1990

Hydrogeological investigation and analysis of a major inundation at Kemira Colliery

Peter William Whittall

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HYDROGEOLOGICAL INVESTIGATION

AND

ANALYSIS OF A MAJOR INUNDATION

AT

KEMIRA COLLIERY

BY

PETER WILLIAM WHITTLALL

A thesis submitted in partial fulfilment of the requirements for the award of the degree of

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Love and special thanks must go to my wife, Leanne, for her support and encouragement throughout the entirety of my studies.
ABSTRACT

Kemira Colliery had been experiencing increasing problematic water inflows at the inbye end of the last pillar extraction panel (W24) and then in subsequent longwall panels. The inflows had never reached a flow rate sufficient to cause delays in production or any other major problems. Pump lines were maintained in the gate roads to remove goaf water as it built up and it was not envisaged that the water was a potential danger.

After Longwall 3 had retreated approximately forty metres, an inundation occurred from the goaf on October 9, 1989, which flooded the panel, halting production of the longwall for nearly four months and changing opinion about the inundation potential of the overlying water.

This thesis deals with investigations leading up to the inundation, analysis of the inundation itself, and subsequent analyses of inflow and piezometric data with a view to accurate prediction of future inflow potential.
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CHAPTER 1

INTRODUCTION

The accurate prediction and analysis of water ingress into underground mine workings is of great benefit to the mine's operations from both a safety and an economic viewpoint.

An unpredicted inundation has the potential to cause months of lost production as well as causing damage to expensive mining equipment.

Although established theoretical methods provide a basis for prediction, the actual ingress depends on numerous factors. This thesis looks at the factors leading to an inundation at Kemira Colliery in October 1989 and proceeds to report on analysis methods used to study the inundation and the prediction of future events.

The objectives of this thesis are firstly to analyse the source or sources of the inundation water. To this end, a comprehensive literature review has been carried out on the origins of mine waters and the hydrogeological properties of the surrounding strata. The background theories thus related in this thesis are both general
theories of hydrology and hydraulics as well applicable analytical tools for the study of the Kemira inundation.

Secondly, this thesis will report on the analyses carried out subsequent to the Kemira inundation and report on the application and effectiveness of the various methods used. Many of the analyses were carried out for practical rather than academic purposes. This resulted in many parameters not being fully defined nor accurately calculated as they were of little or no practical use at the time.

The final objective of the thesis is to formulate an ongoing analytical programme to aid in the prediction of future inflows to the mine's workings.

In the course of the thesis the topics of Mine Hydrology, Origins of Mine Inundations, Stratigraphy of the Kemira Lease, Inundation of W27 Longwall Panel, Mine Dewatering Techniques and Inundation Analysis and Prediction Techniques will be discussed.
2.1 Introduction

The sciences of groundwater hydraulics and geohydrology are based upon the fundamental properties of water itself and the media through which it moves.

The evaluation of inflow into underground workings requires an understanding of the hydrological regime in the area of the mine. This understanding may be derived from a combination of information on both the surface and groundwater systems. The influence of one on the other depends on the interaction of the two systems in the vicinity of the mine.

Mine water inflow problems are associated with those hydrostratigraphic units that have the ability to discharge large volumes of water in a short length of time. This ability is dependent on the hydraulic conductivity of the unit and the hydraulic head gradient at the site.
The system becomes more complex by the properties of heterogeneity and anisotropy. These properties can occur either in a simple single hydrostratigraphic unit system or in a multilayered hydrostratigraphic system. Further difficulties arise as inflow into or through several hydrostratigraphic units is influenced by fracturing. The fracture spacing as well as the orientation and dimension of the fractures play a significant role in the hydraulic properties of the stratigraphy.

The affect on adjacent water resources is a major problem associated with inflow to underground mines. The impact may range from merely dewatering or depressurising the hydrostratigraphic units being mined to affecting surface water bodies such as creeks or lakes.

The inflow of water into a mine necessarily alters the associated ground water system. The inflow also may impact nearby surface water regimes, depending upon the interaction of surface water and ground water systems.

The inflow also inevitably causes a decline in the ground water levels in the vicinity of the mine. This decline may be restricted to a small drawdown zone or it may encompass a large area, depending on the hydrogeological properties of the hydrostratigraphic units.[1]
2.2 Underground Mine Water Inflow

According to Williams et al, 1986 [1], the total hydrological cycle must be considered when evaluating potential ground water problems in a mining environment. Precipitation is the ultimate source of all surface water and essentially all ground water.

Precipitation occurs in different forms and in varying amounts. Mine inflow can be affected in a matter of hours by precipitation events (such as rain, hail or snow) where there is a direct hydraulic interconnection between the mine and the surface through fractures or mine openings.

A portion of the water falling in a topographic basin results in runoff. Some of the water infiltrates the unsaturated soil zone where it either moves laterally and eventually ends up in streams, or it percolates downward to recharge the groundwater system. The unsaturated zone can range from zero to one hundred metres or more in thickness. The saturated zone, or groundwater zone, occurs below the water table where all the pores are filled with water. (Figure 2.1)

Recharge from surface water systems to ground water systems can occur via saturated or unsaturated flow. The
amount of recharge is dependent primarily on the vertical hydraulic conductivity of the formations underlying the stream and the availability of the water. As will later become evident, the recharge of the water system overlying the Kemira workings relies more on the horizontal conductivity of the aquifer.

The variables that affect ground water flow become increasingly complex as the hydrostratigraphic system increases in complexity. Williams discusses the simple, single layer system as well as the more complex multilayered system.
Figure 2.1 - Hydrological Cycle
2.2.1 Simple Single Layer System

The single layer system is the most simple hydrological setting for an underground mine in that it consists of a single hydrostratigraphic unit. The boundaries of this unit may or may not coincide with the conventional geological boundaries defined by lithology, mineralogy or other properties.

The potentiometric surface is a measure of the energy level in the hydrostratigraphic unit; it is well determined by the elevation of the static water level in cased wells open only to the hydrostratigraphic unit. In this thesis it will be expressed as metres above sea level. As the potentiometric surface is an energy level, water flows from a higher to a lower potential and hence from a higher to a lower ground water level. Contour maps of ground water levels are used to determine directions and characteristics of ground water flow. Ground water flow through geological material is governed by Darcy's Law that describes the loss of energy as a fluid moves through porous media. Darcy's Law will be discussed at length in the following chapter.
Darcy's law is valid so long as flow is laminar and is therefore valid for the vast majority of ground water flow situations found at mining sites.

Hydraulic conductivity is a measure of the ability of a geological material to transmit water. It is dependent on the amount of pore space present in the medium (porosity), the degree of interconnection of the pore space and the geometry and size of the pore space.

Hydraulic conductivity is a function of both the porous media and the fluid. Fluid properties can be considered constant for most mining situations.

Most geological materials feature some form of planar features such as bedding or fracture planes. Hydraulic conductivity parallel to these features is usually greater than the hydraulic conductivity perpendicular to these planar features. This property is referred to as anisotropy. The anisotropy near an underground opening will have a major impact on the quantity of water entering the mine.

The quantity of water a single hydrostratigraphic unit may take in or release from storage is called the specific yield or unconfined storage coefficient. Specific yield is the volume of water released from storage via gravity
drainage with a unit decline in hydraulic head per unit surface area of the hydrostratigraphic unit [1]. The volume of water released is due to the drainable porosity and hence the amount of interconnected pore space.

A groundwater flow system includes the entire set of pathways that water follows through the ground between hydraulic boundaries. It includes the recharge area, lateral flow area and discharge area. The flow pattern is controlled by hydraulic boundaries, by the quantity and distribution of recharge, topography and the spatial distribution of hydraulic conductivity.

2.2.2 Multilayered System

The multilayered system is defined as a groundwater flow system consisting of more than one hydrostratigraphic unit. The different units are differentiated by their respective hydrogeological properties.

The multilayered system is frequently defined by hydraulic properties which coincide with geological delineations. The structural setting of a complex multilayered system can control the pattern of groundwater flow in the
vicinity of a mine because the structural setting can control the distribution of hydraulic conductivity.

The hydraulic conductivity should vary considerably from unit to unit in a multilayered system. These differences are especially critical in the formulation of conceptual models of ground water flow systems.

The head distribution within each unit must be defined to predict inflow to an underground mine. A mine introduced into a ground water flow system acts as a potential energy sink that causes the water to flow towards it from adjacent zones of higher potential.

Two different concepts of storage coefficient (confined and unconfined) are necessary to define the quantity of water released from storage when a mine creates a reduction in potential in a multilayered system. This change in potential and associated flow of water is related not only to gravity feed but also the expansion of layers of compressed water as the overlying, confining pressure, is alleviated.

Ground water flow in both single and multilayered systems is controlled by the location and properties of the hydrostratigraphic units, the location of recharge and discharge areas, magnitude and location of the recharge
and discharge, and the location of barrier boundaries. Barrier boundaries are units that have low hydraulic conductivity which will retard ground water flow although they may contain large amounts of water in storage. An example of a barrier boundary may be fault gouge associated with a fault. Hydrogeologic boundaries such as these have been responsible for most of the inrushes of water that have occurred in mining's history [1].

Recharge boundaries can occur due to a unit's contact with a stream or lake or a saturated zone of very high hydraulic conductivity.

In terms of their influence on mine water problems, hydrological boundaries are as important, if not more important, than the average hydraulic properties of the rocks [1]. Recognition of potential hydrological boundaries should be possible with geological maps and any exploration drill holes. Traditionally the geological boundaries mentioned above, such as faults and contacts with relatively less permeable rock, are often treated in pumping test analyses as if they were completely impermeable. This can lead to some very erroneous conclusions regarding the source and magnitude of a potential inflow to a mine. Nind (1965) developed a method to estimate the aquifer parameters on either side of a boundary with drawdown data from observation wells on
either side of the boundary. It has been found [6] that use of this method with an adequate network of observation wells can sometimes eliminate the need for multiple aquifer tests in a "compartmentalised" hydrogeologic system with multiple hydrological boundaries.

2.2.3 Fractured Media

Ground water flow through fractured media requires special consideration. A system of discontinuous fractures may not increase the storage characteristics of the unit significantly, but even a single extensive fracture can significantly alter the hydraulic conductivity of a unit and result in significant mine water inflow [1]. A fracture or fracture system can increase the primary hydraulic conductivity and create heterogenetic and/or anisotropic conditions. Heterogeneity is the term used to describe the variation of hydraulic conductivity within a hydrostratigraphic unit depending on the position in the unit. Anisotropy is the same variation but dependent upon the direction of flow.
CHAPTER 3

HYDROGEOLOGICAL ASPECTS OF GROUNDWATER AND WATER BEARING STRATA

3.1 Sources of Water in the Mine [2]

Water in the hydrological cycle can be divided into three major categories:

(1) Meteoric Water - is the water derived from the atmosphere, generally in the form of rain or sometimes snow or hail. It is the basic source from which the bulk of groundwater is derived.

(2) Connate Water - entrapped in the interstices of sedimentary rock at the time of the formation of the rocks. It may be a marine or fresh water origin and may be highly mineralised.

(3) Juvenile Water - has its origins in molten rocks which underlie the earth's crust at great depths. These rock sometimes find
their way to the surface, or near surface, of the earth. Upon cooling of the rock, water may be trapped or given off as steam from a volcanic vent. From the point of view of worthwhile supplies of groundwater, juvenile water has little or no significance.

The main source of water in the hydraulic cycle is the atmospheric or meteoric water.

3.2 Definitions of Strata Effecting Ground Water Flow

3.2.1 Aquifers

Lohman et al 1972, have described an aquifer as a formation, group of formations or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to bores and springs. Under this definition, an aquifer includes both the saturated and the unsaturated part of the permeable formation.
Commonly used synonyms are Ground Water Reservoir or Water Bearing Formation.

Unconsolidated sand and sandstone are two examples.

3.2.2 Confined (or Pressure or Artesian) Aquifer

A confined aquifer is a completely saturated permeable formation of which the upper and lower boundaries are impervious layers. Completely impervious layers rarely exist in nature and hence confined aquifers are less common than is often realised.

In a confined aquifer the water is under sufficient pressure to cause the water level to rise above the aquifer if given the opportunity e.g. if penetrated by a bore. The level to which the water rises is called the potentiometric level, the standing water level (S.W.L.) or static head.
3.2.3 Unconfined Aquifer

An unconfined aquifer is a permeable formation only partly filled with water and overlying a relatively impervious layer. It contains water which is not subjected to any pressure other than its own weight. If a bore penetrates such an aquifer the water will rise up the bore no higher than the depth at which the water level in the aquifer was first penetrated.

The level at which the water stands in a bore penetrating an unconfined aquifer (the S.W.L.) is known as the water table, and is the depth at which the water in the unconfined aquifer is at atmospheric pressure.

Water in an unconfined aquifer is called unconfined or phreatic water.

3.2.4 Semi-Confined (or Leaky) Aquifer

The confining layers of many pressure aquifers are not completely impervious. The hydraulic conductivity of the confining layer may be very small when compared with that
of the aquifer material, but as the radius of influence of a discharging facility (such as fracture zone) increases, the area through which the confining layer is contributing water becomes very large and the volume of water contributed can be a very significant part of the total water discharged.

Such an aquifer is called a leaky or semi-confined aquifer. The flow of water from the confining layer to the aquifer is assumed to be vertical. The horizontal movement of this layer is negligible.

3.2.5 Semi-Unconfined Aquifer

If the hydraulic conductivity of the fine grained semi-permeable layer overlaying a semi-confined aquifer is so great that the horizontal flow component in the covering layer cannot be ignored, then such an aquifer is intermediate between the semi-confined aquifer and the unconfined aquifer and may be called a semi-unconfined aquifer.

In general, such aquifers do not release their water
instantaneously from storage and exhibit what is called delayed drainage. Such aquifers may be called unconfined aquifers exhibiting delayed drainage or delayed yield effects.

A schematic representation of the aquifer types is given in Figure 3.1

3.2.6 Aquiclude

These are impermeable formations which may contain water but which are incapable of transmitting significant water quantities.

Clay is an example of an aquiclude.
Figure 3.1 - Aquifer Types

AQUIFER TYPES

Fig. 3.1
3.2.7 Aquifuge

An aquifuge is an impermeable formation which neither contains nor transmits water. Granite is an example of an aquifuge.

3.3 Aquifer Functions

An aquifer has three important functions, namely:

Storage
- the aquifer stores water as a reservoir
- the characteristic describing the aquifer's ability to store water is the Porosity.
- the characteristic describing the aquifer's ability to release water under gravity drainage is the Specific Yield.
- the characteristic describing its elastic storage is the Storage Coefficient or Storativity and this is related to both the elastic properties of the water and the
aquifer material.

Transmission - it transmits water like a pipeline. The relevant aquifer characteristic is Transmissivity.

Mixing - it mixes water of different qualities.

3.4 Types of Aquifer Formations

There are two general classes of formation which store and transmit water. These are :

Porous Rocks - spaces between grains of sand or gravel; unconsolidated sands and gravels and consolidated sandstones.

Fractured Rocks - these include crevices, joints and fractures in hard rock; solution channels in limestone; shrinkage cracks and gas bubbles in basalt type volcanic rocks.
3.5 Hydraulic Properties

There are ten main hydraulic properties of the aquifer which need to be taken into account when studying a particular aquifer. These are:

a) Hydraulic Conductivity or Permeability (K)
b) Transmissivity (T)
c) Storage Coefficient (S) - confined aquifers
d) Specific Mass Storativity (Ss)
e) Specific Yield (S) - unconfined aquifers
f) Specific Retention (R)
g) Hydraulic Resistance (C)
h) Leakage Coefficient (C_L)
i) Leakage Factor (L)
J) Drainage Factor (B)

For a complete definition of these terms and the derivation of their respective formulae reference can be made to "Groundwater Hydraulics", a series of lectures presented by C.P. Hazel of the Irrigation and Water Supply Commission, Queensland to the Australian Water Resources Council's Groundwater School, Adelaide in August 1975 [3] or to most groundwater hydrogeology texts.
3.6 Voids

This category includes interstices, pores and pore spaces which make up that portion of rock or soil which is not occupied by solid matter but may be occupied by water.

Original Interstices :- of geological origin governing the formation of sedimentary and igneous rocks.

Secondary Interstices :- fractures, joints, solution openings etc. forming after the rock is formed.

In relation to size the interstices can be either :-

capillary - so small that surface tension will hold the water

sub-capillary - so small that water is held by adhesive forces.

super-capillary - allows water to flow.
Depending on the connection of interstices with others they can be classed as communicating or isolated interstices.

3.7 Porosity

Porosity of rock or soil is a measure of contained interstices. In terms of mine water, granular sedimentary deposits are of major importance.

Porosity of these deposits depend upon the shape and arrangement of the individual particles, distribution by size and the degree of cementation and compaction.

In consolidated rock, solution cavities and degree of fracturing is very important.
Table 3.1 shows some typical porosity percentages for the most common strata types.

<table>
<thead>
<tr>
<th>Geological Material</th>
<th>Porosity %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soils</td>
<td>50 - 60</td>
</tr>
<tr>
<td>Clay</td>
<td>45 - 55</td>
</tr>
<tr>
<td>Silt</td>
<td>40 - 50</td>
</tr>
<tr>
<td>Medium Coarse Sand</td>
<td>35 - 40</td>
</tr>
<tr>
<td>Uniform Sand</td>
<td>30 - 40</td>
</tr>
<tr>
<td>Gravel</td>
<td>30 - 40</td>
</tr>
<tr>
<td>Sandstone</td>
<td>10 - 20</td>
</tr>
<tr>
<td>Limestone</td>
<td>1 - 10</td>
</tr>
</tbody>
</table>

Table 3.1
In 1856 Henry Darcy, a French hydraulic engineer, investigated the flow of water through horizontal beds of sand to be used for water filtration. He concluded that the flow rate through porous media is proportional to the head loss and inversely proportional to the length of the flow path. Darcy's studies followed on experiments started by Hagen and Poiseuille several years earlier into fluid flow in capillary tubes.

Darcy's Law is stated as either

\[ v = k_i \text{ or } Q = KA_i \]

where, \( v \) = flow velocity (m/s)  
\( Q \) = flow rate (m³/s)  
\( A \) = area (m²)  
\( i = dh_1/dh \) = hydraulic gradient  
\( K \) = permeability (m/s)

Darcy's law is valid for laminar flow only. Darcy's law, more than any other contribution serves as the basis for present day knowledge of ground water flow. Analysis and solution of problems relating to ground water movement and
well hydraulics began after Darcy's work.

Several models have since been devised to attempt to study the correlation between $k$ and other parameters. These models include

(i) Straight capillaric model
(ii) Parallel type model
(iii) Serial type model
(iv) Branching type model; and
(v) Random walk models.

3.8.1 Range of Validity of Darcy's Law

In applying Darcy's law it is important to know the range of validity within which it is applicable. Because velocity in laminar flow is proportional to the first power of the hydraulic gradient, it seems reasonable to believe that Darcy's law applies to laminar flow in porous media. For flow in pipes and other large sections, the Reynolds number, which expresses the dimensionless ratio of inertial to viscous forces, serves as a criterion to distinguish between laminar and turbulent flow. Hence, by
analogy, the Reynolds number has been employed to establish the limit of flows described by Darcy's law, corresponding to the value where the linear relationship is no longer valid.

For very low velocities, laminar flow occurs; consequently, from both theory and experiment, no lower limit is known to exist for Darcy's law. On the contrary, however, an upper limit has been identified by experiments on sands and small spheres.

Deviations from Darcy's law may be found in rock aquifers, in unconsolidated aquifers with steep hydraulic gradients, or in those containing large diameter solution openings. Flows in the immediate vicinity of open bodies of water, streams etc., are often associated with steep gradients.

3.8.2 Coefficient of Permeability or Hydraulic Conductivity

Solving Darcy's law for the coefficient of permeability, \( K \), shows that \( K \) has the dimension of velocity. Permeability of a porous medium refers to the ease with which a fluid will pass through it. This depends not only
on the medium but also on the fluid. For this reason, permeability should be expressed independent of terms of viscosity, \( u \), expressing the shear resistance, and the specific weight, \( y \), expressing the driving force of the fluid. For the medium the flow should be related to a pore diameter which can assumed proportionate to a representative grain diameter \( d \).

From these properties, \( K = f(u,y,d) \)

\[
K = C d^2 y/u \quad \text{where } C \text{ is a dimensionless constant.}
\]

\[
k = C d^2 = \text{specific permeability in } \text{cm}^2
\]

Since the value of \( k \) is extremely small, a unit called a darcy has been adopted.

\[
1 \text{ darcy} = 0.987 \times 10^{-8} \text{ cm}^2
\]
Table 3.2 shows ranges of permeability for different strata types.

Specific permeability, \( k \), darcy's

<table>
<thead>
<tr>
<th>( 10^5 )</th>
<th>( 10^4 )</th>
<th>( 10^3 )</th>
<th>( 10^2 )</th>
<th>10</th>
<th>( 10^{-1} )</th>
<th>( 10^{-2} )</th>
<th>( 10^{-3} )</th>
<th>( 10^{-4} )</th>
<th>( 10^{-5} )</th>
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<td></td>
<td></td>
</tr>
<tr>
<td>Clean sands</td>
<td>Very fine sand</td>
<td>Unweathered</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clean sand and gravel</td>
<td>Silt, clay, eroded</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gravel</td>
<td>Glacial till</td>
<td>Clays</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flow</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Good aquifers</td>
<td>Poor aquifers</td>
<td>Impervious</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

Table 3.2
Laboratory measurements of permeability are made with permeameters. Several types of permeameters have been developed to determine the permeability of small samples of aquifers. Such tests can have limited application to some strata types because of the difficulty of placing samples of unconsolidated materials in the permeameter in their natural state and the uncertainty whether a sample is truly representative of the aquifer. Flow in solution cavities or rock fractures and the effects of large boulders in gravel aquifers cannot be duplicated in a permeameter.

a) Constant Head Permeameter (Figure 3.2a)

This type can be used to measure permeabilities of consolidated or unconsolidated formations under low heads. Water enters the medium cylinder from the bottom where \( V \) is the flow volume over time, \( t \), and the other dimensions, \( A, L \) and \( h \) are shown Figure 3.2a. It is important that the medium be thoroughly saturated to remove entrapped air. Several different heads in a series of tests provide a reliable permeability measurement.
b) Falling Head Permeameter (Figure 3.2b)

In the falling head permeameter water is added to a tall column; it flows upward through the medium cylinder and is collected as overflow. The test consists of noting times at which the water level lowers to various graduations on the tube. The permeability expression for this apparatus can be derived from Darcy's law beginning with

\[
dV = \frac{K h A \, dt}{L}
\]

then rearranging and substituting to give

\[
K = \frac{d_t^2 L \ln h_o}{d_c^2 t \, h}
\]

\[
\text{ho = initial head}
\]

\[
h = \text{head any time later}
\]

\[
d_c = \text{diameter of cylinder}
\]

\[
d_t = \text{diameter of tube}
\]

Both unconsolidated and consolidated samples can be tested in this manner.
GROUNDB WATER MOVEMENT

a) Constant Head

Volume $V$ in time $t$

b) Falling Head

Volume $dV$ in $dt$ sec

Equalizing tube

Supply and discharge reservoirs with area, $A$

Sample area, $a$

Constant-temperature chamber

c) Non-Discharging

Figure 3.2 - Permeameters
c) Non Discharging Permeameter (Figure 3.2c)

This type is used for measurements of permeability of unconsolidated formations under very low heads. As shown in Figure 3.2c, a long U-tube containing the medium is connected to supply and receiving reservoirs at the top. The entire instrument is submerged in a constant temperature chamber, while the top is covered to avoid evaporation losses from the reservoirs. The permeability is derived giving

\[ K = \frac{AL \ln h_0}{2at \ h} \]

where \( A, L \) and \( a \) are identified in Figure 3.2c; \( h_0 \) is the head at \( t = 0 \); and \( h \) is the head at a later time, \( t \).

The Falling Head Permeameter was found to be the most suitable test whose theory could be taken into the field and applied to the boreholes in the Kemira lease. These boreholes were connected to both the sandstone aquifer and also to the Bulli Seam approximately 30m above the Wongawilli Seam which is being worked. The application of this test will be described in more detail in the site investigation.
3.10 Tracer Technique

By introducing a tracer substance, such as a dye or salt, into ground water at an upstream location and observing the time required for it to appear at a downstream point, estimates of groundwater velocity can be obtained. This information, together with the existing hydraulic gradient, provides a measure of the permeability of an aquifer.

Measurements with tracers in the field usually have been limited to distances of a few metres, and results obtained are approximates only.

By means of a column packed with sand and supplied continuously with water containing a tracer of a specific concentration, the longitudinal tracer dispersion can be measured. From samples of the water emerging from the column, a tracer concentration can be determined. Besides longitudinal dispersion, a lateral dispersion of tracer also occurs because water is continually dividing and reuniting as it flows around and among grains of a medium.

An ideal tracer must be susceptible to quantitative determination in very low concentrations, should be absent
or nearly so from the natural water, must not react with the water, must not be absorbed by the porous media, and must be cheap and readily available.

3.11 Dating Ground Water

The use of tritium has been suggested as a means of dating ground water. Tritium is produced in the atmosphere by cosmic radiation (and thermonuclear explosions), and its abundance in rain varies roughly with the distance ocean water vapour must travel before precipitation. After rainfall infiltrates into the ground, no further additions of tritium occur; moreover a predictable diminution of the radioactive isotope concentration occurs. Thus from well samples of ground water, estimate of the time the water has been underground can be obtained. The method would be most feasible in confined aquifers recharged from a single recharge area. In fact, from several samples taken from wells scattered over a basin, the direction and rate of movement might be calculated.
CHAPTER 4.

GROUND WATER PROBLEMS IN UNDERGROUND MINING

4.1 Developing a Conceptual Hydrogeological Model [6]

The first essential product from a hydrogeological investigation should be a detailed hydrogeological model that incorporates all the geological and hydrological components that will influence the mining project. Without a good conceptual understanding of the hydrogeological framework and the stresses to be put on the system, no level of effort of numerical or analytical modelling will result in conclusions that will be used with any confidence.

To produce an accurate representation of the hydrological system, the model must be as comprehensive as possible and should include data from available literature; any surface exploration programmes including geological mapping and geophysical surveys; interpretation of topographic maps and aerial photographs, stream gauging; exploration drilling programme; and aquifer tests.
A typical conceptual hydrogeological model will incorporate the following information:

- A description of the general geology including lithology, stratigraphy, and structure;

- Identification of major hydrogeological units including formations or specific intervals within a formation, faults, fracture zones, intrusive bodies, and any discrete zones of particularly high or low permeability;

- Values for the hydraulic properties of the various hydrogeological units including hydraulic conductivity, specific storage and specific yield, and, if thicknesses of hydrostratigraphic units are known, their bulk properties of transmissivity and storativity;

- The elevation and configuration of the water table;

- The size of the drainage basins and discharge of all streams; and

- Hydrological boundaries such as streams, drainage divides, or geological contacts with low permeability materials.
Although not actually part of the conceptual hydrogeological model, the "stresses" on the groundwater system that should be defined at this time in the investigation include:

- The mine plan, including the extent and timing of all extraction;

- The local and regional climatology, with emphasis on precipitation and evapotranspiration.

4.2 Origin of Waters in Mines [7]

Rain falling onto the land may either run-off in the form of streams, evaporate or may percolate into the strata. The mining engineer is chiefly concerned with the last, which may migrate underground for many kilometres along beds of porous and permeable strata. The water may gain access to the colliery workings by any of the following channels:

1. Water in shafts either sunk or sinking through water bearing strata.
2. Surface water entering shallow workings.

3. Water bearing beds in contact with, or in close proximity to, seams of coal.

4. Feeders from fault fissures or from joints in rocks.

5. Water entering from outcrops under overlying unconformable strata.

6. Water from adjacent mines whether working or abandoned.

7. Water from abandoned and waterlogged upper seams.

As shall been explained later, the last four of these channels are particularly relevant to this study.
4.2.1 Seams in Contact With or Adjacent to Water Bearing Beds

At depths greater than those to which water usually percolates, water may gain access to mine workings via porous beds. The shales which are normally found adjacent to coal seams are impervious, but sandstones of varying porosity are encountered which carry water in varying volumes. The sandstone may be in direct contact with the seam, or as in the case of the Wongawilli Seam under study, the sandstone bed may be some distance above the coal seam with an impermeable bed of shale intervening. In the latter case, fissures and cracks formed by the subsidence and breakage of the roof after extraction of the coal, may permit the water to reach the workings. The cost of working a seam with a large inflow of water makes the decision to mine or leave a large area of coal sterilised a very real problem for mining engineers at many collieries.
4.2.2 Inflow Via Fault Planes

These types of inflows are usually in the nature of an inundation. Working panels may suddenly strike a fault which may be of an open nature and be in physical communication with an aquifer closer to the surface, thus occasioning a potential inflow of unpredictable proportions.

Many faults, especially those following the strike of the beds, act as main drainage lines and may yield large volumes of water when tapped by workings. Even with modern geophysical techniques it may not always be possible to ascertain the nature of the faulted zones and their potential water bearing qualities.

4.2.3 Water From Waterlogged and Abandoned Upper Seams

This presents similar problems to those associated with seams in contact with water bearing strata. In some cases the two seams may be joined by staple shafts or by exploratory boreholes. It is important that such channels be properly plugged when they are no longer required as
they form perfect conduits for water to flood into the lower workings.

In the situation where the two seams are in close proximity, the old workings may be tapped when the goaf formed above the extraction in the lower seam propagates up into the old workings. This was one of the major sources of water in the Kemira inundation.

4.3 Causes of Mine Inundations

The previous sections dealt with the various sources of water into the mine. The sources may have provided only small quantities of water over a large period of time. This section relates to "mine inundations". In this thesis, the term inundation refers to a major, sudden inflow of water into the mines workings. These inundations can be categorised in three ways [8]:-

- Event controlled Inundation;
- Accidental Inundation;
- Spontaneous Inrushes.
4.3.1 Event Controlled Inundation

This type of inundation is associated workings where the initial goaf fall has occurred and where main or periodic falls occur at subsequent intervals in the roof strata. The inflow rate of the water is suddenly increased from a background level to a peak rate within a short period of time. The flow rate then recedes exponentially back to the background rate. These types of inundations are governed by the following factors:

- Subsidence patterns around caved mine workings;
- Hydrogeology of the rock mass;
- Geological structures and discontinuities;
- Major and periodic roof falls in the goaf.
4.3.2 Accidental Inundation

Accidental inundation is a major concern to the mining industry. They may occur for the following reasons:

- Accidental connection of present workings or boreholes to old waterlogged mine workings;

- Accidental connection to unstable fluidised strata or natural bodies of water;

- Sudden and unprecedented inflow of surface water to mine workings.

A technique involving the interpretation of mine water chemical analyses has been developed for the detecting of the onset of inundation. The technique involves the "finger printing" of water samples from the mine and plotting their chemical make-up on a triangular graph. The plots can then be used to warn of potential hazards in the mine water regime. This technique and its application at Kemira will be more fully covered in Chapter 5.6.
4.3.3 Spontaneous Inrushes

Spontaneous inrushes are natural events associated with mining in the vicinity of karst aquifers. The inflow usually occurs through the protective barrier between the mine and the aquifer. Spontaneous inrushes are often associated with changes in groundwater flow and regime pressure, with changes in gas flow patterns, and with gas outbursts.

4.4 Failure Zone Development Around Longwall Panels

The controlled development of failure zones above longwall panels is necessary for maintenance of production and safety of personnel. This is particularly so where aquifers exist above and in close proximity to coalfaces. Several methods exist for the analysis of failure zones. The method of finite element analysis and empirical methods are discussed in the following sections.
For rock mechanics to be put into practice successfully, effective techniques are required for predicting the response of the rock mass to mining activity. These techniques must be flexible, rapidly applied and relatively inexpensive for maximum benefit to be derived from their use.

The quantitative approach to rock mechanics problems presents many difficulties. Perhaps the greatest of these is the determination of the properties of the rock mass. Even with exact knowledge of the properties of the rock and its local variations under local stresses, the analysis of its reaction under mining conditions would still present a problem. This is where the finite element approach presents itself as applicable. Brady and Brown [9] proposed that by idealising the continuum into a series of discrete interconnected elements, to which different properties can be assigned, the variable nature of the rock mass can be simulated.

For the longwall mining technique to be effectively employed, the behaviour of the strata surrounding the excavations must be understood. Finite element modelling is a tool which can be used to assist in this area with
The two dimensional finite element method of stress analysis can be used to study the stress distribution and development of the fracturing process within the overlying strata on a longwall face. Kidybinski and Babcock (1973) found through investigations of the stress distribution and progressive failure above a longwall coalface, that intact material properties differed from those of the rock mass in situ.

The method of finite element modelling was not applied to the analysis of stress zones around the Kemira longwalls, however a report by Follington and Isaac [10] investigates the application of this method for longwall situations. Follington and Isaac concluded that the finite element method is a useful technique for modelling strata behaviour around mining excavations. The flexibility of the method enables the lithological sequence to be fairly represented and they found that the ease with which the material properties could be altered enabled relatively straightforward manipulation.

While the results yielded by such processes are presently of only semi-quantitative nature, they found that a close
correlation between predicted and in situ failure zone size was observed in their case study of Wistow Colliery. They found the finite element models to be sensitive to panel width and established a relationship between failure zone size and panel width.

An improvement to the current method of analysis which would be most applicable to situations like those at Kemira would be the inclusion of facilities for modelling bed separation. This would allow more realistic simulation of the behaviour of the rock mass and would allow better correlation with, and hence validation by, empirical formulae currently being applied to subsidence and failure zone prediction.

4.4.2 Empirical Analyses of Fracture Zone Development

Singh (1986) [8] has reported on the development of fracture zones around caved mine workings. Figure 4.1 shows a generalised pattern of fracture zones that may develop above caved mine workings. Immediately above the mining horizon, there is a caving zone extending upwards 3-5 times the extraction height (zone 1). The increase in
1- Caving zone
2- Bed separation zone
3- Vertical relaxation zone
4- Shear and horizontal compression
5- Horizontal compression zone
6- Horizontal extension zone
7- Vertical compression zone
8- Vertical and horizontal compression zone

Figure 4.1 Zone of destressed strata above caved mine workings.
the permeability of the rock is estimated to be 40-80 times that of the intact permeability. This figure gradually decreases as goaf consolidation increases. Immediately above the caving zone is a zone of fractured strata (zone 2), which detaches itself from the main body of the superincumbent caving rock mass. Three main factors govern the height of a fracture zone; the brittleness of the strata, the thickness of the strata and the width of extraction. It has been observed that in strong, brittle strata the height of the fracture zone is higher than in strata of a weaker nature. Figure 4.2 gives empirical estimates for heights of fracturing above a longwall face for various strata types. A general formula to estimate the extent of the relaxation zone is given by $56t^{1/2}$ metres, which gives the height of the relaxation zone, with a safety margin, for seams up to 3.5m thick. In the case of multiple seam extraction, this thickness is the cumulative value. Work by Farmer (1980) [11], based on his observations in the undersea collieries of the Durham coalfield, suggests that the fracture zone may predicted by the following relationship:

$$h = 0.75W + 5$$

where, $W =$ width of extraction (m)

$h =$ height of fracture zone (m)
Height of fracture zone \( h \) above a longwall face for various thicknesses of extraction, \( t \) (m).

Figure 4.2
Singh [8], however, proposed that any empirical relationship to predict the height of the fracture zone should take into account the thickness of extraction, the width of extraction, the nature of the rock mass and the ratio of primitive strata stresses in the lower part of the fracture zone. This ratio is characterised by the development of bed separation cavities. In this fracture zone the horizontal conductivity of the strata is greatly increased and provides a storage for large quantities of water. It can be shown that a bed separation cavity of 25mm x 60m x 90m stores 135,000 litres of water.

Above the fracture zone is a zone of vertical relaxation (zone 3), characterised by the presence of tensile and shear failures and possibly micro-seismic activity. Immediately above this transition zone is a region of high horizontal compression (zone 4) where the hydraulic conductivity of the rock is greatly reduced. This zone acts effectively as an aquiclude.

Overlaying this region of high shear and horizontal compression is a zone of vertical compression which may extend to within 15m of the surface. On the surface, depending on the width of extraction, typical tensile, compression and subsidence zones develop. The compression zones between the mine workings and the subsidence trough act as a protective barrier against water danger under
favourable lithological conditions. In this zone the beds flex without creating a linking vertical fracture pattern. If, however, the surface ground strains, especially in the tensile zone, are high and the surface rocks brittle then cracking and opening of fissures can occur which can effect surface and sub-surface drainage patterns. It is generally thought [12] that the depth below surface of such cracks which have a direct connection with the surface, is limited in extent and does not effect major water bodies such as oceans or lakes. Small ponds, however, have been known to be drained by such subsidence cracks opening at the pond's base, although this greatly depends upon the local geological formations. The likelihood of cracks appearing at the surface greatly decreases with deeper workings since the ground strain effects are more widely spread with a significant reduction in their magnitude.

4.5 Effects of Longwall Mining on Strata Permeability

The behaviour of strata between the extracted coal seam and the ground surface governs the magnitude and distribution of movement at the ground surface. In spite of this, most past mining subsidence research has
concentrated on the effects of subsidence on the surface only. A study in 1986 by Fawcett, Hibberd and Singh [13] described a theoretical investigation into zones of increased hydraulic conductivity caused by rock failure above a longwall panel.

The authors of that paper calculated total stress distributions above the longwall panel using a previously derived analytic solution for induced stress and empirical formulae for primitive stress. Mohr and Griffith failure criteria were applied to predict zones of fracture which were then correlated with experimental data. Fawcett et al showed that the failure was highly sensitive to the ratio of horizontal to vertical primitive stresses. They found that the height of rock failure decreased substantially with increasing primitive stress ratio, whether compressive or tensile were considered, and that failure was negligible at a hydrostatic primitive stress (i.e. where the horizontal to vertical stress ratio equals one).

In April 1990, another investigation [14] into the mechanics of sub-surface deformation caused by caving of the extracted area behind retreating longwall faces was carried out. Changes in strata bulk permeability were also measured by standard packer tests before and after mining.
The investigations were, and still are being carried out at five different collieries in various coalfields of New South Wales.

The strata movement was measured by a multi-wire borehole instrumentation system consisting of mechanical anchors installed at different horizons in a borehole extending from the surface to the coal seam. The mechanical anchors were connected to suspended weights on the surface by stainless steel multi-strand wires. The movement of these weights was monitored as the longwall face approached and retreated past the borehole.

As mentioned, the bulk permeability of the strata was measured before and after mining to determine the hydrogeological changes caused by longwall mining. The tests help establish the effects of relatively shallow longwall mining on aquifers, aquicludes and the natural water table.

The test adopted is called the down-stage pump-in method of water testing (Houlsby 1975) [15] and it was repeated, after mining, in holes adjacent to the one originally tested because of the installation of the packers in the original hole.
4.5.1 Distribution of Subsurface Subsidence and Strains

The subsidence and vertical strains (dilation) were mapped and contoured and the following observations made:

- small vertical compressive strains of magnitude less than 1 mm/m developed in the overburden over the front abutment.

- the entire depth of the undermined overburden was in vertical dilation. Large tensile strains were also noted in the goaf immediately behind the supports but decreased with goaf compaction.

- the horizontal subsidence contours behind the face indicated that goaf compaction was relatively rapid.

- vertical dilation tended to be more closely related to stratigraphy than proximity to the extracted seam roof. Observation and analysis of strains in different strata led to the conclusion that overburden consisting essentially of mudstones which cannot accommodate horizontal shear subsides in blocks, resulting in higher surface subsidence than that associated with overburden consisting essentially of massive sandstones.
4.5.2 Changes in Bulk Permeability

Overall results from the investigations showed an increase in the bulk ground permeability from the seam to the surface. The general increase could be expected as mining under the shallow depth of cover resulted in substantial cracking of the ground surface. The ratio of width of extraction to depth of cover at the mine under investigation was approximately 135m to 110m or 1 : 1.24. This ratio at Kemira is approximately 95m to 120m or 1 : 0.80.

4.6 Hydrogeology Related to Caved Mine Workings

According to Singh [8], the water inflow to caved mine workings depends mainly upon the interaction of several mining, hydrogeological and structural factors. These factors are dealt with in sections 4.6.1 to 4.6.6.
4.6.1 Development and Location of Fracture Zones Around Mine Workings

The bed separation zones provide a major reservoir for storing and transmitting water. The \textit{in situ} permeability and storage coefficient of the bed separation zone may be several orders of magnitude greater than the intact rock mass. The extent of development of a relaxed zone around the mine opening depends upon the width of extraction, depth of the mining horizon and the thickness of the extraction zone. The method of extraction and the extent of the workings beneath an accumulation of surface water or an aquifer is controlled by the following factors, (Singh and Atkins, 1982) [16]:-

(a) the thickness of the barrier between the workings and the water source;

(b) the extent of carbonaceous materials within the barrier;

(c) the thickness and width of extraction in relation to the depth should be such that the tensile strain induced at the aquifer bed or at the bottom of the surface accumulation does not exceed 6 to 10 mm/m;
(d) In shallow workings, partial extraction systems should be designed in order to limit tensile strains;

The maximum tensile strain at the bottom of a surface accumulation of water or disturbance at the bed of an underground aquifer can be estimated by the following equation [8]:

\[ E = \frac{S}{D} = C \times 0.9t/D \]

where,
- \( E \) = surface tensile strain (mm/m)
- \( S \) = maximum surface subsidence (m)
  = 0.9 \times extracted seam height \( t \), (m)
- \( D \) = depth below surface (m)
- \( C \) = disturbance factor at the bottom of the aquifer

Figure 4.3 shows the relationship between the width of workings/depth ratio and disturbance factor for coal measures rock. It can be shown that for a 200m wide face at a depth of 300m extracting 1m the disturbance factor will be 0.71. Utilising the above formula, this can result in a maximum strain of 2.13mm/m. Applying this formula to
Figure 4.3 - Disturbance Factor

Figure 4.3 - Disturbance factor for various ratios of width of working and depth. (Watson 1980)
the parameters at Kemira suggests that a maximum strain calculation of 30mm/m will be apparent at the bottom of the Scarborough Sandstone aquifer. This figure is far in excess of the maximum 10mm/m quoted and analyses described in the site investigation in Chapter 5 indicate that the aquifer was indeed fractured resulting in an inflow to the underlying workings.

Tension cracks, as a consequence of longwall extraction, may develop at the surface at the zone of horizontal tensile stress concentration over rib abutment pillars. However, surface fractures with large apertures have continuity only to 15m from the surface and they do not provide continuity to the mine workings from a surface accumulation of water.

4.6.2 Hydrogeology and Lithology of the Interburden

Major aquifers form underground water reservoirs which will transmit water to the bed separation cavities through the intervening beds by fracture permeability, intergranular permeability and structural discontinuities. Alternative beds of clay, mudstone, shale etc. form aquicludes, acting as protective barriers. That is because
the horizontal movement in such beds due to bending tend to close any pre-existing vertical cracks. Konstantinowicz (1974) [17] has observed that in bedded aquicludes a thickness of strata eight times the extracted seam height provides an adequate protective layer. Any residual inflow in such cases can easily be handled by simple pumping systems. In massive rock masses of sandstone or limestone the natural joints can further extend due to mining extraction, and a protective barrier in the order of fifteen times the extracted seam height is often not enough to prevent inflow.

Singh [8] suggests that the competence of the immediate 20 - 30m of overlying strata plays an important role in determining the severity of the inundation.

4.6.3 Thickness of Overlying Strata

The thickness of the overlying strata plays an important role in the incidence of mine water inflow to longwall workings. Singh proposed that when the thickness of the barrier between the coal seam and the unconfined aquifer exceeds 50m, little or no water is encountered in the workings except where tensional zones from previous
workings have induced breaks. This rule however has numerous exceptions which tend to indicate that while the thickness does play an important role in inundation prevention, the specific thickness required should be ascertained from local conditions and not from generalised empirical values.

4.6.4 Geological Structures

The vertical movement of water from the surface or an aquifer into bed separation cavities can take place through the rock mass via intergranular permeation and flow through joints and faults. Caving and stress relaxing of the strata has a marked effect on the rock mass permeability. The differences between the permeability of intact rock and that of jointed rock with joint spacings of one metre are tabulated in Table 4.1
Joint With More Than One Metre Spacing

<table>
<thead>
<tr>
<th>Rock Type</th>
<th>Permeability Coefficient</th>
<th>Joint Width</th>
<th>Permeability Ratio</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limestone</td>
<td>0.36-23x10^{-15}</td>
<td>0.1</td>
<td>0.7x10^{-6}</td>
<td>2.0x10^9</td>
</tr>
<tr>
<td>Sandstone</td>
<td>0.24-6x10^{-13}</td>
<td>0.4</td>
<td>0.5x10^{-4}</td>
<td>2.0x10^9</td>
</tr>
<tr>
<td>Sandstone</td>
<td>0.21-2x10^{-13}</td>
<td>0.7</td>
<td>2.5x10^{-4}</td>
<td>1.0x10^8</td>
</tr>
<tr>
<td>Granite</td>
<td>0.50-2x10^{-12}</td>
<td>1.0</td>
<td>0.7x10^{-4}</td>
<td>1.5x10^8</td>
</tr>
<tr>
<td>Schist</td>
<td>0.76-1.6x10^{-12}</td>
<td>2.0</td>
<td>0.6x10^{-2}</td>
<td>0.9x10^{10}</td>
</tr>
<tr>
<td>Limestone</td>
<td>0.07-12x10^{-10}</td>
<td>4.0</td>
<td>4.0x10^{-1}</td>
<td>0.75x10^9</td>
</tr>
<tr>
<td>Dolomite</td>
<td>0.05-12x10^{-12}</td>
<td>6.0</td>
<td>1.6x10^{-1}</td>
<td>30x10^{11}</td>
</tr>
</tbody>
</table>

Permeability of Intact and Jointed Rocks

Table 4.1
4.6.5 Main and Periodic Goaf Falls

The main and periodic goaf falls associated with the longwall system of mining results in creating channels between the bed separation zone and the current mine workings. The general flow pattern of such inundations is shown in Figure 4.4 while the corresponding flow pattern, as recorded at Kemira, is shown in Figure 4.5. The significance of this inflow pattern at Kemira will be discussed in the Site Investigation.

The span of main roof and periodic roof falls behind a longwall face in the presence of a massive roof bed has been calculated using simple beam theory, Wilson (1986) [18]. A massive roof bed bridging over a longwall excavation can be considered as a beam clamped at the sides and loaded by the superincumbent strata (Figure 4.6). The vertical strata pressure acting on the beam given by \( y.h \) and the corresponding horizontal pressure by \( m.y.h \), where \( m \) is the ratio of virgin horizontal stress to vertical stress, \( y \) is the strata density and \( h \) is the depth of strata supported.
Flow Pattern of Inrush.

Flow Pattern of Event Controlled Inundations

Figure 4.4
Figure 4.5
Fig 4.6 **Theory of a Massive Bed Bridging** over an Excavation.
Singh further uses Wilson's beam theories to formulate relationships for the estimation of the compressional and tensile loading on the overlying beds. At shallow depths the failure of the beam will be in the tensile mode (Wilson, 1986) [18] when the critical stress equals the tensile strength of the massive bed. Under these conditions the failure of the spanning beam will be "quiet" and remote from the excavation. That is, the failure will be gradual and remote from the working extraction zone.

At a deep level, the failure mode will be compressional as characterised by abrupt failure in close proximity to the face line. For compressional failure to occur, the critical stress should be equal to the uniaxial compressive strength of the rock.

4.7 Effects of Mine Water

Many water inflows may cause only minor mining problems, however the indirect effects are easily overlooked. Most lead to cost items, many to hazards. The following is a list of the effects that mine water can have on operations.[19]
4.7.1 Direct effects of water in the mine:

a. Cost, perhaps becoming a principal item (though in some cases the water may be able to be used in treatment processes or otherwise)

b. Inrushes or other failure to handle inflow may interrupt production and damage the mine, perhaps beyond recovery, perhaps with loss of life.

4.7.2 Indirect effects of water in the mine:

a. Freezes in cold shafts, is a hazard to shaftmen and corrodes shaft ropes.

b. Reduces efficiency of crews, equipment, hinders materials handling.

c. Adds to maintenance of equipment, the cost of increased tyre wear and the potential hazard of using electrical equipment in wet conditions.

d. Washes weak ground into mine openings.
e. Flows of hot water heat and humidify ventilating air.

f. Carries dissolved gases into the mine.

g. Promotes deterioration of some rock and caving in blastholes.

h. Washes fines from conveyances, increasing work on accessways.

i. Interferes with certain explosives.

j. Physical discomfort to the mining personnel.

k. Reduction of machine operational efficiency.

l. Corrosion of machines, ropes etc.

m. Loss of lubricants.

n. Catastrophic inflow if power failure occurs.

o. May result in "excess water" payments to workforce.

p. Fine sediments in the water increase the power required to pump the water as well as increasing
the abrasiveness of the water and subsequently wearing pumps and pipes more quickly

4.7.3 Indirect effects outside the mine:

a. Moisture in product increases shipping, treatment and handling costs.

b. Effluent may pollute surface water.

c. Drawdown may take water from wells and lower quality of water remaining, or improve it.

d. Drawdown may be apparent cause of surface subsidence, sometimes violent.

Many of these effects were noted during the inundation at Kemira and still continue to add to the time, discomfort and ultimately the cost of coal production at the mine.
5.1 Introduction

BHP Kemira Colliery, located on the escarpment overlooking the city of Wollongong, NSW, is the oldest continuously operating colliery in Australia. First opened in 1857, the Bulli Seam was mined until the early 1980's. Kemira is currently extracting coal from the Wongawilli seam at approximately 100 to 120 metres below the surface. The working section of the Wongawilli seam is located some 33 metres below the Bulli seam which was partially extracted in the now abandoned Mt Kembla Colliery. Production ceased in Mt Kembla Colliery in the mid 1960's and was then abandoned and partially sealed, leaving open haulageways and partially, to fully goafed areas to fill with water.

The current Wongawilli seam longwall blocks are located on the western flanks of the Kemira Dome (formed from a deep seated intrusion). The overlying Bulli seam workings follow the same structure and conform to a closed
synclinal feature (basin) immediately to the west of the current working panels.

The position of the rest of the overlying stratigraphy is shown in Figure 5.1. The main units to be discussed later in this investigation are the Scarborough Sandstone, the Wombarra Shale and the Bulli and Wongawilli coal seams. Figure 5.2 gives a more detailed section of the coal measures.
Figure 5.1 – Stratigraphic Column
Figure 5.2 - DDH9 Bore Log
5.2 Background Hydrogeological Investigations

In 1987 hydrogeological investigations were carried out at Kemira to investigate the increasing water flows in development roadways in down dip areas of the development panels [20]. These initial investigations were aimed mainly at determining the effects of groundwater on roof and rib stability. Follow-up investigations in 1988 [21] looked more closely at the possible effects of the groundwater regime on the colliery. Among it's conclusions and recommendations, this study made recommendations for increased pumping capacity to cope with the predicted water outflows, gave estimates of expected outflow rates in development and longwall panels and suggested possible sources of a water problem.

In May 1989 [22], a reappraisal of the known groundwater parameters was carried out based on estimated water flows from longwall 2, W26 Panel. The in situ hydrogeological parameters were determined from holes drilled from W24 Panel (Wood and Filipowski - Kemira Groundwater Investigations, Progress Report February 1988) [21]. Water flows into longwall 2 were predicted as 63 m³/day after equilibrium conditions were established. Early transient flows were predicted at up to twice that figure.
The limited figures available on the inflows to Longwall 2 estimate -

<table>
<thead>
<tr>
<th>Date</th>
<th>Flow Rate (m³/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre 13/4/89</td>
<td>380</td>
</tr>
<tr>
<td>13/4/89</td>
<td>Water flows dropped considerably</td>
</tr>
<tr>
<td>7/5/89 - 10/5/89</td>
<td>648</td>
</tr>
</tbody>
</table>

The pre 13/4/89 figures may well have been underestimated, however they were consistent with, if somewhat greater than, predicted non-equilibrium flows. The observation of the considerable reduction in water flow is consistent with the establishment of equilibrium flows. The large increase in subsequent inflow rate in May indicated a large deviation from the predicted inflows.

The possible explanations for the increased flow were -

1. Water saturation of the Bulli seam Mt Kembla workings to a much greater extent than indicated from previous measurements.

2. Significant recharge from the surface due to recent rainfalls.
3. Permeability of the seam 20 times larger than the 10 millidarcy previously determined. This may have been influenced by local stress regimes induced by the remaining overlying Bulli pillars.

Measured subsidence (max. 1.6m) and tensile strains of 4mm/m prompted visual inspection and further investigation of the surface above the longwall panels. Open cracks (up to 20mm wide) were observed in the creek bed and the surface soil indicating the possibility of significant recharge into the groundwater system.

These cracks occurred on the western goaf edge of Longwall 2 approximately 400 metres inbye of the start of the longwall block. At this position a subparallel goaf edge also existed in the Bulli seam workings. Tensile strains were expected to be greater where the two goaf edges coincided, vertical percolation was expected to be greatest where tensile strains were greatest and the most efficient vertical conduits were expected where old tensile fractures were reworked.

Wood concluded that the degree of interaction of the surface water with the Wongawilli seam workings was dependent on the location of the extraction areas and goaf areas in the Bulli seam. At the time the major source of
water in the mine, and the major source of direct recharge to the Bulli seam, was believed to be surface water percolating downward through fissures. Wood thus also concluded that a major surface drainage feature with superimposed goaf edges provided an ideal environment for increased recharge into the groundwater system irrespective of surface weather conditions.

Wood predicted the peak inflow into Longwall 3 to be in the order of 300 m$^3$/day while the equilibrium inflow could be expected to be in the order of 75 m$^3$/day.

Unfortunately the conclusions and recommendations arising from these reports were not sufficient to forewarn the colliery of the inundation which occurred on Monday October 9, 1989 in Longwall 3, W27 Panel. The flooding of the longwall panel halted production for four months and subsequent production was at a much reduced rate for several months to follow.
5.3 Inundation In Longwall 3

5.3.1 Chronology of Events

On the afternoon of Monday, October 9, 1989, Longwall 3 had retreated approximately 40 metres from its installation face. Because of the good caving characteristics of the Wongawilli seam, the panel had already experienced its first goaf fall and the goaf was following the face as it retreated.

There had been an accumulation of water in W27 "B" Hdg (the heading adjacent to the maingate) since the wall had started. This was assumed to have its origin in both the dust suppression water from the face and from some remnant water which may have flowed across the face from the previous longwall goaf. The evening shift deputy reported that the water in the panel rose approximately 300mm in three hours. At this stage the water was inflowing from behind the chocks in the maingate at a rate later calculated to be approximately 420 m³/hr or 116 litres/sec.

A 4" Kelly and Lewis pump was procured from a neighbouring colliery during the night and was installed along with the 4" Mono pump already on site. The two pumps combined were
not able to keep up with the inflow which was gaining on the pumps in the order of 130 m$^3$/hr. During the following day another K & L pump was organised as well as a Sykes. With the new pumps on site, the colliery would have a theoretical pumping capacity of 280 m$^3$/hr.

5.3.2 Water Evacuation Options

The options of what to do with the water were limited to two choices in the short term. These were either to pump the water up to a point where it would gravitate out of the mine or to use the panel at the downdip end of the mine as a storage sump. It was decided to split the pumps into two outflow lines and to use both options. The storage capacity of the panel (W2 Panel) was calculated to be approximately 50 000 m$^3$.

Options of where to put the water were restricted by several factors:

1. If the water were to be pumped into the old Bulli Seam workings there was chance of flooding Cordeaux Colliery which was on the down dip side of the lease;
2. Pumping to the surface via a borehole would mean getting permission from the Water Board to discharge into the Water Board Catchment Area for Cordeaux Dam.

3. Letting the water outflow via Kemira Tunnel (the belt haulage tunnel connecting the underground bin with the surface at a remote site to the colliery pit top) would risk polluting several creeks which flowed down into the residential suburbs.

At this stage the colliery surveyor estimated the potential storage capacity above the workings to be 1.2 to 1.5 Mm$^3$. This was based on the estimated head of water, the seam contours and an approximate storage coefficient of 30% for the Bulli goaf. The general concept at the time was that this volume may have been in the form of a free flowing lake, capable of spilling over into the workings via the longwall goaf. This analogy proved to be partially true although an over simplified concept.

Meetings were held to formulate plans to drain the water both in the short term and over successive longwalls. The following is a brief summary of some of the alternatives discussed and investigated. The methods were assessed both on their practicality and their cost.
1. Drill a hole from the flooded panel to the escarpment, a distance of some 600m through a major fault zone. The drilling would be made more difficult by the talus slope on the escarpment which would make it difficult to keep the hole open.

2. Drill a fully cased hole into Kemira Tunnel and drain the water to the surface via the Tunnel. This hole would also be approximately 600m in length and would have a reasonable small target to hit. To ensure accuracy, a down-hole directional drilling rig would be needed.

3. Drive a special stub heading off W2 panel and drill up into the base of the reservoir to allow a dedicated pumping station to be set up.

4. Drill upholes from the longwall panel to the Bulli seam, install standpipes, attach pipes and pumps directly to the pipes and pump the water out of the mine.

5. Drill from the Wongawilli seam vertically down to Kemira Tunnel and attach pipe lines to both the top and the bottom. The distance between the Wongawilli
seam and the Tunnel at that point is approximately 110m.

5.3.3 Pumping Options

A number of possible pumping options were forwarded by pumping consultants:

1) Staging of pumps to the top-of-bin area in 1500m lengths via a holding dam half way. The approximate dam size would have to be 25m x 5m x 1.5m deep. No price was available at the time for this option, however it was deemed an unfavourable option because of several factors including the need to constantly maintain the dam and keep it free of fines buildup.

2) To pump out 15 x 10^6 litres per day:

- 1 x 300mm diameter poly pipe: $550 000
- Pumping Equipment: $35 000
- Starting Equip to suit 2 x 150 Kw Motors: $30 000
- Valves etc: $5 000

**Total Price** $620 000
3) Using 2 x 200mm dia. steel pipe (11 000m) $220 000

This would provide the option of removing one line in the future if two were no longer required. To use 11 000m of the poly pipe would cost approximately $500 000.

4) Submersible borehole pump via a borehole from the surface to the Kembla workings.

<table>
<thead>
<tr>
<th>Depth</th>
<th>150m + friction loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pump Output</td>
<td>4.5 x 10^6 litres/day</td>
</tr>
<tr>
<td>Pumping Equipment</td>
<td>$28 000</td>
</tr>
<tr>
<td>Cable</td>
<td>$12 000</td>
</tr>
<tr>
<td>Starter</td>
<td>$10 000</td>
</tr>
<tr>
<td>Drilling 300mm I.D.</td>
<td>$70 000</td>
</tr>
</tbody>
</table>

fully cased bore
500m of surface pipes
steel pipes | $12 000 |
| poly pipe | $25 000 |

Total Cost = $132 000 to $145 000
5) Pumping from W28 (the panel downdip of W27) to the top of the bin area.

<table>
<thead>
<tr>
<th>Distance</th>
<th>3400m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pump Equipment</td>
<td>$170,000</td>
</tr>
<tr>
<td>Starter</td>
<td>$20,000</td>
</tr>
<tr>
<td>Valves etc</td>
<td>$5,000</td>
</tr>
<tr>
<td>Flow Meters</td>
<td>$2,000</td>
</tr>
</tbody>
</table>

It was decided to further investigate the option of dewatering from W28 panel.

As will be further discussed in Section 5.7.1, the Metropolitan Water, Sewerage and Drainage Board was concerned that the release of water from the mine via surface boreholes would constitute a serious impact on the quality of water in the Cordeaux Dam catchment area. The further problems of water disposal identified in Section 5.7.1 led to the decision to further investigate the option of dewatering from W28 Panel.

The most practical and cost effective system devised incorporated a system of two by 200mm pipelines running out of the longwall panel (collecting water both directly from upholes, connecting W27 with the Kembla workings, and also off the floor) and connecting to the top of two by 200mm cased boreholes running vertically from a point in
the Wongawilli seam near the top of the coal bin to Kemira Tunnel. At the bottom of the holes, the two lines would be connected into a 300mm pipeline and gravity fed to the surface.

Several of the major cost components of this option were:

Drill and line 2 x 110m x 200mm down holes $ 72 335
Supply 2400m x 300mm pipe $399 603
Install 2400 x 300mm pipe $ 67 015.

The down holes were drilled concurrently with the commencement of an uphole drilling programme. The downholes were completed in January 1990 and the 300mm pipeline was then layed from the surface to connect with these holes. All the work was completed by contract labour and equipment.

5.3.4 Interseam Upholes

Using a plan of the old Mt Kembla workings overlaid onto the current Wongawilli seam panels, the sites for a series of upholes were planned. Figure 5.3a shows the Mt Kembla workings in the Bulli seam and Figure 5.2b shows the
The current Wongawilli seam workings at Kemira. Figure 5.3c is the result of overlaying the two plans. Using the overlay plan, the upholes were able to be positioned in such a way as to hit roadways in the old workings.

Inaccuracies in historic survey techniques and the difficulty of aligning the plans from two different collieries meant that often the holes did not hit the desired target.

The upholes were drilled by contractors using an Atlas Copco Roc 601 Airtrack. Initially the holes were drilled with pilot holes of 60mm and then reamed to 90mm. This did not allow any way of stemming the flow of the water if it was hit. After the first two holes hit coal, the third, fifth and sixth holes all struck water although it was believed that the limited outflow indicated that they had struck goaf rather than open roadways.

An abortive attempt over the weekend to stem the flow from the holes with timber props highlighted the need to install standpipes and valves in each hole before it was drilled through to water. It was decided to use PVC plastic pipe as the standpipe to a height of six metres above the two metre length of steel standpipe. The eight
Figure 5.3a – Bulli Seam Workings
Figure 5.3b - Wongawilli Seam Workings
Figure 5.3c – Overlay Plan
metre length was deemed necessary to take the pipe above
the top of the Wongawilli seam (six metres above the roof
level) to prevent the water from saturating the coal seam
and weakening the roof.

In subsequent weeks a series of upholes were drilled to
try to hit the roadways in as many places as possible.
With each success (and failure), the overlay plan was
recorrelated to give a better chance of success on
subsequent holes. All the holes are shown on Figure 5.3c.

The uphole drilling programme in W27 proved a success. It
enabled the level of the water in the Kembla workings to
be determined with a sufficient degree of accuracy to
confirm the water levels being reported from the surface
borehole, Kemira 20 (see Section 5.3). The water flow from
the upholes drilled in W27 also suggested that it may be
possible, by the systematic placement of a number of
holes, to predrain the workings above the next longwall
block from the W28 roadways.

Of the twenty-three (23) holes drilled in W27, W28 and
Longwall 5 Installation Face, only ten (10) holes actually
hit a free flowing, full head of water. Of these ten, a
further two were located in goaf material with a low
permeability and soon reduced to a limited flow (see
Section 5.4.3.7). A system of upholes is also planned to
dewater the workings above Longwall 5 from W29 Panel.

5.4 Methods of Determining Water Level

The volume of the water stored in the Kembla workings was naturally directly proportional to the level of the water in that seam. It was therefore essential to closely monitor the water level in the Bulli seam so that the potential for future inflows could be predicted and trends in recharge to the Bulli seam could be observed. The level of the water in the Scarborough Sandstone aquifer was also required to be monitored as this was thought to be a potential recharge source.

Water levels were monitored using surface boreholes, manometers and piezometers. These methods are described in the following sections.

5.4.1 Surface Boreholes

The first hole drilled down to the Bulli seam from the surface (Kemira 18) returned a reduced level of the water
in the Bulli seam of 204.5m and a seam floor R.L. of 201m. This first hole was abandoned and replaced by Kemira 20 down to the Bulli seam and Kemira 21 which was stopped in the Scarborough Sandstone.

Piezometers were lowered into and installed in each of the two surface bores. A Geokon CR10 continuous monitoring datalogger was attached to the piezometers and was set to record the piezometric level every 15 minutes. This data was collected and processed every 12 to 24 hours depending on the variations shown in the previous readings.

To keep a physical check on the piezometers an electronic dip meter was used. This device was a probe which was lowered down the hole until an audible beep was emitted. The beep occurred when the water provided and electrically continuous circuit between the tip of the probe and a contact about 20mm from the tip. The dipmeter correlated well with the piezometer, the two methods usually within centimetres of one another. Had a discrepancy been detected, the dipmeter would have been checked to ensure it was not caught in the hole. If the dipmeter appeared correct, then the piezometer would have been recorrelated against a second piezometer.
5.4.2 Manometric Survey

After the first upholes were drilled as described in 5.2.3, several different methods were used to monitor the Bulli seam level from within the mine.

On November 3, it was decided to set up a manometer to get a physical check on the Kembla water level. The simple U-tube manometer is based on the theory that over horizontal planes within continuous columns of the same fluid, pressures are equal. This meant that a "tube" being fed by the Kembla water would reach equilibrium at a level in the tube equal in RL to the water level in the Kembla workings.

The first method was to isolate the existing 4" fire line from the rest of the reticulated water supply system and use this as the U-tube. A 25mm air/water hose was connected between the borehole and an outlet in the isolated line. The valve on the borehole was then opened and the water allowed to flow into the fire line. In order to establish a continuous column of water, the 25mm outlets in the line were systematically opened and any air in the line bled off. This was continued up the incline of the panel until a valve was found from which no water flowed when it was opened. This valve was then left opened.
to ensure an equal pressure differential. At the valve on the downdip side which was the last to emit water, a plastic tube with a coupling was attached. This was then run out up the roadway until a point was reached where the water no longer flowed from the tube. The tube was then tied up in the rib and the surveyors read to the top of the water. The result obtained by this method showed an RL in the Kembla workings of 203.9m. This was 0.6m lower than the level in the surface hole Kemira 20 obtained one week earlier.

Due to the apparent success of this trial it was decided to establish a permanent manometer. The existing method could not be used because of the statutory requirement of the fire line being operational. An alternative method was devised.

The manometer consisted of a valve attached to the bottom of one of the boreholes and about 1200m of 12mm clear plastic tube. The intent was to use the same basic theory of pressure equilibrium to determine the level of the Bulli seam water.

In order to make an absolute pressure differential, it was essential to remove all the bubbles from the tube. This took approximately two shifts of tapping and shaking the tube but a continuous column of water was achieved. The
open end of the tube was affixed to a plaster ventilation stopping once the approximate equilibrium had been reached. Calibrations on the stopping then made the task of determining the Bulli level a simple matter of reading the scale at the meniscus of the water in the tube. There are several practical considerations to be applied to accurate manometry [28] although most can be ignored unless dealing with minute fluctuations in applications requiring great accuracy. The major consideration in this manometer was the frictional resistance of such a long tube which may have lead to erroneous results. The extent of this effect was unable to be determined.

Readings from this manometer over the ensuing days were somewhat erratic. The reason for this soon became apparent. The manometer outlet was to the side of the main valve so that water was still able to be drained from the hole. It can be appreciated that the manometer would not be able to be read while the water was flowing because of lack of static head so a small valve was installed to stop the water flowing back along the tube when the main gate valve was opened. This valve was not always closed at the time the main valve was opened, however, and the vacuum caused by the high outflow velocity of the borehole as well as the head of the water in the tube, severely reduced the water level in the tube in a very short time.
The water level in the tube was reduced to such an extent that:

a) it would take several hours to regain its original level due to the high frictional resistance of the 1200m of tube; and

b) bubbles would again be trapped in the line when it was refilling and would require removing.

On November 24, the survey department calculated the volume between the 204.5m contour and the 200m contour to be $1.05 \times 10^9$ litres (assuming a 30% porosity in the Kembla workings). To that stage the pumping had removed approximately $220 \times 10^6$ litres. This equated to a calculated drop of 0.857m assuming no recharge. Assuming the original RL of 204.5m from Kemira 18 borehole then the then present level should have been 203.643m. The manometer returned a value of 203.6m. This degree of accuracy may be somewhat coincidental however it serves to illustrate the effectiveness of the simple U-tube manometer.

Although its initial successes were valuable in determining the static head in the Kembla workings, the long term impracticality of the manometer increased the need for a better method of determining the water level.
5.4.3 Packers and Piezometers

5.4.3.1 Packer Installation

To better ascertain the water level via the upholes, it was then decided to insert up the hole an inflatable rubber packer with a piezometer attached. The packer was an ACIRL supplied device with an inflatable rubber annulus to block off the hole. Running through the packer, a steel tube with side perforations provided a connection for water flow and static head measurement. A valve was opened on the packer to allow water flow through the hole and ease of installation while the packer was inserted. Once in place, the packer, connected via a 4mm high pressure tube to a bottle of either compressed air or compressed nitrogen, was inflated to block of the hole. The rubber annulus, approximately 1 to 1.5m in length, is supple enough to conform to the contours of the hole up to a diameter of approximately 90mm depending on the head of water and the surface of the hole.
5.4.3.2 Vibrating Wire Piezometers

Once the packer had been inflated a vibrating wire piezometer was attached via a U-tube pipe to allow the piezometer to operate in the vertical position in which it had been calibrated. It is believed that the piezometer would have operated equally effectively had it been inverted but it was decided to cut out as many error factors as possible. A diagram of the arrangement of the piezometer position used in the test described in 5.4.1.3 is shown in Figure 5.4.

A vibrating wire piezometer/pressure transducer is used to measure fluid pressures in boreholes, embankments, foundations, pipelines, wells, pressure vessels etc. Vibrating wire piezometers make use of the theory that the resonant frequency of a vibrating wire is proportional to its tension. Electromagnetic coils located close to the wire are used to pluck the wire and to convert the wire vibrations so produced into electrical current output the frequency of which is identical to the natural resonant frequency of the wire. Changing pressure causes deflection of a diaphragm thereby altering the tension of the wire and its resonant frequency of vibration. Thus for each pressure there is a corresponding frequency output.
Figure 5.4 - Piezometer Arrangement

Bulli Seam Boreholes - 13 Line W27
KEMIRA COLLIERY

Note - Diagrammatic only

Figure 5.4
5.4.3.3 Uhole Piezometer Test (January 1990)

The following is a report on a piezometer test carried out on January 19, 1990, several months after the inundation, in an attempt to answer several anomalies which were arising in the interpretation of the event. The objectives and various concepts expressed at the time of the tests have since been either validated or discredited as will be shown later in this report.

Objectives

1. To validate the hypothesis that water inflow into the roof holes in 13 line was fed by flow along the floor of a heading in the Bulli seam workings.

2. To determine the absolute pressure head in the roof of the Wongawilli seam workings.

3. To explain the occurrence of water flow in a roof hole drilled from the Wongawilli to the Bulli seam in A Heading, W27 panel, while a similar hole drilled in B Heading, at a lower reduced level (RL), was dry.
4. To test the suitability of vibrating wire piezometers to underground conditions.

Conceptual Basis

Possible mechanisms for the inflow of water into boreholes in W27 included -

1. Free Water Body

Would have expected an immediate response to shutting off borehole flow. The pressure head recorded would immediately rise to that equivalent to the level of the surface of the water body.

2. Free water with a drawdown established into surrounding permeable goaf material.

Would have expected a rapid pressure rise to the top of the hole (or to the top of the localised pounded water) followed by a period of slower pressure rise. The rate of pressure rise would decrease with time until equilibrium conditions were established.
3. Water from a remote source flowing in an eroded channel and feeding directly into 13 line (and A Hdg) holes.

The observation that the A Hdg hole was flowing water (19/1/90) while a hole in B Hdg was dry at a relatively lower RL is consistent with the presence of discrete flow channels in the Bulli seam.

An interaction between pressure measured in 13 line holes with the rate of flow from the A Hdg holes was expected.

**Methodology**

Flow from the 3 holes in 13 line was interrupted by the insertion of the inflatable packers, while flow from the A Hdg hole was sealed by means of the standpipe gate-valve. Pressure head measurement was made on the central hole using a Geokon vibrating wire piezometer, Geokon CR10 datalogger and Husky Hunter computer. Data was initially logged at a 10 second sampling rate. This rate was decreased to 30 second intervals after approximately 45 minutes.
When the packers were installed in the holes the compressed air had insufficient pressure (about 700 KPa) to completely block off the water flow although it was greatly reduced. At subsequent installations compressed nitrogen was used which provided about 1000 Kpa and succeeded in completely stemming the flow of water from the hole.

**Interpretation**

The full piezometric record (Fig 5.5) (corrected according to manufacturers calibration) exhibits the expected sharp rise when the borehole opened to the piezometer. The maximum pressure appears constant due to the scale of the pressure axis. The deflation curve is consistent with approximately 8 metres head of water remaining in the water line. The 8 metres comprised :

- 4.5 metres of water in the installation rods
- 2.0 metres of water in the packer assembly
- 1.5 metres induced by back pressure due to flow around the packer.
Figure 5.5

Piezometer Test 13 Line

Water Head (metres water)

Packer deflated
Packer ejected
Residual pressure in packer assembly
Tube hitting floor
Piezometer connection
Valve opened
Valve closed

Time (19/01/90)

01:26:24 PM 01:55:12 PM 02:24:00 PM 02:52:48 PM 03:21:36 PM

Full Record

Figure 5.5
The pressure record from the central part of the test (Fig 5.6) clearly illustrates the difficulty experienced in closing all the holes, the slowly tapering rate of pressure increase is consistent with water accumulation above the top of the holes, and the influence of opening the holes in A hdg.

Conclusions

1. The water head on the piezometers at the conclusion of the test was 28.234 metres above the current roof level of the central borehole. This was later corrected for atmospheric pressure to a value of 28.314m. The atmospheric pressure was obtained by lying the piezometer on the floor of the roadway and recording mine pressure for several minutes.

These figures are quoted to three decimal places to maintain accuracy throughout the calculations. Rounding off during stages of the calculation would compound inaccuracies. The order of accuracy for practical purposes would require rounding of the figures to the second decimal place.
Figure 5.6

Piezometer Test 13 Line

- Water Head (metres)
- Time (19/01/90)

- 01:26:24 PM: 28.76
- 01:55:12 PM: 28.84
- 02:24:00 PM: 28.88
- 02:52:48 PM: 28.98
- 03:21:36 PM: 29

- Hole full of water
- Packer pressure released
- 3rd hole plug damaged
- Pressure increase due to sealing 3rd hole (4cm water approx)
- 3rd hole plug reinstalled
- Pressure increase due to sealing rib hole (7cm water approx)
- Rib hole plug installed

Figure 5.6
This absolute level (19/1/90) was determined by an accurate survey of the roof elevation of the borehole as being 201.52m which is approximately one metre above the recorded collar of the hole and approximately one metre below that derived by Kemira 20 surface borehole.

2. There was direct connection, in the Bulli seam, between holes in 13 line and the single hole in A Hdg between 12 and 13 lines.

3. The pattern of pressure rise recorded during the very limited period between when maximum head appeared to be reached and when the valve in A heading was opened (the shut-in period) indicates the presence of a discrete flow channel along a heading in the Bulli seam.

4. The presence (or absence) of a shallow drawdown cone in the Bulli seam goaf material was not proven. The contribution of such a drawdown cone, if present, into the LW3 goaf was expected to be less than the then current inflow out of 13 line boreholes (less than 1.5 Ml/day).

5. The presence (or absence) of the influence of groundwater reservoirs above the Bulli seam to
longwall extraction in the Wongawilli seam was not addressed in this investigation.

6. The use of surface vibrating wire piezometers was found to be a viable method of underground fluid pressure measurement in boreholes.

5.4.3.4 Further Piezometric Studies

The longwall recommenced production on January 29, 1990. As the longwall retreated the outflow from the goaf continued at a reduced but steady flow. The face was soon up the slope far enough to be above the contour of the high water mark and out of danger of being flooded.

While pumping was still carried out on a regular basis, attention turned to dewatering the Kembla workings above the next longwall block in an attempt to prevent an inundation.

The general concept of the water problem at this time was that the majority of the potential inflow water was held as free goaf water in the overlying workings. While it was realised that the Kembla workings must have a recharge
source from somewhere, this source was believed to be a
direct recharge in the form of a stream inflow via an old
adit or ventilation shaft. While surface investigations
were carried out to locate all possible adits etc., not
all were able to be located because of the dense bushland.
The course of action decided upon therefore, was to drill
a number of upholes to the Bulli seam and attach them to a
large capacity pump and 200mm pump out line. To provide
enough volume for a 200mm pipe would require five free
running 90mm upholes. These were drilled in the same
manner as those in W27, using the overlay plan of the old
workings to position the holes to hit what were expected
to be open haulage ways. Figure 5.3c shows the position of
these holes. The holes that did hit water with an
appreciable flow were connected together via 100mm lines
and fed into the 200mm pump through a surge tank (the
"Dead Cow" as it was named, due to its unusual shape).

It was during the monitoring of these holes that an
anomaly was found in the calculated piezometric water
levels. With the benefit of hindsight the reason became
obvious but at the time it seemed inexplicable.

Of the five holes drilled in 14 C/T, W28, holes #3 and #4
gave a full flow of water upon holing while the other
three gave only trickles. It was assumed that these two
had hit open roadways, which was indicated by the full
flow, while the others had missed. The driller indicated that the other holes had hit goaf or broken material. When all the valves were turned off and a piezometric survey carried out on them all, they gave a reduced level within millimetres of one another. This level, however, was several metres above the roof of the Bulli seam.

The first thought was that there may be a difference in the atmospheric pressure in the Bulli seam. This was discounted as an unlikely source of a several metre error in results.

In order to rule out the possibility of an error in the calibration of the piezometer, it was taken to the surface and recalibrated by suspending a tube of water 10 metres up a tower above the piezometer and then taking readings as the water level was systematically dropped to different levels. These levels were measured by tape from the horizon of the piezometer and later analysis of the results showed the instrument to be within a maximum range of several centimetres either side of the measured head. It was decided to return to the holes, open all the valves and observe the period for which the water flowed. When this was done it was noted that all the holes, including those which had previously produced only a trickle, now burst forth with a full head of water. After only a short period of time, however, these holes reduced back to a
trickle while #3 and #4 continued to flow. At the risk of allowing even more water into the already flooding panel these two holes were allowed to continue to flow unabated. Within five minutes they also had reduced to almost no flow.

Unfortunately the piezometer was not available at this time to record this rise, so it was planned to carry out a Rising Head test on several of the holes as soon as possible. (See sections 5.4.3.6 and 5.4.3.7)

5.4.3.5 Falling Head Tests 14/06/90

Falling Head Tests were carried out on the surface boreholes - Kemira 20, which penetrates to the Bulli seam, and Kemira 21, which penetrates to the Scarborough Sandstone. Before the tests were carried out, the piezometer was once again rechecked using the dipmeter.

RL indicated by the piezometer 202.1m
Depth to water (dipmeter) -113.915m
RL datum 316.070m
RL water 202.155m
The piezometer returned a value of 202.1m while the dipmeter returned a value of 202.155m. This gave a maximum indicated error of 55mm which was quite within the accuracy range for the dipmeter at that level (approximately 114m below the surface). The conclusion therefore was that the piezometer was recording the correct water level in the Bulli seam.

Falling Head Test - Kemira 20

To simulate a falling head test in the field it was necessary to introduce a large volume of water into the borehole while the piezometer was recording and determine the time required for equilibrium to be regained. Approximately 273 litres of clean water was pumped down the borehole via a 25mm hose from a water tanker by means of a petrol driven motor. This volume was sufficient to fill the 100mm casing to a height of 34m if no continuity with the Bulli seam existed.

The piezometric response, uncalibrated for ambient atmospheric pressure, is shown as Figure 5.7. The maximum
Figure 5.7
measured head was 300mm. The response time was clouded by the water running down the 100 metres of casing. The test indicated that the permeability of the Bulli seam was infinite around the borehole.

**Falling Head Test - Kemira 21**

Depth to water (static)        -55.317m
Base of Scarborough            approx. 80m
Saturated Thickness           approx 25m

Approximately 270 litres of clean water was injected into this hole using the same procedure as in the other hole. This volume was again sufficient to fill the cased hole to a height of 34m. The piezometric response (Figure 5.8) indicates a maximum head of 200mm generated throughout the test.

This test indicated an almost infinite permeability for the lower section of the Scarborough Sandstone in this area. This would support the observation of the core log during the drilling of Kemira 6 down through these stratum over a fully extracted Bulli Seam panel. A total of 21
Borehole Kemira 21 (Scarborough SS)
Falling Head Test

Figure 5.8
separate falling head tests were carried out in that hole. Kemira 6 indicated significant horizontal fracturing within the lower Stanwell Park Claystone and the full sequence of the Scarborough Sandstone. Permeability testing indicated a significant order of magnitude increase in the permeability of the sequence downwards from the lower Stanwell Park Claystone. Those measured increases corresponded with visible fracturing in the core sample approximately 100m above the Bulli seam.

By inference, the permeability increase was associated with an increase in fluid storage capacity of the strata. The permeability was also inferred to be in a horizontal direction with only minor increase in vertical permeability.

Kemira 7 on the other hand, which was drilled in an area considered to be free of mining effects or geological anomalies but close enough to Kemira 6 to share the same stratigraphic sequences, indicated all sequences had low permeability. No anomalous fractures were recorded in the Bulli overburden and standing water levels, after overnight recharge, were erratic and consistent with low permeability.
Conclusions

Falling Head tests in the above ground boreholes, Kemira 20 and 21, indicated that the holes were in good connection with the respective zones. The elevation of water levels measured from these holes and their respective response with time was therefore a true indication of the water levels in the respective zones.

5.4.3.6 Rising Head Test 15/06/90

The hole used to carry out this test was located in the installation headings of the next longwall (Longwall 5). The piezometer was used to measure the pressure response in the open hole after all the water was drained. Sampling of the pressure was at 10 second intervals.

The piezometer response (Figure 5.9) can be divided into a number of stages.

1. Removal and replacement of the piezometer due to leaky joints
Kemira Colliery LW 5 No 1 Uphole
Rising Head Test 15/06/90

Figure 5.9
2. Rapid rise rate to the top of the Wongawilli seam

3. "Normal" rise to the base of the Hargrave seam

4. Fluctuating response in, and above, the Hargrave seam

5. "Normal" pressure increase above the Bulli seam floor

6. Dramatic response (levelling out of the pressure rise curve) at 201.98m indicated by the surface piezometer

The correlation between piezometer response and stratigraphy was determined from exploration borehole Kernira 15, approximately 1 Km west of Kernira 20 and 21.

**Conclusions**

The water head measured underground in this hole corresponded well with the then current level of 202.1 metres measured in the surface borehole.

Interaction of water flow between the open hole and strata between the Wongawilli workings and the Bulli seam had been established. This was believed to be evidenced by the jagged nature of the pressure line, indicating a pressure
buildup in the hole and then a drop as water was released further into the interseam layers.

Once again the water flow from the hole (approximately 21 litres/sec) was not consistent with the pressure head measured in the hole. It was therefore recommended that the water be used as the basis for determining the presence of water rather than flow [23].

5.4.3.7 Rising Head Test - 14 Line 16/07/90

A rising head test was conducted on Borehole 3 in 14 Line W28 on July 16, 1990. This time a piezometer and manual plucking box were used to record instantaneous head measurements rather than a data logger.

The readout box measured the period of wire vibration directly. This was then converted to frequency by the manufacturers equations. To obtain a head value, measurements were taken with all holes flowing equating to zero datum. The manufacturers calibration factor was then applied to the frequency readings.

This test, plotted in Figure 5.10, indicated that the
Kemira Colliery - 16/07/90
Rising Head Test 14 line

Figure 5.10

Water Head - Arbitrary Datum (m water)

Elapsed Time (mins)

Arbitrary datum
All other bores open

No. 4 bore closed
Nos 1 and 2 bores closed
No. 3 borehole (With Piezo) closed
water pressure achieved a head of 33.40 metres of water after 25 minutes. Figure 5.10 shows that the borehole took some 7 minutes to fill (the linear part of the curve). This indicates that the surrounding permeability is moderately low.

The low permeability observed during this test as well as the limited flow described in 5.4.3.4 were in direct contrast to the high flows being maintained from the holes in 16 Line and in the roadway some metres away. It is evident from these tests that the overlying goaf is composed of several main haulageways which have remained standing and which are acting as water courses of infinite permeability, as well as large goafed areas of low permeability which, although they indicate a large head of water, produce very little flow when tapped.

This supported the drilling programme of locating overlying roadways and drilling up into them rather than just drilling in the lowest contour basin areas.
5.4.4 Barometric Efficiency [3]

The storage coefficient of a confined aquifer may be approximated by utilising the barometric efficiency (BE) of the aquifer.

A reduction in barometric pressure results in a rise in groundwater levels. The ratio of the change in groundwater pressure to the change in atmospheric pressure is called the barometric efficiency.

The dimensionless barometric efficiency is defined as:

\[ \text{BE} = \frac{\rho g \cdot h}{\Delta p_a} \]

Where,
- \( \rho \) = density of the water (kg/m\(^3\))
- \( g \) = gravitational acceleration (m/s\(^2\))
- \( h \) = change in potentiometric level due to \( \Delta p_a \) (m)
- \( \Delta p_a \) = change in atmospheric pressure (N/m\(^2\))

The barometric efficiency can be interpreted as a measure of the competence of the overlying confining beds to resist pressure changes; thick impermeable confining strata are associated with high barometric efficiencies,
whereas thinly confined aquifers will display low values.

The barometric efficiency on unconfined aquifers is zero; i.e. a change in atmospheric pressure does not result in a change in the water level.

It can be shown that barometric efficiency is related to the storage coefficient of an aquifer by the following equation.

\[ S = \frac{p \cdot g \cdot b \cdot \theta}{E_w \cdot \text{BE}} \]

Where

- \( S \) = storage coefficient (dimensionless)
- \( \theta \) = porosity (dimensionless)
- \( p \) = density of the water (kg/m\(^3\))
- \( g \) = gravitational acceleration (m/s\(^2\))
- \( b \) = thickness of the aquifer (m)
- \( E_w \) = bulk modulus of elasticity of the water
  \( (@20^\circ = \text{approx } 2.17 \text{ GPa.}) \) [20]
- \( \text{BE} \) = barometric efficiency (dimensionless)

Thus from the barometric efficiency of a confined aquifer, an estimate of its storage coefficient can be found.

Due to the effects of barometric pressure on confined aquifers it was decided to continuously monitor the local
barometric pressure at the bore sites and to correlate the recorded atmospheric pressure with changes in the water level in the Scarborough Sandstone.

An example of plotting both the water level in Kemira 21 (in the Scarborough Sandstone aquifer) and the barometric pressure on the same graph are given in Figures 5.11 and 5.12.

The plot of the water level has already been adjusted against the influence of the ambient atmospheric pressure on the piezometer as related to the mean pressure of 96.99 KPa (a theoretical mean used for calculation purposes). This is done mathematically by saying that an increase of 9.98 KPa in atmospheric pressure equates to a water level increase above the piezometer of 1000mm. If the barometric pressure rises or falls, the proportional amount of water level must be adjusted for, as the actual level of the water has not really changed. Any other variation remaining in the water level must then be attributed to the effect of the atmospheric pressure on the aquifer. That is, the Barometric Efficiency.

By calculating a mathematical regression of the water level throughout the period of the graph, a mean gradient can be obtained. The instantaneous water levels can then
Kemira 21 - Scarborough Sandstone
Water Level Variation

Figure 5.11

Water RL (metres AHD)

Atmospheric Pressure (kPa)


Date

- RL - Corrected
- Barometer

Figure 5.11
Figure 5.12

Kemira 21 - Scarborough Sandstone
Water Level Variation

Water RL (metres AHD)


Date

RL - Corrected
Barometer

Atmospheric Pressure (KPa)
be related to that line to obtain the effect of the barometric pressure on the water level at that time ($h$). The barometric pressure relative to 96.99KPa ($Pa$) can then be used in conjunction with the water level variations to calculate the barometric efficiency. Although it is difficult to evaluate a figure for barometric efficiency because of the amount of water being drained from the aquifer, it is obvious that a direct relationship does exist. The steady gradient of the plot indicates that although the water level in continuing to drop, the vertical migration paths must be constant and only allowing a constant drainage from the aquifer. Further mining induced fracturing of the aquifer would be expected to increase this discharge rate and hence increase the gradient of the plot.

5.5 Methods of Determining Inflow

In order to calculate the inflow to the workings several methods were used with varying degrees of success. The methods used are described below.
5.5.1 V-Notch Weir

For measuring large and small open flows in the field or in the laboratory, the weir finds wide application. A weir may be defined in a general way as "any regular obstruction over which flow occurs." Thus for example, the overflow section (spillway) of a dam is a special type of weir and may be utilised for flow measurement. However, weirs for flow measurement are usually of a more simple and reproducible form, consisting of smooth vertical flat plates with upper edges sharpened. Such weirs are called sharp crested weirs and appear in a variety of forms.

The flow of water over a sharp crested weir is at best an exceedingly complex problem and impossible to solve analytically [28]. An appreciation of the complexities of the flow is necessary for an understanding of experimental results and of the deficiencies of simplified weir formulas.

The complexities may be realised by imagining the flow over a sharp crested weir. It is obvious that the head of water above the weir (H) is the primary cause of the flow (Q) to occur, although no simple relationship between these two variables can be derived for two fundamental reasons: (1) the shape of the flow pattern; and (2) the
effect of turbulence and frictional processes cannot be calculated.

For small flow rates, notch weirs are widely used as measuring devices; of these the most popular is the triangular or V-notch weir.

The fundamental formula used to calculate the volumetric flow through the weir is [20]:

\[ Q = C_w \left(\frac{8}{15}\right) \tan(\alpha) \left(2 g_h\right)^{1/2} H^{5/2} \]

Where
- \( Q \) = flow rate (m³/s)
- \( C_w \) = weir coefficient (dimensionless)
- \( \alpha \) = 0.5 \times V-notch angle (radians)
- \( g_h \) = gravity (m/s²)
- \( H \) = height of water flow above base of notch (m)

Triangular weirs of 90° notch angle (2 \times \alpha) have coefficients \((C_w)\) near 0.59. Experiments carried out by the author under laboratory conditions gave a range of values between 0.6 and 0.62 but these are affected by viscosity, surface tension and weir plate roughness.

A V-notch weir was constructed and installed in the return heading of the longwall panel (W27 B Hdg) in order to
ascertain the outflow from the goaf. The weir was positioned in the panel in a place that most, if not all, the water would have to flow over.

To calculate the flow rate, the value of H was measured each shift using a steel ruler glued to the weir. The flow rates thus calculated were used more as relative values than as absolute values as it was not possible to direct all the water down the required roadway. By way of explanation, the trend of the inflow rates was as useful as an actual volumetric record. The recorded flows were used to predict pump requirements in the longwall for such purposes as planned downtimes. Inflow rates were used to determine the maximum time the power was able to be turned off to the pumps before a certain predetermined level would be reached. This period changed with the inflow rate, and the V-notch results were used to observe trends in these rates.

5.5.2 Tide Gauges

Another method of determining the inflow was to do a volumetric check on the water standing in the panel.
To calculate this volume, measuring tapes were suspended from roof bolts above low sections of the roadway where water was collecting. The tapes were surveyed/levelled so that each tape was individually referenced to the roof and the floor. The floor levels of the sump area were then profiled on a computer.

The system thus in place, for any water level reading on any tape, the standing volume in the sump could be calculated. This method also assisted in the correlation of the pump outputs:

- When no water was being pumped for a period, the increase in water level could be related to an inflow rate.

- When pumping was occurring the decrease in water level could be related to the pump output having allowed for the pre-calculated inflow rate.

When the pumps were initially installed there were some discrepancies between their theoretical output and the amount of water apparently being removed. This tide gauge system helped in establishing more accurate outflow rates.
5.5.3 Flow Meter

The most recent device used to measure the inflow to or outflow from the mine is a vane type flow meter installed in the 300mm pipe line in Kemira Tunnel. All the water now leaving the colliery, via the pump lines, flows along this pipeline and hence this flow meter is able to keep an accurate record of pump out figures.

The cumulative total on the meter is read every four hours by the belt attendant or some other person and the figure recorded for later analysis. As the inflow into the panel reduces there is less need to run the pumps to clear the water. This means that the pumps may only be run 25% of the time. Because of this it is necessary to look at the outflow rates over a 24 hour period during these times to get a more balanced view.

Since the meter was installed in August 1990, the average outflow has been about $0.75 \times 10^6$ litres/day with a peak of $3 \times 10^6$. Figure 5.13 shows a plot of the daily outflows through the 300mm pipe in Kemira Tunnel. The graph at first seems somewhat erratic, however closer inspection and correlation with other colliery records can give far greater detail.
OUTFLOW AT KEMIRA TUNNEL

Figure 5.13

MEGALITRES PER DAY


Figure 5.13
During the early part of the time scale depicted on this graph, the longwall (especially the maingate) was operating in a considerable amount of water. In fact the bootend return roller was operating underwater for a large majority of the time. This meant that the belt was picking up a lot of water itself as well as being fed an almost slurry of coal. This slurry of coal caused numerous delays and associated problems in outbye belts and the underground storage bin. Such problems as belt slip were common place and more serious problems such as slumps of an estimated 80 to 100 tonne of slurry from the bin occurred on several occasions and were directly attributable to the water being picked up in the longwall.

To look at the graph in Figure 5.13 and to assume that this outflow represented the inflow to the mine at the time would be to discount the large volume of water being taken out of the colliery mixed with the coal. The outflow indicated on the graph for September 1 is approximately 1 megalitre yet on the following day that increased to 2 megalitres. Lack of any other information would indicate an increased inflow to the mine. The plot of the Kemira 20 Bore (Bulli Seam level) does not substantiate this. It shows a steady reduction across this period. The crucial factor in this rise was that on September 1, the longwall was not run and therefore no coal, and subsequently no water, was removed via the belt system. Therefore, in
order to keep the water level in the workings to the same safe level, more water, one megalitre more, had to be pumped from the panel. The same trend is repeated in the following days as the wall is still down. The increase to three megaliters is also related to the opening of the roof boreholes to the Bulli seam via the "Dead Cow".

Most of the peaks on this outflow graph are related to either down times in the longwall production or to extra outflow from the upholes. By correlating production records with pumping rates it can be shown that during this period a large percentage of the "coal" going across the weightometer on the main belt was in fact water being picked up by the belts and on the face. For example, the flat section of the graph between 31/08/90 and 01/09/90 shows that approximately one megalitre, or 1000 tonnes, of water was pumped from the longwall. On that day, 5228 tonnes of longwall coal was also produced. On the following day no coal was produced and approximately two megalitres of water were needed to be pumped. If the inflow can be assumed to be constant, which the Kemira 20 graph indicates, then the extra megalitre of water was transported out with the coal on the previous day. Allowing that not all the water leaving the longwall will stay on the belt through all the transfer points etc. until it goes over the weightometer, it can still be estimated that between 10% and 20% of the "coal" produced
from the longwall that day was actually $\text{H}_2\text{O}$.

The conclusion of this observation is that during these periods when the longwall face and maingate were actually operating in water, more accurate inflow figures can be obtained from the outflow on days when the 'wall was not operating.

To this end, current figures are more indicative of inflow rates as the 'wall is now above the water level contour and the face is dry. The pumps are operating in "B" Hdg inbye of the goaf, which is the tailgate of the next longwall and is therefore still standing.

5.6 Summary of Position as at July 27, 1990

In July 1990, Professor Raghu Singh, Head of the Civil and Mining Engineering Department of the University of Wollongong, was invited to visit the colliery and to formulate some hypotheses on the present situation at Kemira and on future inflow potential. The next longwall, Longwall 4, was due to commence production in the following weeks. The meeting was attended by senior management of the company as well as senior technical
staff to assess the current status of the mine.

Professor Singh's analogy of the situation was discussed with the aid of the on site experience of the colliery staff and other technical personnel and data. The following is a summary of the then current status of the mine's analysis of the inundation based on correspondence from Mr Jeff Wood, Senior Geoscientist, BHP Collieries, in response to Professor Singh's recommendations [24].

Source of Water

The start of Longwall 4 was located beneath relatively high surface topography, with no constant surface drainage. Possible activation of conduits to the surface, where a water source was present (Kembla Creek and tributaries), would not occur until LW 4 was approximately 50% extracted. Recharge was believed to be mainly from the escarpment (LW's 2 and 3) and the flow in Kembla Creek had stabilised.
Study of Water in Aquifers

Study of water pressures in the Scarborough Sandstone was then being monitored on at least a daily basis. That frequency increased to hourly before longwall 4 commenced.

The pressure in the Bulli seam was then being measured at least three locations - one surface and two underground.

Water in Old Workings

As explained in previous sections, goaf compaction and the presence of goaf seals had caused variable flows from underground boreholes. Pressures measured had been relatively consistent and indicated drawdown into a drainage gallery in the Bulli workings - namely an old haulageway or set of haulageways still standing and acting as water courses in the Bulli seam.

No unexpected water was present in the immediate roof of the Bulli seam (ie. no stratigraphic confinement). An unknown volume of water was, and still is, present in the Scarborough Sandstone, mainly in localised bedding separations. The water in the Scarborough Sandstone is
isolated from the Bulli seam and the immediate roof material by the Wombarra Shale which is, for the most part, composed of plastic swelling clay. A finite leakage of Scarborough water was then occurring over a large area (particularly over Wongawilli seam extracted areas). At the time, the volume of this leakage was estimated to be in the order of 0.5 Ml/day.

Detailed Studies Required

At that stage, chemical analyses were being carried out on a routine basis from various key outflow points. These included from the floor in both the main and tailgates, the upholes in the maingate (W28) and from the upholes in 13 Line, W27. The frequency of the sampling was to be increased when LW4 commenced production and the pumping capacity was increased.

Professor Singh intimated that the inflow to the mine may increase with the extraction of subsequent panels. This was thought to be due to the increased fracturing up to the Scarborough Sandstone aquifer which was seen to be the major source of inflow potential. This assumption was thought to be only partially true due to several factors:-
- it did not take account of the sealing potential of the Wombarra Shale which could seal up old migration paths;

- it assumed an increase in connection with surface water as the goaf area increased; and

- it assumed that the major source of the inundation was the Scarborough Sandstone and discounts the large "free water" area of the Bulli seam which was being continuously diminished by pumping from upholes.

At the time it was known that the level of the Scarborough water had progressively fallen since LW4 extraction had commenced. More Scarborough water was diverted through the cracks in the Wombarra aquiclude as LW3 had retreated. This was evidenced by the steeply dipping curve on the level graph. Equilibrium conditions were evident after LW3 was completed.

Conclusions

The following are the conclusions and observations of Mr Wood following the meeting and utilising the latest data
1. The initial inrush of water would be significantly less than the peak in LW3 (450 000 litres/hour or 10.8 Ml/day) and it would continue for a shorter period (<1 day).

2. The initial inflow would be from the Bulli seam with only minor contributions from the Scarborough Sandstone because of the small size of the goaf and the lack of initial effect on the Wombarra Shale.

3. The major conduit from the Bulli seam at the time was the roadway feeding the upholes in 16 C/T. By examination of the contours, this roadway was expected to be dry in the vicinity of the area above the longwall even when compared to the highest water heads measured (surface borehole). The highest head of water measured, 204.5m, was from the abandoned Kemira 18 borehole. This was subsequent to the LW3 inrush.

4. Leakage from the Scarborough Sandstone was expected to increase as extraction progressed past a square goaf and the underground subsidence profile interacted with the existing LW3 goaf. The initial flows from that source were not expected to be greater than 5 Ml/day.
5. The flows predicted were well within the pumping capacity of the colliery at the time - problems were expected only with maintaining suspended solids to a level consistent with the colliery's discharge limitations.

6. The chemical analyses of water taken from the mine were trending towards surface characteristics (higher Ca and Mg and lower Na). Comparison of the various water chemistries and their relevance to the source of the water will be discussed in Section 5.7.

The validity of these predictions were, for the most part, ratified by observation of the inflow patterns following the main goaf fall and subsequent retreat of Longwall 4. No major inflow was experienced and the pumps installed were capable of handling the inflow rate. The discussion and conclusions at the end of this thesis will further describe the features of the LW4 inflow and their effect on the prediction of future inundation potential at Kemira.
Chemical analysis of the mine water following the initial inundation in October '89 had a twofold purpose. Several state government authorities, including the State Pollution Control Commission (SPCC) and the Metropolitan Water, Sewerage and Drainage Board (Water Board), required specific analyses be carried out on water to be discharged into the surface drainage system. The analysis would be for all contaminating species which could effect the surface drainage system. The second purpose of the analyses was to trace the source of the initial inundation and to observe any changes in the chemistry of the inflowing water over a period which would indicate the recharge source.

Initial sampling in November '89 showed that the Bulli Seam water differed substantially from that of the surface drainage system. Significant differences included water clarity, pH, coliforms and Ca/Mg salts. The result of initial discussions with these statutory bodies was that multiple sampling points for the Bulli seam would be required for future reservoir management. At least one surface borehole was required down to the Bulli seam and another was required to an intermediate sampling point between the surface and the Bulli seam to assess the
nature, extent and mechanism of recharge. These two requirements were met by the previously discussed Kemira 20 and Kemira 21 boreholes.

It was proposed to build a data base of chemical samples from both the Bulli seam and the Scarborough Sandstone and all other water involved in the potential recharge cycle to the Bulli seam.

5.7.1 Water Board Requirements

In November 1989 discussions were held with a representative of the Water Board to determine the Board's attitude to the disposal of a then estimated 20 Megalitres/day of water from the Bulli seam reservoir and any other water source feeding the mine which would require drainage. The proposal at this time was to pump the water to the surface via boreholes which would have necessitated releasing the water into the Water Board's catchment area to the west of the escarpment. The following are the major issues concerning the discharge of water to the catchment area.
5.7.1.1 Major Issues

1. Finite quantity of water for discharge.

2. Influence of water extraction on the surface water table in the catchment area.

3. Chemistry of the water, including pollutants suspended or dissolved from mining debris in the Bulli seam workings.

4. Possibility of recharge from Cordeaux Dam along faults or other geological anomalies.

5. Possibility of varying water quality with time.

5.7.1.2 Discussion

The Water Board was particularly concerned with the sensitivity of the catchment area to large quantities of mine water as they considered it to be a "pristine" environment. This concern revolved around the sub-catchment micro-environment at the point of discharge,
erosion of surface soil profile and subsequent modifications to vegetation.

5.7.1.3 Conclusion

The conclusion to the discussion was that approval to discharge to the catchment area was dependent on a BHP sponsored Environmental Assessment of the effect of the discharge of a large quantity of water into the Goondarrin Creek subcatchment of Cordeaux Dam. Assurances of continued constant water quality were also required.

5.7.1.4 Disposal Alternatives

1. Surface extraction via submersible pumps to a point vertically above the lowest accessible part of the Bulli seam workings, followed by distribution into the headwaters of Brandy and Wine Creek (the escarpment) or into Kembla Creek which feeds the Cordeaux Reservoir.
2. Underground pumping of the water up a borehole to the surface in the immediate vicinity of the Goondarrin Creek catchment of the Cordeaux Reservoir. The option of pumping over the escarpment in this location was found to be very expensive and would have significant detrimental erosional effect on a significant portion of the escarpment.

3. As has been described earlier in this thesis, the option chosen was to drill down into Kemira Tunnel and to discharge the water on the escarpment into American Creek and hence to the coast.

5.7.1.5 Water Quality

Some chemical and biological analyses of the Bulli seam water were available at the time. Unfortunately, collection of samples at different locations in the Bulli seam was impossible due to lack of access to the old workings so the initial sampling was done from outflow from the longwall goaf. The following is an analysis of the contaminants in the goaf water which was believed to be primarily from the Bulli seam.
Faecal Coliforms

Thermotolerant microorganisms, derived from warm blooded animals - indicate faecal contamination. No faecal coliforms should be present in potable (drinkable) water.

Samples of water from both the Bulli and Wongawilli seams did not indicate the presence of any faecal coliforms.

Coliforms

Coliforms include viral and bacterial microorganisms which are derived from non-faecal sources. Guidelines indicate that no coliforms should be present in 95% of samples, 10 coliforms/100 ml may occasionally be tolerated.

The Water Board sets a limit of 10 000 counts/100 ml for fishing and boating activities, while accepted standards for swimming (American Creek) were unknown.

Comparison of Bulli seam coliform levels (50 coliforms/100 ml) with those from the Wongawilli seam (100 coliforms/100 ml) indicated pollution within the Wongawilli seam.
Standard Plate Counts

Standard plate counts are not a measure of faecal pollution but are used as a general indication of the microbiological quality of the water system. In well maintained private or public water supplies, values exceeding 100 organisms/ml would not be expected if disinfected, while values less than 500 organisms/ml would be expected if the water were not disinfected.

Contamination of water in the Wongawilli seam workings was indicated by comparison of a standard plate count of 900 organisms/ml for Bulli seam water with a count of 70 000 organisms/ml for the Wongawilli seam water sampled.

Oil and Grease

This measure included mineral oils and emulsified hydrocarbons and should not have exceeded 10 micrograms/litre for drinking water. Water directly extracted from the Bulli seam contained 500 micrograms/litre compared with the contaminated Wongawilli seam water which contained 1 700 micrograms/litre.
Conclusions

The analysis led to the conclusion that the biological contaminants would require chlorination if directly discharged to Water Board catchment. The oil and grease values were also at least 50 times greater than the accepted levels.

In order to have a control sample of water from the Bulli seam, a sample was taken and analysed from the Bulli seam in Cordeaux Colliery which is the colliery next to Kemira. The Cordeaux Bulli sample was significantly different to the Kemira Bulli water.

Differences included -

- Higher pH indicates more alkaline water.

- Higher relative sodium and lower potassium indicated sodium carbonate species rather than the high sodium bicarbonate species characteristic of Kemira. Chemical analysis of an outflow in Kemira Colliery in the Bulli seam by Williamson (1978) [25] showed the water to be a sodium bicarbonate type. This is commonly characteristic of waters in deep sedimentary rocks, e.g. the Scarborough Sandstone near the base of the
Narrabeen Group, and not of waters such as the Hawkesbury Sandstone or surface water.

- Lower magnesium and calcium compared to Kemira.

- Lower manganese and higher total iron.

The relatively high arsenic content was consistent with leaching of treated timber, probably from the old Corrimal workings which are now a part of the Cordeaux mine.

5.7.2 Sourcing Mine Water by Hydrogeochemistry

The study of groundwater geochemistry is a much larger field than it is possible to cover here. The main application in this thesis will be the study of the main cations in fresh water aquifers. Hydrochemistry involves the study of the chemical reactions which take place when water is flowing through an aquifer. A popular misconception is that a water type can be uniquely related to the rock or aquifer type in which it is found. As water flows through an aquifer various reactions take place between the water and the rock which constantly change both the composition of the water and the minerals which
constitute the aquifer. The rate of change of the chemical composition of the water as it flows through the aquifer is governed by the rates of the chemical reactions which are taking place i.e. by thermodynamics, and by the rate at which the water is flowing i.e. by hydrodynamics. [26]

The application of hydrogeochemistry to determine the source of the water recharge to the workings at Kemira is the second major use of water sampling from the mine.

During the months following the inundation at Kemira, the source of the water and the potential for subsequent inundations was of primary concern. Facts, or even sound hypotheses were not available to the mine management. The upheole drilling programme led to the conclusion that the Bulli goaf above the Wongawilli workings was a certain source of the inundation water, however the extent of this source or its recharge potential were still unknown. Other potential sources such as the Scarborough Sandstone were also suspected but there was little supportive evidence.
5.7.2.1 Sampling and Analysis

A programme of sampling and chemical analysis was undertaken to define the source of future inflows to the mine. Samples were collected in sterilised plastic water bottles from various sampling points at irregular intervals. If the samples were to be analysed for coliforms, the bottle had to be completely filled with the sample to remove all free air from the bottle. The reaction of the water with the air in the bottle could effect the results of the test. If the sample wasn’t able to be delivered to the lab immediately, it was kept refrigerated to reduce reactions with any air in the bottle.

The samples were originally sent to both the Central Laboratory at the BHP Steelworks in Port Kembla and also to the Department of Chemistry at the University of Wollongong. Eventually, the samples were only sent to the steelworks because of the tardiness of the University in returning results. The samples were tested for a full spectrum of minerals and other features. While only several of these were used for analysis, it was thought prudent to carry out exhaustive tests in case different techniques were developed in the future which may require the results of analysing other features of the water. The
following is a list of the analyses carried out on the water samples and the associated cost of each test.

1. Water samples for Source Tracing

<table>
<thead>
<tr>
<th>Analysis</th>
<th>Cost per Analysis ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
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</tr>
<tr>
<td>TDS (total dissolved solids)</td>
<td>18</td>
</tr>
<tr>
<td>Conductivity</td>
<td>6</td>
</tr>
<tr>
<td>Sulphate</td>
<td>25</td>
</tr>
<tr>
<td>Chloride</td>
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<tr>
<td>Nitrate</td>
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</tr>
<tr>
<td>Fluoride</td>
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<tr>
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<td>Arsenic</td>
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<tr>
<td>Calcium</td>
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<td>Sodium</td>
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<td>Potassium</td>
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</tr>
<tr>
<td>Manganese</td>
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</tr>
<tr>
<td>Total Iron</td>
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</tr>
<tr>
<td>Fixed Iron</td>
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TOTAL = $297 per sample
2. Water Samples for Suitability for Releasing onto Water Board Property

<table>
<thead>
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<td>Faecal Coliform</td>
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<td>Total Coliform</td>
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<tr>
<td>Total Plate Count</td>
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</tr>
<tr>
<td>BOD$_5$</td>
<td>25</td>
</tr>
<tr>
<td>Oil and Grease</td>
<td>24</td>
</tr>
<tr>
<td>NFR (non filterable residue)</td>
<td>10</td>
</tr>
</tbody>
</table>

TOTAL = $169 per sample plus $50/hour for sampling

Figures 5.14 and 5.15 are typical laboratory analyses of water samples from the colliery and from other surface and borehole locations.
12th December, 1989

Mr. Jeff Wood,
Senior Geochemist,
Collieries Division,
BHP Steel

Dear Mr. Wood,

May I present you with the results to date for water samples from Kemira Colliery:

<table>
<thead>
<tr>
<th></th>
<th>W27 Panel</th>
<th>V Notch</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>13-CT B.H.</td>
<td>Weir W-27</td>
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<td>Total coliforms (per 100mL)</td>
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<td>100</td>
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<tr>
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<td>&lt;1</td>
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<tr>
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T.W. LEWIS

Figure 5.14
### Certificate of Water Analysis

**BNF Steel - Slab and Plate Division - Port Kembla**

**Chemical Department - Water Analysis Section**

**Description:** Coal Geology Samples

**Date Sampled:** As shown

**Date:** 9-9-1990

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**Method Reference (see below):**

A B C D E F G H I J

| Remarks: | Zn, Cu, Cr, Sn and Ni <0.1 Mn Mg goaf <0.1 Bulli seam 0.3 |

**Copy to:**

Mr. PETER WITHALL (Original)

**Method Reference: **

- A Standard Methods APHA 16th Ed Part 423
- B Standard Methods APHA 16th Ed Part 305
- C Standard Methods APHA 16th Ed Part 305
- D Standard Methods APHA 16th Ed Part 305
- E Standard Methods APHA 16th Ed Part 305
- F Standard Methods APHA 16th Ed Part 305
- G Standard Methods APHA 16th Ed Part 305
- H Standard Methods APHA 16th Ed Part 429
- I Standard Methods APHA 16th Ed Part 429
- J Standard Methods APHA 16th Ed Part 403

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Figure 5.15
5.7.2.2 Methods of Comparing Analyses

A paper written by Singh (1989) [27] discusses several methods of comparing these hydrogeochemical analyses. A brief review of these methods as found in Singh is given below.

1. Comparing chemical components (mg/l) as a percentage of the dissolved solid.

2. Kimpe's Method

   In this method, water compositions are reported in milli-equivalents per litre and plotted as logarithmic values with the points joined to form a "hydrogram". This method emphasises the similarity of water samples rather than the differences, and therefore is not suitable for identifying the onset of an inundation.

3. Comparison of the equivalent ratios of related ions Na/Mg, Ca/Mg and Cl/SO\textsubscript{4}: These parameters show a considerable overlap from different sources of water and a comparison between different samples from various sources is therefore difficult.
4. Triangular Graph Method (Figure 5.16)

The main problems with the interpretation of water analysis results with this method include identifying the various factors to be studied in the analysis, and data handling and analysis, especially when a large number of results are available. An analysis of earlier work enabled Singh to make the following conclusions:

a) No individual characteristics can unequivocally identify the source of water inflow;

b) The inter-relationship of proportions of the various components may be relevant in ascertaining the source of underground water. In this context, Na, Ca and Mg form 99% of the metals in solution (milliequivalents/litre by dividing by equivalent weight). The active components of Na, Ca and Mg (mg/l) are converted to milliequivalents/litre by dividing by equivalent weights obtained from chemical tables.
Figure 5.16 - Triangle Analysis
The data is summarised as the Na/(Total Cations) ratio and
the Mg/(Mg + Ca) ratio. The total cations includes the sum
of Ca, Mg, Na, Fe, Mn and Ba, however, since
the Ca, Mg and Na make up more than 99% of the solution,
an accurate analysis can be made knowing only these three
components of the solution.

The remainder of the paper by Singh deals with the
comparison of water samples with the data base of
several thousand samples from the Coal Measures of
Great Britain. Unfortunately this sort of data base is
not available for comparison of water analyses from
the Illawarra Coal Measures. The triangle method was
however applied with excellent results to the Kemira
analyses. This application will be dealt with in
Section 5.7.3.

5. Piper (or Trilinear) Diagrams [26]

Piper (1944) developed a useful scheme for the
presentation of chemical types based on the dominant
anions and cations. Figure 5.17 is an example of a
Piper diagram, commonly referred to as a Trilinear
diagram. The Piper classification scheme is similar to
classification schemes for igneous rocks.
Figure 5.17 - Piper Diagram
To plot a water sample on a Piper diagram, the individual percentages of each of the cations (Ca$^{++}$, Mg$^{++}$ and SumNa$^{+}$ + K$^{+}$) and the individual percentages of each of the anions (Cl$^{-}$, SO$_4^{+}$ and SumHCO$_3^{-}$ + CO$_3^{+}$) are first calculated in milliequivalents per litre. The points for the cations and for the anions are plotted at their respective positions and projected to obtain the third point on the diagram. A trend of water analyses plotting progressively across a Piper diagram indicates that the water in the aquifer is reacting with the minerals of the aquifer and changing its composition as it moves down the flowpath.

The Piper diagram was applied to the chemical analyses relating to the Kemira inundation but with inconclusive results. Unfortunately most of the samples plotted too close to the corners of the three figures to allow any trends to be deciphered.

It was decided that the Triangle method was the most applicable to the water types thus far collected and therefore this method was applied to the Kemira samples in an attempt to draw conclusions about the source of the inflow and recharge facilities above the Wongawilli seam workings.
5.7.3 Application of Triangle Method to Kemira Analyses

As has been previously discussed, since the initial investigations into the possible source of the inundation, it had been thought that the majority of the water had come from the goaf water in the overlying Bulli seam. Study of the characteristics of the stratigraphy overlying the Bulli seam also led to the theory that the Scarborough Sandstone, a known aquifer overlying the impermeable Wombarra Shale, may also be a potential recharge source of the Bulli goaf and a direct inflow source to the Kemira workings.

A programme of collecting water samples from several locations was thus instigated to provide data for geochemical analysis. Water samples were collected underground from upholes in W27 Panel, upholes in W28 Panel, the floor in W27 Panel, the floor in W28 Panel, the goaf edge in W27 and the goaf edge in W28. The object was to observe the chemical trend of the water flowing at these points. To set the ends of the scale, several control samples were collected from Kemira 21 (directly from the Scarborough Sandstone), Kemira 20 (directly from the Bulli workings) and the Bulli seam at Cordeaux Colliery. Another sample was collected from an outflow spring from the Scarborough Sandstone on the escarpment.
several hundred metres to the south of the swamp area believed to be the recharge zone for this aquifer. The fact that this sample was almost the same as the surface water collected near the swamp indicated that this spring was a "short circuit" of some of the water entering the escarpment at the swamp and returning to the surface after only a short migration through the aquifer. Although similar to the surface water it had already picked up some of the characteristics of the aquifer.

5.7.3.1 Discussion of Triangular Graph - Figure 5.18

The samples have been broken into two groups for ease of study. The first group plotted on the triangle in Figure 5.18 is made up of three samples taken from Kemira 21 in the Scarborough Sandstone, two samples taken from the goaf and 13 C/T in W27 Panel, two samples taken from the goaf on the main gate side (W28) of Longwall 4 and a sample from the Bulli seam at Cordeaux Colliery. Many other samples were also taken at these locations at various intervals but only the above mentioned have been plotted to avoid overcrowding of the graph.
Figure 5.18 - Triangle Analysis: Kemira
The calculated coordinates on the triangle of the sample taken from the Scarborough spring are approximately 37 on the Sodium/Sum Cations axis and 51 on the Mg/(Mg+Ca) axis. As can be seen, this does not plot on the graph but it is sufficient to note that it is in the middle of and well below the Mg/(Mg+Ca) axis. For all intents and purposes, this represents the fresh water recharge from the escarpment to the Scarborough Sandstone.

Firstly, observe the plots of the Kemira 21 samples. From the plot of the water on 17/01/90 to the 09/08/90, a period of almost 7 months, the chemical composition has moved towards that of the diluting fresh water by about 5%. This may be attributed to the steady outflow of the Scarborough water into the Bulli goaf and/or directly into the Kemira workings and the subsequent recharging of the aquifer from the escarpment. In the following 8 days to the 17/08/90, the chemistry moves towards that of the fresh water a further 5%. The reason for this dramatic change can be directly attributed to the commencement of Longwall 4 and the formation of the first major goaf fall on about August 15. It is believed that this goafing increased fracturing up through the confining Wombarra Shale to the Scarborough Sandstone and hence opened new migration paths of water from the aquifer to the underlying strata. This is supported by the change in grade of the decreasing water level in the Scarborough
Sandstone as depicted on the graph in Figure 5.20. The dramatic drop in water level in the Bulli seam at this time can be seen in Figure 5.21.

The remaining five samples can be discussed simultaneously as they serve to strengthen the theory of the direct connection between the Kemira workings and the Scarborough aquifer. It can be seen that the Bulli seam sample plots up in the apex of the triangle and provides the other end of the scale to the fresh water sample. The two samples taken from the goaf on the maingate side of the longwall indicate a high "Bulli seam" content although the samples, taken six weeks apart, are trending towards the recharging fresh water. The two samples taken from the tailgate side in W27 are closer to the Scarborough water in composition. When these samples were taken the water level in the Bulli seam was already well below the level of the seam above W27. This fact, and the observation that the water in the tailgate is chemically closer to the aquifer water than it is the tailgate, would indicate that direct fracturing to the aquifer was allowing water down through the goaf into the tailgate side of the longwall.
This graph is made up predominantly of uphole samples from W28 panel. The samples were taken from different locations, and as has been discussed in earlier sections, the conditions in the Bulli seam above each of the borehole sites is considerably different.

By observing the various plots and their relative dates, a similar trend as that described in 5.7.3.1 can be observed. Except for the plots of the samples from Cordeaux, the Bulli seam sample taken from the surface bore, Kemira 20, and the Kemira 21 Scarborough sample, the other samples are taken directly from the Bulli seam via the upholes. The samples taken from the same sites at different times shows the trend towards the fresh water.

The plots of water taken from different points on the same day, however, plot quite differently. Take for example the samples taken from 14 Line and 16 Line on July 13. Although these sites are only a couple of hundred metres away from each other, their geochemical composition is quite different. The 16 Line sample has much more of the characteristic of the fresh water from the Scarborough recharge than the water at 14 Line. For an explanation of
Figure 5.19 - Triangle Analysis: Kemira
this, reference can be made to the rising head tests in 14 Line and the relative outflows from these two sites. It will be recalled that the 14 Line boreholes proved to be in a semi-compacted goaf area with low to medium permeability. The 16 Line bores, on the other hand, are tapped into a main haulageway of infinite permeability and constant running water. A reasonable analogy of the differences in chemistry would therefore be that the water in the 16 Line sample has been continuously diluted by recharge from the aquifer as it was drained away by the pumps etc., while the water surrounding the holes in 14 Line have had relatively little drain off and therefore have not been diluted by the recharge water so extensively.

5.7.3.3 Discussion of Hydrogeochemical Analyses

The use of the Triangle method on the water analyses proved a useful tool in the prediction of the inundation potential in Longwall 4 but will prove an invaluable tool in the prediction of future inundations in subsequent longwalls.

The conclusions drawn from the plots prior to the
commencement of Longwall 4 indicated that the major source of water inflow to the workings in Longwall 3 had been from Bulli seam goaf storage and that some recharge was evident from the Scarborough aquifer. The amount of the recharge or the capacity for a further inundation in the next longwall could only be theorised. Plots of the response of the Bulli seam level and the aquifer level in Figures 5.20 and 5.21 indicated that the dewatering programme using the upholes was reducing the water in the Bulli goaf and that the water migration fractures through the Wombarra Shale were starting to close up and reduce the recharge of the Bulli seam. These observations led to the theory that the first major goafing of Longwall 4 would not produce a major inundation as had been experienced in the previous longwall due to the lowered head of water in the Bulli seam.

This theory proved to be correct since, while there was a considerable outflow of water from the goaf, it was nowhere near the magnitude of the previous inundation.

Analysis of water samples since the commencement of Longwall 4 in mid August '90 are included in the plots in Figures 5.18 and 5.19. These analyses are helping to strengthen the theory of the recharge and indicate that if a continued programme of dewatering of the Bulli goaf is continued in subsequent panels down dip from the current
Kemira 21 - Scarborough Sandstone

Water Level Variation

Figure 5.20
**Figure 5.21**

Bore S1097 (Kemira 20)

Water Level Variation to Nov. 1990

Water Level RL (metres AHD)

- **Start of Pumping from Roof**
- **Start of LW4**
- **40 m Advance (First Goaf Fall)**
- **No Pumping from Roof**

Date:
- 08-Dec
- 27-Jan
- 18-Mar
- 07-May
- 26-Jun
- 15-Aug
- 04-Oct
- 23-Nov
longwall, then the problem of inflow in future longwalls should remain a manageable one.

Figure 5.22 is a cross-sectional representation of the stratigraphy overlying the Wongawilli seam workings at Kemira Colliery. The figure highlights the flowpaths believed to be the source of water inflow to the Kemira workings. Figure 5.22 is effectively a pictorial summary of the inundation analysis in that it shows the inter-relationship of the water bearing strata and the underlying stratum.
Graphic Representation of Escarpment Above Kemira Colliery's Wongawilli Seam Workings
CHAPTER 6

CONCLUSIONS

The analysis of an inundation to a mine is a complex process. Many factors are involved such as location of bed separation zones and stress relaxation zones around the mine workings, the position of any aquifers above the workings, the hydrogeology of the intervening strata, sub-surface and surface subsidence profiles, thickness of the intervening strata as well as its permeability characteristics and the location of surface or sub-surface recharge facilities.

The following observations have been made and conclusions drawn by the author after the thirteen months that this investigation was carried out:

1. The direct source of the original inundation in W27 was the stored water in the Bulli seam goaf overlying the Wongawilli seam workings.

2. The Bulli seam water involved in the initial inundation may have had several sources, including surface inflow via old adits, inflow through the talus slopes into old workings close to the escarpment,
water make from mining operations accumulating in the low point in the mine, and inflow via strata fracturing to the Scarborough aquifer caused by mining operations in Kembla Colliery. These are only suppositions, however, as there is no evidence one way or another to indicate the original source of the Bulli seam goaf water.

The primary source of recharge to the Kembla workings (Bulli seam), however, and the indirect source of any future inflows to the Kemira workings appears to be the Scarborough Sandstone aquifer.

3. In determining the head of water in the Bulli seam, the vibrating wire piezometer proved a quick and accurate device. While the manometer, once installed, should be a better, quicker reference of head, the maintenance problems negated the ease of use.

4. Hydrogeochemical analyses carried out on water samples from various sampling points indicate a trend of inflow water towards the diluting Scarborough aquifer water.

The use of the analysis techniques and plotting on the triangular graph proved a valuable tool in determining the source of the inundation and in predicting the
source, and hence the possible magnitude, of the inflow to subsequent workings.

5. Application of various analysis techniques, such as barometric efficiency or Darcy's law, to practical mining problems do not always have to be quantitative to be of value. Observation of relative values can be of great use in determining trends and predicting future events. Often not all the variables are known to be able to apply many theoretical formulae to events such as inundations. Empirical relationships should therefore be developed on site to cater to the needs of the particular event.

6. The problem of inflow to the Wongawilli seam workings at Kemira Colliery will continue while the seam is being mined below the high water level in the Bulli seam. Continued dewatering from upholes should maintain a lowered water level and prevent the buildup of a large volume of water in the Bulli seam goaf. It is essential that these holes target open roadways to maximise the outflow potential of each hole. Low permeability goaf regions should be avoided unless there is no alternative. Current pumping capacity at the mine should be sufficient to manage future inflow volumes.
7. The effect of rainfall on the water levels in the Bulli seam was not quantitatively examined. In the period since a good understanding of the recharge facilities was reached, there has been very little rainfall on the escarpment overlying the colliery. Some visual observations were made of the piezometric levels in the Bulli seam during the brief rain periods, however these were insufficient to prove or disprove the direct recharge effects of an extended period of heavy rain. Old adits and possibly other unknown accesses to the Kembla workings may only act as recharge facilities if submitted extended rainfall periods. The water level in the surface and underground boreholes should be closely monitored during future periods of heavy rain to quantify any effects on the level.

8. Future monitoring of the piezometric levels and analysis of water samples from the surface holes, the upholes and the goaf outflow should be maintained on a routine basis. This will allow any changes in the inflow regime to be detected early and the colliery warned of potential increases in outflow or even of potential inundation to the workings.

To this end a programme of sampling should be established, the results plotted on the triangle
graphs and analysed for changes in the water chemistry which may indicate changes in the recharge source.
REFERENCES

1. Williams R. E. Mine Hydrology - Published 1986


5. Todd D. K. Ground Water Hydrology, 1959


7. Sinclair J. Water in Mines and Mine Pumps, 1958
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14. Holla and Buizen

15. Houlsby A. C.

16. Singh R. N. & Atkins A. S.

Kumminiat Nr. 651, G.G. Katowice, Poland, 1974.


22. Wood J. H.  Senior Geoscientist, BHP Collieries Division. Personal Correspondence, 2/6/89

23. Mohen F. J.  Principal Engineer, Australian Groundwater Engineers. Personal Correspondence, 2/7/90.
24. Wood J. H.  
Notes on Recommendations by Prof. Singh, Kemira 27/07/90, Private Correspondence.

25. Williamson W. H.  
"Hydrogeological Aspects of Coal Mining Under Stored Waters Near Sydney, Australia" - Water in Mining and Underground Works SIAMOS78, Granada, Spain.

26. Blake R.  

27. Singh R. N.  
"Origin of Mine Water from Interpretation of Water Analysis Data" - Mining Science and Technology, 9 (1989)

28. Vennard J. K.  
Elementary Fluid Mechanics, 1982

and Street R. L.
APPENDIX 1

ABRIDGED CHEMICAL ANALYSES SHOWING ONLY

SODIUM, Na, POTASSIUM, K, CALCIUM, Ca, and MAGNESIUM, Mg.

THESE ANALYSES WERE USED IN PLOTTING THE SAMPLES ON THE

TRIANGLE GRAPHS
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### Water Analysis

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### Water Analysis

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### Water Analysis

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CORD. BULLI SEAM

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<td>Ca</td>
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<td>0.12</td>
</tr>
<tr>
<td>Mg</td>
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<td>0.05</td>
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Water Analysis

bulli surface 17/01/90

<table>
<thead>
<tr>
<th></th>
<th>Lab Results (ppm)</th>
<th>Lab Results (MEquiv/litre)</th>
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<tbody>
<tr>
<td>Na</td>
<td>593.0</td>
<td>25.79</td>
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<td>K</td>
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<td>Ca</td>
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<td>Mg</td>
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Water Analysis

14 line 15/6/90

<table>
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<td>Mg</td>
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Water Analysis

LW5 Inst Hdg 15/6/90

<table>
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<th>Lab Results (MEquiv/litre)</th>
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<td>Mg</td>
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Water Analysis

W28 141 13/7/90

<table>
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<tr>
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<th>Lab Results (MEquiv/litre)</th>
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<tbody>
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<tr>
<td>Mg</td>
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<tr>
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<tr>
<td><strong>Na</strong></td>
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<tr>
<td><strong>K</strong></td>
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<td><strong>Ca</strong></td>
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</tr>
<tr>
<td><strong>Mg</strong></td>
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<td>1.48</td>
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**Water Analysis**

**MG GOAF 21/8/90**

<table>
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<th></th>
<th>Lab Results (ppm)</th>
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<tbody>
<tr>
<td><strong>Na</strong></td>
<td>587.0</td>
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<td><strong>K</strong></td>
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<td><strong>Mg</strong></td>
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**Water Analysis**

**W28 Goaf 09/10/90**

<table>
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<th></th>
<th>Lab Results (ppm)</th>
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<tr>
<td><strong>Na</strong></td>
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**K21 17/01/90**

<table>
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<tbody>
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<td>Mg</td>
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**Water Analysis**

**K21 BORE 9/8/90**

<table>
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<th>Lab Results (ppm)</th>
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<tbody>
<tr>
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<td>K</td>
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**Water Analysis**

**K21 17/08/90**

<table>
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<td>K</td>
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<td>Ca</td>
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<td>0.50</td>
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<tr>
<td>Mg</td>
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**Water Analysis**

**W27 Goaf 8/8/90**

<table>
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<tbody>
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