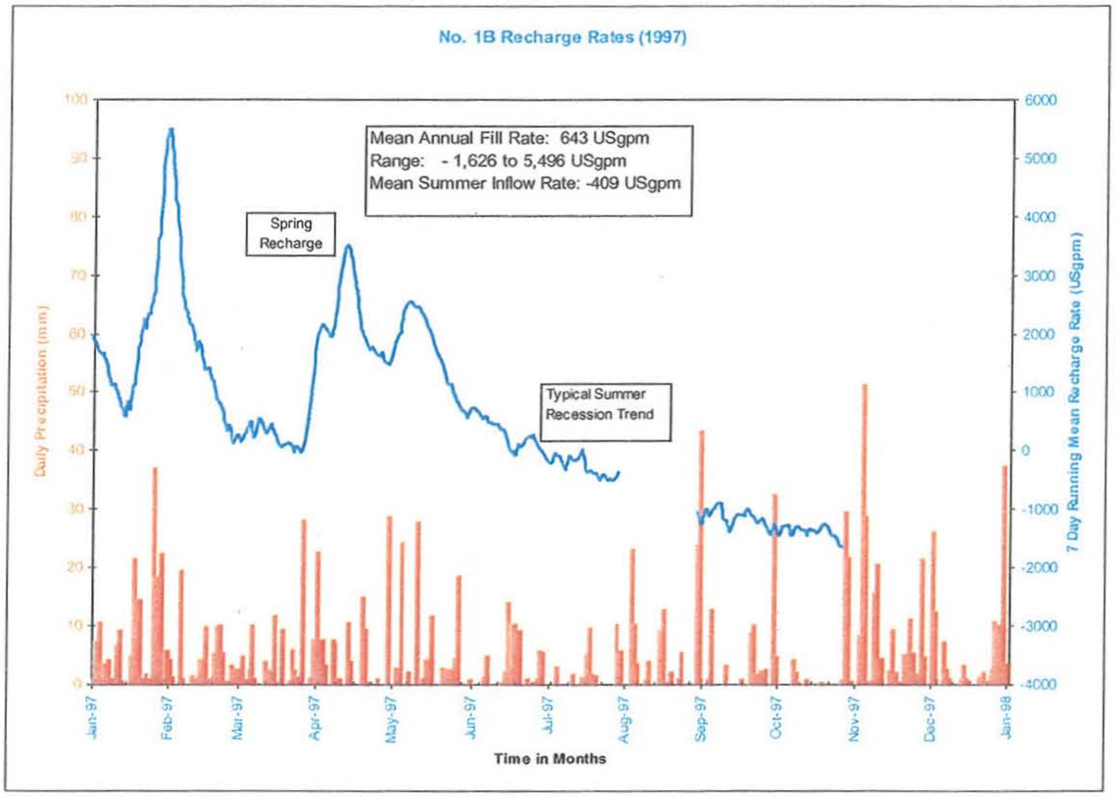


Figure A19. No. 1B Hydraulic System Annual Recharge Distribution (1996)

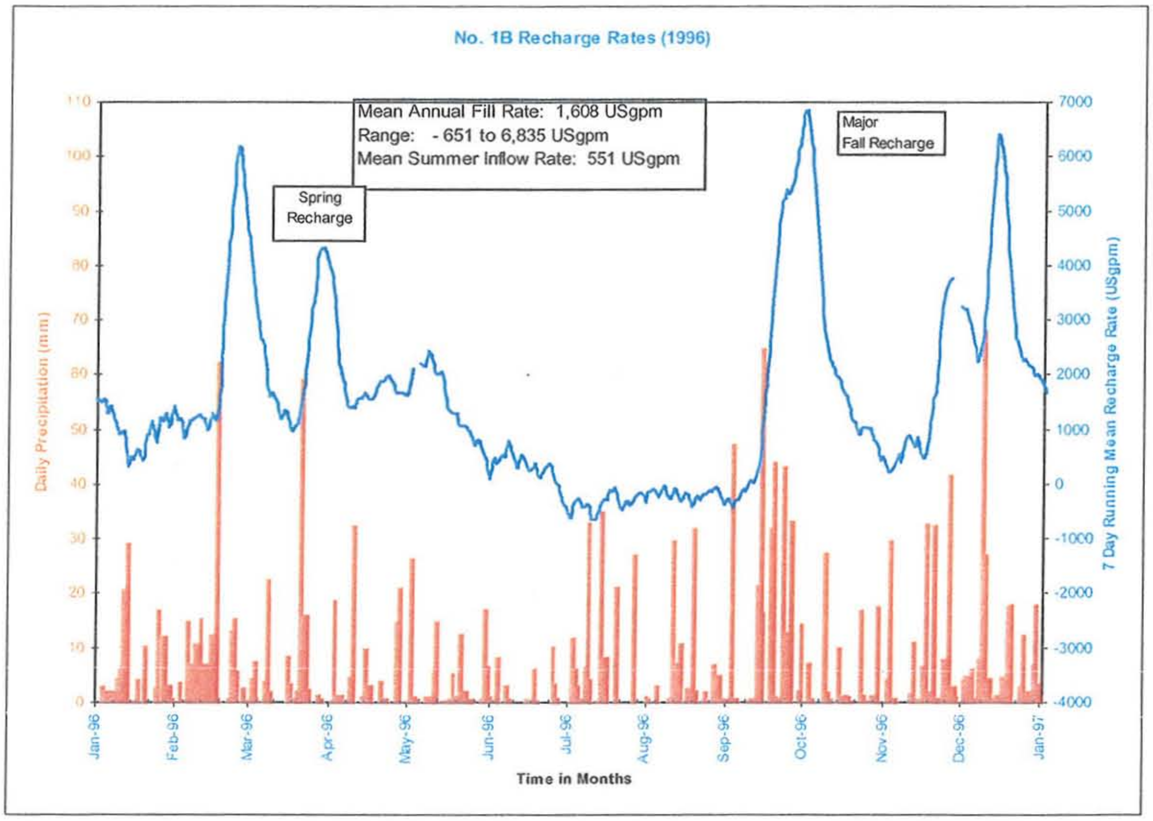


Figure A20. No. 1B Hydraulic System Annual Recharge Distribution (1995)

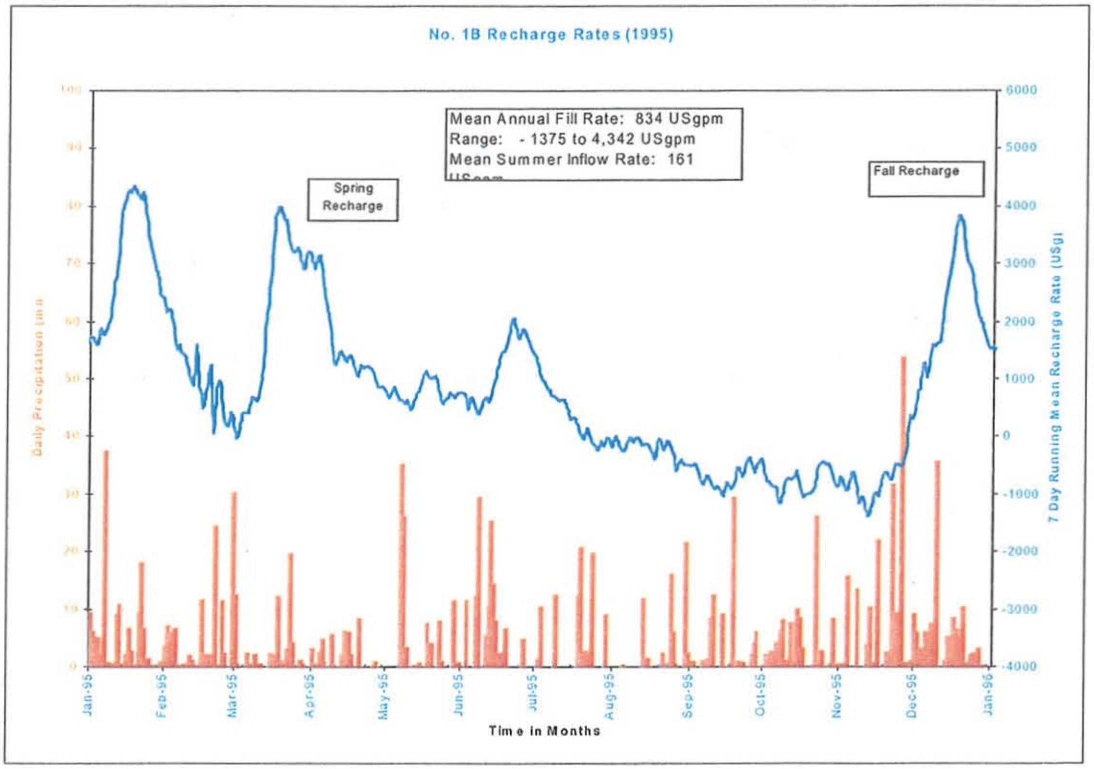


Figure A21. No. 1B Hydraulic System Annual Recharge Distribution (1993-1994)

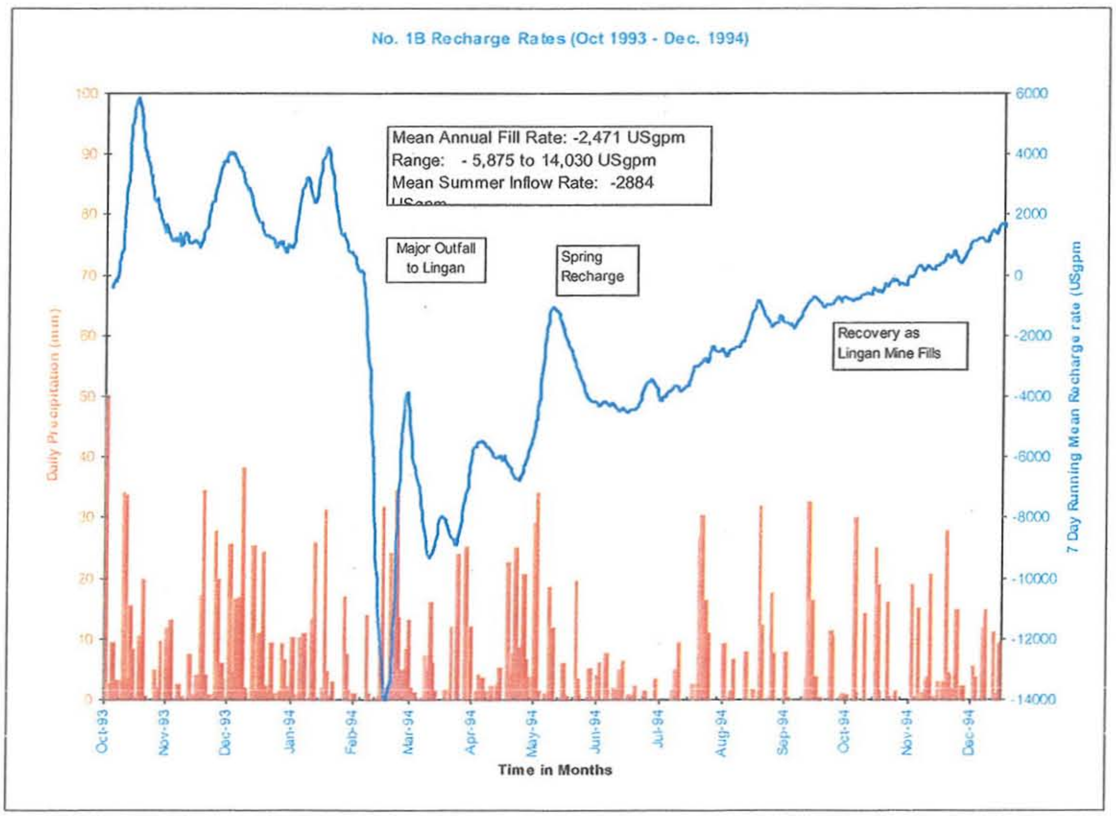


Figure A22 Distribution of Peak Flow No. 1B System (1996 to 2001)

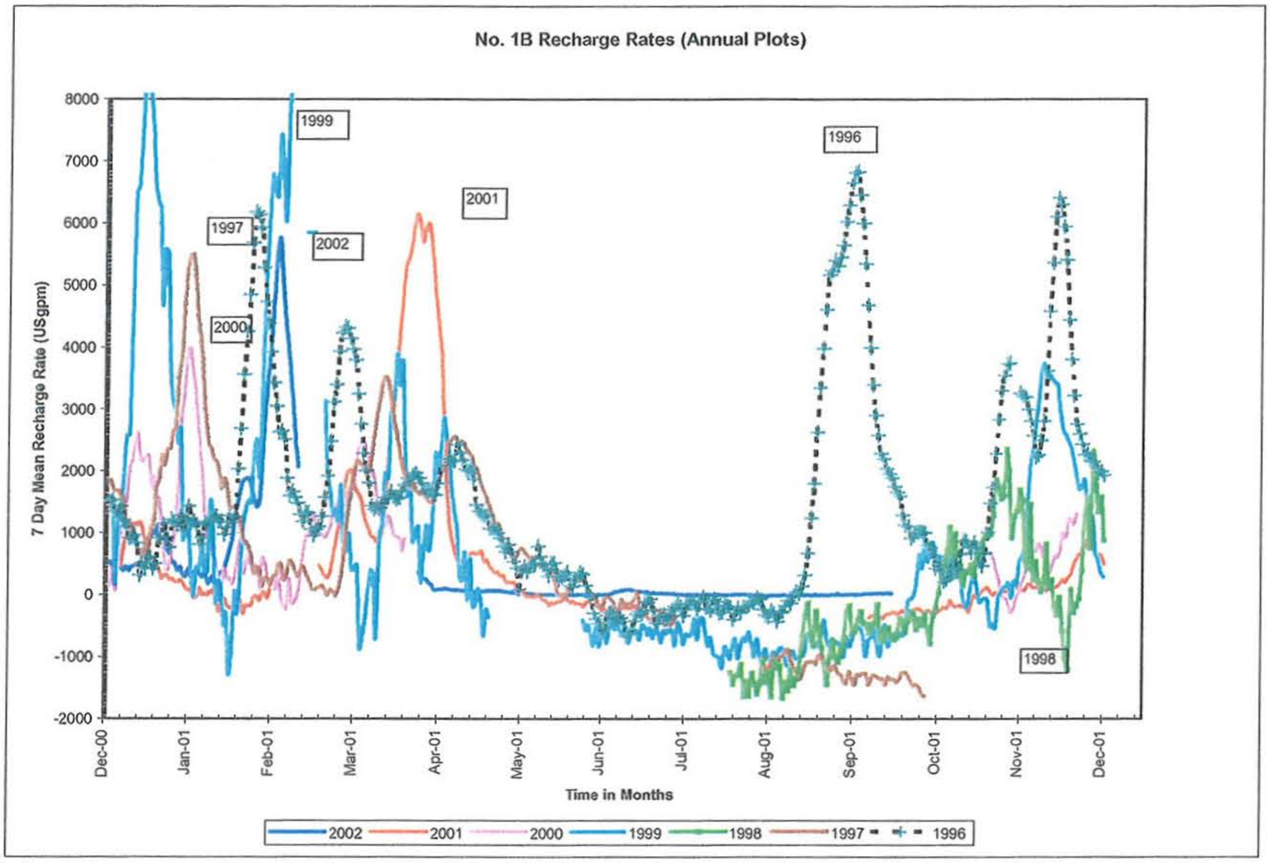


Figure A23 Distribution of Mine Recharge Using Monthly Means. No. 1B System

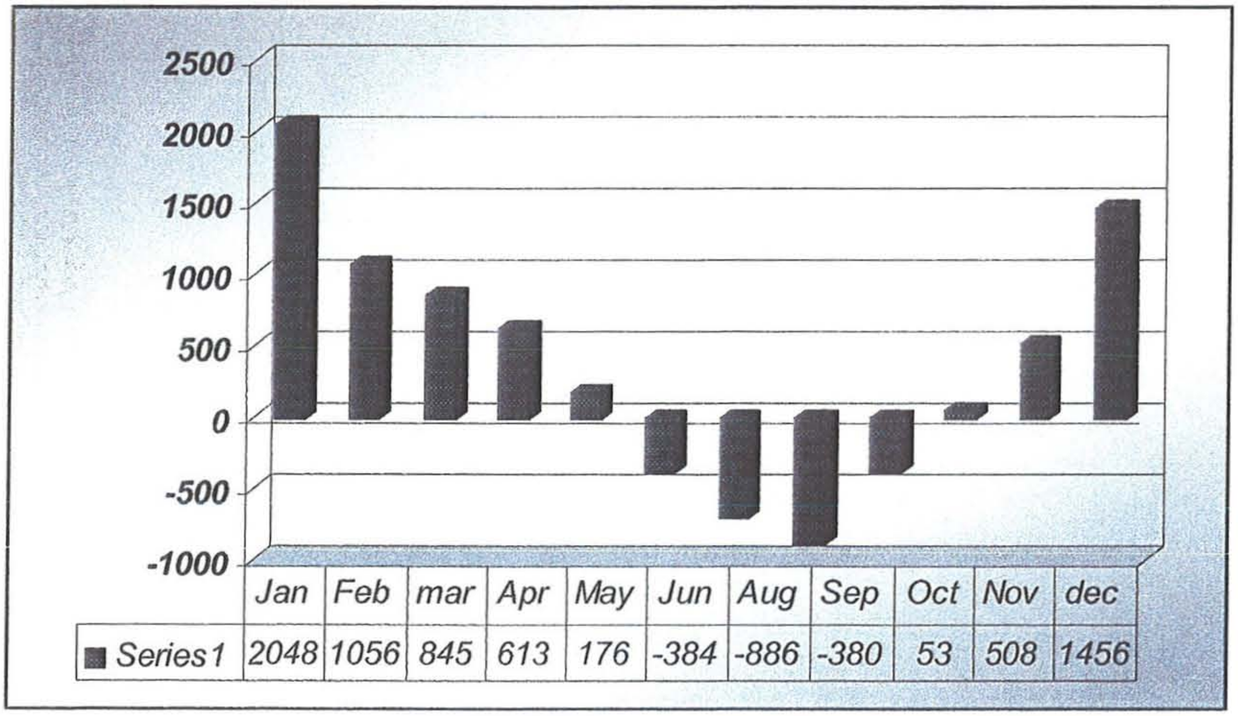


Figure A24 Lingan Annual Recharge Distribution (1992 to 2002)

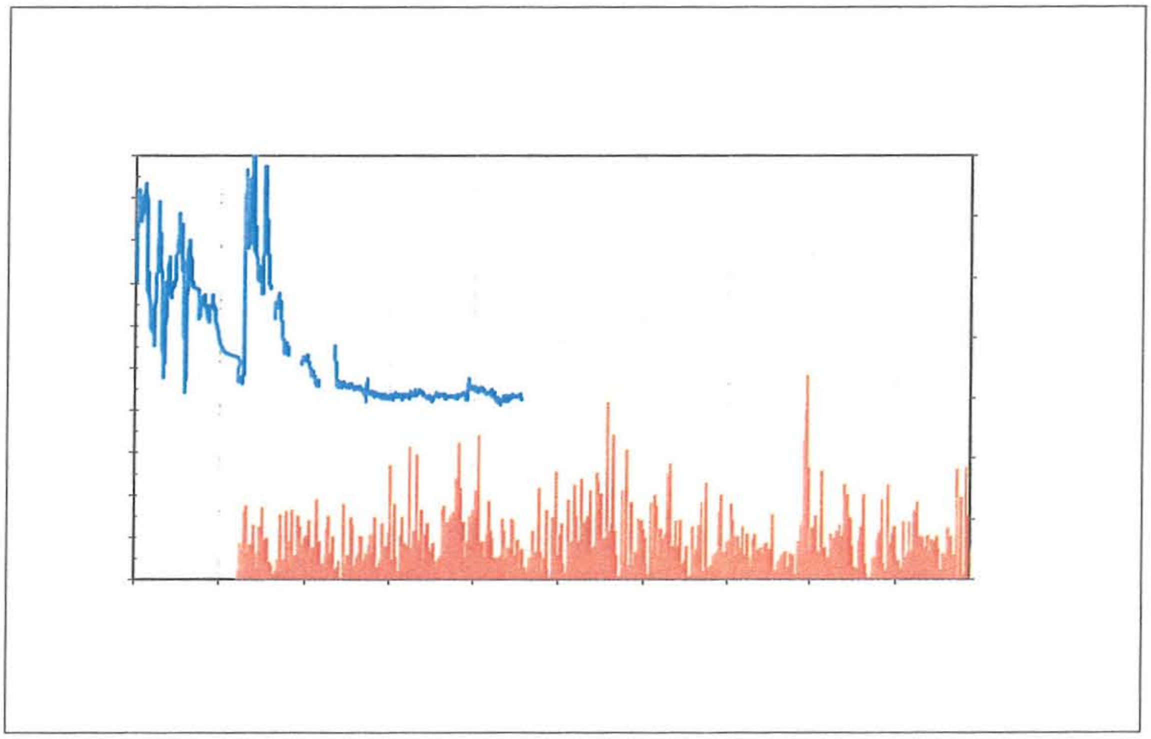


Figure A25 Lingan Annual Recharge Distribution (2002)

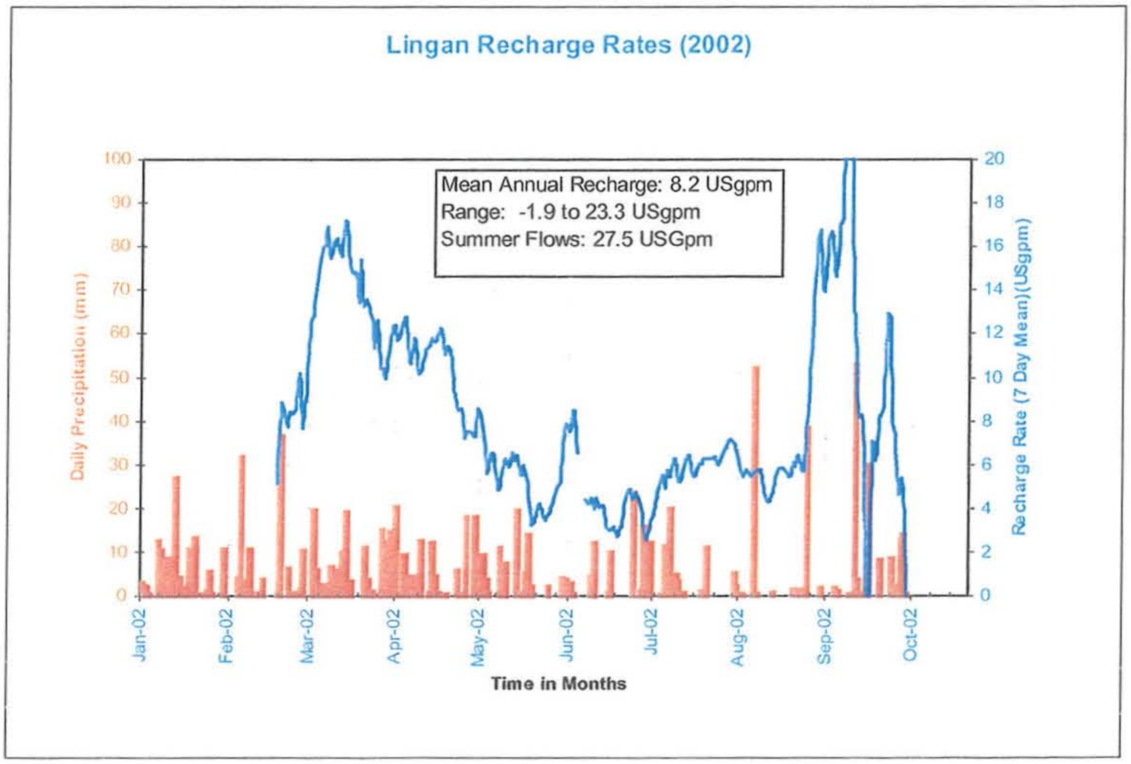


Figure A26 Lingan Annual Recharge Distribution (2001)

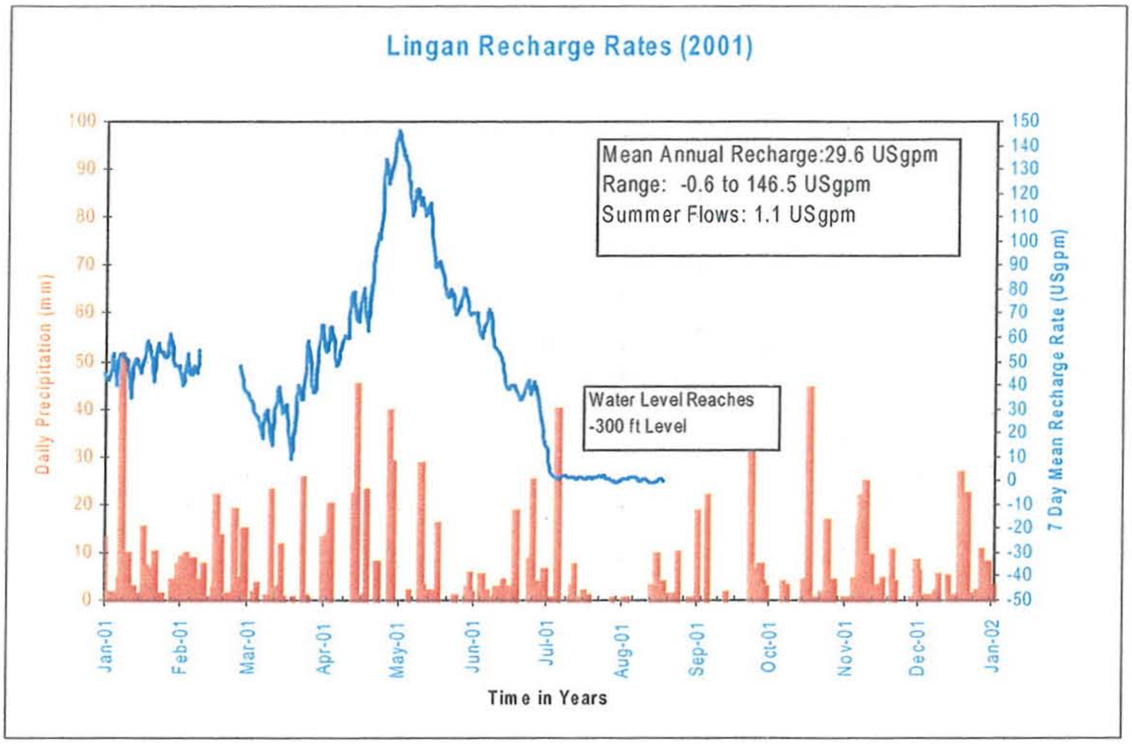


Figure A27 Lingan Annual Recharge Distribution (2000)

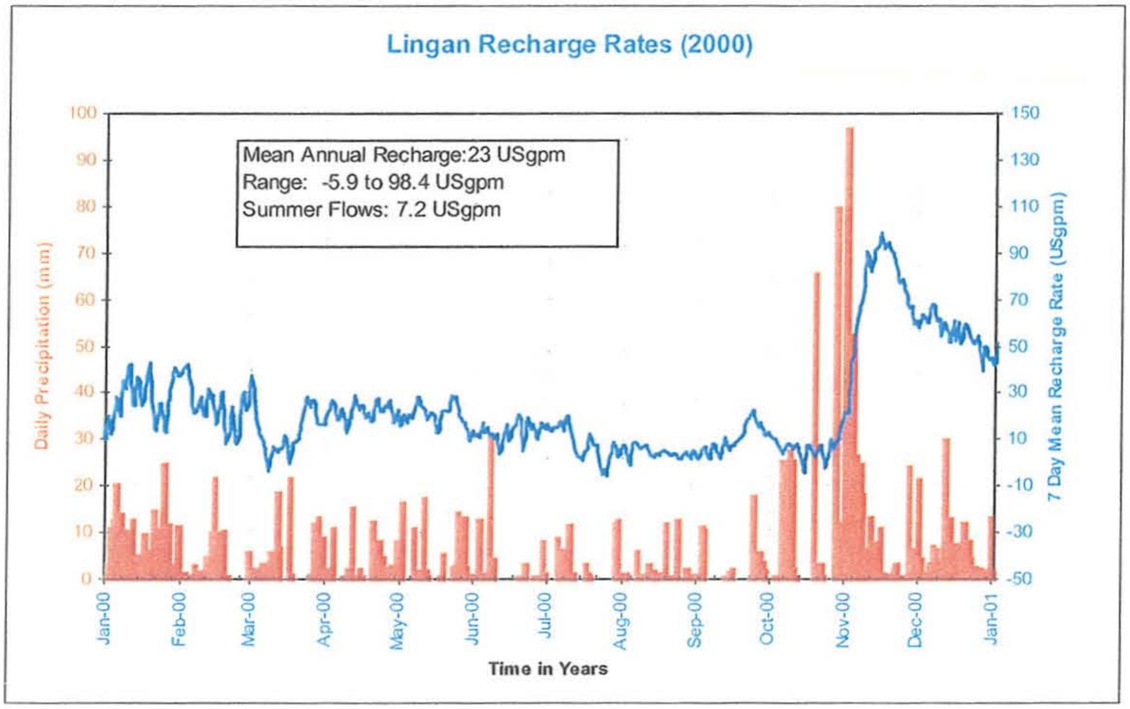


Figure A28 Lingan Annual Recharge Distribution (1999)

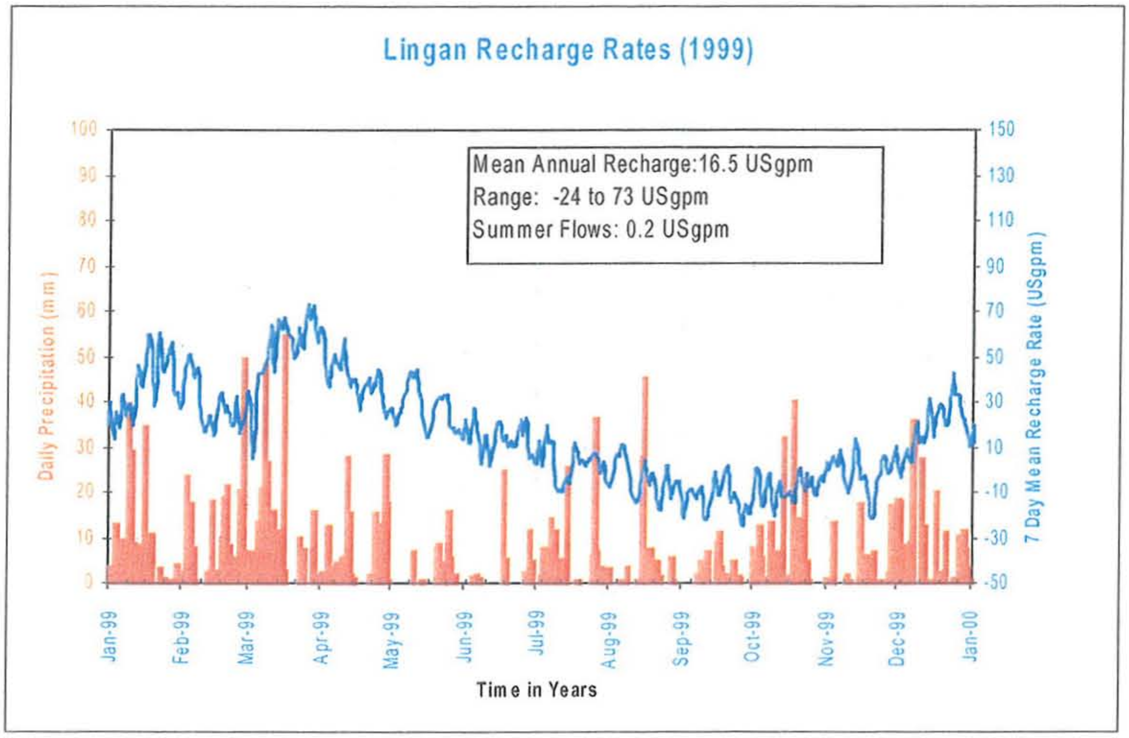


Figure A29 Lingan Annual Recharge Distribution (1998)

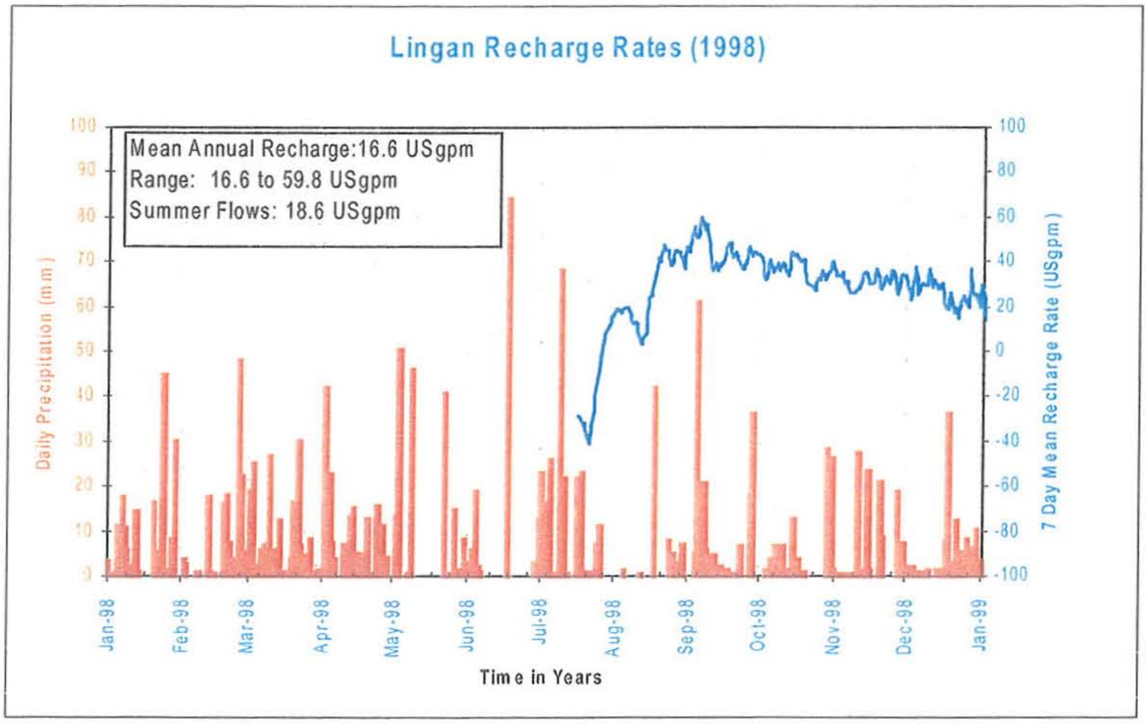


Figure A30 Lingan Annual Recharge Distribution (1997)

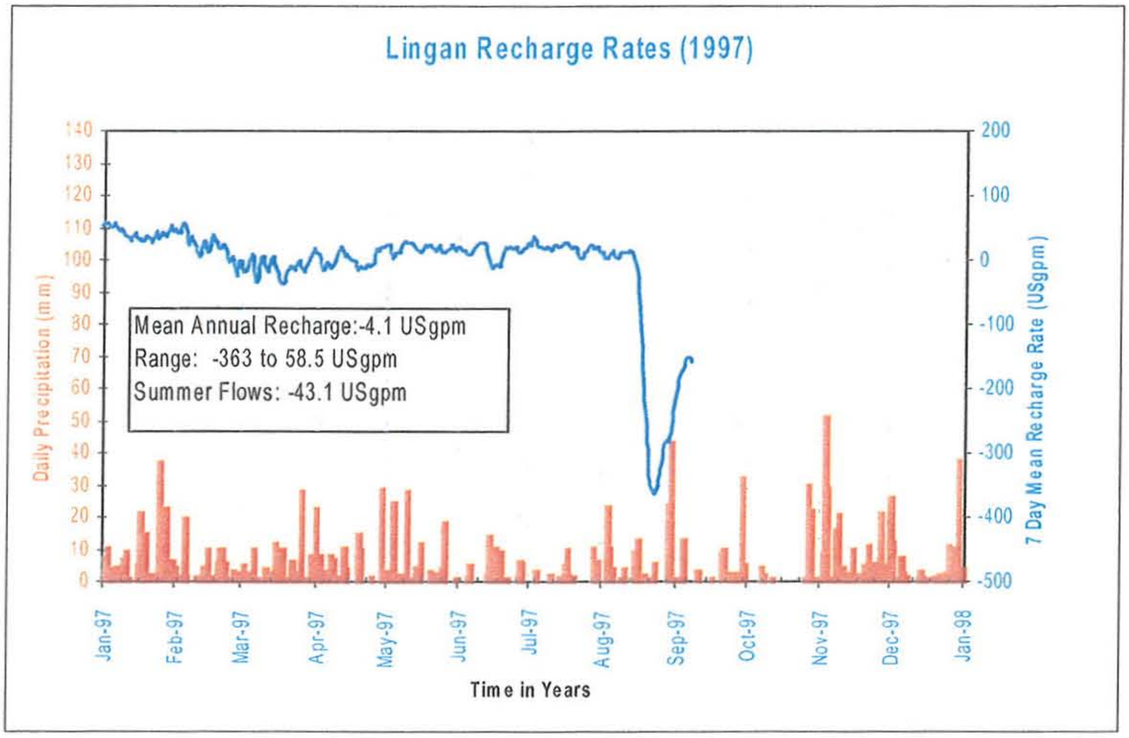


Figure A31 Lingan Annual Recharge Distribution (1996)

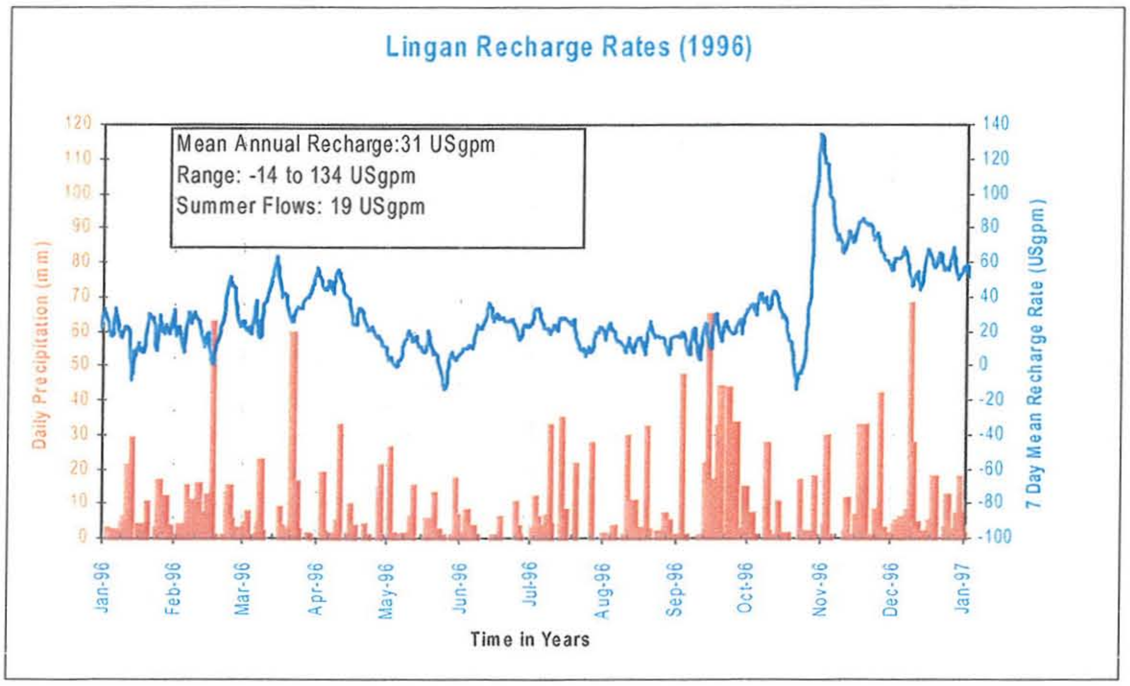


Figure A32 Lingan Annual Recharge Distribution (1995)

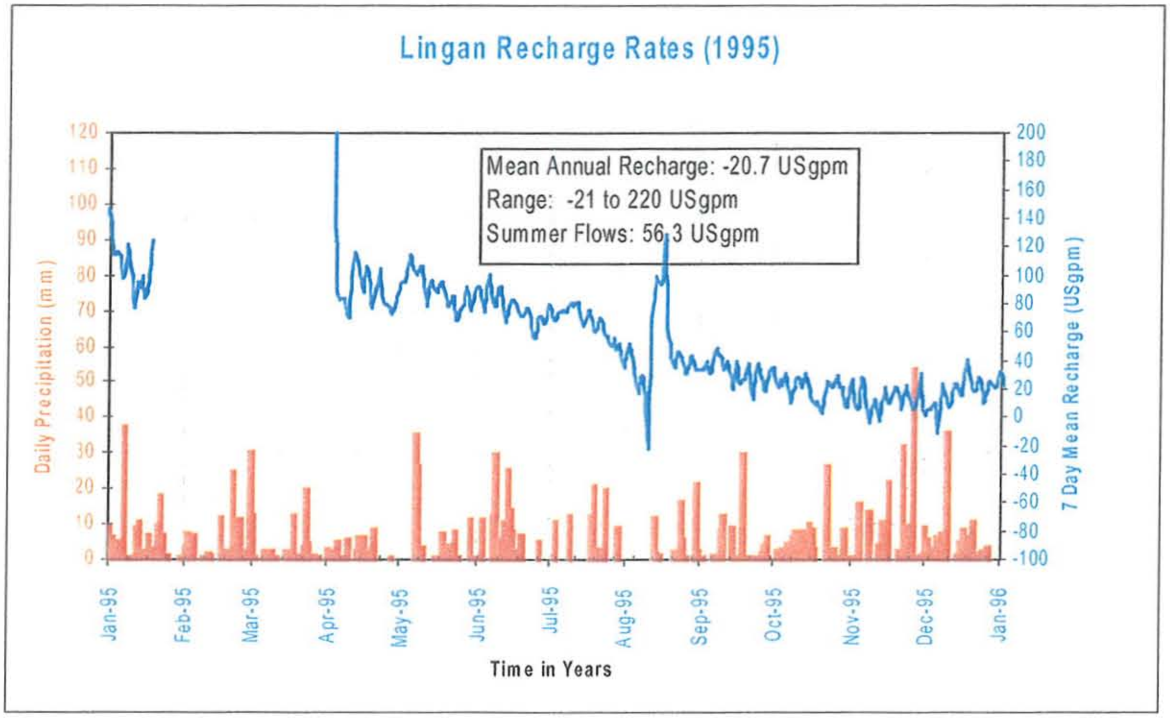


Figure A33 Lingan Annual Recharge Distribution (1994)

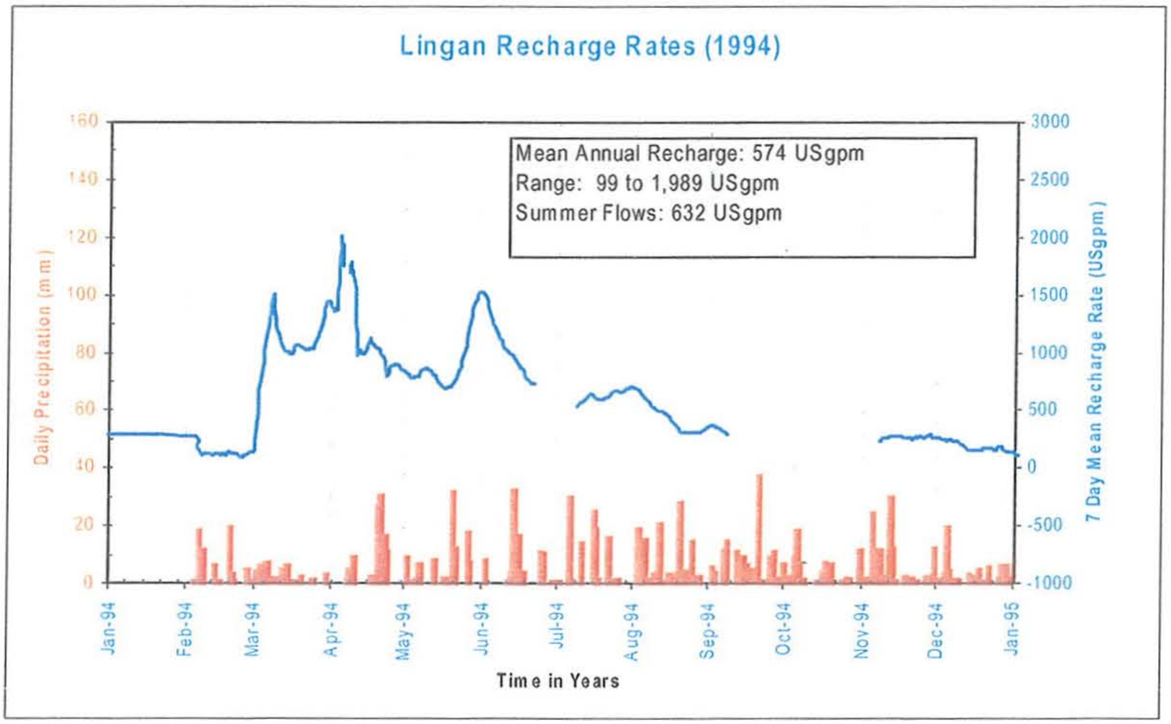


Figure A34 Lingan Annual Recharge Distribution (1992-1993)

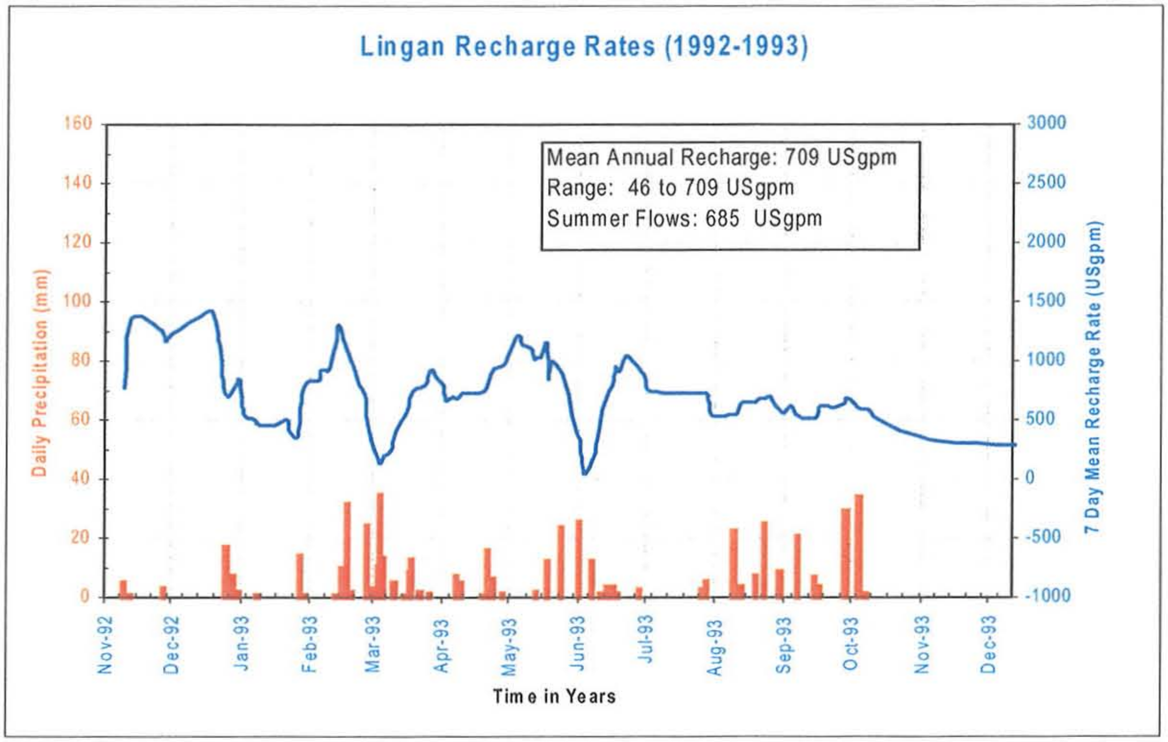


Figure A35 Phelan Recharge Distribution (2000-2002)

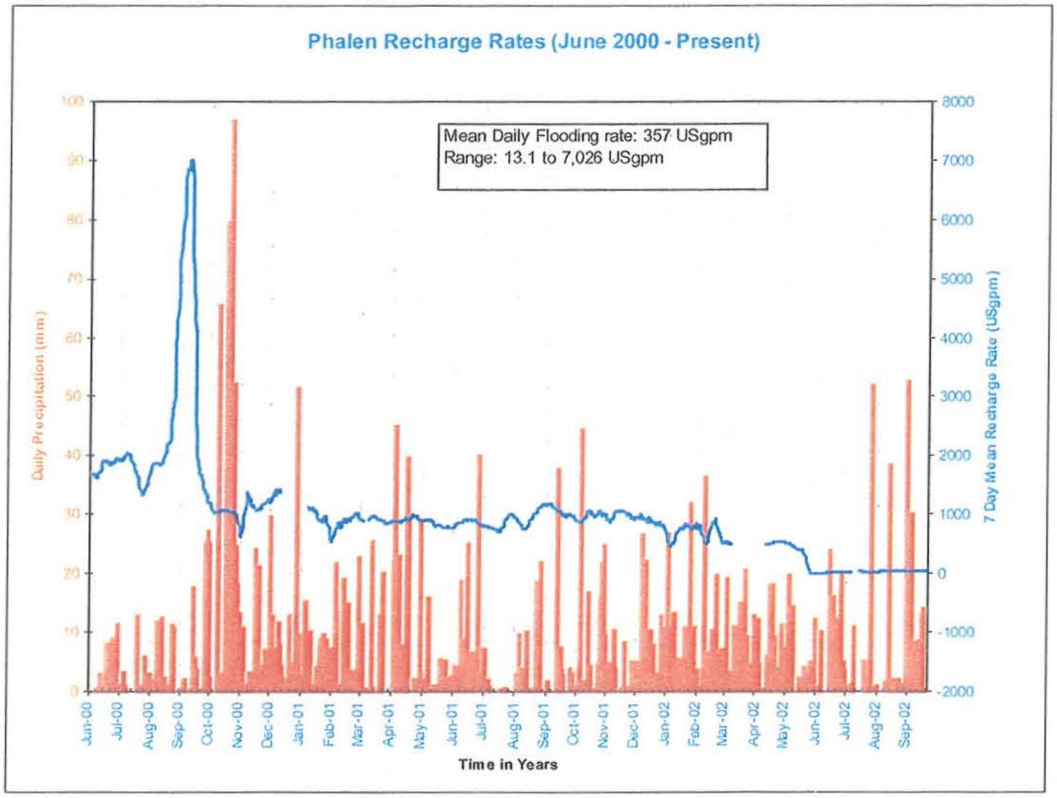


Figure A36 Phelan Annual Recharge Distribution (2002)

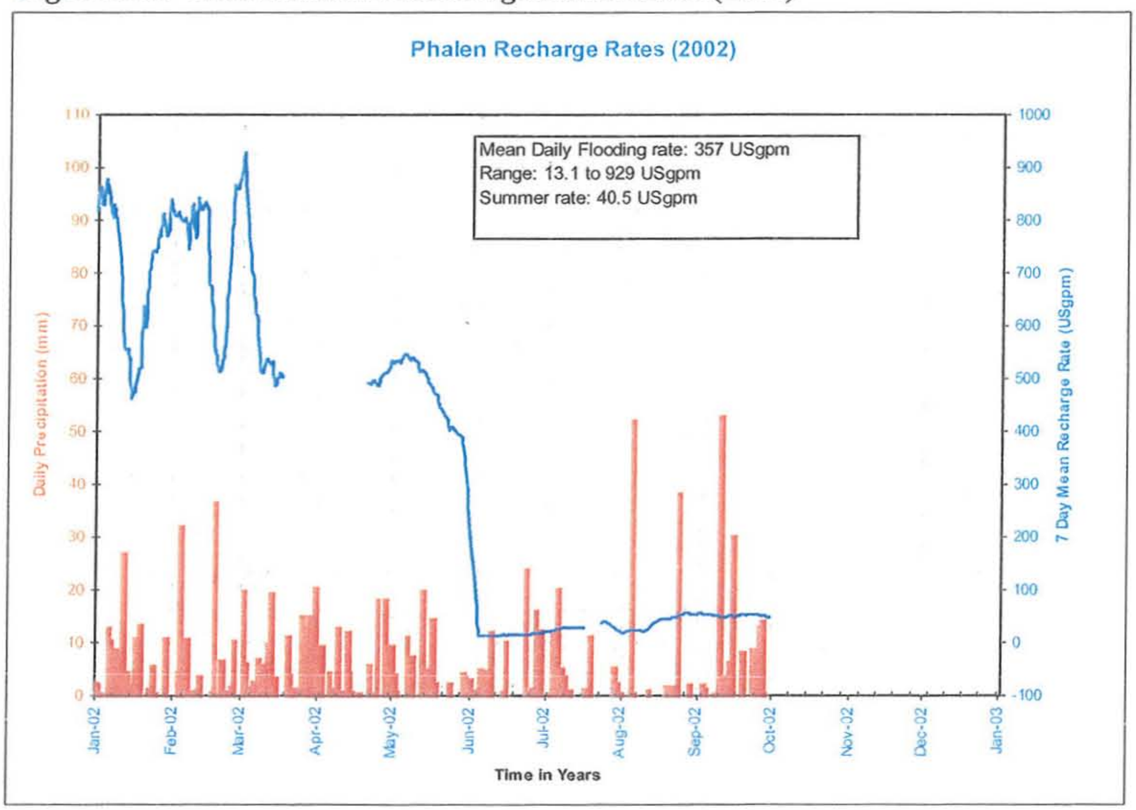


Figure A37 Phelan Annual Recharge Distribution (2001)

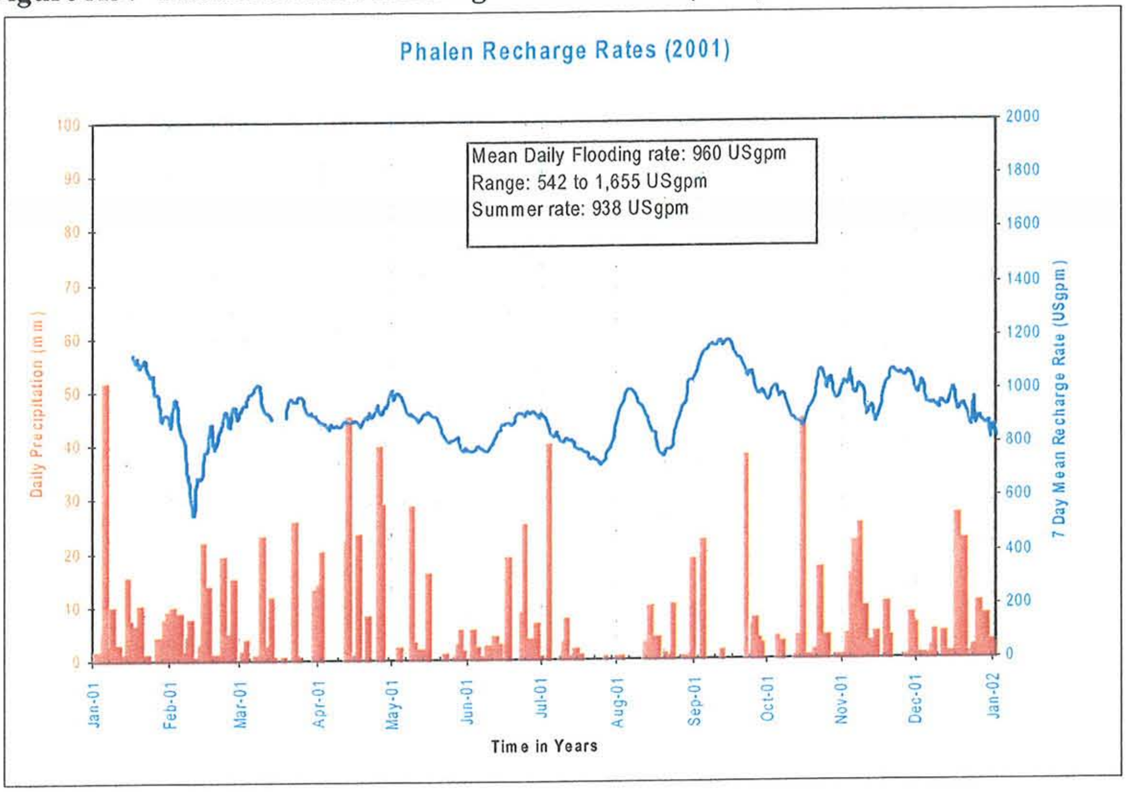


Figure A38 Phelan Annual Recharge Distribution (2000)

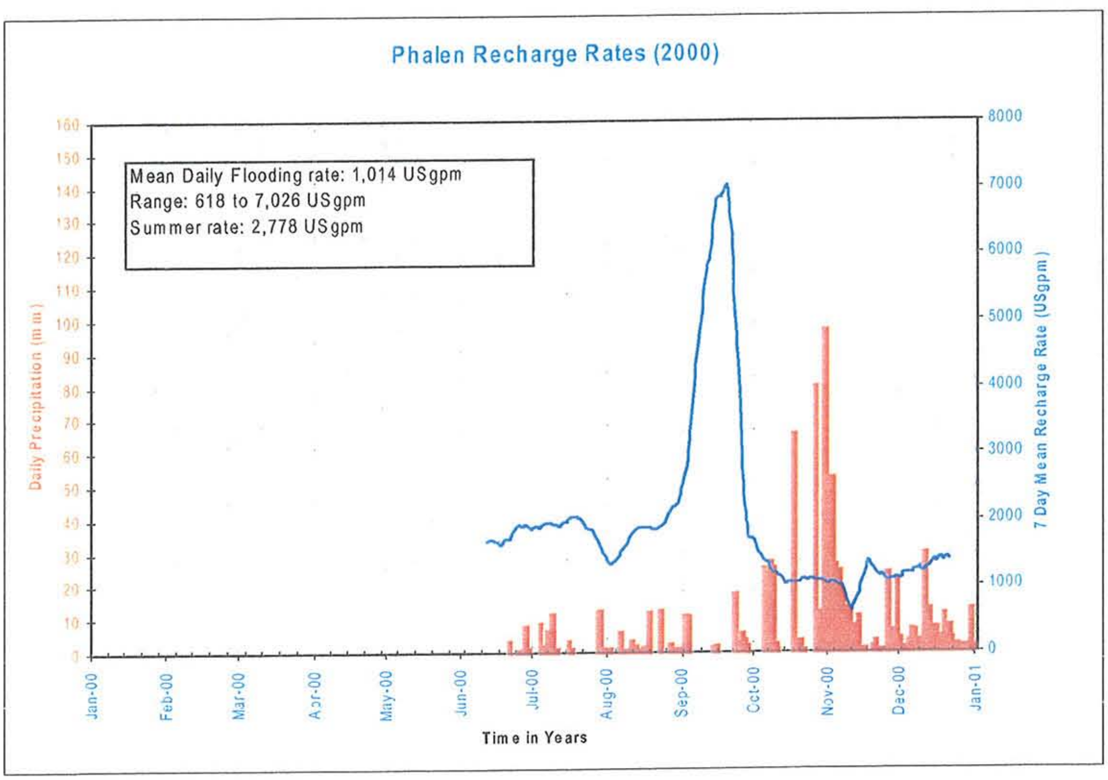
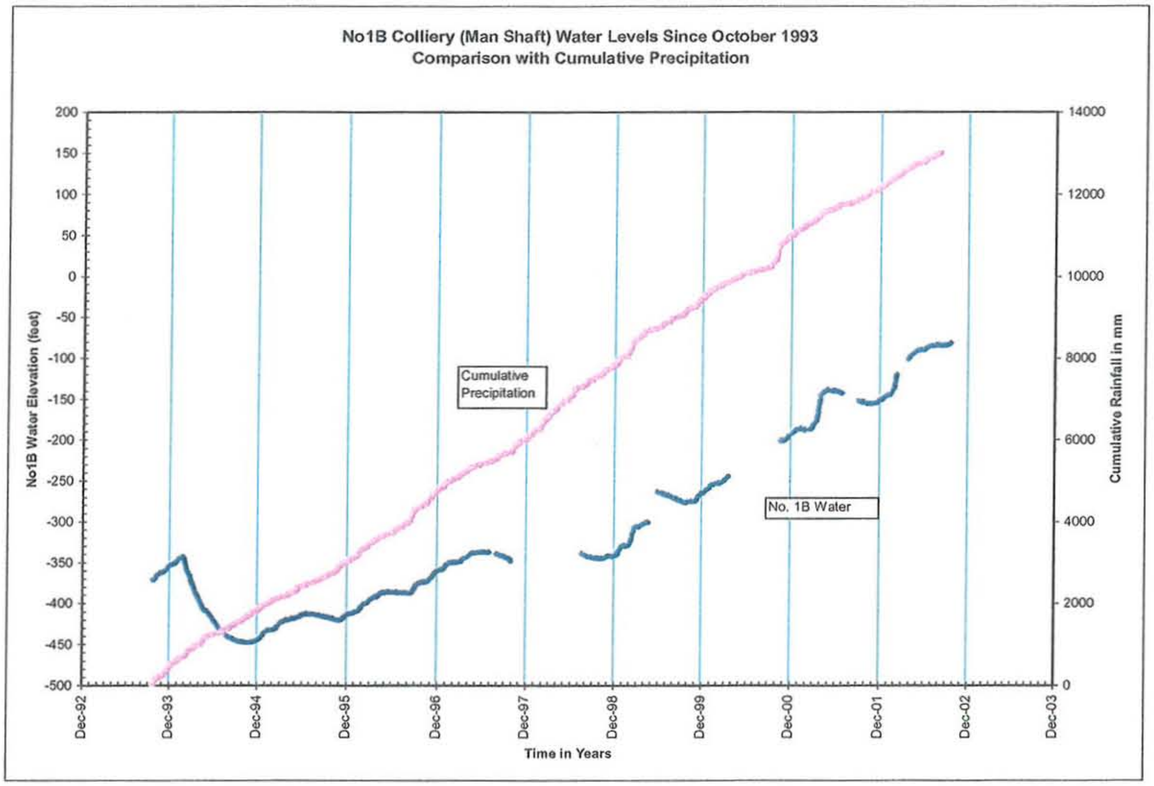


Figure A39. No. 1B Hydraulic System Water Level 1984 to 2002



APPENDIX B

WATER BALANCE DEVELOPMENT

B.0 WATER BALANCE DEVELOPMENT

B.1 Background and Approach

Section 3.0 and Appendix A defined "*how much*" water was getting into the 1B mine system, as well as "*when*" and "*how fast*", based upon analysis of the rise in water level within the mine openings.

This section summarizes a water balance investigation designed to not only determine "*how*" and "*where*" the water identified in Section 3.0 and Appendix A is infiltrating into the workings, but also to define "*how much*", or the relative contributions from different areas. The results of this approach are summarized as follows:

"*How*" is outlined in Section 4.2 and Appendix B.2 through development of a conceptual model of the hydrological cycle for the study area. This delineates ground and surface water flow patterns and the associated controls.

"*Where*" is outlined in Section 4.3 and Appendix B.3 by delineating watershed areas contributing water to the mines through the flow patterns defined above.

"*How much*" (Section 4.4 and Appendix B.4) combines Sections 4.2/Appendix B.2 and 4.3/Appendix B.3. Groundwater head level hydrograph data was not available within the time constraints for this study. Therefore, the analysis uses the McAskill Brook streamflow data to quantify the flows from each watershed area. The resultant flows are calibrated against the mine water ingress evaluation in Section 3.0 and Appendix A to determine the accuracy of this approach.

The results of the water balance analysis are summarized in Map 4 (in pocket at the back of this report). The reader is requested to have this map available while reviewing the following text.

B.2 Conceptual Flow Model - "How is the Water Moving?"

B.2.1 Model

Hydrological Setting

The Glace Bay study area lies within the Northeastern Appalachian Hydrogeological Province (Heath, 1988). It is hydrologically positioned within the Lowland Hydrological Region, specifically, the Homoclinal Flank District (Figure B.1) as defined by Baechler et al (2002).

The study area is principally characterized by gently undulating bedrock controlled topography ranging from 0 to 75 metre (0 to 200 ft). It terminates abruptly with 10 to 15 metre (30 to 45 ft) high vertical wave cliffs along the Atlantic Ocean coastline, forming the northern perimeter of the study area (Figure B.1). One notable topographic feature is a north-south trending broad valley associated with Cadegan Brook, which transects the Glace Bay peninsula. Within the upper reaches of this valley around MacKay's Corner, the valley floor takes the form of a 300 to 450 metre (1000 to 1500 ft) wide, 1600 metre (5300 ft) long depression, infilled with organic deposits.

Rising sea levels of 0.3 metres (1 ft per 100 years) (Grant, 1994) has created a deeply indented coastline of submergence. The heavy wave cliff erosion of 0.3 to 1.5 metres (1 to 5 ft) per year is removing the geological units, minimizing the groundwater flow systems, raising the base level for streams and providing a notable long, linear groundwater discharge point. By flooding low-lying river valleys, it has created the two brackish estuaries that form the western (Bridgeport Basin) and eastern (Big Glace Bay Lake) boundaries to the study area. The overall effect is to allow saltwater intrusion into the fresh groundwater flow field on three sides of the study area.

A large portion of the land surface is under urban-suburban landuse within the communities of Glace Bay, Reserve Mines and Dominion, which are serviced with piped sewer and water systems. This landuse generally enhances surface water runoff and reduces groundwater infiltration.

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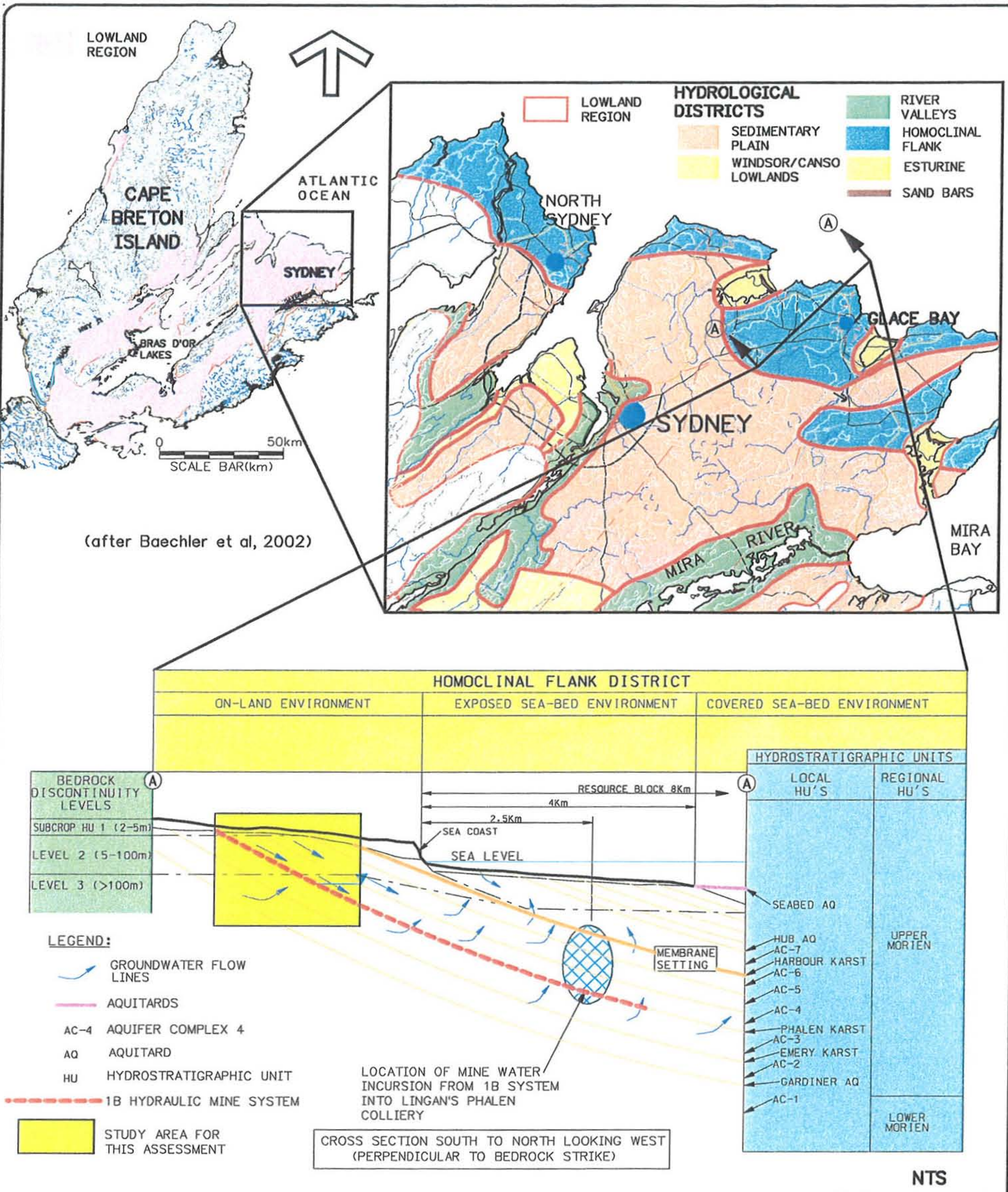

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Jacques Whitford

Steve Forgeron Consulting Geologist

Proj.
WATER BALANCE ASSESSMENT
No.1B HYDRAULIC SYSTEM

Dwg.
FIGURE B.1
REGIONAL HYDROLOGICAL SETTING OF 1B HYDRAULIC SYSTEM

Proj. No. 5285-001.1	
Drawn By:	NEB
Dwg. Standards Chk. By:	
Designed By:	FEB
Dwg. Design Chk. By:	
Date: OCT 29, 2002	
Rev.	0

Hydrostratigraphic Units

A total of seven hydrostratigraphic units (HUs) (geological units with similar hydrogeological properties) have been identified within the study area (Baechler, 1986 and ADI Nolan Davis, 1993) which control the flow of surface and groundwaters. The configuration of these units is provided in concept on Map 4, Figure B.

The glacial overburden is divided into three HUs. At ground surface, this includes a roughly 0.3 metre thick, permeable (bulk K ranging from 10^{-1} to 10^{-2} cm/sec) podzol soil profile (Podzol HU). This is developed over a 1 to 7 metre (3 to 20 ft) thick, lower permeability (10^{-5} to 10^{-6} cm/sec) silty sand basal till (Till HU). In the MacKay's Corner area, organics create a Peat HU positioned over the Till HU.

These overburden units overly fractured sedimentary bedrock comprised of an additional five HUs. These include a relatively higher permeability (10^{-4} to 10^{-6} cm/sec), 30 to 60 metre thick sandstone/siltstone complex (Arenaceous HU), interbedded between each of five lower permeability (10^{-7} to 10^{-8} cm/sec), 2 to 4 metre (5 to 12 ft) thick mudstone/coal units (Coal HU).

Four of the coal seams (Emery, Phalen, Harbour and the Hub) have been extensively mined out forming an extremely high permeability (>1 cm/sec), karst-type system (Karst HU). This karst zone includes not only the 3 to 4 metre (10 to 15 ft) high extraction zone, but also the collapse zone induced above it, which could extend some 20 metres (60 ft) into the roof. Where coal mining lies within approximately 15 metres (50 ft) of ground surface (Forgeron, pers. comm.), subsidence of overlying bedrock and overburden units into infilled collapsed zones creates subsidence zones, and at times sinkholes, with expected highly variable permeabilities (1 to 10^{-3} cm/sec) (Subsidence HU).

This entire bedrock HU package dips seaward at approximately 5 degrees; the structure of which is controlled by the northeast-southwest trending, northeast plunging (7 to 10 degrees) Glace Bay syncline. Additional near subcrop fracturing is enhanced by stress relief, valley rebound, as well glacial scouring loading/unloading activities. This creates a higher permeability (10^{-2} to 10^{-4}

cm/sec) pathway within the top approximately 1 to 5 metres (3 to 15 ft) of the bedrock surface (Subcrop HU).

Climate

The study area is characterized by a humid continental climate, with one of the two highest precipitation regions in Canada. Precipitation is high (1500 mm). Low evapotranspiration losses result in a large water surplus (294 mm) and minor deficit (5.8 mm) felt predominately in July and August (Baechler, 1986). The result is elevated groundwater recharge volumes. Variations in climatic variables delineate two groundwater recharge windows which will direct inflow into mine workings; principally, during the fall and spring, although numerous melt events during mild winters can also contribute infiltration. Most rainfall is associated with low intensity, long duration events that further enhance recharge.

Groundwater Flow Systems

With rainfall, the first flow system activated is interflow created by rapid saturation of the Podzol HU, perched over the Till HU. This exerts the primary control over runoff processes, as defined by the Variable Source Runoff Model (Dunne and Leopold, 1978). During this process, a large volume of water is quickly directed laterally down topographic gradient into adjacent streams, the sea cliffs and/or the Subsidence HU. A portion is also diverted vertically to recharge the water table.

The second flow system activated is the saturated groundwater flow field. For this system, the Till HU forms an aquitard (a semi-confining layer over the Bedrock HUs). The Coal HU forms an Aquitard, which separates the interbedded Arenaceous HUs into a series of Aquifer Complexes.

Recharging water moves vertically through the Till HU to the water table, which depending upon topography, is within the till (topographic low areas) or close to the till/bedrock interface in topographic high areas. Depending upon the permeability contrast, a perched system may also be developed at the contact.

The bedrock HUs are all fully saturated under normal conditions. Given the high water surplus, water tables closely resemble surface topography. Therefore, surface and groundwater watersheds are similar. Each Aquifer Complex exhibits a water table system in its outcrop area, which quickly become artesian down dip due to the overlying Coal HU aquitard. Fracture permeability is expected to be active down to approximately 100 metres (Randall et al, 1988). This has also been noted in mine workings (S. Forgeron, pers. comm.). Groundwater is not expected to flow down-basin under the ocean floor due to reduction in permeability and the presence of dense hypersaline mine waters at depth (ADI Nolan Davis, 1993).

Within the active on-land portion of the groundwater flow field, fluid potential (hydraulic head) is expected to be the primary driving mechanism. Therefore, the groundwater flow field model outlined by Toth (1962) is expected to adequately model the system. First order flow systems, where groundwater recharge and discharge zones are adjacent to each other, are pertinent for near surface flow within the Aquifer Complex subcrop areas. At depth, the Coal HU aquitards are expected to contain flow within the Aquifer Complex and minimize development of 2nd or 3rd order flow systems. Given the height of the sea cliffs, lateral flow along strike to discharge points along the coast is not expected to dominate the flow field.

The mined zones will alter the above model in two regards. First, the Karst HU can be expected to act as a drain until filled, creating a localized linear drawdown cone. Second, the removal of the Phalen Coal HU Aquitard will allow the lower Aquifer Complex above the underlying Emery Coal Seam to combine with the upper Aquifer Complex below the Back Pit seam, resulting in one large Aquifer Complex, allowing flow into the Karst HU from above and below.

Surface Water Flow Systems

Topographic relief, coupled with the rainfall-runoff-flow field processes defined above, has combined to create a coarse surface water drainage network within the study area (Map 1).

The watersheds within the Sydney Coalfield are characteristically small, thereby reducing the total volume of water transiting the study area in any one stream. Their low drainage densities and texture ratios create a coarse drainage system, implying they are poorly drained (Baechler, 1986). The length of time for generated flow to reach stream is relatively long and more is potentially available to be intercepted by sinkholes, except in urbanized areas where roadside drains create a high drainage density.

The three primary streams pertinent to the study area (Dominion, Cadegan and Renwick Brooks) drain north to the coast. Some portion of each forms a trellised pattern following the semi-circular pattern of coal seam outcrop, although this is more dominant in Dominion Brook. The remaining two watersheds exhibit primarily a dendritic pattern, which crosses strike and, therefore, the coal seams at right angles.

Even the larger channels are not deeply incised into the terrain. They exhibit high width/depth ratios created by the development of a lag pavement derived from underlying stony glacial till. Therefore, the major HUs contributing direct flow into the channels are "interflow" and saturated groundwater flow in the Till HU. Bedrock is only sporadically exposed in streambeds.

Implications for Mine Water Inflow

The climatic and geological conditions have created favourable conditions to maximize infiltration and, therefore, inflow to the workings. High rainfall from low intensity storms creates a large water surplus that recharges groundwater during at least two periods every year (fall and spring) and possibly a third during winter, if it is mild.

This recharge maximizes the extent of saturation of the groundwater providing high water tables to drive the flow system. Drainage densities are low, enhancing recharge and minimizing runoff. Streams are not deeply incised, thereby controlling only shallow groundwater flow -- the remainder is available for deeper flow.

Urban land use within the study area should generally act to minimize recharge. The mining activities near the outcrop of the Phalen Coal Seam creates subsidence and increased permeability, further enhancing recharge directly into the mines. This is exacerbated by one of the longest on-land extent of cropline in the study area, some 9.36 km (5.7 miles) long.

Sea level rise will continue for an additional 2 to 7 metres, if equilibrium is to be achieved with the last interglacial period. However, at 1 ft per 100 years it is too slow to impact mine water decision-making.

B.3 Watershed Areas – "Where is the Water Getting In?"

B.3.1 Delineating The Watershed

By understanding the flow systems (Section 4.2/Appendix B.2), it was then possible to delineate watershed areas contributing flow by these processes to the mine workings. This included not only natural "watersheds" (drainage controlled by ground surface topography), but also "Minesheds" (drainage controlled by extent of mine workings) and "Sewersheds" (drainage controlled by storm/sanitary sewers).

The aerial extent of these "sheds", as they relate to the Phalen Coal Seam, are delineated in Map 4 and summarized below.

Sinkholes and their Drainage Area

It was expected that in areas exhibiting sinkholes, all precipitation would recharge directly into the underlying mine workings. This area would also include the localized drainage areas to these sinkholes, as defined from a 1:10,000 scale digital mapping with 1 metre contour intervals. Where isolated sinkholes were noted, an arbitrary three times their diameter was used to delineate the drainage area.

Sinkholes associated with the Phalen Coal Seam were delineated from:

A. Nova Scotia Department of Natural Resources 1 in. = 100 ft mapping, with 5 ft contour interval and 2.5 ft auxiliary contours compiled from 1971 air photographs;

B. Air photo interpretation of 1999 air photographs;

C. Groundtruthing; and

D. CBDC experience.

This watershed type covers a total of some 40.3 hectares (99.6 acres). There is a scattering of localized sinkholes along the entire crop of the seam, but with a high frequency in five localized areas, including:

A. One in the Town of Dominion centered over the No. 1A outlet extension colliery workings (Mineshed), covering 10.5 hectares (25.9 acres),

B. Two around the MacKay's Corner wetland and one in the McLeod's Crossing area, over the No. 5 Colliery Mineshed, covering 14.1 hectares (34.9 acres), and

C. One in Passchendaele over the No. 3 Colliery Mineshed, covering 4.98 hectares (12.3 acres).

Bootleg Workings

A potential zone of bootleg and old formal workings was expected to be present down dip of the Phalen Coal Seam crop. Experience indicates that it is only within a zone where cover is less than 15 metres (50 ft) that notable collapse of overlying rock and overburden into the mine occurs, thereby creating a "chimney" effect with higher permeabilities, but insufficient to create a sinkhole. It is within this zone that increased direct recharge to the No. 1B mine system could also occur.

It was assumed, from CBDC's experience with bootleg workings, that this zone could potentially extend for the entire length of the seam crop. Outlining the 15 metre (50 ft) depth contour on the floor of the seam delineated the aerial extent, as defined on CBDC mine plans.

This zone varies in width from 105 to 255 metre (350 to 850 ft), covering some 119 hectares (294 acres). Its' narrowest zone is positioned over the No. 1A Outlet Extension Colliery Mineshed, the largest over the No. 4 Colliery Mineshed.

Drainage Area to Bootleg Workings

Drainage into the bootleg workings would include "interflow," as well as the shallow portion of the saturated groundwater flow field. Surface watersheds delineated this area.

The configuration of the surface topography, in relation to the strike of the coal seam, keeps this drainage area relatively small, comprising some 155 hectares (384 acres). The largest area of 90.7 hectares (224 acres) drains into the No. 4 Colliery Mineshed.

Groundwater Flow Field

Additional input to the unsaturated mine workings would include leakage through the roof and the floor from the saturated portion of the deeper groundwater flow system within the Aquifer Complex.

The downward leakage factor was calculated by utilizing the 100 metre (300 ft) depth limitation on the active portion of the groundwater flow field. This translated into an average lateral distance of some 1100 metres (3600 ft), not accounting for varying topographic relief.

This leakage applies while the mine is flooding. With rise in water level, the gradient reduces to very low values expected within a natural groundwater flow system. As a result, this component will reduce with time.

Ground-Surface Water Interaction

A potential source of direct inflow to the mine workings could be associated with influent reaches of streams as they cross the zones of bootleg workings, sinkholes and their drainage areas.

Drainage patterns indicate that there are three dominant locations where this has the potential for occurring, including:

Western Zone: A watershed associated with a tributary of Dominion Brook crosses a relatively narrow 150 metre (500 ft) wide bootleg working zone and minor scattered sinkholes over the 1A Colliery Mineshed within the Town of Dominion.

Middle Zone: A watershed within the headwaters of Cadegan Brook crosses a 200 metre (660 ft) wide bootleg working zone and two associated dense zones of sinkholes overlying the No. 5 Colliery Mineshed at MacKay's Corner.

Eastern Zone: The headwater portion of Renwick Brook crosses a 200 metre (660 ft) wide bootleg working zone within the No. 4 Colliery Mineshed within the Town of Glace Bay.

The latter two form the critical zones for the No. 1B Hydraulic System. Of these, the Cadegan Brook – MacKay's Corner crossing is of paramount importance, since it is positioned over the No. 5 Colliery Mineshed, which is in direct link to the No. 1B System. In addition, the reach is relatively long, occurs within a large wetland with a lake and includes two dense areas of sinkholes. Finally, of the three crossings, it is positioned at the highest topographic elevation (30 metres) and is known to have a higher hydraulic head in the surface water system than in the underlying unsaturated mine workings; thereby, creating a downward driving head and confirmed influent conditions. Three localized sinkholes have already been infilled by CBDC where surface water within the wetland was noted flowing directly into the mine workings.

The other two reaches are positioned at lower elevations (15 to 16 metres - Eastern Zone and 20 to 22 metres - Western Zone). At this time, it is unknown whether the Eastern Zone crossing is influent or effluent. On-going monitoring is being undertaken to confirm leakage rates and will be provided, when available, under separate cover.

Sewersheds

The three communities within the study area have combined storm/sanitary sewer systems. It is possible that leakage could contribute direct flow into the mines where they cross bootleg workings and/or sinkholes. However, none of this could be documented with the exception of the MacKay's Corner Lift Station. At this site, storm/sanitary sewage is directed toward the lift station, which pumps it over a knoll to drain into the Glace Bay System. CBRM acquired formal permission from CBDC to dump excess water from this station directly into the No. 5 Colliery workings during periods of flow in excess of pump capacity. The volume and timing of this inflow is unknown. If fully inundated, the overflow pipe could theoretically discharge some 1700 USgpm into the workings.

<u>Minesheds</u>

There are four colliery workings which mined the Phalen Coal Seam immediately downdip of the cropline, including from west to east the No. 1A, No. 5, No. 3 and No. 4 Collieries. These four Minesheds potentially link to the No. 1B Mine System.

Inflow to the No. 1A Mineshed over 1200 metres (4000 ft) along the cropline is diverted by the No. 1A mine water drain northwest along strike to the seacoast. This study assumes interior half dams prevent water from flowing down slope into the 1B System. There is also an 833 metre (2730 ft) long eastern extension to this mine water drain, which may or may not also be active, referred to as the 1A Outfall extension.

The No. 5 Colliery Mineshed is exposed along 3657 metres (12000 ft) of the cropline and is in direct contact with the No. 1B System at depth. This may include the 1A Outfall extension.

The 528 metres (1733 ft) of cropline exposed by the No. 3 Colliery Mineshed and 2987 metres (9800 ft) of the No. 4 Colliery Mineshed could divert infiltrating groundwater laterally through intersecting mine roadways, if still open, and/or collapsed but hydraulically active, into No. 5 Colliery.

B.3.2 Implications for Mine Water Inflow

In summary, the seven "shed" areas described above could be combined into three Watershed Scenarios, for determining contribution to the No. 1B Hydraulic System, namely:

Scenario A – No. 5 Colliery Mineshed, with a drainage area of 87 hectares (214 acres) along 3.6 km (2.3 miles) of cropline.

Scenario B – Scenario A plus No. 1A Outfall extension, with a drainage area of 109 hectares (286 acres) along 4.5 km (2.8 miles) of cropline.

Scenario C – Scenario B plus No. 3 and 4 Colliery Minesheds, with a drainage area of 269 hectares (664 acres) along 8.0 km (5.0 miles) of cropline.

Of the three stream crossings, MacKay's Corner exhibits the highest potential for allowing inflow. This is a result of not only sewer inflow, but also due to the presence of two relatively large areas of sinkholes within the confines of a large wetland that is constantly saturated to variable extent and includes a lake.

B.4 Contribution from Contributing Areas – "How Much?"

B.4.1 Approach

Having defined *"how"* the water could infiltrate into the mines (Section 4.2/Appendix B.2) and *"where"* (Section 4.3/Appendix B.3), the next step was to quantify the flows. This was undertaken using the water balance approach to calculate inflows on an *Average Annual Basis*:

The simplified water balance equation for a watershed of known size without man-made diversions is:

$$\mathbf{P = Rsw + Rgw + ET \pm S}$$

Where:

P = precipitation
Rsw = surface water runoff
Rgw = groundwater runoff
ET = evapotranspiration
S = change in storage

For this investigation, the equation was re-written to quantify groundwater infiltration as:

$$\mathbf{Rgw = P - (ET + Rsw \pm S)}$$

Precipitation was obtained from the Sydney A station. The 30-year Normal value was taken as 1524 mm (60 inches). However, the last decade has shown an overall decline in precipitation and increasing air temperatures (Baechler, 1999). To best reflect existing conditions, the last 10 years were assessed for high, low and normal precipitation years. The selection was also based on having adequate No. 1B System hydrograph records to allow for calibration of the analysis. This resulted in the year 1995 taken as a normal year (54.27 inches of precipitation), 1996 as the wet year (69.01 inches) and 2001 as the dry year (46.09 inches).

Changes in the storage component were assumed to be negligible given the absence of major surface water lakes in the study area and in the absence of groundwater level hydrographs.

Surface water runoff was taken from the McAskill Brook gauging station records representing a 17.2 km^2 watershed.

Evapotranspiration losses calculated theoretically from the Thornthwaite method gave an annual value of 535 mm (21inches) (Baechler, 1986). However, difficulty was noted in using the method in a humid climate such as in the study area. Initial calculations using that range indicated minimal water available for recharge, exemplifying the problem.

This left an equation to solve with two unknowns, namely Rgw and ET. This problem was resolved by undertaking a baseflow recession analysis of the streamflow data to determine the groundwater runoff component of streamflow. It was assumed that this volume equalled the amount of precipitation recharging the groundwater flow system.

The streamflow hydrographs developed from mean daily flow data for the three selected years are provided on Map 4. A modified Kunkle (1962) method of baseflow analysis was undertaken on each annual hydrograph to develop minimum and maximum groundwater flow component. The area under the curves was integrated on a daily flow basis to derive annual volumes of maximum and minimum groundwater, as well as surface runoff for each of the three years. These volumes were converted to depth of water over the watershed.

The maximum groundwater flow component resulted in 28.9 to 29.4 inches of annual groundwater recharge over the three years. The minimum groundwater flow ranged from 14.5 to 15.5 inches. This is far in excess of the 152 mm (6 inches) (Brown, 1967) and the average used in the Sydney Coalfield for numerical computer models of 380 mm (15 inches) (JDAC, 2001).

Given consideration to the conceptual flow model and watershed areas, the following recharge values were utilized to quantify groundwater inflow to the mines:

A. Sinkholes and their drainage areas (all precipitation).

B. Bootleg workings (maximum groundwater inflow).

C. Bootleg working drainage area (minimum groundwater inflow).

D. Inflow leakage from the Groundwater Flow Field (GW-FF) was calculated using the equation:

Q=KIA

Where:

Q = leakage discharge
K = hydraulic conductivity (assumed to be 10^{-9} cm/sec)
I = vertical gradient (assumed to be 0.40)
A = area (as calculated) for 100 metre depth of active groundwater flow field.

The value derived above was arbitrarily multiplied by two to account for upward leakage.

B.4.2 Average Annual Mine Inflow

The resulting calculations are summarized in tabular format on Map 4. In summary, they indicate:

DRY YEAR (2001): In a dry year, the average annual flows theoretically range from 376 to 936 USgpm, depending upon which Watershed Scenario is selected. When compared with the average annual inflow from the mine water hydrograph analysis of 539 USgpm, the closest approximately is Scenario B (459 USgpm). This underestimates inflow at 85% of calibrated value. Given consideration of the errors involved in deriving the water balance and calibration values, this suggests that when rainfall is not high, direct inflow through the No. 5 Colliery including the No. 1A Outfall extension (Scenario B) dominates. Most of the water enters through the bootleg workings (38%), followed by the sinkholes (31%).

NORMAL YEAR (1995): In a normal year, the average annual flows theoretically range from 395 to 997 USgpm. When compared with the mine water hydrograph analysis of 834 USgpm, the most representative value is Scenario C of 997 USgpm. This overestimates inflow at 120% of calibrated value. This suggests that as conditions become wetter, the No. 3 and No.4 Colliery Minesheds become hydraulically active and direct inflow to the No. 1B System. Most of the water continues to enter through the bootleg workings (32%), followed by the drainage area to the bootleg workings (28%) and the sinkholes (27%).

WET YEAR (1996): In a wet year, the average annual flows theoretically range from 422 to 1072 USgpm. When calibrated against the hydrograph analysis of 1610 USgpm, the most representative value is again Scenario C of 1072 USgpm. This underestimates inflow at 67% of calibrated value. This confirms what was noted above, that as conditions become wetter the No. 3 and 4 Colliery Mineshed become more important in directing flow into the workings. Since the percent error of calibration is larger and becomes an underestimation compared to a normal year, it also suggests that other factor(s) also become active as conditions become wetter, including, but not limited to:

- Enhanced leakage from storm/sanitary sewers (i.e., MacKay's Corner Lift Station); and
- Enhanced leakage from streamflow crossing the bootleg workings, combined with expansion of the sinkhole and bootleg working watershed areas due to extension of storm saturated overland flow, particularly in the MacKay's Corner wetland area. Most of the inflow now appears to originate from the sinkholes (32%), followed by the bootleg workings and their drainage area at 30% and 26%, respectively. This increased importance of the sinkhole system further supports the above contention.

Additional investigations into No. 3 Colliery since October 31, 2002, suggest there is no strong direct hydraulic link between No. 3 and No. 5 Collieries. However, indirect hydraulic connection through low permeable collapsed zones is still possible. These would be expected to provide enhanced leakage during periods of higher head in No. 3 Colliery.

B.4.3 Maximum Daily Peak Inflows

To assess maximum peak inflow rates in each of the three years, the wettest period was selected, baseflow components broken out and quantified on a daily basis and applied to the three Mineshed scenarios.

At the level of detail required for individual storm events, two additional issues require consideration. First, isolated peak streamflows may not result in peak mine inflows due to antecedent storm conditions. Second, "lag" times occur between when peaks in precipitation, streamflow, as well as maximum and minimum groundwater inflows occur. Therefore, a long duration wet period was first isolated to ensure the system was fully saturated prior to the peak event. Deep groundwater inflow from leakage through the roof and floor of the mine opening was assumed to be negligible for these short periods. The analysis indicated:

DRY YEAR (2001): A 21 day duration period during snowmelt spring runoff occurred from 13 April to 03 May inclusive, with a peak period on 23 April. On this day, the theoretical maximum groundwater component was 249,696 m^3/day and the minimum was 44,150 m^3/day. This was in response to a precipitation event of 7.8 mm the previous day and the loss of 4 cm of snowpack over the previous 19 days. This event resulted in a theoretical peak mine inflow for Watershed Scenarios A, B and C of 2,624, 3,609, and 6,402 Usgpm, respectively.

NORMAL YEAR (1995): A nine day duration wet period occurred during fall rains from 22 November to 30 November inclusive with a peak period on 27 November. On this day, the maximum groundwater component was 121,565 m^3/d with a minimum of 26,698 m^3/d. This was in response to a precipitation event of 53.8 mm on the previous day. This resulted in a theoretical peak mine inflow for Watershed Scenarios A, B and C of 2,078, 3,164 and 5,400 Usgpm, respectively

WET YEAR (1996): An 18 day duration wet period occurred during fall rains from 14 September to 01 October 2002 inclusive with a peak period on 19 September 2002. On this day, the maximum/minimum groundwater component was 84,586 and 6,653 m^3/d, respectively. This was in response to a precipitation event of 31.8 mm on the 18th and 43.8 mm on the 19th. This event resulted in a theoretical peak mine inflow for Watershed Scenario A, B and C of 2,398, 3,882 and 6,304 Usgpm, respectively.

Of note is the close resemblance of flows between all three years for each Watershed Scenario. This suggests that regardless of the annual climatic conditions there will be at least one such event of this magnitude each year.

Also of importance is that regardless of year, or Watershed Scenario, most of the inflow occurs from the sinkholes and their drainage area, ranging from 47 to 89%. However, there is a secondary trend to the data that shows that the percentage increases as "wetness" increases. In the dry year, the percentage ranged from 47 to 60% over the three scenarios; in the normal year, the range was 67 to 78% and in the wet year 82 to 89%. This trend supports the contention developed from analysis of the average annual flows of the importance of "other" mechanisms during the wetter periods; specifically, those associated with the expansion of storm saturated overland flow in the low areas such as MacKay's Corner wetland. Such mechanisms would be more prevalent in the sinkhole drainage areas.

Unfortunately, these peak flow values cannot be accurately calibrated against volumes calculated from mine water hydrographs, due to the relatively long lag time between inflow from the model and the time for it to be recorded on the hydrographs. However, the closest inflow peaks on the mine hydrographs to the above events showed 3800 USgpm (1995), 6836 USgpm (1996) and 6,000 USgpm (2001), which roughly correspond to what the model predicted.

B.4.4 Implications for Mine Water Inflow

The water balance model provides approximately similar results to that provided by analysis of mine hydrograph records at both average annual and maximum peak daily inflows. Therefore, the conceptual model appears to provide an acceptable description of the main flow phenomenon diverting flow into the mine workings.

The degree of error between model and hydrographic analysis enhances, with the former providing underestimates, as wetter and wetter conditions prevail. This is believed due to other processes becoming more dominant, such as sewer inflows and storm saturated overland flow within the MacKay's Corner wetland.

On an average annual basis, inflow rates are expected to range between 450 (dry year) to 1070 (wet year) USgpm, with an average of approximately 1000 USgpm. Most of the inflow enters via bootleg workings and their drainage area, except in the wet year when sinkhole drainage assumes priority.

On a maximum one day duration peak storm event, inflow rates are expected to range from 2,000 to 2,500 USgpm for the Scenario A, 3,100 to 3,900 USgpm for Scenario B and 5,400 to 6,400 USgpm for Scenario C. The close resemblance of flows between all three years for each Watershed Scenario suggests that regardless of the annual climatic conditions there will be at least one such event of this magnitude. Regardless of year, or Watershed Scenario, most of the inflow occurs from the sinkholes and their drainage area, ranging from 47 to 89%; with higher values associated with wetter conditions. There is, therefore, a high probability that a "large" portion of peak storm inflow is from the MacKay's Corner wetland area.

Refinements will be possible to these calculations with additional information now being collected including: head levels from monitoring wells in to No. 3 and possibly No. 4 Colliery Minesheds, availability of natural groundwater level hydrographs, monitoring during wet periods at MacKay's Corner Lift Station discharge into workings, mine water outfalls, definition of extent of MacKay's Corner wetland, monitoring of any loss in streamflow across subcrop areas, and more detailed analysis of seasonal and storm hydrographs to assess the relevance of lag times on understanding inflow mechanisms and volumes at the seasonal and individual storm event level.

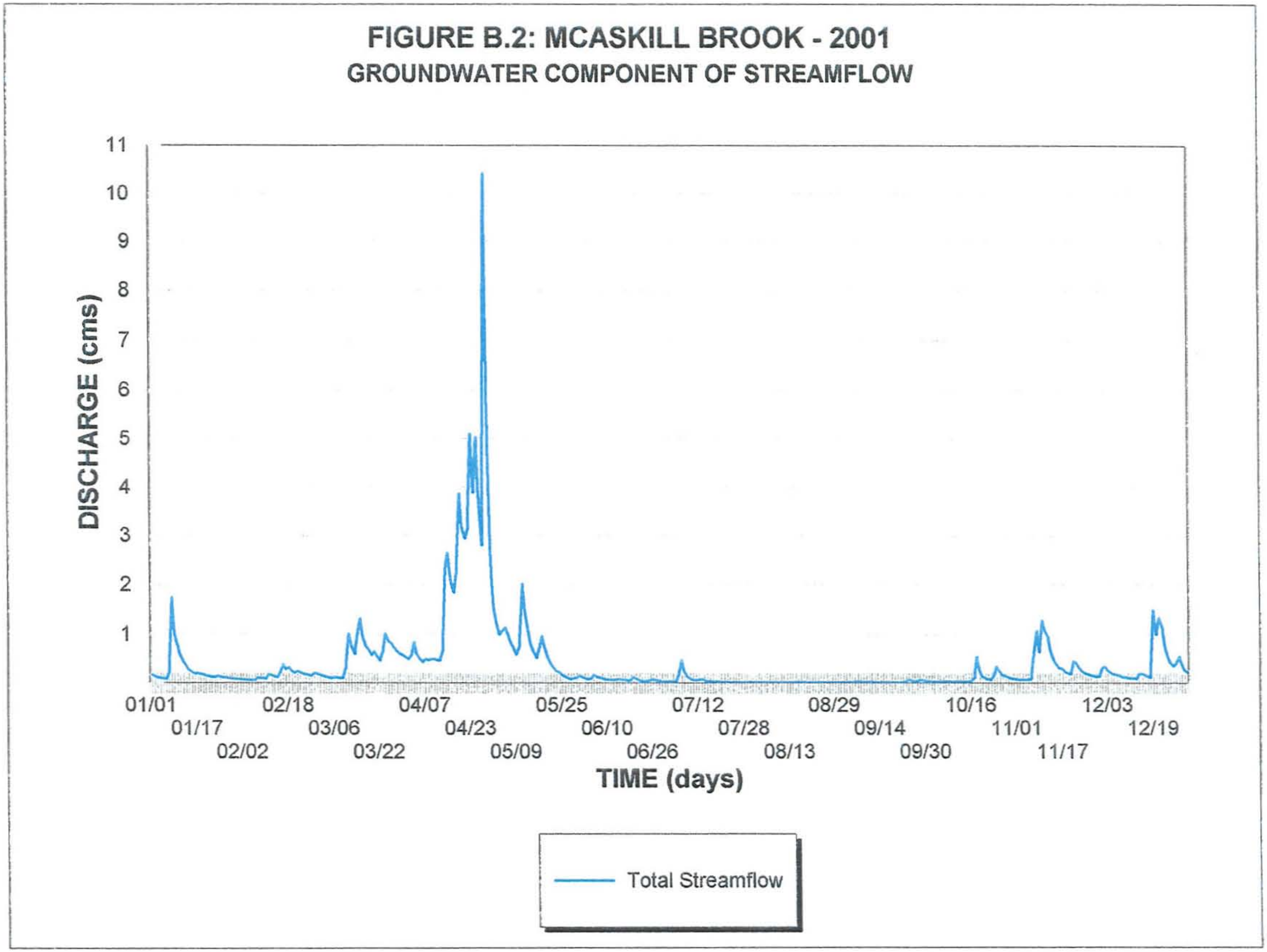


FIGURE B.2: MCASKILL BROOK - 2001
GROUNDWATER COMPONENT OF STREAMFLOW
DISCHARGE (cms)
11
10
9
8
7
6
5
4
3
2
1
01/01
01/17
02/02
02/18
03/06
03/22
04/07
04/23
05/09
05/25
06/10
06/26
07/12
07/28
08/13
08/29
09/14
09/30
10/16
11/01
11/17
12/03
12/19
TIME (days)
Total Streamflow

FIGURE B.3: MCASKILL BROOK - 1995
GROUNDWATER COMPONENT OF STREAMFLOW

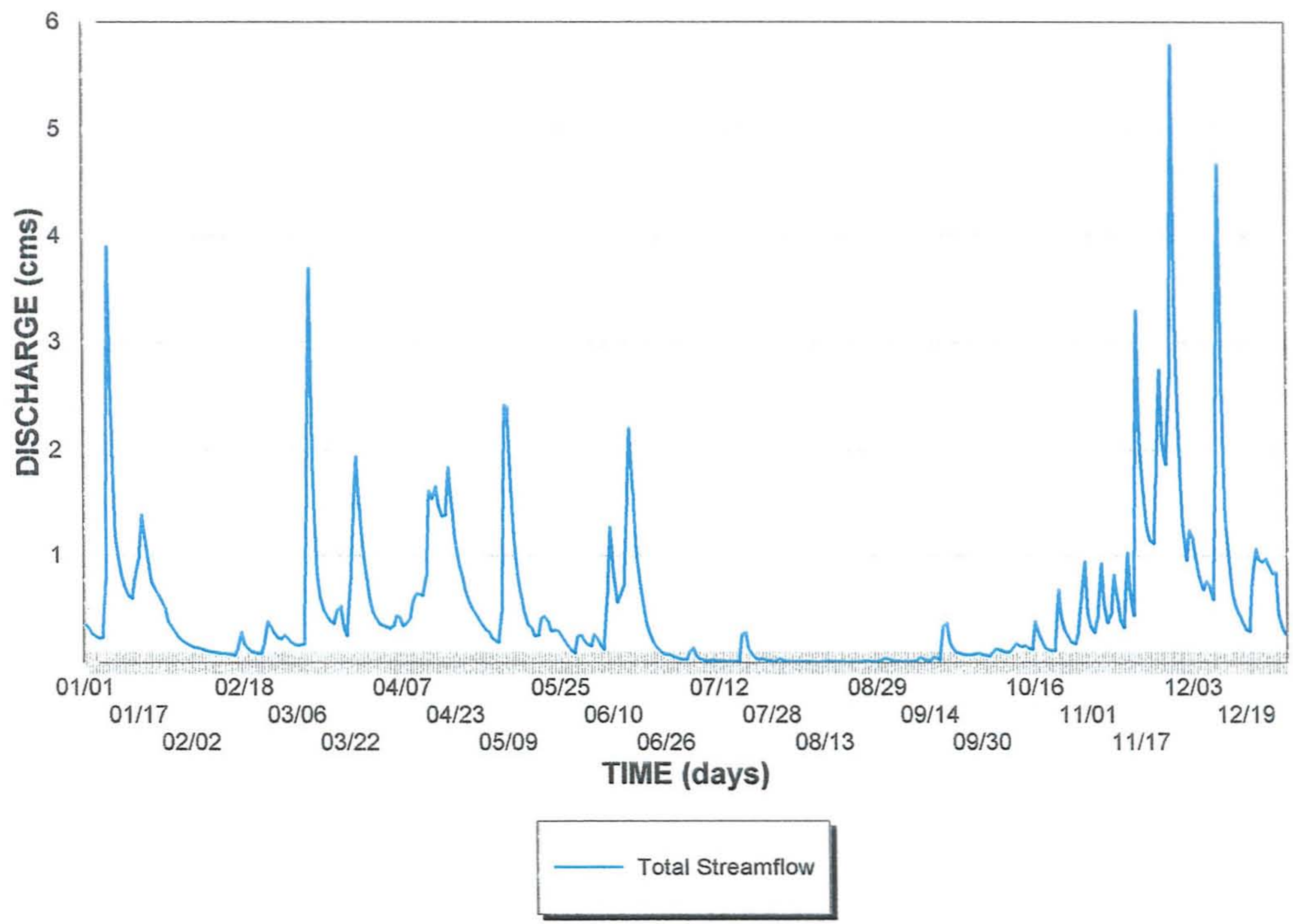
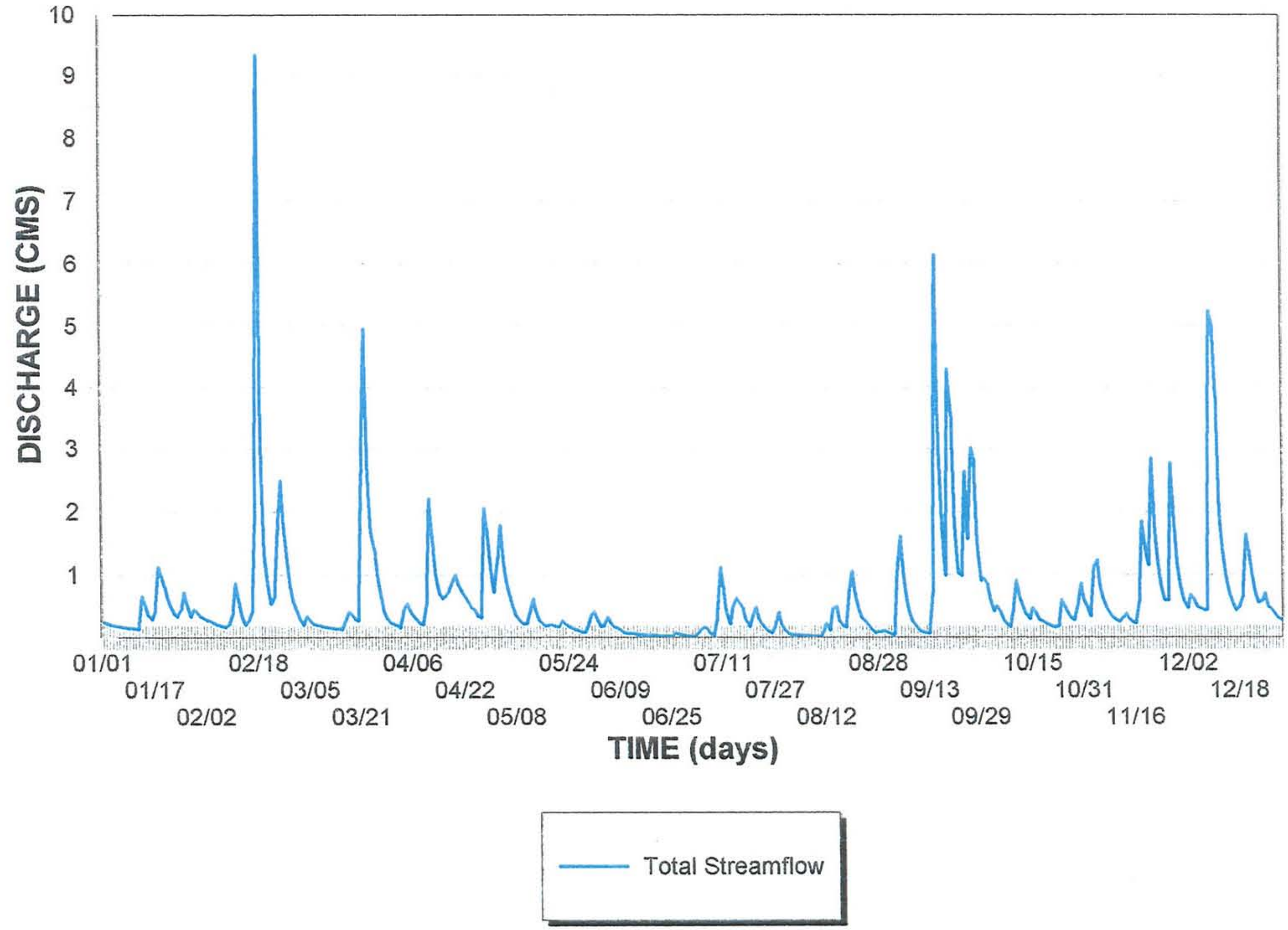


FIGURE B.4: MCASKILL BROOK - 1996

GROUNDWATER COMPONENT OF STREAMFLOW



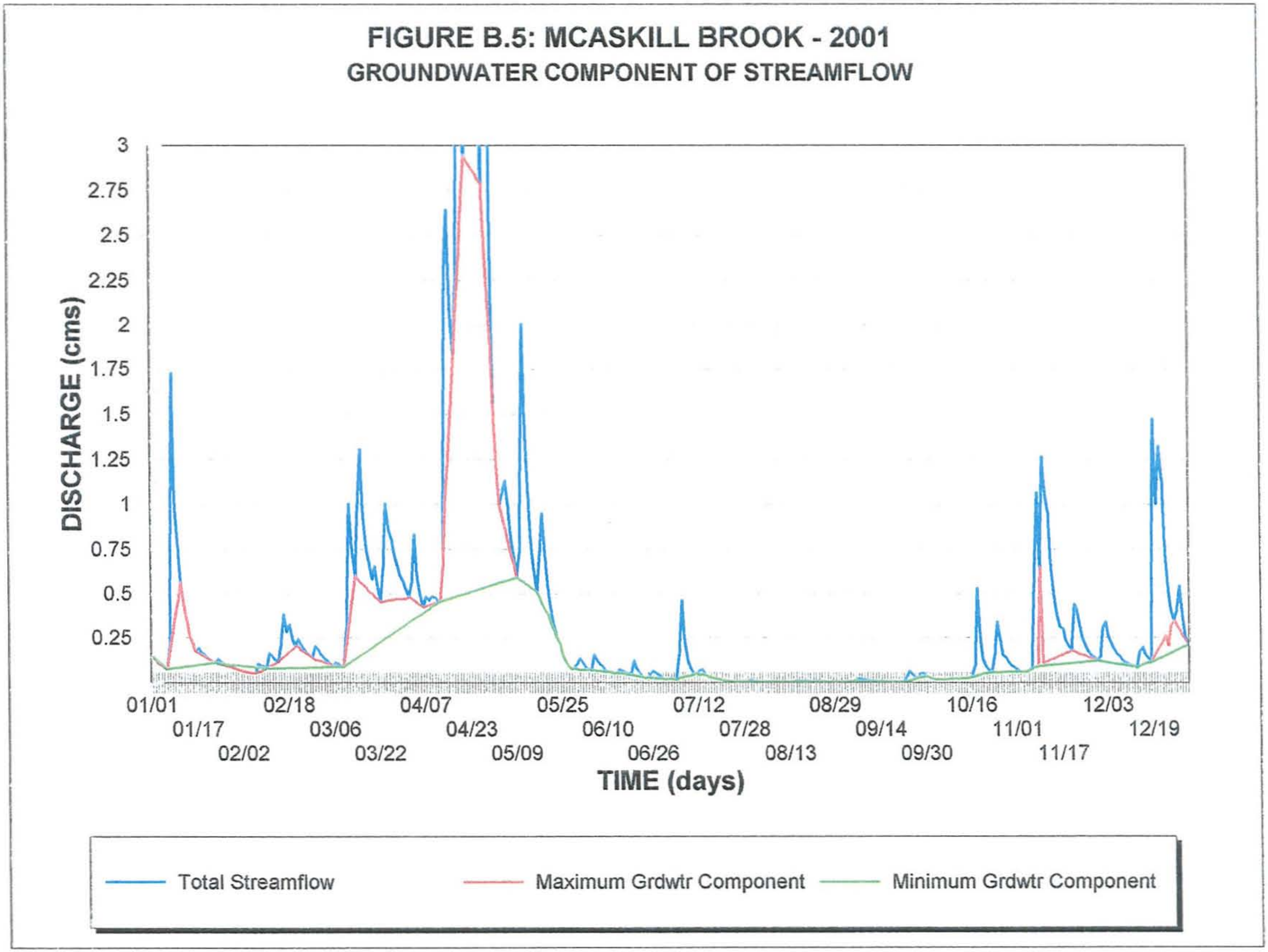


FIGURE B.5: MCASKILL BROOK - 2001
GROUNDWATER COMPONENT OF STREAMFLOW
DISCHARGE (cms)
3
2.75
2.5
2.25
2
1.75
1.5
1.25
1
0.75
0.5
0.25
01/01
01/17
02/02
02/18
03/06
03/22
04/07
04/23
05/09
05/25
06/10
06/26
07/12
07/28
08/13
08/29
09/14
09/30
10/16
11/01
11/17
12/03
12/19
TIME (days)
Total Streamflow
Maximum Grdwtr Component
Minimum Grdwtr Component

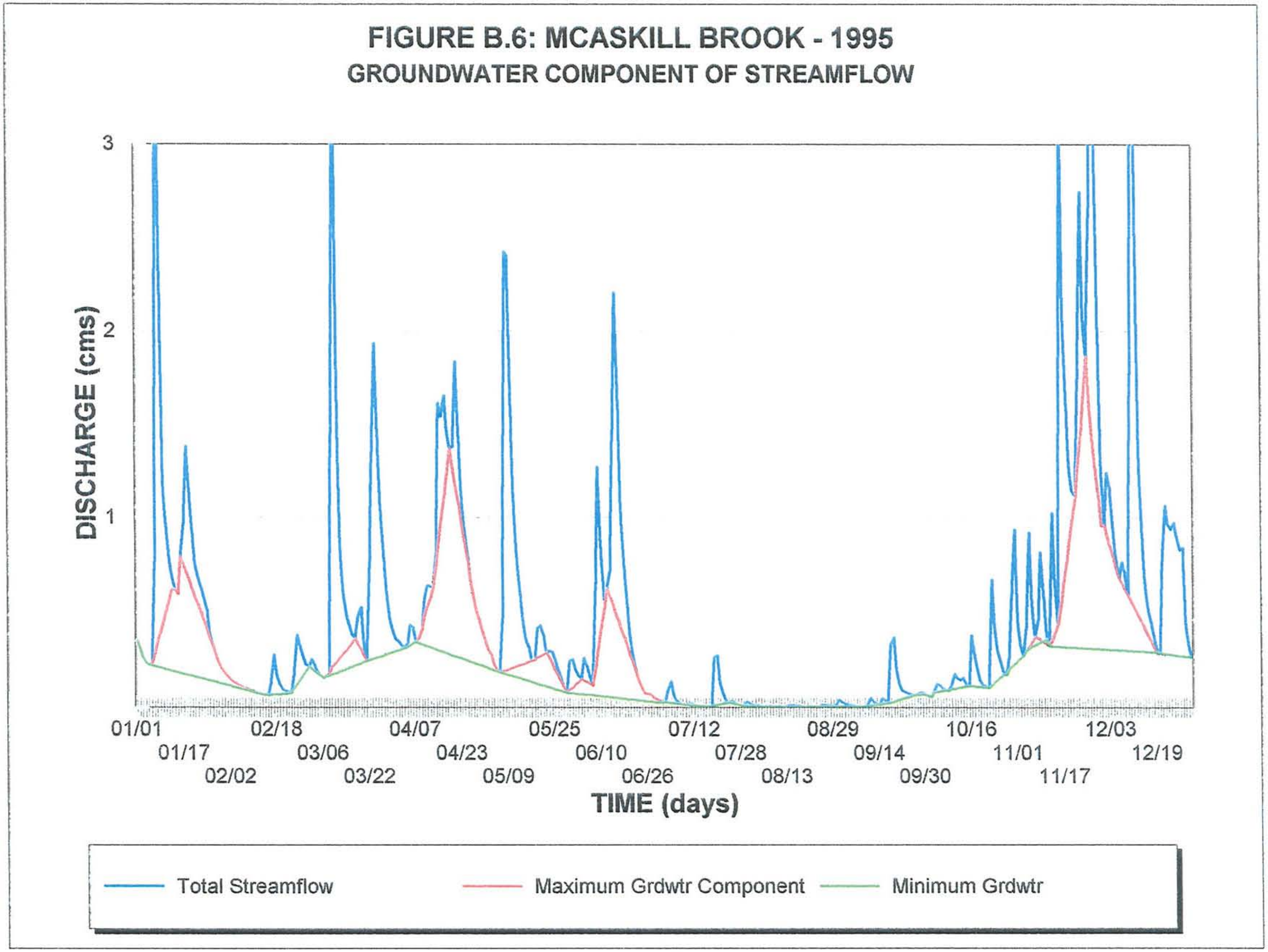


FIGURE B.6: MCASKILL BROOK - 1995
GROUNDWATER COMPONENT OF STREAMFLOW
DISCHARGE (cms)
3
2
1
01/01
01/17
02/02
02/18
03/06
03/22
04/07
04/23
05/09
05/25
06/10
06/26
07/12
07/28
08/13
08/29
09/14
09/30
10/16
11/01
11/17
12/03
12/19
TIME (days)
Total Streamflow
Maximum Grdwtr Component
Minimum Grdwtr

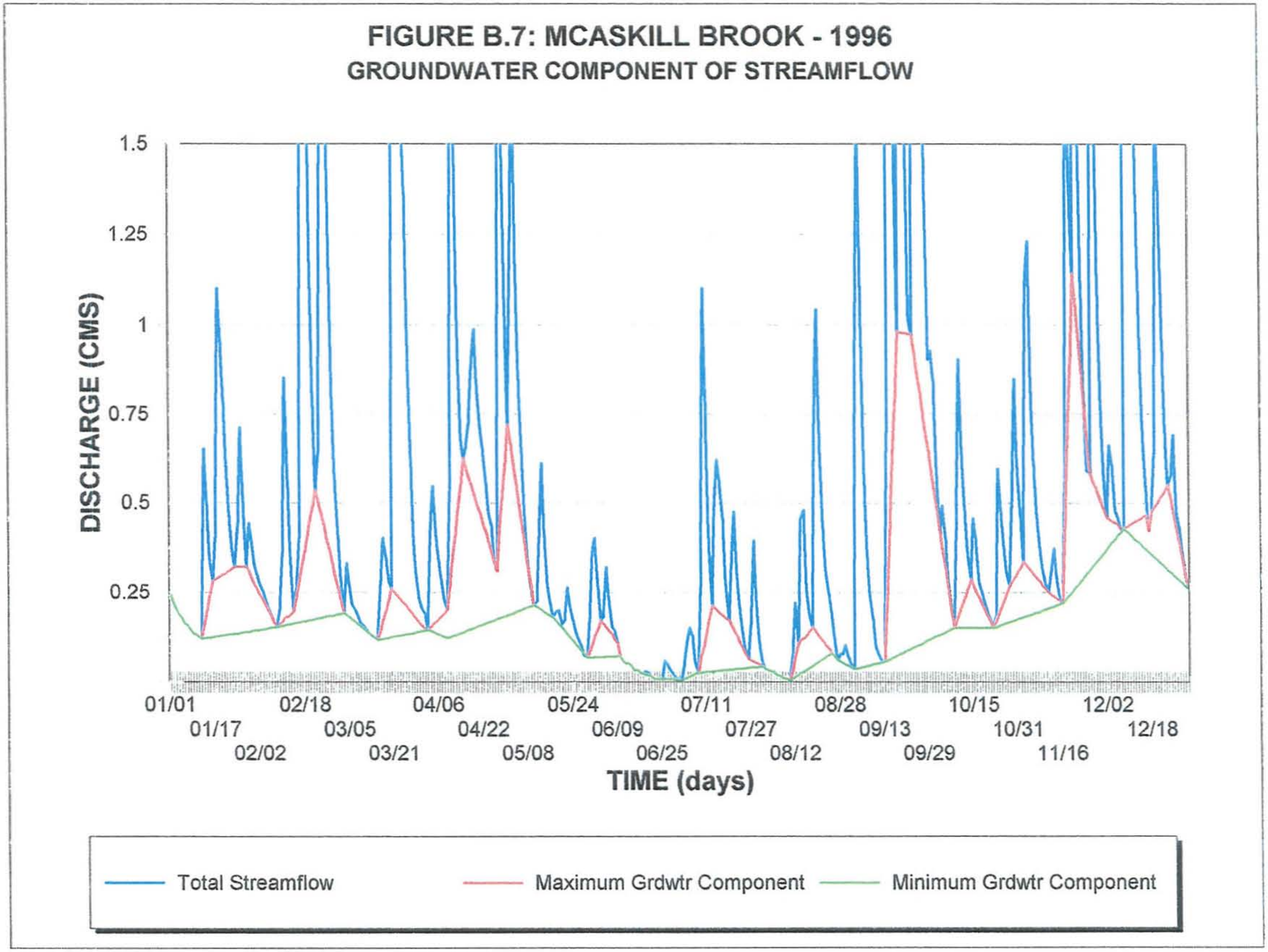
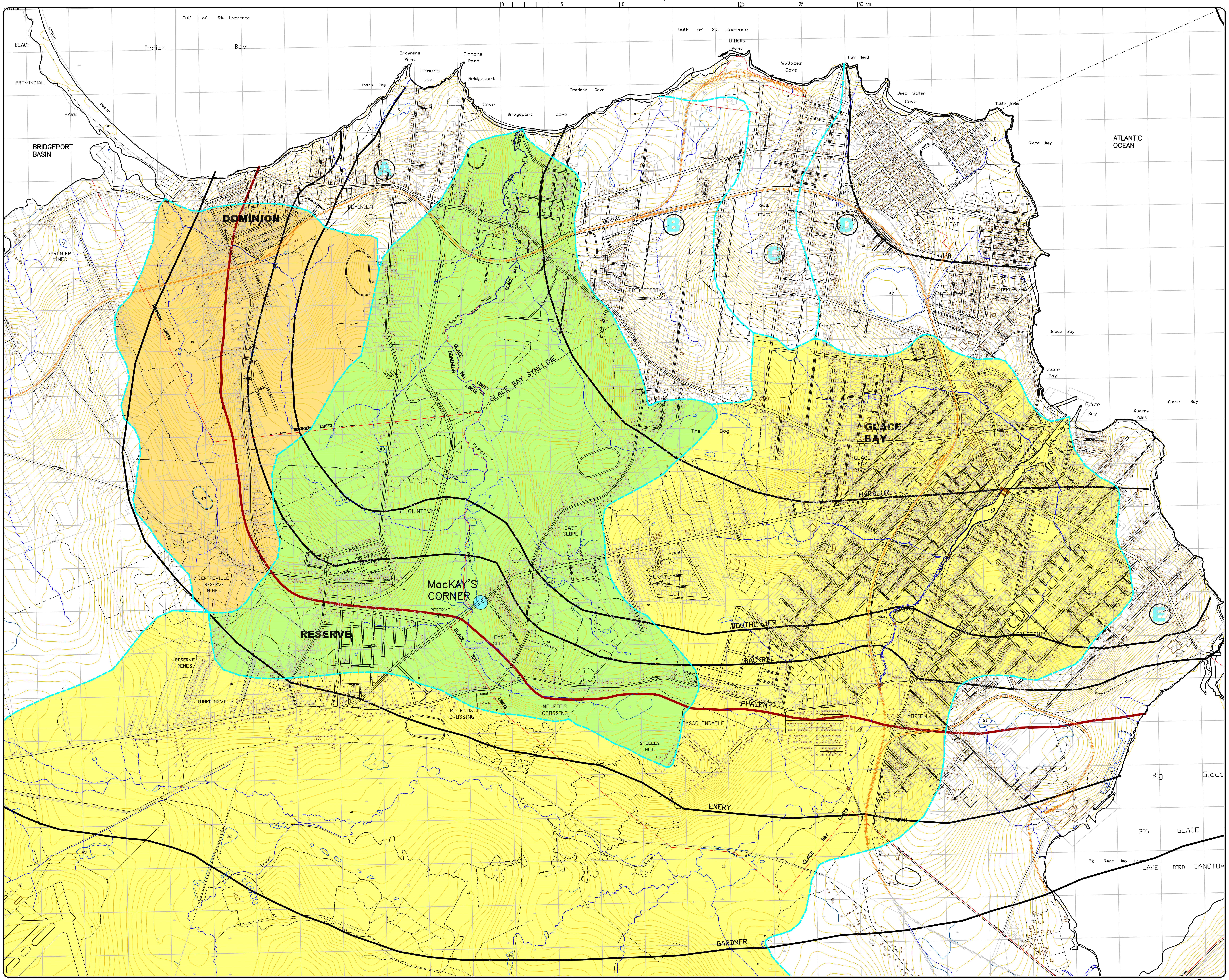


FIGURE B.7: MCASKILL BROOK - 1996
GROUNDWATER COMPONENT OF STREAMFLOW
DISCHARGE (CMS)
1.5
1.25
1
0.75
0.5
0.25
01/01
01/17
02/02
02/18
03/05
03/21
04/06
04/22
05/08
05/24
06/09
06/25
07/11
07/27
08/12
08/28
09/13
09/29
10/15
10/31
11/16
12/02
12/18
TIME (days)
Total Streamflow
Maximum Grdwtr Component
Minimum Grdwtr Component



No.	Issue	Date
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LEGEND:

- RENWICK BROOK WATERSHED (PROVINCIAL WATERSHED IFJ-7)
- CADEGAN BROOK WATERSHED (PROVINCIAL WATERSHED IFJ-SD35)
- DOMINION BROOK WATERSHED (PART OF PROVINCIAL WATERSHED IFJ-SD36)
- SHORE DRAINAGE (PROVINCIAL WATERSHEDS IFJ-SD34 AND IFJ-SD33)
- A INDIAN BAY
- B BRIDGEPORT
- C NEW ABERDEEN
- D STERLING
- E COASTAL AREA, BIG GLACE BAY LAKE
- MAJOR COAL SEAMS
- PHALEN COAL SEAM
- TOPOGRAPHIC CONTOURS (1m INTERVAL GENERATED BY HDI)

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Jacques Whitford

Steve Forgeron Consulting Geologist

Project Title

1B COLLIERY HYDRAULIC SYSTEM WATER BALANCE ANALYSIS

Dwg. Title

STUDY AREA SURFACE WATERSHEDS

Project No. 5285-001.1

Dwg. No. MAP 1

Rev. No. 0

Scale 1:10,000

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No.	Issue	Date
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LEGEND:

- SINKHOLES
- EXTENT OF MINING FOR INDIVIDUAL COLLIERIES
- PHALEN COAL SEAM OUTCROP
- WORKINGS ABSTRACTED FROM RASTER IMAGES OF CBDC MINE PLANS
- APPROX. EXTENT OF FULL EXTRACTION AREAS

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Jacques Whitford

Steve Forgeron Consulting Geologist

Project Title

1B COLLIERY HYDRAULIC SYSTEM WATER BALANCE ANALYSIS

Dwg. Title

UNDERGROUND PHALEN MINE WORKINGS/SUBSIDENCE AREAS

Project No.	5285-001.1
Dwg. No.	MAP 2
Rev. No.	0
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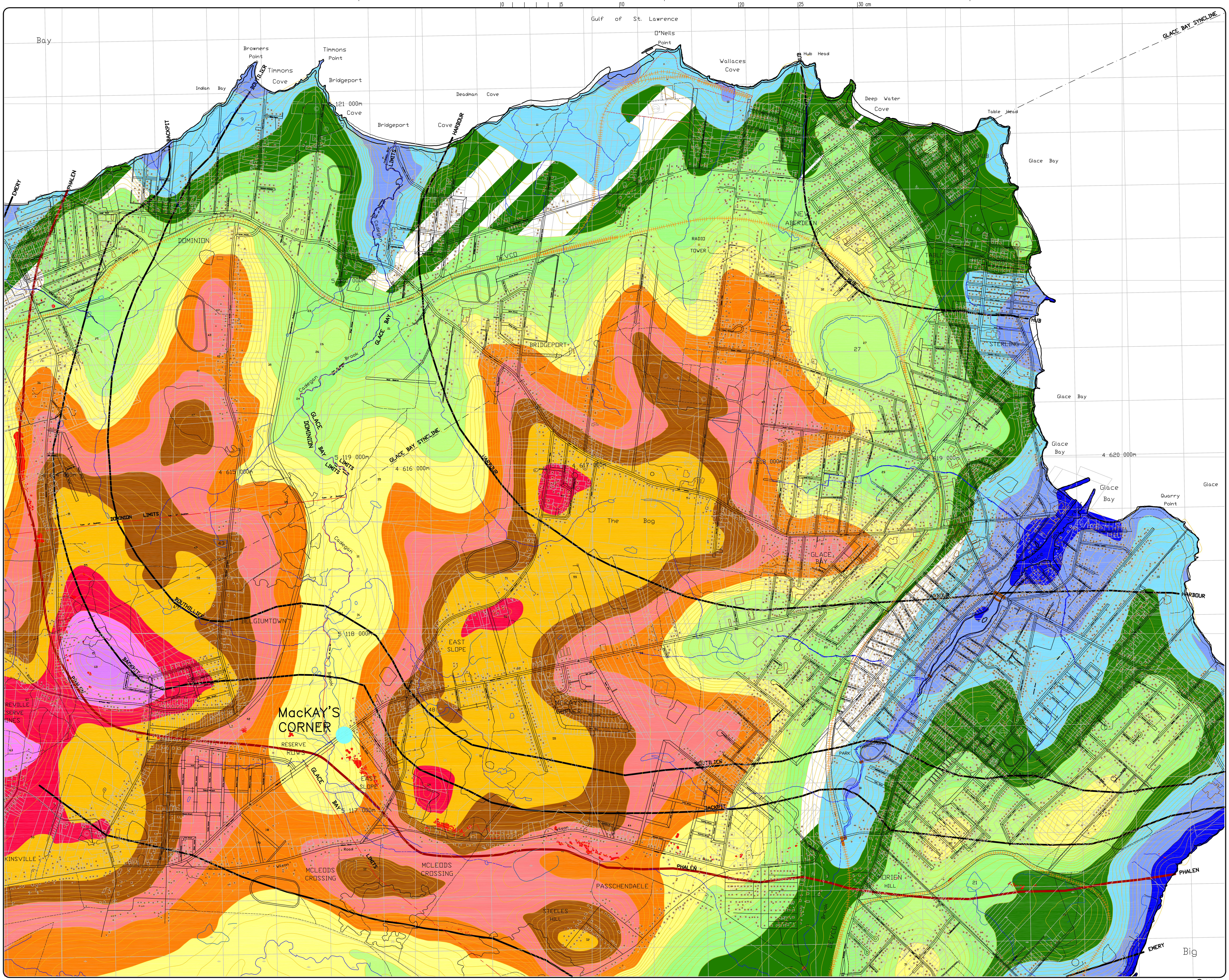

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LEGEND:

MAJOR COAL SEAMS

SINKHOLES NOTED AT SURFACE

ELEVATIONAL RANGES

- 0m to 5m
- 5m to 10m
- 10m to 15m
- 15m to 20m
- 20m to 25m
- 25m to 30m
- 30m to 35m
- 35m to 40m
- 40m to 45m
- 45m to 50m
- 50m to 55m
- 55m to 60m
- 60m to 65m
- 65m to 70m

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Jacques Whitford

Steve Forgeron
Consulting Geologist

Project Title

1B COLLIERY HYDRAULIC SYSTEM WATER BALANCE ANALYSIS

Dwg. Title

GROUND SURFACE TOPOGRAPHY

Project No.	5285-001.1
Dwg. No.	MAP 3
Rev. No.	0
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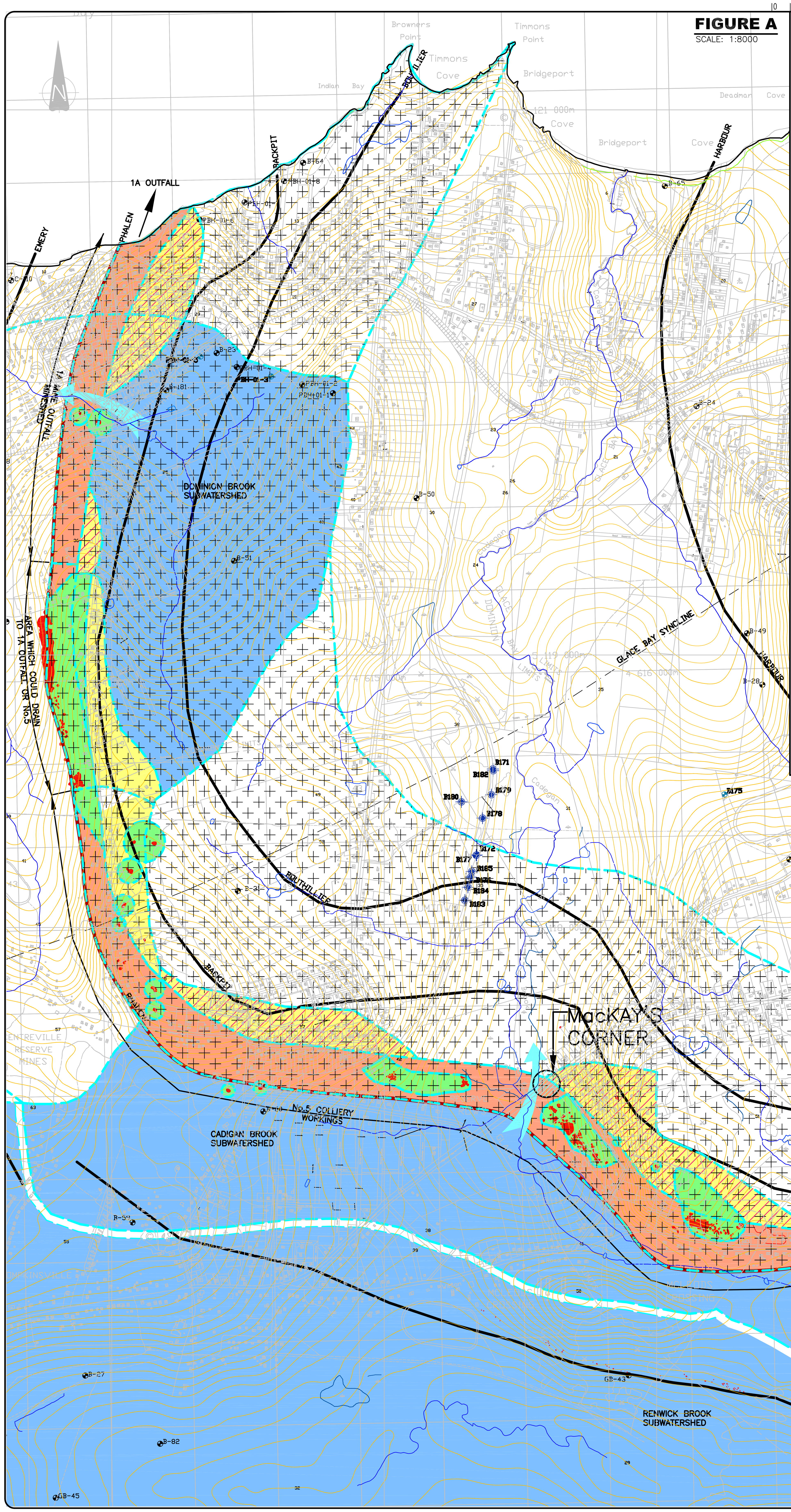

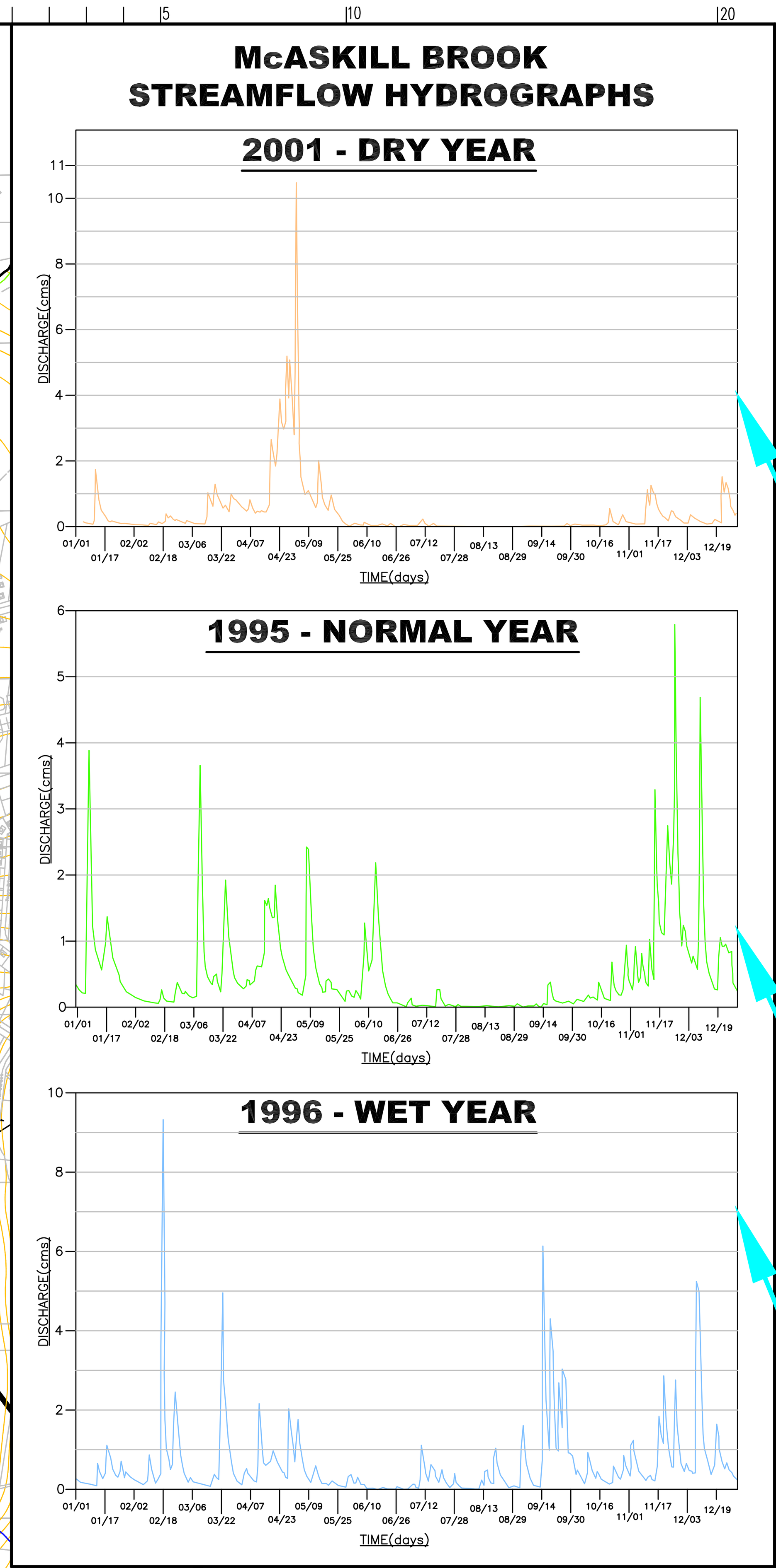

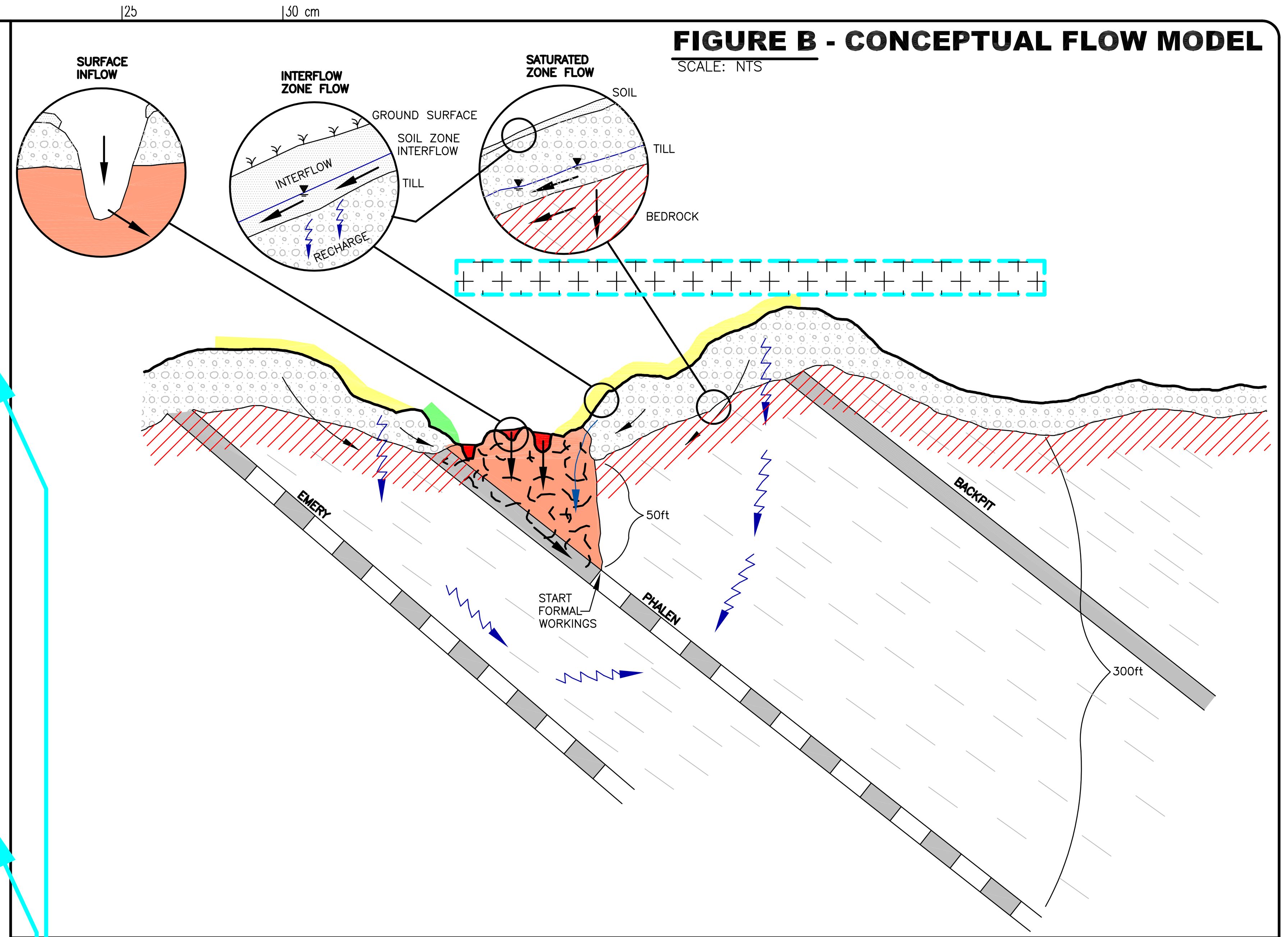

AVERAGE ANNUAL WATER BALANCE FOR THE 1B MINE HYDRAULIC SYSTEM

TYPE OF YEAR	WATERSHED OPTIONS	DRAINAGE AREAS S-DA (acres)	BW (acres)	BW-DA (acres)	GW-FF (acres)	TOTAL without GW-FF (acres)	THEORETICAL VOLUME INFLOW TO MINE S-DA (cu ft/yr)	BW (cu ft/yr)	BW-DA (cu ft/yr)	GW-FF (cu ft/yr)	TOTAL INFLOW (cu ft/yr)	TOTAL INFLOW (Usgpm)	CALIBRATION WITH MINE WATER HYDROGRAPH (Usgpm)
DRY(2001)	SCENARIO A	34.9	116.8	62.4	1378.8	214.1	5,837,737	12,261,617	3,288,954	4,966,371	26,354,680	376	539
	SCENARIO B	61.2	116.8	89.6	1378.8	267.6	10,236,948	12,261,617	4,722,601	4,966,371	32,187,538	459	
	SCENARIO C	97.1	212.2	354.3	2362	642	16,241,956	22,276,671	18,674,303	8,504,208	65,697,138	936	
NORMAL(1995)	SCENARIO A	34.9	116.8	62.4	1378.8	214.1	6,871,503	12,363,373	3,506,406	4,966,371	27,707,653	395	834
	SCENARIO B	61.2	116.8	89.6	1378.8	267.6	12,049,741	12,363,373	5,034,839	4,966,371	34,414,325	490	
	SCENARIO C	97.1	212.2	354.3	2362	642	19,118,136	22,461,540	19,908,967	8,504,208	69,992,851	997	
WET(1996)	SCENARIO A	34.9	116.8	62.4	1378.8	214.1	8,741,403	12,465,130	3,479,224	4,966,371	29,652,128	422	1610
	SCENARIO B	61.2	116.8	89.6	1378.8	267.6	15,328,764	12,465,130	4,995,809	4,966,371	37,756,074	538	
	SCENARIO C	97.1	212.2	354.3	2362	642	24,320,637	22,646,408	19,754,634	8,504,208	75,225,888	1072	

DATA SUMMARIZED IN USgpm AND % OF TOTAL FOR EACH SCENARIO WITHIN TABLE 4.1 IN TEXT

NOTES:

1) 1B System watershed options
Option A) No.5 colliery
Option B) No.5 colliery plus 1A outlet extension
Option C) Option B plus No.3 & No.4 colliery

2) Total Annual Precipitation: 2001 – 46.09 inches; 1995 – 54.27 inches; 1996 – 69.01 inches

3) Maximum Groundwater from baseflow analysis: 2001 – 28.9 inches; 1995 – 29.2 inches; 1996 – 29.4 inches

4) Minimum Groundwater from baseflow analysis: 2001 – 14.5 inches; 1995 – 15.5 inches; 1996 – 15.3 inches

5) Drainage Area:
S-DA sinkholes with drainage area
BW zone of potential bootleg workings
BW-DA drainage are to bootleg workings
GW-FF groundwater flow field

6) Volume Inflow:
S-DA: S-DA * total annual precipitation
BW: BW * Maximum Groundwater from baseflow analysis
BW-DA: BW-DA * Minimum Groundwater from baseflow analysis
GW-FF: using Q = KIA where
K(permeability) = 1x10-9m/sec and I (gradient) = 0.4

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LEGEND FOR FIGURE A – WATERSHED AREAS
MAJOR COAL SEAM OUTCROPS
SINKHOLES NOTED AT SURFACE
DRAINAGE AREA FOR SINKHOLES(S-DA)
AREA OF POTENTIAL BOOTLEG WORKINGS(BW)
DRAINAGE AREA TO BOOTLEG WORKINGS(BW-DA)
GROUNDWATER FLOW FIELD LEAKAGE AREA
SURFACE WATER DRAINAGE BASINS CONTRIBUTING TO STREAM FLOW CROSSING BOOTLEG WORKINGS
STREAM REACH CROSSING BOOTLEG WORKINGS

LEGEND FOR FIGURE B
HYDROSTRATIGRAPHIC UNITS
OVERBURDEN
PODZOL HU
TILL HU (AQUITARD)
BEDROCK
ARENACEOUS HU (AQUIFER COMPLEX)
COAL HU (AQUITARD)
KARST HU (MINED OUT COAL SEAMS)
SUBSIDENCE HU (POTENTIAL BOOTLEG WORKINGS)
SUBCROP HU
BEDROCK SURFACE

INFLOW RATE
USE 100% RAINFALL
ZONE BOOTLEG WORKINGS (USE MAX. GROUNDWATER)
SURFACE WATERSHED TO BOOTLEG WORKINGS (USE MIN. GROUNDWATER)
ZONE OF LEAKAGE – ZONE TO 300ft ACTIVE DEPTH OF FLOW FIELD (AT 5° DIP = approx. 1km; NOT ACCOUNTING FOR SURFACE TOPO.) – USE Q = KIA – X2 FOR FLOW UP

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Steve Forgeron Consulting Geologist

Project Title
1B COLLIERY HYDRAULIC SYSTEM WATER BALANCE ANALYSIS

Dwg. Title
CONCEPTUAL WATER BALANCE FOR 1B HYDRAULIC SYSTEM GLACE BAY

Project No. 5285-001.1
Dwg. No. MAP 4
Rev. No. 0
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Neil Jun 24, 2008 11:26am
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