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CAPE BRETON DEVELOPMENT CORPORATION

ENVIRONMENTAL ENGINEERING STUDY
UPDATE STATUS OF FLOODING MINES

JWEL PROJECT NO. 11545

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REPORT TO

CAPE BRETON DEVELOPMENT CORPORATION

ON

ENVIRONMENTAL ENGINEERING STUDY
UPDATE STATUS OF FLOODING MINES

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Executive Summary

Jacques Whitford Environment Limited (JWEL) was retained by Cape Breton Development Corporation (CBDC) to carry out an assessment of historical water level records and water chemistry data compiled over ten years by CBDC for several mines near Lingan, Cape Breton N.S. of 27 collieries previously operating in the area, all but one, the Phalen mine, are currently abandoned.

The Phalen mine is currently operating beneath and adjacent to abandoned collieries which are flooded to various degree.

The objectives of this project were to: (1) validate the CBDC projections of water level rise time line and associated mitigative milestones; (2) assess the practicality of using the Phalen emergency waste water treatment plant to control water rise by pumping and treatment of mine water from the Lingan "connection"; and (3) to rationalize the disparity in water quality between Phalen inflow waters, and the Lingan-No. 26 Colliery mine water.

Work involved a thorough review of CBDC water level and water chemistry data from monitoring points in the 1B shaft, Lingan mine, No. 2, No. 4 and No. 9 mines, and active Phalen mine panels. A summary of water inrushes in Phalen, and the recharge history of the Lingan and 1B Hydraulic System was prepared. The conceptual hydrogeological model prepared in 1993 (ADI, 1993), and the interactions between the various mines (JWEL, 1993) was updated using the recent information.

Mine Recharge Rates and Surface Discharge Predictions

Since the abandonment of No. 26 colliery in 1984, flooding of the 1B hydraulic system has been controlled by a combination of seasonally varying recharge from landward abandoned mines, outfall to adjacent interconnected mines when water levels reach an interconnection point prior to 1992, outfall to Lingan mine through at least three strata breaks caused by Phalen undermining since 1992, and apparent increasing percolation between the flooded 1B-Lingan workings and the active Phalen mine since 1994.

The 10 year average apparent recharge rate into the 1B-Lingan Hydraulic System was approximately 900 usgpm, with seasonal peak inflows up to 6,000 usgpm. The current apparent recharge rate has slowed to an average rate of 710 to 750 usgpm, with seasonal range from 2,400 usgpm in spring and fall, to less than 500 usgpm during the dry summer months. Assuming constant recharge conditions, the 1B hydraulic system is expected to reach the sea level outfall within 7.2 to 7.6 years (year 2004). It is suspected that this time line will likely be longer, due to apparent increasing degree of hydraulic interaction between the 1B system and the Phalen mine, and probable location and sealing of significant recharge points on land.

Flooding of the Lingan mine is controlled almost entirely by inflow from the 1B system through two strata breaks across the barrier pillar between the No. 26 and Lingan mine workings. The Lingan mine is currently flooding at a rate of about 22 to 50 usgpm. Decreasing flooding rates are attributed to pressure head equilibrium across the barrier pillar strata breaks, and possible vertical seepage to Phalen mine. The Lingan water levels are currently 100 feet lower than the 1B water levels, and are expected to equilibrate with the 1B water levels within 5 years.

Pumping from the Lingan Connection

The hydraulic connection between the Lingan mine and the 1B system is expected to remain open indefinitely due to significant subsidence-induced fracturing across the barrier pillar between the No. 26 and the Lingan mines. Further breaks are expected to occur as mining at Phalen progresses and undermines this barrier pillar.

Control of water levels in the 1B system should therefore be feasible by pumping from the Lingan mine and treating effluent at the waste water treatment plant. Effluent quality, initially better than the 1B system, is expected to evolve towards water chemistry consistent with the 1B system as pumping progresses. Water level depression is limited to the elevation of the -1100 to -1400 strata breaks, unless further barrier pillar breaks occur between the two flooded mines due to subsidence induced by Phalen mining.

Phalen-1B System Interactions

It is concluded that mines 1B, 2, and Lingan are hydraulically interconnected, No. 4 mine may be indirectly connected through No. 5, and No. 9 mine in the Harbour Seam is not influenced by the 1B system. The Lingan mine is now part of the 1B Hydraulic System. Phalen mine appears to be receiving increasing proportions of water from flooded No. 26 + Lingan ~~1B mine workings~~. Potential interaction with the No.12/14 mines to the northwest is currently unknown.

Phalen mine water is a combination of deep saline strata water, less saline mine waters from flooded workings, and pyrite oxidation products within the Phalen mine. The proportion of mine water from flooded 1B system mine workings is increasing with time, and is currently estimated to exceed 60 %. Inflow chemistry at Phalen panels 6E and 7E is evolving from a highly saline brine towards predominantly meteoric water chemistry consistent with the 1B system. The degree of chemistry evolution appears to be proportional to flow rates in the panels, and proximity to the bottom of the Lower Sandstone Aquifer.

Two mine water recharge pathways into the Phalen mine are identified. Both involve transport through the lower sandstone aquifer. Vertical percolation of No. 26 and Lingan mine waters through 140 metres of interburden between the overlying Harbour seam and Phalen seam may occur via subsidence-induced fracturing and interconnection of sandstone aquifers. Horizontal migration of mine water from No. 1B colliery located immediately east of Phalen panels 5E through 8E, could occur via the Lower Sandstone Aquifer, which provides a direct hydraulic pathway between the 1B and the Phalen long wall panels across a 76 to 91 m wide barrier.

If the observed trends continue, there is a possibility that the Phalen mine will become indirectly connected to the 1B hydraulic system via subsidence-induced fracturing of the Lower Sandstone Aquifer. Pumping rates from Phalen may continue to increase, water chemistry may continue to shift towards 1B chemistry, and treatment of effluent may eventually be required. It is also expected that the rate of water level rise in 1B system could continue to decrease, extending the time to surface outfall.

Recommendations

An investigation should be implemented on the potential movement of water between the abandoned 1B workings and the east side of the Phalen mine across the barrier pillar on the Phalen seam, through the Lower Sandstone Unit. The risk of strata breaks or increasing seepage caused by subsidence-induced fracturing of the Lower Sandstone Unit or other strata across the 1B-Phalen barrier should be investigated.

Additional isotope analysis should be done to better define the proportion of 1B or Harbour seam water entering Phalen mine. Hydraulic and hydrochemical modelling of the 1B-Lingan-Phalen mine complex should be considered to refine mine water interactions, and to predict water levels and inrush risks as mining progresses. Major subsidence sinkholes throughout the landward portion of the 1B hydraulic system should be identified, and sealed as a means of reducing recharge and slowing water level rise in the 1B hydraulic system. The on-going water level and water quality monitoring should be reviewed on an annual basis to identify trends.

1.0 INTRODUCTION

This report is submitted by Jacques Whitford Environment Limited (JWEL) to the Cape Breton Development Corporation (CBDC) in response to CBDC request for proposal No. 82943, dated August 14, 1996.

1.1 Background

The Sydney coal field is the largest coal resource in Eastern Canada, and in recent decades has been the centre of coal mining in Nova Scotia. The coal field is located on the northeast coast of Cape Breton Island. Coal Bearing beds extend along the coast for 50 km from Cape Dauphin east to Morien Bay (Figure 1.1). While many major seams outcrop on land within this zone, over 98 percent of the known coal beds lie underneath the ocean, extending eastward from Cape Breton to the south coast of Newfoundland (Calder et al, 1985).

Coal mining from the Harbour, Phalen and other coal seams of the Sydney Coal Fields area for more than a century has resulted in 27 underground and under sea collieries. Only one of these mines (Phalen Mine) was still active in 1996; the remainder have naturally flooded following closure or are in the process of flooding. The No. 26 (Harbour Seam) and No. 1B (Phalen Seam) collieries in the 1B Hydraulic System (Figure 2.1) were abandoned in April of 1984, after a mine fire, and have been flooding since then. The most recent mine abandonment was the Lingan colliery (Harbour Seam), which was abandoned in February 1994, after a second in-rush of water from the adjacent No. 26 colliery.

Up until the mid 1980's, mining within the seaward stratigraphic units (Harbour and Phalen Seams) was essential "dry", with minimal incursions of mine water or reported pumping problems. This was largely due to the low permeability of the sedimentary bedrock and use of room and pillar mining methods which provided roof support and minimized subsidence. After the inception of longwall retreat mining at No.1B, Lingan and Phalen Mines in the 1980's, increasing volumes of sump water and sudden "in-rushes" of mine or formation waters began to occur.

With the occurrence of a sudden in-rush of about 1,000 usgpm into Phalen 1E panel in November, 1988, a program of extensive monitoring of water flow and water chemistry was implemented throughout the Lingan-Phalen mine complex. Assessments of mine water inorganic and isotope chemistry, between 1988 and 1992, indicated that the source of the water in-rushes in Phalen 1E and 5E panels, was most likely connate formation waters stored in sandstone aquifers above and adjacent to the mined coal seams (a number of joabs carried out by JWEL from 1988 to 1993). X

A major in-rush of 2,000 usgpm into Lingan 2E panel in November, 1992, and a subsequent in-rush of up to 7,000 usgpm in February, 1994 into the Lingan 5E panel, resulted in the premature closure of the Lingan mine due to costs associated with pumping and treating high volumes of mine water. This in-rush was found to be associated with a strata break within the barrier pillar between Lingan 2E panel and the adjacent No. 26 Colliery, near the -1100 ft level, and possibly associated with undermining as a result of mining the Phalen 4E, 5E and 6E panels (see Section 2.5). The common consideration in these inflows was that Phalen was mining beneath Lingan and No. 26 workings on the Harbour Seam.

After the Lingan strata break in November, 1992, the 1B shaft was pumped for a period of 10 days to determine if the inflows to Lingan could be controlled by pumping from the 1B system. The project was halted due to concerns about the poor water chemistry entering the Atlantic Ocean.

In 1993, JWEL was retained to conduct an extensive study of mine water inflows and hydraulic interactions between several of the active and abandoned collieries in the Cape Breton Coal Fields (JWEL, 1993). This project evaluated mine interconnections, sources of mine water, rates of mine recharge upon abandonment, mine water discharge pathways, mine flooding rates and prediction of discharge time lines, rates and water quality at flood equilibrium. Recommendations were made for intra-mine monitoring and testing, the majority of which were implemented by CBDC.

Concurrent with the JWEL work, an assessment of the origin of saline groundwater entering the Phalen 6E panel was conducted by ADI Nolan Davis Ltd (ADI, 1993). A conceptual hydrogeological model for the coal strata in the vicinity of the mines was compiled, and used with hydrochemical assessment to determine groundwater flow patterns within the mine complex.

As a result of continuing water inflows and roof instability in the Phalen, the Engineering and Safety Department of CBDC undertook a detailed assessment of the risks of working the Phalen Colliery under the flooded Harbour Seam for the next five years (CBDC, 1994). This assessment included input from submarine mining experts, and local environmental consultants. The risk assessment included three components: risk to the underground workers, risk to the asset, and risk to the environment. This report included detailed information on geology, rock stresses, and water inflow characteristics on a panel by panel basis.

Between 1994 and 1996, CBDC geologists have been carrying out monitoring of water levels and water chemistry at numerous locations to relate activities in the Phalen mine with geological conditions, and water levels in the Lingan, No. 2, No. 4, No. 9 and 1B Collieries.

Several trends have been observed in water levels in the abandoned flooded workings, and water quality in the Phalen mine which may have a bearing on the long term operation of the Phalen mine. Since abandonment, a group of these abandoned collieries, specifically Nos. 1A, 1B, 2, 5, 9, 20, and 26, comprising the 1B Hydraulic System, have been slowly filling with water originating from a combination of surrounding bedrock groundwater, seawater, up-slope sources, and adjacent active or abandoned workings. If allowed to continue, there is concern that surface discharge of potentially acidic water laden with high loads of suspended solids, metals, and other pyrite oxidation related compounds could occur from the above sea level portions of the 1A mine in the Town of Dominion, and localized mine-induced subsidence areas.

Several significant drops in water level in the large 1B Hydraulic System reservoir have occurred over the past 10 years while Phalen has been active. While much of this water level fluctuation appears to be associated with strata breaks between the Lingan mine and the 1B system and/or seasonal factors, there is concern regarding potential hydraulic interaction between the flooded 1B system and active Phalen workings.

Water pumped from the Phalen mine is currently discharged directly to the Atlantic Ocean. Current water quality does not require treatment prior to discharge. Trends in water chemistry over the past three years suggest a possibility that treatment may be required at some point. An emergency water treatment plant was constructed at the Lingan mine to treat mine waters prior to discharge, if required. This treatment plant may be used to treat water from the Lingan, Phalen or 1B mines, as pumping is needed to control water levels.

Monitoring by CBDC since 1993 has found that the rate of mine water rise predicted in 1993 (JWEL, 1993) in the 1B system, and Lingan mine in particular, has been dramatically reduced due to undetermined hydraulic interactions within the mine complex, and will not reach discharge levels within the very near future. The time to discharge to the surface has a bearing on the overall economics and operation of mining in this location.

Recent investigations of the relationship between subsidence-induced sinkholes and recharge to 1B system has shown that some reductions in the rate of water level rise can be achieved by sealing surface water-influent sinkholes which focus recharge to the abandoned mines (G. Ellrbrook, personal communication).

Since 1994, Phalen 5E, 6E and 7E panels have been plagued by roof falls and structural problems found to be associated with proximity to a massive sandstone unit located above the workings. Mining is currently progressing on the 7E panel beneath the flooded Lingan and No. 26 workings.

1.2 Purpose

The purpose of this work is to re-visit the 1993 investigations (JWEL, 1993) into the cause and implications of mine water flooding, and to up-date several specific issues in light of the new monitoring information collected between August, 1993, and November, 1996, by CBDC. Specific requirements identified in the RFP include:

- Provide an explanation of how flows between these workings could be affecting the rate of rise in the overall "system".
- Validate the CBDC projections of the water level rise time line and associated mitigative milestones;
- Assess the practicality of using the Phalen emergency waste water treatment plant to control water rise by active pumping and treatment of mine water extracted from the Lingan "connection"; and
- Rationalize the disparity in water quality between Phalen inflow waters, and Lingan - No. 26 Colliery mine water.

1.3 Scope of Work

The scope of work involved several defined tasks:

Task 1 - Site visit, inception meeting and data collection
Task 2 - Data compilation and review
Task 3 - Assess the hydraulic interactions between mines
Task 4 - Review inter-mine water chemistry
Task 5 - Validate projected rate of water level rise and associated milestones
Task 6 - Assess feasibility of mine water level control options
Task 7 - Provide recommendations for on-going investigations by CBDC

The scope of work was limited to a detailed review of mine monitoring activities conducted by CBDC between 1993 and the present; with specific emphasis on water level and water chemistry monitoring records, or other relevant work conducted by CBDC or their consultants. The field work component was limited to one trip to CBDC offices in Glace Bay on October 1, 1996, to review the work done and compile data for evaluation.

1.4 Approach and Rationale

The scope of work outlined in the RFP was discussed with CBDC at a series of meetings on October 1, 1996. Relevant monitoring data, mapping and other documentation related to the mine water inflow problem were collected. Discussions also covered the CBDC revised water level rise time line estimations, recent mine mapping updates, environmental effluent monitoring at Lingan and Phalen, the latest conceptual models of mine water/structural interactions, and a field inspection of the new waste water treatment plant.

The following information provided by CBDC was reviewed:

- water level data from automated monitoring stations at 1B Shaft, Lingan, No. 2, No. 4 and No. 9 mines;
- water quality data from numerous in-mine sources from Phalen operations;
- water quality data from Lingan and Phalen sump effluent monitoring;
- revised mapping for all mines of concern;
- 1993 assessment report by ADI Limited;
- 1994 risk assessment report by CBDC; and
- 1993 Mine Interconnection Assessment by JWEL.

An updated history of the mine water in-rushes and geological breaks within the Lingan and Phalen mines was generated from the three major studies of mine-water problems at CBDC (JWEL, 1993; ADI, 1993; CBDC, 1994). Chemistry data from in-mine and effluent monitoring was assessed to identify hydrochemical trends, and possible correlations with abandoned mine water level responses and Phalen panel discharge rates. This historical framework provides a temporal reference for the mine water level and water quality assessments.

2.0 HYDROGEOLOGICAL SETTING

The following summary of geological setting, and the probable hydrogeology of the mine areas is derived from a review of the historical data (ADI, 1993; CBDC, 1994).

2.1 Mine Hydraulic Systems

A total of 27 collieries were identified within the study area which have been subdivided into twelve hydraulically-interconnected "systems" (JWEL, 1993). With respect to the Phalen mine operations, the most important systems include the 1B Hydraulic System overlying and immediately east of the Phalen mining operation, and the No. 12/14 Hydraulic System, located to the west. The interpreted hydraulic interconnections between the various abandoned mines are summarized on Table 2.1, and illustrated on Figure 2.1 (JWEL, 1993).

Table 2.1 Summary of Mine Interconnections

Hydraulic System	Interconnected Mines				
	Harbour Seam	Phalen Seam	Emery Seam	Gardiner Seam	Hub Seam
1B	9, 20, 26, Lingan	1A, 1B, 2, 5, (3)	10, 24		
No. 4 (Caledonia)		3, 4, 6			
Nos. 12/14	12, 14				
No. 18	17, 18	16			
No. 8	8, Sterling, Old Harbour				
Isolated Collieries	Old Victoria	15, 23, Phalen	11, Old Emery	25, Pioneer Strip Mine	7

Figure 2.2 (after CBDC, 1994) illustrates the spatial distribution of the abandoned workings relative to the active Phalen mine. The Phalen mine is isolated from flooded mines (Lingan, No. 26, No. 14) on the Harbour Seam by 130 to 140 m of intervening strata, and from adjacent mines on the Phalen Seam by barrier pillars of coal. Abandoned mine workings on the Phalen Seam include the No. 1B on the east, and the No. 16 workings located to the west. A 76 m to 100 m wide barrier pillar separates Phalen 1E through 8E panels from the 1B flooded workings on the east, and a nominal 91 m barrier exists between the Phalen 1W through 4W panels and No. 16 colliery on the west.

The 1B workings on Phalen Seam are hydraulically interconnected with the No. 26, Lingan and other mines on the Harbour Seam possibly including the No. 3 mine (Table 2.1). The No. 1B mine is currently flooded to about -380 feet below sea level. The overlying Lingan mine complex is flooded to -480 feet, and the No. 26 colliery is believed to be in equilibrium with the 1B at -380 feet. The No. 16 mine is hydraulically interconnected with Nos. 17 (Harbour Seam) and 18 (Phalen Seam), and are flooded to sea level.

On the overlying Harbour Seam, the Lingan mine complex is separated from the No. 26 Colliery (1B System) by a nominal 90 m barrier pillar on the east, which narrows to 70 to 76 m at the east end of Lingan 5E panel. Lingan is separated from the No. 12/14 collieries on the west by a 155 m barrier pillar. Lingan is now part of the 1B mine system, and is slowly approaching hydraulic equilibrium with the 1B and No. 26 collieries (See Section 3.2).

2.2 Geology

The coal seams occur within an extensive sedimentary bedrock sequence of sandstone and shale of Upper Westphalian age (315 million years before present {bp}). These units were deposited in a slowly subsiding basin, possibly associated with coastal lowlands. The oldest rocks consist of coarse-grained pebbly sandstone of the South Bar formation (Lower Morien Group). This unit locally exceeds 900 m in thickness, and stratigraphically underlies the coal-bearing Sydney Mines formation (Upper Morien Group).

As time progressed, the rate of land subsidence slowed, and fine grained sandstone, siltstone and mudstone was deposited by slowly meandering rivers on extensive low-lying flood plains, possibly coastal in nature. Also during these times, extensive basin-wide swamps were developed which resulted in extensive thicknesses of peat deposits. Eventually the peat accumulation ceased, and the area was buried by successive layers of sediments. The coal-bearing Sydney Mines formation resulted from a dozen or more of these cycles of deposition and burial of peat (Calder et al 1993).

The Sydney coalfield is located on the western rim of the Sydney Basin. This area had a relatively quiet tectonic history, resulting in gentle folds plunging northeast under the sea. The study area is bounded on the west by the New Waterford anticline, and on the east by the Glace Bay Syncline; the Bridgeport Anticline trends northeast through the middle of the site. On average, bedrock strike is northwest to southeast, with dips ranging from 16 degrees near the coast to 4 degrees near the north limit of the resource block (ADI, 1993). No faulting greater than 1 m displacement has been detected at the Phalen and Harbour Seams (CBDC, 1994).

Stratigraphy between the Harbour and Phalen Seams is characterized by a series of cyclothems consisting of coal and limestone overlain by fine-grained sediments, typically with 6% mudstone/shale; 28% sandstone, 23% siltstone, 2% coal and 1% carbonaceous limestone.

Figure 2.3 illustrates the stratigraphic sequence of coal and intervening sandstone aquifers (ADI, 1993). In the study area, seven coal Seams are identified, and from to youngest (shallowest) to oldest (deepest) they are: Hub, Harbour, Bouthillier, Backpit, Phalen, Emery, and Gardner. Each of these coal-bearing units is separated by one or more sandstone aquifers with minor coal and shale units. The interburden between the Phalen and overlying Harbour Seam is as follows:

Stratigraphic Member	Height Above Phalen Seam
Lower Sandstone	0 to 15 m
Backpit Seam	30 m average
Bouthillier Seam	53 m average

Upper Sandstone	79 m average
Harbour Seam	140 m average

2.3 Hydrogeology

A conceptual hydrogeological model of the Sydney Mines formation was compiled using geological data provided from CBDC drill holes (ADI, 1993). This model (Figure 2.4) provides a useful reference for discussion of hydraulic interactions between the various mining activities. The model consists of a series of sandstone and shale aquifer complexes bounded by relatively thin coal-shale aquitards and aquicludes, subdivided into four hydrogeological environments, namely:

1) On Land - 0 to 75 metres depth where groundwater movement is controlled by meteoric precipitation recharge and flow to the sea coast or into mine workings;

2) Exposed Sea Bed - 0 to 75 m depth, up to 4 km from shore where groundwater discharges to the sea, and where seawater recharge could occur to strata depressurized by mines;

3) Covered Sea Bed - 0 to 75 m depth, increasing distances from shore, where less direct seawater interaction is likely; and

4) Membrane Setting - Depths exceeding 75 m where groundwater movement is controlled by hydrostatic pressure and drainage into openings.

Superimposed on this regime, are three zones of secondary fracturing which control flow:

1) Level 1: Upper few metres of exposed bedrock on land or below seabed. Characterized by weathering, exfoliation or bedding plane fractures;

2) Level 2: Upper 75 metres of bedrock where fracturing due to folding and minor faulting occurs. Reasonably high degree of fracture connectivity. Flow is controlled by a combination of primary and secondary permeability; and

3) Level 3: Depths greater than 75 m, (mining depths), poor fracture interconnectivity, minor faulting. Flow dominated by primary intergranular permeability and diffusive flow.

Each coal seam with associated fine-grained sediments is considered to behave hydraulically similar to an aquitard, and each intervening zone of more permeable sandstone, siltstone and shale strata is assumed to behave hydraulically similar to an aquifer. An **aquifer** is defined as a "formation, group of formations or part of a formation that contains sufficient saturated permeable material to yield economical quantities of water to wells". An **aquitard** is defined as a "formation, group of formations or part of a formation through which virtually no water flows". In a stratigraphic sedimentary sequence, an aquitard would be orders of magnitude lower in hydraulic conductivity (permeability) than an aquifer.

At the depths and pressures involved in the Cape Breton mines, these assumptions are reasonable. However, due to the processes of mining, considerable alteration of the hydraulic properties of the coal shales is imparted both by direct removal of coal, and by mining-induced subsidence. A third type of hydrogeological unit is used to describe the disturbed aquitard zone. An **aquiclude** is defined as a "formation, group of formations or part of a formation that does itself not yield water freely, but which may transmit considerable volumes of water to or from adjacent aquifers. These units typically involve secondary permeability (fracturing, open voids or pipe flow), and can behave hydraulically like a drain or a karst flow system. The mined areas are expected to consist of a mixture of open voids (room and pillar operations), crushed zones where the roof has fallen to fill the gob, and an extensive zone of subsidence-induced secondary fracturing. The **"gob"** or **"goaf"** defined as the area of a mine panel where the roof has subsided behind the advancing longwall coal cutter.

In addition to voids created by mining itself, secondary voids may form where strata parting takes place above a mine. For example, it is theorized that contact zones between relatively rigid sandstone and plastic shales or coal shales may part along planes of weakness, thereby forming discontinuous zones for storage or transmission of formation waters derived from surrounding beds. It is likely that this strata parting occurs close to mined zones, and may be induced to occur adjacent to overlying mined zones by subsidence (see conceptual drawing, Figure 2.4). Subsidence up to 1.2 metres was measured in the Lingan 2E panel which was attributed to Phalen longwall mining beneath Lingan (CBDC, 1994).

A detailed discussion of groundwater flow potential in the vicinity of Phalen mine was presented in ADI, 1993. The zone between Phalen and Harbour Seams includes three aquifer complexes (Nos. 4, 5 and 6, after ADI, 1993), separated by two unmined coal seam aquitards (Backpit and Bouthillier Seams, Figure 2.3). Two major sandstone channels identified by CBDC drill holes include the 20 to 25 m thick, Lower Sandstone Unit (Bridgeport Channel Sandstone), located 0 to 15 metres above the Phalen Seam, and the Upper Sandstone Unit (Lingan Channel Sandstone), located 30 to 35 metres below the Harbour Seam and 75 to 90 metres above the Phalen Seam (ADI, 1993).

With respect to groundwater movement in the vicinity of the Phalen workings, the Lower Sandstone is the more important. Where this unit occurs within a few metres of the roof of the coal seam, bedding plane partings, higher than average water inflows and roof falls tend to occur. This unit is more permeable than the surrounding shale and mudstone which acts as an aquitard. The sandstone formation, where it occurs within 0 to 3 metres above the Phalen Seam, forms a channel structure which trends northwest from the Phalen 1B mine, across the barrier pillar and over the Phalen 5E through 9E panels, then in a general northerly direction from the intersection of 9E and the main slopes, over the east end of panels 4C through 6C (Figure 15 in CBDC, 1994). Based on 33 samples, this unit has a mean hydraulic conductivity of 0.1 millidarcys (1 x 10^{-7} cm/s), ranging from <0.01 to 1.34 millidarcys, (<10^{-12} to 10^{-4} cm/sec), and a matrix porosity of 0.027 to 0.129; mean 0.08 (ADI, 1993).

Groundwater flow through these hydrostratigraphic units near the outcrops is expected to be essentially horizontal along bedding plane discontinuities, and within the more porous channel sandstones. At the depths of mining, the combination of low matrix permeability (e.g. < 10^{-7} cm/sec to 10^{-12} cm/sec for sandstones and shale units respectively), and lack of appreciable fracturing or faulting is expected to be sufficient to prevent those unit from acting as a major groundwater flow field. Although hydraulic potential is low, total porosity of these units has been reported to range from 2 to 20 percent (ADI, 1993), which provides a large volume of groundwater in storage.

Prior to mining, groundwater movement would be typical of a deep sedimentary basin, and controlled by upward migration of high pressure waters into overlying strata, and osmotic pressure driven diffusion across aquitards between aquifers (Freeze and Cherry, 1979). The presence of a mined cavity with associated overlying subsidence-induced fracturing, provides a drain which controls flow in the immediate vicinity and stratigraphically above the opening. Secondary permeability caused by subsidence-induced fracturing and bedding plane parting can connect previously isolated aquifers, releasing stored fossil groundwaters to voids either in the mines themselves, or indirectly through voids created in bedding planes as subsidence occurs. This mechanism could account for the sudden in-rushes of highly saline formation waters, followed by rapid declines in water volumes as aquifer reservoirs depressurize. Continuing subsidence and fracturing would then provide pathways for slow migration of groundwaters between flooded workings.

2.4 History of Mine Water Inflows

2.4.1 Lingan-No. 26 Colliery Strata Breaks

Three known hydraulic breaks have occurred between the flooded No. 26 colliery and the active Lingan colliery. Both these mines are located on the Harbour Seam, approximately 140 m stratigraphically above the Phalen Seam. These breaks are assumed to have been caused by subsidence induced fracturing and strata partings caused by mining on the Phalen Seam (Nos. 5E, 6E and 7E panels), beneath the Lingan and No. 26 barrier pillar.

2.4.1.1 Lingan-No. 26 Barrier Breach (November 29, 1992)

A significant flow of water was detected in pipes installed through the sump bulkhead at Lingan 2E panel bottom level, on November 29, 1992. The Lingan mine was operational at this time. This water flow was later found to be associated with an in-rush of up to 2,000 usgpm into the Lingan 2E panel near the -1100 ft level in Lingan. The rate of inflow declined to an estimated 1,500 usgpm within a few weeks and further reduced to 500 to 700 usgpm by September, 1993 (CBDC, 1994). The source of this in-rush was determined to be from panels 1 North and 2 North in the adjacent No. 26 colliery, also developed on the Harbour Seam, and separated from the Lingan workings by a typical 90 m wide coal barrier. In the area of the -1,100 foot elevation, where the break is assumed to have occurred, the barrier pillar was 107 m wide.

The mechanism of the break is assumed to be caused by subsidence-induced fracturing and strata parting caused by mining in the Phalen 5E panel under the Lingan and 1B workings. During the Lingan break, an in-rush of 250 usgpm also occurred in the Phalen 5E panel. This flow rate declined quickly to about 10 usgpm within a week (Figure 2.5), and remained stable throughout the remainder of the 5E panel.

Continuous water level monitoring was available for the 1B system at the 1B mine shaft (Figure 3.1). The water level in 1B shaft dropped 30 ft from -387 to -413 feet as a result of a combination of this event, and pumping of the 1B shaft from November 25 through December 1, 1992. Lingan water levels rose rapidly from the -2,600 sump level to -2,200 ft over this period.

2.4.1.2 Lingan-No. 26 Barrier Breach (Feb. 17-25, 1994)

A second major breach of the Lingan-No. 26 colliery pillar occurred in the Lingan 5E panel, near the -1400 ft level on or about February 17, 1994, as a consequence of mining in Phalen 6E panel. Phalen 6E was advancing beneath the Lingan 3E and 4E panels, at a point where the barrier between the No. 26 and Lingan mine workings was reported to be only 90 metres wide. The flow rates into Lingan increased rapidly to an estimated 7,000 usgpm, before dropping to 2,000 usgpm (Figure 6.2).

This event caused water level responses at both the Lingan and 1B shaft monitoring points (Figure 3.1). Static water levels at the time of this event were -343 ft in the 1B and -1,750 ft in the Lingan respectively, with a hydraulic gradient of about 0.7 between the two mines at the -1,100 ft level. The 1B recorded a 108 ft (33 m) water level drop between February 17, 1994 and November 18, 1994, and Lingan water levels rose by an estimated 1,880 ft (573 m) over the same time period. The decline in water levels at 1B reversed after November, 1994, when water levels in the Lingan mine passed the elevation of the assumed break in the 2E panel. Prior to this event, Lingan was flooding at a rate of about 1.04 ft/day or 800 usgpm. Subsequent to the break, the flooding rate increased to 4 to 6 ft/day, or more than 3000 usgpm (Section 5.2.3).

2.4.1.2 Lingan-No. 26 Barrier Breach (October 28, 1996)

The most recent strata break was reported by CBDC (Gary Ellerbrook) on November 4, 1996. A sudden rise in the rate of water level inflow was observed in Lingan mine on Monday, October 28, 1996 (Figure 3.8). The rate of rise of water levels in the Lingan system increased fivefold from about 0.2 ft/day to 1.0

ft/day, and rose from 479.7 ft to 476.8 ft (3 ft) over the next three days. No discernable change in the 1B water levels was observed during this same time period. At the time of the water rise rate increase, the difference in water level elevations between 1B and Lingan was 102.6 ft. It was suspected that Lingan was taking in water from the far end, some distance from the 1B/Lingan barrier pillar (G. Ellerbrook, pers. com.).

2.4.2 Phalen Mine Weightings and Water Occurences

This section refers to weightings and associated water inflows and roof instability within the Phalen mine, which is located about 140 m stratigraphically below Lingan and No. 26 colliery. A weighting occurs when excess stress is placed on the roof of a mine, resulting in unstable rock conditions.

Rock breaks or "weightings" and water in-rushes have plagued the Phalen mine since its inception in 1986. Prior to 1988, mining was essentially "dry", with minimal measurable inflows of formation waters or seepages. Several in-rushes of formation-derived mine water were reported from the Phalen panels on November 15, 1988 (1E), October 22, 1992 (5E), February 17, 1994 (6E) and June 27, 1996 (7E). Each event is described below.

2.4.2.1 Phalen 1E In-rush

At 2300 hrs on November 7, 1988, a sudden in-rush of water in the order of 600 to 1,000 usgpm into the Phalen 1E panel gob stopped production and flooded the panel workings (JWEL, 1993). The inflow rate declined quickly to less than 10 usgpm within 12 days, and remained low over the remainder of the panel. The Phalen 2E panel was starting to undermine the Lingan No. 3 mine east room and pillar workings at the time of the inflow. At about the same time, about 200 usgpm was observed to be discharging from the Lingan A No. 11 seal. This in-rush occurred as water levels in the 1B system were rising rapidly between September 15, 1988 and November 28, 1988 (Figure 3.1).

2.4.2.2 Phalen 5E

A small in-rush of about 300 to 400 usgpm occurred in late November, 1990, and declined to about 76 usgpm within a few weeks (JWEL, 1993). It was determined by CBDC that this inflow originated from strata water in the roof behind the gob at the production face. Both the 1988 and 1990 inflows are believed to be associated with highly saline formation waters released from storage in the sandstone aquifer by subsidence-induced fracturing as longwall mining progressed.

Weighting conditions with roof breaks and inflows occurred as the wall advanced under the Lingan-No. 26 inter-seam barrier pillar. Saline formation water (5 to 10 usgpm) was observed by October 9, 1992. Flow rates increase from 10 to 250 usgpm between October 10 and October 26, then decreased quickly to 90 usgpm, and continued to drop to an average of 30 usgpm as mining proceeded (Figure 2.5). Additional weightings occurred on Dec. 31, 1992 and February, 1993, where water from the gob increased from 30 to 50 igpm between February 24 and May 3, 1993, and then decreased to about 10 usgpm over the remainder of this panel (CBDC, 1994).

2.4.2.3 Phalen 6E

With detailed monitoring, numerous weightings and water inflows were observed during mining of the Phalen 6E panel (Figure 2.6). A weighting occurred on Aug. 27, 1993 as 6E advanced under 2N and 3N panels of No. 26. Significant roof falls in 6E panel were accompanied by inflows of about 10 usgpm from the panel walls, and a maximum of 45 usgpm from the gob. Water chemistry determined the water source to be a mixture of formation waters and Harbour Seam waters.

Several moderate water inflows occurred in Phalen 6E panel (mining under Lingan 3E and 4E panels), about the same time as the February 17, 1994, strata break at Lingan (Section 2.4.1.2). Minor inflows (50 to 75 usgpm) were reported at Phalen 6E panel on December 3, 1993 (80 usgpm, declining to 30-40 usgpm); January 14, 1994, and February 2-8, 1994, from the gob, which quickly declined to < 10 usgpm over a few days. During this period, the rate of rise in 1B was flattening out. As 6E panel approached the Lingan side of the Lingan and No. 26 barrier pillar, an in-rush of about 200 usgpm occurred on February 17, 1994, declining to about 59 usgpm within 5 days.

Another major weighting with up to 250 usgpm (115 usgpm at face, 135 at gob) of water inflow took place on April 6, 1994. Total flows dropped rapidly to about 50 usgpm by April 20. Phalen 6E panel was now beneath the pillar between Lingan 3E and 4E panels on the Harbour Seam. Several additional inflows in the order of 250 usgpm occurred in the 6E panel throughout the summer. Roof falls, creating up to 9 m void heights, were reported (CBDC, 1994). Total gob inflow rates began to increase after September, 1994, from 50 to about 200 usgpm (Figure 2.6).

Based on the panel prognosis maps provided by CBDC, these "in-rushes" occurred within 2 months after the panel passed areas where the massive Lower Sandstone Unit was within 1.5 metres of the roof. This suggests subsidence fracturing of the sandstone aquifer.

2.4.2.4 Phalen 7E

An inflow occurred within the Phalen 7E panel as it was advancing beneath panels 6 North and 7 North of No. 26 Colliery and Lingan 5E panel (Figure 2.7). Inflow to the gob increased slowly from 10 to 100 usgpm as the wall advanced. Three in-rushes of 300, 450 and 550 usgpm were reported over the last 275 metres of panel 7E between October and November, 1995. Major roof falls then halted mining. The Lower Sandstone Unit was less than 1.5 m from the panel roof over the last 500 m of mining. Cumulative gob flows increased from 100 to 450 usgpm over the later phases of mining.

3.0 HYDRAULIC INTERACTIONS BETWEEN MINES

This section is an assessment of the hydraulic interactions between individual mines, and flows within Phalen panels. The assessment is based on water level records for mines 1B, 4, 2, 9 and Lingan, as well as flow monitoring in Phalen panels 5E, 6E, 7E and Phalen mine outfall.

3.1 Procedure

The water level data was organized into a series of continuous hydrograph records using one reading per day for monitoring stations at No. 1B (July, 1986 through November, 1996), Lingan (February, 1996 through November, 1996), No. 4 Quarry Point (November, 1993 to January, 1994), and Nos. 2 and 9 collieries (August, 1995 to January, 1996). Records with similar time scales were superimposed to illustrate relative head responses between the five monitored mines. Hydrographs of water inflows to Phalen panels 5E, 6E and 7E were prepared using the CBDC mine water chemistry database. Daily rainfall data for Sydney Airport was obtained from Environment Canada to assess the effects of precipitation on minor water level fluctuations observed in the various mine water level hydrographs.

Water Level Database

The water level data was provided by CBDC as ASCII files from the various data loggers. Each file contained information on time, date and water level expressed as feet below mean sea level. The water levels contained in files provided by CBDC had been corrected for barometric reference, and head references by CBDC at the time the logger data was processed. For the purposes of this assessment, and to reduce file volume, only information pertaining to time/date and water levels was retained for generation of hydrographs. No further correction of file data was carried out, other than some isolated spikes in the data. Each file contained some 4,000 water level readings.

Some files (e.g. 1B shaft) had three sets of water level readings generated from three separate data logger transducers set in this location. The longest period of record is from Transducer No. 1; the most accurate record is assigned to Transducer No. 3 which was set on a surveyed stainless steel cable. Overall, the variance between the three separate data logger records at 1B was about 2 feet. Since No. 3 sensor was removed intermittently for water sampling, the No. 1 sensor was used in the assessments as the only long term consistent sensor.

The logger used at No. 2 mine contains two sensor logs; one for the No. 9 mine workings, and one for the No. 2 mine, located stratigraphically beneath No. 9. Water level records and periods of coverage for the various mines are summarized in Table 3.1.

Table 3.1 Summary of Mine Water Level Monitoring, Cape Breton Coal Fields (1988 to 1996)

Mine Location	Period of Record	Type	Frequency
1B Shaft	Dec. 23, 1986 to Dec. 27, 1990 Jan 1, 1993 to Nov 7, 1996	Intermittent Continuous	15 min Hourly
Lingan	Feb. 3, 1994 to Nov. 4, 1996	Intermittent	Hourly
No. 2	March 9, 1995 to Jan. 7, 1996	Continuous	Hourly
No. 4 (Quarry Point)	Nov. 15, 1993 to Dec. 15, 1993 April 1, 1995 to Nov. 4, 1996	Intermittent Continuous	Hourly
No. 9	March 9, 1995 to Jan 4, 1996	Continuous	Hourly

3.2 Lingan-1B System

Figure 3.1 illustrates the water level responses in the Lingan and 1B shaft between July, 1986 and November, 1996. The 1B system had been flooding since April, 1984. Lingan was allowed to flood beginning in early 1994. This hydrograph summarizes the history of flooding in the 1B system. Periods of water level decline occur when water levels in 1B system reach an outfall point to an interconnected mine such as No. 2 and No. 26 collieries. The 1B system is being recharged from a wide area of outcropping mines included in the IB hydraulic interconnection system (JWEL, 1993). Detailed examination of the water level hydrographs shows a seasonal effect on water levels in the order of 1.5 ft.

With reference to the mine interconnections (Figure 2.1), and the history of strata breaks and weightings (Section 2.4), the following observations are relevant:

1. Prior to November 7, 1986, the 1B was losing water to No. 20 colliery from No. 2 colliery.

2. The 1B system water levels rose 31 ft between November 7, 1986 and July 15, 1987 at an average rate of 0.196 ft/day until an elevation of -580 ft was reached. This may represent the elevation of the cross barrier tunnels between the No. 2 and the No. 1B. At this time water from the 1B may have began to flow into the No. 2 mine.

3. There was negligible water level change from July, 1987 to September 15, 1988, which may represent water flowing into the No. 2 mine from the 1B. A 3 ft seasonal water level decline was also observed.

4. Water levels rose rapidly (35 ft in 50 days), once No. 2 mine was filled and the water level rose to the No. 26 mine connection at an elevation of between -558 and -547 ft.

5. Water levels declined 45 ft between November 28, 1988, and June, 1990. During this period, an in-rush occurred on November 7, 1988 in Phalen 1E.

6. Another minor water level drop occurred about March 15, 1990. Both Lingan and Phalen (5E) were in operation at this time.

7. Water levels in 1B system rose steadily at an average rate of 0.175 ft/day between July, 1990, and November, 1992, when the break between No. 26 and Lingan 2E occurred.

8. The effects of major strata breaks across the coal pillar between Lingan 2E and No. 26 Colliery are clearly shown. A rapid decline in the 1B coincident with rising water level responses in the Lingan water levels are seen after the two breaks on November 29, 1992 (2,000 usgpm) and February 17-25, 1994 (7,000 usgpm).

9. The rapid decline in 1B water levels after the 1992 event reversed after water levels in Lingan rose above the inferred break point (-900 to -1100 ft).

10. Water level declines after June 15, 1995, and July 4, 1996, are attributed to seasonal decline in recharge rate to the 1B system. During dry periods, water flowing out of the 1B system (e.g. to Lingan or Phalen) exceeds the rate of recharge.

11. The 8.5 ft water level decline after June, 1995, was greater than expected (typically 3 ft) for summer periods. While this event may be entirely attributed to seasonal factors, it is suspected that some recharge to the Phalen 7E panel may have been masked by the summer dry period.

The scaling of Figure 3.1 does not adequately show the hydraulic responses of Lingan mine to 1B changes after the summer of 1995. Figure 3.2 shows the fluctuations in 1B and Lingan water levels between October 7, 1995 and November 4, 1996. Note that the Lingan water levels rose at a relatively constant rate of 0.12 ft/day with minimal fluctuation, while 1B water level exhibited significant fluctuation.

Figure 3.3 shows the difference between water levels in 1B and the Lingan mine between October 7, 1995 and November 4, 1996. This difference was determined by subtracting the Lingan water level from the 1B water level. The 1B system exhibited two anomalies, in November, 1995, and September, 1996, and exhibited a similar average recovery rate of 0.16 ft/day between these anomalies. Since the Lingan mine exhibited negligible water level fluctuation during this time, the observed events are due to the 1B system.

The initial part of the curve to about November 1, 1995, reflects the convergence of water levels between the mines as Lingan rapidly floods from -1800 ft to -500 ft as a consequence of the 7,000 usgpm in-rush on February 17 to 24, 1994. Between November, 1995, and June, 1996, the 1B water levels rose faster than the Lingan levels. This is attributed to seasonal recharge effects over the winter and spring of 1995-96 (e.g. periods of frozen ground with no direct recharge to the 1B system, and winter-spring rain storms). The flat zone from January 20 to about March 1, 1996, is attributed to frozen ground conditions in the winter months (e.g. reduced recharge to 1B with outfall to Lingan exceeding inflow from recharge). Peaks on April 10, 1996 and April 2, 1996 are associated with heavy rains recharging to 1B.

A period of rapid convergence between the two mine water levels (e.g. Lingan rising, 1B falling or stable) between June 4, 1996 and September 16, 1996 is attributed to summer drought conditions in June and August when outflow from 1B exceeded the recharge rate (Figure 3.1).

The effects of a major recharge to the 1B system by Hurricane Hortense on September 14, 1996, is seen as a rapid increase in the water levels in 1B (Figures 3.2, 3.3). Sealing of one major sinkhole near Glace Bay resulted in a reversal of this trend.

It is suspected that another break may have occurred in the Lingan-1B system on or about October 28, 1996, resulting in an increased rate of rise in the Lingan mine. This may also be due to lag behind the Hortense event in 1B.

3.3 Quarry Point No. 4 Mine

The Nos. 3, 4 and 6 mines on Phalen Seam are interconnected with No. 5 mine, by two openings across the barrier pillar, both of which were reported as sealed in our 1993 report. The No. 5 mine is in turn connected with the 1A, which is also on the Phalen Seam. Because water levels in the Nos. 3, 4 and 6 are +16 ft above sea level, and 500 ft higher than the 1B, no direct interconnection was assumed in the JWEL 1993 study.

Figure 3.4 illustrates the water levels at the Quarry Point shaft between April 3, 1995 and September 20, 1996. Prior to April, 1995, this hydrograph record is discontinuous, but exhibits a relatively consistent water level elevation averaging +16 ft above sea level, with 1 ft of climate-induced fluctuations. While Figure 3.4 does not cover the major hydraulic break events of November, 1992 and February, 1994, it does show a 3 ft drop in water levels correlating with the July 15 to November 28, 1995, water level decline in the 1B system (Figure 3.7). The responses of the 1B system to Hurricane Hortense in September, 1996, are also seen at No. 4 mine. Water level fluctuations due to climatic sources in the order of 1 to 3 ft are also apparent. It is concluded that No. 4 mine at Quarry Point is not hydraulically connected to the 1B system, and the 3 ft water level drop is attributed to climate.

3.4 No. 2 Mine

No. 2 mine is situated on the Phalen Seam, and is connected to the No. 2 (1B Hydraulic System) by at least two open tunnels and to No. 9 on the overlying Harbour Seam by a borehole (JWEL, 1993).

Figure 3.5 illustrates the water level responses in No. 2 mine between March, 1995 and January 7, 1996. This hydrograph record covers an apparent Lingan-1B breach which may have occurred during the summer of 1995 when Phalen 7E panel was undermining Lingan (Section 3.2). Prior to July 15, 1995 both the 1B and the No. 2 were recovering at average rates of 0.12 ft/day and 0.29 ft/day respectively. When 1B began to decline after July 15, 1995, the No. 2 system also showed a significant flattening and slight decline. Water levels continued to rise after November 28, 1995, similar to 1B.

Figure 3.7 compares the hydraulic responses between the two mines. No. 2 mine water levels appear to be about 6 to 7 ft higher than the 1B system, assuming survey elevations are correct. While this response could indicate seasonal effects (e.g. a period of low or no recharge during summer and fall 1995), the correlation in water level responses, and close water level elevations confirms that these mines are in direct hydraulic connection.

3.5 No. 9 Mine

The No. 9 mine on the Harbour Seam is situated directly above the No. 2 mine which is on the Phalen Seam (Figure 2.1). This mine is known to be interconnected with No. 2 by a partially-restricted borehole (JWEL, 1993). Figure 3.6 illustrates the water level responses in No. 9 mine between March 9, 1995 and January 7, 1996. The No. 9 water levels correlate closely with the No. 2 water levels, but do not exhibit the responses to the July 15, 1995 water level drop at 1B (Figure 3.7). This mine exhibited negligible water level rise over 250 days (0.5 ft), and appears to be isolated from seasonal recharge factors.

Water levels in the No. 9 average 22 to 35 ft higher than the 1B system, and approximately 15 to 25 feet above the No. 2 water levels. It is possible the No. 9 is recharging the No. 2 (and 1B system) via the inferred borehole connection, however, these workings do not appear to respond to major hydraulic events between Lingan and No. 1B (Figure 3.7).

3.6 Climate Effects on Mine Water Levels

Hydrograph data is available for all five monitor locations between April 1, 1995 and February, 1996. During this period, a slow decline in water level in 1B (8.5 ft) occurred between July 15, 1995, and late October 1995. No. 2 mine, which is in direct connection with 1B system, exhibited a significant reduction in the rate of water level rise, and a small decline of 1 ft over this period (Figure 3.5). Mine No. 4, which is flooded to +16 ft above sea level and not assumed to be in direct hydraulic connection with 1B system, also dropped approximately 3 ft over the same period (Figure 3.4).

To determine whether this event was caused by seasonal or mining-induced events, daily rainfall records from Sydney Airport were examined to determine if the water level decline was climatic in nature. Figure 3.9 illustrates the relationship between daily rainfall and water levels in 1B mine during this period. April of 1995 was extremely dry, however no drop in water level was observed in the mines. May, June and July precipitation was at or above normal monthly rainfall levels. August and September levels were 30 to 40 percent lower than average. It is therefore concluded that some of the drop in water levels observed between June 15, 1995 and November 28, 1996 is caused by 1B drainage, most likely into the Lingan system, and possibly into the Phalen mine.

It is also likely that the rate of drainage of the 1B system is greater in dry periods when the outflow to Lingan exceeds the inflow from recharge. During periods of heavy rainfall, this trend is reversed, and water levels again rise in the 1B and connected mines. The last year of data (Figures 3.8, 3.9) shows that heavy rainfalls exceeding 50 mm result in water level rises in 1B, followed by declines after a few days to weeks.

3.7 Sinkhole Effects on 1B System

A sudden increase in the rate of 1B water level rise after September 14, 1996, was caused by intense rainfalls due to Hurricane Hortense. The No. 1B system exhibited 10 ft of rise, No. 4 at Quarry Point exhibited 1.5 ft of rise, and No. 2 showed a small (about 1 ft) increase. Surface water was observed to be recharging a subsided wetlands area near Glace Bay at several thousand usgpm (G. Ellerbrook, pers com). The depression was determined to be caused by mine subsidence. This sinkhole was sealed in late September and monitoring showed a dramatic decrease in the rate of water level rise in the 1B system after October 10 (Figure 3.8). This event demonstrates the utility of locating and sealing any influent sinkholes over mine workings connected to the 1B-Lingan system.

4.0 MINE WATER QUALITY

4.1 Procedure

There still remains some questions regarding the disparity between the chemical quality of mine waters in the Phalen, Lingan, and No. 26 collieries. Water chemistry data has been collected from numerous sources throughout the Lingan-Phalen mine complex since the initial water in-rush event in Lingan Mine in November, 1988. Several assessments of mine water chemistry have been presented between the initial November, 1988 in-rush to Phalen 1E panel, and the 1993, ADI report which dealt with sources of saline groundwater in Phalen 6E panel.

Table 4.1 Summary of Water Chemistry Data for 1B System and Phalen Mines

Mine	No. Samples	Period of Record
Phalen 7E Wall @ 8E Top (Gob)	80	Apr 27, 1995 - Feb 05, 1996
Phalen Outfall	61	Aug 22/89 - Aug. 20, 1996
Lingan Outfall	30	Aug 23/89 - Dec 10, 1992

Prior to assessing the hydrochemical data, it was necessary to determine suitable indicators of mine water quality. For example, the mode of sampling may preclude use of some parameters such as metals which vary with turbidity, or other parameters which are highly reactive within the mine. Based on previous assessments of mine water chemistry for Lingan and Phalen 1E (JWEL, 1988 to 1993), and the hydrochemical assessments by ADI (1993), plots of chloride, alkalinity, electrical conductance, and sulfate were prepared for several panels. Statistical summaries of useful mine water indicator parameters were prepared for each source, and chemical evolution trends for increasing concentration with time (+), and for decreasing concentration with time (-) , were indicated (Table 4.2).

Due to the very large volumes of data available, the mine chemistry assessment is limited to a review of the monitoring data from panels 5E, 6E and 7E, comparison of these chemistries with previous panels and mine waters, and evaluation of whether the chemistry data supports the previous conclusions that the mine water encountered in Phalen is a combination of strata water, Harbour Seam and water from the 1B mine on the Phalen Seam. This work basically is a continuation of the 1993 work done by JWEL and ADI.

In addition to general inorganic chemistry, sampling and monitoring also included environmental isotopes, which were very useful in confirming sources and degrees of mixing between mine waters (JWEL, 1993, ADI, 1993).

4.2 Chemical Characterization of Mine Waters

Table 4.2 summarizes average concentrations of key mine water chemistry parameters (e.g. those parameters which exhibit significant temporal chemical evolution within a mined area, or which are unique to a particular mine). This table exhibits typical range and mean concentrations for the Lingan A mine and the Lingan 2E panel after the 1990 break, and both strata and gob effluent chemistry for Phalen panels 1E, 4E, 5E, 6E and the current 7E panel. Effluent chemistries for Phalen, Lingan and 1B (during the December, 1992 pumping tests) are included for comparison.

To determine the differences between mine waters, the most recent (January to February, 1996) analysis for Phalen panels 1E, 4E, 5E, 6E and 7E were compared with the most recent analysis for 1B shaft (pumping),

Table 4.2. Statistical Summary of Lingan and Phalen Mine Water Chemistry

Location	2CWF-Strata (10/18/94 - 7/12/95)					2CWF-GOB (6/13/95 - 10/18/95)					4EWF-GOB (11/13/92 - 1/31/96)					5EWF-GOB (5/26/92 - 11/05/95)					6EWF-STRATA (7/14/93 - 2/20/96)				
Parameter	MIN	MAX	MEAN	N	Trend	MIN	MAX	MEAN	N	Trend	MIN	MAX	MEAN	N	Trend	MIN	MAX	MEAN	N	Trend	MIN	MAX	AVG	N	Trend
SODIUM	15650	38450	22564	14	-	2100	42000	20181.17	277	-	15000	25400	19793.29	589	-	17150	31750	25963.84	277	+	7600	44050	23297.12	227	-
CALCIUM	2915	14700	5706	14	-	2750	14700	4915.98	277	-	1290	12000	6012.01	589	-	3500	11000	8048.88	277	+	1335	15200	6348.15	227	-
MAGNESIUM	995	2935	1511	14	-	784	4930	1323.38	277	-	860	2890	1698.43	589	-	1125	2620	2049.28	277	+	483	3980	1472.30	227	-
ALKALINITY	9	125	63	14	+	0.4	184.6	57.63	277	+	0.4	225.4	136.44	589	+	0.4	148.5	35.04	277	+	0.4	402	90.60	227	+
SULFATE	34	2782	1949	14	+	25.9	2543.4	1973.81	277	+	442.6	2178.6	1025.54	589	+	460	2808.5	1109.81	277	-	1	3637	1753.72	227	+
CHLORIDE	29801	96660	48038	14	-	4345	102045	42588.43	277	-	34043	58862	45373.07	589	-	33959.6	70340	59732.19	277	+	12428	100039	50994.27	227	-
AMMONIA	22	57	32	14	-	13.79	59.3	28.37	277	-	1	45.95	29.59	589	-	16.72	56	37.42	277	+	11.3	60.7	31.75	226	-
BORON	0.02	0.02	0.02	7	0	0.02	2	0.03	192	0	0	0.43	0.05	535	0	0	0.24	0.03	270	0	0	1.22	0.04	215	0
MANGANESE	-	-	-	0	0	-	-	-	0	0	5.88	12.02	8.40	21	0	1.3	16	8.67	23	0	0	6.1	4.14	5	0
IRON	0.02	13.58	3.28	14	-	0.02	77	1.61	277	-	0	83.4	25.51	586	+	0.02	42.6	10.67	274	0	0	139	4.06	222	-
STRONTIUM	248	846	431	7	-	116	746	243.14	192	-	15	1600	289.96	536	-	37.6	1350	371.64	271	-	0	1400	414.80	215	-
CONDUCTIVIT	14600	176500	129900	14	-	122	200000	137277	277	-	64100	179900	135102	586	-	88900	189700	150561	275	+	33100	200000	134498	226	-
PH	6.1	7.7	7.14	14	+	6	9.1	6.94	277	+	4.1	7.7	6.51	589	+	4.5	7.7	6.60	277	0	5.6	8.1	7.14	225	+
FLOW RATE	45	600	109.29	14	0	0	600	54.46	277	+	-	-	-	0	0	10	250	25.56	277	-	0	265	71.20	227	+

Location	6EWF-GOB (9/1/93 - 1/22/96)					7EWF-STRATA (7/31/95 - 2/21/96)					7EWF-GOB (3/22/95 - 2/7/96)					7EWF-GOB@8ET (4/27/95 - 2/5/96)					1B Shaft (11/22/92 - 12/10/92) Pumping				
Parameter	MIN	MAX	MEAN	N	Trend	MIN	MAX	MEAN	N	Trend	MIN	MAX	AVG	N	Trend	MIN	MAX	MEAN	N	Trend	MIN	MAX	AVG	N	Trend
SODIUM	7990	41500	18146.60	300	-	6490	47800	20211.65	100	-	2370	30800	15428.31	59	-	16700	43000	26631.28	80	-	100	920	714.60	14	+
CALCIUM	585	14900	4472.67	300	-	1080	15100	5107.30	100	-	470	8000	3163.54	59	-	1660	12400	6034.88	80	-	225	1100	464.00		+
MAGNESIUM	474.5	2915	1131.61	300	-	386	3330	1219.81	100	-	80	2200	852.21	59	-	951	5410	1572.34	80	-	155	910	503.00		+
ALKALINITY	0.4	282	98.74	300	+	0.4	214	108.84	100	+	0.4	176	87.47	59	+	0.4	151	51.93	80	+	<1	79	11.60		+
SULFATE	1	3677	1655.00	300	+	1	4346	2509.58	100	+	14.7	4078	2269.44	59	+	1	2320	1253.44	80	+	602	7096	5492.00		+
CHLORIDE	13150	100342	37944.26	300	-	9718	103974	41109.36	100	-	4800	69525	29949.71	59	-	35301	98362	54898.29	80	-	1155	2100	2474.00		-
AMMONIA	0	61.81	25.70	300	-	9.1	66	26.88	100	-	0.01	50.5	18.99	59	-	11.18	51	31.87	80	-	<0.5	67.3	21.53		+
BORON	0.002	0.14	0.03	232	0	0.27	0.27	0.27	1	0	0.02	0.16	0.07	3	-	0.45	0.45	0.45	1	0	0.2	8.6	6.07		+
MANGANESE	4.5	4.5	4.50	1	0	-	-	-	0	0	-	-	-	0	0	-	-	-	0	0	1	66	52.40		+
IRON	0.01	50.8	2.71	299	-	0.02	33.8	4.65	100	-	0.07	128	8.51	59	0	0.29	342	22.59	80	0	4.1	2050	1550.00		+
STRONTIUM	66.8	1244	310.90	232	-					0	95.4	606	292.33	3	-	2080	2080	2080.00	1	0	1	-			+
CONDUCTIVIT	34900	200000	117518	300	-	105	178300	88869	100	-	17000	158300	93160	59	-	156	174500	134558	80	-	9100	48400	15992		+
PH	4.7	8	7.27	299	+	5.4	8.3	7.17	100	+	5.6	8.1	7.00	59	+	4.3	7.1	6.22	80	.0	3.9	7.2	4.60		-
FLOW RATE	0	265	101.40	300	+	55	580	331.81	69	+	1	570	236.24	51	+	na	na	na	na	0	-	-	1500.00	-	

Table 4.2. (Con't.). Statistical Summary of Lingan and Phalen Mine Water Chemistry

Location	Lingan "A" (5/10/88 - 11/30/93)					Lingan 2E Top (11/2/92 - 12/22/92)					Lingan 2E Bottom (11/10/92 - 6/10/94)					Lingan 3E Bottom (12/16/92 - 2/10/94)					Phalen 1E (11/16/88 - 12/4/94)				
Parameter	MIN	MAX	MEAN	N	Trend	MIN	MAX	MEAN	N	Trend	MIN	MAX	MEAN	N	Trend	MIN	MAX	MEAN	N	Trend	MIN	MAX	AVG	N	Trend
SODIUM	4100	10600	8067	130	+	4100	9300	5665.00	27	0	2670	11500	5862.00	100	-	3400	19000	5672.00	71	-	10600	17200	12636.00	66	-
CALCIUM	331	2000	1138	130	0	400	1200	824.00		0	553	2000	919.00		-	607	5000	955.30		0	1226	5870	2936.00		-
MAGNESIUM	138	1400	953	130	0	500	1400	747.00		-	406	1700	799.00		-	517	1860	784.00		-	882	2560	1248.00		-
ALKALINITY	<1	124	4804	130	-	0.4	177	102.50		+	11	243	146.00		0	14	223.5	136.60		+	26.2	110	75.00		+
SULFATE	970	2752	1823	130	+	1435	8947	6826.00		+	3805	7958	5646.00		-	1939	7554	5966.60		-	285	1480	1065.00		+
CHLORIDE	8100	18067	15719	130	0	5561	11899	8414.00		-	4026	16625	9863.00		-	6188	42667	10024.00		-	21800	43700	27635.00		-
AMMONIA	0	9	6	130	-	2.54	41.7	19.60		-	4	50	16.00		-	0	62.5	20.11		-	15	27	19.00		-
BORON	<0.1	1.65	0.69		+	0.08	7.58	5.21		+	0	6	3.00		-	0.94	7.84	3.02		-	<0.1	2	0.11		+
MANGANESE	3.7	27	1.09	119	0	24.8	50.5	2.11		-	4.4	58	35.70		-	-	-	21.30	1	0	1.1	5.9	3.37		+
IRON	<0.1	755	16.30	130	0	200	2000	1314.50		+	226	1600	942.00		-	460	2250	1120.10		-	<0.5	3.1	<0.5		0
STRONTIUM	<0.5	282	62	100	-	5	50.8	31.20		-	7.8	65	35.50		-	20	120	33.20		-	0.15	650	235.20		-
CONDUCTIVIT	28770	67500	57739	130	0	32800	43800	38185		-	17860	50500	37019		-	25600	91900	37303		-	79500	150000	97832		-
PH	2.6	8.3	6.90	130	-	5.5	6.3	6.02		+	5.4	6.3	5.92		+	4.5	6.4	5.88		+	6.9	8.5	8.00		-
FLOW RATE	-	-	200.00	-		-	-	-	-		-	-	-	-		-	-	-	-		10	600	10.00		-

Location	Lingan Outfall (8/23/89 - 12/10/92)					Phalen OutFall (08/22/89-08/20/96)					No. 4 Mine Outfall (8/21/86)					Gardiner Mine Outfall (05/28/92 - 09/09/96)					Ocean Water				
Parameter	MIN	MAX	MEAN	N	Trend	MIN	MAX	MEAN	N	Trend	MIN	MAX	MEAN	N	Trend	MIN	MAX	MEAN	N	Trend	MIN	MAX	AVG	N	Trend
SODIUM	5450	9700	7344.4	28	-	2050	20700	9386.0	61	-	-	-	263.0	1		9.4	9.75	9.55	2	-	7500	9300	8669.0	7	-
CALCIUM	752	1660	1089.0	29	+	479	5158	2306.0	61	-	-	-	345.0	1		10.6	21	15.80	2	-	230	451	353.0	7	-
MAGNESIUM	185	1070	690.3	29	-	146	2160	702.0	61	-	-	-	74.0	1		3.8	7.4	5.60	2	-	757	1224	928.0	7	-
ALKALINITY	<0.4	99	28.5	83	-	28.9	163.8	91.6	61	+	-	-	75.8	1		12.9	4.4	8.60	2	-	62	120	86.0	7	-
SULFATE	535	5006	1349.0	30	-	43.7	2503	1036.0	61	+	-	-	928.0	1		22.7	44.6	33.60	2	-	975	2440	2012.0	7	-
CHLORIDE	9750	19547	13972.0	29	+	3970	41273	19390.0	61	-	-	-	341.0	1		10.7	11.6	11.20	2	-	13000	17000	15198.0	7	-
AMMONIA	-	-	6.1	1	0	3.4	28.5	17.4	28	+	-	-	-	0		-	-	<0.01	1	-	-	-	<0.5	1	-
BORON	0.21	4.28	2.2	2	0	0.02	0.33	0.1	26	+	-	-	-	0		0.03	0.05	0.04	2	-	1.74	3.7	2.98	6	-
MANGANESE	1.69	43.4	7.2	30	+	0.76	16.1	6.6	60	+	-	-	65.6	1		0.6	1.15	0.87	2	-	0.01	0.11	0.04	5	-
IRON	0.18	884	95.3	30	+	0.02	20	4.0	61	+	-	-	99.0	1		0.72	20.8	10.76	2	-	0.03	0.52	0.11	6	-
STRONTIUM	-	-	-	0	0	33.7	237	99.5	8	-	-	-	-	0		-	-	0.37	1	-	5	7.3	6.15	2	-
CONDUCTIVIT	37200	60000	48974.0	31	+	4020	505000	64000.0	65	-	-	-	2808	1		129	247	188	2	-	34700	65300	49230	7	-
PH	4.7	8	6.4	31	-	5.9	8.1	7.0	66	-	-	-	6.39	1		6.7	7.4	7.06	2	-	7.8	8	7.90	7	-
FLOW RATE	-	-	-	-	-		1200			+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 4.2 Statistical Summary of Lingan and Phalen Mine Water Chemistry strata waters from Point Aconi tunnel and Donkin mine tunnel, outfall chemistry from Phalen, Lingan, No. 4 and Prince mines, and sea water.

Figure 4.1 is a Durov mixing plot of major ion chemistry for various mine waters. This figure clearly shows a chemical difference between the deep mine waters in Lingan and Phalen mines, and shallow mine waters indicative of No. 4, Gardiner, 1B and 1A. The very low TDS at 1A is consistent with a shallow sample bailed from the top of the water column. The No. 4 and Gardiner outfall chemistry is representative of groundwater flow through mines above sea level.

A possible mixing curve between the shallow landward mines and deep strata waters in the Phalen mine is apparent. Water quality appears to evolve from a moderately dilute $CaHCO_3$ type at No. 1A, No. 4 and Gardiner outfalls, becoming progressively more saline through 1B to a water chemistry slightly less saline than sea water at Lingan 2E, Lingan 3E, Donkin Tunnel and Prince Outfall, to sea water, to water more saline than sea water at Phalen panels 1E through 7E. While pH generally increases along the same mixing trend, the distribution of pH is likely controlled by the degree of pyrite oxidation within individual mines. This chemistry shift is consistent with the conceptual groundwater flow pathways discussed by ADI (1993), and suggests that the shallower portions of the Harbour Seam and near shore Phalen mine are mixtures of meteoric-origin groundwater and sea water, and that the deep portions of Phalen are controlled by membrane filtration and possibly up-welling deep saline formation waters. A similar chemistry distribution was reported in the coal fields of Great Britain (Singh, 1989).

4.3 Variations in Mine Water Within Phalen Panels

Figure 4.2 presents the distribution of major ion chemistry as a series of bar charts. The left side of each pair of charts includes cations (Na, K, Ca and Mg) and the right side includes anions (Bicarbonate, sulfate and chloride). It is possible to see differences in major ion chemistry in the mine panels in Figure 4.2.

An evaluation of chemical trends was performed for each set of monitoring data for the Phalen panels. In general, all panels except panel 5E exhibited a general decline in sodium, chloride, calcium, magnesium, ammonia, conductance and TDS, and a general increase in alkalinity, iron and pH over periods of 2 to 4 years of monitoring. It is also noted that a shift in overall chemistry usually occurred after about one year of mining in each panel. Figures 4.3 through 4.9 illustrate temporal concentrations of chloride-conductance and sulfate-alkalinity for gob waters (total of all inflows from strata drips, wall seepage and floor discharge) for Phalen panels 1E, 4E, 5E, 6E and 7E respectively.

It is apparent that the Phalen 4E and 5E mine waters differ chemically from the Phalen 6E and 7E strata and gob waters. This may be a function of panel discharge rates which control the rate of displacement of saline formation waters by recharging groundwater. The 4E and 5E flows were much lower (about 30 usgpm) than the 6E and 7E panels (150 to 550 usgpm). In comparison to the other mine waters, the 6E and 7E strata and gob waters most closely resemble Lingan A and Lingan outfall waters. The Phalen 4E and 5E resemble saline formation waters at the end of the monitoring periods January, 1996, and May, 1995, respectively. The Phalen 1E and outfall chemistry resembles a mixture of Phalen strata and Lingan or Harbour Seam water by October, 1990.

Comments on water chemistry at each panel are presented below:

Phalen 1E

Mine water chemistry was monitored at 1E panel between November, 1988, and November 30, 1990. After the initial 600 usgpm in-rush in November, 1988, flows from Phalen 1E declined rapidly to about 10 usgpm after a few weeks. Major ion concentrations dropped from a chemistry consistent with highly saline formation brine with about five times more TDS than sea water, to a chemistry only slightly above that of sea water. Figure 4.3 illustrates the distribution of chloride, conductance, sulfate and alkalinity in Panel 1E. A detailed assessment of 1E panel, including isotope analysis was conducted by JWEL (1988 to 1990).

Phalen 4E

Mine water chemistry was monitored at panel 4E between November, 1992, and January, 1996. This panel was reported to have experienced low inflow rates. Major ion concentrations declined consistently from a chemistry consistent with highly saline formation brine, to a chemistry about twice the salinity of sea water (Figure 4.4). Water quality at 4E panel has not evolved to the low TDS seen at 1E panel, possibly a consequence of lower overall flow rates , and less hydraulic connection with the Lower Sandstone Aquifer. Sulfate concentration remained low (900 mg/L) and began to increase after January, 1995 (Figure 4.4b). The fluctuating alkalinity and distribution of sulfate and iron concentrations implies low flow rates, and limited acidic drainage within this panel.

Phalen 5E

With the exception of a 250 usgpm in-rush in October, 1992, flow rates in Panel 5E were relatively low (10 to 30 usgpm) (Figure 2.5). Chemistry monitoring was performed between May, 1992, and January, 1995. During this period, major cations, alkalinity and chloride increased gradually, and sulfate decreased, opposite to other panels (Figure 4.5). A sudden reversal in this trend occurred on or about April 24, 1994, resulting in a significant decrease in chloride (65,000 to 40,000 mg/L), and an increase in alkalinity (600 to 2,700 mg/L) and sulfate (900 to 1,900 mg/L). No changes in panel inflow rate were noted at this time (Figure 2.5), however, a major strata break between No. 26 and Lingan had occurred on February 17, 1994.

This suggests a two-month transit time between Harbour Seam and Phalen, if Harbour Seam is the source of the water entering Phalen 5E.

Phalen 6E

Water chemistry from the Phalen 6E panel was monitored from April, 1994, through February, 1996. Chemistry generally declined in major ions, TDS and conductance from saline formation waters to chemistry about twice the salinity of sea water (Figure 4.6a, Table 4.2). Sulfate concentration increased throughout the period of monitoring. Both iron and alkalinity exhibited a rapid increase (250 to 1,750 mg/L and 1.7 to 7.0 mg/L respectively) after mid-September, 1994, to January 1995, then levelled off. These changes in chemistry trend correlate with the cessation of water level decline in 1B as a consequence of the February 1994, 6E panel break.

Water level monitoring at this panel exhibited several weightings with associated in-rushes of 175 to 260 gpm between February and September, 1994 (Figure 2.6). Flow rates in this panel increased steadily from 10 to 190 usgpm.

The 6E panel strata waters showed similar responses as the gob waters (Figure 4.7a and b), with a reduction in the rate of TDS decline after about November, 1994. Concentrations declined more rapidly than the gob water, and chloride in the strata approached 12,000 mg/L compared to 30,000 mg/L in the gob, suggesting that saline strata water is being replaced by less saline mine waters, possibly from the Harbour (No. 26 or Lingan) or the adjacent flooded Phalen Seam (No. 1B).

More detailed assessments of mine water chemistry at 6E panel was done by ADI (1993).

Phalen 7E

Phalen 7E panel was monitored between March, 1995 and February, 1996. The Phalen 7E panel exhibits the same chemical trends as the previous panels. During the period of monitoring, chloride concentrations from the strata declined from about 100,000 mg/L to 12,000 mg/L, and chloride concentrations from the gob outflows declined from 50,000 mg/L to 20,000 mg/L (Figure 4.8). Major cations exhibited decreasing concentrations with time, and alkalinity and sulfate both increased as in previous panels (Table 4.2). Total flow rates from this panel began to increase after June, 1995, and rose to over 550 usgpm (Figure 2.7), and correlates with a drop in water levels in 1B system. Numerous weightings and water inflows were reported while mining this panel.

A significant change in strata water chemistry occurred after November, 1995 (Figure 4.9). This is a point when water levels stopped dropping in the 1B system, and began to rise (Figure 3.1). The change in strata quality also correlates with an increase in gob flow from 100 to over 550 usgpm.

4.4 Phalen Discharge Water Quality

Water discharging from the Phalen colliery is a composite of all of the groundwater entering the Phalen mine since 1989 (Table 4.2). This water is characterized by high TDS (likely from the highly saline strata waters). Due to the absence of sulfate in the strata water, the rising levels of sulfate and alkalinity in effluent is attributed to increasing components of Harbour Seam water (e.g. No. 1B) in the effluent, and/or natural buffering of acidic drainage within the mine complex.

The pH is generally declining from a high of 8.0 to 6.2-6.5 by late 1996. Sulfate and alkalinity initially declined (100 to 50 mg/L alkalinity, and 1,000 to 500 mg/L sulfate), remained stable from January 1993, through June 1994, and then rose (50 to 165 mg/L alkalinity and 500 to 2,500 mg/L sulfate). A decline in both parameters was observed after July 1996. Sodium, chloride, calcium and magnesium exhibit similar responses. Concentrations were constant from 1989 to early 1991, rose similar to the alkalinity and sulfate to about June, 1995, and have been declining since.

Phalen effluent flow rates rose from about 200 usgpm in 1993, to 1,200 usgpm in 1996. A sudden increase in flow rate (300 usgpm to 600 usgpm) occurred after July, 1994, due to in-rushes with similar water chemistry trends at Phalen 6E panel, and correlates with a shift in outfall chemistry towards the 1B water type.

The calcium/magnesium ratio is approximately 3.5. This ratio declines to 3.0 after June, 1995, indicating a greater proportion of magnesium over calcium. Elevated magnesium is typical of sea water and the Harbour Seam which is believed to be recharged by seawater and suggests a connection with the No. 1B water.

4.5 Lingan Discharge Water Quality

Table 4.2, contains a summary of the range and mean of water chemistry for the Lingan effluent (average of LM-2 and LM-3 which cover the largest period of record). In comparison to the Phalen waters, the Lingan effluents are generally lower in TDS, ammonia, alkalinity, pH and major cations than the Phalen, and higher in sulfate, boron, iron and manganese.

The hydrochemical trend at Lingan is opposite to that observed at Phalen. Prior to the inflows of November, 1992 and February 10, 1994, Lingan waters were evolving towards a mixture of sea water and mine water. Since the inflow, this mine water has evolved towards chemistry consistent with 1B shaft water. These trends were supported by isotope analysis. Figures 4.1 and 4.2 suggest that the Lingan 2E and 3E panel waters are a mixture of Lingan strata water and Harbour Seam waters typical of the 1B shaft.

4.6 No. 1B System Water Chemistry

Water chemistry for the 1B system is derived from the 1992 discharge testing, and several bailed samples collected between 1985 and present. After one day of pumping, the 1B shaft chemistry was relatively consistent. This water is described as a moderately brackish, sodium chloride water type with a TDS at approximately 50 % that of sea water (Table 4.2, Figure 4.2). After 14 days of pumping, the water exhibited an average pH of 4.2, and elevated concentrations of iron (2050 mg/L), ammonia (67.3 mg/L) and sulfate (7,100 mg/L). Low chloride concentrations (1,155 to 2,100 mg/L) suggested a high proportion of shallow groundwater in the shaft. The pumping was terminated due to excessive turbidity and iron precipitate from the outfall.

In comparison to the pumped waters, two samples bailed in October 16, 1996, from depths of -650 and -725 ft, indicate a moderate TDS (7,100 to 8,100 mg/L), acidic (acidity 95 to 2,200 mg/L), mixture of meteoric water and mine water with elevated iron (21 to 35 mg/L), sulfate (1,409 to 3,040 mg/L and higher pH (5.7 to 6.5). Chemical stratification is present in the well bore, with pH and alkalinity increasing with depth from 5.7 to 6.5 and 10.7 to 124 mg/L respectively. It is apparent that recharge from shallow mine sources and precipitation dominates the shallow mine water quality in the 1B system.

5.0 MINE WATER SOURCES

5.1 Hydrogeological Considerations

In general, mine water discharging from an abandoned or operational panel is derived from several sources, and is essentially a mixture of these sources, each with its own distinct chemistry:

1. Fossil groundwater (strata water)
2. Up welling deep groundwater from underlying Windsor Evaporites
3. Flooded workings both above worked seam or adjacent on the same seam
4. Mine waters chemically altered by acidic drainage and buffering
5. Sea water recharged to workings underlying near shore zones of the Harbour Seam
6. Groundwater from up-dip outcrop areas

In a preliminary literature search, a few references on sub-sea mine hydrogeology were identified for sub-sea collieries in the South Durham area of northeastern England. Because of the similarity in water quality, the sources of mine waters within the Sydney coal basin are expected to parallel the United Kingdom cases. These mines produce similar volumes of water at the work face (in the order of 100 to 150 gpm, peak 700 usgpm) to the Sydney Coal Basin mines, largely due to the presence of a permeable, extensively faulted, Permian-aged limestone and anhydrite aquifer overlying the carboniferous-aged coal measures which are very similar to the Sydney units. Studies of mine water flows within sub-sea workings in the United Kingdom have demonstrated the importance of mine chemistry monitoring in identifying sources of mine water. These investigations also identified some physical conditions affecting degree of mine water inflow to longwall workings (Singh, 1989).

Increasing TDS of strata water quality with depth in UK mines is associated with movement along bedding planes, and vertical movement across beds due to artesian pressure and membrane (hyper filtration) effects. Sulfate was found to decrease with depth; bicarbonate initially increases with depth, then decreases; and major ions such as sodium, chloride, ammonia, strontium, manganese and barium generally increase with depth. The chemistry of flooded workings is characterized by a combination of recharge from surrounding aquifers, and pyrite oxidation products (e.g. sulfate, iron), moderate pH in the range of 5.3 to 6.8, and low redox (e.g. dissolved oxygen) potential.

These observations resemble trends at the Sydney coal field, where TDS of strata waters generally increases with depth in the coal mine complex, ranging from <1,000 mg/L in shallow landward mines in the Harbour and Gardiner Seams, to greater than 100,000 mg/L in the most recent Phalen panels. Sulfate concentration is negligible in freshly encountered strata waters in the Phalen. Both sulfate and alkalinity are initially low in the Phalen strata, and then increase with time as mining progresses. The combination of increasing sulfate and alkalinity, and decreasing TDS in Phalen strata immediately adjacent to the mines is attributed to recharge from adjacent flooded mine workings. Increasing sulfate in the gob is a combination of this effect, and in-mine acidic drainage buffering.

5.2 Mine Water Recharge Pathways

The United Kingdom investigations (Singh, 1989) also showed parallels to the Sydney situation with respect to mine water flows. Frequent sudden in-rushes occurred, followed by exponential declines in flow rate. The intensity of a water inflow was found to be associated with attitude of strata, method and sequence of workings, presence of faults, strain on the base of overlying beds due to subsidence, accumulation of water in old workings, and thickness of barrier pillars between workings on the same seam. No historical records of direct sea water inflow have been documented, and most of the inflow waters were derived from the host aquifers, or abandoned flooded workings.

The direction of advance, and width of longwall extraction panels was also found to affect the degree of weighting and water inflows. For example, panels progressing perpendicular to a major source of water (fault, or in the case of Phalen, overlying pillars or adjacent pillars) were found to produce twice the tensile stress on overlying beds than the same extraction progressing parallel to these features (Singh, 1989). Also, for the same seam extraction height and depth, a narrower longwall face resulted in less overburden strain, and less water inflow. One example cited indicated a 610 to 320 usgpm reduction in inflow when face width was reduced to 78 m from 135 m. Face widths at the Phalen mine exceed 200 metres.

5.2.1 On-Land Mine Workings

Unconfined, landward mines and landward portions of sub-sea mines are recharged by infiltrating rainwater (about 15 to 20 percent of annual precipitation) and through direct surface water recharge through bootleg workings, unsealed shafts, and subsidence-induced sinkholes. This water is characterized as a mixture of low TDS (<2,000 mg/L) meteoric waters and pyrite oxidation products with pH in the order of 6.4 to 7.4. Examples included the Gardiner and No. 4 mine outfalls (Table 4.2).

The Harbour Seam mines, including Lingan A, Lingan, and others, are recharged from up-dip groundwater moving along bedding planes, and infiltrating seawater, particularly in areas near shore where minimal insulation by marine sediments are present (Figure 2.3). These water chemistries are characterized by moderate TDS (20,000 to 30,000 mg/L), sodium-chloride waters resembling a mixture of sea water and pyrite oxidation products (elevated of iron, sulfate), and pH averaging 6.9 (Table 4.2).

5.2.2 Interconnection System 1B

Investigations to date suggest that the 1B mine complex is recharged by a combination of, in order of the relative proportion, meteoric, groundwater, seawater, and mine water from older flooded workings. Surface water and groundwater enter older, on-land flooded and un-flooded workings through bootleg workings, unsealed adits and shafts, and subsidence-induced sinkholes, thence flowing seaward and down-dip along bedding planes (groundwater) and mine workings (meteoric water). This water chemistry is modified by acid drainage processes and pyrite oxidation products within the mine workings. Hydraulic interconnections are known to occur between numerous mine workings on the Harbour and Phalen Seams, and drainage between abandoned workings affects water level in the 1B system. The effects of precipitation events on water levels are readily apparent (e.g. water level rise due to Hurricane Hortense on September 14, 1996).

Water chemistry exhibits a chemical stratification within the 1B shaft. Samples bailed from the top of the 1B shaft or 1A mine, typically exhibit low TDS typical of shallow mine waters. Samples collected from increasing depth increase in TDS, alkalinity, iron, and metals.

5.2.3 Lingan Mine

Prior to the break between No. 26 and Lingan mine into the 2E panel at or near the -1,100 elevation, the Lingan A mine was recharging at a rate of about 200 usgpm. Chemistry indicated a mixture of sea water and meteoric groundwater. After the 1992 strata break, Lingan recharged at a rapid rate, and is currently rising at a rate of about 50 usgpm. Evaluation of water levels confirms that the majority of the mine recharge was from flooded workings in No. 26 colliery on the Harbour Seam.

5.2.4 Phalen Mine

It has been assumed that the Phalen mine is hydraulically isolated from the flooded abandoned mine workings. Information to date suggests that the Phalen panels are being recharged by a combination of highly saline strata waters and water from flooded workings, as discussed below.

5.2.4.1 Fossil Groundwater Drainage

Assuming that groundwater flow is upward from depth to the sea, it is possible that the observed declines in TDS in strata water may reflect saline basin brines from the underlying Windsor Group evaporite deposits, or drainage of water stored on the saline side of a geomembrane, with subsequent drainage of less saline waters on the opposite sandstone side of the filter. In the case of the Phalen mine, the saline side would be the coal seam and associated mudstone and shale, and the aquifer side would be the Lower Sandstone. The sandstone aquifer generally contains minimal concentrations of alkalinity, and sulfate, and lower concentrations of major ions, TDS and conductivity than the aquitards.

Deep mine workings on the Phalen Seam are typically "dry' until subsidence-induced fractures intersect a saturated sandstone aquifer or bedding plane partings. At this point, there is a sudden in-rush of highly saline strata water (up to 600 usgpm reported), followed by an exponential decline in flow rates. Strata waters adjacent to deep mines typically exhibit very high TDS (>100,000 mg/L), increasing with depth of panel, with high concentrations of cations, negligible or low concentrations of alkalinity and sulfate, and high pH in the order of 8.0 or higher (Table 4.2). Iron and manganese concentrations are generally low, in the order of 1 to 5 mg/L and 5 to 10 mg/L respectively; iron tends to reflect flow rate and turbidity. After the initial in-rush, strata water chemistry slowly evolves towards one consistent with lower TDS waters. The lower TDS waters are either stored water in the overlying aquifer, mine water from adjacent workings, or a combination of both.

5.2.4.2 Harbour Seam (Lingan and No. 26 colliery)

Investigations in 1993 using isotopes suggested a link between the Harbour Seam and waters flowing into Phalen panels 5E and 6E. It is noted from the current database that the water chemistry at that time (September, 1993) had not evolved to the point where a significant decline in TDS occurred (e.g. after 1995). Isotope determinations concluded that the Phalen waters in September, 1993, were a mixture of 40 percent Harbour Seam water and 60 percent Phalen strata waters (B. Drimmie, in ADI, 1993).

Based on geology, direct migration of mine waters between the overlying Harbour Seam and Phalen Seam seems unlikely. Over 137 m of strata are present between seams, and several layers of plastic coal-shale (Bouthillier and Backpit seams) are present, which should act as effective aquitards. It is noted that subsidence in the Phalen seam is affecting strata in the Harbour seam, and causing breaks between workings on that seam. For water from the Lingan or No. 26 colliery to reach Phalen mine, considerable fracturing would need to occur to provide continuity between the various sandstones and strata between the seams to permit slow percolation of mine waters between the Phalen and Harbour Seams.

However, as the area of the Phalen workings increases with time, the potential for interaction between the Harbour and Phalen seams increases. The expected pathway would be an indirect one, created by interconnection of previously unconnected fracture sets, permeable aquifers, and subsidence fracturing. The main mechanism limiting flow between the two coal seams are the Bouthillier and Backpit aquitards, as well as other plastic beds which would tend to seal off vertical pathways between strata.

5.2.4.3 Phalen Seam (No. 1B Workings)

A third potential source of mine water in the Phalen mine has not been addressed to date. Based on geology and the mode of mining (longwall), it is possible for waters stored in the flooded 1B workings east of the Phalen mine to cross the coal barrier via the Lower Sandstone Unit. This sandstone aquifer contacts the longwall workings in the 1B mine and the longwall workings in the Phalen panels on the west side of the barrier pillar. This pathway appears to be a potential source of mine waters in Phalen panels 5E to 7E, and explains the variations in water flow rates and chemical evolution history of inflow waters in these panels. Based on the database, the following points are relevant:

<u>Chemistry</u>

- Isotope chemistry in 1993 exhibited some detectable tritium in Phalen 1E, and later Panel 5E, but none in Phalen 6E strata water prior to the shift in chemistry. Tritium is an indicator of significant meteoric water content and a direct link to 1B shaft water (tritium = 8.8 T.U.).

- The chemistry of Phalen 6E and 7E panel water which underlie the Lower Sandstone aquifer, have decreased significantly in concentration and increased in sulfate and alkalinity concentration towards a water quality similar to 1B water chemistry. Chloride concentrations as low as 10,000 mg/L at Phalen 6E and 7E panels are closer to 1B water quality than Lingan water prior to the strata breaks (16,000 mg/L).

- By September 9, 1993, the Phalen 6E panel inflow water had evolved to a 40/60 percent mixture of Harbour Seam/strata water. Since this evolution has continued over the intervening three years, the mix ratio is likely a majority of Harbour Seam water from Lingan, No. 26 or 1B.

- The chemistry in the 1B deeps is expected to resemble the No. 26 waters currently recharging the Lingan mine. Therefore, the 1993 isotope data could also refer to a 1B source on the Phalen Seam, which is in direct hydraulic connection with No. 26 colliery.

Geology

- The 1B workings on the Phalen Seam are separated from the east side Phalen mine workings (Panels 1E through 9E), by a 76 to 99 m wide coal barrier.

- The Lower Sandstone aquifer shown on Figure 15 of the CBDC, 1994, report, is in direct hydraulic connection with flooded workings in the 1B mine, and extends over the barrier pillar east of Phalen 5E, 6E, 7E and 8E panels.

- A portion of the sandstone aquifer which varies from 0 to 3 m above the top of the Phalen coal seam, trends northwest and north through the Phalen mine, and is closest to the mine roof (<1.5 m) over portions of panels 6E, 7E and 8E, and to a lesser extent in 5E (see Figure 15, CBDC, 1994).

- The greatest inflow rates (250 to 550 usgpm), most unstable roof, and highest degree of chemistry evolution towards 1B mine water quality, occurs along this trend (e.g. at panels 6E and 7E). Panels 1E through 4E were located outside of the channel and exhibited slow inflow rates, and very slow evolution in mine water quality, although a trend towards flooded mine waters is apparent in all cases.

- Baseline flow rates at Panel 6E increased from 10 to 190 usgpm after the February, 1994, strata break between Lingan and No. 26 colliery. An undetected break between 1B and Phalen may have occurred at the same time as the Harbour Seam break.

- Baseline flow rates began to increase significantly in Phalen 7E panel after June 15, 1995, which correlated with a 8 to 10 ft drop in water levels in the 1B system (Figure 3.1), and TDS decreased in gob and strata waters in panels 6E and 7E about November, 1995, when the water levels at 1B began to recover. These observations suggest a possible strata break between 1B and Phalen during the summer of 1995. The lag in water quality response at panels 6E and 7E may reflect delayed drainage through the Lower Sandstone Unit (about 5 months).

Water Levels

- The 1B water level hydrograph and assessment of 1B recharge history (Section 3.2), suggests that there may have been some hydraulic interaction between 1B shaft during the Phalen 1E in-rush in November, 1988, and more recently in June, 1995 and July, 1996. It is not certain whether these interactions are directly from 1B, or via Lingan and No. 26 collieries.

The above comments suggest that the Lower Sandstone Unit is acting as a hydraulic pathway or channel between the flooded 1B workings on the Phalen Seam west of the active Phalen mine and the current Phalen mine workings. This results in increasing roof and wall flows in areas intersecting the sandstone channel, and evolution of water chemistry from a highly saline strata water towards less saline mine water, with increasing concentrations of sulfate, alkalinity and iron. Panel inflow rate correlates with proximity to the channel.

Fractures caused by mine subsidence in both the 1B and Phalen longwall panels likely provide hydraulic interconnections with bedding plane partings and the porous sandstone units (porosity estimated to be 6 to 20 percent). This would depressurize the sandstone immediately above the Phalen workings (resulting in the in-rushes of highly saline strata waters). Water in the flooded 1B workings would then migrate up into the depressurized lower sandstone and then move laterally through additional subsidence-induced fracturing towards Phalen.

Assuming a sandstone K in the order of $<10^{-12}$ to 1.3×10^{-4} cm/s (mean 1×10^{-7} cm/s), a sandstone width of about 600 metres at the barrier pillar which contacts the coal seam, having an average thickness of 20 metres, and a hydraulic gradient of 180 % across the 472 m barrier between the mines at Panel 5E, flow rates in the order of 1.9 m^3/day (<0.5 igpm) would be expected. With fracturing, the channel K could increase orders of magnitude, resulting in the inflow rates observed at panels 5E, through 7E. It is apparent that the undisturbed sandstone would not pose a significant pathway to the mine. Therefore flows are expected to be controlled by subsidence-induced fracturing.

6.0 MINE WATER RECHARGE RATES

6.1 Procedure

Work involved review of the Lingan, 1B System, and Phalen mine mapping, and recalculation of rates of water level rise based on the more recent monitoring data. The detailed mine water monitoring records were combined with the revised void volumes, where applicable, and used to generate a series of graphs showing the rate of mine water rise for Lingan and 1B systems.

For the 1B system which exhibited a total recovery of 267 ft since July, 1986, a recharge rate per 10 ft section was estimated. Total mine volumes (Nos. 26, 20, 9 on the Harbour Seam, and Nos. 1A, 1B, 2, and 5 on the Phalen Seam), were estimated on a 100 ft interval. Because using a 100 ft interval to calculate recharge rates would provide only a few data points, each 100 ft interval was divided into 10 equal volumes, and the date of water level passing each 10 ft interval was determined. Average mine water recharge rate was then calculated by dividing the incremental volume by the number of days between increments and a plot of time verses water level rise was then constructed. The volume of Lingan mine openings was added to the 1B system after the November, 1992, strata break. For the Lingan mine, which recovered a total of 1,270 feet since November, 1994, the same procedure was applied.

Estimates of mine volume used in this assessment are taken from Table 1 of CBDC, 1994 report, and are represented on Tables 6.1 and 6.2. These volumes included the 1993 volumes calculated by JWEL, and the revised volume calculations for the Harbour Seam mines done by CBDC for the 1994 risk assessment.

6.2 No. 1B Hydraulic Interconnection System

Figure 6.1 illustrates the rate of water level rise in 1B system in the usgpm between July, 1986, and present. The 1B mine water levels in feet below sea level are superimposed for comparison. This figure indicates a highly variable recharge rate over ten years. The following observations are derived from Table 6.1 and Figure 6.1.

1. A series of "breaks" with apparent reduced or negative recharge occur after periods of increasing recharge rate when 1B water levels reach an outfall point to adjacent interconnected mines (specifically No. 2 and No. 26 collieries).

2. The effects of the two strata breaks into Lingan from No. 26 colliery in November, 1992, and February, 1994, are clearly shown.

3. Negative recharge after June 15, 1995, and July 10, 1996, are attributed to outflow from 1B to Lingan or Phalen which exceeds inflow from recharge during the dry summer months.

4. A period of very rapid recharge (mean 3,150 usgpm) occurred after No. 26 reached equilibrium with No. 1B, and continued until the first strata break between No. 26 and Lingan in November, 1992.

5. Peak inflows in spring and fall average 2,400 usgpm, and can range as high as 7,300 usgpm.

Table 6.1. Mine Water Recharge Rate Calculations - 1B Hydraulic System

Mine Increment		Harbour Seam Volumes				Phalen Seam Volumes			Volume Factor	Increment Volume	Water Level (ft)	Date	Days to Flood 10 ft	Recharge Rate (usgpm)	Comments
From (ft)	To (ft)	Lingan (ft3)	No. 26 (ft3)	No. 9 (ft3)	No. 20 (ft3)	1A+1B (ft3)	No. 2 (ft3)	No. 5 (ft3)		(ft3)					
	-610	656217	1561588	533297	3268859	4570834	7517012	0	1.0	17451590	-610	17-Nov-86			
-610	-600	656217	1561588	533297	3268859	4570834	7517012	0	1.0	17451590	-600	19-Dec-86	32	2832.9	losing water to No. 2 mine
-600	-590	571027	1305279	2061635	2518613	8372881	2256928	0	1.0	16515336	-590	06-Mar-87	77	1114.1	
-590	-580	571027	1305279	2061635	2518613	8372881	2256928	0	1.0	16515336	-580	20-Apr-87	45	1906.4	
-580	-570	571027	1305279	2061635	2518613	8372881	2256928	0	1.0	16515336	-570	05-Oct-88	534	160.7	Losing water to No. 2 and 20 mine @ -580 ft air shaft
-570	-560	571027	1305279	2061635	2518613	8372881	2256928	0	1.0	16515336	-560	26-Oct-88	21	4085.1	
-560	-550	571027	1305279	2061635	2518613	8372881	2256928	0	1.0	16515336	-550	20-Apr-91	906	94.7	x-measure, and No. 9 @ehole -540 ft), No. 5, 1A
-550	-540	571027	1305279	2061635	2518613	8372881	2256928	392849	1.0	16908185	-540	18-May-91	28	3136.7	
-540	-530	571027	1305279	2061635	2518613	8372881	2256928	392849	1.0	16908185	-530	25-Jun-91	38	2311.3	
-530	-520	571027	1305279	2061635	2518613	8372881	2256928	392849	1.0	16908185	-520	26-Aug-91	62	1416.6	
-520	-510	571027	1305279	2061635	2518613	8372881	2256928	392849	1.0	16908185	-510	17-Oct-91	52	1689.0	
-510	-500	571027	1305279	2061635	2518613	8372881	2256928	392849	1.0	16908185	-500	20-Nov-91	34	2583.2	
-500	-490	621659	1599432	3128701	1879413	9132392	0	1155891	1.0	16895829	-490	07-Dec-91	17	5162.6	
-490	-480	621659	1599432	3128701	1879413	9132392	0	1155891	1.0	16895829	-480	01-Jan-92	25	3510.6	
-480	-470	621659	1599432	3128701	1879413	9132392	0	1155891	1.0	16895829	-470	20-Jan-92	19	4619.2	
-470	-460	621659	1599432	3128701	1879413	9132392	0	1155891	1.0	16895829	-460	14-Feb-92	25	3510.6	
-460	-450	621659	1599432	3128701	1879413	9132392	0	1155891	1.0	16895829	-450	20-Mar-92	35	2507.6	
-450	-440	621659	1599432	3128701	1879413	9132392	0	1155891	1.0	16895829	-440	01-Apr-92	12	7313.7	
-440	-430	621659	1599432	3128701	1879413	9132392	0	1155891	1.0	16895829	-430	16-Apr-92	15	5851.0	
-430	-420	621659	1599432	3128701	1879413	9132392	0	1155891	1.0	16895829	-420	29-Apr-92	13	6751.1	No. 2 system is full.
-420	-410	621659	1599432	3128701	1879413	9132392	0	1155891	1.0	16895829	-410	22-May-92	23	3815.8	
-410	-400	621659	1599432	3128701	1879413	9132392	0	1155891	1.0	16895829	-400	11-Jun-92	20	4388.2	
-411	-410	62165.9	159943.2	312870.1	187941.3	913239.2	0	115589.1	0.1	1751749	-410	28-Nov-92	170	53.5	Nov. 28/92 Lingan Break; Q = 3000 usgpm.
-410	-400	621659	1599432	3128701	1879413	9132392	0	1155891	1.0	17517488	-400	23-Mar-93	115	791.2	
-400	-390	380590	946131	5570842	726934	9790204	0	1296472	1.0	18711173	-390	11-Jun-93	80	1214.9	
-390	-380	380590	946131	5570842	726934	9790204	0	1296472	1.0	18711173	-380	02-Sep-93	83	1171.0	
-380	-370	380590	946131	5570842	726934	9790204	0	1296472	1.0	18711173	-370	17-Oct-93	45	2159.9	
-370	-360	380590	946131	5570842	726934	9790204	0	1296472	1.0	18711173	-360	05-Dec-93	49	1983.6	
-360	-350	380590	946131	5570842	726934	9790204	0	1296472	1.0	18711173	-350	17-Jan-94	43	2260.3	
-350	-343	266413	662292	3899589	508854	6853143	0	907530	1.0	13097821	-343	12-Feb-94	26	2616.8	
-447	-440	621659	1599432	3128701	1879413	9132392	0	1155891	0.7	17517488	-440	14-Jan-95	336	270.8	Feb. 1994 Lingan Break; Q = 7000 usgpm.
-440	-430	621659	1599432	3128701	1879413	9132392	0	1155891	1.0	17517488	-430	15-Mar-95	60	1516.6	Spring Recharge
-430	-420	621659	1599432	3128701	1879413	9132392	0	1155891	1.0	17517488	-420	22-Apr-95	38	2394.6	Spring Recharge
-420	-410	621659	1599432	3128701	1879413	9132392	0	1155891	1.0	17517488	-410	27-Jan-96	280	325.0	Losing water to Phalen (?) in summer
-410	-400	621659	1599432	3128701	1879413	9132392	0	1155891	1.0	17517488	-400	06-Mar-96	39	2333.2	Spring Recharge
-400	-390	380590	946131	5570842	726934	9790204	0	1296472	1.0	18711173	-390	29-Apr-96	54	1799.9	Spring Recharge
-390	-380	380590	946131	5570842	726934	9790204	0	1296472	1.0	18711173	-380	30-Sep-96	154	631.1	Losing water to Phalen in summer
-380	-374	228354	567678.6	3342505.2	436160.4	5874122.4	0	777883.2	0.6	11226704	-374	06-Nov-96	37	1576.1	Fall Recharge
-374	-300	2816365	7001371	41224233	5379312	72447512	0	9593889	1.0	138462681	-300				Unsaturated
-300	-200	508624	0	36376114	544205	52712616	0	15509177	1.0	105650736	-200				
-200	-100	521738	0	1945284	0	24297764	0	26490593	1.0	53255379	-100				
-100	0	377816	0	0	0	18444558	0	55502822	1.0	74325196					

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Table 6.2. Mine Water Recharge Rate Calculations - Lingan Mine

Increment From (ft)	Increment To (ft)	Increment Volume (ft3)	Cumulative Vol (ft3)	Saturation Ratio (%)	Date	Workings Flooding	Days per Increment	Recharge Rate (usgpm)
-2700	-2600	92628	92628	0.00	20-Nov-92			
-2600	-2500	314736	407364	0.00				
-2500	-2400	1034894	1442258	0.01	05-Dec-92		15	358.4
-2400	-2300	4017542	5459800	0.03	20-Dec-92	13E	15	1391.3
-2300	-2200	9122922	14582722	0.07	13-Jan-93	12E	24	1974.5
-2200	-2100	8848266	23430988	0.11	25-Feb-93	11E	43	1068.9
-2100	-2000	12399271	35830259	0.17	16-May-93	7W/11E	80	805.1
-2000	-1900	14255375	50085634	0.24	08-Aug-93	6W/A0E	84	881.5
-1900	-1800	15376598	65462232	0.31	05-Dec-93	6W/9E	119	671.2
-1800	-1700	17186316	82648548	0.40	09-Mar-94	5W/8E	94	949.7
-1700	-1600	15964926	98613474	0.47	26-Mar-94	4W/7E	17	4878.2
-1600	-1500	16145981	114759455	0.55	07-Apr-94	3W/6E	12	6989.1
-1500	-1400	17399116	132158571	0.63	24-Apr-94	2W/5E	17	5316.4
-1400	-1300	14318134	146476705	0.70	14-May-94	1W/4E	20	3718.7
-1300	-1200	7033537	153510242	0.73	31-May-94	4E	17	2149.1
-1200	-1100	7025058	160535300	0.77	15-Jun-94	3E	15	2432.8
-1100	-1000	9325768	169861068	0.81	03-Jul-94	2E	18	2691.2
-1000	-900	5033824	174894892	0.84	30-Jul-94	2E	27	968.4
-900	-800	6462050	181356942	0.87	06-Oct-94	1E	68	493.6
-800	-700	3639611	184996553	0.89	21-Nov-94	1E	46	411.0
-700	-600	6562169	191558722	0.92	31-Mar-95	A	130	262.2
-600	-500	5710267	197268989	0.94	16-Apr-96	A	382	77.6
-500	-480	696,765	197965754	0.95	30-Sep-96	A	167	21.7
-480	-400	5519824	dry					
-400	-300	3805898		Volume Remaining to +88 ft = 11,034,692 ft3.				
-300	-200	508624		Volume remaining to sea level = 10,783,900 ft3.				
-200	-100	521738						
-100	0	377816						
0	88	300792						
Total Volume (ft3)		209000446						

Notes:
1. Water elevations prior to February 1994 taken from Figure 4, CBDC 1994.
2. Water Levels after February 3, 1994 taken from CBDC Lingan Water Level Measurements (Figure 3.1, thi

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6. Low inflow rates in summer and during winter freeze periods can be as low as a few hundred gallons per minute, or may be negative when inflow is less than outflow to other mines prior to 1992, and to Lingan or Phalen after the 1992 and 1994 breaks.

7. Rates of recharge to the 1B system are declining. Peak inflows have declined from over 4,000 usgpm prior to 1992, to about 2,400 usgpm by 1996. Summer inflow rates also seem to be declining, from an estimated 2,000 usgpm in 1986, to about 500 usgpm in the last two years.

8. The declining recharge rates appear to correlate reasonably well with the rising discharge rates from Phalen mine (less than 250 usgpm in 1993 to the current 1,200 usgpm). The average recharge rate between May, 1991, and the November, 1992, Lingan break was 3,150 usgpm. The wet season rates of recharge dropped to 1,460 usgpm after the 1992 event, dropped again to 1,860 usgpm after the February, 1994, event, and averaged 750 usgpm between January 27, 1996 and May 1, 1996, at the beginning of the summer dry season.

9. Average apparent recharge rates (average of peak flow and summer low flow) to the 1B system have been estimated for various time periods. The 10 year average recharge rate was in the order of 900 usgpm; this rate reflects filling of No. 2, No. 26, and Lingan Collieries.

10. The current apparent average recharge rate to the 1B-Lingan system between January, 1995 (the end of the drawdown effect caused by the February 1994 Lingan break), to November, 1996, is 710 usgpm, ranging from 2,400 usgpm in spring and fall, to less than 500 usgpm during the summer months.

11. Actual recharge to the 1B system exceeds the apparent recharge rate, because some water is continuously lost from 1B by percolation into the Lingan and Phalen mines. When the estimated outfall to Phalen is taken into account (estimated to be in the order of 600 to 800 usgpm), the current rate of recharge to 1B system appears to be in the order of 1,300 to 1,900 usgpm, and may reach 3,200 usgpm during periods of heavy rain, and 500 usgpm or less during periods of drought when outfall exceeds recharge.

6.3 Lingan Mine

Water level monitoring at Lingan implies that the Lingan system recharge will be much slower than originally envisioned (e.g. 1,500 ± usgpm fill rate measured in 1993 has slowed to less than 100 usgpm in 1996). The current rates of rise are considerably slower than the rates of infill projected by JWEL in 1993.

Figure 6.2 illustrates the interpreted rate of water level rise in Lingan mine in usgpm between the initial break in 1992 and present. The Lingan mine water levels in feet below sea level are superimposed for comparison.

Three observations are apparent. Peak inflow rates from 1B to Lingan of 2,000 and 7,000 usgpm are indicated for the two strata breaks on November 20, 1992, and March, 1994, respectively. These peaks correlate with the steepest rates of water level rise in Lingan. The rate of mine water recharge is declining at an exponential rate from about 1,000 usgpm in early 1993, to the current 47 usgpm.

When the water level in Lingan rose above the inferred break zone at about -1,100 ft, the rate of mine water recharge began to decline, likely a consequence of pressure head differential on both sides of the break. As the pressure differential decreased with increasing water level in the Lingan, the rate of inflow across the break zone also declined. The exponential decline in water level rise may also indicate that inflow to Lingan from No. 26 is approaching the quantity of water inflow into the Phalen mine via seepage through the Lower Sandstone Unit.

The rate of mine recharge to Lingan was relatively constant, compared to the seasonal and break-induced variations in 1B. This suggests that most of the flow was controlled by movement of water from 1B to Lingan across the barrier pillar breaks. The reduction in rate of recharge was due to equilibration of pressure head on either side of the break (e.g. a "U-tube" effect). The flow rate into Lingan is therefore proportional to hydraulic gradient which continually declines as the head difference between the mines converges, and assuming hydraulic conductivity and cross-sectional area are constant. Order of magnitude estimates of inflow rate using Darcy's law, shows that flow rates into Lingan between 1993 and 1996, should decline to about 130 usgpm, which is reasonably consistent with the exponentially declining rates observed in 1996.

6.4 Recharge Time Lines

The estimated recharge rates were divided into the remaining mine volumes to determine time to fill-up (Lingan) and time to outfall at the sea coast (1B System).

6.4.1 Lingan Mine

Lingan recharge rates have declined significantly as the water levels rose above points of inflow from No. 26 Colliery. Apparent inflow rates in 1996 have continued to decline from 100 to 22 usgpm (Table 6.2, Figure 6.2). Assuming an average inflow rate of 22 usgpm, this mine should reach equilibrium with the 1B hydraulic system at an elevation of -370 ft, within about 4.3 years, assuming no further breaks between the two mine systems.

Based on current observations and rates of water level rise, Lingan mine is expected to approach equilibrium with the 1B system, and thence fill at about the same rate. Once the 1B system begins to discharge at sea level, further recharge to Lingan will be from up-dip groundwater sources, which are expected to be considerably lower than the potential outfall to 1B system. At this point, water level rise in Lingan should cease, and remain in equilibrium with the 1B system. Assuming continued hydraulic interconnection between Lingan and No. 26, this mine water should never discharge at the pithead (+88 ft elevation).

6.4.2 1B System

The 1B hydraulic system is expected to discharge to the Atlantic Ocean via a shoreline drainage tunnel at 1A mine (JWEL, 1993). Calculations were made on the estimated time to fill the remaining mined voids between the current (November, 1996) levels and sea level. Once water levels reach sea level, no further rise in water levels should occur, unless the outfalls are sealed.

Based on the last year of records, apparent recharge to the 1B mine system currently averages 710 to 750 usgpm, with peak flows up to 2,400 usgpm expected in spring and fall, and summer recharge rates in the order of 500 usgpm.

Two time lines are apparent for the 1B Hydraulic System. One time line assumes no further outfalls to the Phalen mine or other abandoned collieries. Under this scenario and using the average recharge rate of 750 usgpm, the 1B system should reach a surface outfall at sea level in about 7.2 to 7.6 years (2004). Assuming increasing proportions of mine water leaving 1B system and entering Phalen, this time line could be extended by several years. Further monitoring is needed to confirm this.

It is apparent from declining rates of recharge in 1B during wet periods and very small rates of rise in Lingan, that some mine water is being lost from the 1B system to the Phalen mine. The rapid increases in mine effluent flow rate and significant shifts in chemistry towards 1B mine water quality after June, 1994, suggest movement of 1B or Harbour seam waters into Phalen 5E and 6E panels.

Based on the chemistry trends and degree of apparent decline in recharge rate to the 1B system, it is suspected that Phalen mine water may contain in excess of 50 percent, and possibly up to 80 percent of mine waters directly from the 1B system.

Assuming increasing proportions of discharge to the Phalen mine, the rates of water level rise in the 1B system are expected to decline proportionally over the next few years. If the magnitude of outfall to Phalen mine exceeds the recharge rate, then 1B system may never reach outfall to the surface until Phalen mine is abandoned and allowed to flood.

The chemistry suggests that a large proportion of recharge to the 1B Hydraulic System originates from landward recharge sources. Based on the results of the October, 1996, sinkhole remediation near Glace Bay, it is apparent that recharge rates and the time remaining to fill the 1B system could be further delayed if more of the significant recharge points are located and sealed. On-going monitoring is needed to confirm post-remediation trends and establish their effectiveness.

7.0 MINE WATER PUMPING OPTIONS

7.1 Introduction

Several concerns have been raised with respect to the control of water levels in the 1B-Lingan system, and Phalen mine. CBDC has requested JWEL to evaluate the feasibility of pumping from Lingan Mine as a means of controlling water levels in the entire 1B hydraulic system as water levels approach potential surface discharge points. Several possible pumping strategies were identified, and the advantages and disadvantages of each strategy was evaluated, and summarized on Table 7.1. Assessment criteria included interpreted water movement pathways, water quality trends, hydraulic interactions between mines, and proximity to the treatment plant.

Currently, only the Phalen mine is being actively pumped to surface at an estimated rate of 1200 usgpm. Pumping rates have been increasing as a consequence of inflows at panels 6E and 7E which are in close proximity to the Lower Sandstone aquifer. No treatment is currently implemented prior to discharge to the Atlantic Ocean, however the water chemistry is evolving in a manner which may require effluent treatment at some time in the future. An emergency waste water treatment plant (WWTP) has been constructed at the Lingan mine site to deal with mine effluents should the need arise.

7.2 Potential for Continuing Mine Interconnection Between 1B and Lingan

One of the mine water management options considered by CBDC is to pump from the Lingan Colliery, thereby reducing inflows to the active Phalen colliery via the "Harbour Seam Connection ", and possibly extending the life of the Phalen operation.

Pumping from Lingan (or 1B shaft) as a means of controlling water levels in the entire 1B system, are dependent on whether a direct hydraulic interaction is maintained between the two mines, and whether the inferred breaks at -1,100 and -1,400 levels and other undefined possible strata breaks, remain open sufficiently to allow hydraulic continuity between the mines. If the connections closed, pumping Lingan would not control water levels in the 1B system, or reverse.

Table 7.1 Advantages and Disadvantages for Selected Mine Pumping Options

Pumping Option	Advantage	Disadvantage
Pumping 1B Shaft	Prevent discharge of 1B mine water at surface; Reduce hydraulic pressures above Phalen by lowering both 1B and Lingan mine water levels; Control water levels in entire 1B-Lingan system to about -1,400 ft depth; Possibly improve Phalen outfall chemistry (e.g., greater proportions of strata water).	Large volumes of potentially poor quality water need to be handled and treated; Lingan system will not be de-watered below strata breaks (-1,100 to -1,400 ft); Inflow to Phalen mine will continue to increase as mine expands; Pumping point long distance from WWTP; Will need two pumping systems (1B and Phalen); Possible strata breaks between Lingan and 1B as head differential increases.
Pumping From Lingan	Prevent 1B discharge at surface; Reduce pressure head in underlying Phalen mine workings; Better water quality than 1B system; Proximity to existing WWTP; Control water levels in entire 1B-Lingan System to about -1400 ft level;	Large volumes of water require handling and treatment; May not be able to affect 1B system below strata break elevations (-1,100 and -1,400 ft); Two pumping systems (Lingan @ 2,000± usgpm and Phalen @ 1,200± usgpm) would be required;
Pumping from Phalen Only	Best potential water quality; less treatment required; Intermine waters naturally attenuated along flow path or by in-mine storage and mixing; Mine water volumes should remain lower than other options (e.g; 1,500 to 5,000 usgpm); Only one mine effluent in operation; Possibility that inflow to 1B-Lingan system may reach equilibrium with outflow to Phalen, resulting in no discharge of 1B at surface.	Does not relieve pressure on Phalen system (e.g. inflow continues to increase); Risk of strata breaks across 1B-Phalen barrier on Phalen seam; Does not eliminate potential for 1B system to discharge at sea level, unless outflow to Phalen increases to about 2,200 usgpm.

Seam. Based on the interpreted hydraulic interconnection between mines, pumping from Lingan should induce flow from No. 26 and the 1B system, thereby controlling water levels in all interconnected mines.

The main disadvantage to pumping from the 1B-Lingan system is the large volume of water (estimated at 1.56 billion US gallons), that will likely require treatment prior to discharge to the ocean. A comparison of water chemistry indicates the Lingan mine should have better overall effluent quality than the shallow zones of the 1B shaft. Over the long term, however, the chemistry is expected to evolve towards a 1B water type.

Partial de-watering of Lingan may reduce, but not eliminate, roof instability and the frequency of in-rushes of strata waters at Phalen in close proximity to the Lower Sandstone aquifer. This hydrostratigraphic unit is likely storing and transmitting water recharge from deep formation brines, fossil groundwater, and mine water originating from flooded workings on both Harbour and Phalen seams.

Based on current information, the Lingan connection should be able to lower water levels in 1B system to the -1,100 or -1,400 ft break levels. While this elevation will be sufficient to prevent discharge of 1B system waters at the surface, further dewatering of 1B system to the levels of Phalen mining (e.g. greater than -1,400 ft depth) would require pumping from the 1B shaft, unless undetected deeper strata breaks are present.

Dewatering Lingan at a rate faster than recharge from the 1B system would increase the potential for further strata breaks between the two mines. Finally, pumping from the 1B-Lingan system would result in two simultaneous pumping operations; one from the 1B system, and one from Phalen which would still produce water, with both possibly requiring treatment based on current water quality trends.

If the 1B-Lingan pumping is considered, it is recommended that pumping be conducted from the Lingan mine, rather than from the 1B shaft. Based on apparent hydrochemical stratification within the mines, pumping should be done from a point deep within the mine, rather than from shallow zones, where greater proportion of pyrite oxidation products (acidity, aluminum, iron, sulfate) are expected (see recommendations for 1B shaft pumping, JWEL, 1993).

7.4 Phalen Pumping

There are two issues to be addressed in considering pumping strategies at the Phalen mine; increasing discharge rates, if the 1B system is not depressurized, at Phalen panels 5E through 8E which are in hydraulic connection with the Lower Sandstone aquifer, and potential decline in chemical quality of Phalen mine effluent as the water becomes dominated by increasing proportions of Harbour Seam mine water. Advantages and disadvantages to pumping only from the Phalen mine are considered in Table 7.1.

The main advantages to pumping only from the Phalen mine are that it would result in only one outflow, (e.g. from Phalen), that there would be lower pumping rates, and that there would be potential for less water quality treatment requirements prior to discharge.

The primary disadvantage of pumping only from the Phalen mine is that water inflows to Phalen will continue or possibly increase over time as the 1B system floods to equilibrium. This will result in a gradual shift in mine water chemistry towards one consistent with typical "mine water", while possibly will require treatment prior to discharge.

Flow Rates

Although Phalen mine water quantities are expected to rise as mining proceeds, the rate that water inflows increase in each new panel should decline as the base of the Lower Sandstone Unit increases in distance from the top of the Phalen coal seam. This should reduce water inflows, providing no major strata breaks occur between the No. 1B and the Phalen mine workings across the barrier pillar.

There is a possibility that Phalen mine is in indirect hydraulic connection with the flooded workings on the Harbour seam, mainly via the Lower Sandstone aquifer which provides a hydraulic pathway between the east side of the Phalen workings (5E, 6E and 7E panels) and the No. 1B mine also located on the Phalen seam. If this sandstone structure is found to be a major "drain" or conduit for strata waters and mine waters moving through subsidence-induced fractures, an increasing proportion of the Phalen mine water is probably from the 1B system. It is possible, therefore, that water inflows and mine water pumping from the Phalen mine, may eventually control water levels in the entire 1B-Lingan-Phalen mine complex, thereby eliminating the need for further pumping at other locations.

Based on the observed rates of inflow into the Phalen mine from adjacent aquifers and/or flooded workings, it is highly unlikely that pumping Phalen will lead to dewatering of the entire 1B-Lingan mine complex. However, the rate of rise in the 1B Hydraulic System should decline proportionally to the volumes of water outflow to the Phalen seam. This will subsequently increase the time line for 1B to discharge at surface.

In September, 1993, isotope chemistry indicated that 40 percent of Phalen water likely originated from the Lingan or 1B system. Since water chemistry has evolved significantly towards a less saline chemistry in the intervening three years, the Phalen now contains a higher proportion of 1B water, possibly in excess of 60 percent.

Flow rates into the Phalen mine panels are only in the order of 30 to 250 gpm each, and cumulative flows into panels 1E through 7E are reported to be about 1,200 usgpm. This inflow is approximately half of the estimated average annual recharge rate to the 1B system, prior to the 1992 Lingan break (Figure 6.1). Over

60 percent of this volume originates within panels 6E and 7E, which are recharged from the Lower Sandstone aquifer which is connected to the 1B workings.

Projected total inflow rates into the Phalen mine are expected to increase gradually until the base of the lower sandstone no longer intersects or is exposed to the top of the Phalen coal seam in the longwall mining panels. Once this sandstone is isolated from the mine panels, inflow rates should stabilize with a slower rate of increase due to the lower permeability of the host rocks between the top of the coal seam and the bottom of the Lower Sandstone unit.

Quality of Effluent

Another issue is the chemical quality of effluent from the Phalen mine. Temporal monitoring to date indicates a gradual decrease in pH, with consequent increasing levels of iron and other metals. Further, the overall mine water chemistry is shifting from one consistent with a highly saline formation brine, to less saline mine water, similar to Harbour Seam waters. As the mine volume increases, it is also noted that the degree of acidic drainage within the workings is increasing, resulting in increasing concentrations of sulfate, acidity, iron and manganese.

While effluent quality from the Phalen mine currently meets guidelines, it is possible that at some point in the future, effluent will need to be treated prior to discharge to the sea. If the 1B system is not pumped, it is likely that total inflow to Phalen will increase, and the water quality in Phalen will shift towards one that is chemically similar to the 1B system. However, due to mixing with progressively more saline strata waters, the effluent from Phalen should remain better in overall pre-treatment quality than that from the 1B or Lingan mines.

7.5 Effluent Management Options

Several techniques could be considered for the management of effluent within the mines which may make it possible to pre-treat mine waters prior to discharge to the surface.

In the case of the Phalen mine, this may mean development of a series of settling basins above the sump locations, where acidic mine water can be allowed to interact with calcium-rich bedrock and precipitate iron and metals flocs. Chemical reagents may be added to neutralize and promote precipitation of metals and suspended solids. It is our understanding, that some mine waters in Phalen were stored in abandoned panels until rock-water interactions resulted in a better overall discharge chemistry (e.g. higher alkalinity and pH and lower suspended solids). This water could then be directed towards the main sumps for discharge. This strategy may delay the need for effluent treatment, or reduce the volumes of reagent needed at the WWTP. Implementation of this procedure would require construction of storage reservoirs in the workings (which prevents acid drainage), and chemical assessment of appropriate processes. A monitoring and contingency program would be needed to ensure the stored water was not escaping to other panels through the Lower Sandstone aquifer.

Based on recharge estimates, continuous pumping rates in excess of 2,.200 usgpm will be needed to control water levels in the 1B-Lingan system during wet periods. Since the recharge rates are expected to vary seasonally (500 to 6,000+ usgpm), an opportunity is available to manage discharge rates at a lower than peak flow average pumping rate by use of water storage management in the mines. For example, water could be pumped and treated during the dry seasons, with a resultant drop in overall water levels and a net gain in storage in the mine reservoir. During periods of heavy rains, when inflows could exceed 6,000 usgpm, there would be room for storage, but no requirement for additional pumping and treatment.

8.0 SUMMARY OF CONCLUSIONS

8.1 Mine Flooding Rates and Time Lines

1. The history of mine flooding in the 1B system is controlled by a combination of seasonal recharge variations, outfall to adjacent interconnected mines (No. 2, No. 26, No. 5) when water levels reach an interconnection point, and periodic strata breaks into Lingan mine, and possibly Phalen mine (since 1995).

2. The 10 year average apparent recharge rate into the 1B-Lingan Hydraulic System was 900 usgpm, with seasonal peak inflow up to 6,000 usgpm and periods of apparent negative recharge when adjacent interconnected mines were filling.

3. Based on the past year of record, the current 1B mine system is flooding at an average rate of 710 to 750 usgpm, with seasonal range from 2,400 usgpm in spring and fall, to less than 500 usgpm during the dry summer months.

4. The rate of apparent recharge to the 1B-Lingan system has been declining over the past 10 years. This is attributed to an increasing proportion of flow moving from the 1B system to the active Phalen mine via the Lower Sandstone Unit.

5. The flooding of the Lingan mine is controlled almost entirely by inflow from the 1B system through at least two strata breaks across the barrier pillar between the No. 26 mine and the east side of the Lingan mine workings at the -1100 and -1400 ft levels.

* November 29, 1996 - 2,000 usgpm to Lingan 2E at -1100 ft level while Phalen 5E was being mined.

* February 17, 1994 - 7,000 usgpm to Lingan at -1400 ft level while Phalen 6E was being mined.

* October 28, 1996 - unknown inflow to Lingan during Phalen 7E mining

3. Based on the observed mine water levels, it appears likely that recharge pathways may exist from No. 9 to No. 2 to No. 1B to No. 26 to Lingan.

4. Water quality monitoring suggests a further, less direct, pathway between the No. 1B and Lingan mines into the Phalen mine. Increasing inflows into the Phalen 6E and 7E panels, and significant shifts in water chemistry at these locations after June, 1994, infer that mine water with a chemistry resembling 1B water is entering the Phalen mine via the Lower Sandstone unit.

5. Seasonal water level fluctuations up to 3 ft were observed at 1B and No. 4 Quarry Point mines. The 1B system responds quickly to heavy rainfall events exceeding 30 to 50 mm. Recurring water level drops in the 1B system between June and late October are believed to reflect periods when the rate of drainage to Lingan (or Phalen) from 1B exceeds the recharge rate into 1B.

8.4 Sources of Phalen Mine Water

1. Phalen mine water is a combination of saline strata waters, mine waters from flooded workings and pyrite oxidation products within the Phalen mine. The proportion of mine water from flooded mine workings is increasing with time.

2. Mine geology and hydrochemical trends suggest two mine water recharge pathways into the Phalen mine:

   (1) Vertical percolation of No. 26 and Lingan mine waters from the overlying Harbour Seam, through 140 metres of interburden between the Harbour and Phalen seams via subsidence-induced fracturing and interconnection of sandstone aquifers, and

   (2) Horizontal migration of No. 1B mine water from the 1B colliery located immediately east of Phalen panels 5E through 8E, via the Lower Sandstone Unit aquifer, which provides a direct hydraulic pathway between 1B and the Phalen longwall panels across a 76 to 91 m wide barrier pillar.

3. It is expected that flow rates into the Phalen mine will continue to rise as the hydraulic gradient between Phalen and the 1B system increases, or until equilibrium between the two systems is achieved.

4. Inflow rates into Phalen should be greatest in those panels contacting the Lower Sandstone Unit. Inflow rates into subsequent panels should decline as the bottom of the sandstone formation increases in height from the top of the Phalen coal seam.

8.5 Mine Water Chemistry

1. Groundwater entering each new panel in the Phalen mine is a mixture of saline formation waters, mine waters stored in up-dip abandoned panels, and mine waters from adjacent flooded workings.

2. Mine water chemistry in the Phalen mine panels exhibits a consistent trend in water chemistry. Over two to three years, initial water chemistry at a panel or adjacent strata evolves from a highly saline formation brine towards a less saline chemistry resembling 1B system mine water.

3. Chemistry trends generally exhibit decreasing concentrations of major ions, TDS and conductance, and increasing concentrations of alkalinity and sulfate. These trends are interpreted to reflect replacement of saline strata waters with less saline mine waters or formation waters.

4. The degree of evolution appears to be proportional to flow rates in the panels, and proximity to the Lower Sandstone Unit aquifer. For example, water in panels 6E and 7E have evolved towards 1B mine water chemistry to a much greater degree than waters from "drier" panels 4E and 5E.

5. The Phalen mine water chemistry trends indicate an increasing proportion of mine water originating from the 1B Hydraulic system. Based on isotope and chloride ratios, the proportion of 1B system water in Phalen effluent appears to be increasing, from an estimated 40 % in September, 1993 (based on isotopes), to an estimated 60 % to 80 % by late 1996.

8.6 Mine Pumping Options

1. Pending further confirmatory monitoring, it is suspected that pumping rates in the Phalen mine will increase with time due to increasing inflow of waters from flooded 1B and/or Harbour Seam mines.

2. Based on current hydrochemical trends, it is likely that water quality of the Phalen effluent may become dominated by mine waters from the Harbour Seam and the 1B system on the Phalen Seam.

3. Two long term pumping scenarios are envisioned: pumping only from Phalen with a contingency to control water levels in the 1B system, and a dual pumping strategy involving pumping from Phalen with simultaneous pumping from the 1B system via the Lingan connection. The optimum pumping strategy will be determined based on a need for control of inflows into the Phalen panels, the pumping capacity at Phalen and the potential requirement to treat the mine water prior to ocean discharge.

4. Pending further monitoring, it is possible that the Phalen mine could eventually become part of the 1B Hydraulic System if flow rates between the 1B system and the Phalen mine continue to rise. At present there is not a direct connection between Phalen and any of the other flooded mines. Water level monitoring at the 1B shaft suggests the liklihood that a portion of the 1B system recharge is being lost to both the Lingan and Phalen mines. The connection appears to be related to permeable sandstone aquifers and subsidence-induced fracturing of sandstone units and adjacent aquitards located between the Phalen and Harbour seam and/or the 1B mine.

5. Due to strong seasonal variation in recharge to the 1B system (500 to 2,400, with peak inflows up to 6,000 usgpm), it should be possible to seasonally-optimize pumping by drawing down the Lingan-1B water levels in summer when recharge rates are lowest, and using the increase storage for additional recharge expected in spring and fall during high precipitation and runoff events.

9.0 RECOMMENDATIONS

Phalen Mine

1. There is still some uncertainty respecting the proportion of Phalen mine water originating from the overlying flooded workings on the Harbour Seam and from the adjacent 1B mine on the Phalen seam. On-going monitoring and investigation should focus on the potential movement of water through the Lower Sandstone Unit, between the 1B workings and the mining panels on the east side of the Phalen mine across the barrier pillar on the Phalen seam.

2. There is a potential for mine water from 1B to move laterally and into Phalen mine across the barrier pillar due to longwall mining in both 1B and Phalen. The risk of strata breaks or increasing seepage caused by subsidence-induced fracturing of the Lower Sandstone Unit or other strata across the 1B-Phalen barrier should be investigated.

3. Consideration should be given during mining of the east side panels in the Phalen mine, to avoid the Lower Sandstone Unit where it approaches or contacts the top of the Phalen coal seam. This may mean modifying longwall panel spacing and length.

4. The hydraulic interaction between the abandoned No. 12/14 mine system and the west side of the Phalen mine is presently unknown, and should be addressed with water level instrumentation to monitor water levels, and to confirm that no interactions occur with Phalen mine.

1B System

1. Based on the results of precipitation from major storm events like Hurricane Hortense and sinkhole plugging near Glace Bay, a program should be implemented as soon as possible to locate, and seal significant surface recharge pathways.

2. Hydraulic modelling of the 1B-Lingan-Phalen mine complex should now be considered as a tool for predicting future mine water inflows, and assessment of interactions between flooded workings. The physical and chemical information at these mines can be used to construct and calibrate a mine model.

Lingan Mine Pumping

1. If a water inflow risk at Phalen can be accepted, pumping from the 1B and Lingan mine systems could be delayed until water levels approach outfall levels. At that time, water levels in the 1B system should be controlled by pumping from the Lingan mine and utilizing the water treatment plant.

2. Prior to implementing any pumping strategy, the expected continuity of the hydraulic connection between the Lingan and No. 26 mine should be confirmed with a pumping test of sufficient scale to cause drawdown in the 1B system. All available mine monitoring points and effluents should be closely monitored during this testing. This testing program will also provide data on optimum continuous or short term pumping rates, optimum pump intake depth in the water column, water quality trends under pumping conditions, and water treatability requirements. The recommendations provided in the 1993 JWEL report for the 1B shaft testing remain relevant.

Mine Monitoring

1. The current water level and water quality monitoring at the 1B-Phalen mine complex should be continued. Some opportunities for reduced analysis and sampling frequency may be practical. For example, daily readings appear to be sufficient for water level monitoring, and water quality monitoring at Phalen in-mine panels could be reduced to key indicators of mine water chemistry.

2. Environmental isotope sampling and analysis should be done on an annual basis to confirm the 1B connection with strata waters overlying and entering the Phalen 6E and 7E panels, and to estimate

the proportion of 1B mine water entering the Phalen mine. Results should be compared to the baseline interpretation done as part of the ADI, 1993 report.

3. Hydrochemical modelling should be considered to obtain a better assessment of mine water mixing from the various sources.

4. The water level monitoring data and the predicted mine recharge rates and 1B System discharge time lines should be reviewed on an annual basis, due to continuing declines in apparent mine recharge rates within the coalfield.

10.0 REFERENCES

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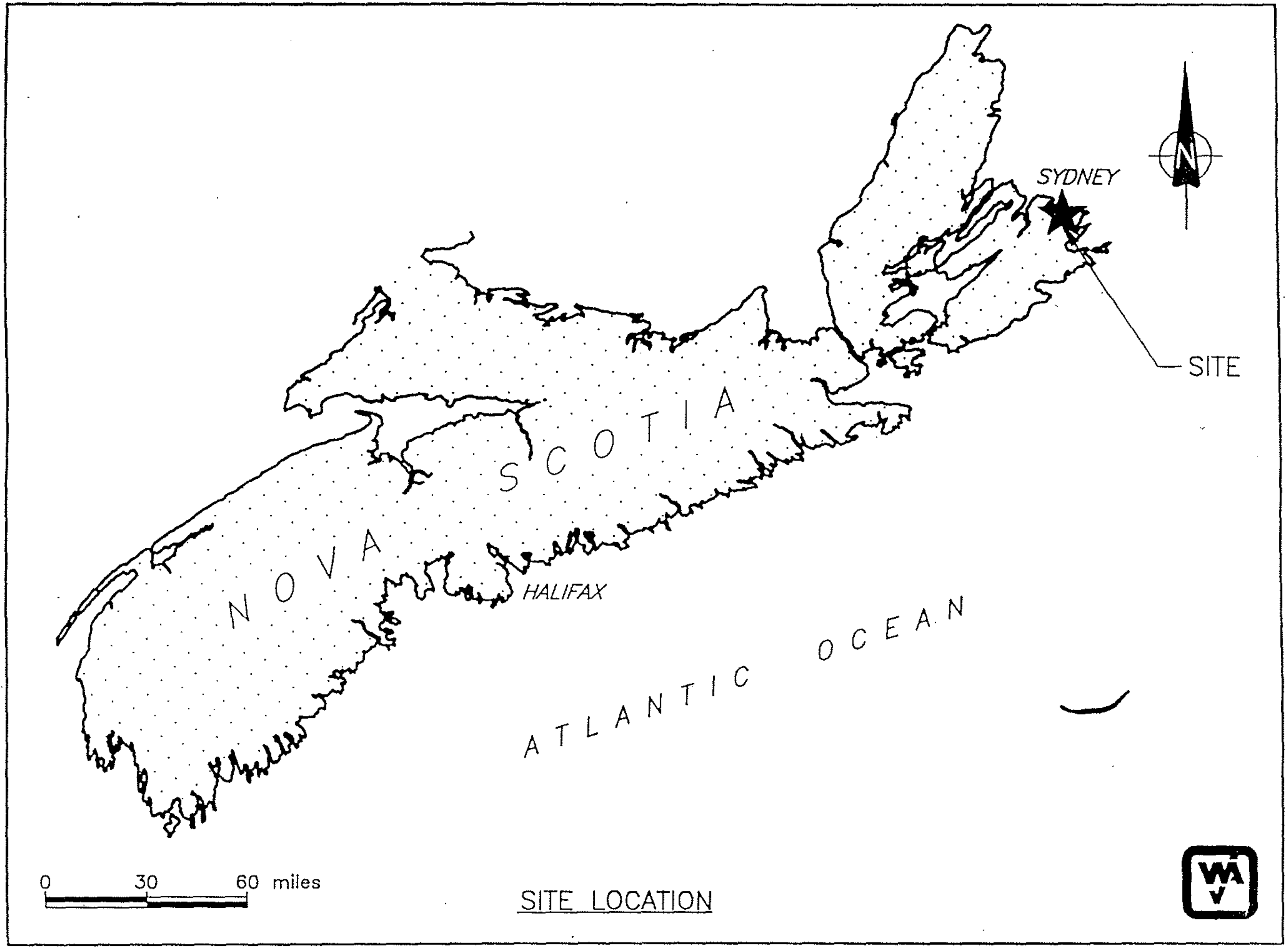
APPENDIX 1

FIGURES



SITE LOCATION

8728

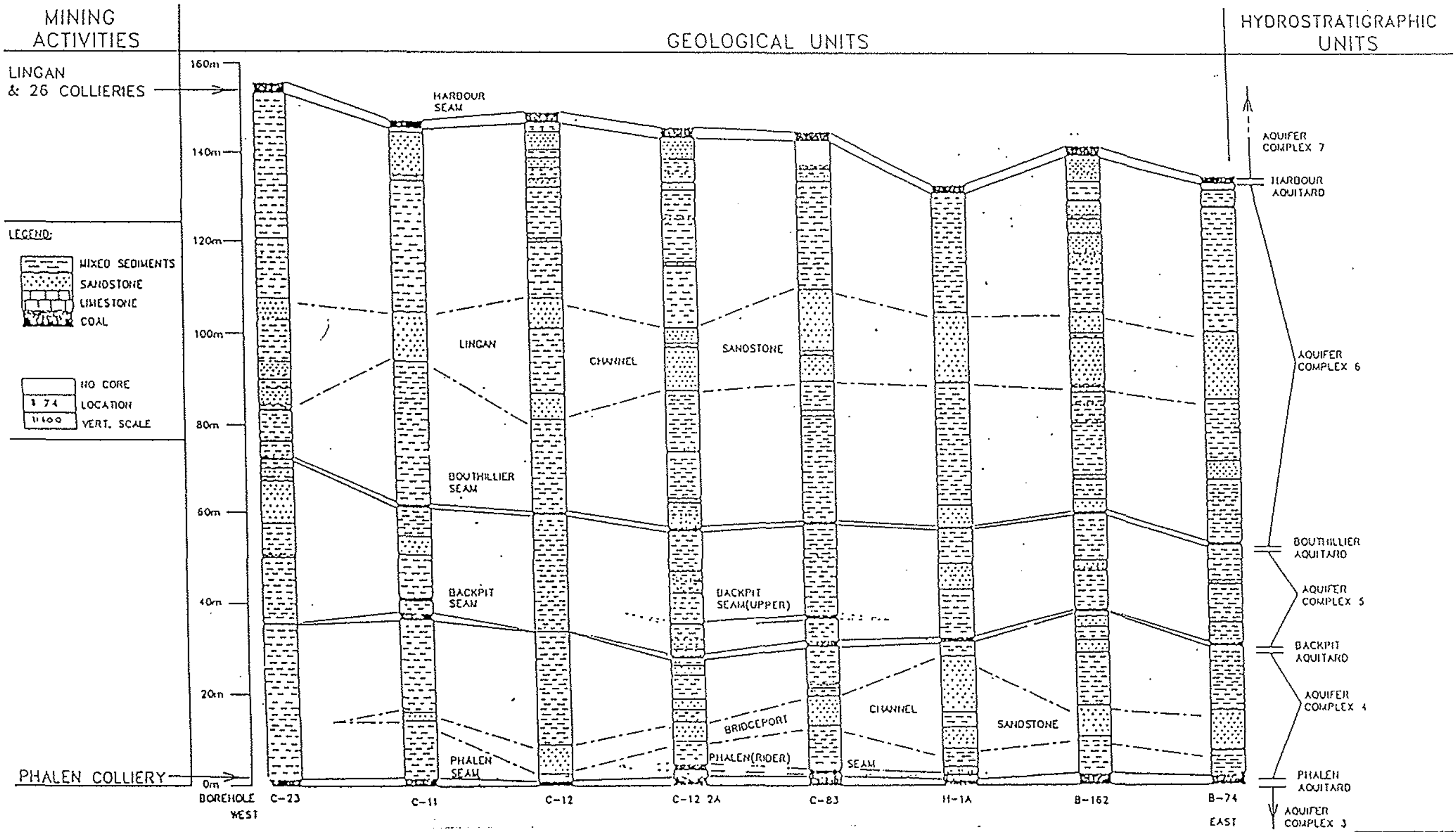


FIGURE 2.3 GEOLOGY AND HYDROSTRATIGRAPHIC UNITS BETWEEN HARBOUR SEAM AND PHALEN SEAM (AFTER ADI NOLAN DAVIS, 1993).

NOTE: THIS FIGURE IS NOT TO SCALE

Jacques Whitford

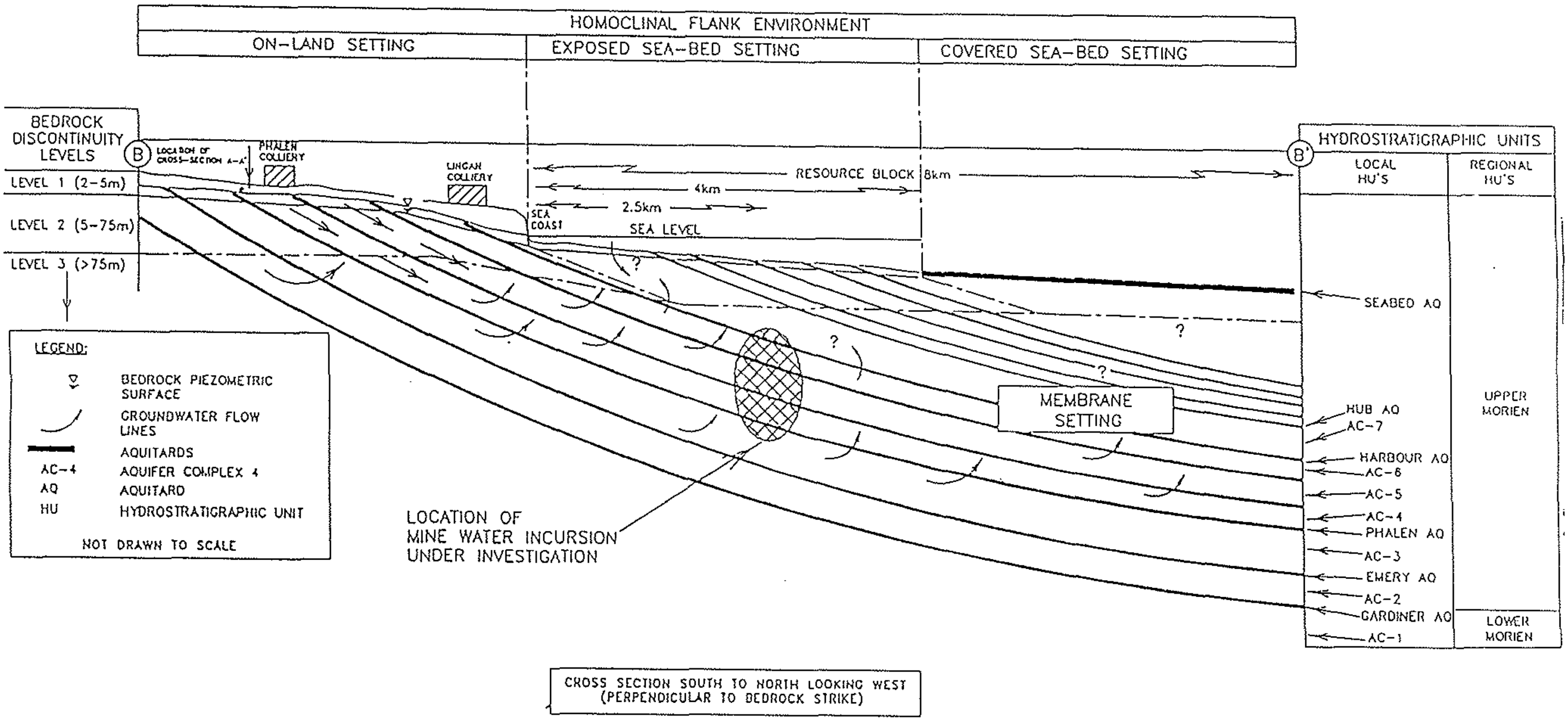
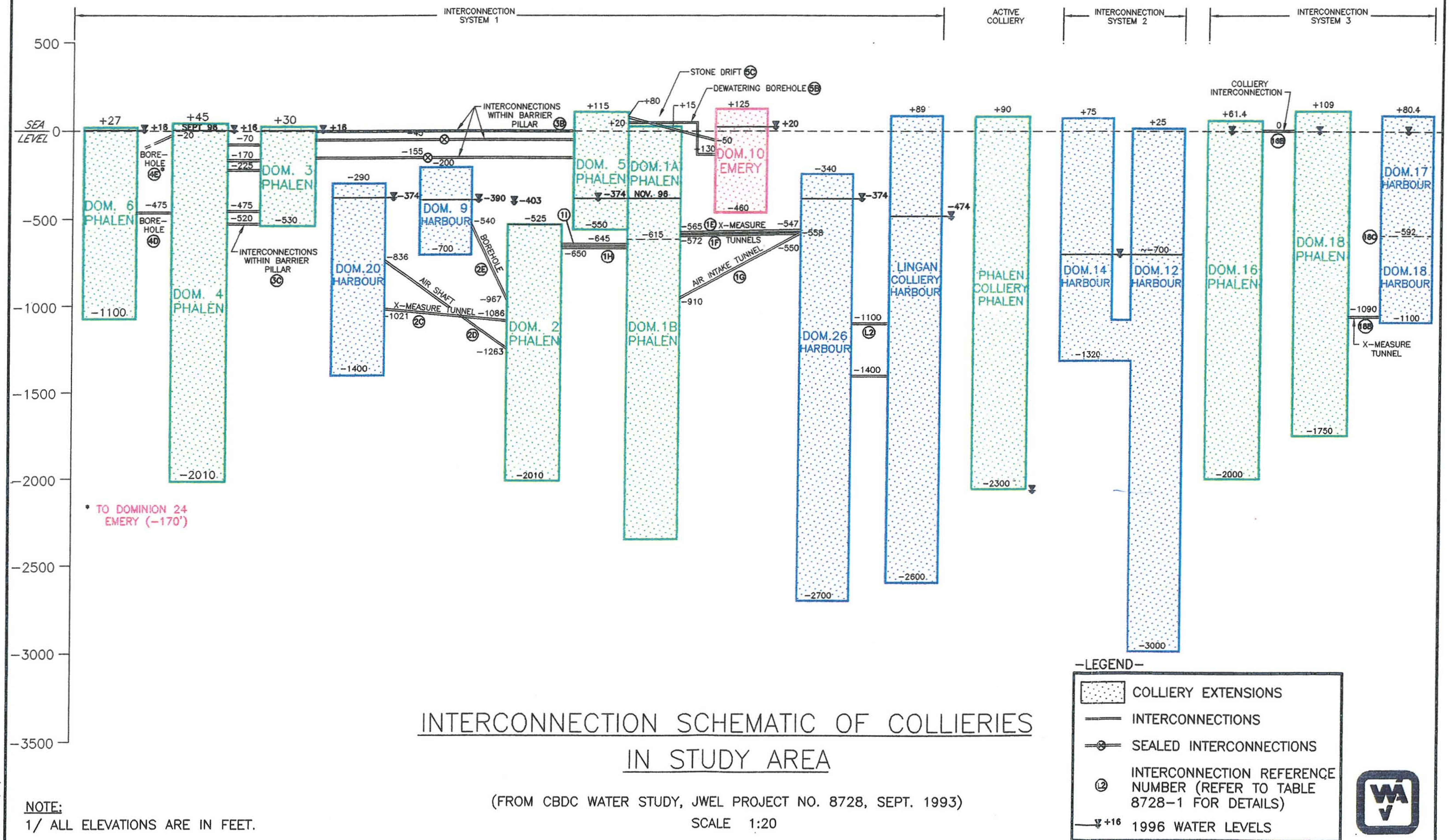


FIGURE 2.4 CONCEPTUAL MODEL OF NATURAL GROUNDWATER FLOW FIELD
LINGAN - PHALEN MINE AREA
(AFTER ADI NOLAN DAVIS LTD., 1993)

Jacques Whitford



INTERCONNECTION SCHEMATIC OF COLLIERIES IN STUDY AREA

(FROM CBDC WATER STUDY, JWEL PROJECT NO. 8728, SEPT. 1993)

SCALE 1:20

NOTE:

1/ ALL ELEVATIONS ARE IN FEET.

11545F21 96/12/06

11545

FIGURE 2.1

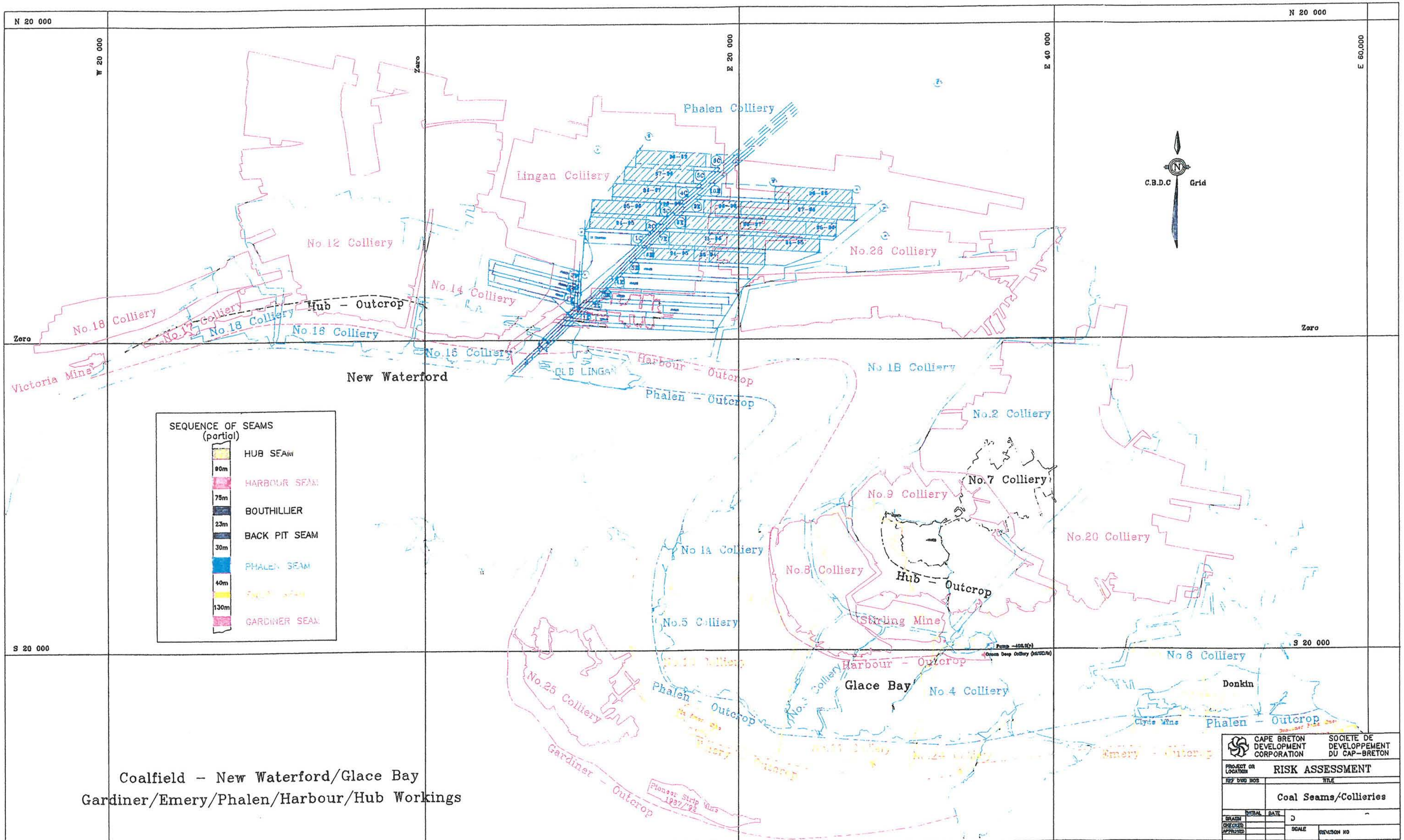

N 20 000
W 20 000
Zero
E 20 000
E 40 000
E 60,000
Phalen Colliery
Lingan Colliery
No.12 Colliery
No.26 Colliery
No.14 Colliery
Hub - Outcrop
No.18 Colliery
No.17 Colliery
No.18 Colliery
No.16 Colliery
No.15 Colliery
Victoria Mine
New Waterford
OLD LINGAN
Harbour - Outcrop
Phalen - Outcrop
No 1B Colliery
No.2 Colliery
C.B.D.C
Grid
SEQUENCE OF SEAMS (partial)
HUB SEAM
90m
HARBOUR SEAM
75m
BOUTHILLIER
23m
BACK PIT SEAM
30m
PHALEN SEAM
40m
130m
GARDINER SEAM
No.7 Colliery
No.9 Colliery
No.20 Colliery
No 1A Colliery
No.8 Colliery
Hub - Outcrop
No.5 Colliery
Stirling Mine
S 20 000
No 6 Colliery
Harbour - Outcrop
Glace Bay
No.4 Colliery
Donkin
No.25 Colliery
Phalen - Outcrop
Phalen - Outcrop
Gardiner - Outcrop
Pioneer Strip Mine
Coalfield - New Waterford/Glace Bay
Gardiner/Emery/Phalen/Harbour/Hub Workings
CAPE BRETON DEVELOPMENT CORPORATION
SOCIETE DE DEVELOPPEMENT DU CAP-BRETON
RISK ASSESSMENT
Coal Seams/Collieries

Figure 2.2

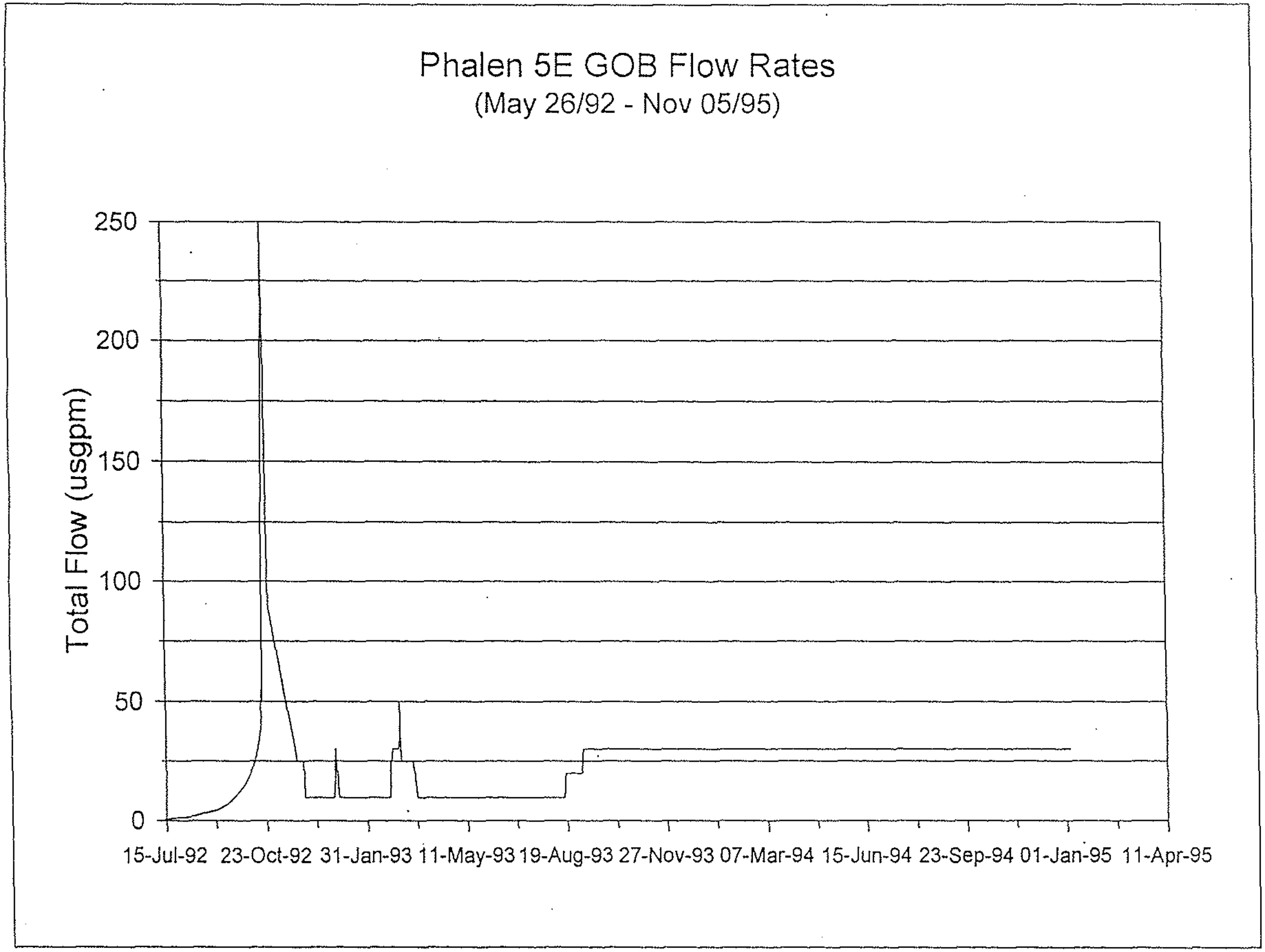

Phalen 5E GOB Flow Rates
(May 26/92 - Nov 05/95)
Total Flow (usgpm)
250
200
150
100
50
0
15-Jul-92
23-Oct-92
31-Jan-93
11-May-93
19-Aug-93
27-Nov-93
07-Mar-94
15-Jun-94
23-Sep-94
01-Jan-95
11-Apr-95

FIGURE 2.5

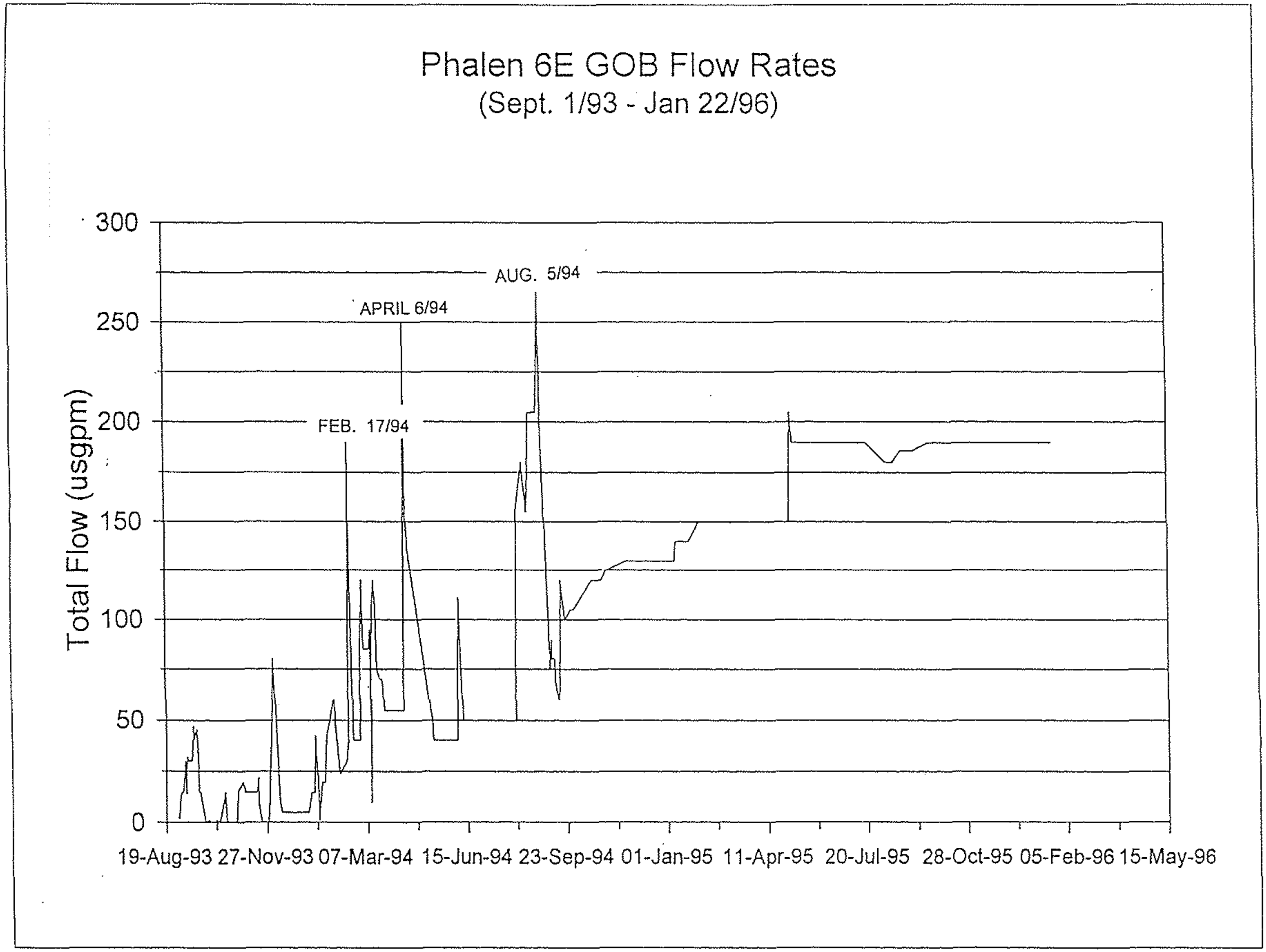
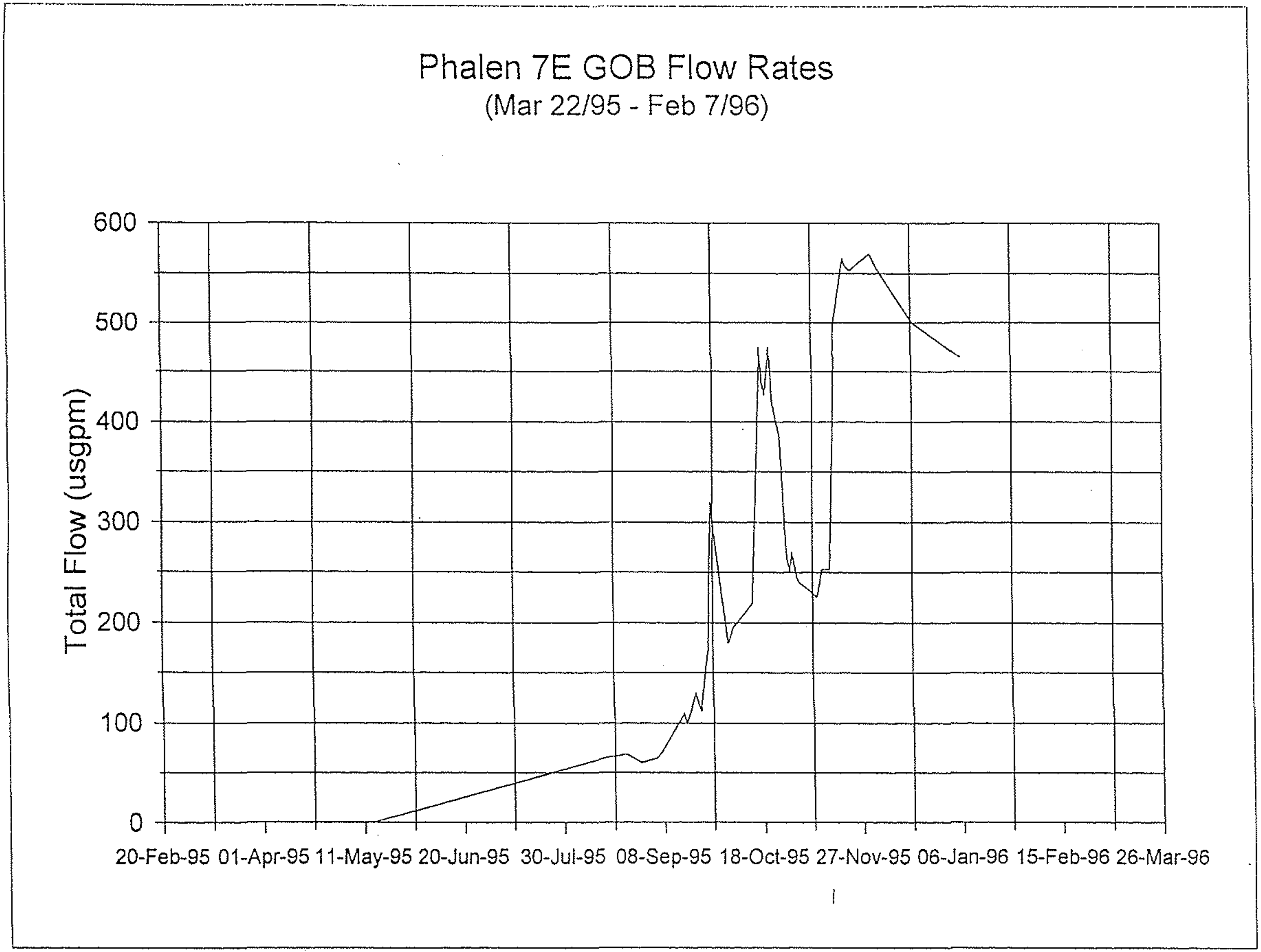

Phalen 6E GOB Flow Rates
(Sept. 1/93 - Jan 22/96)
Total Flow (usgpm)
300
250
200
150
100
50
0
AUG. 5/94
APRIL 6/94
FEB. 17/94
19-Aug-93
27-Nov-93
07-Mar-94
15-Jun-94
23-Sep-94
01-Jan-95
11-Apr-95
20-Jul-95
28-Oct-95
05-Feb-96
15-May-96

FIGURE 2.6



Phalen 7E GOB Flow Rates
(Mar 22/95 - Feb 7/96)
Total Flow (usgpm)
600
500
400
300
200
100
0
20-Feb-95 01-Apr-95 11-May-95 20-Jun-95 30-Jul-95 08-Sep-95 18-Oct-95 27-Nov-95 06-Jan-96 15-Feb-96 26-Mar-96

FIGURE 2.7

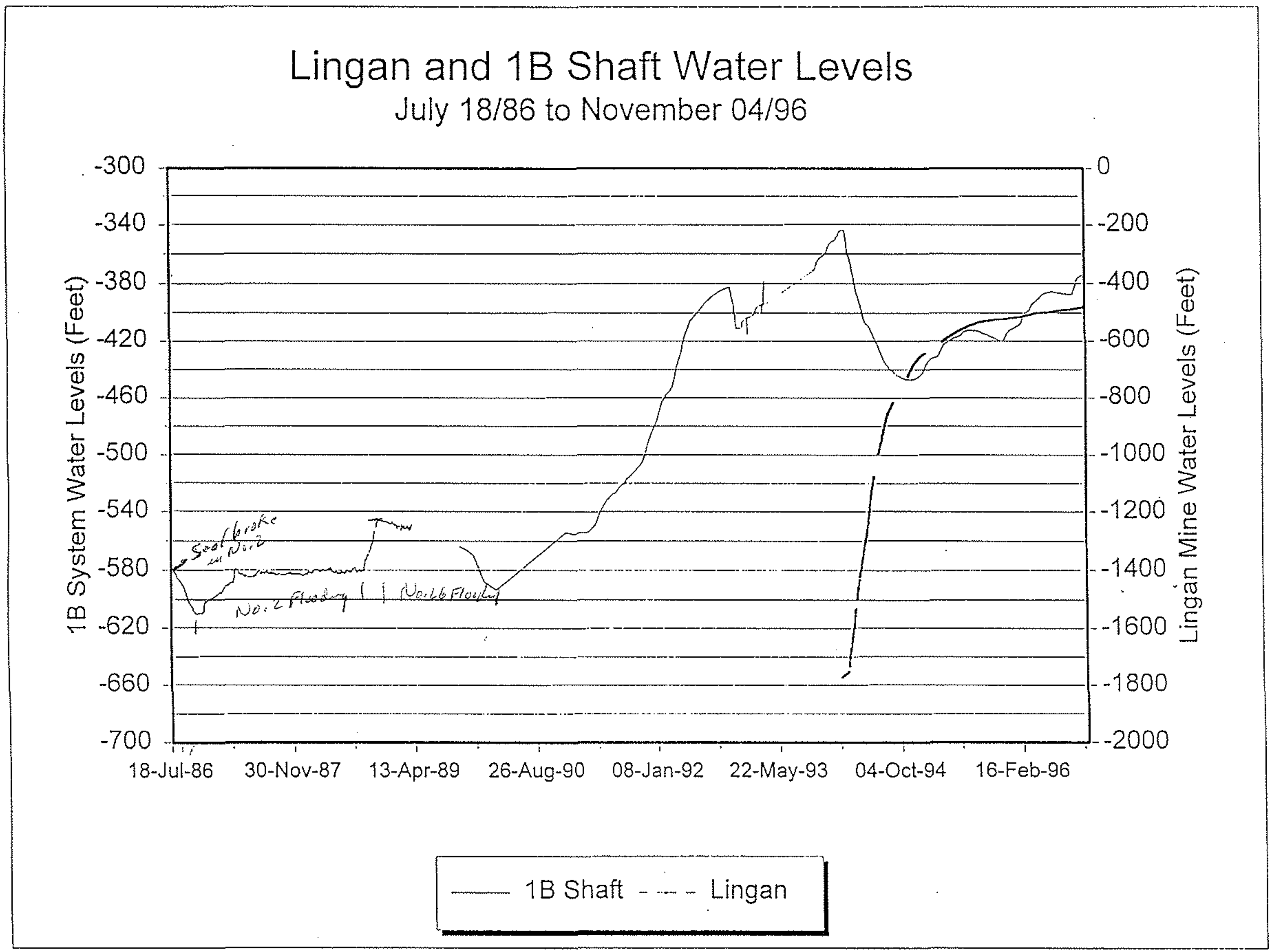
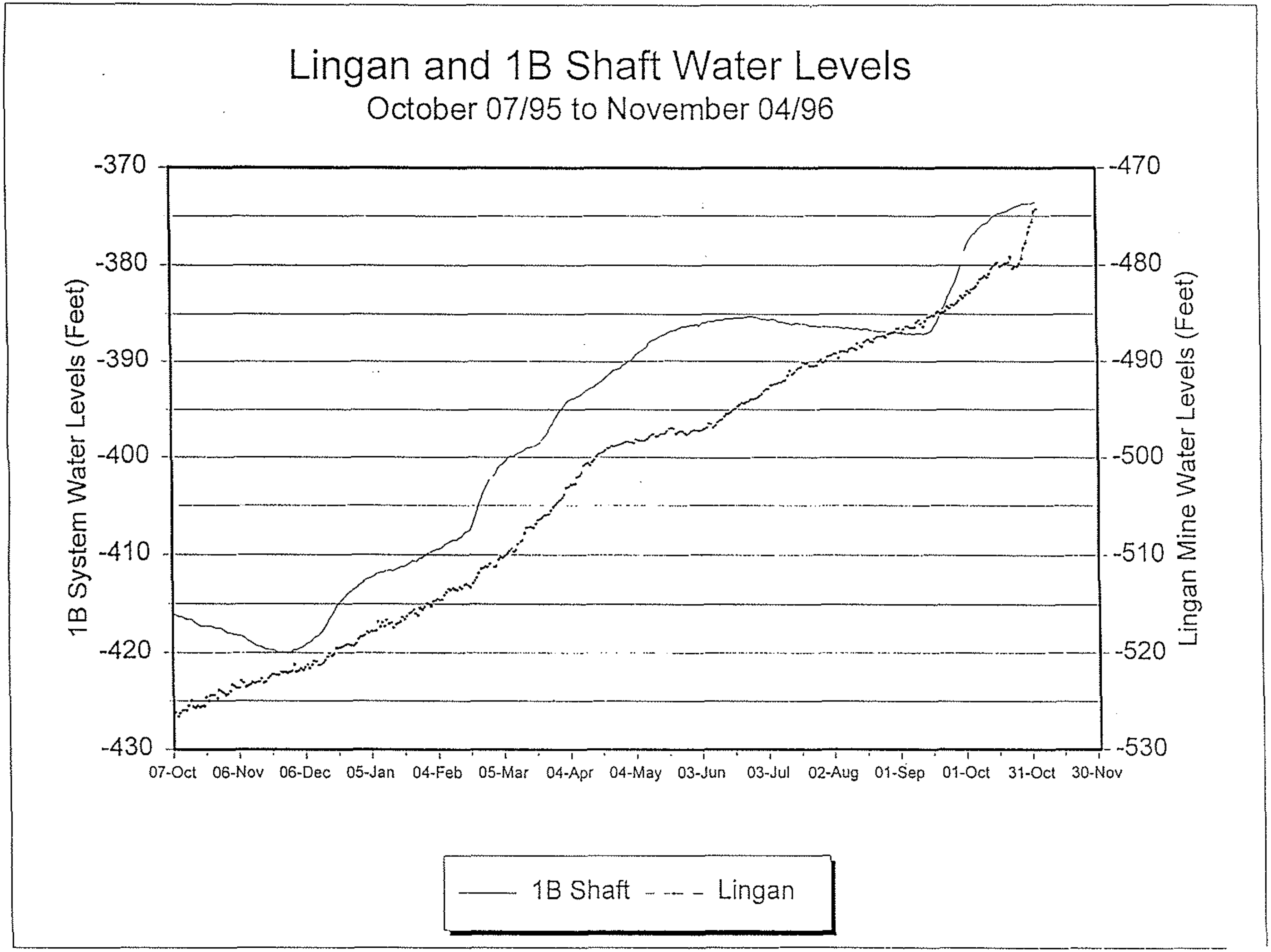

Lingan and 1B Shaft Water Levels
July 18/86 to November 04/96
1B System Water Levels (Feet)
Lingan Mine Water Levels (Feet)
-300
-340
-380
-420
-460
-500
-540
-580
-620
-660
-700
0
-200
-400
-600
-800
-1000
-1200
-1400
-1600
-1800
-2000
18-Jul-86
30-Nov-87
13-Apr-89
26-Aug-90
08-Jan-92
22-May-93
04-Oct-94
16-Feb-96
1B Shaft
Lingan
Seal broke
No. 2 Flooding
No. 1b Flooding

FIGURE 3.1



Lingan and 1B Shaft Water Levels
October 07/95 to November 04/96
1B System Water Levels (Feet)
Lingan Mine Water Levels (Feet)
-370
-380
-390
-400
-410
-420
-430
-470
-480
-490
-500
-510
-520
-530
07-Oct
06-Nov
06-Dec
05-Jan
04-Feb
05-Mar
04-Apr
04-May
03-Jun
03-Jul
02-Aug
01-Sep
01-Oct
31-Oct
30-Nov
1B Shaft
Lingan

FIGURE 3.2

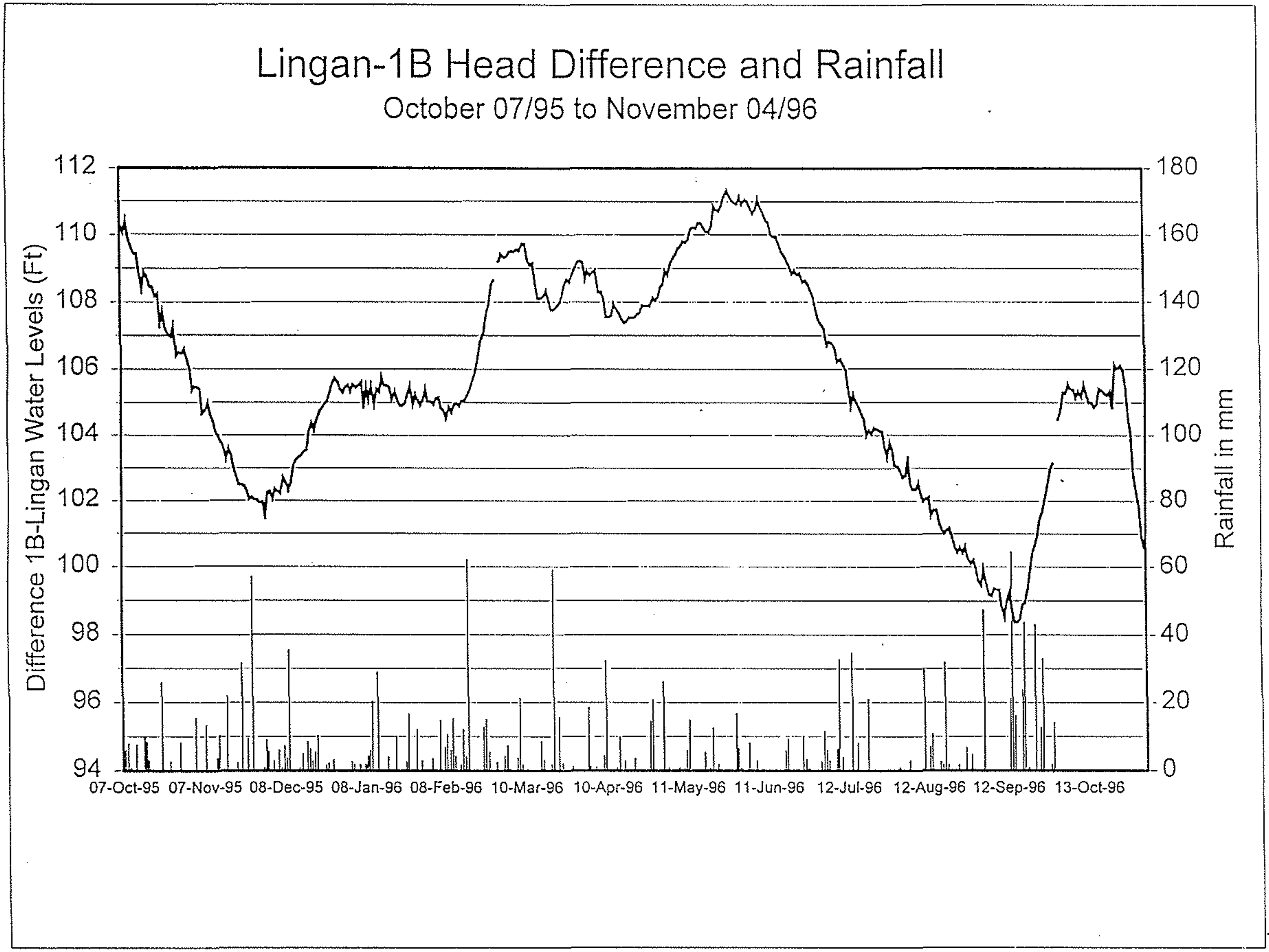

Lingan-1B Head Difference and Rainfall
October 07/95 to November 04/96
Difference 1B-Lingan Water Levels (Ft)
Rainfall in mm
112
110
108
106
104
102
100
98
96
94
180
160
140
120
100
80
60
40
20
0
07-Oct-95
07-Nov-95
08-Dec-95
08-Jan-96
08-Feb-96
10-Mar-96
10-Apr-96
11-May-96
11-Jun-96
12-Jul-96
12-Aug-96
12-Sep-96
13-Oct-96

FIGURE 3.3

No. 4 Quarry Point Mine Water Levels

April 3, 1995 to September 20/96

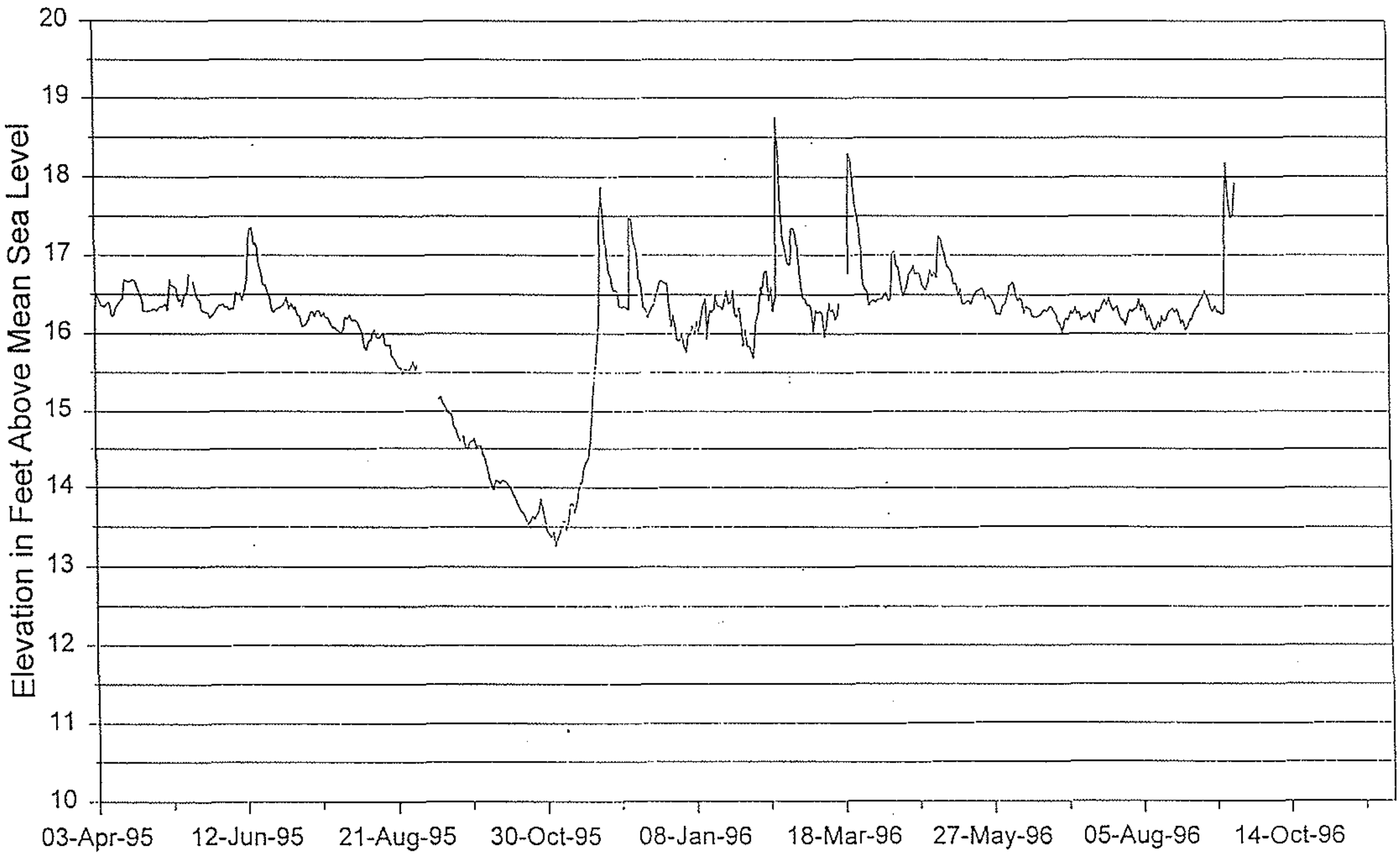


FIGURE 3.4

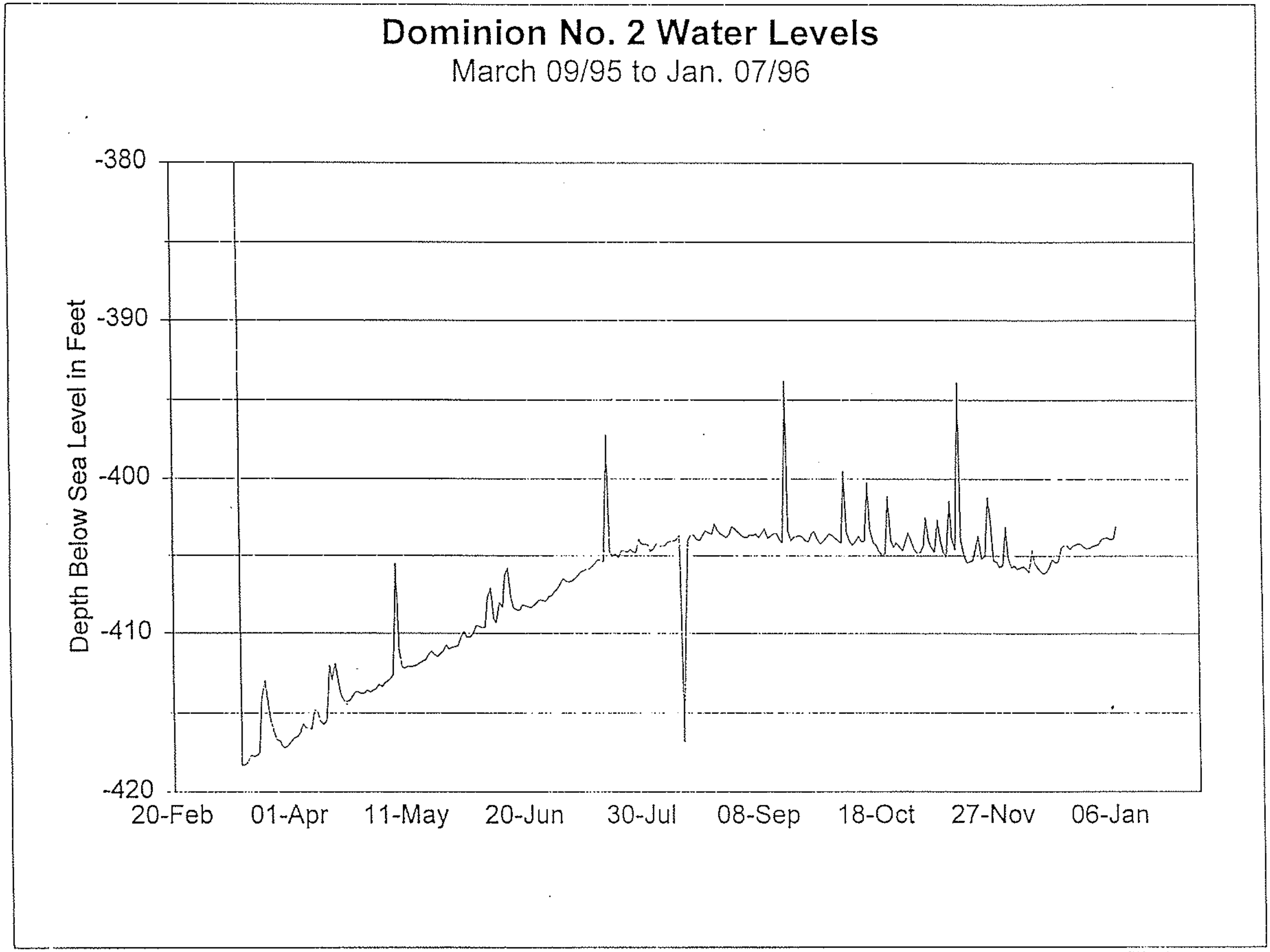
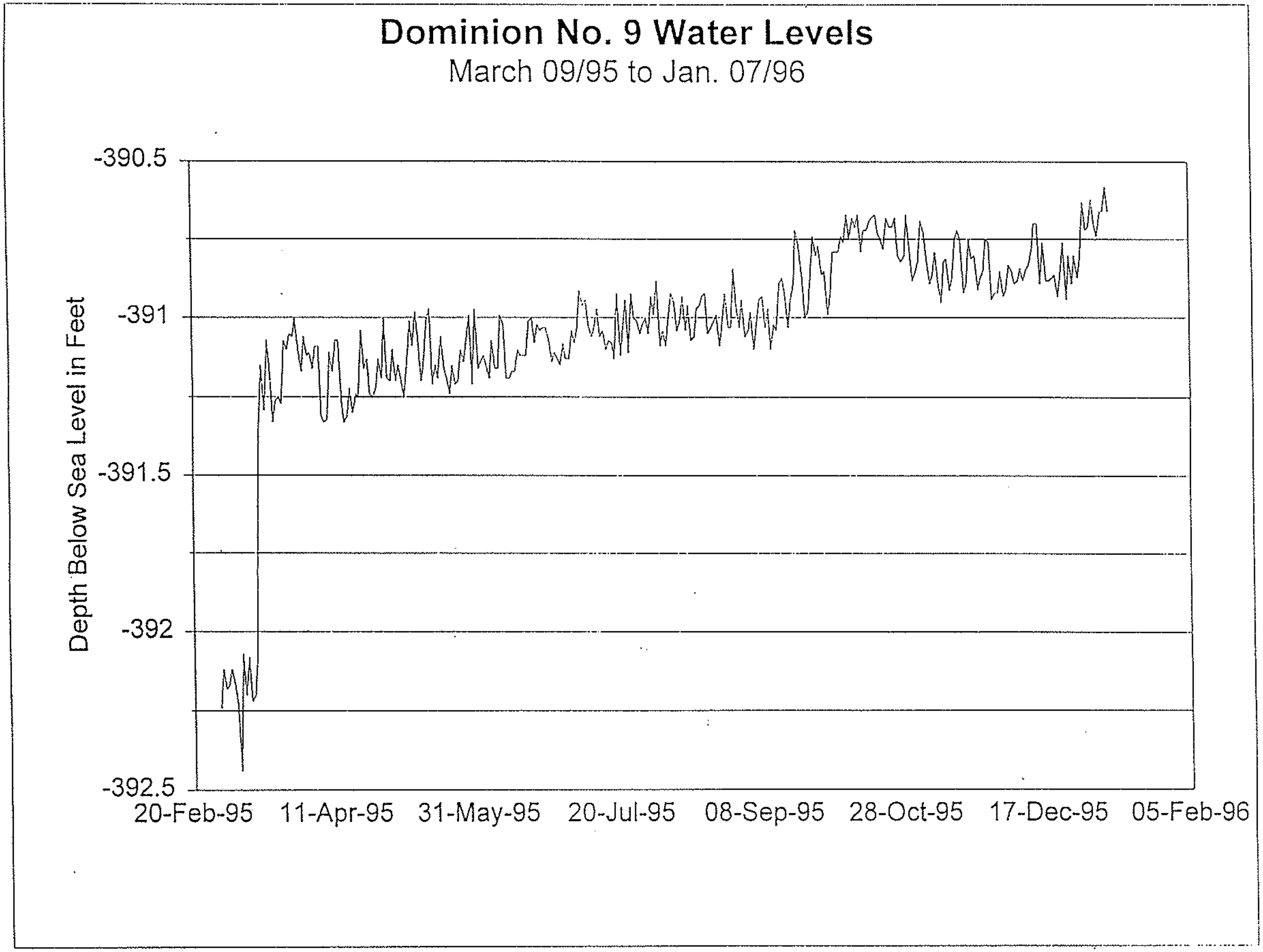
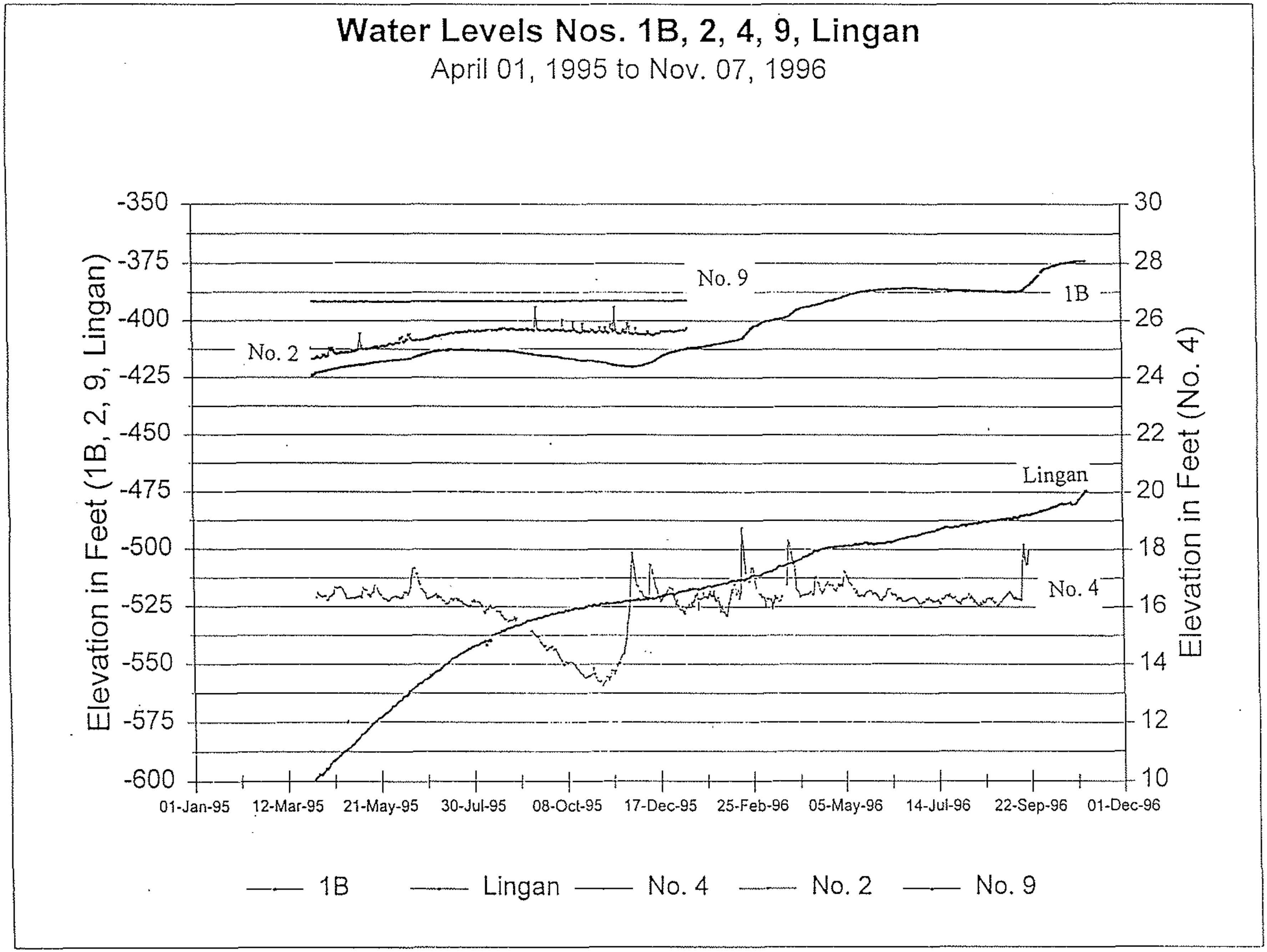

Dominion No. 2 Water Levels
March 09/95 to Jan. 07/96
Depth Below Sea Level in Feet
-380
-390
-400
-410
-420
20-Feb
01-Apr
11-May
20-Jun
30-Jul
08-Sep
18-Oct
27-Nov
06-Jan

FIGURE 3.5



Dominion No. 9 Water Levels
March 09/95 to Jan. 07/96
Depth Below Sea Level in Feet
-390.5
-391
-391.5
-392
-392.5
20-Feb-95
11-Apr-95
31-May-95
20-Jul-95
08-Sep-95
28-Oct-95
17-Dec-95
05-Feb-96

FIGURE 3.6



Water Levels Nos. 1B, 2, 4, 9, Lingan
April 01, 1995 to Nov. 07, 1996
Elevation in Feet (1B, 2, 9, Lingan)
Elevation in Feet (No. 4)
-350
-375
-400
-425
-450
-475
-500
-525
-550
-575
-600
30
28
26
24
22
20
18
16
14
12
10
No. 9
1B
No. 2
Lingan
No. 4
01-Jan-95
12-Mar-95
21-May-95
30-Jul-95
08-Oct-95
17-Dec-95
25-Feb-96
05-May-96
14-Jul-96
22-Sep-96
01-Dec-96
1B
Lingan
No. 4
No. 2
No. 9

FIGURE 3.7

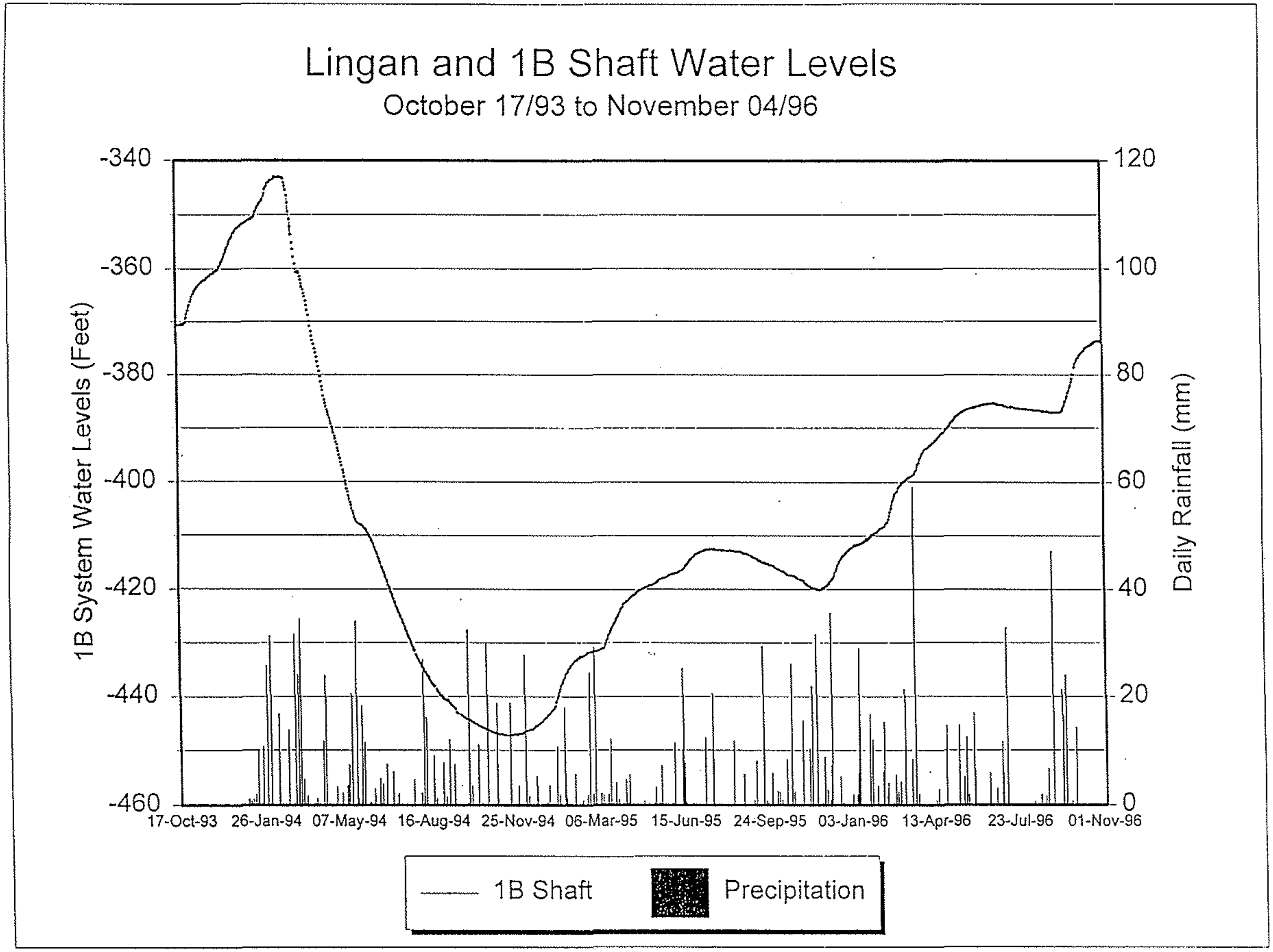

Lingan and 1B Shaft Water Levels
October 17/93 to November 04/96
1B System Water Levels (Feet)
Daily Rainfall (mm)
-340
-360
-380
-400
-420
-440
-460
120
100
80
60
40
20
0
17-Oct-93
26-Jan-94
07-May-94
16-Aug-94
25-Nov-94
06-Mar-95
15-Jun-95
24-Sep-95
03-Jan-96
13-Apr-96
23-Jul-96
01-Nov-96
1B Shaft
Precipitation

FIGURE 3.8

CBDC MINE WATER CHEMISTRY ASSESSMENT
Distribution of Mine Water Major Ion Chemistry

LEGEND

1 7E-Gob
2 7E-Strata
3 6E-Gob
4 6E-Strata
5 5E-Gob
6 4E-Gob
7 1E-Gob
8 Phalen Outfall
9 Lingan Outfall
10 No.4 Outfall
11 Gardiner Outfall
12 1B Pumping
13 1A Bailed
14 Lingan A
15 Lingan 2EB
16 Lingan 3EB
17 SEA
18 Prince Outfall
19 Donkin strata
20 PT. Aconi Strata

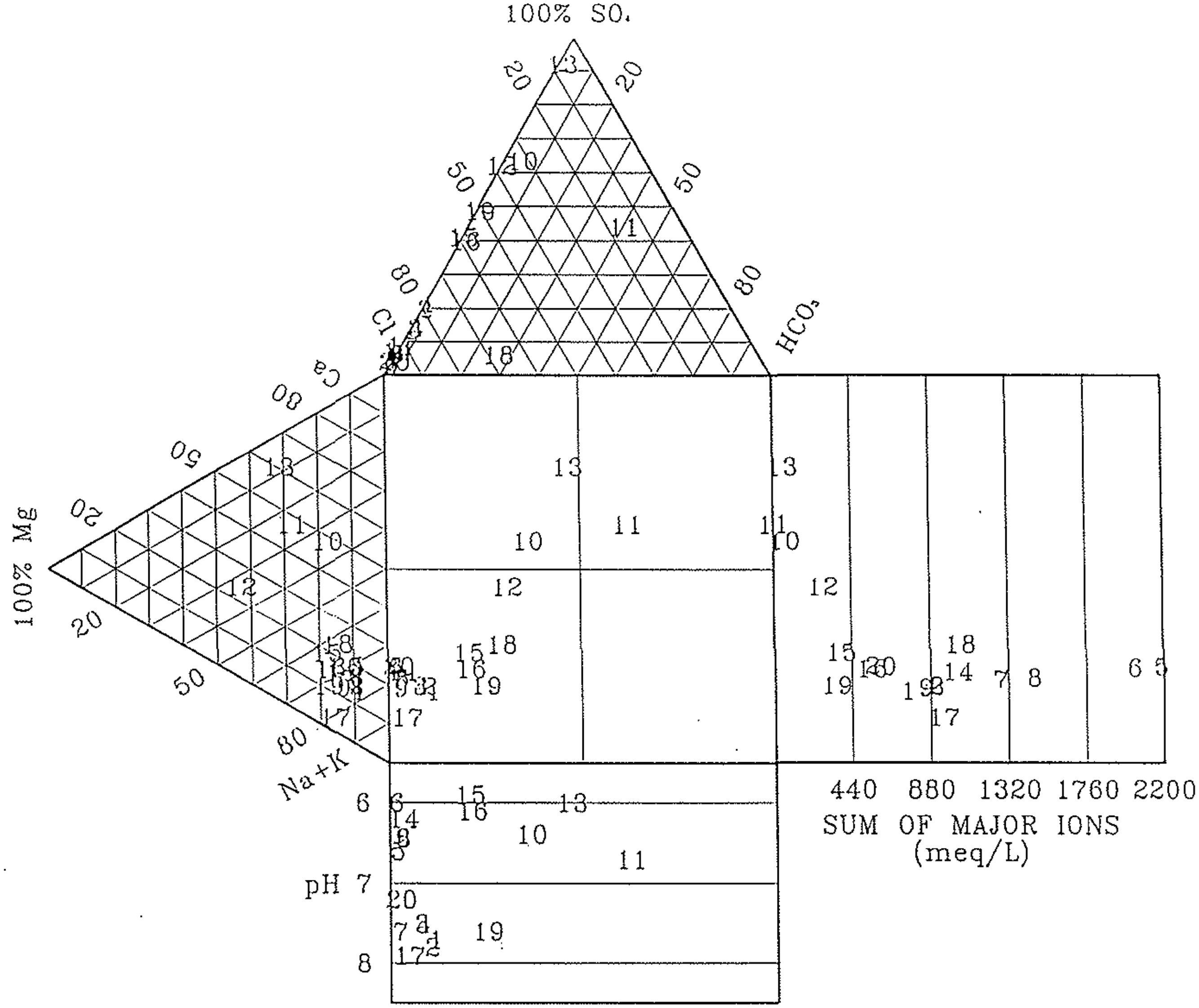
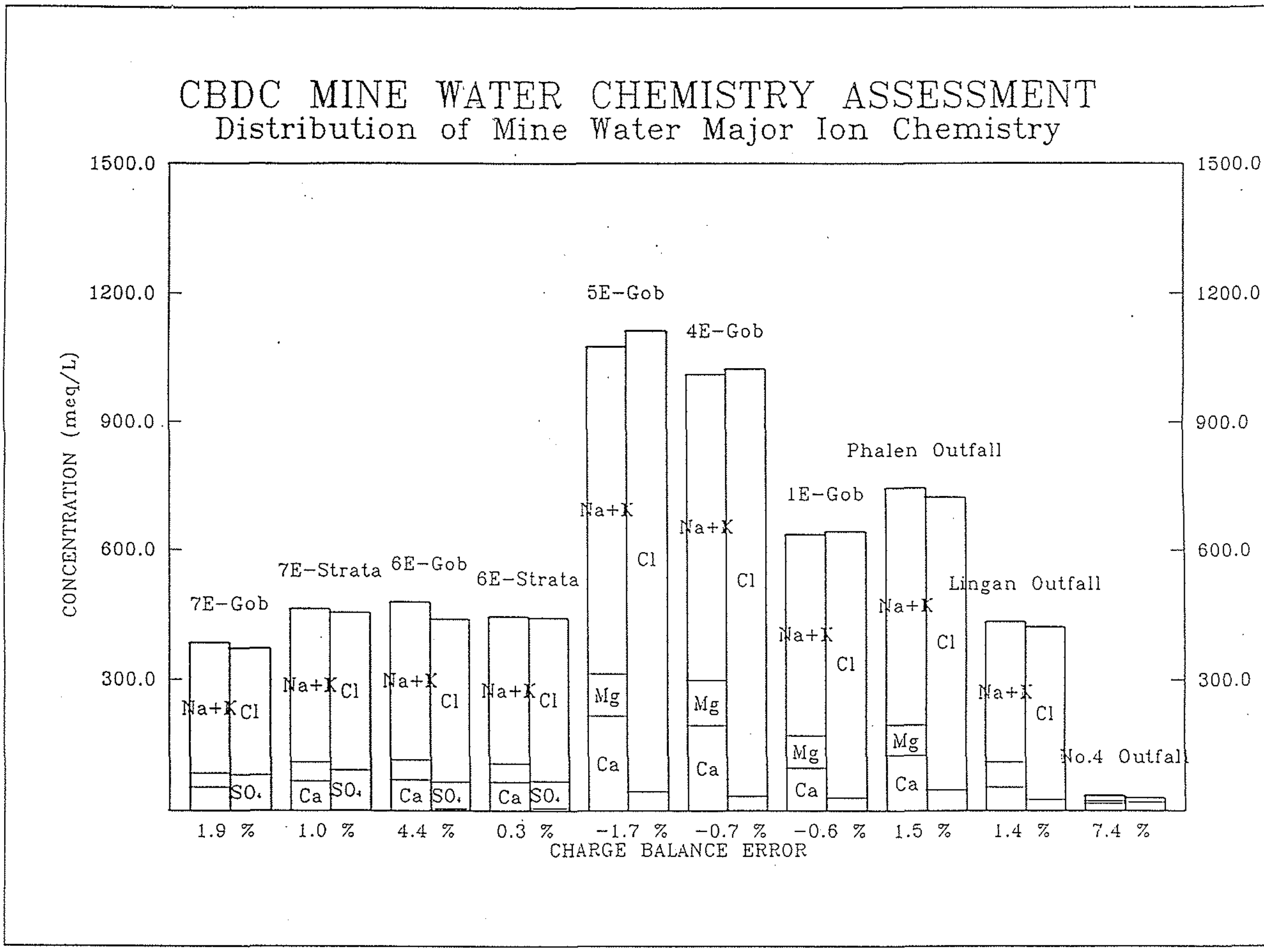


FIGURE 4.1


CBDC MINE WATER CHEMISTRY ASSESSMENT
Distribution of Mine Water Major Ion Chemistry
CONCENTRATION (meq/L)
1500.0
1200.0
900.0
600.0
300.0
7E-Gob
7E-Strata
6E-Gob
6E-Strata
5E-Gob
4E-Gob
1E-Gob
Phalen Outfall
Lingan Outfall
No.4 Outfall
Na+K
Cl
Mg
Ca
SO4
1.9 %
1.0 %
4.4 %
0.3 %
-1.7 %
-0.7 %
-0.6 %
1.5 %
1.4 %
7.4 %
CHARGE BALANCE ERROR

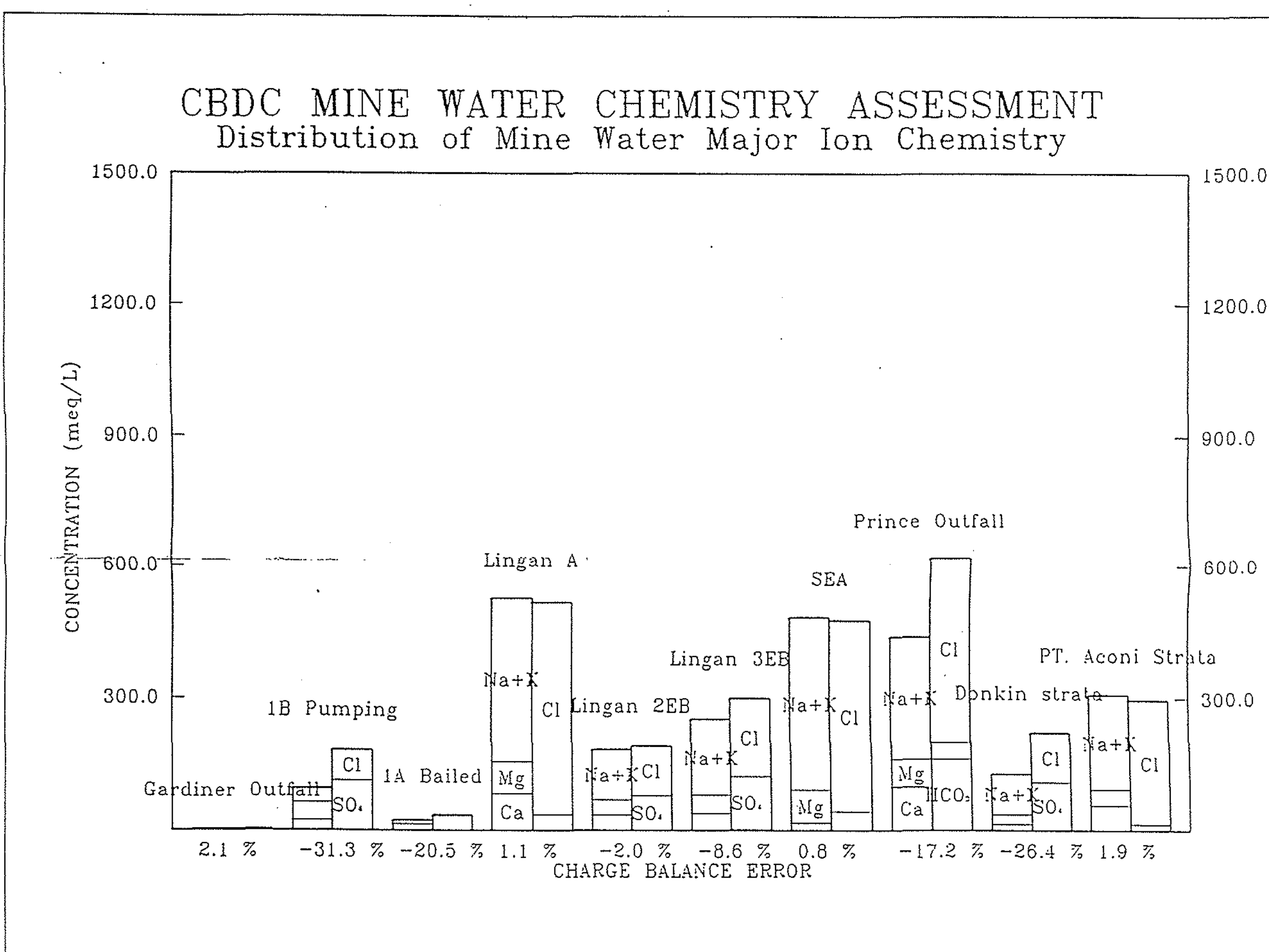
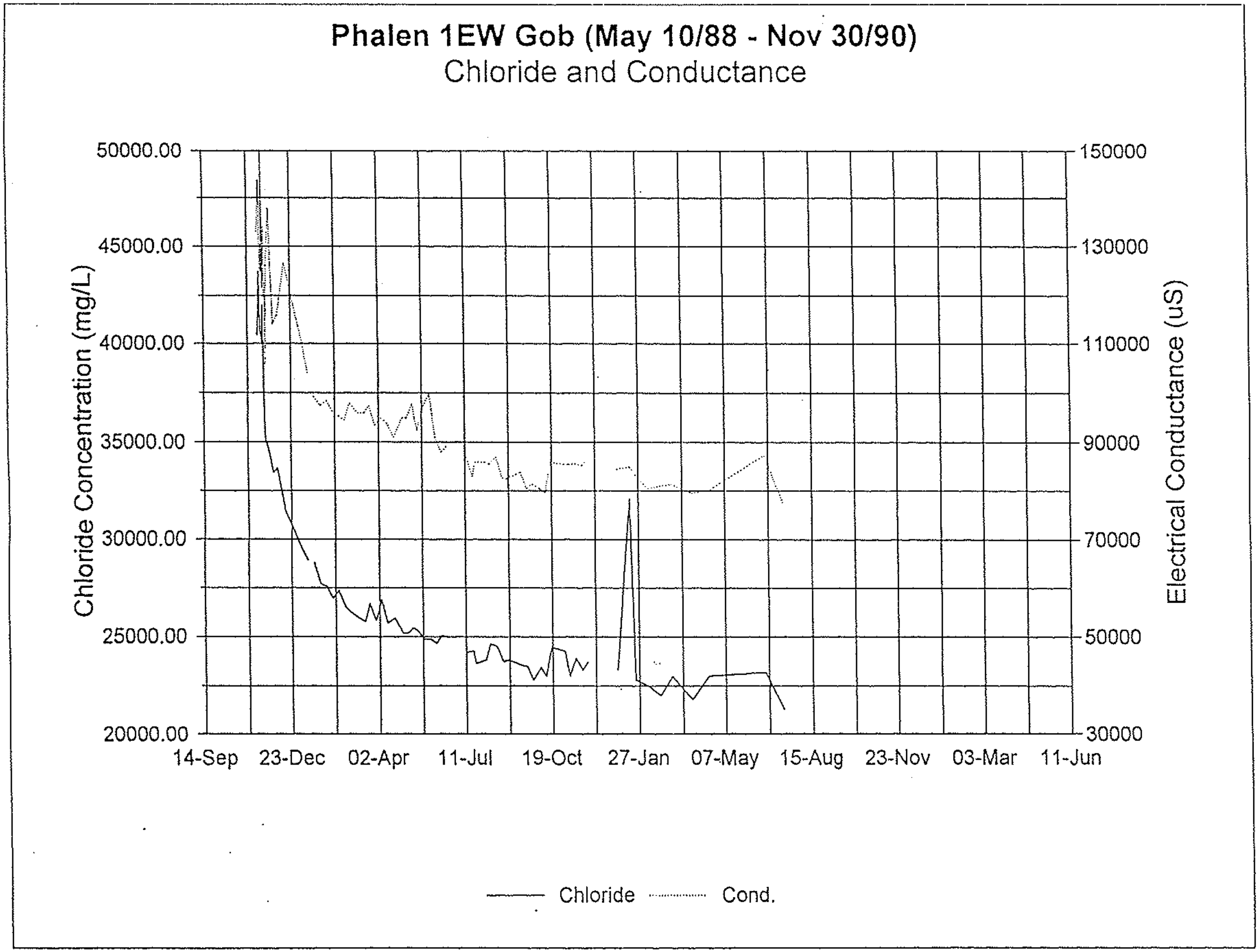
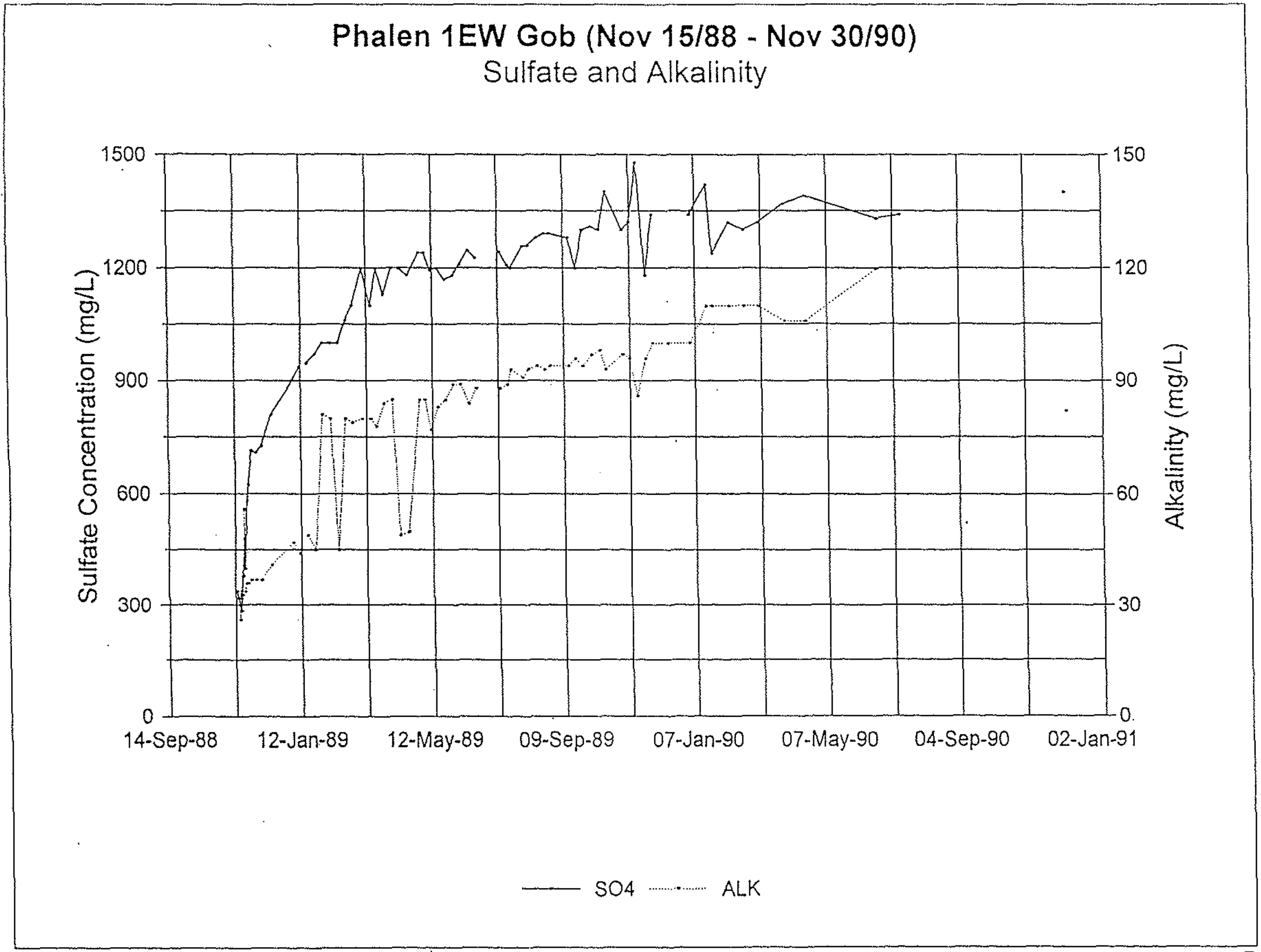

CBDC MINE WATER CHEMISTRY ASSESSMENT
Distribution of Mine Water Major Ion Chemistry
CONCENTRATION (meq/L)
1500.0
1200.0
900.0
600.0
300.0
Gardiner Outfall
1B Pumping
1A Bailed
Lingan A
Lingan 2EB
Lingan 3EB
SEA
Prince Outfall
Donkin strata
PT. Aconi Strata
Na+K
Cl
Mg
Ca
SO4
HCO3
2.1 %
-31.3 %
-20.5 %
1.1 %
-2.0 %
-8.6 %
0.8 %
-17.2 %
-26.4 %
1.9 %
CHARGE BALANCE ERROR

FIGURE 4.2



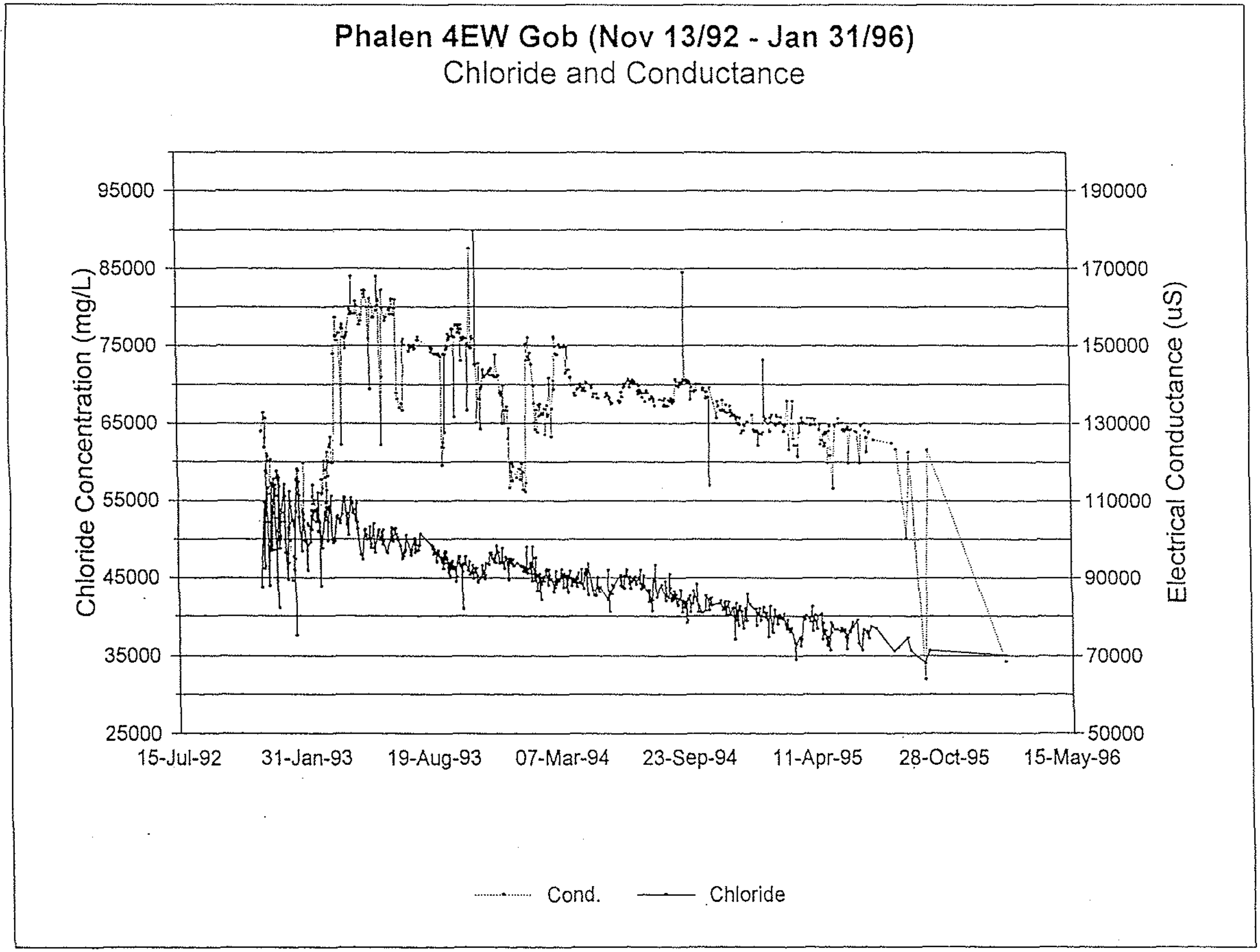
Phalen 1EW Gob (May 10/88 - Nov 30/90)
Chloride and Conductance
Chloride Concentration (mg/L)
50000.00
45000.00
40000.00
35000.00
30000.00
25000.00
20000.00
Electrical Conductance (uS)
150000
130000
110000
90000
70000
50000
30000
14-Sep
23-Dec
02-Apr
11-Jul
19-Oct
27-Jan
07-May
15-Aug
23-Nov
03-Mar
11-Jun
Chloride
Cond.

FIGURE 4.3A



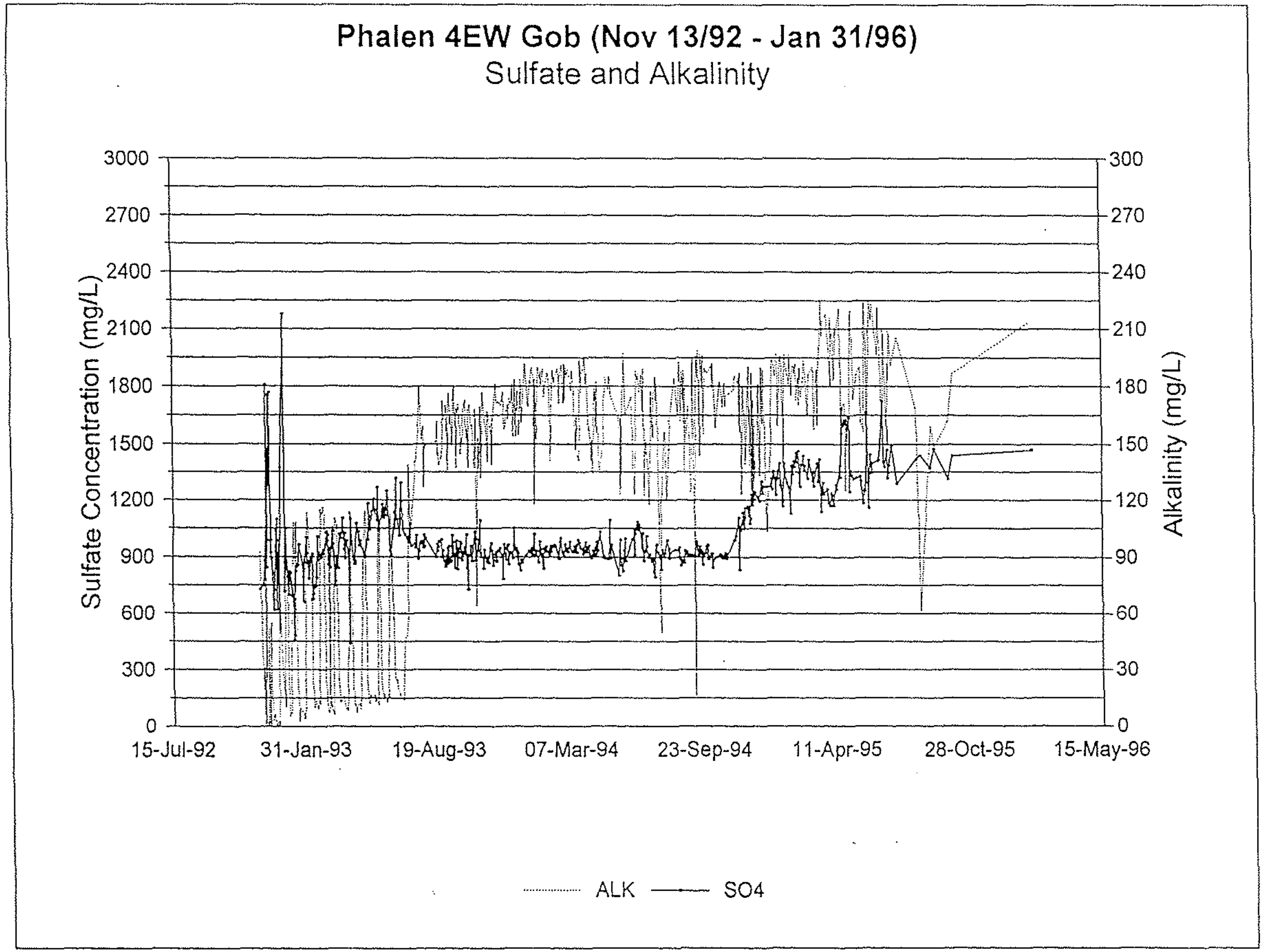
Phalen 1EW Gob (Nov 15/88 - Nov 30/90)
Sulfate and Alkalinity
Sulfate Concentration (mg/L)
Alkalinity (mg/L)
1500
1200
900
600
300
0
150
120
90
60
30
0
14-Sep-88
12-Jan-89
12-May-89
09-Sep-89
07-Jan-90
07-May-90
04-Sep-90
02-Jan-91
SO4
ALK

FIGURE 4.3B



Phalen 4EW Gob (Nov 13/92 - Jan 31/96)
Chloride and Conductance
Chloride Concentration (mg/L)
95000
85000
75000
65000
55000
45000
35000
25000
Electrical Conductance (uS)
190000
170000
150000
130000
110000
90000
70000
50000
15-Jul-92
31-Jan-93
19-Aug-93
07-Mar-94
23-Sep-94
11-Apr-95
28-Oct-95
15-May-96
Cond.
Chloride

FIGURE 4.4A



Phalen 4EW Gob (Nov 13/92 - Jan 31/96)
Sulfate and Alkalinity
Sulfate Concentration (mg/L)
Alkalinity (mg/L)
3000
2700
2400
2100
1800
1500
1200
900
600
300
0
300
270
240
210
180
150
120
90
60
30
0
15-Jul-92
31-Jan-93
19-Aug-93
07-Mar-94
23-Sep-94
11-Apr-95
28-Oct-95
15-May-96
ALK
SO4

FIGURE 4.4B

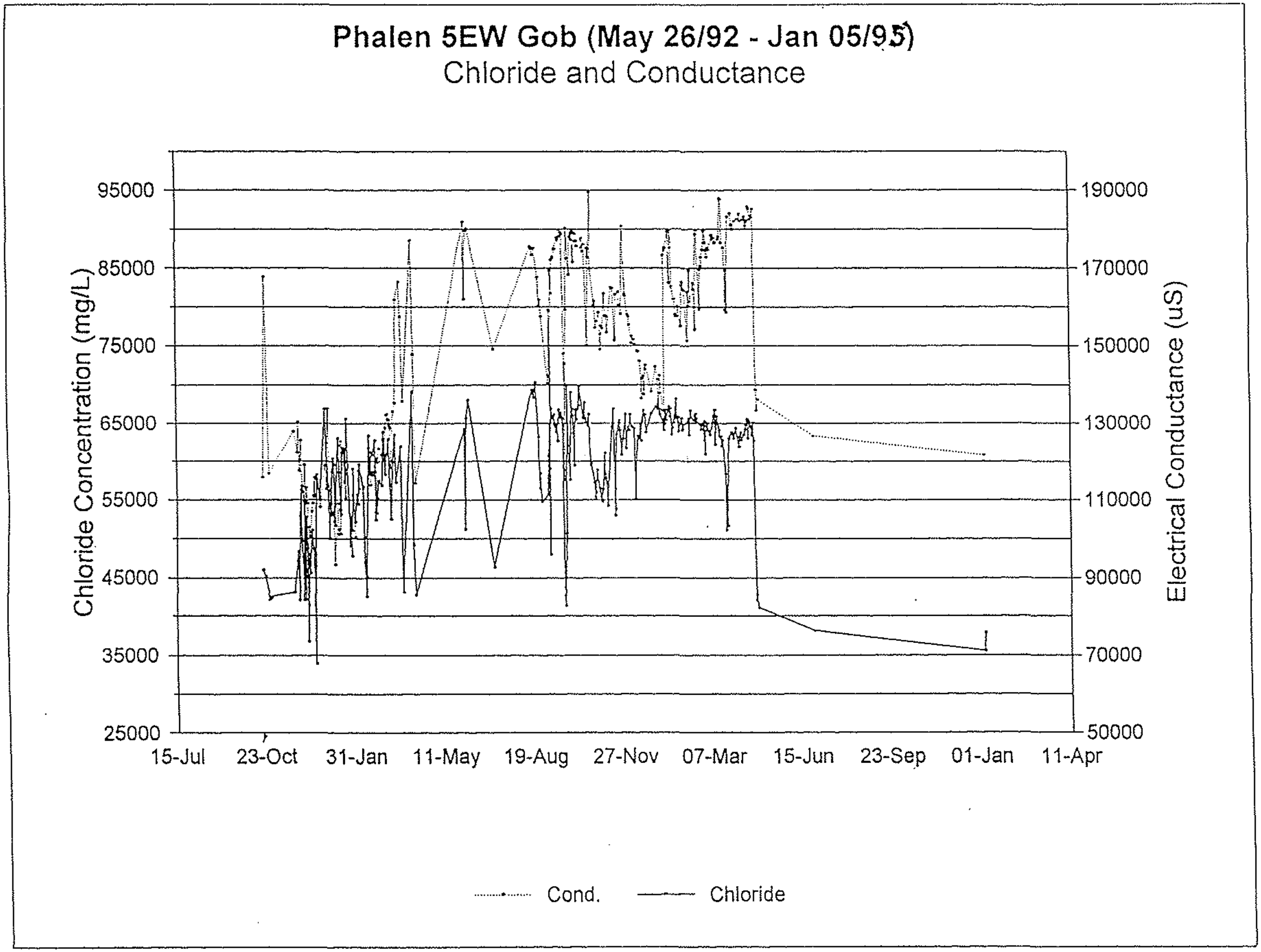
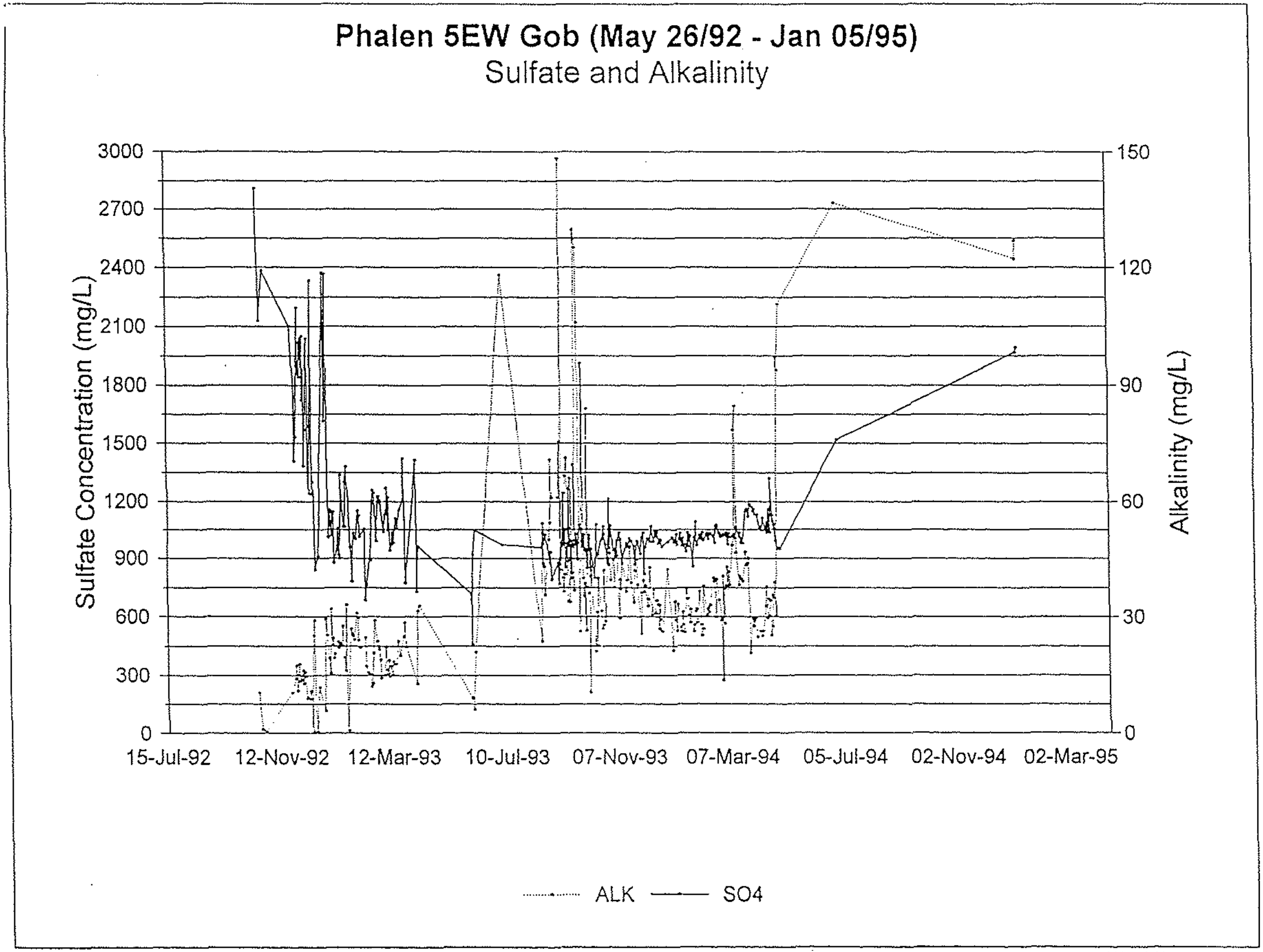
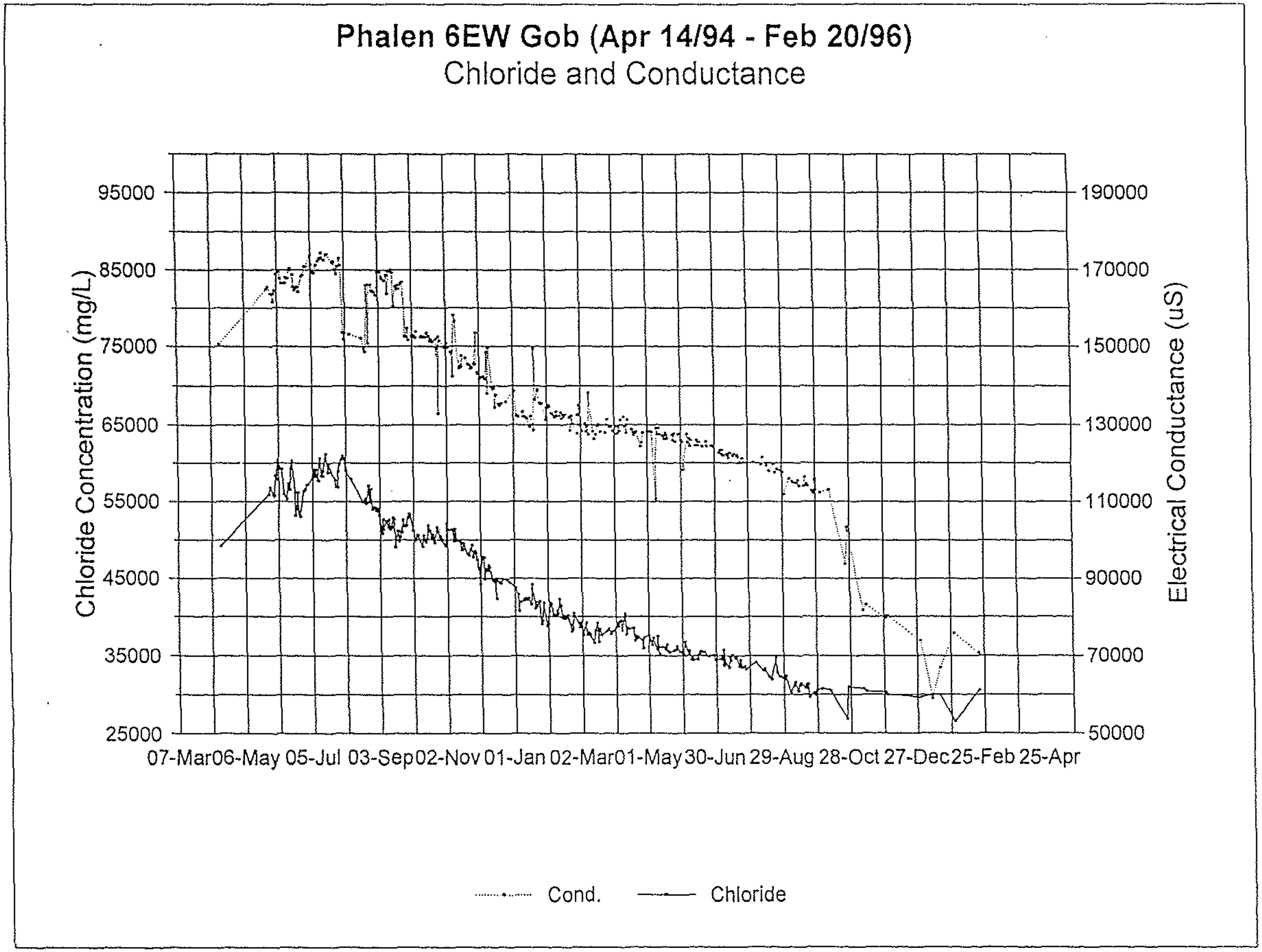

Phalen 5EW Gob (May 26/92 - Jan 05/95)
Chloride and Conductance
Chloride Concentration (mg/L)
Electrical Conductance (uS)
95000
85000
75000
65000
55000
45000
35000
25000
190000
170000
150000
130000
110000
90000
70000
50000
15-Jul
23-Oct
31-Jan
11-May
19-Aug
27-Nov
07-Mar
15-Jun
23-Sep
01-Jan
11-Apr
Cond.
Chloride

FIGURE 4.5A



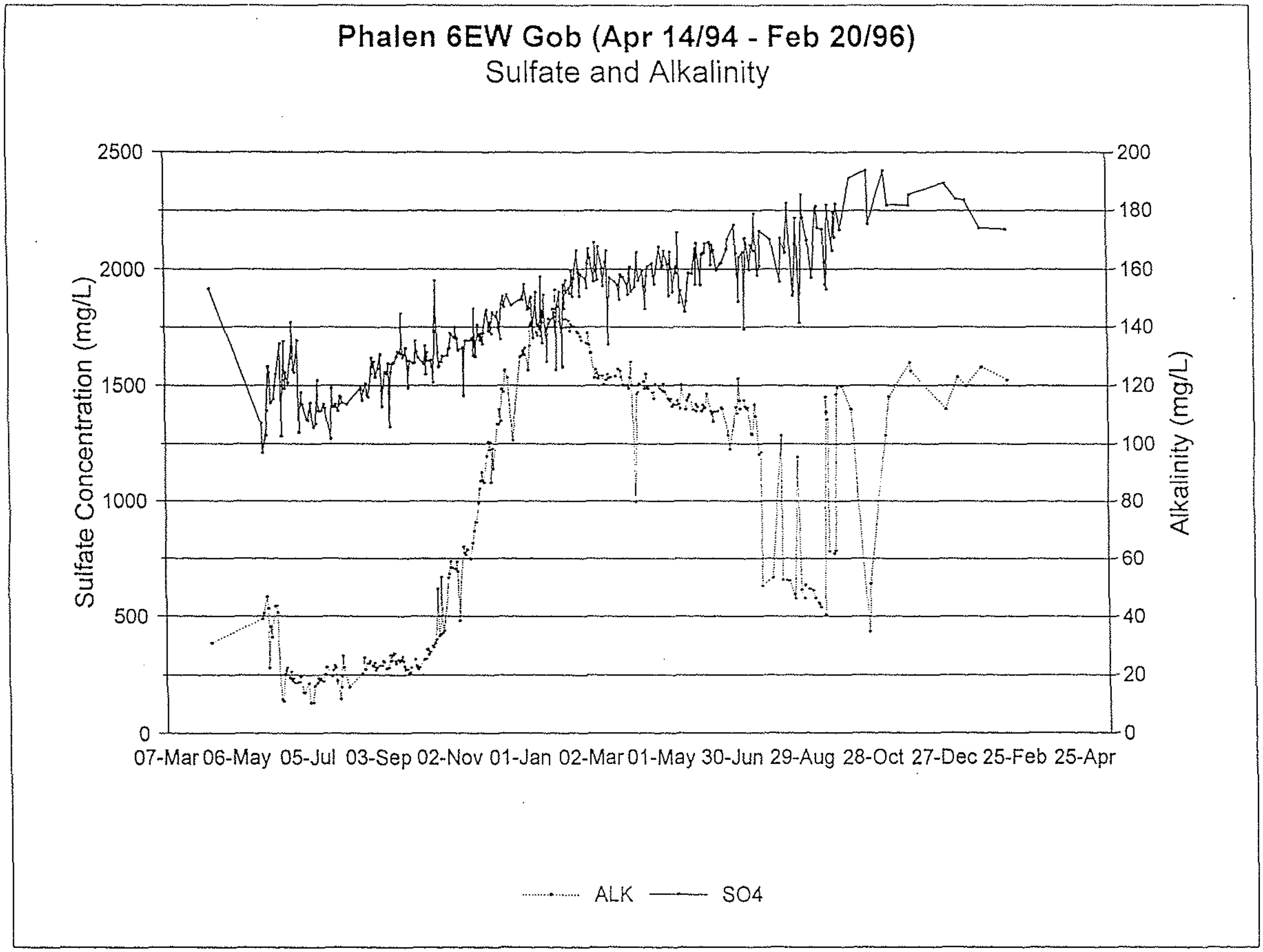
Phalen 5EW Gob (May 26/92 - Jan 05/95)
Sulfate and Alkalinity
Sulfate Concentration (mg/L)
Alkalinity (mg/L)
3000
2700
2400
2100
1800
1500
1200
900
600
300
0
150
120
90
60
30
0
15-Jul-92
12-Nov-92
12-Mar-93
10-Jul-93
07-Nov-93
07-Mar-94
05-Jul-94
02-Nov-94
02-Mar-95
ALK
SO4

FIGURE 4.5B



Phalen 6EW Gob (Apr 14/94 - Feb 20/96)
Chloride and Conductance
Chloride Concentration (mg/L)
Electrical Conductance (uS)
95000
85000
75000
65000
55000
45000
35000
25000
190000
170000
150000
130000
110000
90000
70000
50000
07-Mar 06-May 05-Jul 03-Sep 02-Nov 01-Jan 02-Mar 01-May 30-Jun 29-Aug 28-Oct 27-Dec 25-Feb 25-Apr
Cond.
Chloride

FIGURE 4.6A



Phalen 6EW Gob (Apr 14/94 - Feb 20/96)
Sulfate and Alkalinity
Sulfate Concentration (mg/L)
Alkalinity (mg/L)
2500
2000
1500
1000
500
0
200
180
160
140
120
100
80
60
40
20
0
07-Mar 06-May 05-Jul 03-Sep 02-Nov 01-Jan 02-Mar 01-May 30-Jun 29-Aug 28-Oct 27-Dec 25-Feb 25-Apr
ALK
SO4

FIGURE 4.6B

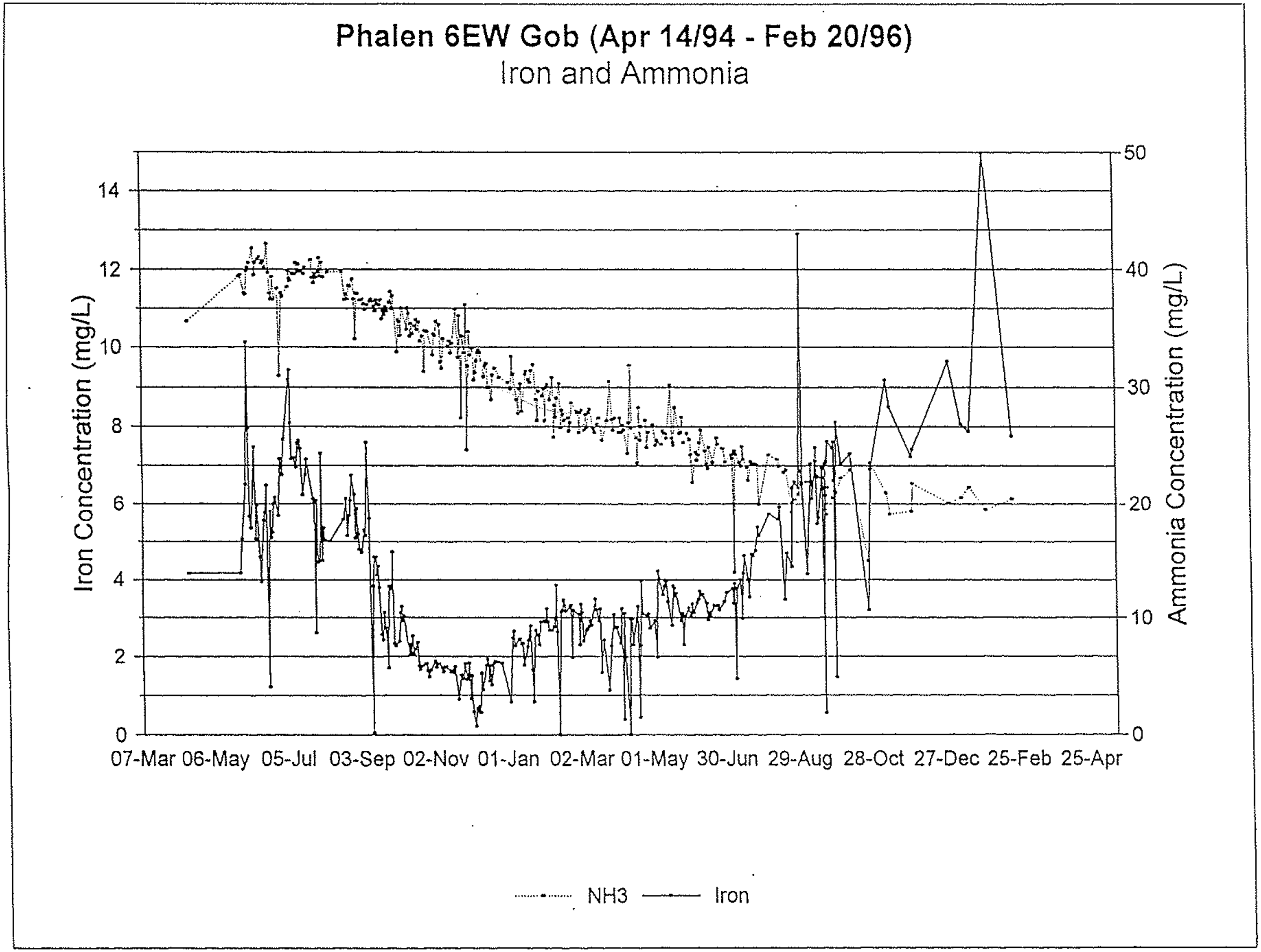

Phalen 6EW Gob (Apr 14/94 - Feb 20/96)
Iron and Ammonia
Iron Concentration (mg/L)
Ammonia Concentration (mg/L)
0
2
4
6
8
10
12
14
0
10
20
30
40
50
07-Mar 06-May 05-Jul 03-Sep 02-Nov 01-Jan 02-Mar 01-May 30-Jun 29-Aug 28-Oct 27-Dec 25-Feb 25-Apr
NH3
Iron

FIGURE 4.6 C

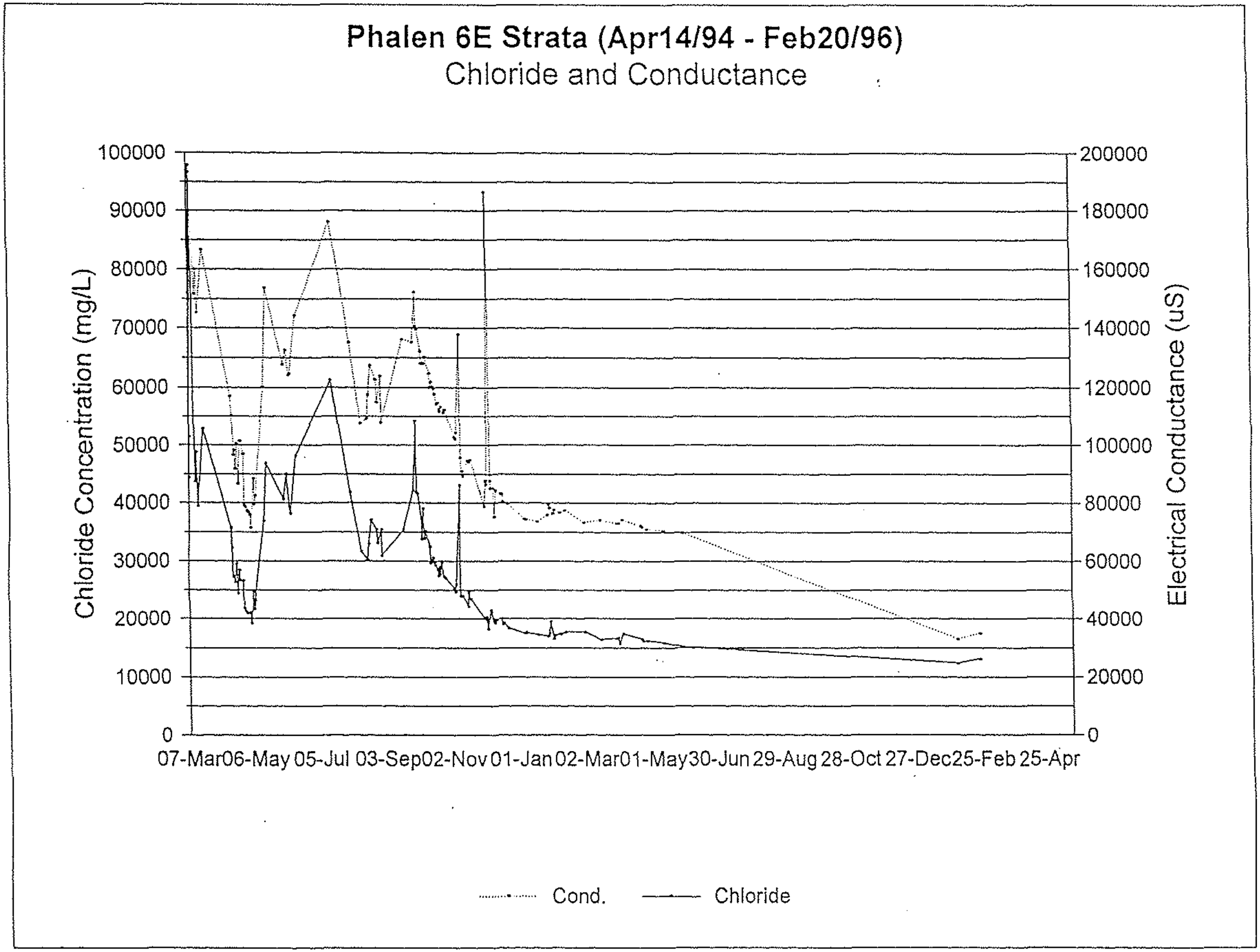
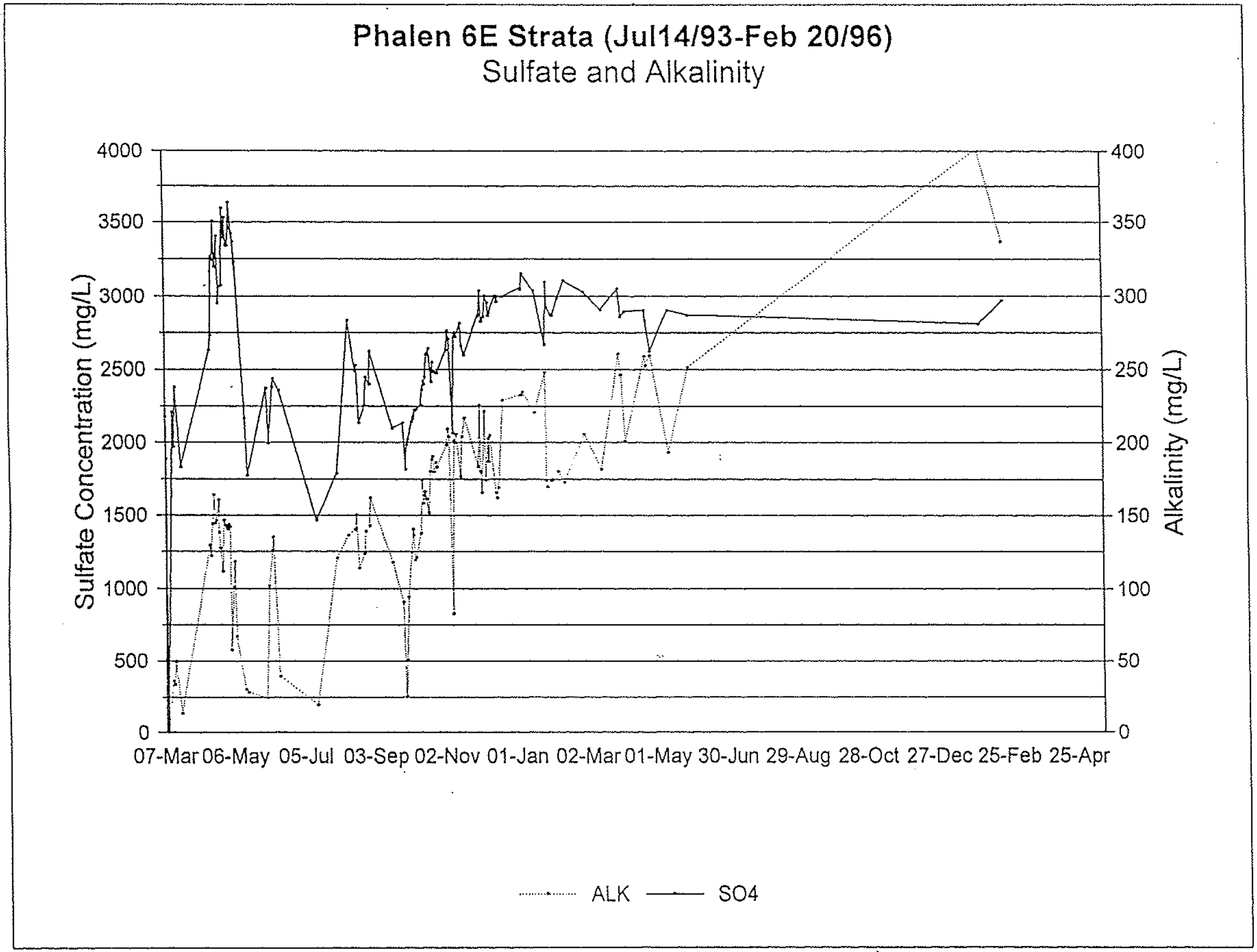

Phalen 6E Strata (Apr14/94 - Feb20/96)
Chloride and Conductance
Chloride Concentration (mg/L)
Electrical Conductance (uS)
100000
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
200000
180000
160000
140000
120000
100000
80000
60000
40000
20000
0
07-Mar 06-May 05-Jul 03-Sep 02-Nov 01-Jan 02-Mar 01-May 30-Jun 29-Aug 28-Oct 27-Dec 25-Feb 25-Apr
Cond.
Chloride

FIGURE 4.7A



Phalen 6E Strata (Jul14/93-Feb 20/96)
Sulfate and Alkalinity
Sulfate Concentration (mg/L)
Alkalinity (mg/L)
4000
3500
3000
2500
2000
1500
1000
500
0
400
350
300
250
200
150
100
50
0
07-Mar 06-May 05-Jul 03-Sep 02-Nov 01-Jan 02-Mar 01-May 30-Jun 29-Aug 28-Oct 27-Dec 25-Feb 25-Apr
ALK
SO4

FIGURE 4.7B

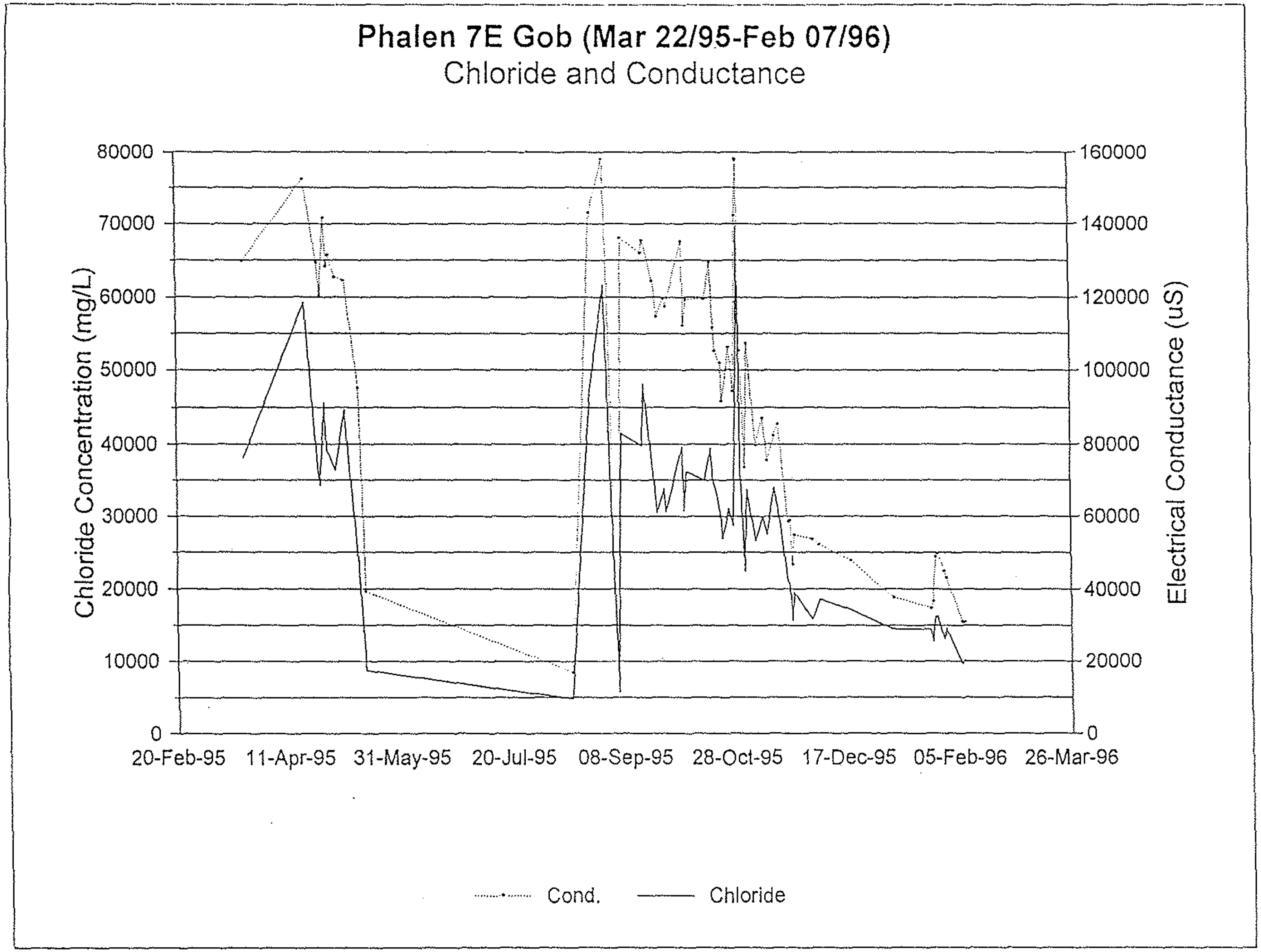
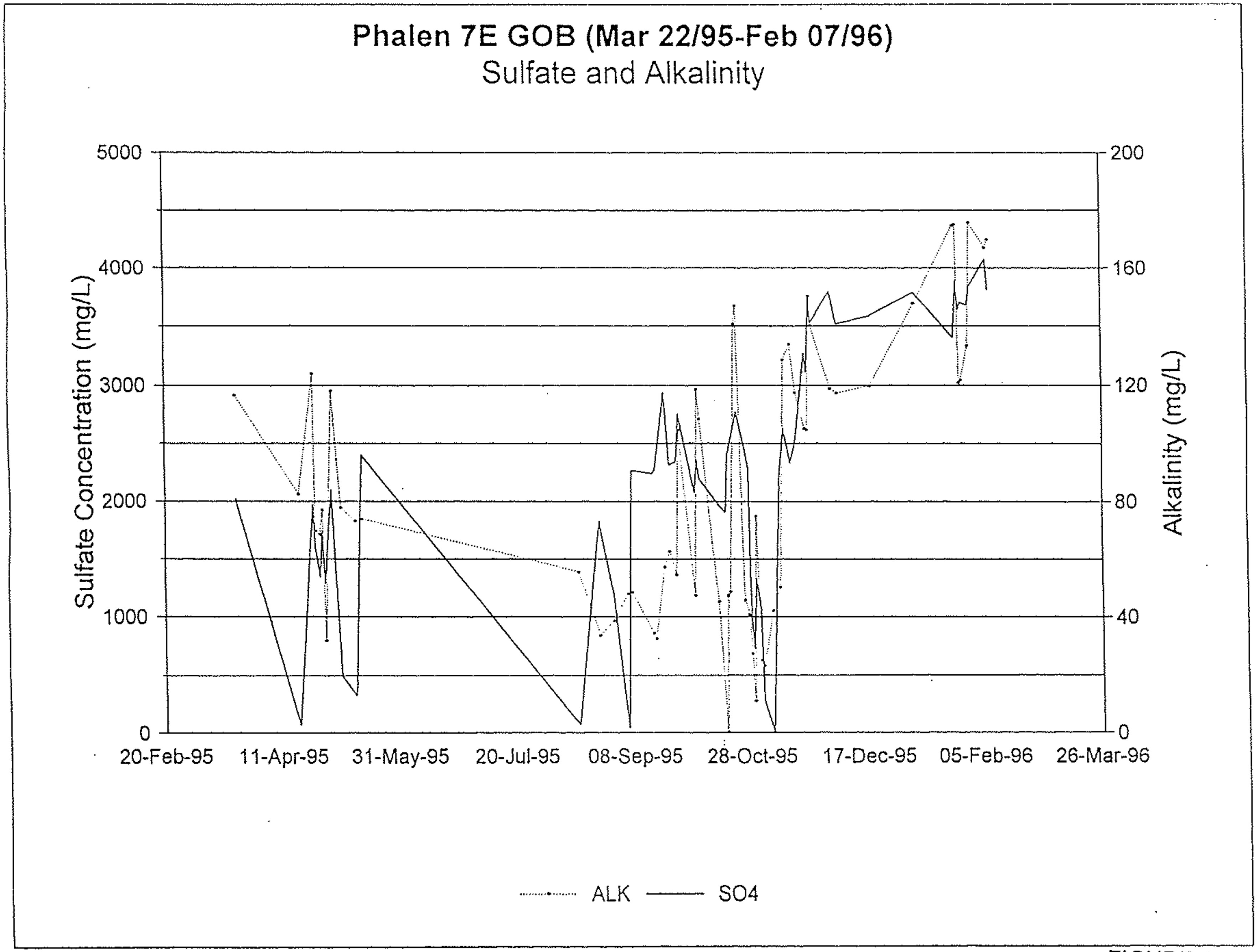
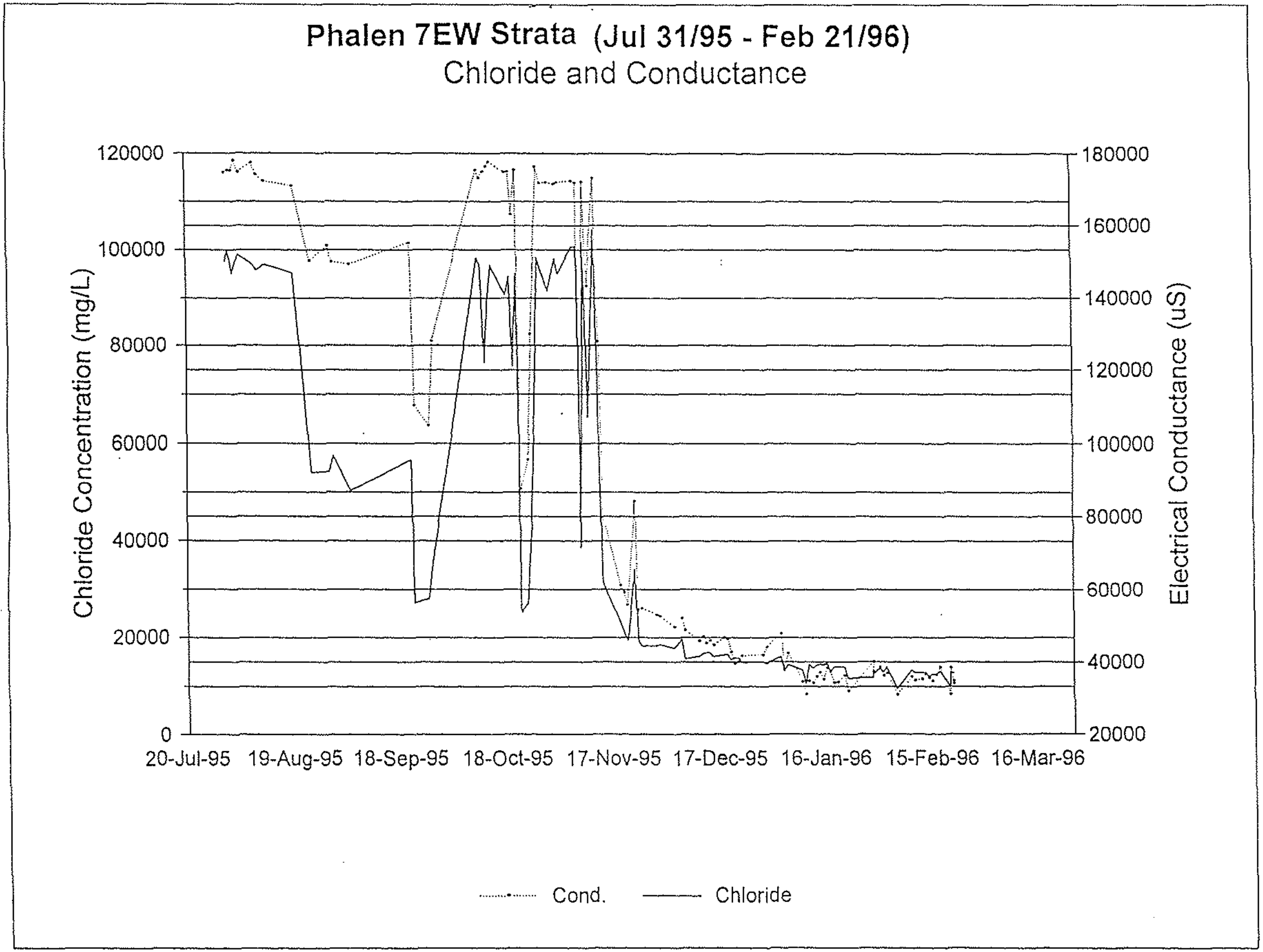

Phalen 7E Gob (Mar 22/95-Feb 07/96)
Chloride and Conductance
Chloride Concentration (mg/L)
Electrical Conductance (uS)
80000
70000
60000
50000
40000
30000
20000
10000
0
160000
140000
120000
100000
80000
60000
40000
20000
0
20-Feb-95
11-Apr-95
31-May-95
20-Jul-95
08-Sep-95
28-Oct-95
17-Dec-95
05-Feb-96
26-Mar-96
Cond.
Chloride

FIGURE 4.8A



Phalen 7E GOB (Mar 22/95-Feb 07/96)
Sulfate and Alkalinity
Sulfate Concentration (mg/L)
Alkalinity (mg/L)
5000
4000
3000
2000
1000
0
200
160
120
80
40
0
20-Feb-95
11-Apr-95
31-May-95
20-Jul-95
08-Sep-95
28-Oct-95
17-Dec-95
05-Feb-96
26-Mar-96
ALK
SO4

FIGURE 4.8B



Phalen 7EW Strata (Jul 31/95 - Feb 21/96)
Chloride and Conductance
Chloride Concentration (mg/L)
Electrical Conductance (uS)
120000
100000
80000
60000
40000
20000
0
180000
160000
140000
120000
100000
80000
60000
40000
20000
20-Jul-95
19-Aug-95
18-Sep-95
18-Oct-95
17-Nov-95
17-Dec-95
16-Jan-96
15-Feb-96
16-Mar-96
Cond.
Chloride

FIGURE 4.9A

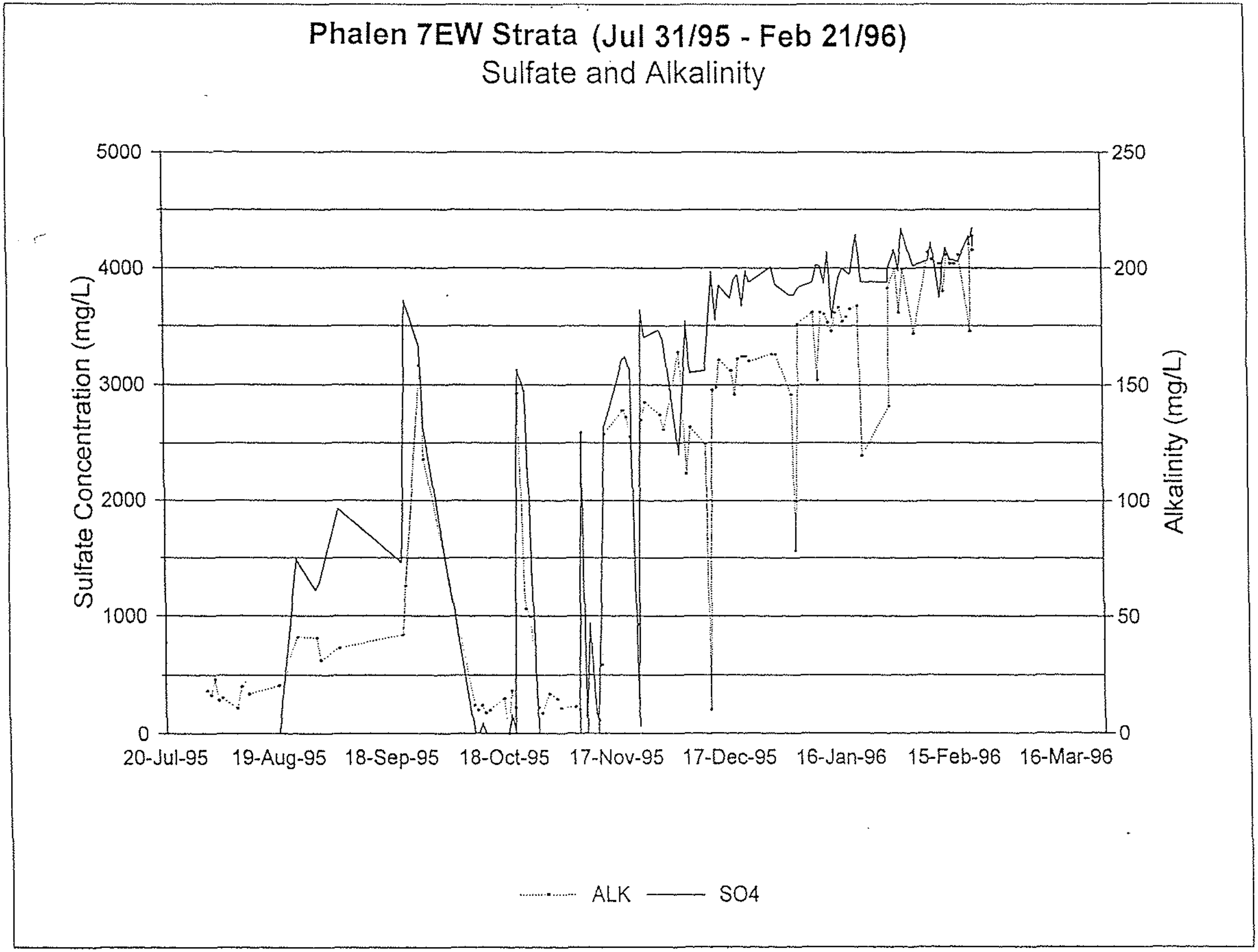

Phalen 7EW Strata (Jul 31/95 - Feb 21/96)
Sulfate and Alkalinity
Sulfate Concentration (mg/L)
Alkalinity (mg/L)
5000
4000
3000
2000
1000
0
250
200
150
100
50
0
20-Jul-95
19-Aug-95
18-Sep-95
18-Oct-95
17-Nov-95
17-Dec-95
16-Jan-96
15-Feb-96
16-Mar-96
ALK
SO4

FIGURE 4.9B

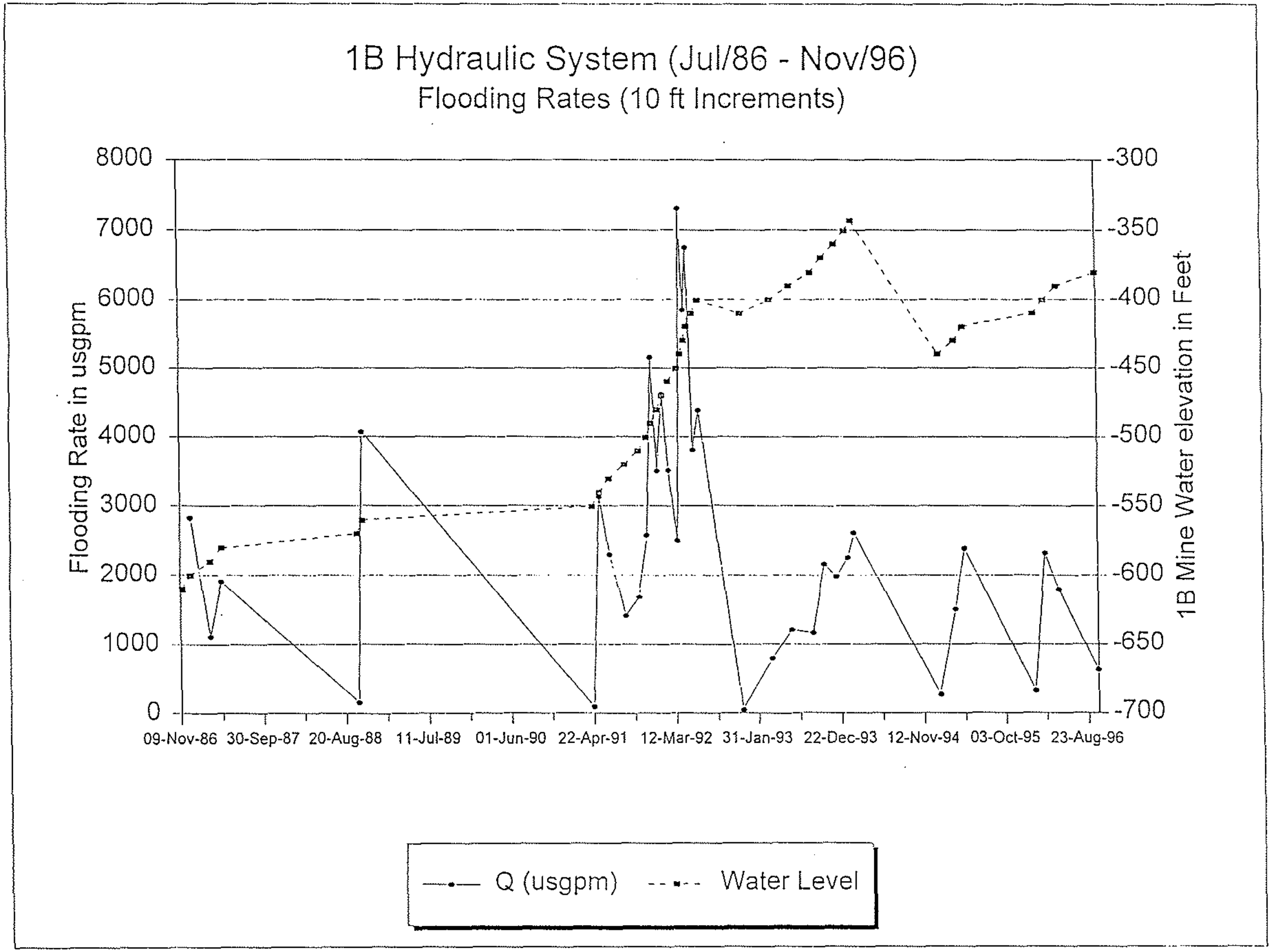

1B Hydraulic System (Jul/86 - Nov/96)
Flooding Rates (10 ft Increments)
Flooding Rate in usgpm
1B Mine Water elevation in Feet
8000
7000
6000
5000
4000
3000
2000
1000
0
-300
-350
-400
-450
-500
-550
-600
-650
-700
09-Nov-86
30-Sep-87
20-Aug-88
11-Jul-89
01-Jun-90
22-Apr-91
12-Mar-92
31-Jan-93
22-Dec-93
12-Nov-94
03-Oct-95
23-Aug-96
Q (usgpm)
Water Level

FIGURE 6.1

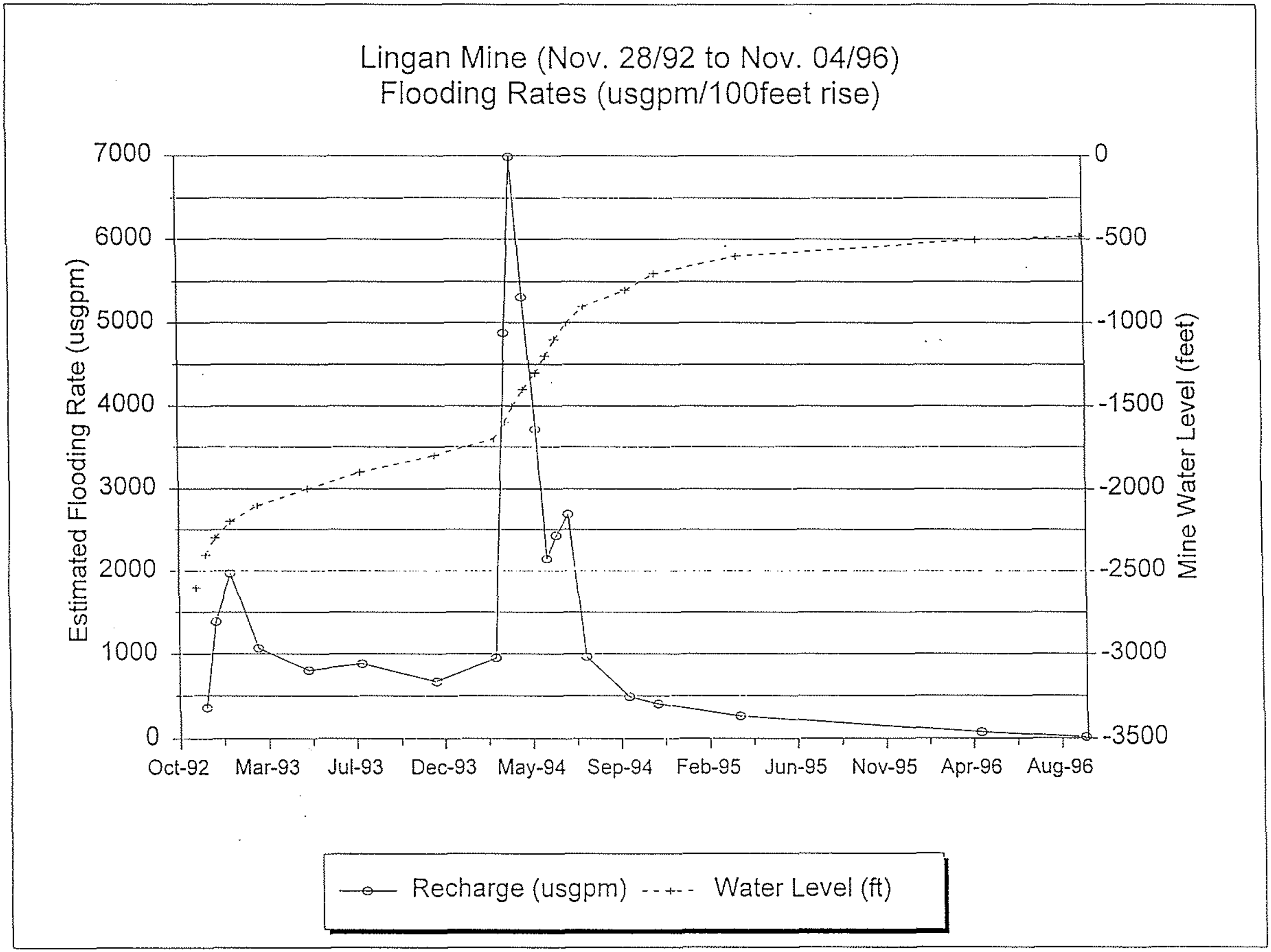

Lingan Mine (Nov. 28/92 to Nov. 04/96)
Flooding Rates (usgpm/100feet rise)
Estimated Flooding Rate (usgpm)
Mine Water Level (feet)
7000
6000
5000
4000
3000
2000
1000
0
0
-500
-1000
-1500
-2000
-2500
-3000
-3500
Oct-92
Mar-93
Jul-93
Dec-93
May-94
Sep-94
Feb-95
Jun-95
Nov-95
Apr-96
Aug-96
Recharge (usgpm)
Water Level (ft)

FIGURE 6.2