WATER USAGE IN THE SOUTH AFRICAN PULP AND PAPER INDUSTRY

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Preface

I, Christopher James Moore Macdonald, declare that unless indicated, this dissertation is my own work and that it has not been submitted, in whole or in part, for a degree at another university or institution.

CJM Macdonald

November 2004

As the candidate's supervisor, I have approved this dissertation for submission.

Professor CA Buckley

November 2004

Abstract

The pulp and paper industry holds a reputation in the public eye for being a large consumer of water. This dissertation analyses water usage within the industry with a particular application to the South African pulp and paper industry.

Unlike in other paper-producing countries, water in South Africa is a scarce commodity with a wide range of consumers. Faced with this, it is important for the leaders of the paper industry to have a tool with which to manage water consumption.

This dissertation analyses the water usage aspects (including volumes needed and water quality needed) of the different processes, as well as the impact of different products, describing the reasons for water usage in each process. The application of best available technologies for water reduction is discussed.

A theoretical or expected range and norm for water usage for each of seventeen South African mills is derived, based on each mill's particular processes, capacities and products. The actual water usage by each mill was surveyed by personally interviewing personnel at each mill. Comparisons are made between expected and actual water usage, and the total daily water consumption of the industry is derived.

Only two mills operate below the expected norm level, most smaller mills operate close to the norm level, while five of the larger mills need to apply various techniques to reduce their water usage. The approximation of mill water usage to the predicted or expected norm clearly supports the hypothesis that water usage can be predicted by analysing process and capacity, and indicates that this dissertation can be used as a tool to manage water usage within the industry.

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….in the sixties, my mother and the Head Master, Fr Carty, in discussion, decided that I had a *Masters degree brain* and so the seed and the standard were set. My mother always set high standards….

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Glossary

A

Accepts
Usable pulp that has passed a screening or cleaning operation

Acid sulphite
Sulphite pulping process based using very low pH and usually calcium based

Alkaline sulphite
Sulphite pulping process operated at a pH of 10 or higher

Approach Flow
The final part of the stock preparation as the stock is delivered to the headbox

As Na_2O
Concentration of kraft or soda cooking liquors with values expressed as g l^{-1} sodium oxide

B

Black liquor
Liquor stream separated from pulp in alkaline pulping

Blowing
Release of pulp and liquor from a digester by opening the valve (blow valve)

Bleached softwood kraft (BSK)
Bleached pulp made by the kraft process using softwood timber

Bulk
A specific volumetric measurement of paper expressed as ml g^{-1} (inverse of density)

C

Calendar
Assembly of rolls at the dry end of the paper machine imparting a finish to the paper, reducing bulk and roughness

Cartonboard
Sometimes called folding boxboard, a multiply board used for making folding boxes

Causticising
The process of converting sodium carbonate (green liquor) to sodium hydroxide (white liquor) by reacting with slaked lime

Chemical Oxygen Demand (COD)
A water quality term which describes organic pollutant concentration in terms of the amount of oxidation required to chemically break it down

Chemical pulp
Wood pulp produced by chemically breaking down woody material

Chemithermomechanical pulp (CTMP)
A mechanical pulping process where wood is chemically treated prior to refining

Cleaning
A process of removing contraries by treatment in hydrocyclones

Closed mill
Refers to a mill with zero liquid effluent; sometimes refers to pulp mill only

Clothing
Collectively, the felts, wires and fabrics used on a papermaking machine

Cold blow
Cold blow refers to digester discharge at a temperature lower than the cooking temperature, usually around 100°C

Consistency
Weight percentage of pulp in a pulp and water mixture

Contraries
Material unsuited for papermaking, present in some waste paper sources

Cooking liquor
The solution of chemicals prepared for the digestion process

Corrugating Medium
Sometimes referred to as fluting; used as the fluted material in middle of corrugated box board (between linerboard)

D

Deculator
A device which removes air from papermaking stock by vacuum, in the approach flow

Digester
In chemical engineering terms, the reactor where wood is reacted with cooking chemicals

Dilution factor
A measurement of how much wash water is added to the black or red liquor

Disperger
A device used to smear stickies onto the fibres to prevent them causing problems on the paper machine

Displacement ratio
Related to dilution factor, the ratio of wash water applied to the mass of water remaining in the pulp

Draw
Difference in speed between two adjacent sections of a paper machine, The term also is applied to the tension in the sheet caused by the speed differential

Drier
A device to dry pulp or paper

E

ECF
A bleach sequence which does not use elemental chlorine (or hypochlorite)

F

Fine paper
Normally, white paper for printing and writing

Former
The part of the paper machine which forms the fibre web

Freeness
Describes the readiness with which a fibre stocks disengages from its water

Furnish
The specific mixture of raw materials, both pulp and chemicals, from which a particular grade is manufactured

G

Groundwood (GW)
Pulping process whereby wood is reduced to fibres by pressing against a grindstone, refers to the pulp as well

H

Hardwoods
Wood from trees from the angiosperm class, usually with broad leaves and deciduous in temperate zones. Hardwood fibres are short in relation to softwood fibres

Headbox
The part of a paper machine where the stock is transferred from pipe flow to the slice; the pressure is set to determine jet speed

I

Isothermal cooking
: A modification of the continuous upright digester operation whereby the temperature is maintained throughout the digester

K

Kappa number
: An industry measure of the lignin remaining in a pulp after cooking

Kraft
: Refers to an alkaline pulping process where sodium sulphide is included in the cooking liquor; also to products made by this process including bleached pulps and packaging papers

L

Latency
: The property of refiner produced pulps to be twisted

Linerboard
: The outer board of the corrugated cardboard box

M

Market pulp
: Pulp sold as a raw material to non-integrated paper mills

Mechanical pulp
: Pulp produced from wood by a mechanical process, grinders or refiners

Modified continuous cooking
: A modification of the continuous upright digester operation whereby the cooking liquor is added at different stages of the process

N

Newsprint
: Lightweight paper produced from mainly mechanical pulp for newspaper use

Neutral sulphite semichemical (NSSC)
: A partial chemical pulping process whereby a pulp with good bonding capabilities but an inherent stiffness is produced for packaging papers

Noodle pulp
: Wet pulp (~50% consistency) stored on the floor

O

OWL
: Kraft white liquor where the sulphide is oxidised to sulphate for use in bleaching processes

P

Press
: The second dewatering stage on a paper machine where water is removed by pressing adjacent to a felt.

Pressure groundwood (PGW)
: A modified groundwood process which is operated under pressure

Primary refiner
: The first refiner in TMP or CTMP processing, used for fiberisation

Printings and writings
: See fine paper

Protectors
: In oxygen bleaching, the use of magnesium compounds or EDTA to reduce cellulose reactions

R

Red liquor
: The resultant liquor from sulphite pulping, similar to black liquor

Refiners
: Mechanical devices with close rotating plates which are used to adjust the paper making properties of fibre stocks

Refining
: Treatment in refiners

S

Saveall
: A device at the wet end used for recovering fibres from machine back water

SC
: Super calendered newsprint type papers for magazines, fliers etc

Screening
: A process of removing contraries by treatment on screens

Secondary refiner
: The second refiner in TMP or CTMP processing, used for fibre property development

Semi-alkaline sulphite anthraquinone (SASAQ)
: A pulping process using alkaline sulphite assisted with anthraquinone

Short column test (SCT)
: a test for packaging papers to evaluate the paper under linear load

Size press
: a paper machine device for applying starch to the paper surface

Slasher deck
: In pulp mills, the slasher is used to cut logs to the correct length for the process

Soda
: The original alkaline cooking process using caustic soda

Softwoods
: Cone bearing trees. Also called evergreens. Produce longer fibres

Stiffness
: A paper property of rigidity of the sheet

Stock
: Wet pulp of any type at any stage of the manufacturing process. More specifically, the prepared papermaking furnish.

Stone groundwood (SGW)
: Another name for groundwood

SuperBatch®
: A modified batch cook which achieves some of the energy efficiency of the continuous cook

T

TCF
: A bleach sequence which does not use any chlorine based bleaching chemicals

Tensile
: A measurement of the resistance to stretching

TEA
: Tensile Energy Absorbed, a measure of the energy absorbed in stretching during a tensile test

Thermo mechanical pulp
: A pulping process using refining under pressure after preheating the wood chips

Tissue
: A very lightweight paper product, normally creped and used for toilet paper, facial wipes, towelling etc

U

UBSK
: Unbleached softwood kraft pulp

W

Wash water
: An all encompassing term for water/recycled water/other waste streams used for washing pulp

Web
: Term applied to the full width of the paper sheet in the process of being formed, pressed, dried, finished, or converted

White liquor
: The product of causticising of green liquor after clarification. It is a solution of sodium salts, hydroxide, sulphide and carbonate

Chapter 1 Introduction

Traditionally the paper industry has been associated with trees and water, both essential commodities required for the success of production within the industry. The availability of trees or other fibrous vegetable matter is a function of the availability of suitable land and weather conditions for growth.

Forestry operations are not considered as part of this investigation, which focuses on the use of water within the pulp and paper industry.

The importance of the management of water usage within the pulp and paper industry is a relatively recent problem which has really only developed since the 1960s. The reasons for this are multifold, but the growing awareness of the importance of the earth's natural resources, the increasing size of the industry and, in particular, the increase in the size of individual production plants and the consequent larger impact on the immediate environment all played a major role.

Prior to the improvement in attitude of the industry the specific usage of water was substantial, 156 kl t^{-1} in 1975 and the concept of letting the river run through the mill was prevalent [Canadian Pulp and Paper Association, 1997]. From an operational viewpoint, there are a lot of advantages in this manner of processing in a pulp and paper mill as the ionic species which cause problems in processing are rinsed from the water circuits.

An excellent description of the changes in water usage in paper making is given by the following table on a recycled fibre mill, summarised from work by Webb [Webb, 2003]

Table 1.1 Changes in water usage in a recycled fibre mill [Webb, 2003]

Year	Paper Production t d^{-1}	Water Use kl d^{-1}	Specific Water Use kl t^{-1}
1950s	100	10 000	100
1960s	150	7 500	50
1970s	400	10 000	25
1980s	500	2 500	5
1990s	1000	3 000	3
2003	1200	2 400	2

It must be remembered that the industry technology was considered to be an art rather than a science even into the 1960s; decisions as to modification of the process variables were based on *feel, rattle, chew* etc of the paper produced [personal experience].

In this type of operational environment, it was appropriate to remove as many interfering variables as possible, including insidious ions as well as microorganisms. This was achieved by dilution and washing out. As mills were relatively small by the standards of today, the inefficiency of chemicals had a lesser influence on the overall efficiency than the fixed costs. The chemicals used were also less sophisticated and hence less expensive.

It is probably true to say that the turning point for the industry, from a water and effluent perspective, revolved around the increasing size of bleached chemical pulp mills in the 1960s which were, by necessity, associated with large water sources for a water reserve and an effluent sink. Two examples are the Great Lakes of North America and the Baltic Sea. Within a decade, these two natural resources were dying from misuse; particularly from bleach mill effluent, mainly from the chlorination stage and the use of acid sulphite pulping. Bleaching technology was CEH or

CEHD (see Appendix 5). Acid sulphite pulping had not yet been taken over by the Kraft process despite the lower quality of the pulp. The main reason for this is the less expensive raw materials, limestone and sulphur, which were not recovered after the pulping process but disposed to effluent with the woody waste material.

The pressure placed on the industry to reduce effluent volume and improve effluent quality resulted in the rapid demise of the acid sulphite processing technology [Springer, 1986]. Some mills developed to magnesium or ammonium based sulphite pulping with recovery of the red liquor to cooking chemicals and although this allowed pulping at higher pH values with resultant improved pulp strength, no new capacity was installed in low pH sulphite pulping. Developments were made by usage of the Kraft pulping process.

From the 1960s on, focus was placed on reducing the effect of effluent on the environment and, particularly, the effect of chlorine based bleaching chemicals on receiving water systems.

The reluctance to move away from chlorination was to some extent understandable and the following reasons were put forward [Capps, 1990]:

- chlorine was relatively inexpensive.
- chlorine was co-generated with caustic soda, a necessary chemical in the pulping and bleaching processes.
- chlorine, if controlled properly, was a very selective bleaching chemical which did very little damage to the cellulosic components.
- the alternatives all had problems:
  - chlorine dioxide requires six times more electrical power to produce.
  - ozone was tested and found to be far too reactive and not at all selective.
  - oxygen had a selectivity problem despite the development of protectors.
  - *closed mill* technology was also unfruitful due to major corrosion problems.

Fortunately, the development of chlorine dioxide generation technology in the early 1950s was available to take up some of the bleaching demand. Chlorine dioxide is a very selective bleaching agent, causing very little damage to the holocellulose of the fibre [Smook, 1989]. This ability to bleach without damage was used to create whiter pulps and used as a selling advantage rather than to reduce the amount of bleaching load at the beginning of the sequence. Instead of reducing the C part of CEHD the processes were developed to CEHDED and then CEDED, with little or no reduction on the C-stage (see Appendix 5).

Continuing pressure from environmental groups in the 1970s and 1980s forced the industry into further improvements in environmental performance. Faced with little success in removing chlorine for its pollution effect, the opponents of the chlorine bleaching process targeted the generation of by-products of the chlorine bleaching process, dioxins and in particular 2,3,7,8 tetrachlorodibenzodioxin, which was scientifically associated with carcinogenic problems in hamsters [Callaghan, 1999]. The generation of dioxins in bleaching, whilst proven, is minuscule compared to industrial incinerators and forest fires but the carcinogen link proved very effective in Europe and America in increasing the awareness of chlorine as a problematic bleaching agent [Capps,1990].

At the same time, the mills were being forced into increasing their production capacity to remain financially viable. If the specific water usage and effluent generation was not reduced, the ability of water sources to supply the needs and receive the effluents would be severely stressed.

So, in the 1970s, the drive to reduce water consumption began [Webb, 2003]. The need or driving force to reduce water consumption depended on the requirements of the region.

Water-rich countries such as Sweden, Finland, Canada and the northern United States are far less driven to reduce water consumption and to a large extent the volume of water consumed by the industry in these countries did not reduce and in fact increased. However, improvements were achieved in specific water consumption [Canadian Pulp and Paper Association, 1999; Finnish Forest Industries Federation, 1998].

However, there is an understanding in these countries of the impact of water usage by the paper industry and the need to conserve [Greenbaum, 2002]. This means that the percentage reductions are good but the specific consumption does not match Central Europe.

The main reason for the decrease in specific water consumption was more likely derived from the attempt to reduce investment costs in water treatment and effluent treatment facilities. Even today, in northern Europe and North America, no great emphasis is placed on overall water usage. Typically, the Finnish industry environmental report makes no mention of overall or specific water consumption in the paper and pulp industry [Finnish Forest Industries Federation, 1998].

Other countries have more stringent water requirements. The chemical pulping facilities in these countries are limited. Central Europe has relatively few chemical pulp mills as a result of the environmental pressures placed on the industry and because of the competing requirements for water, particularly for domestic consumption downstream [European Commission, 2000].

In Germany, Austria, France, Britain, one finds increased use of recycled fibres, mechanical pulp and imported chemical pulp where necessary. This is usually evidenced by a disproportionate ratio of paper to pulp production capacity. A balanced pulp to paper capacity would typically be 0,7 to 0,9 (depending to some extent on the types of products produced and the degree of recycled fibre used).

The USA at 0,65 imports pulp from Canada which has a ratio of 1,25. USA does not recycle a great deal; neither does Canada which exports pulp around the globe. Western Europe, which produces the same amount of paper as the USA, has a ratio of 0,43. This is a result of the pressure against pulp wood production and results in a high level of recycling, especially in Western Europe [Pulp and Paper International, 2000].

1.1 History of the South African pulp and paper industry

South Africa is a relatively young industrial nation having entered into industrial development late in the nineteenth century, mainly to satisfy a growing mining industry. In the early part of the twentieth century, commodity products such as paper were imported into this country and the demand was small.

Before 1950, five mills existed in the country: Premier Paper (1920) (on the same site as Nampak Kliprivier Mill); SA Board Mills (1938) (on the Umgeni River in Durban); Sappi Fine Paper's Enstra Mill (1938); Cellulose Products in Johannesburg (1949) and Trans African Paper Products in Benoni (1950). These mills provided wrapping paper, ticket board, carton board, writing papers, toilet tissue and suitcase board [Pamsa, 1986].

The period 1950 to 1984 was the era of major growth and capacity building in the South African pulp and paper industry. Thirteen new greenfield mills were developed: SA Adamas Fibre Board and Paper Mill (now Sappi Fine Paper) (1952); Ngoye Paper Mills (now Felixton Mill) (1953); Sappi Tugela Mill (1954); Southern Paper Industries (now Nampak Bellville) (1958); SA Board Mills in Cape Town (1963); Piet Retief Paper Mills (1963); Carlton Paper Mills at Wadeville (1966); Sappi Ngodwana (1966); Kimberly Clark, Enstra (1967); Paper and Packaging Industries (Rosslyn Pretoria) (1971); Mondi Paper Company (Durban) (1971); Stanger Pulp and Paper at Stanger (now Sappi Fine Paper) (1976); Mondi Richards Bay (1984) [Pamsa, 1986].

In addition to the greenfield sites developed, a number of these sites became massive concerns by adding capacity to the site. Notably, Sappi Ngodwana expanded massively in 1983/4. Mondi Merebank increased from 1 machine in 1971 to 5 machines by 1981. Sappi Tugela added pulping capacity and paper making capacity. Sappi Enstra mill added paper making and pulping capacity, at one stage operating six machines [Pamsa, 1986].

After 1985, new developments were of a small nature and mostly related to tissue and wadding products; the Nampak tissue mill at Kliprivier being the most notable. South African companies moved to an era of upgrading facilities rather than expanding through new capital developments. Upgrades have occurred at Mondi Merebank, Mondi Richards Bay, Sappi Enstra Mill, Sappi Stanger Mill and Sappi Tugela Mill amongst others.

The main feature of the industry today is the consolidation of the companies with two major paper making players, Sappi and Mondi. Both these companies are international concerns with operations in Europe, North America and Asia.

The following mills are operated by Mondi as parts of Mondi Packaging or Mondi Business Paper: Merebank, Richards Bay, Felixton, Piet Retief, Springs.

Sappi Fine Paper manages three mills: Stanger, Enstra and Adamas and Sappi Kraft manages three mills: Ngodwana, Tugela and Cape Kraft.

Nampak is a major packaging undertaking but only operates Rosslyn Mill for packaging papers. Nampak Tissue operates four mills at Kliprivier, Greenfern, Bellville and Riverview.

Kimberly Clark operates a tissue and converting mill at Enstra.

Another feature of recent years is the proliferation of smaller tissue and packaging mills [pers comm. Steyn, 2004].

The industry now produces in excess of 2,5 million tons of product each year, which is somewhat less than 1% of international capacity. However, a significant portion of the product is exported which generates foreign capital and the manufacturing part of the paper industry contributes significantly to the wealth of the eastern part of South Africa.

South African per capita consumption of paper products is 46 kg per annum, which approximates to the international average. By comparison, European countries average at about 150 kg per person per annum with Finland topping at 320 kg per person per annum. The United States consumes 347 kg per person per annum [Pulp and Paper International, 2000].

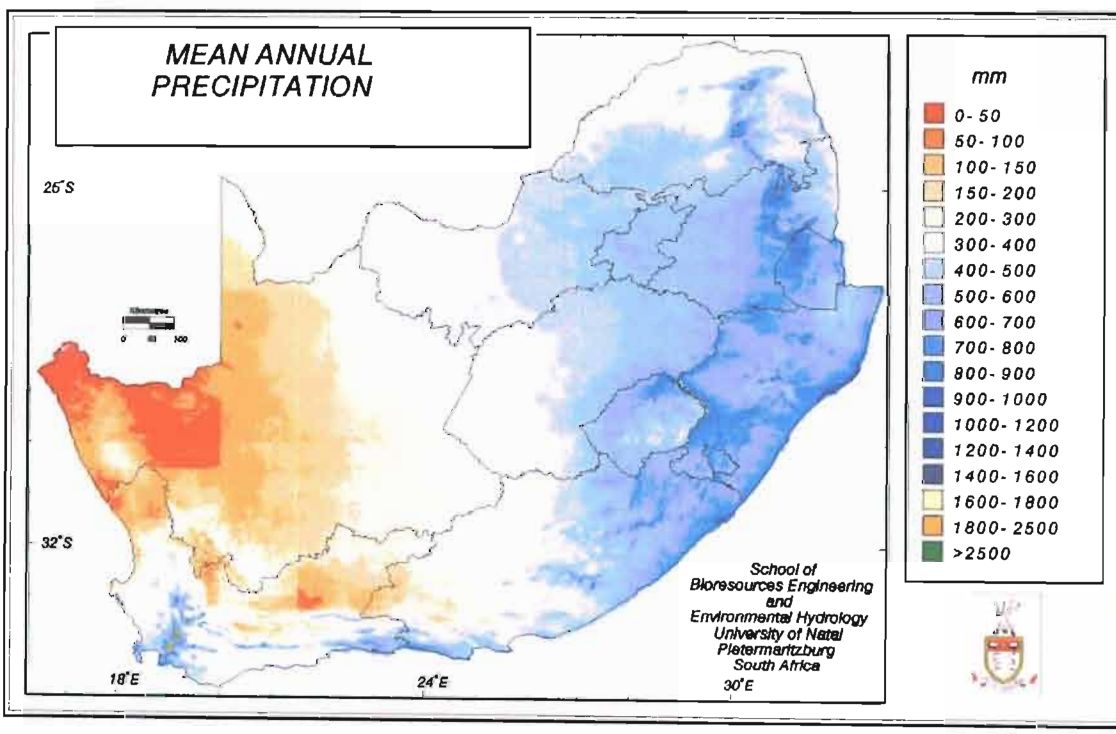
1.2 Geographical environment of the South African pulp and paper industry

The distribution of rainfall and forestry activities, which are related, determine the distribution of wood based pulp and paper mills. Only the waste based mills which tend to locate around metropolitan areas will be independent of water and wood resources.

1.2.1 Geographical conditions in South Africa and their effect on water availability

The availability of surface water has two important effects on the location of pulp and paper mills. Firstly, surface water in the soil is required to sustain forestry operations and this surface water is sustained by sufficient rainfall, usually in excess of 500 mm per annum. Secondly, pulp and paper mills require sufficient water to operate. The amount required is dependent on the type of operation as will be described elsewhere in this dissertation. Whilst there are paper and pulp mills in the world which require very little water, it is generally accepted that paper and pulp mills consume considerable amounts of water and discharge a little bit less than they consume.

Rainfall in South Africa.



[UKZN, School of Bioresources Engineering and Environmental Hydrology, web page, 2004]
Figure 1.1 Mean annual precipitation

Rainfall regions

In terms of rainfall, South Africa can be divided into four regions. The rainfall of a region has a major effect on the economic, agricultural and social activities of the region. These can be read in conjunction with Figure 1.1.

The Eastern Coastal Plain

The first region is the eastern region, between the Drakensberg and the sea and the Eastern Cape and the Limpopo. This region receives more than adequate rainfall in most years. It is a summer rainfall area but does get some rain throughout the year. Normal rainfall will exceed 1 000 mm near the coast and somewhat less closer to the mountains [Dept of Water Affairs, 1986].

This makes the region ideal for forestry operations. However, it is also an ideal climate for sugar, grain crops and animal husbandry. The forestry sector is therefore forced onto land less suitable to competitor agriculture i.e. sloping land and less suitable soil/rock structures.

The presence of water as a result of the higher rainfall also makes the area suitable for manufacture of paper because of the stronger flowing rivers in the region.

The storage of the water in the rivers is much more complicated. The stronger flowing rivers, the Sabi, Pongola, Umfolozi, Tukela, Umkomazi etc, flow from the mountains in the west to the sea. In this flow path are areas of high soil erosion. This increases the solids load of the rivers and lends them unsuitable for damming for storage except in their upper reaches. Damming is possible on the shorter rivers, especially those not traversing soil erosion areas, the Umkomati, Bivane, Umvoti and Umgeni [Dept of Water Affairs, 1986]. However, to a large extent, the two of the basic requirements for paper and pulp manufacture are met, fibre and water. The other requirements, people, power, markets and technology are more portable. In most cases, integrated pulp and paper mills and non-integrated pulp mills generate their own power. Transport and housing infrastructure resolve the 'people' and 'market' issues and technology is normally imported from Europe, North America and the Far East.

As a result, ~90% of South Africa's pulp and paper making capacity is resident on the eastern coastal plain. The only pulp mill outside this region is Sappi Fine Paper's Enstra Mill in Springs, which has developed special technologies to meet its requirements. All other paper mills outside this region are waste-based and, as a result, do not require wood raw materials or large volumes of water.

The Western Cape

The second region is the Western Cape, which has a *Mediterranean* type climate, hot dry summers and warm wet winters. This area is also well suited to forestry and as in the first region, forestry is found on less competitive agricultural soils. The main agricultural crops are fruit, especially grapes, and grains [Dept of Water Affairs, 1986].

Due to the mountainous nature of the region, storage of water is limited. As a result, forest products generated in this region are not used for paper manufacture, but for construction and wooden packaging purposes.

The Highveld

The third region is the higher rainfall agricultural region of Free State, Mpumalanga (west of the Drakensberg), Limpopo Province, Gauteng and North West Province. Rainfall in this region is insufficient, and occasionally erratic in nature, to sustain large amounts of forestry and the region is used for other seasonal agricultural crops and animal husbandry, except for some higher lying grounds in Northern Province at Tzaneen and Louis Trichardt [Dept of Water Affairs, 1986].

The Barren Western Areas

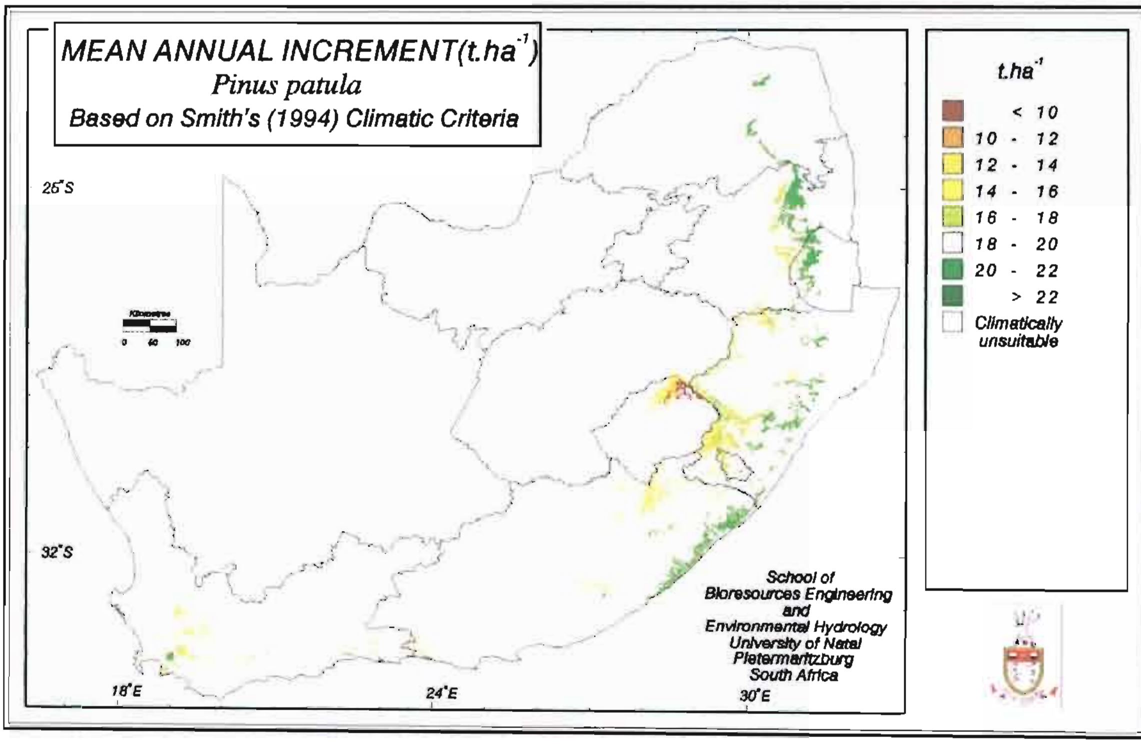
The balance of the country, the northern part of Cape Province, the western portion of the Free State and the Northern Cape are essentially semi desert and the only agricultural activities centre on sheep and goat farming [Dept of Water Affairs, 1986].

1.2.2 Forestry activities

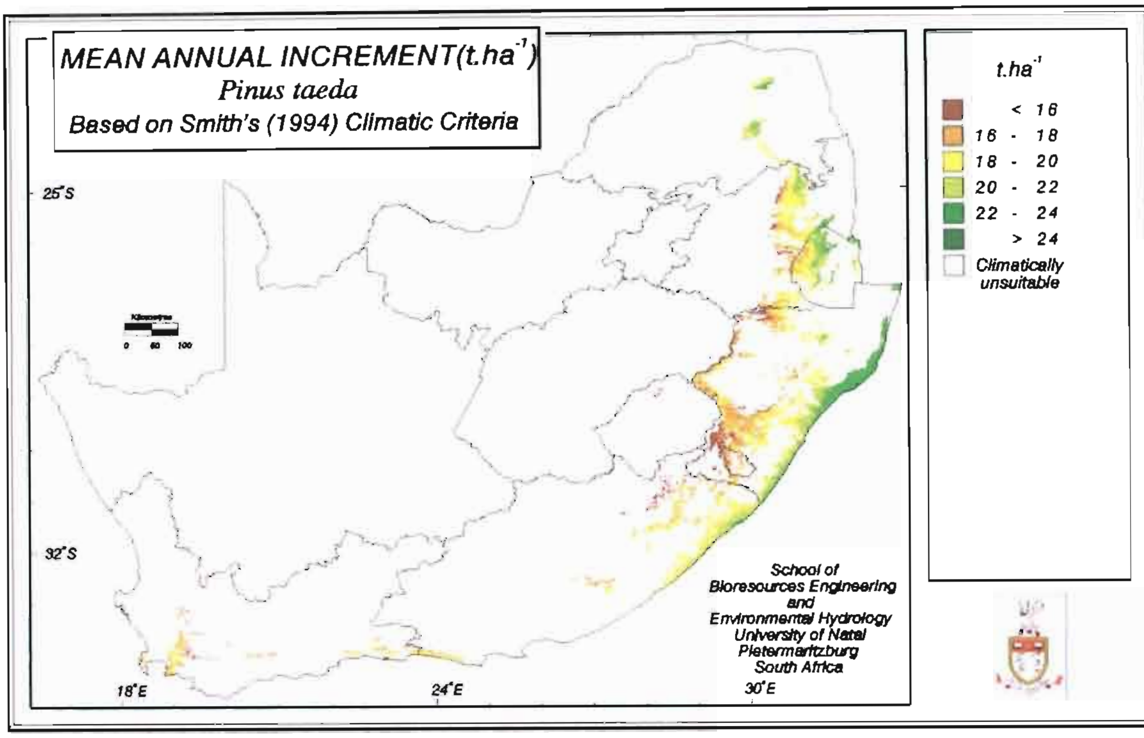
Commercial forestry in South Africa is based on exotic species of trees. The indigenous tree species either grow too slowly or are unsuitable for manufacture of paper. The exotic tree species find the climate suitable for fast growth provided sufficient water is available.

Softwoods

Softwood trees are grown in northern and central KwaZulu-Natal, the Eastern Cape, the Western Cape, Limpopo Province and Mpumalanga province. Timber from these softwood forests is used for construction and wood pulp production.



[UKZN, School of Bioresources Engineering and Environmental Hydrology, web page, 2004]
Figure 1.2 Mean annual increment *Pinus patula*



[UKZN, School of Bioresources Engineering and Environmental Hydrology, web page, 2004]
Figure 1.3 Mean annual increment *Pinus taeda*

It is clear from the above maps that softwood timbers used for wood pulp production are best sourced from Mpumalanga Province, Swaziland, KwaZulu-Natal east coast, KwaZulu-Natal midlands and the Eastern Cape [UKZN, School of Bioresources Engineering and Environmental Hydrology, web page, 2004]

The principal mills using softwood timber for pulp production are (in order of consumption) Sappi Ngodwana, Sappi Tugela and Mondi Merebank. Some softwood is used at Mondi Richards Bay.

The timber is converted to bleached softwood kraft (BSK) and to the mechanical pulp grades, thermomechanical pulp (TMP) and groundwood (both stone, SGW and pressure, PGW). Some Semi Alkaline Sulphite Anthraquinone (SASAQ) pulp is produced at Mondi Piet Retief.

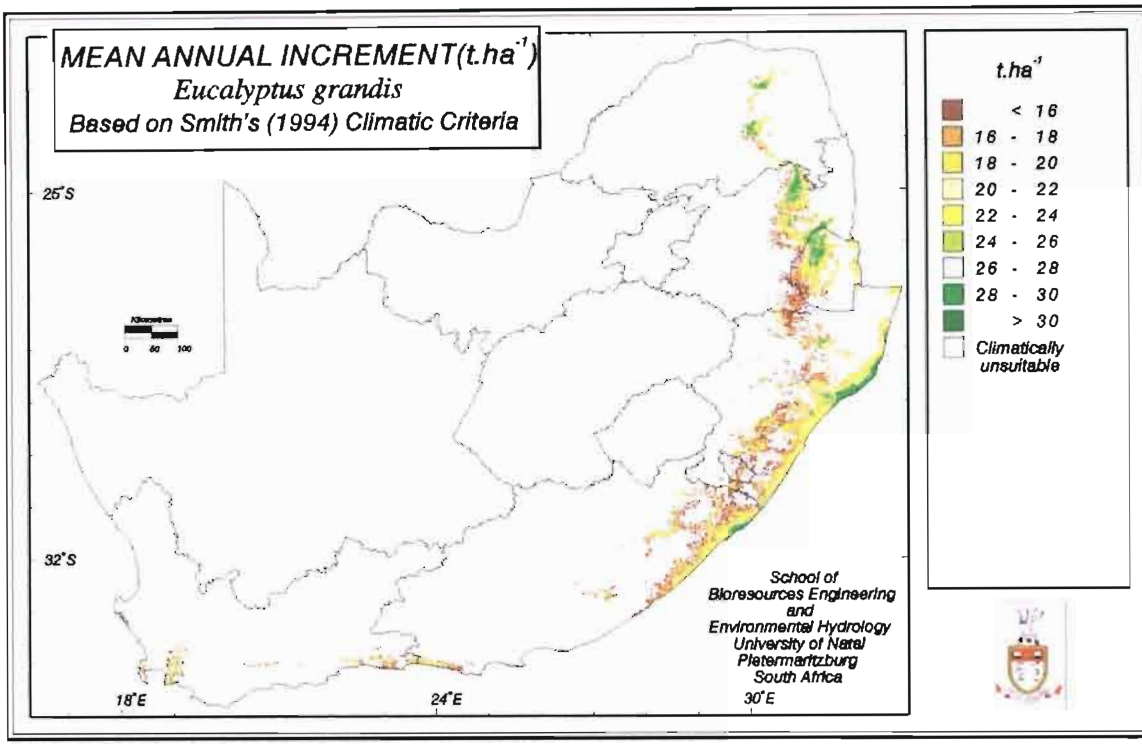
The principal species used for softwood pulp are *Pinus patula*, *Pinus taeda* and *Pinus elliotii*.

Hardwoods

Hardwoods are grown in KwaZulu-Natal, the Eastern Cape and Mpumalanga provinces. Hardwood timbers are used for construction, mine shoring and woodpulp.

The main pulp mills using hardwood timbers are (in order of capacity) Sappi Saiccor, Mondi Richards Bay, Sappi Tugela, Sappi Enstra and Mondi Piet Retief [Pamsa, 1986].

The principal hardwood species grown for wood pulp are *Eucalyptus grandis*, *Eucalyptus nitens* and *Eucalyptus saligna*. *Eucalyptus grandis* has proven particularly successful in northern KwaZulu-Natal, whilst *Eucalyptus nitens* has proven to be a very suitable supplier of fibres for fine papers.



[UKZN, School of Bioresources Engineering and Environmental Hydrology, web page, 2004]
Figure 1.4 Mean annual increment *Eucalyptus grandis*

Other hardwood species used are the acacias, in particular black wattle, the bark of which is used for production of tannin, which process leaves a by-product of pulp wood.

Exotic hardwoods, in particular eucalypts, have a notorious reputation for uptake of subterranean water. This has led to particular attention from environmental lobbies and probably led to the *rain tax* levied on exotic commercial forests [Dept of Water Affairs & Forestry, 2000].

1.3 The importance of this study

The pulp and paper industry has always been seen in the public eye as a major water consumer. This dissertation shows the application of water within the industry and the application of best practices to optimise that water usage and the conservation of South Africa's water resources. Comparisons can be made between the specific water consumption of the South African industry and those of international industries.

This dissertation will form the basis for further more specific work on the water usage and effluent generation within the South African pulp and paper industry.

For management of operating units, the dissertation can be used as a reference to determine standard water consumption and as a guideline for applying further water reduction technologies.

The information can also be used to guide decision making for site location and technology utilisation for new investments.

1.4 Aims and objectives

This dissertation aims to:

- investigate the relationship between processes employed by the pulp and paper industry and water used within those processes
- investigate individual South African pulp and paper mills with respect to their products, capacities, processes employed and water consumption with a view to determining specific water consumption ranges at these mills
- to make a comparison between specific water consumptions of the mills and specific consumption should best practices have been applied
- to show the total water usage of the South African pulp and paper industry and possibilities for improvement

1.5 Hypothesis

The prime hypothesis which will be tested is that the specific water consumption of a pulp and paper mill will be determined by the processes used and the type of products produced. Analysis of the different processes and specific water usage implications will give typical water usages. This hypothesis will be tested by analysing the products and capacities of each product of different mills in South Africa and the water consumption of those mills.

Chapter 2 Methodology

This chapter sets out the processes, the products and the mills which were evaluated, and the methodology used to test the hypothesis.

2.1 Prediction of water usage from literature and experience

The following processes were evaluated for water usage and opportunities for water reuse based on personal understanding of the processes, application of mass balancing principles and literature search techniques into best operating practices:

- Woodyard operations
- Thermomechanical pulping
- Groundwood pulping (including pressure groundwood)
- Chemical pulping
- Waste paper recycling
- Pulp bleaching
- Paper making as a process

These processes were chosen as they represent those used in the South African industry. Others such a chemithermomechanical pulping (CTMP) are not currently used in South Africa.

2.2 Effect of different paper products

In addition, the aspects of water usage in paper making for the following different paper products were investigated as an expansion of the water usage for paper making above:

- Linerboard
- Corrugating medium
- Folding boxboard
- Fine paper including coated fine paper
- Tissue products
- Newsprint
- Market pulp

This was used to contribute to the estimation of water consumption of different South African mills.

2.3 Verification of water usage at South African mills

This study is restricted to mills operated under the auspices of the Paper Manufacturing Association of South Africa (PAMSA).

The following mills were investigated:

- Mondi Mills
  - Richards Bay
  - Merebank
  - Piet Retief
  - Felixton
  - Springs

- Sappi Mills
  - Ngodwana
  - Enstra
  - Saiccor
  - Stanger
  - Cape Kraft
  - Tugela
  - Adamas

- Nampak Mills
  - Klipriver
  - Rosslyn
  - Bellville
  - Riverview

- Kimberly Clark Mill
  - Enstra

Each investigation describes the mill in terms of the mill name, the mother company, the date the mill was started up, the region in which it operates, the water region in which it operates as defined by the Department of Water Affairs and Forestry, the paper machines in operation including the manufacturer, the date of installation, the width and capacity and, if applicable, if the machine has been upgraded and when.

The pulping processes and capacity are described with any special items about the processes in general, after which the overall water consumption is described together with the type of water used. The predicted specific water consumption was calculated as upper value, lower value and norm value. The information was determined by personal interviews with mill personnel.

2.4 Comparison of predicted and actual water usage and evaluation

The predicted water usage is compared with the actual usage. This highlights efficient and inefficient water users. Reasons for discrepancies are discussed. This information is compiled to give an overall water usage for the South African industry.

Chapter 3 Process Results

In this chapter, each process listed in 2.1 is described.

3.1 Water usage in the woodyard

South African Mills with Woodyards:

Hardwood: Mondi Richards Bay, Mondi Piet Retief, Sappi Ngodwana, Sappi Enstra, Sappi Tugela, Sappi Saiccor.

Softwood: Mondi Merebank, Mondi Richards Bay, Sappi Ngodwana, Sappi Tugela.

In South Africa, water is not used to transport wood and wood arrives at the mill by rail or road. Water transport is used at Sappi Saiccor to wash the wood in a flume; the extent of this is not significant. Generally, wood is transported by mechanical means; to prevent abrasion of mechanical components, including conveyors, debarkers, chippers and screens, it is necessary to wash the wood with water. The water for this purpose should be a low grade waste stream such as contaminated condensates from the evaporation process. Consumption for washing varies between 0,4 to 1,1 kl t^{-1} pulp produced [Springer, 1986].

3.1.1 Water usage in a hardwood woodyard

Water imported with the wood is not as high as for softwoods. As seen in Chapter 1, the hardwoods used in South Africa are eucalypts and acacias. These wood species have very stringy bark which is easily removed mechanically or manually at the felling site. This has advantages for pulp industry in that less wood is transported and imported to the mill. In addition less water is imported. From a process perspective, in-mill debarking is not done.

The debarked wood, however, is inclined to pick up adherent dirt and sand particles in the felling and transport operations. This requires water washing before processing to prevent product contamination and mechanical abrasion.

3.1.2 Water usage in a softwood woodyard.

South African softwoods are debarked at the pulp mill. It is not necessary to wash softwood logs as the grit and sand is removed with the bark which is either combusted in a bark boiler or converted into agricultural by-products.

3.1.3 Woodyard summary

Specific water consumption for woodyard operations ranges from 0,4 to 1,1 kl t^{-1} pulp [Springer, 1986].

Water quality requirements for woodyard processing are not stringent and use of waste streams from other processes is common. The waste water generated is sewered and may contain solid material from the wood such as woody fractions and sand or soil.

3.2 Water usage in thermomechanical pulping

Only one South African mill uses the thermomechanical pulping (TMP) process: Mondi Merebank [Pamsa, 2002].

3.2.1 Process description for thermomechanical pulping

The wood requirement for this process is not as specific as with the groundwood process and is normally determined by the end use requirements of the pulp. In the case of Mondi Merebank the product is newsprint which requires the longer fibre of softwood. As with groundwood, this means that at least 1 kl t^{-1} pulp of water is received into the process with the wood.

The wood is received as 2,4 m (or longer in some cases) logs of pine species. The logs are debarked by the use of dry debarking and then reduced in size to wood chips with a thickness of approximately 5 to 7 mm.

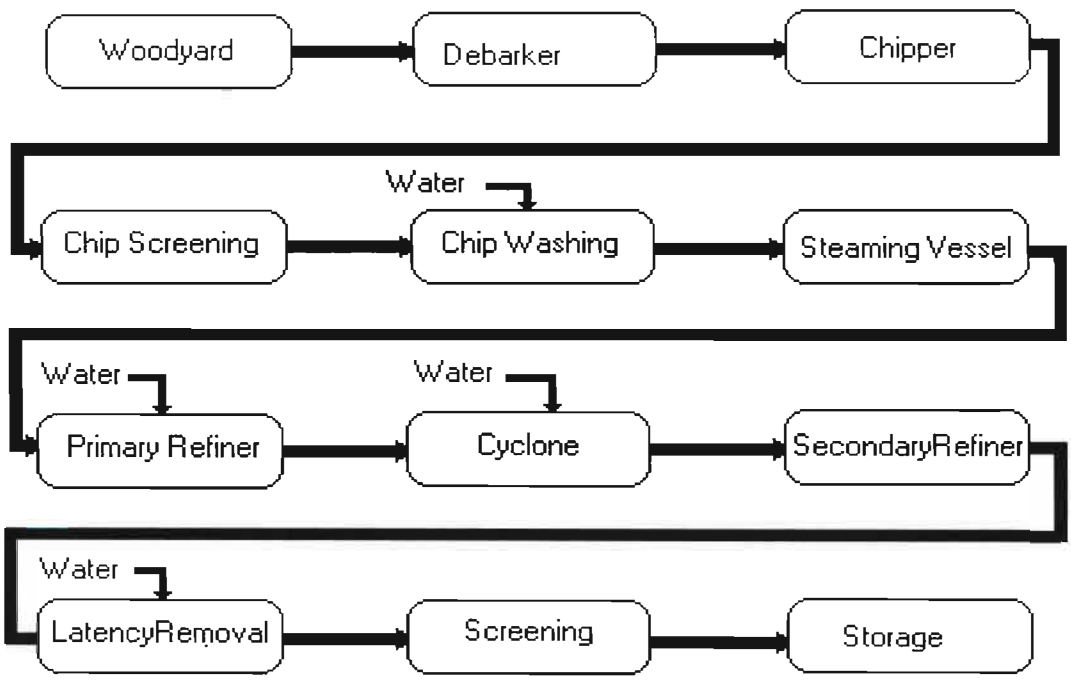


Figure 3.1 Water addition points for thermomechanical pulping process

These chips are screened to remove oversize and undersize fractions and then washed to remove any sand or dirt (including metal fragments, etc) prior to forwarding to the main TMP plant.

The chips are heated to approximately 115 °C by use of recycled excess process steam, which is generated within the primary or high pressure refiner. No water is introduced into the process from the steam application as the steam is generated from the refining energy applied within the process (except at start up).

The hot chips are fed with sufficient water into the eye of the primary or high pressure refiner, which operates at about 2 bar or 133°C. Water is required to adjust the 'consistency' from about 40% to 22%; this is approximately 2 kl water t^{-1} pulp (see Appendix 1 and Appendix 2 for typical consistency and mass balance calculations).

The resultant pulp is *blown* to a cyclone, which allows separation of flash steam. The flash steam can be recovered but it does contain wood volatiles and is often released to atmosphere. The mass of steam released is 0,006 kl water t^{-1} pulp.
The pulp is diluted with water and processed in a secondary or low pressure refiner to produce the required properties. Dilution in this case is much less; approximately 0,01 kl water t^{-1} pulp is applied.

After refining, the pulp is usually processed at a consistency of ~ 1,0%. This means that between 95 and 100 kl water t^{-1} pulp is associated with the pulp, that is about 94 kl water t^{-1} pulp must be applied.

Processing includes latency treatment and cleaning or screening. By implication, there is some water wastage from the cleaning and screening process.

3.2.2 Water usage in thermomechanical pulping

The pulp transferred to the paper process via a storage chest is normally at a consistency of ~5%; ie it is carrying 19 kl water t^{-1} pulp. The process has an internal water recycle via heat exchangers of 75 to 80 kl t^{-1} pulp. The balance of 19 kl t^{-1} pulp must be made up from another source. A small amount of water is lost as steam.

As with groundwood pulp mills, it is common practice to return paper machine backwater to the TMP plant as the primary source of water. In this case the paper machine must discharge only the 1 kl t^{-1} pulp of water received with the wood less any losses in the pulping process.

If the paper making process has a condition which precludes recycling of backwater to the pulp mill, then the pulpmill will have to make up an additional 19 kl of process water t^{-1} pulp and the paper mill will have an additional effluent of 20 kl t^{-1} pulp.

Again, this can be alleviated by increasing the consistency at which the pulp is transferred between the two processes. This is demonstrated in the following table:

Table 3.1 Consistency of pulp and water required

Consistency of pulp transferred, %	5	7	10	15	20
Water required by pulp mill, kl t^{-1} pulp	18.0	12.3	8.0	4.7	3.0

It should be noted that thermo-mechanical pulp is already refined for papermaking and hence is less easy to de-water. It is most often transferred at 5% consistency.

3.2.3 Best applied practices for thermomechanical pulping

The following are the techniques to be used for the TMP process.

3.2.3.1 Use of paper machine back water in the TMP pulp mill [Springer, 1986; European Commission,2002].

The use of paper machine back water has clear advantages in overall mill water usage. The reasons for not applying this practice are minimal and can normally be overcome. The water can be used for chip washing where there is some loss for removal of the contraries but this is a very small stream. The bulk of the water feeds forward with the chips. The total usage of water for washing is of the order of 0,5 kl t^{-1} pulp. Wastage is somewhat smaller, say 0,1 kl t^{-1} pulp if machine back water is used.

3.2.3.2 Use of increased de-watering between pulp mill and paper machine

As with groundwood pulping, the use of paper machine back water as the main pulp mill water supply should be considered. The extent of inter-section contamination can be minimised by increasing the concentration (consistency) of the pulp transferred. This does not reduce the overall amount of water used between the two processes.

3.2.3.3 Treatment of rejects

As with groundwood pulping, the cleaner and screen rejects are mostly oversize wood particles, which indicates that recovery of the wood is encouraged. This recovery through a reject refiner not only increases process yield, but reduces water consumption as well.

3.2.4 Thermomechanical pulping summary

The TMP process is invariably associated with the manufacture of newsprint which allows for transfer of process water between the pulping process and the paper making process provided no additives in either process disturb the other process.

This means that the 19 kl water t^{-1} pulp requirement for the TMP process can be supplied from paper machine back water.

The range for specific water usage in an integrated TMP mill should be 4 to 10 kl t^{-1} pulp; paper machine water is not included [European Commission, 2000]. Zippel indicates an average specific water consumption in Europe for integrated newsprint of 15,3 kl t^{-1} [Zippel, 2001]. Springer indicates an average of 25 kl t^{-1}, with a range from 6 to 100 kl t^{-1} [Springer, 1986].

There appears to be some difference, but by inference between the sources it appears that:

Minimum water usage in an integrated newsprint/TMP mill is: 6 kl t^{-1}
Maximum water usage in an integrated newsprint/TMP mill is: 30 kl t^{-1}
Average water usage in an integrated newsprint/TMP mill is: 16 kl t^{-1}

The maximum and minimum are taken from the sources above except that the value of 100 kl t^{-1} is reduced to a more realistic 30 kl t^{-1}; the average favours the value given by Zippel as the Springer data is older and less likely to include best technology practices. It is assumed that woodyard consumption is included. Steam from the cyclones is not significant in terms of overall water usage (0,05 kl t^{-1} pulp), but there are other considerations such as aerial contamination and energy usage which may be considered.

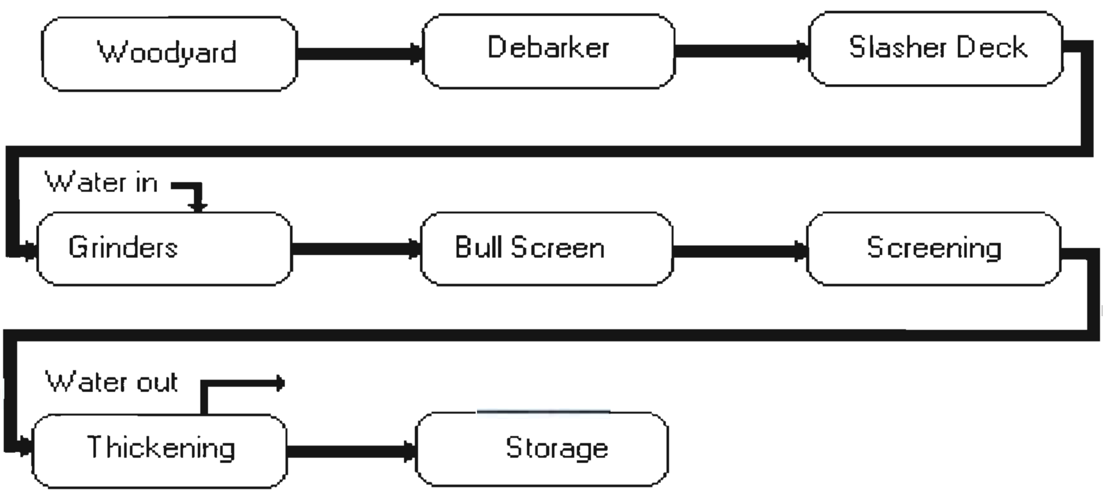
Water quality requirements for thermo mechanical pulping processing only require that the water is not carrying material which will precipitate in the processing. It needs to be correct in pH. Water discharged from the process will have a higher level of COD contamination from dissolved and undissolved woody components.

3.3 Water usage in groundwood pulping

In South Africa, two processes are used for Groundwood pulp production, Stone Groundwood (SGW) and Pressure Groundwood (PGW). In terms of water usage, the two processes can be considered the same.

Two mills in South Africa use the groundwood pulping process. Firstly, Mondi Merebank uses groundwood to manufacture SC (supercalendered) papers, and secondly, Sappi Ngodwana uses groundwood and pressure groundwood for the manufacture of newsprint [Pamsa, 2002].

3.3.1 Process description of groundwood pulping



F

igure 3.2 Flow diagram of the groundwood process

The wood requirement for these processes is very specific; only softwood species can be used and the moisture content must be ~ 50%. This means that at least 1 kl t^{-1} pulp of water is received into the process with the wood.

The wood is delivered to the mill in lengths, which are equal to the width of the grinder or some multiple thereof. The wood is debarked to a greater extent than most other wood for pulping except possibly the wood for bleached chemical pulp. The debarking process will not require water if dry debarking is employed. Some minor water may be required for dust suppression of bark processing but this is not significant.

The wood is then cut on a slasher deck to the correct length for grinding and then fed onto a conveyor to feed to the grinders.

Water is applied to the grinders to provide a lubrication medium and to act as a carrier for the pulp produced.

After grinding, the pulp is usually processed at a consistency of ~ 1,2 to 1,6%. This means that water between 61 and 82 kl t^{-1} pulp is associated with the pulp, ie 60 to 81 kl t^{-1} pulp has been applied in the pulping process (See Appendix 2 for calculation).

The pulp transferred to the paper process is normally at a consistency of ~5%; ie it is carrying 19 kl water t^{-1} pulp. The process has an internal water recycle via heat exchangers of 41 to 62 kl t^{-1} pulp. The balance of 18 kl t^{-1} pulp must be made up from another source.

3.3.2 Best Applied Practices for groundwood pulping

The following techniques should be applied for groundwood pulping:

3.3.2.1 Debarking and wood processing

Debarking and wood processing should be done dry. Where water is used for bark treatment to suppress dust generation, the water applied should be kept as low as possible.

Dry wood is not suitable for groundwood pulping and extended wood storage at the mill (and elsewhere for that matter) requires that the wood be wetted on a regular basis to maintain the internal moisture to be at least 45%. This water must be recovered and recycled to the storage yard for repeated use. Evaporation will increase the concentration of impurities in the water, thus relatively low impurity waters (such as clarified paper machine back water) should be considered.

3.3.2.2 Integration with paper water system

In order to maintain temperatures and reduce heat loss, it is ideal to circulate the white water of the paper machine as the carrier water in the pulp mill. In this way, the temperature of the paper machine can be maintained at optimal levels by controlling heat removal at the groundwood plant. The volume of water employed across the pulp/paper system will be minimised.

The degree of contamination of the water in the pulping process is not sufficient to cause significant bio-growth in the paper machine water circuits, but additional attention to cleanliness and bio-treatments will be necessary.

3.3.2.3 Reduction of reject losses

Reducing reject streams at cleaning will reduce water consumption at the same time. Re-refining of reject streams is common practice to recover both woody material and water.

3.3.2.4 Recovery of condensate and energy from pressure groundwood

In the case of pressure groundwood, it is possible to recover condensate and energy from the pressure release. The steam generated would be condensed and the energy transferred to create steam or hot water.

3.3.3 The impact of groundwood pulping on water usage

In mills using groundwood pulp to produce newsprint type products (newsprint, directory paper, some cheaper scholastic grades, SC paper, etc) it is common to return paper machine backwater to the groundwood plant. In this case the paper machine must discharge only the 1 kl t^{-1} pulp of water received with the wood less any losses in the pulping process.
If the paper making process has a condition which precludes recycling of backwater to the pulp mill, then the pulp mill will have to make up an additional 18 kl of process water t^{-1} pulp and the paper mill will have an additional effluent of 19 kl t^{-1} pulp.

This can be alleviated by increasing the consistency at which the pulp is transferred between the two processes. This is demonstrated in the following table:

Table 3.2 Effect of consistency on water required

Consistency of pulp transferred, %	5	7	10	15	20
Water required by pulp mill, kl t^{-1} pulp	18.0	12.3	8.0	4.7	3.0

Clearly, increasing the consistency of pulp transfer improves the water situation noticeably. The nature of groundwood pulp does not lend itself to processing to higher consistencies because of its high wetness or low freeness (CSF values between 50 and 150 are common).

In an integrated mill the specific water usage should range from 5 to 15 kl t^{-1} pulp [European Commission, 2000]. For the purpose of this dissertation, it will be assumed that specific water usage for integrated groundwood/publication grades will be the same as for TMP/Newsprint integrated facilities.

3.3.4 Groundwood pulping summary

Minimum water usage in an integrated newsprint/groundwood mill is: 6 kl t^{-1}
Maximum water usage in an integrated newsprint/groundwood mill is: 30 kl t^{-1}
Average water usage in an integrated newsprint/groundwood mill is: 16 kl t^{-1}
It is assumed that woodyard water consumption is included.

Newsprint made from groundwood requires ~ 25% bleached softwood kraft; if this is market pulp then the above figures apply; if the pulp is made at the same site then consideration must be given for the water consumption of bleached softwood kraft which is significant.

As with thermo mechanical pulping, groundwood water requirements are not stringent. Waste water will contain additional COD but not as high as for thermo mechanical pulp.

3.4 Water usage in chemical pulping

South African mills pulping chemically are: Sappi Ngodwana (HW and SW Continuous Kraft), Sappi Enstra (HW Batch Soda), Sappi Stanger (Bagasse Continuous Soda), Sappi Saiccor (HW Batch Acid Sulphite), Sappi Tugela (HW Continuous NSSC and SW Continuous Kraft), Mondi Piet Retief (HW Continuous Alkaline Sulphite), Mondi Richards Bay (HW (&SW) Batch Kraft), Mondi Felixton (Bagasse Continuous Soda) [Pamsa, 2002].

For the purposes of this dissertation, chemical pulping will include the pulp washing and screening processes.

3.4.1 Description of different chemical pulping processes

All alkaline pulping processes operate at a pH over 12 and use a reaction between caustic soda and lignin as the basis of the process.

Soda pulping

Soda pulping refers to an alkaline pulping process where the active pulping chemical is sodium hydroxide alone or with anthraquinone. To a large extent, the process has been superseded by Kraft. There are applications where soda pulping is favoured over Kraft and the application of anthraquinone has been beneficial in accelerating the reaction to partly match the reaction rate of Kraft. The process was developed in the 1850s, together with sulphite pulping, to meet an increasing demand for papermaking pulp. The alkalinity causes the pulp produced to be brown in colour.

Kraft pulping

As mentioned previously, Kraft pulping grew out of soda pulping, where sodium sulphide was produced by reducing sodium sulphate in the recovery furnace. Sodium sulphide, at sulphidity levels of 20 to30%, modifies the soda cooking reaction to give less cellulose degradation and a higher pulping rate. Chemically these are achieved by the sulphide hydrolysing to hydroxide as the initial hydroxide is depleted by reaction. Like soda pulp, the pulp colour is brown.

Acid sulphite and bisulphite pulping

Acid sulphite pulping, using calcium carbonate (limestone) and sulphur, was developed almost simultaneously with soda pulping. The cheap raw materials (limestone and sulphur) were favoured by pulp makers and the process was the dominant pulping process throughout the first part of the twentieth century.

The process has two main downfalls. In order to prevent re-precipitation of lignin compounds after pulping, the pH must be maintained very low with sulphurous acid. This leads to acid hydrolysis of the cellulose unless operated at very low temperatures (<135°C) (compare Kraft 165 to 175°C). The low temperatures lead to very long cooking times of 8 to 10 hours resulting in the need for large digesters in order to achieve required pulping capacities.

The other main problem with the acid sulphite process is that the cheap chemical raw materials do not warrant an expensive recovery process. This results in excessive pollution as the reaction products are disposed to waterway. The use of magnesium oxide as the base has reduced this problem. Magnesium base also allows operation at a slightly higher pH which is beneficial to pulp strength. This is the bisulphite process. The pulp produced is much lighter in colour than alkaline pulps.

Other sulphite processes

Neutral sulphite semi-chemical (NSSC)

NSSC process is highly favoured by packaging paper makers. The process produces a pulp at a high yield from wood (~80%), yet the pulp has a surface similar to low yield chemical pulps which is suitable for fibre bonding. The pulp fibres are also stiff which imparts good TEA, stiffness and bulk to the papers.

The process is carried out with sodium sulphite as the active chemical at a pH of ~7,5, achieved by neutralising with sodium carbonate. High temperature (185°C) and fast reaction times (20 minutes) provide for easy processing.

Alkaline sulphite

Alkaline sulphite is an extension of NSSC where the pH is operated closer to the alkaline region (pH – 11). The resultant pulp is slightly stronger than NSSC because of increased delignification.

Semi alkaline sulphite anthraquinone (SASAQ)

SASAQ is a further development which produces an alkaline sulphite pulp at a yield of ~65% which can be bleached very effectively. The pulp is relatively strong. The main advantage of this process is the higher yield, which is 10 to 15% greater than Kraft yields.

All these sulphite processes have relatively simple technology for *recovery* of the waste pulping liquors.

Other chemical pulping processes are employed within the industry, such as the solvent pulping processes. However, the above processes cover those used within the industry in South Africa.

3.4.2 Water usage in pulping processes

The effect of equipment, the wood raw material and the chemicals used on the water usage in the pulping processes is described.

3.4.2.1 Effect of equipment used

There are three basic digester configurations, vertical and horizontal continuous digesters and batch digesters. Each has a unique effect on water consumption.

Vertical continuous digesters

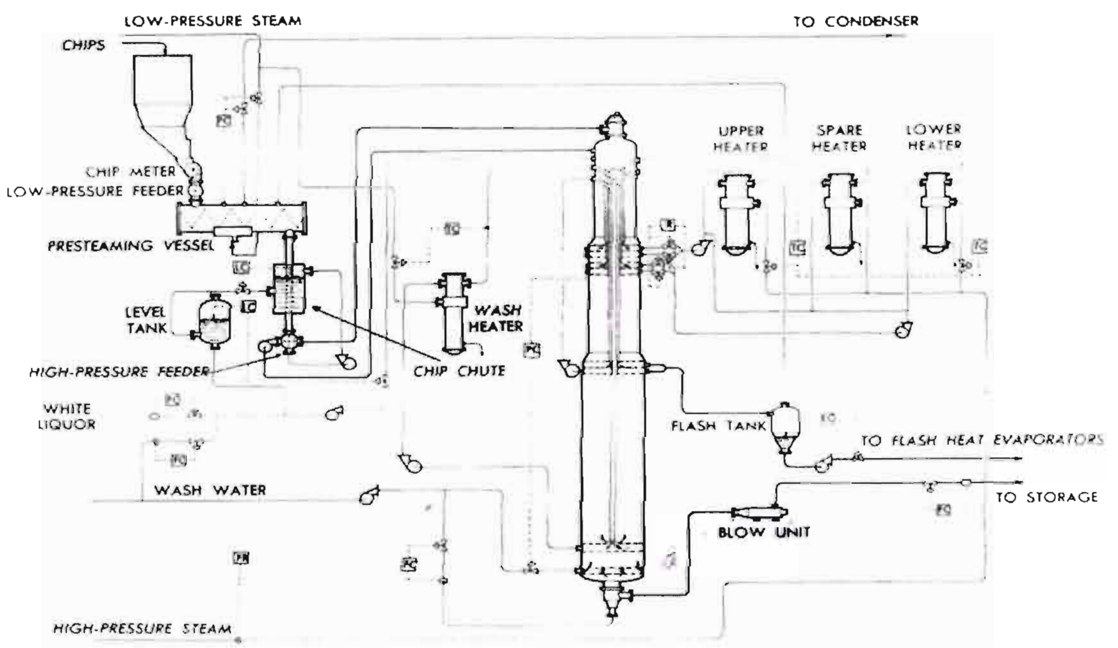


Figure 3.3 Vertical Continuous Digester with ancillary equipment [Smook, 1989]

Vertical continuous digesters are used at Mondi Piet Retief, Sappi Ngodwana (x2) and Sappi Tugela (x2). There is no fresh water added to these digesters. Water is applied through cooking liquor addition, wood moisture, steam and wash liquor.

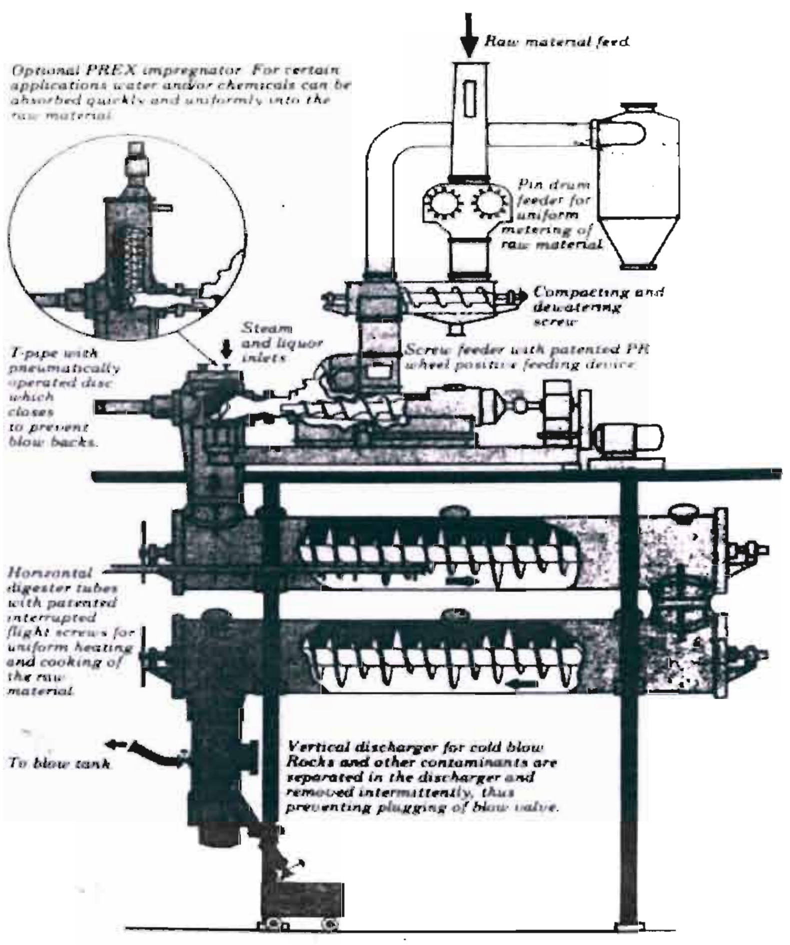
Water in the cooking liquor is taken into account in the liquor recovery section.

Water from wash liquor is dealt with later in this section and water, which is added as part of the wood is unavoidable and will become part of the mill liquid or gaseous effluent.

NB it is very important that the wood moisture is retained. Dry wood is very difficult to pulp because chemical diffusion is almost impossible.

All steam applied is through indirect heating so the condensate is recovered, except in the case of flash steam used for heating the incoming chips where the steam directly contacts the chips and hence water is transferred back to the process. This steam has been derived from flash cooling process liquors and not from external sources. The mass of water through steam condensation is 300 to 600 kg t^{-1} pulp with the lower values associated with hardwood pulping.

<u>Horizontal Continuous Digesters</u>



In South Africa, these digesters are only used for bagasse pulping at Sappi Stanger and Mondi Felixton, but they could be used for pulping sawdust as well.

As with vertical continuous digesters, water is added via the bagasse, steam applied and with the cooking and blowing liquors.

As the bagasse has been processed in water immediately prior to pulping, it carries 4 to 5 tons (or kl) of water per ton of dry bagasse. This water will end up in the recovery circuit.

The cooking liquor is made from caustic soda and recycled black liquor. Water addition is negligible.

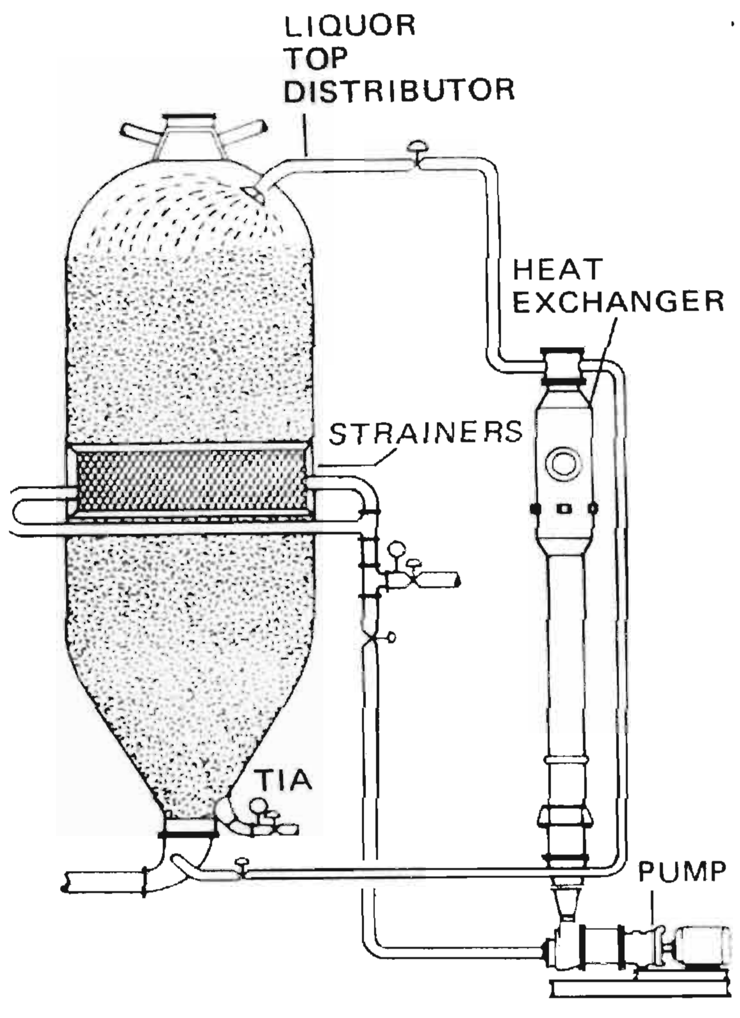
Figure 3.4 Horizontal Continuous Digester [Smook, 1989]

Black liquor is added at the end of the digester to allow for *cold* blowing to take place. This does not affect the water applied.

Steam is applied directly to this type of digester and the condensate remains as part of the pulp discharged from the digester. The mass is significant at 2 000 to 2 500 kg t^{-1} pulp. This steam condenses to water, which will remain in the black liquor and pulp passed from the digester.

When this type of digester is applied to bagasse, there is a processing requirement for the amount of pith in the bagasse to be reduced by rinsing. This process requires application of water. The extent of water applied is varied but the bagasse is increased in water content from about 50% to about 75% and there is a waste stream removing the pith to effluent. The specific water consumption associated with wet depithing of bagasse is between 12 and 20 kl t^{-1} bagasse pulp.

<u>Batch digesters</u>



Batch digesters are employed at Mondi Richards Bay, Sappi Saiccor and Sappi Enstra.

Batch digesters take in water as part of the wood applied, in recycled black liquor, within the cooking liquor applied and in the steam applied.

As with other digesters, the water in the wood is unavoidable. Significant black liquor is recycled to ensure that all the wood is covered in the digester, this impacts the amount of steam required for heating, but does not affect the water balance.

The water addition via the cooking liquor is dealt with within liquor recovery.
Steam applied for heating is more than in the case of the vertical continuous digester because of the increased black liquor recycle. This steam is normally applied indirectly and the condensate is recovered.

Figure 3.5 Batch digester [Smook, 1989]

Some steam however, is applied directly to achieve chip de-aeration and better chip packing. Although this offsets some of the heating steam required, the condensate is not recovered and dilutes the cooking liquor.

Some older batch digesters use indirect heating. In these digesters, condensate from the steam used for heating will be included in the pulp discharged. The increased water consumption will be noted in the steam generation facility.

3.4.2.2 Influence of woody raw material

Raw materials for pulping in South Africa are hardwoods, softwoods and bagasse, the waste product of the sugar industry. These materials are supplied to the industry with different water content as a result of the botanical physiology.

Hardwood chips

Hardwood chips tend to carry slightly less water into the process than softwoods at about 0,6 kl t^{-1} pulp produced. This has no bearing on overall water usage but marginally increases effluent discharged.

The usage of white liquor for hardwoods is also slightly lower due to the lower lignin content. This will be reflected in recovery water usage. NB. The recovery section for hardwood pulping is significantly smaller than that for softwood pulping.

Softwood chips

In contrast to hardwood, softwood chips carry more water due to the larger lumen. The water brought into the process is approximately double that of hardwood chips per ton of pulp produced. It is conceivable to introduce dry chips for pulping, but this will lead to severe processing problems.

In addition, the usage of white liquor is likely to be higher for softwood pulping by approximately 25%.

Bagasse

Bagasse is received from the sugar mill at about 50% moisture. The fibrous mat is stored externally and hence is transferred to process at moisture content determined by the current weather conditions. As the process requires the bagasse to be pulped to a consistency of about 4%, the moisture content of incoming bagasse does not have a significant impact on water usage.

3.4.2.3 Influence of pulping chemicals

For a number of reasons, pulping chemicals (sodium hydroxide, sodium sulphide, calcium sulphite, sodium sulphite etc) are required to be supplied as a solution. The most important reason is to ensure that the cooking chemical is evenly dispersed into the woody material. If this is not achieved, uneven cooking will result.

The concentration of alkaline chemicals is a function of optimisation of evaporation duty, causticising efficiency and storage costs. It is normally supplied to the cooking process at about 120 g l^{-1} as Na_2O.

The source of water for alkaline processes, which are attached to a recovery circuit, will be covered in the section dealing with chemical recovery.

In cases where chemicals are not recovered, the diluent for the chemicals can be fresh water or recovered contaminated condensate from the evaporators or another process stream. The volume of diluent is dependent on the concentration applied.

Products of the chemical cooking process

The products, pulp and black liquor, of the cooking process will have no real impact on water usage in the pulping process but may marginally affect it in the subsequent processes.

High yield pulps, for example, by their nature will have higher lignin still in wood form and lower dissolved lignin in the matter discharged from the digester. This implies less washing effect will be required and hence less *wash water* to achieve the same degree of 'cleanliness'.

3.4.2.4 The washing process

Measurement of washing effect

Because of the dominance of the Kraft process, the method of indication of washing effect has become the sodium sulphate loss. Technically, it is a measure of the specific sodium content of the washed pulp expressed as sodium sulphate. Sodium sulphate is used because it was the original chemical used to restore the sodium balance. The washing loss is expressed in kg Na_2SO_4 per ton of pulp.

Equipment used

Initially, washing pulp entailed discharging the cooked pulp into a pit and then adding water, followed by draining the diluted pulp to effect a rinse. This was proven to be an inefficient method of rinsing dissolved wood material from the pulp. To a large extent, this method is not used any more except in some sulphite mills.

For many years, multiple wash filters have been used to wash wood pulp. Normally, these would comprise three or four washers in series, together with required filtrate tanks. The *wash water* is applied counter current to the pulp flow.

Either the dilution factor or the displacement ratio describes the amount of water applied. (See Appendix 3 and Appendix 4 for calculation od the dilution factor and the displacement ratio).

Displacement Ratio is the mass of water applied to the pulp washer divided by the mass of liquor associated with the pulp on the pulp washer. Typically, the displacement ratio for pulp processing is in the range 1,2 to 1,5. For a pulp at 10% consistency, the amount of applied *wash water* will be 10,8 kl t^{-1} to 13,5 kl t^{-1}.

Dilution Factor is a term, which describes the washing effect on the subsequent evaporation process. It is the amount of water added which needs to be evaporated. In terms of measurement it is the amount of *wash water* applied more than the water already contained within the pulp. Typical Dilution Factors used are 1 to 4 kl t^{-1}. In other words, for a pulp at 10% consistency, the amount of applied wash 'water' will be 11 kl t^{-1} to 14 kl t^{-1}.

It is clear that water applied to conventional pulp washers is in the range 10,5 to 14 kl t^{-1}. Historically, it is proven that this amount of water is necessary to effect a good wash. In operations, which require a cleaner pulp to go forward the wash applied will approach 14 kl t^{-1}. Where the wash demand is less, particularly in packaging paper mills, the *wash water* will be less.

The main method used to reduce the mass of *wash water* applied is by operating the washer at a higher consistency.

This is achieved by higher vacuum on the washer or by changing to a wash press. The advantage is a result of there being less water to displace. The current trend is towards use of wash presses to reduce the water usage and to improve the washing effect.

If the consistency is increased from 30%, then there is only 2,33 kl t^{-1} of water being carried with the pulp. A dilution factor of 3 kl t^{-1} will require 5,33 kl t^{-1} of *wash water* and this will indicate a displacement ratio of 2,3.

In a continuous vertical digester, some degree of washing is achieved within the digester using the spent liquor from external washing. This effect is lessened to some extent by the use of the full digester for cooking as in the extended modified continuous cooking (EMCC) cooking model. Here, the wash is used for dilution at the bottom of the digester only but this has a small positive effect on washing.

The benefit achieved can be used to improve the quality of pulp sent forward or to reduce the load on the evaporator plant. The choice is normally affected by the requirements of the operation.

Washing of wood pulps after digestion

Wash water types

It will be noted that through this section, the term *wash water* has been deliberately italicised. This is because *wash water* applied to the process need not be fresh process water but some other waste stream such as recycling bleach filtrates or decontaminated condensates from digester steam discharges and from evaporator waste streams (NB. Primary condensate from the evaporators will be returned to the boiler plant if uncontaminated).

Effect of bleaching process

Noting the discussion on bleach plant effluents and the recycling of bleach waste streams in that section, when oxygen (delignification) or ozone or peroxide bleaching are used, before application of any chlorine containing bleach agent, then that bleach filtrate from those stages can be used for washing in the pulp mill.

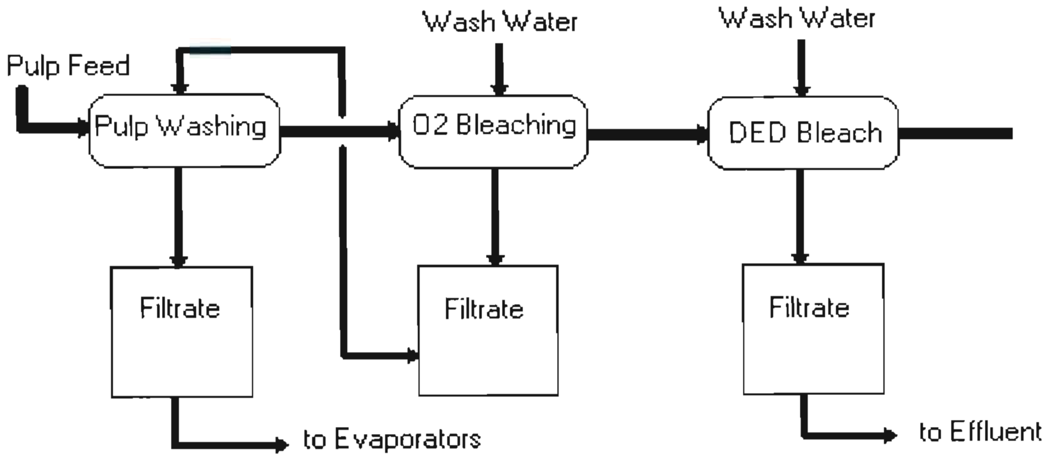


Figure 3.6 Effect of elemental chlorine free (ECF) bleaching

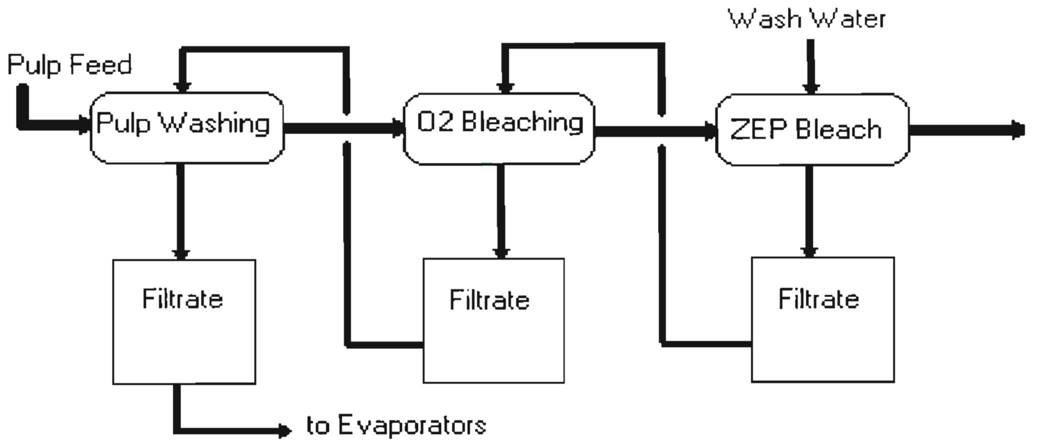


Figure 3.7 Effect of totally chlorine free (TCF) bleaching

When totally chlorine free (TCF) sequences are used and the bleach plant washing is applied counter current, all the bleach plant filtrate can be recycled through the pulp washing to the recovery circuit. In order to balance the sodium in the mill, oxidised white liquor (OWL) is used for caustic soda in the bleach plant. The totally closed concept shown in Figure 3.7 requires careful attention to build up of non-process elements which must be removed [Pekkanen and Kiiskila, 1998].

The main advantage is that organic matter does not finish up in the effluent treatment plant as COD and it is converted to steam by combustion in the recovery furnace. The only disadvantage is that the calorific value to solids ratio of the black liquor fed to the recovery furnace is slightly lower as the extra organic material has been partially oxidised in the bleach plant.

Application of evaporator condensates

The water in black liquor is derived from the following sources:

- water in the wood which has been digested
- water in the steam used for digester packing in batch digesters, where applicable or water from steam condensate where direct steam is used (eg bagasse pulping in horizontal continuous digesters)
- water in white liquor
- water in the *wash water* applied to the pulp washing system
- in closed screening systems, water used for screen dilution

less the water in the following process streams

- water or *wash water* in the pulp moving forward to the next stage
- any water lost as vapour in blowing

The most significant masses of water are:

- the *wash water* applied and
- that in the white liquor

Hence, it makes sense that if condensates are to be treated and reapplied to the process, then the application should be to pulp washing or white liquor generation in the causticising section.

Paper machine back water

Use of paper machine back water is not common in pulp processing. This is especially true in the production of white papers where high levels of calcium carbonate are present in the back water. Excess water from pulp up-take machines and newsprint machines could possibly be used as sources for water in pulp processing and recovery circuits.

Newsprint machines are normally associated with TMP plants, which can use machine back water.

It is not uncommon to find pulp uptake machine back water in use in non-integrated pulp mills.

Pulp Screening

It is common to subject freshly produced pulp to a screening and possibly cleaning process. This is necessary to prevent any oversize woody particles from progressing to the next process, be it bleaching or papermaking.

Cleaning will only be necessary where there is a high probability of small high density material in the pulp. This is common in bagasse processing and possible when dirty wood is processed. In South Africa, this will only affect hardwood, which is debarked in the forest.

From a water usage aspect, it is important that the screening (and cleaning, where applied) is included as part of the counter current stream and not processed *open.*
From a processing view, open screening leads to additional water usage and consequential higher effluent volume. This cost however is offset to some extent by the production of a cleaner pulp which will reduce the pollution load of downstream processes.

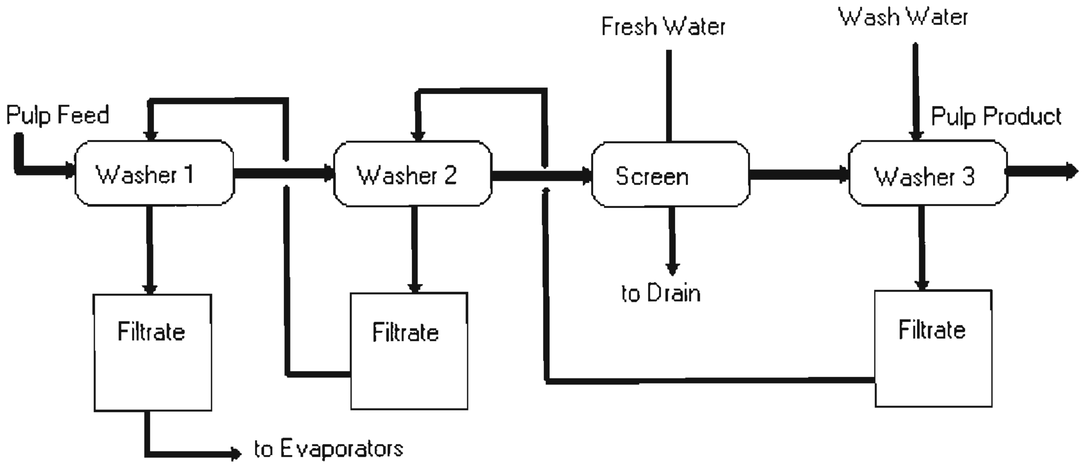


Figure 3.8 Open screening

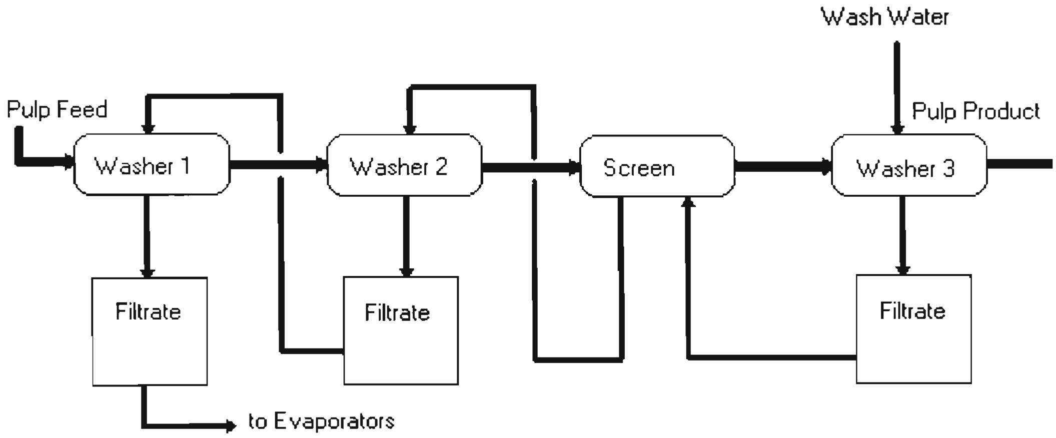


Figure 3.9 Closed screening

3.4.3 Application of best practices in chemical pulping and washing.

In chemical pulping digesters and immediate peripheral areas, there is no need for water usage under normal circumstances. The water applied is incurred at other parts of the plant such as in the recovery section for white liquor and in boilers where direct steam is used.

The different chemical pulping processes have little impact on water usage except that calcium sulphite pulping which has no recovery attached incurs an additional water consumption for washing of about 20 kl t^{-1}.

Different equipment configurations make little difference to water consumption except that the horizontal continuous digester, which has direct application of steam, has no recovery of steam condensate and hence requires additional boiler water make up. Most modern batch digesters have indirect steam heating.

Water usage in pulp washing can be up to 20 kl t^{-1} pulp. However, in recent years significant use of other process streams has reduced the use of fresh process water.

In cases where the bleach sequence is TCF or the initial parts of an ECF sequence which contain no chloride and the washing is only counter current, then the full bleach plant effluent from the first washer can be diverted to replace water on the pulp washers. The bleach plant liquor is then recovered in the recovery plant. This will fully replace process water usage at the pulp washers.

Use of evaporator condensates is common. However, it must be noted that in the drive to reduce water usage, there are a number of competing processes for the use of evaporator condensates. Condensates can be used in the woodyard for wood or chip washing, the recovery plant for weak white liquor make up via salt cake washing or for cooling purposes. In addition, closure can lead to interference from insidious ions, eg silica, which are not removed from the process leading to pitch, scale, corrosion etc [Gleadow *et al.*, 1998]. Removal of ionic species may be necessary [Patt *et al.*, 1998].

In this case, the condensates will make up about 80% of the wash water requirement. However, there are a number of other suitable uses for evaporator condensates. Typical other good uses are in the water make-up to the white liquor production, wood washing and in the case where bleach filtrates are used for pulp washing, then as the *wash water* in the bleach plant. As described before, this will only supply 80% (or possibly slightly less due to wash losses) of the wash water requirement.

Springer indicates a specific water usage for unbleached pulp of 9 kl t^{-1} pulp, including woodyard operations, reduced from a maximum of 20 kl t^{-1} [Springer, 1986]. The European Commission, using Finnish data, indicate that the range for unbleached pulp is 20 to 80 kl t^{-1}, which seems excessive. It has been mentioned that Finnish, and Canadian, specific water consumptions tend to be higher [European Commission, 2000; Riebel, 2001].

3.4.4 Chemical pulping summary

For the purposes of this dissertation, the following values will be used:

Minimum specific water consumption for unbleached Kraft pulp:	9 kl t^{-1}
Maximum specific water consumption for unbleached Kraft pulp:	20 kl t^{-1}
Average specific water consumption for unbleached Kraft pulp:	12 kl t^{-1}

Springer shows bleaching will add an additional 5 to 10 kl t^{-1} for TCF bleaching and 12 to 30 kl t^{-1} for ECF or conventional bleaching [Springer, 1986].

For the purposes of this dissertation, the following values will be used as no TCF bleaching is applied in South Africa:

Minimum specific water consumption for bleached kraft pulp:	21 kl t^{-1}
Maximum specific water consumption for bleached kraft pulp:	50 kl t^{-1}
Average specific water consumption for bleached kraft pulp:	32 kl t^{-1}

The average is not derived from literature, but is an interpolation between the maximum and minimum based on other processes.

Springer indicates that NSSC pulp processing makes extensive use of paper machine back water (this is possible because it is used for packaging grades) [Springer, 1986]. It is assumed that the same applies for alkaline sulphite pulping. He shows the following values which will be used in this dissertation:

Minimum specific water consumption for unbleached NSSC pulp:	1 kl t^{-1}
Maximum specific water consumption for unbleached NSSC pulp:	34 kl t^{-1}
Average specific water consumption for unbleached NSSC pulp:	5,7 kl t^{-1}

Sulphite pulping has historically used excessive water as a result of the Calcium process whereby all the pulping liquor residue is wasted to sewer. European Commission shows a range of 40 to 100 kl t^{-1} pulp for magnesium based plants (fully bleached) [European Commission, 2000]. Ekono Inc and Duoplan Oy show usages of 60 to 130 kl t^{-1} pulp when including calcium based mills. For simplicity, these will be combined [Ekono Inc & Duoplan, 1995]. Clearly, use of calcium is not best practice. Calcium based sulphite requires approximately 30 kl t^{-1} extra water.

Minimum specific water consumption for bleached Mg sulphite pulp:	40 kl t^{-1}
Maximum specific water consumption for bleached Mg sulphite pulp:	100 kl t^{-1}
Average specific water consumption for bleached Mg sulphite pulp:	45 kl t^{-1}

Minimum specific water consumption for bleached Ca sulphite pulp:	70 kl t^{-1}
Maximum specific water consumption for bleached Ca sulphite pulp:	130 kl t^{-1}
Average specific water consumption for bleached Ca sulphite pulp:	75 kl t^{-1}

These values include bleaching processing.

Water applied to chemical pulping processes for washing will be carried forward to the next process whether it be bleaching or the paper machine and therefore the tolerances of those processes needs to be considered. Some recovery processes are intolerant of insidious ions and these ions need to be avoided [Clarke *et al.*, 1999].

Resulting liquors are normally very high in COD and can not be disposed to drain but have to be recovered.

3.5 Water usage in waste paper recycling

South African mills with waste fibre recycling facilities:

Mondi Richards Bay, Mondi Piet Retief, Mondi Felixton, Mondi Merebank, Mondi Springs, Sappi Ngodwana, Sappi Cape Kraft, Sappi Tugela, Sappi Adamas, Nampak Rosslyn, Nampak Kliprivier, Nampak Bellville, Kimberley Clark Enstra, Nampak Riverview. All the mills outside the range of this study also use recycled fibre.

Waste paper received at paper mills is deemed to contain 90% solids or 10% moisture but the latter value can range from 5 to 20% or more. As an average, the value of 10% is probably reasonably accurate. Hence waste paper imported into a mill will bring 0,11 kl of water per ton of dry waste received.

Processing of waste paper will depend on two main factors, which are inter-related. The first factor is the type of waste being used and the second is the type of pulp produced from the waste. Clearly, low quality waste can not be used to produce high quality pulp without a good deal of processing input. Hence, the choice of waste type is dependent on the type of pulp required for production.

Internationally, recycled fibre is most commonly used in the manufacture of newsprint, tissue and towelling grades and for most packaging grades of paper. In some cases, printings and writings are made from recycled fibres but this is not the common practice. The extent of the recycled furnish varies according to a number of factors including cost of recycled furnish compared to virgin furnish, the availability of the different furnishes, legislation amongst others.

Generally speaking, recycled furnish for newsprint production comprises old newspapers and magazines.
The furnish for packaging grades comprises recycled packaging, packaging process off-cuts and general mixed waste.

Tissue products normally use old office waste but can use general waste if additional processing is applied.

3.5.1 Processing of recycled fibres

The processing sequence is largely determined by the following factors.

- The nature and mass of contraries in the waste fibre
- The extent to which the contraries must be removed

3.5.1.1 The effect of nature and the mass of contraries

Contraries can be big or small, dense or light, attached or unattached.

Easiest to remove are big dense non-tacky contraries. These can be simply removed in a screen or cleaner (hydrocyclone).

Big particles can always be removed by screening. Dense particles can always be removed by cleaning. Attached particles, which are sticky are difficult to deal with. These particles are referred to as stickies. Attached particles, which can be disengaged from the fibre by either breaking the bonding agent or breaking the surface of the fibre, can be removed by cleaning or screening.

Cleaners use centripetal force to separate contaminated and clean fractions into different streams. Screens remove particles by size; larger particles having lower probability of passing the screen.

3.5.1.2 The effect of required cleanliness

All separations are based on a percentage depending on the nature of the contaminant and if the separation is difficult and important then an increasing number of stages will be necessary to effect the separation to the required value. Therefore a difficult separation will have a higher reject fraction at each stage and a greater number of stages.

3.5.1.3 Contraries which are very difficult to remove

The most difficult to remove are what are termed stickies. These are materials, which have been added to the paper and are tacky. Typical stickies are lattices and glues. The main problems resulting from stickies is that they attach to process surfaces in paper making causing defects and they remain as an intact piece in the final product causing imperfections.

Ink tends to give pulped fibre a grey look. For better quality of pulp to be used for making printing grades or white tissue it is necessary to remove ink. Separation of ink from the fibre surface is relatively easy. It is achieved by chemical action via dissolution of the binding chemicals or by causing hydration of the fibres which makes them swell, resulting in dislodgement on the surface. Mechanical action will also dislodge ink by abrasive action of the fibre surfaces. As a rule, both mechanisms are normally used.

The main issue with ink is to separate the ink from the fibre suspension. This is the part often referred to as deinking. The problem is that the size and density of the ink particles precludes normal pulp separation methods. There are two methods in use and they have different impacts on water use and waste generation.

The first mechanism is wash deinking. The pulp suspension is diluted to less than 1% consistency and then rapidly dewatered on a screen. The ink particles are drawn with the water. This technique is effective in removing ink, especially in multistage operation, but leads to a high volume waste stream which clearly requires additional water supply to the process. This problem means that the process is not often used.

Floatation deinking is the more commonly employed process. Here the pulp suspension is reduced in consistency and then contacted in a series of vessels with small air bubbles which attract the ink particles due to their hydrophobicity. The waste stream is much more concentrated by this technique.

3.5.1.4 Process configurations

Processing of recycled fibres consists of a pulping operation, followed by different cleansing processes and possible thickening.

Pulping

In order to process the waste into a usable pulp, the first step is to reduce the dry waste into a pulp suspension. The consistency to which the pulp is processed depends on the age of technology used. Older units will pulp to a lower consistency than newer technology plants. The main motivation for pulping at higher consistency is energy cost. The energy of pulping is used to work on the fibres not the water, but water usage is affected.

The equipment can be continuous or batch operated. The choice is user driven. There is no major effect on water consumption.

Some extra larger contraries can be removed at the pulping stage. This is achieved in junk traps, rotary screens, ragger rope systems and high density cleaners. The nature of contaminants removed is higher density (>1 300 kg m^{-3}) and greater size (> 3 mm).

Simple separations

Simple separations include those already mentioned in the pulping system but are mostly focussed around removal of larger size particles and high density particles. Equipment includes high density cleaners, rotary drum screens, centrisorters, large hole screens and larger slot screens.

Combined separations

The centrisorters also have a capability of removing light weight contaminants such as styrofoam.
Complex separations

These include deinking, ash (filler) removal and stickies. Deinking has already been discussed. Ash is removed in the same way as ink in the wash deinking process. It is necessary to remove ash when making tissue or market grade deinked pulp.

Stickies cause most problems when the contrary material exists as very small particles not adhered to the fibre. In this form they can agglomerate in water systems in the machine and be deposited on clothing etc. The best way to deal with this is by disperging, whereby the pulp is increased in consistency, heated to a temperature greater than the softening point of the contrary and then subjected to shear. This smears the sticky onto the fibre and it does not disengage during the paper making process.

3.5.2 Best applied techniques in recycled fibre operations

The basis of water reduction in recycled fibre operations is the reuse of water streams. Application of water pinch technology would be fruitful. Clearly, paper machine backwater must be used for pulping and dilution of the stock. Specific water usage will be dependent on the following factors:

- the extent of contamination of the recycled fibres
- the cleanliness requirement of the paper product
- the nature of removal of contraries

Obviously, dirtier waste will develop more waste streams, cleaner requirement will increase waste streams and contaminants which are removed at low consistency will increase water usage eg cleaner or screen rejects.
Clarification of waste water for reuse is also common and should be practised where possible.

3.5.3 Summary of water usage in recycled fibre processing

Table 3.3 Typical specific water usage for recycled fibre paper making processes [European Commission, 2000]:

Process	Specific Water Consumption, kl t^{-1}
Uncoated folding boxboard	2 to 10
Coated folding boxboard	7 to 15
Packaging papers/Corrugating medium	1,5 to 10
Newsprint	10 to 20
Tissue	5 to 100
Printings and Writings	7 to 20

These values include the water consumed in the paper making process.

Water used for recycling is normally paper machine backwater. It is necessary to ensure that contaminants are removed by the process steps. Clearly some bleed will have to made from the paper system if contaminants are excessive and not removed.

3.6 Bleaching

Bleaching of chemical pulps removes contaminants from the pulp which are often high in COD contribution and hence lead to pollution problems. This has lead to attention to bleaching systems in terms of water usage.

3.6.1 Description of bleaching and bleaching issues

The bleaching of chemical pulps is the process in pulp and paper manufacture, which has attracted most attention with regard to high effluent volumes, organic load and toxicity.

Toxicity of bleach plant effluents

Chlorine based developments

The toxicity was first observed in the closed waterways associated with large bleached pulp mills; notably the Great Lake system in United States/Canada and the Baltic Sea adjoining the industries of Finland, Sweden and northern Germany.

The nature of bleach plant effluent toxicity is based around the reaction products of chlorine and chlorine derivatives, chlorine dioxide and hypochlorites, and wood chemicals. The products of reaction are numerous as a result of the nature of the woody chemicals, lignin and saccharrides, which are not simple chemicals.

The products in question are chlorinated organic materials of which the significant portion is absorbable organic halides (AOXs). Absorbable refers to the ability to adsorb into specific solutions.

The extent to which a bleaching sequence will generate AOX in the effluent is directly related to the extent of different chlorine containing bleaching agents used.

$AOX = 0,12*(Cl_2 + 0,5*OCl + 0,2* ClO_2)$ [Macdonald, 1994]

where:

AOX = kg absorbable organic halides in the effluent per ton bleached pulp produced

Cl_2 = kg of chlorine used per ton of bleached pulp

OCl = kg of hypochlorite used per ton of bleached pulp

ClO_2 = kg of chlorine dioxide used per ton of bleached pulp

It is clear that the largest contribution to AOX generation is a result of elemental chlorine usage followed by hypochlorite.

To illustrate the effect, if a bleach plant required the following specific chemical usages to reach the desired brightness effect with a CEHDED sequence:

Chlorine: 50 kg t^{-1} bleached pulp

Chlorine dioxide: 15 kg t^{-1} bleached pulp

Hypochlorite: 15 kg t^{-1} bleached pulp

The AOX generated per ton of bleached pulp would be given by:

AOX = 0,12* (50 + 0,5 * 15 + 0,2 * 15)

= 7,26 kg absorbable organic halides per ton bleached pulp produced

If the sequence is changed to DEDED with the following usages:

Chlorine dioxide: 65 kg t^{-1} bleached pulp

The AOX generated per ton of bleached pulp would be given by:

AOX = 0,12* (0,2 * 65)

= 1,56 kg absorbable organic halides per ton bleached pulp produced

Finally, if the sequence ODED is used with halide base chemicals used:

Chlorine dioxide: 20 kg t^{-1} bleached pulp

The AOX generated per ton of bleached pulp would be given by:

AOX = 0,12* (0,2 * 20)

= 0,48 kg absorbable organic halides per ton bleached pulp produced

The move away from elemental chlorine to chlorine dioxide based sequences has a dramatic effect on the reduction of AOX generated.

This part of pulp and paper chemistry has attracted most of the pulp and paper environmental research in the last three decades. Initial focus was directed at chlorine bleaching because of the toxicity and high effluent volume associated with this process. The high volume is a product of the inability of the industry to process chloride containing streams in recovery circuits and the necessity to dissolve the chlorine in the pulp stream of the chlorination stage.

Attempts have been made to remove chlorides from the recovery circuit since the late sixties.

The well documented work of Dr Howard Rapson of University of Toronto [Rapson *et al*, 1973] whereby the chlorides generated in the countercurrent D_CEDED bleach/pulp washing sequence were removed by selective crystallisation during evaporation of strong white liquor. Condensates from the white liquor evaporation are combined with other evaporator condensates, which have been steam stripped, for use in bleach plant washing.

Potential problems with this system are increased investment cost, increased recovery boiler smelt tank explosions and increased corrosion risk.

With regard to capital investment, it was estimated that the increased pulp mill investment would be offset against the investment and operational savings of the water treatment facilities.

Smelt tank explosion risk was evaluated and found to be not significantly more likely than the risk of smelt tank explosions for other reasons. [Reeve, 1976]. Other mills have operated with high chlorides in their recovery circuits; in fact 60 – 70 g l^{-1} has been achieved without explosions occurring.

However, the main Rapson process practical test at Great Lakes Paper, Thunder Bay Mill experienced extensive mill corrosion problems associated with chlorides and comprehensive alloys. Use of more expensive and higher alloy compounds did not resolve the problem. The closed cycle concept at Thunder Bay Mill was abandoned in 1974 [Reeve, 1976]. Closure generally increases the risk of corrosion [Clarke *et al.*, 1999]

Failure of this proposal to get around the effluent problem threw the industry into disarray. The clear problems of bleach plant effluents in closed or inland water systems (and sea discharge for that matter) required a move away from chlorine based bleaching, despite the cost and process effectiveness of chlorine based bleaching. The chief advantage from a process point of view is that chlorine bleaching is largely a selective bleaching agent in that it does not react as an oxidant at standard process conditions.

A number of approaches were broached in order to deal with the problem at hand. The groups fighting to stay with chlorine chose methodologies, which promoted reduction in the extent of the chlorine stage. These mostly tried to reduce the degree of delignification, which needed to be applied in chlorination.

For example, increased cooking reduced the kappa number of incoming pulp. Initially, this implied reduced pulp quality. However, later developments with Kraft pulping enabled lower kappa number pulp to be produced successfully (these were SuperBatch, Modified Continuous Cooking and IsoThermal Cooking). Without these pulp property enhancements, reducing Kappa number of pulp fed to bleaching sequences led to poorer quality pulps.

The second approach to resolve the "chlorine problem" was to, partially or fully replace the chlorination stage with chlorine dioxide. Thus the CEDED sequence became D/CEDED or C_DEDED or D_CEDED or DEDED. There are two main factors here. Firstly, the larger chlorine dioxide plants of the era were of the order of 5 to 6 t d^{-1} for a 400 t d^{-1} bleach plant. The requirements for DEDED required more than double this quantity and chlorine dioxide plants had not yet been built to this scale. This prompted the trend to partial replacement. The second issue is that major bleach plant process and equipment changes are not required.

Benefits achieved include lower AOX in effluent, better effluent colour and improved brightness reversions, especially at partial replacements [Singh, 1979].

Oxygen bleaching

The third approach was to develop alternative bleaching technologies. Oxygen bleaching had been investigated since the early 1950s but always failed due to excessive cellulose degradation. In the late 1960s, Robert of Air Liquide discovered that some measure of cellulose protection was given by application of magnesium to the pulp surface. Sappi scientists used this technology, together with Air Liquide and Sunds to develop the first commercially successful oxygen bleaching process, SAPPOXAL. The chief disadvantage of this process was the limitation on degree of lignin removal before cellulose damage became excessive, despite the use of magnesium. However, a number of installations were placed internationally during the 1970s and early 1980s.

The prime advantage of oxygen bleaching is that the wash liquors from the oxygen bleaching can be recovered with the pulping liquors provided the 'O' stage occurs before any chlorine based stages in the bleach sequence. Although the wood chemicals have been partially oxidised, there is still sufficient organic matter to contribute to heat and chemical recovery.

Typical successful sequences would be ODED, ODEP.

The SAPPOXAL process became known as the high consistency oxygen bleaching process. Medium consistency technology was also developed with equal success in the market place.

Ozone

Experimentation with ozone in the 1970s was not successful, and the research was abandoned until the early nineties when special reactors were designed to deal with the very high reactivity of ozone (at high consistencies, the retention time required is in the order of 20 s). Eventually, high, medium and low consistency technologies were designed for ozone bleaching to overcome the high reactivity and very low selectivity. The main problem associated with ozone bleaching is to bring the two desired reactants, ozone and lignin, together equally throughout the reactive mass. If this is not done, some lignin is reacted and some is not and the ozone in strong concentration zones reacts with saccharide parts.

Ozone reaction products can also be recovered in the Kraft circuit as they contain no chlorides. As with 'O' bleaching, no chloride based processes may occur before the 'Z' stage, for recovery to take place.

Typical sequences would be OZED, OZEP.

Other environmentally less debilitating bleaching agents.

Hydrogen Peroxide

Hydrogen peroxide has been used successfully to 'whiten' mechanical pulps for a number of years. More recently, the application to chemical pulps has been successful. The advantage of peroxide is that it contains no chlorine; the main disadvantage is the relatively low cost effectiveness.

Initially, peroxide was added to the extraction stage to improve brightness and to improve the colour of the effluent. More recently, it has been added as an individual stage in totally chlorine free (TCF) bleaching sequences such as OZEP.

Unfortunately, the bleaching effect per unit of cost is not very high when compared to other bleaching agents and the result is lower brightness achievements in peroxide containing sequences.

The industry has moved out of chlorine bleaching into other types such as chlorine dioxide, ozone, peroxide, oxygen etc and had considerable success reducing AOXs and dioxins [Harris, 1990; Cooper, 1993]

3.6.2 Water usage in bleaching

Having developed an historic understanding of the environmental impacts of bleaching, the usage of water in bleaching needs to be threaded into the equation. Water is necessary in bleaching for a number of reasons. As in most pulp and paper processes, water is used as a carrier of both the pulp and the bleaching agent and provides a medium for chemical transfer. Water is able to absorb the heat of the bleaching reaction and hence suppress temperature increases. In addition, displaced water carries away the reaction by-products of bleaching.

Bleaching of pulps in the first two thirds of the twentieth century required a specific water consumption in the region of 80 kl t^{-1} pulp. This water needed to be disposed of in a waterway. The high demand for both water and an effluent sink saw the development of bleaching pulp mills in water rich areas. Note: pulp mills were not the size they are today, 200 t d^{-1} was considered very big, modern mills produce 2000 t d^{-1}.

There are two reasons for the high water usage, chlorine bleaching and use of fresh water for rinsing at each stage. Chlorine bleaching is carried out at a lower consistency than other bleach sequences ie ~3% consistency. This low consistency is necessary in order to provide sufficient solute to dissolve the chlorine gas. At 5% or 50 kg Cl_2 per ton pulp, 16 (50/71 * 22,4) m^3 of gas is dissolved into 33 m^3 of pulp suspension at 3% consistency or 0,5 m^3 of gas per m^3 of pulp suspension. The bulk of the required liquid is provided by recycling of filtrate. However, it is clear that large volumes of water are involved in chlorine bleaching.

In order to understand the water usage for washing, it is necessary to briefly look at the process layout of one single conventional bleach stage.

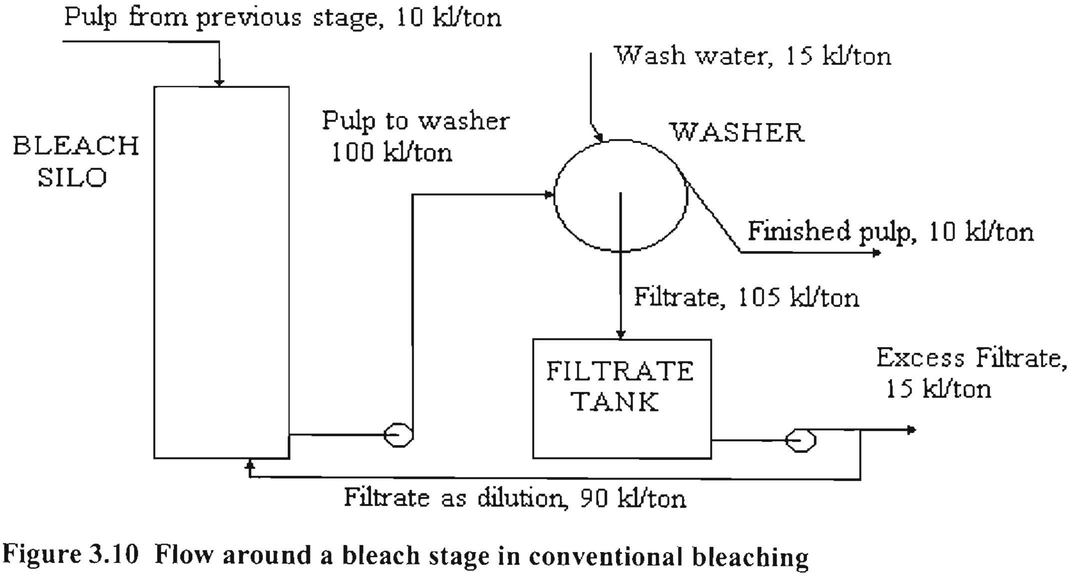


Figure 3.10 Flow around a bleach stage in conventional bleaching

Pulp suspension from the previous stage is normally supplied at approximately 10% consistency, being the consistency achieved on a washer. This pulp is conveyed to a steam heater, if it is necessary to raise the temperature. The heated pulp is then introduced to the bleach chemical to be used in the process followed by a chemical mixer. If the chemical is a liquid, the bleaching reactor vessel or silo will be a downflow vessel and if it is a gas, it will be an upflow vessel. In order to convey the pulp to the washer, the pulp is then diluted to approximately 1% consistency and transferred to the vat of the washer. On the washer, *water* is applied to the pulp to displace the *water* in the pulp which contains the reaction products. This displaced *water* passes to the centre of the washer and down to the filtrate tank where it is stored prior to use as the diluent for reduction of consistency after the wash tower or some other purpose or is overflowed to drain.

The amount of *water* used for displacement is normally 1,3 to 1,5 times the amount of *water* in the pulp. This is known as the displacement ratio. So if the consistency is 10% and therefore the amount of water per ton of dry pulp is 9 tons, at a displacement ratio of say 1,4, then 12,6 tons (1,4*9) of wash *water* will be required.

In the early days of sequential bleaching, fresh water was used for washing on each stage. On a five stage sequence, say CEDED, more than 60 kl of water were used per ton of pulp for washing alone. Add this to other water requirements such as gland sealing, it is easy to see why 80 kl of water ton^{-1} of pulp was used. The chief advantage of this washing methodology was very clean pulp moving forward to the next stage.

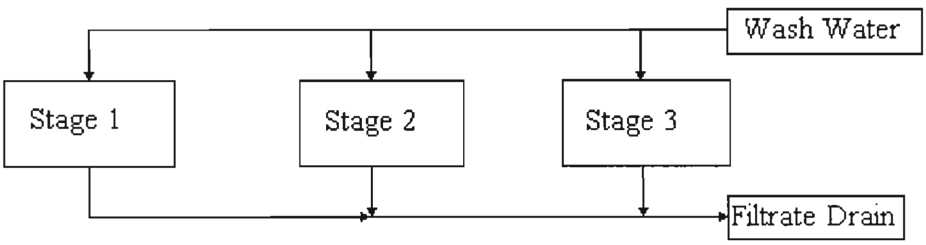


Fig 3.11 Open bleach sequence

Clearly, the use of 80 kl of water ton^{-1} of pulp in a mill producing 100 t d^{-1}, requires 8000 kl d^{-1}, or 5,5 kl min^{-1}. Pumping this volume of water is significant but not overwhelming; however when the size of bleach facilities grew to 500 then 1000 t d^{-1}, the task became enormous at 55 kl min^{-1} and clearly something had to be done to reduce the specific consumption.

Closing the water systems in the bleach plant via water reuse became necessary. This meant that the filtrate from the subsequent stage was used for washing the prior stage. The system is referred to as counter current washing [Springer, 1986].

Strictly applied, it means that the 100 t d^{-1} bleach plant, referred to above, would used 3200 kl d^{-1}, or 2,2 kl min^{-1} and with attention to other water reduction, significantly less; and a 1000 t d^{-1} plant would consume about 12 to 20 kl min^{-1} depending on other water efficiency measures taken.

There are some disadvantages of counter current washing. The chemical usage tends to be slightly higher than the open systems but the necessity for pH correction is reduced.

The specific water consumption of conventional bleach plants is then between 15 and 30 kl t^{-1}.

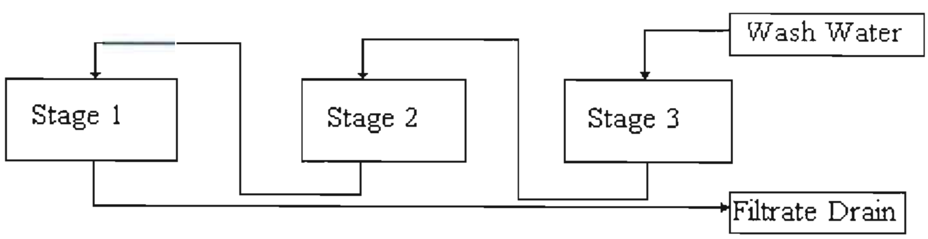


Fig 3.12 Closed bleach sequence

Effect of use of non-chlorine based stages early in the bleach sequence

Although it was not initially implemented, one of the main advantages achieved from oxygen bleaching was the ability to recover the pulping liquors via the recovery circuit.

Chemicals used in oxygen bleaching are oxygen, sodium hydroxide and very small quantities of magnesium salt. Oxygen is consumed in reaction to give oxidised organic chemicals, magnesium to a large extent adheres to the wood pulp and sodium hydroxide reacts as a solubiliser for the oxidised wood chemicals.

Similarly, ozone bleaching uses ozone and an acid usually sulphuric acid and peroxide bleaching uses hydrogen peroxide in an alkaline medium provided by caustic soda.

What is important is that none of these bleach stages uses any chlorine based chemicals as active oxidising agent or a pH control chemical. The oxidising agent generates a reaction product of oxidised organic material. If the pH-controlling chemical is selected to be compatible with the recovery circuit then bleach liquor recovery in the pulping liquor recovery circuit is possible; this normally means sulphuric acid for Kraft.

In order to further balance the water circuit, wash water used in the bleach process, associated with the recovery circuit, should partially consist of cleaned contaminated condensate. This condensate would previously have been applied to brown stock washing, which now uses bleach plant waste liquors.

Mechanical solutions to improving water usage in bleaching

There are two primary mechanical means used by the industry to reduce water consumption.

The first is the employment of wash presses. The main advantage of a wash press is to increase the consistency of the pulp produced at the end of each bleach stage. As mentioned earlier, the rinsing effect of washing is improved by increasing the displacement ratio to between 1,2 and 1,5. Hence if the amount of *water* carried by the pulp is reduced, then the amount of *wash water* will be reduced by the same ratio.

Taking two examples of washers using a displacement ratio of 1,2. Firstly, a conventional drum washer running at 10% consistency; here the amount of *wash water* applied is 10,8 kl t^{-1}. If a wash press is able to achieve 20% consistency, the specific *wash water* consumption reduces to 4,8 kl t^{-1}, a saving of 6 kl t^{-1}. Some steam savings may be achieved by use of wash presses.

The other option is to use a displacement bleach tower. To some extent, these units are not favoured because of their mechanical complexity, which arises out of the need to reduce drag within the units. The displacement screens rise with the pulp for a short distance and then drop to start rising again.

As with wash presses, water usage is reduced about 60% but associated with this are reductions in steam consumption and power usage. Steam is reduced as there is no need to cool and reheat the pulp and as the chemical liquors are partially recycled. Electricity is reduced as the pumping is restricted to only one pumping of the pulp suspension and there is very little pumping of chemical solutions [Springer, 1986].

Use of other process waters

Recycling of paper machine back waters is often considered for bleach and pulp mill use. The complexity of additives used in papermaking has to be considered when investigating these applications.

In the case of mechanical pulping, it has already been shown to be a suitable application to use machine water in the pulp mill and to return the water with the pulp to the paper machine.

3.6.3 Best practices in bleaching

Best practices in bleaching over the last thirty five years have been focused on use of non-halogen based bleaching agents and reducing water usage [Patt *et al*, 1998]. Increased usage of chlorine dioxide, hydrogen peroxide and oxygen and to some extent ozone has been noticed. Current trends include pressurised peroxide, and enzyme treatments which reduce bleach chemical requirements.

Counter current washing in conventional bleach plants is now standard.

The use of displacement bleaching systems reduces the water used, the effluent volume and load and the power consumed in the bleach plant. However, mechanical complexity and higher bleach chemical usage are incurred.

The complexity of the equation is that the market demands whiter pulps with less pollution.

Summary of water usage in bleached Kraft and Sulphite pulps is included in the section on chemical pulping.

3.6.4 Bleaching summary

In summary, water usage in bleaching will vary from 15 to 40 kl ton^{-1}, with the norm being around 25 to 30 kl ton^{-1}.

Minimum specific water consumption for bleaching process:	15 kl t^{-1}
Maximum specific water consumption for bleaching process:	40 kl t^{-1}
Average specific water consumption for bleaching process:	25 kl t^{-1}

Wash *water* in bleaching will carry through to the next process. So the requirements of the following process need to be considered. Some also carries through into the bleach sequence and these requirements also need to be considered. Normally, clean water is used for the final stage of bleaching with counter current washing afterwards.

Bleach plant effluents are normally not suitable for other purposes except in the case of oxygen, ozone or peroxide stages which have not been preceded by a chlorine based stage, which can be recovered for pulp washing.

3.7 Water usage in paper making

The following paper machines are in operation within South Africa:

Pamsa affiliated:

Kimberly Clark: 2 tissue machines
Mondi Felixton: 1 corrugating medium machine
Mondi Merebank: 1 SC machine, 2 fine paper machines, 2 newsprint machines
Mondi Piet Retief: 1 linerboard/corrugating medium machine
Mondi Richards Bay: 1 pulp uptake machine, 1 linerboard machine
Mondi Springs: 1 carton board machine

Nampak Bellville: 2 tissue machines
Nampak Riverview: 1 tissue machine
Nampak Kliprivier: 1 tissue machine
Nampak Rosslyn: 1 linerboard/corrugating medium machine

Sappi Adamas: 2 paper machines
Sappi Cape Kraft: 1 linerboard machine
Sappi Enstra: 3 fine paper machines
Sappi Tugela: 4 packaging paper machines
Sappi Ngodwana: 1 pulp uptake machine, 1 newsprint machine, 1 linerboard machine
Sappi Saiccor:3 pulp uptake machines
Sappi Stanger: 1 coated fine paper machine, 1 tissue machine
[Pamsa, 2002]

Other independent paper machines have not been considered for the purposes of this dissertation.

3.7.1 Process description including water consumption variables

As a general rule, pulp stock on a paper machine is reduced in consistency to as low as 0,2% consistency, but more frequently about 0,3 to 0,5% consistency, and then the consistency is increased to about 95% or as it is more commonly stated, 5% moisture.

Paper machines consist of three main operational areas. These areas can be used to describe the water consumption on a machine. The three areas are stock preparation, the wet end and the dry end. This order represents the extent of water involvement and complexity.

3.7.1.1 Stock preparation

Stock preparation as an area must also be divided into subsections. Firstly, pulping, if required, secondly stock modification and thirdly water management.

Pulping is the action of reducing the consistency of the stock to that required for processing. Pulp supplied to a paper machine is very rarely at the correct consistency. If market pulp is used, then the nominal consistency is 90%. In the case of integrated mills, the pulp is invariably stored in high density chests at a consistency determined by the type of pulp and the thickening equipment. The consistency of chemical pulps is normally greater than 10% whilst that of mechanical pulps is around 5%.

In most cases, machine back water is used to reduce the consistency to around 4% in a pulper. The value of 4% is derived from efficient pulp processing; it is simpler and more economical to pump, refine and screen at this consistency. Some operations prefer to operate at higher consistencies to improve the refining effect.

The pulp is now ready for further processing and is stored separately in chests at the required consistency.

The subsequent stages of processing will take place at the stored consistency. These processes may include refining, blending, thick stock screening and some chemical additions.

The pulp is then sequentially reduced in consistency for processing in the approach flow to the headbox.

The approach flow is a short circuit whereby the 4% pulp stock is reduced in consistency to about 1% before processing in low consistency cleaners and, possibly, a de-aeration step. The accepts from the cleaners, after further dilution to about 0,5% consistency, pass to the low consistency screening system prior to feeding to the machine headbox. The rejects from cleaners and screens constitute part of the waste from the papermachine system and it is required that the volume and mass be managed.

The water which is removed from paper stock in the forming section is referred to as *white water* or *back water*. This water is used for the dilution steps referred to earlier. Recovery of solids from excess *white water* is achieved by the use of a saveall. The saveall is a device, which separates *white water* solids from the white water. The solids are returned to the blend chest, whilst the clarified liquor can either be reused in the machine or wasted to sewer.

In the stock preparation area there are a number of areas, which require attention if water consumption is to be effectively managed.

Firstly, the operation of the saveall. The saveall, by partially separating solids from the *white water*, enables machine management to make decisions about the reuse of water. The clarified *white water* can be used in various areas to avoid application of fresh water.

Suggested areas for use of clarified white water are:
- Makeup water in the stock preparation area
- Wash up water on the paper machine
- Possible use in liquid ring vacuum pumps (where recycling of the seal water is not practised)
- Wire and roll cleaning applications

Clarified white water is not recommended for the following unless additional clarification is applied:
- Felt cleaning (felt and nozzle fouling)
- Gland sealing (erosion of pump parts)
- Trim squirts (blockage of nozzles)

The second most important area of attention is the sealing of pumps. Sealing of pumps, to prevent a) water and fibre loss and b) air ingress to the stock, is very important. The stock preparation area of a paper machine might house in excess of 100 pumps and hence shaft sealing is vital. Traditionally, the shaft sealing of pumps has been achieved with gland packing lubricated with water through a lantern ring. In older systems, gland sealing contributes up to 5 kl water usage t^{-1} paper [Springer, 1986].

Modern approach flow system pumps are sealed either with mechanical or dynamic seals, this reduces water usage for sealing to almost nil. The problem arises with the expense of retrofitting these seals to older systems.

Opportunities to use excess water in other mill operations should be investigated. Unfortunately, the chemical additions to the wet end make this more complicated. Where wet end chemistry is minimal, especially sizing as with newsprint, cartonboard and tissue making, reuse of water in pulping operations is a possibility.

The flow volumes of water associated within the stock preparation and wet end are huge. Flows in excess of 1 kl s^{-1} are common in large machines. Specific water usage, at the wet end, ranges from almost zero in recycled fibre mills to 20 kl t^{-1} in fine paper operations.
The reason for this difference lies in the complexity of operation, the requirement of cleanliness of stock and the application of chemicals to the systems.

3.7.1.2 Wet end operations (including pressing)

The conventional fourdrinier paper machine will be used to describe the activities of forming and pressing. Other machine configurations are not significantly different to warrant discussion in a thesis of this nature. Even vat forming is not that different.

The prime function of the wet end is to form a paper web and begin the dewatering process. In fact, the bulk of dewatering happens in the forming and pressing. These configurations are the cheapest means of removing water.

The prepared stock is transferred from the stock preparation area to the headbox part of the paper machine via the short circulation. The diluted stock (0,2 to 1% consistency) is spread onto the forming wire(s) via the slice of the headbox at approximately the speed of the forming wire. This ensures that the fibres are evenly spread across the width of the forming wire. The traverse of the forming wire across the forming table and its elements contributes to formation improvement whilst removing the bulk of the water, 95 to 98 % of the water passing through the headbox slice does not reach the end of the forming table. The solids content of the water removed decreases along the table and this fact can be used to separate different qualities of white water. At the end of the forming table, the paper web, which has reached a consistency of around 22% is transferred from the forming wire to the pressing area via a felt.

In the press section, the paper web is dewatered by sequentially pressing the web and felts between rolls. The consistency of the web leaving the press section is between 40 and 50%. Clearly, 50% is more desirable in terms of drying load and drier section capacity.

Water usage in the wet end and pressing areas is mainly focussed on clothing cleaning and liquid ring vacuum pumps. Water recovered from the wet end is separated according to solids content (as mentioned previously, the water recovered closer to the head box tends to be higher in solids than that further from the headbox).

Liquid ring vacuum pumps are used for vacuum. These types of pumps are used for their suitability to the loads of paper machine vacuum systems. The operating principle is based on a liquid ring in the casing which changes shape due to the shape of the pump casing and hence acts as a liquid piston. The mechanical activity of the water causes it to heat up. If the water is not replaced with cooler water the temperature will continue to increase until the temperature and the vacuum created are in balance and evaporation will occur. This means that the vacuum pump will be moving its own vapour, which increases its volumetric load and decreases the vacuum generated. The normal maximum temperature is about 50°C. Water added to the system will be sufficient to maintain the water within the pump between 45 and 50°C and excess water is removed with the outlet gases and separated in the vacuum pump channel. Originally, this water overflowed to drain and contributed about 6 kl ton^{-1} paper to the water usage [Lindholm, 1998].

Modern, water-conscious operations make provision for vacuum pump seal water either by adding a cooling tower and recycling the water or by diverting the warm water to an alternative consumer of warm water. Examples of other areas where the water can be used are pulping in stock preparation and bleaching wash water (if available).

The cooling tower option will still consume some water, which is evaporated. This amounts to about 5% of the total water flow and so represents an approximately 95% water saving.

The other important water usage in the felt section is the showers for cleaning the felts. The operator has a choice between high volume, low pressure or low volume high pressure. For water saving the lower volume, high pressure option is the obvious choice. However, high pressure/low volume showering implies small nozzle sizes, which will increase the liability of blockages unless the water used is of high quality.

This poses a dilemma: should the operator use higher volumes of lower quality recycled water or lower volumes of fresh water? Good filtration of lower quality water can be considered but the filtration systems are complex and require frequent attention.

Felt lubrication can be achieved with well cleaned recycled water.

3.7.1.3 Drying section

Water usage in the drying section is associated with condensing of excess blow through steam, screen cleaning and washing up operations. Condensate from the dryers is collected and returned to the boilers.

Water used to condense excess steam will be returned to a warm water tank where it can be used for various applications within the paper machine, such as stock dilution, trim squirts, felt and wire cleaning. Excess warm water must be cooled and returned to main water supply. This can be achieved by use of heat exchangers or more commonly by cooling towers.

The amount of water is not a lot, being less than 0,4 kl ton^{-1} paper. However, the water is generally of a good quality and requires reuse within the machine. There is also the potential to save heat energy.

Screen cleaning systems need to be treated in the same way as felt cleaning systems; this means high pressure, low volume operation is favoured. Water used for drier screen cleaning is partially recovered in a vacuum box. This water can be recycled to the wet end of the machine.

3.7.2 Paper making processes and products impact on water usage

Although the processes described above are applicable to all paper making there are differences in approach in making different grades of paper. Different paper products require different pulps, chemical additions and process intensity in order to make products, which satisfy market requirements.

The implication of different types of products on water usage is complex. Generally, packaging grades of paper are more favourable when reducing water usage and fine papers are less favourable.

3.7.3 Implications of closing up paper machine water circuits

With increased closure, a number of process conditions are likely to change [Bosch *et al., 2001*].

Firstly, the temperature will be inclined to go up due to the higher temperature required to displace the system energy in a lower volume of water. It is generally noted that paper machine effluents are higher in temperature than the water feed. The temperature increase is a result of added electrical energy and possibly added steam energy.

If steam is added to the wet end of the machine, the mass of steam added can be reduced as the water circuits are closed to maintain system temperature. However, as the closure forces specific water consumption below 10 kl t^{-1}, the steam addition should be almost closed and the temperature of the wet end will begin to rise.

Increased wet end temperature can cause a number of system changes to take place.

The biological contamination of the wet end may change. As most modern machines operate at temperatures in excess of 30°C, the increase in temperature is likely to stress the organisms into change. The bio-system is likely to shift to more temperature-resistant strains, which may be resistant to the bio-control program or may induce different types of biological outbreak effects. Certainly, a new bio-control program should be considered.

Increased system temperature will change the reactivity of wet end additives. Although the changes are not easily predicted, the machine operator could expect changes to sizing, colour control, drainage and filler fixing amongst others.

Increased temperature will also affect the operation of drainage elements and pressing. A number of these effects are likely to be positive, such as drainage rate, press effect etc. but there are some effects which are negative such as loss of vacuum due to increase vaporisation of machine water under vacuum conditions. This occurs in higher temperature machines where the system temperature exceeds 50°C.

The second effect of closure is increase in system concentrations of a number of components. The components, which increase in concentration, are system specific and hence very unpredictable. Vendries and Pfromm showed that the extent of closure on aluminium, sulphur, sodium and chloride concentrations [Vendries and Pfromm, 1998]. Typical components are fines, inorganic salts and wet-end additive residues. Because of the unpredictable nature of this problem, it is difficult to indicate what kind of problems will occur in a given system.

Typical process difficulties are poor sizing, poor colour control, interference with inter-fibre bonding and increased microbiological activity [Springer, 1986; Curley *et al.*, 1998].

What is clear is that when closing up a paper machine wet end, it is essential that machine personnel are well trained in wet end process control and are ever alert to changing process conditions. Continuing the practices of open system management is a sure route to poor runnability and poor product quality.

3.7.4 Best applied practices

In the earlier part of the twentieth century, a large paper machine may have produced 30 000 to 40 000 tons year $^{-1}$, whilst using water at a specific rate of 100 kl t $^{-1}$. This necessitates supplying 0,13 kl s $^{-1}$ to the machine (8 kl min $^{-1}$). Whilst the wet end technology of the time enhanced the specific water consumption, it is clear that today's machines, which are ten times the size can not use water at that rate. In fact, the tendency is to use about the same volume of water to give a specific consumption of around 10 kl t $^{-1}$. This requires much better wet end chemistry and much better machine management.

The value of 10 kl t $^{-1}$ is a guideline. The specific consumption on a machine is dependent on a number of factors including the age of the machine and the grades of paper produced.

In order to reduce specific water consumption on a machine the following best practices need to be applied. Clearly, the cost of each of these changes on an existing machine must be measured against the benefit achieved [Boyko *et al.*, 1997; Webb, 2003].

3.7.4.1 Vacuum pump seal water

The vacuum pump seal water should not be an open circuit but should be a closed loop with a cooling tower in the circuit. The water consumption for this system will only be for evaporation loss. Specific consumption will reduce from 6 kl ton^{-1} to <1 kl ton^{-1}.

3.7.4.2 Shower water

Showering of felts and forming fabrics consumes 5 to 10 kl ton^{-1} of process water. Machine clarified water can be used if it is further clarified to prevent shower nozzle blocking. Water consumption is optimised by using lower volume/higher pressure showers. By recycling machine water, the consumption for this essential activity can be reduced to almost zero. However, closer machine management is required and additional filtration is essential.

3.7.4.3 Chemical dilution and addition

1 to 2 kl t $^{-1}$ process water is required for chemical dilution and addition. It is generally required that the water be cool to prevent early reaction. This means that machine backwater is not suitable. In addition, machine backwater contains particulate matter, which may pre-empt certain reactions.

3.7.4.4 Cooling

This includes cooling of oil for bearing and roll lubrication, vacuum condenser water and hydraulic oil. The water used for this purpose is normally returned to the warm water tank, from which it is distributed for use within the machine. The gland seal water can also be returned to the warm water tank. In a water efficient machine, it is well possible that the warm water generated will significantly exceed the water requirements of the machine. In this case it is necessary to circulate the warm water through a cooling tower and return the water back for cooling purposes, saving 4 kl t^{-1} [Lindholm, 1998].

Reducing cooling water requirement by introduction of a cooling tower, it is possible that warm cooling water will make up the 5 to 6 kl t^{-1} necessary to purge the wet end of excess temperature and harmful contrary material.

3.7.4.5 Miscellaneous requirements

Seal water and washing of the machine are the final uses of water which need to be considered. Machine washing is a necessity, which needs careful management. An over zealous cleaning regime can be a considerable consumer of water and yet no cleaning leads to an unsightly process environment.

Seal water, on the other hand, requires a modern engineering approach to ensure that the water used for sealing of pumps and equipment is returned to the process for reuse.

The water can only be returned if it is clean. This is the main motivation for use of mechanical seals.

The volume of water used for sealing will, obviously, depend on the number of pieces being sealed but a rough estimate gives 2 kl t^{-1} of seal water.

3.7.5 Effect of different paper products

The effect of different paper products depends on the effect the wet end chemistry and clothing condition monitoring have on the properties of the final product.

3.7.5.1 Sensitive products

Fine papers have the highest sensitivity to wet end chemistry and felt condition. These products require intensive sizing, colour control, dimensional stability, pulp cleanliness and surface properties. Instability in the wet end will make their manufacture very difficult.

The tendency will be to use an additional amount of water in manufacture of these products. It is not easy to estimate how much additional water as it is dependent on the age of the machine and the competency of the operatives and machine management.

It is anticipated that the water usage will be between 8 and 18 kl t^{-1} for these grades.

3.7.5.2 Less sensitive products

News and tissue grades will require less water in the paper machine area but are invariably highly linked to the pulping processes involved. Tissue manufacture requires a lot of water for clothing management and because of the low grammages produced this leads to higher specific usage.

Water usage for these grades will depend on the pulping process. Newsprint will require about 15 to 18 kl t^{-1} of water when associated with the pulping process. Under the same circumstances, tissue will require another 5 kl t^{-1}.

When considered on their own, these machines will use between 4 and 10 kl t^{-1}.

3.7.5.3 Packaging grades

Generally speaking packaging papers have a higher grammage and a much less stringent colour specification than other papers. The prime property considerations are functional strength based, which are derived to a large extent from the grammage. However, there is considerable pressure being placed to reduce grammage.

With these factors in mind it is clear that the reduction in water usage on packaging machines can be achieved without seriously impairing the paper properties.

It is not uncommon to find packaging paper machines maintaining a water usage which results in zero discharge, ie the water used is sufficient to maintain the water passing through the press section only.

Specific water usage ranges from 3 to 10 kl t^{-1} for packaging grades.

A summary table for this chapter is included in the summary table for chapter 4.

Chapter 4 Product Results

In this chapter, each of the commodity type papers are evaluated in terms of their impact on water usage.

4.1 Linerboard

4.1.1 Fibre resources for linerboard

Linerboard constitutes the exterior of corrugated boxes and contributes the bulk of the strength of the container. This determines that the bulk of the fibre should be able to contribute to this strength. The product is a multi-ply board, either two or three plies. For three-ply, the middle ply can be made from recycled fibres whilst the outer ply may be virgin unbleached fibre. Alternatively, one of the outer plies could be bleached fibre. Two ply could consist of a virgin unbleached ply and a recycled ply.

4.1.2 Processes for manufacturing linerboard.

The stock preparation would comprise a system for each ply with cleaning and screening not as stringently applied as with fine papers. Addition of starches for ply and sheet strength, drainage and retention aids, wet end sizing chemicals is carried out in the stock preparation area. Refining is applied to match the ply requirements; more for the outer ply to achieve good bonding, less in the inner ply to develop bulk.

Each stock will be delivered to the relevant headbox. The webs are contacted so that the top webs will travel with the lower web to the press section. The press section should retain bulk to improve stiffness as measured by the short column test.

The drying section will include a size press and may include a calender. The paper is normally sold in reel form. Grammage ranges from 110 gsm to 190 gsm.

If the raw material contains more than 90% recycled fibre it is referred to as test liner.

4.1.3 Linerboard summary

Water usage can range between 3 and 20 kl t^{-1} paper. The application of water will depend on the age of the machine and the systems in place to reduce water consumption [European Commission, 2000].

4.2 Corrugating medium

Corrugating medium is the material which is manufactured to provide the inner part of a corrugated cardboard product. Technically, it is used as a bulking material to give stiffness.

4.2.1 Fibre resources for corrugating medium

The fibre resource should be cheap. Typical fibre products used are NSSC hardwood, recycled fibres and, in South Africa, bagasse (this may be used in other countries like India).

4.2.2 Processes for manufacturing corrugating medium

The stock preparation will include recycled fibre processing if used. The machines used for corrugating medium are often older machines. Generally, the standard fourdrinier machine is used with mechanisms in place to maintain bulk and reduce the draws. Wet end sizing is normally applied and sometimes surface size is also applied.

4.2.3 Corrugating medium summary

Water usage will be similar to that of linerboard ie 3 to 20 kl t^{-1} [European Commission, 2000].

4.3 Folding boxboard (cartonboard)

4.3.1 Fibre resources for folding boxboard

The bulk of folding boxboard mass is produced from waste fibres with some products using white fibre blends for the outer layers. The use of low grade waste fibres allows for the reduction in the manufacturing cost of these products.

4.3.2 Processes for manufacturing folding boxboard

Clearly, waste fibre processing equipment is necessary in a format that will convert the waste supplied to the quality of the pulp required for board manufacture.

The forming of the product is achieved by producing a number of layers of paper which are wet pressed together to create a bond between the layers. Lower quality layers form the inner part of the sheet and the better quality is exposed at the surface.

Pressing requires special loading procedures to ensure that "crushing" does not occur as this will separate the plies of the multilayer product. Drying requires more area as the board is thick.

4.3.3 Folding boxboard summary

The specific water consumption for folding boxboard ranges from 2 to 20 kl t^{-1} with approximately 5 kl t^{-1} being common [European Commission, 2000].

4.4 Fine paper including coated fine paper

4.4.1 Fibre resources for fine paper products

Fine papers are almost invariably made from fully bleached chemical pulp fibres. The term woodfree is often applied to these types of papers as a result of the furnish which has been used. This term is applicable to papers made from a fibre furnish which comprises more than 90% fully bleached chemical pulps.

The usual blend would be approximately 20% softwood and 80% hardwood. The softwood is used to increase the strength and the hardwood gives good opacity, better formation and sometimes a cheaper furnish.

4.4.2 Processes for manufacturing fine paper products.

The stock preparation and approach flow for these machines is invariably more complex because of the need to have a very clean pulp, free of dirt, broke chips etc. Hence cleaning and screening systems will be required to remove all contrary material and will have multiple stages. Refining of the different furnish streams introduces further complexity. In order to improve formation and drainage, air will be removed either in the cleaner system or using a deculator.

The paper machine will consist of a forming section comprising of a high resolution headbox, a forming table with a top former, all set to maximise formation. The press section will comprise either an extended nip press or a fully sheet supporting multinip press combination. The drying section will include a film press/size press for application of size or coating. The final drying will include mechanisms for curl control. Infrared zone control drying can also show advantages with uniform moisture in the sheet. A calender is often included at the end of the machine or before the size press.

Should the paper be coated, then a coater with coating kitchen for coat preparation and supercalendering is needed.

Fine papers are often cut to sheets within the factory. This requires a finishing section.

4.4.3 Fine papers summary

The specific water consumption for a fine paper machine will range from 5 to 20 kl t^{-1}. The higher end of the range is common on older machines whilst a new installation will be designed to meet the lower consumption rate. Improvements would include closed loop vacuum seal water system, improved gland seal systems, high pressure-low volume shower systems using polished machine backwater, recycle of excess hot water through cooling to machine water feed and other water conserving measures [European Commission, 2000].

Coating facilities use very little water for coating mixes and the cooling systems for supercalendering should be closed loop.

Fine paper mills use fully bleached chemical fibres and hence the water usage associated with bleaching and pulping are normally associated with the paper production, whether the mill is integrated or not. The high specific water usage of bleached chemical fibre can add 30 to 40 kl t^{-1} to the specific water consumption.

4.5 Tissue and associated products

4.5.1 Fibre resources for tissue products

Tissue products have the highest range of quality standards in the paper industry and this is reflected in the raw materials used for manufacture. The fibres can be bleached chemical pulps or a wide range of recycled fibres.

4.5.2 Processes for manufacturing tissue products.

The fibre preparation on a tissue machine depends almost entirely on the match of the raw fibre purchased and the product requirement.

Starting with the product requirement, tissue products have main characteristics which are best described as whiteness, absorbency and softness. The order of importance of the characteristics depends on the market requirements for the product produced. Clearly facial tissues have softness as the prime characteristic whilst kitchen towelling will rank absorbency as the most important attribute.

The raw waste fibres range from the common mixed waste to the recycled office papers to fully bleached chemical pulps. Clearly the processing required is very dependent on the type of fibre used.

Firstly, fully bleached chemical pulps require very little processing, possibly some refining and cleaning. These pulps produce good whiteness, good absorbency but need to be modified to give improved softness because of their propensity to bond together.

Recycled office waste is generally accepted as the most expensive recycled fibre because of its scarceness. In addition, the paper has a high degree of ash or filler, up to 30%. This ash causes wastage in processing as it tends to get lost in the water systems.

Common mixed waste requires pulping, contrary removal (multi-stage), deinking and bleaching.

The tissue machine consists of a pressure former or blade former followed by a Yankee drier from which the tissue is creped off. The creping action is very important with respect to tissue feel. Grammage ranges from 12 to 50 gsm, with toilet and facials at the lower end and toweling at the higher end.

The jumbo reels are wound into sizes required for converting which may be on site.

4.5.3 Tissue papers summary

Specific water usage in tissue manufacture is apparently higher than is expected. This is due to the low mass of paper produced on a very fast machine. Use of lower grades of waste induces a high requirement to attend to clothing cleanliness. Machines producing higher quality, hygiene products tend to use more water.

Typical specific water consumption ranges from 10 to 50 kl t^{-1} [European Commission, 2000].

4.6 Newsprint including super calender and other mechanical printing papers

4.6.1 Fibre resources for newsprint type products

Newsprint, supercalendered papers (SC) and light weight coated papers (LWC) are manufactured from a mixture of mechanically processed softwood fibres and recycled magazines and newspapers.

4.6.2 Processes for manufacture of Newsprint type products

For newsprint, the main fibre resource would be softwood processed through a thermo mechanical pulping plant. However, there are still mills using groundwood (GW) or pressure groundwood (PGW) pulps.

Strengthening fibres are bleached softwood Kraft (BSK) which would be imported to the mill as the demand is normally quite low, ~ 5 to 10% of the furnish.

In some mills, recycled fibres are used. These would normally consist of old newspapers or old magazines. The advantage of old magazines would be a higher percentage of stronger chemical pulps in the make up.

Newsprint is manufactured using a paper machine comprising a twin wire gap former, extended nip pressing and multidrum driers, trending towards single layer. Sizing is not applied. The sheet is fully supported throughout the machine to allow for higher speeds. Typical machine speeds approach 2000 m min^{-1}.

For SC papers a supercalender is added at the end of the machine, and for LWC papers an on-machine coater is added.

In summary, a typical system for manufacturing newsprint consists of a fibre line of TMP (or in older machines GW) with facility to add BSK to the furnish or TMP with a recycled fibre line to pulp and de-ink old news and magazines and a machine as described above.

4.6.3 Newsprint manufacture summary

Water consumption for news manufacture will vary from approximately 5 kl t^{-1} to 20 kl t^{-1}. The lower value is achieved in a modern machine with good water saving techniques applied and the machine back water used in the pulp mill. As newsprint is not very colour-sensitive or requiring sizing water, management is simpler and the machine systems are more tolerant of higher contamination levels [European Commission, 2000].

Use of deinking processes to treat recycled fibres will lead to higher water consumption as it is necessary to remove the ink containing waste. Floatation deinking is preferred as the ink stream is more concentrated than with wash deinking.

4.7 Market pulp

4.7.1 Fibre resources for market pulp

Market pulp is normally fully bleached hardwood or softwood pulp. In some cases unbleached hardwood or softwood pulp is produced for the pulp market.

4.7.2 Processes for manufacturing market pulp.

Stock preparation for market pulp is all about ensuring the pulp is clean and maintains brightness. Cleanliness is achieved with cleaners and screens. Brightness is maintained by addition of clean water to the machine.

The machine will consist of headbox, fourdrinier table, press section and then an air drying system. The web is too thick and bulky to be dried by heat conduction so air impact convection is used. The web is conveyed on an air pad which also achieves the drying action.

4.7.3 Market pulp summary

The water used for making market pulp would normally be used counter current in the bleaching process. The bleach process requires at least 15 kl t^{-1} of water for washing, probably 20 kl t^{-1}. This means that specific water usage on the machine can be 22 kl t^{-1}, which should be more than sufficient to maintain brightness [European Commission, 2000].

Table 4.1 - Summary table of expected water usages

Process train	Usage Range, kl t^{-1}		
	Lower	Upper	Norm
Unbleached Kraft including woodyard	9	20	12
Bleached Kraft including woodyard (conventional or ECF)	27	42	32
Unbleached NSSC including woodyard	1	34	6
Bleached Sulphite including woodyard (Calcium based)	70	130	75
Bleached Sulphite including woodyard (Magnesium based)	40	100	45
Recycled fibre based carton board (uncoated)	2	10	5
Recycled fibre based carton board (coated)	7	15	8
Recycled fibre based packaging papers	1,5	10	5
Recycled fibre based newsprint	10	20	15
Recycled fibre based tissue	5	100	20
Recycled fibre based fine paper	7	12	12
General printings and writings not integrated	7	20	12
General linerboard/packaging papers	3	20	10
General corrugating medium including unbleached pulpmill	12	30	15
Newsprint/SC papers	6	30	16

Some interpolation has taken place to determine the norm where this was not available in the literature.

Chapter 5 Results of Survey of South African Mills

In this chapter, each selected mill is considered in turn.

5.1 Results of surveys of a selection of South African mills

5.1.1 Mill: Mondi, Richards Bay Mill

Parent:	Mondi Business Paper
Started Up:	1984
Region:	KwaZulu-Natal
Water Region:	Usutu to Umhlatuze [Department of Water Affairs and Forestry, 1999]
Product Range:	Linerboard, market pulp

Table 5.1 Machines at Mondi Richards Bay

Machines	PM 42	PM 41
Type	Fourdrinier – Voith	
Product	Linerboard	Market pulp
Width	5,1 m	6,8 m
Capacity	280 000 tpa	490 000 tpa
Installed	1984	1984
Upgraded	1999	

[Pamsa, 1986] [pers. comm. Barton Hobbs, 2004; Terreblanche, 2001]

Basic Raw Material:
Although this mill is primarily a hardwood mill, softwoods are pulped in order to meet the requirements of the linerboard machine. An additional 100 t per day is produced as noodle pulp for Mondi Piet Retief.

General Description:
The pulpmill consists of a batch kraft pulping operation of hardwoods (eucalypts) and softwoods; recovery is achieved using a conventional Kraft recovery furnace. The hardwood and softwood pulp produced is bleached by an ODE$_O$DED sequence. Unbleached softwood pulp is also fed to the linerboard machine without bleaching. The paper mill consists of one linerboard machine and one pulp machine.

Water Usage:
Water is received from Umhlatuze Water Authority. Water Usage: 55 Ml d $^{-1}$ [pers. comm. Barton Hobbs, 2004]

Estimated Overall Water Consumption (using Table 4.1):
1 400 t d^{-1} BHWK requires 27 kl t $^{-1}$ to 42 kl t $^{-1}$ with a probable norm of 32 kl t $^{-1}$ of water; 800 t d $^{-1}$. Linerboard + pulpmill requires 3 kl t $^{-1}$ to 20 kl t $^{-1}$ with a probable norm of 10 kl t $^{-1}$ of water; 100 t d ^{1} noodle pulp requires 9 kl t $^{-1}$ to 20 kl t $^{-1}$ with a probable norm of 12 kl t $^{-1}$ of water.

Table 5.2 Summary of water usage analysis for Mondi Richards Bay

	Total water consumption in Ml d $^{-1}$			
Process	Lower	Upper	Norm	Actual
1400 t d^{-1} BHWK	37,8	58,8	44,8	
800 t d^{-1} Linerboard + pulpmill	2,4	16,0	8,0	
100 t d^{-1} noodle pulp	0,9	2,0	1,2	
Totals	**41,1**	**76,8**	**54,0**	**55,0**

5.1.2 Mill: Mondi Merebank

Parent: Mondi Business Paper
Opened: 1971
Region: KwaZulu-Natal
Water Region: Umvoti to Umzimkulu [Department of Water Affairs and Forestry, 1999]
Product Range: Newsprint, supercalendar, directory, printings and writings

Table 5.3 Machines at Mondi Merebank

Machines	No 1	No 2	No 3	No 4	No 5
Type	Beloit Walmsley	Beloit Walmsley	Beloit Walmsley	Beloit Walmsley	Voith
Product	SC, Directory	Printings and writings	Printings and writings/news	News	News
Width	5,6 m	5,6 m	5,6 m	5,6 m	5,6 m
Capacity	100 000 tpa	120 000 tpa	175 000 tpa	110 000 tpa	110 000 tpa
Installed	1971	1972	1976	1980	1981

[Pamsa, 1986] [pers. comm.van Rooyen, 2001; 2004]

Basic Raw Material:
For newsprint, the mill uses a combination of thermo mechanical pulp (TMP), minimal market softwood and deinked recycled news and magazine papers; for printings and writings grades, market pulp is used and for super calender (SC) grades, groundwood and market pulps are used.

General Description:
Mondi Merebank is an integrated mechanical grade mill using market pulps for news strengthening and for woodfree grades. The pulp mill consists of a groundwood plant including 13 grinders having a capacity of 170 000 tpa and a TMP plant consisting of four lines capable of 180 000 tpa. The balance of fibre requirements are resourced from market pulp and the use of recycled news and magazine papers which are processed in a modern recycled fibre plant which includes ink removal. The paper capacity is derived from the five installed paper machines above. PM 1 is almost entirely dedicated to SC and directory grades. PM 2 is used for fine paper production as is PM 3;. PM 4 and PM 5 are used for newsprint production.

Water Usage:
Water is received from Umgeni Water Authority and recycled water from eThekwini Southern Sewerage Works. Water Usage: 31 Ml d $^{-1}$ recycled sewerage plus 3,5 Ml d $^{-1}$ potable water
[pers. comm. van Rooyen, 2004]

Estimated Overall Water Consumption (using Table 4.1)
630 t d $^{-1}$ newsprint based on old magazine and news pulp and TMP requires 6 kl t $^{-1}$ to 30 kl t $^{-1}$ with a norm of 16 kl t $^{-1}$ of water; 840 t d $^{-1}$ office paper requires 7 kl t $^{-1}$ to 20 kl t $^{-1}$ with a probable norm of 12 kl t $^{-1}$ of water; 285 t d $^{-1}$ GW base SC paper requires 6 kl t $^{-1}$ to 30 kl t $^{-1}$ with a probable norm of 16 kl t $^{-1}$ of water.

Table 5.4 Summary of water usage analysis for Mondi Merebank

	Total water consumption in Ml d $^{-1}$			
Process	**Lower**	**Upper**	**Norm**	**Actual**
630 t d^{-1} newsprint	3,8	18,9	10,1	
840 t d^{-1} office paper	5,9	16,8	10,8	
285 t d^{-1} GW base SC paper	1,7	8,6	4,6	
Totals	**11,4**	**44,3**	**25,5**	**34,5**

5.1.3 Mill: Mondi Packaging, Piet Retief Mill

Parent: Mondi Packaging
Opened: 1963
Region: Mpumalanga
Water Region: Usutu to Umhlatuze [Department of Water Affairs and Forestry, 1999]
Product Range: Linerboard (sometimes corrugating medium)

Table 5.5 Machines at Mondi Piet Retief

Machines	PM 1
Type	Fourdrinier Twin Wire
Product	Linerboard, corrugating medium
Width	4,0 m
Capacity	120 000 tpa
Installed	1963

[Pamsa, 1986] [Burch, 2001], [pers. comm. Strong, 2004]

Basic Raw Material:
The mill uses hardwood timber sourced from the KwaZulu-Natal and Mpumalanga regions and UBSK from Richards Bay for primary fibre and recycled Kraft waste for secondary fibre.

General Description:
The pulpmill consists of a 80 000 tpa NSSC/ASAQ HW pulping process; recovery is carried out in a Copeland reactor; the recovered sodium carbonate/sulphate is sold in the market place. The paper mill consists of a fourdrinier twin wire paper machine. An extended nip press was installed in 1997.

Water Usage:
Water is received from Heyshope dam release. Water Usage: 2,5 Ml d $^{-1}$ [pers. comm. Strong, 2004]

Estimated Overall Water Consumption (using Table 4.1)
340 t day $^{-1}$ linerboard requires between 3 and 20 kl t $^{-1}$ water with a probable norm of 10 kl t $^{-1}$;
230 t day $^{-1}$ unbleached NSSC/ASAQ requires between 1 and 34 kl t $^{-1}$ with a norm of 5,7 kl t $^{-1}$.

Table 5.6 Summary of water usage analysis for Mondi Piet Retief

	Total water consumption in Ml d $^{-1}$			
Process	**Lower**	**Upper**	**Norm**	**Actual**
340 t d $^{-1}$ linerboard	1,0	6,8	3,4	
230 t d $^{-1}$ unbleached NSSC/ASAQ	0,2	7,8	1,3	
Totals	**1,2**	**14,6**	**4,7**	**2,5**

5.1.4 Mill: Mondi Kraft, Felixton Mill

Parent: Mondi Kraft Division
Opened: 1953
Region: KwaZulu-Natal
Water Region: Usutu to Umhlatuze [Department of Water Affairs and Forestry, 1999]
Product Range: Corrugating Medium

Table 5.7 Machines at Mondi Felixton

Machines	PM 1
Type	Fourdrinier Twin Wire Er-We-Pa
Product	Corrugating Medium
Width	4,45 m
Capacity	104 000 tpa
Installed	1954

[Pamsa, 1986] [pers. comm. Nelson, 2000; Mahommed, 2004]

Basic Raw Material:
The mill uses bagasse waste from Tongaat-Huletts Sugar, Felixton Sugar Mill and recycled Kraft waste fibre.

General Description:
The pulpmill consists of a 50 000 tpa soda pulping of bagasse and a 45 000 tpa recycled fibre plant; waste fibre from Mondi Richards Bay is also used; recovery is not carried out in the mill but the black liquor is transferred to Mondi Kraft Richards Bay Mill. The paper mill consists of one fourdrinier paper machine for manufacture of corrugating medium.

Water Usage:
Water is drawn from the nearby uMhlatuze river, which has its source in the Babanango district in KwaZulu-Natal. Water Usage: 5,9 Ml d^{-1} [pers. comm. Mahommed, 2004]

Estimated Overall Water Consumption (using Table 4.1):
Based on 50% fibre from recycled fibre and 50% from soda bagasse; 150 t d^{-1} from recycled fibre requires 1,5 kl t^{-1} to 10 kl t^{-1} with a probable norm of 5 kl t^{-1}; 150 t d^{-1} from unbleached soda bagasse requires 12 kl t^{-1} to 30 kl t^{-1} with a probable norm of 15 kl t^{-1}

Table 5.8 Summary of water usage analysis for Mondi Felixton

	Total water consumption in Ml d^{-1}			
Process	**Lower**	**Upper**	**Norm**	**Actual**
150 t d^{-1} from recycled fibre	0,2	1,5	0,75	
150 t d^{-1} from unbleached soda bagasse	1,8	4,5	2,25	
Totals	**2,0**	**6,0**	**3,0**	**5,9**

5.1.5 Mill: Mondi Packaging, Springs Mill

Parent:	Mondi Carton Board
Opened:	1954
Region:	Gauteng
Water Region:	Upper Vaal [Department of Water Affairs and Forestry, 1999]
Product Range:	Carton Board, folding boxboard

Table 5.9 Machines at Mondi Springs

Machines	BM 3	BM 6
Type	SemiFormer Vat; Bertrams Dorries	Pressure Former/Short Fourdrinier
Product	Carton Board/ Chip Board	Carton Board
Width	2,45 m	3,85 m
Capacity	35 000 tpa	105 000 tpa
Installed	1954	1971

[Pamsa, 1986] [pers. comm. Robba, 2000; Cheesman, 2004]

Basic Raw Material:
Common mixed waste, recycled kraft waste (various) and white waste ex Merebank; waste pulp mill fibres; fully bleached softwood is used for the top liner.

General Description:
The pulp mill repulps recycled fibres and chemical pulps with machine backwater. The machines use both recycled clarified effluent and fresh water. The vacuum system is cooled via cooling towers. The board produced on BM 6 is coated.

Water Usage:
Water is received from East Rand Water Authority. Water Usage: 4,0 Ml d^{-1} [pers. comm. Cheesman, 2004]

Estimated Overall Water Consumption (using Table 4.1):
This evaluation will be treated as a mill totally using waste fibre; the small amount of bleached Kraft used will be ignored. 300 t d^{-1} of coated carton board requires between 7 kl t^{-1} and 15 kl t^{-1} with a probable norm of 8 kl t^{-1} of water; 100 t d^{-1} of uncoated carton board requires between 2 kl t^{-1} and 10 kl t^{-1} with a probable norm of 5 kl t^{-1} of water.

Table 5.10 Summary of water usage analysis for Mondi Springs

	Total water consumption in Ml d^{-1}			
Process	**Lower**	**Upper**	**Norm**	**Actual**
300 t d^{-1} of coated carton board	2,1	4,5	2,3	
100 t d^{-1} of uncoated carton board	0,2	1,0	0,5	
Totals	**2,3**	**5,5**	**2,8**	**4,0**

5.1.6 Mill: Sappi Forest Products, Ngodwana Mill

Parent: Sappi Forest Products
Opened: 1966
Region: Mpumalanga
Water Region: Inkomati [Department of Water Affairs and Forestry, 1999]
Product Range: Newsprint, linerboard, unbleached and bleached market pulp

Table 5.11 Machines at Sappi Ngodwana

Machines	PM 1	PM 2	No2 Fibreline	No1 Fibreline
Type	Fourdrinier Triple Wire, Beloit, Mitsubishi, Tampella	Fourdrinier Twin Wire, Beloit Bel Baie		
Product	Linerboard	Newsprint	FBSW Pulp	UB Market pulp
Width	6,8 m	6,8 m		
Capacity	260 000 tpa	135 000 tpa	133 000 tpa	120 000 tpa
Installed	1984	1984	1984	1966

[Pamsa, 1986] [pers. comm. Slabbert, 2001; Brink, 2004]

Basic Raw Material:
Softwood is required for the no.2 fibre line to produce fully bleached softwood (FBSW) Kraft and for the groundwood mill for newsprint. Hardwoods are used to produce unbleached hardwood (UBHW) Kraft.

General Description:
The pulpmill consists of two Kraft fibre lines; No 1 is a UBHW Kraft fibre line and No 2 is a FBSW Kraft line using an OZDED sequence. Each fibre line has a separate Kraft recovery circuit. The paper mill consists of two paper machines; one for newsprint manufacture and one for linerboard. There are two pulp uptaking machines; the FBSW Kraft is cut and baled whilst the UBHW is sold as rolls.

Water Usage:
Water is received from Ngodwana Dam on the Ngodwana river. Water Usage: 35 Ml d^{-1}
[pers. comm. Brink, 2004]

Estimated Overall Water Consumption (using Table 4.1):
385 t d^{-1} Newsprint requires 6 kl t^{-1} to 30 kl t^{-1} with a norm of 16 kl t^{-1} of water; 735 t d^{-1} Linerboard requires 3 kl t^{-1} to 20 kl t^{-1} with a probable norm of 10 kl t^{-1} of water; 545 t d^{-1} bleached Kraft requires 27 kl t^{-1} to 42 kl t^{-1} with a norm of 32 kl t^{-1} of water; 85 t d^{-1}unbleached Kraft requires 5 kl t^{-1} to 15 kl t^{-1} with a norm of 10 kl t^{-1} of water.

Table 5.12 Summary of water usage analysis for Sappi Ngodwana

	Total water consumption in Ml d^{-1}			
Process	**Lower**	**Upper**	**Norm**	**Actual**
385 t d^{-1} Newsprint	2,3	11,5	6,2	
800 t d^{-1} Linerboard + pulpmill	2,2	14,7	7,4	
545 t d^{-1} bleached Kraft	14,7	22,9	17,1	
85 t d^{-1}unbleached Kraft	0,4	1,3	0,9	
Totals	**19,6**	**50,4**	**31,6**	**35,0**

5.1.7 Mill: Sappi Fine Paper, Enstra Mill

Parent: Sappi
Opened: 1938
Region: Gauteng
Water Region: Upper Vaal [Department of Water Affairs and Forestry, 1999]
Product Range: Office Papers

Table 5.13 Machines at Sappi Enstra

Machines	PM 2	PM 3	PM 6
Type	Bertrams	Walmsley	Beloit Walmsley
Product	Fine papers	Fine papers	Fine papers
Width	2,7 m	3,1 m	4,7 m
Capacity	17 000 tpa	50 000 tpa	138 000 tpa
Installed	1938	1952	1961
Upgraded			1982, 1991, 1996

[Pamsa, 1986] [pers. comm. Stroebel, 2004]

Basic Raw Material:
FBSW is sourced from Sappi Ngodwana mill. 107 000 t year $^{-1}$ FBHW is produced by the mill from various eucalypts.

General Description:
The pulpmill consists of a soda pulping operation of hardwoods (eucalypts); recovery is achieved using a Copeland reactor but lime is not recovered.

The hardwood pulp produced is bleached by an ODED bleach sequence. The oxygen stage effluent is recovered in the pulp mill. The paper mill consists of three paper machines.

Water Usage:
The mill makes extensive use of treated sewerage water (about 50% of incoming water). The balance of the water is drawn from Rand Water Board. Total water usage: 25,5 Ml d $^{-1}$
[pers. comm. Stroebel, 2004]

Estimated Overall Water Consumption (using Table 4.1):
590 t d $^{-1}$ fine paper requires 7 kl t $^{-1}$ to 20 kl t $^{-1}$ with a probable norm of 12 kl t $^{-1}$ of water; 305 t d $^{-1}$ bleached HW pulp requires 21 kl t $^{-1}$ to 50 kl t $^{-1}$ with a probable norm of 32 kl t $^{-1}$ of water.

Table 5.14 Summary of water usage analysis for Sappi Enstra

	Total water consumption in Ml d $^{-1}$			
Process	**Lower**	**Upper**	**Norm**	**Actual**
590 t d $^{-1}$ fine paper	4,1	11,8	7,1	
305 t d $^{-1}$ bleached HW pulp	6,5	15,3	9,8	
Totals	**10,6**	**27,1**	**16,9**	**25,5**

5.1.8 Mill: Sappi Forest Products, Saiccor

Parent: Sappi Forest Products
Region: KwaZulu-Natal
Water Region: Umvoti to Umzimkulu [Department of Water Affairs and Forestry, 1999]
Product Range: Market pulp (dissolving pulp for cellulose by-products, viscose, cellophane etc)

Table 5.15 Machines at Sappi Saiccor

Machines	4, 3 operational
Type	Various
Product	Market pulp
Width	n/a
Capacity	580 000 tpa

[Pamsa, 1986] [pers. comm. Bentley, 2000; Herd, 2004; Airey, 2004]

Basic Raw Material:
Hardwood [both eucalypt and acacia] is most suitable for dissolving pulp manufacture because of the higher cellulose content. In excess of 9000 td $^{-1}$ is required by the mill at full production.

General Description:
The pulpmill consists of two sulphite fibre lines; the first and oldest is based on calcium technology [950 t d $^{-1}$] and the second magnesium based (700 t d $^{-1}$). The magnesium waste liquor is fully recycled via a recovery circuit and the calcium waste liquor is partially converted in a lignosuphonate plant; the balance being discharged to sea outfall. The pulp is bleached using an OD(0,85%)Eo(2,2% NaOH)D(0,6%)H(0,5%) sequence. The pulp is converted into boards on 'paper' machines or bales via spray drying and compaction.

Water Usage:
Water is sourced from the Umkomazi river. Approximately 131 Ml is withdrawn daily of which 12% is returned as filter backwash. 3 Ml are sold to local municipalities. Mill water usage: 112 Ml d^{-1}[pers. comm. Airey, 2004].

Estimated Overall Water Consumption (using Table 4.1):
950 t d $^{-1}$ calcium based bleached sulphite pulp requires 70 kl t $^{-1}$ to 130 kl t $^{-1}$ with a norm of 75 kl t $^{-1}$ of water; 700 t d $^{-1}$ magnesium based bleached pulp requires 40 kl t $^{-1}$ to 100 kl t $^{-1}$ with a norm of 45 kl t $^{-1}$ of water.

Table 5.16 Summary of water usage analysis for Sappi Saiccor

	Total water consumption in Ml d $^{-1}$			
Process	**Lower**	**Upper**	**Norm**	**Actual**
950 t d^{-1} calcium based bleached sulphite pulp	66,5	123,5	71,3	
700 t d^{-1} magnesium based bleached pulp	28,0	70,0	31,5	
Totals	**94,5**	**193,5**	**102,8**	**112,0**

5.1.9 Mill: Sappi Fine Papers, Stanger Mill

Parent: Sappi
Opened: 1976
Region: KwaZulu-Natal
Water Region: Umvoti to Umzimkulu [Department of Water Affairs and Forestry, 1999]
Product Range: Coated Woodfree Papers and Tissue

Table 5.17 Machines at Sappi Stanger

Machines	PM 1	PM 2
Type	Fourdrinier Beloit Walmsley	Yankee Escher Wyss
Product	Fine Papers	Tissue
Width	3,28 m	3,4 m
Capacity	75 000 tpa	29 000 tpa
Installed	1976	1977

[Pamsa, 1986]

Basic Raw Material:
FBSW is sourced from Sappi Ngodwana mill. FB bagasse pulp is produced by the mill from sugar mill waste from the adjacent Gledhow sugar mill.

General Description:
The pulpmill consists of a soda pulping operation of bagasse; recovery is not carried out in the normal sense but black liquor is oxidised to sodium carbonate using a Copeland reactor. The sodium carbonate is sold.

The paper mill consists of one fourdrinier with top wire paper machine for manufacture of coating base stock, one Yankee tissue machine and an off machine coater.

Water Usage:
Water is drawn from the nearby Mvoti river, which has its source in the Greytown district of KwaZulu-Natal. Water Usage: 21,0 Ml d $^{-1}$

Estimated Overall Water Consumption (using Table 4.1):
210 t d $^{-1}$ fine paper requires 7 kl t $^{-1}$ to 20 kl t $^{-1}$ with a probable norm of 12kl t $^{-1}$ of water; 80 t d $^{-1}$ tissue requires 5 kl t $^{-1}$ to 100 kl t $^{-1}$ with a probable norm of 20 kl t $^{-1}$ of water; 160 t d $^{-1}$ bleached bagasse pulp requires 21 kl t $^{-1}$ to 50 kl t $^{-1}$ with a probable norm of 32 kl t $^{-1}$ of water.

Table 5.18 Summary of water usage analysis for Sappi Stanger

	Total water consumption in Ml d $^{-1}$			
Process	**Lower**	**Upper**	**Norm**	**Actual**
210 t d $^{-1}$ fine paper	1,5	4,2	2,5	
80 t d $^{-1}$ tissue	0,4	8,0	1,6	
165 t d $^{-1}$ bleached bagasse pulp	3,4	8,3	5,3	
Totals	**5,3**	**20,5**	**9,4**	**21,0**

5.1.10 Mill: Sappi Cape Kraft

Parent:	Sappi Forest Products
Opened:	1981
Region:	Western Cape
Water Region:	Berg [Department of Water Affairs and Forestry, 1999]
Product Range:	Testliner (some corrugating medium)

Table 5.19 Machine at Sappi Cape Kraft

Machines	PM 1
Type	Suction Fourdrinier Vat (Voith Dorries)
Product	Testliner
Width	2,45 m
Capacity	57 200 tpa
Installed	1981
Upgraded	

[Pamsa, 1986] [pers. comm. Horne, 2004]

Basic Raw Material:
Recycled Kraft Waste (various)

General Description:
Sappi Cape Kraft is a Kraft recycled fibre operation based in the Western Cape producing testliner for the packaging market which services the export fruit and wine industry.

Raw material waste Kraft fibres are resourced in the area by Sappi Waste and other recycling agencies. The waste is stored in a large area to the north of the mill site.

The recycled fibre is pulp and cleaned before processing on a suction fourdrinier type paper machine. Linerboard in the 180 to 250 gsm range is produced.

Water Usage:
Fresh Water (Potable): 0,72 Ml d^{-1}, Industrial Water: 0,72 Ml d^{-1}; Water Usage: 1,44 Ml d^{-1} [pers. comm. Horne, 2004]

Estimated Overall Water Consumption (using Table 4.1):
163 t d^{-1} RCF based linerboard requires 1,5 kl t^{-1} to 10 kl t^{-1} with a probable norm of 5 kl t^{-1} of water.

Table 5.20 Summary of water usage analysis for Sappi Cape Kraft

	Total water consumption in Ml d^{-1}			
Process	**Lower**	**Upper**	**Norm**	**Actual**
163 t d^{-1} RCF based linerboard	0,25	1,63	0,82	1,44

5.1.11 Mill: Sappi Forest Products, Tugela Mill

Parent: Sappi Forest Products
Opened: 1954
Region: KwaZulu-Natal
Water Region: Thukela [Department of Water Affairs and Forestry, 1999]
Product Range: Packaging papers

Table 5.21 Machines at Sappi Tugela

Machines	PM 1	PM 2	PM 3	PM 4
Type	Fourdrinier Walmsley	Fourdrinier Beloit Walmsley	Fourdrinier Er-We-Pa	Fourdrinier Beloit Walmsley
Product	Liner/Corrugating Medium	Linerboard	Special Kraft	Extensible Kraft
Width	4,1 m	4,8 m	2,5 m	4,8 m
Capacity	98 000 tpa	204 000 tpa	11 000 tpa	98 000 tpa
Installed	1954	1954	1954	1966

[Pamsa, 1986] [pers. comm. Ramkooar, 2004]

Basic Raw Material:
The mill uses hardwood and softwood timber sourced from the KwaZulu-Natal region for primary fibre and recycled Kraft waste for secondary fibre.

General Description:
The pulpmill consists of a 210 000 tpa SW Kraft pulping process and a 105 000 tpa NSSC HW pulping process; recovery is carried out in a conventional recovery boiler for the Kraft process and in a Copeland reactor for the NSSC process (the recovered sodium carbonate/sulphate is used as salt cake makeup for the Kraft process or sold in the market place). The paper mill consists of four fourdrinier paper machines for manufacture of different packaging grades of paper/board.

Water Usage:
Water is drawn from the nearby Tugela river, which has its source in the Drakensberg mountain range. Water Usage: 52 Ml d $^{-1}$ [Sofijanic et al, 2001; pers. comm. Ramkooar, 2004]

Estimated Overall Water Consumption (using Table 4.1):
1170 t d $^{-1}$ packaging paper requires 3 kl t $^{-1}$ to 20 kl t $^{-1}$ with a probable norm of 10 kl t $^{-1}$ of water; 600 t d $^{-1}$ unbleached kraft pulp requires 9 kl t $^{-1}$ to 20 kl t $^{-1}$ with a norm of 12 kl t $^{-1}$ of water; 300 t d ^{1} NSSC pulp requires 1 kl t $^{-1}$ to 34 kl t $^{-1}$ with a norm of 5,7 kl t $^{-1}$ of water.

Table 5.22 Summary of water usage analysis for Sappi Tugela

Process	Total water consumption in Ml d $^{-1}$			
	Lower	Upper	Norm	Actual
1170 t d $^{-1}$ packaging paper	3,5	23,4	11,9	
600 t d $^{-1}$ unbleached kraft pulp	5,4	12	7,2	
300 t d $^{-1}$ NSSC pulp	0,3	10,2	1,7	
Totals	**9,2**	**45,6**	**20,6**	**52,0**

5.1.12 Mill: Sappi Fine Papers, Adamas Mill

Parent: Sappi
Opened: 1952
Region: Eastern Cape
Water Region: Fish to Tsitsikamma [Department of Water Affairs and Forestry, 1999]
Product Range: Coated woodfree papers and tissue

Table 5.23 Machines at Sappi Adamas

Machines	PM 3	PM 4
Type	Fourdrinier Carcano	
Product	Kraft RCF Products	Fine Paper
Width	2,57 m	2,88 m
Capacity	12 500 tpa	25 000 tpa

[Pamsa, 1986] [pers. comm. Langford, 2004]

Basic Raw Material:
Fully bleached SW and HW kraft pulps are used to supplement waste fibre recovery plant

General Description:
The paper mill consists of two fourdrinier paper machines for manufacture of fine paper and kraft products

Water Usage:
Water received from Port Elizabeth municipal system. Water Usage: 1,7 Ml d^{-1} [pers. comm. Langford, 2004]

Estimated Overall Water Consumption (using Table 4.1):
36 t d^{-1} recycled packaging paper requires 1,5 kl t^{-1} to 10 kl t^{-1} with a probable norm of 5 kl t^{-1} of water; 72 t d^{-1} recycled fine paper requires 7 kl t^{-1} to 20 kl t^{-1} with a probable norm of 12 kl t^{-1} of water.

Table 5.24 Summary of water usage analysis for Sappi Adamas

	Total water consumption in Ml day^{-1}			
Process	**Lower**	**Upper**	**Norm**	**Actual**
36 t d^{-1} recycled packaging paper	0,05	0,36	0,18	
72 t d^{-1} recycled fine paper	0,5	1,44	0,87	
Totals	**0,55**	**1,8**	**1,05**	**1,70**

5.1.13 Mill: Nampak Tissue, Klipriver Mill

Parent: Nampak Tissue
Opened: 1920 as a light board mill
Region: Gauteng
Water Region: Upper Vaal [Department of Water Affairs and Forestry, 1999]
Product Range: Tissue

Table 5.25 Machines at Nampak Klipriver

Machines	TM1
Type	Escher Wyss
Product	Tissue
Width	2,5 m
Capacity	24 000 tpa
Installed	1990

[pers. comm. Steyn, 2004]

Basic Raw Material:
This mill uses better quality waste fibre, mainly office waste, which is prepared for papermaking by processing in a deinking plant.

General Description:
Apart from the fibre preparation, the mill consists of a tissue machine. The site was used for the first paper machine installed in South Africa.

Water Usage:
Water is received from the Klipriver and boreholes on the site. Water Usage: 1,7 Ml d^{-1}
[pers. comm. Steyn, 2004]

Estimated Overall Water Consumption (using Table 4.1):
69 t d^{-1} tissue from recycled fibre requires 5 kl t^{-1} to 100 kl t^{-1} with a probable norm of 20 kl t^{-1}

Table 5.26 Summary of water usage analysis at Nampak Klipriver

	Total water consumption in Ml d^{-1}			
Process	Lower	Upper	Norm	Actual
69 t d^{-1} tissue from recycled fibre	0,35	6,90	1,38	1,70

5.1.14 Mill: Nampak Rosslyn Mill

Parent:	Nampak Packaging
Opened:	1970
Region:	Gauteng
Water Region:	Crocodile West and Marico [Department of Water Affairs and Forestry, 1999]
Product Range:	Testliner and corrugating medium

Table 5.27 Machines at Nampak Rosslyn

Machines	PM 1
Type	Fourdrinier Triple Wire
Product	Test Liner and Corrugating Medium
Width	2,5 m
Capacity	40 000 tpa
Installed	1970

[Pamsa, 1986] [pers. comm. Laing, 2000]

Basic Raw Material:
Recycled Kraft Waste (various)

General Description:
Fibre preparation includes a disperger which reduces stickies problems on the machine. The machine is a triple headbox fourdrinier machine.

Water Usage:
Water is received from local Water Authority. Water Usage: 1,0 Ml d^{-1} [pers. comm. Laing, 2000]

Estimated Overall Water Consumption (using Table 4.1):
115 t d^{-1}packaging from recycled fibre requires 1,5 kl t^{-1} to 10 kl t^{-1} with a norm of 5 kl t^{-1}

Table 5.28 Summary of water usage analysis for Nampak Rosslyn

Process	Total water consumption in Ml d^{-1}			
	Lower	Upper	Norm	Actual
115 t d^{-1}packaging from recycled fibre	0,06	1,14	0,60	1,00

5.1.15 Mill: Nampak Tissue, Bellville Mill

Parent: Nampak Tissue
Opened: 1958
Region: Western Cape
Water Region: Berg [Department of Water Affairs and Forestry, 1999]
Product Range: Tissue

Table 5.29 Machines at Nampak Bellville

Machines	TM3	TM4
Type	Voith	Escher Wyss
Product	Tissue	Tissue
Width	2,1 m	2,5 m
Capacity	8 000 tpa	24 000 tpa
Installed	1973	1985

[Pamsa, 1986] [pers. comm. Steyn , 2004]

Basic Raw Material:
This mill uses better quality waste fibre, mainly office waste, which is prepared for papermaking by processing in a deinking plant.

General Description:
Two machines are operated using deinked pulp. Two other machines are mothballed.

Water Usage: Municipal. Water Usage: 2,2 Ml d^{-1} [pers. comm. Steyn, 2004]

Estimated Overall Water Consumption (using Table 4.1):
91 t d^{-1} tissue from recycled fibre requires 5 kl t^{-1} to 100 kl t^{-1} with a probable norm of 20 kl t^{-1}

Table 5.30 Summary of water usage analysis for Nampak Bellville

	Total water consumption in Ml d^{-1}			
Process	Lower	Upper	Norm	Actual
91 t d^{-1} tissue from recycled fibre	0,46	9,10	1,82	2,20

5.1.16 Mill: Nampak Tissue, Riverview Mill

Parent:	Nampak Tissue
Opened:	1997
Region:	KwaZulu-Natal
Water Region:	Umvoti to Umzimkulu [Department of Water Affairs and Forestry, 1999]
Product Range:	Tissue

Table 5.31 Machines at Nampak Riverview

Machines	TM1
Type	Yankee
Product	Tissue
Width	2,5 m
Capacity	10 000 tpa
Installed	1997

[pers. comm. Steyn , 2004]

Basic Raw Material:
This mill uses better quality waste fibre, mainly office waste or market pulp.

General Description:
One single machine with deinking facilities.

Water Usage: Municipal. Water Usage: 0,7 Ml d $^{-1}$ [pers. comm. Steyn, 2004]

Estimated Overall Water Consumption (using Table 4.1):
28 t d $^{-1}$ tissue from recycled fibre requires 5 kl t $^{-1}$ to 100 kl t $^{-1}$ with a probable norm of 20 kl t $^{-1}$

Table 5.32 Summary of water usage analysis for Nampak Riverview

	Total water consumption in Ml d $^{-1}$			
Process	Lower	Upper	Norm	Actual
28 t d $^{-1}$ tissue from recycled fibre	0,14	2,8	0,56	0,7

5.1.17 Mill: Kimberly Clark, Enstra Mill

Parent: Kimberly Clark
Opened: 1967, previously a converting operation
Region: Gauteng
Water Region: Upper Vaal [Department of Water Affairs and Forestry, 1999]
Product Range: Tissue (various) and wadding

Table 5.33 Machines at Kimberly Clark Enstra

Machines	PM1	PM2
Type	Yankee Twin Felt (Beloit)	Yankee (Escher Wyss)
Product	Tissue	Tissue
Width	3,5 m	3,5 m
Capacity	20 000 tpa	28 000 tpa
Installed	1967	1976

[Pamsa Brochure, 1986] [pers. comm. Heimann, 2001]

Basic Raw Material:
Recycled Fibre (Mixed Waste)

General Description:
The mill is a completely integrated operation converting low grade paper waste into tissue and wadding products. The converting operation resides within the mill site.

The waste paper is pulped, cleaned, deinked and bleached prior to use on the paper machines.

Water Usage:
Water is received from East Rand Water Authority. Water Usage: 2,7 Ml d^{-1} [pers. comm. Heimann, 2001]

Estimated Overall Water Consumption (using Table 4.1):
140 t d^{-1} tissue from recycled fibre requires 5 kl t^{-1} to 100 kl t^{-1} with a probable norm of 20 kl t^{-1}.

Table 5.34 Summary of water usage analysis for Kimberly Clark Enstra

	Total water consumption in Ml d^{-1}			
Process	**Lower**	**Upper**	**Norm**	**Actual**
140 t d^{-1} tissue from recycled fibre	0,7	14,0	2,8	2,7

5.2 Summary of mill estimated and actual water usage

A summary of the lower, upper and norm of estimated water usage and the actual consumption for each of the mills which were assessed is shown in the table below. The table is set in order of company.

Table 5.35 Summary of All Mill Water Usage Analyses

Mill	Total water consumption in Ml day $^{-1}$			
	Lower	Upper	Norm	Actual
Mondi Richards Bay	41,1	76,8	54,0	55,0
Mondi Merebank	11,4	44,3	25,5	34,5
Mondi Piet Retief	1,2	14,6	4,7	2,5
Mondi Felixton	2,0	6,0	3,0	5,9
Mondi Springs	2,3	5,5	2,8	4,0
Sappi Ngodwana	19,6	50,4	31,6	35,0
Sappi Enstra	10,6	27,1	16,9	25,5
Sappi Saiccor	94,5	193,5	103,0	112,0
Sappi Stanger	5,3	20,5	9,4	21,0
Sappi Cape Kraft	0,25	1,63	0,82	1,44
Sappi Tugela	9,2	45,6	20,6	52,0
Sappi Adamas	0,55	1,8	1,05	1,7
Nampak Klipriver	0,35	6,9	1,38	1,7
Nampak Rosslyn	0,06	1,14	0,6	1,0
Nampak Bellville	0,46	9,1	1,82	2,2
Nampak Riverview	0,14	2,8	0,56	0,7
Kimberly Clark Enstra	0,7	14,0	2,8	2,7

Chapter 6 Discussion

For the discussion of water usage at the mills, the mills will be split into two groups initially, larger users and smaller users. Clearly the larger users have the greater impact and have the greater potential to change. Smaller users, on the other hand, are able to operate in areas which are water stressed.

6.1 Discussion on water usage of larger mills

For the purpose of this investigation, large users of water will be defined as those using more than 10 Ml d^{-1}. This is an arbitrary choice but actually suits the data perfectly. Mills will be evaluated in usage order, highest to lowest.

Mills which fit into this description are: Sappi Saiccor, (112 Ml d^{-1}), Mondi Richards Bay, (55 Ml d^{-1}), Sappi Tugela, (52 Ml d^{-1}), Sappi Ngodwana, (35 Ml d^{-1}), Mondi Merebank, (34,5 Ml $^{-1}$), Sappi Enstra, (25,5 Ml d^{-1}) and Sappi Stanger, (21 Ml d^{-1}).

The total water used by these mills constitutes 93,5% of the water used by all the mills evaluated in the study and probably more than 90% of all water used by the paper industry in South Africa.

Table 6.1 Specific water usages for larger water using mills

Mill	Production t d^{-1}	Water usage Ml d^{-1}	Specific water usage kl t^{-1}
Sappi Saiccor	1600	112	70,0
Mondi Richards Bay	2300	55	23,9
Sappi Tugela	1170	52	44,4
Sappi Ngodwana	1851	35	18,9
Mondi Merebank	1755	34,5	19,6
Sappi Enstra	590	25,5	43,2
Sappi Stanger	290	21	72,4

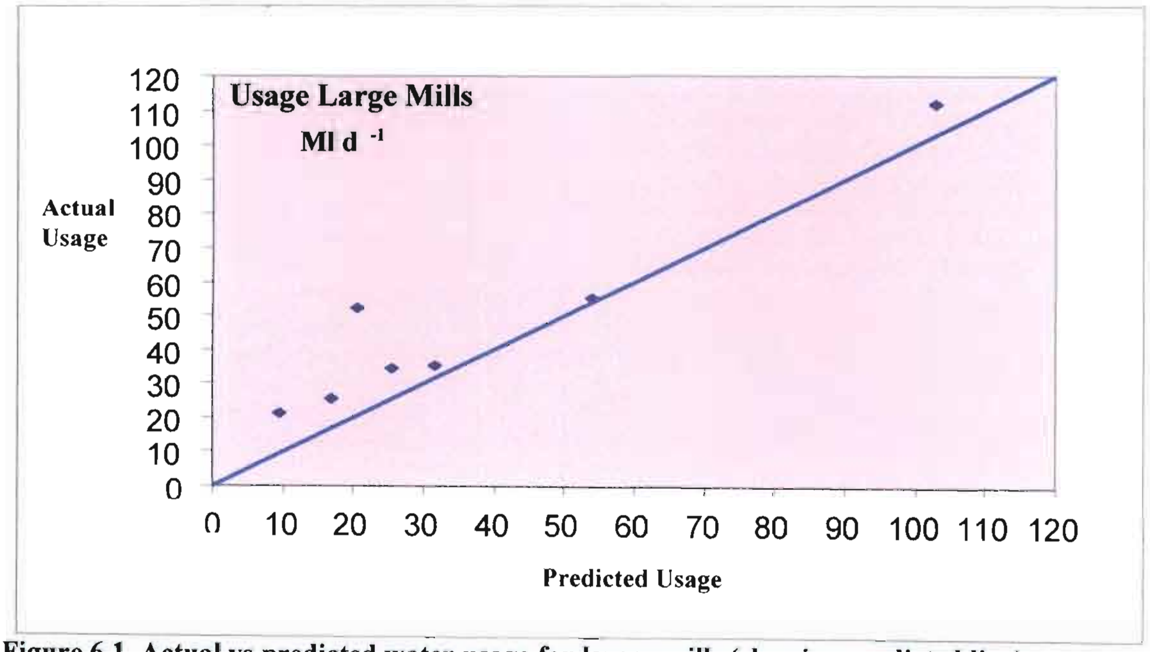


Figure 6.1 Actual vs predicted water usage for larger mills (showing predicted line)

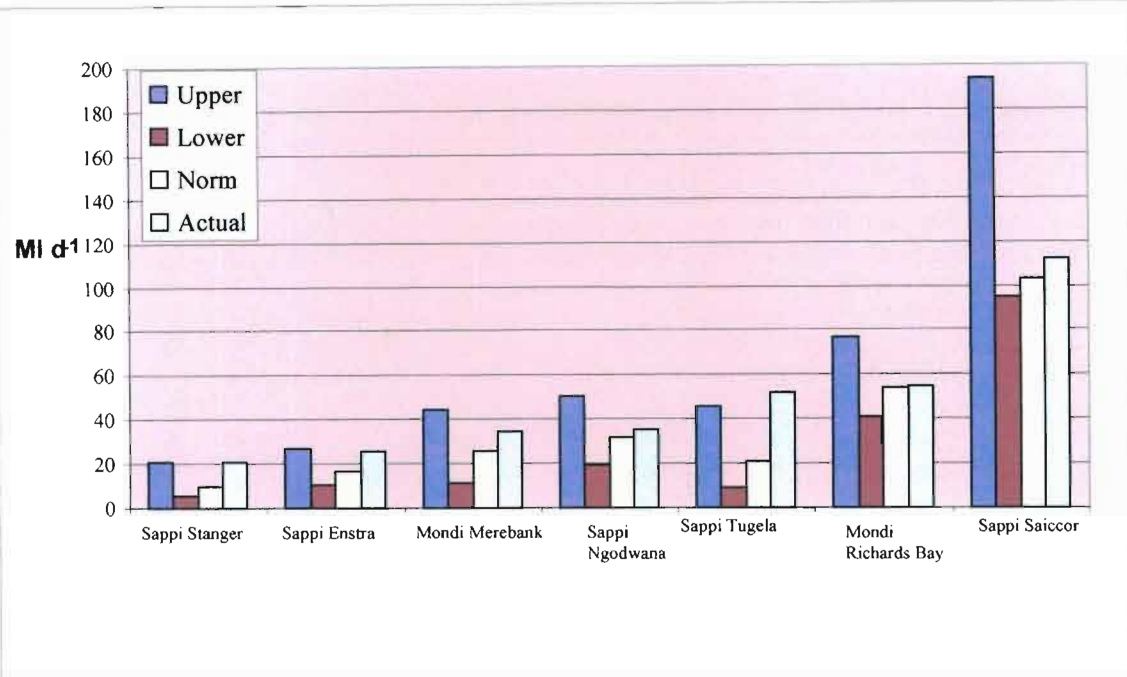


Figure 6.2 Larger water users showing upper, lower, normal and actual usage

Each discussion will consider whether there are opportunities to reduce water usage and any other factors which may affect water usage at the mill.

6.1.1 Discussion - Sappi Saiccor

Using almost 30% of the water used by the South African paper industry, Sappi Saiccor must warrant high rating for water reduction. However, this is a prime example of one of the reasons why the industry moved away from acid sulphite pulping. From Saiccor's point of view, reduction in water consumption would require a major process change. The investment to change would probably be in the order of tens of billion rands, which clearly removes this option.

The best opportunity for Saiccor would be to approach the lower consumption figure of 95 Ml d^{-1} through a water reduction program.

6.1.2 Discussion - Mondi Richards Bay

It is clear that water usage is well managed at Mondi Richards Bay. There is a small opportunity to reduce but this may require some capital investment.

6.1.3 Discussion - Sappi Tugela

Sappi Tugela is the only mill of the selected mills which uses in excess of the upper calculated value. For a packaging grade mill, there is a lot of opportunity to reduce the usage to below 20,6 kl d^{-1}. This reduction represents 60% less than the current usage. The mill is 60 years old and clearly the technology in use needs a review.

The limitations of effluent concentrations as opposed to effluent loadings may be a factor, but this is short sighted.

6.1.4 Discussion - Sappi Ngodwana

Sappi Ngodwana was built to use less water. The mill could reduce its water draw by a further 20 to 40%.

6.1.5 Discussion - Mondi Merebank

Almost all the water used at Mondi Merebank (about 90%) is recycled sewerage. In reality, the fresh water specific usage is 2 kl t^{-1}. There are some opportunities for water reduction but the benefit should be evaluated against the cost. It is not necessary to reduce recycled water usage.

6.1.6 Discussion - Sappi Enstra

The specific water usage of Sappi Enstra is slightly higher than would be expected but, like Mondi Merebank, Enstra uses recycled sewerage. The recycled water is approximately half of the water input. The specific fresh water usage is therefore only 22 kl t^{-1}. Despite this there appears to be a good opportunity to reduce water consumption.

6.1.7 Discussion - Sappi Stanger

Sappi Stanger uses about double the amount of water than the calculated value. The model used has not been applied to bagasse processing as there are no literature values for bagasse. It will be seen later that the other bagasse processor, Mondi Felixton, also over uses. An estimation for the excess usage associated with bagasse processing will be covered later. However, Sappi Stanger needs to address water usage to reduce by about 40% or 8 Ml d^{-1}.

6.2 Discussion on water usage of smaller mills

Table 6.2 Specific water usages for smaller water using mills

Mill	Production t d^{-1}	Water usage Ml d^{-1}	Specific water usage Kl t^{-1}
Mondi Felixton	300	5,9	19,6
Mondi Springs	400	4,0	10,0
Kimberly Clark Enstra	140	2,7	19,2
Mondi Piet Retief	340	2,5	7,3
Nampak Bellville	91	2,2	24,1
Nampak Klipriver	69	1,7	24,6
Sappi Adamas	108	1,7	15,7
Sappi Cape Kraft	163	1,4	8,6
Nampak Rosslyn	115	1.0	8,7
Nampak Riverview	28	0,7	25,0

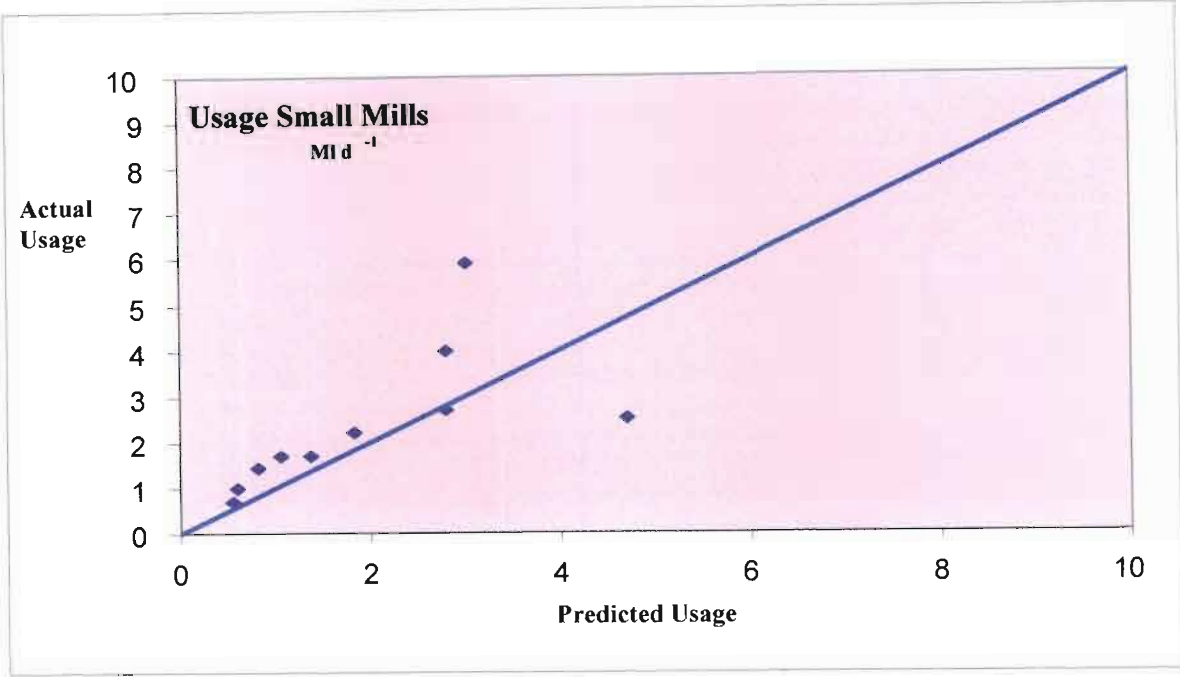


Figure 6.3 Actual vs predicted water usage for smaller mills (showing predicted line)

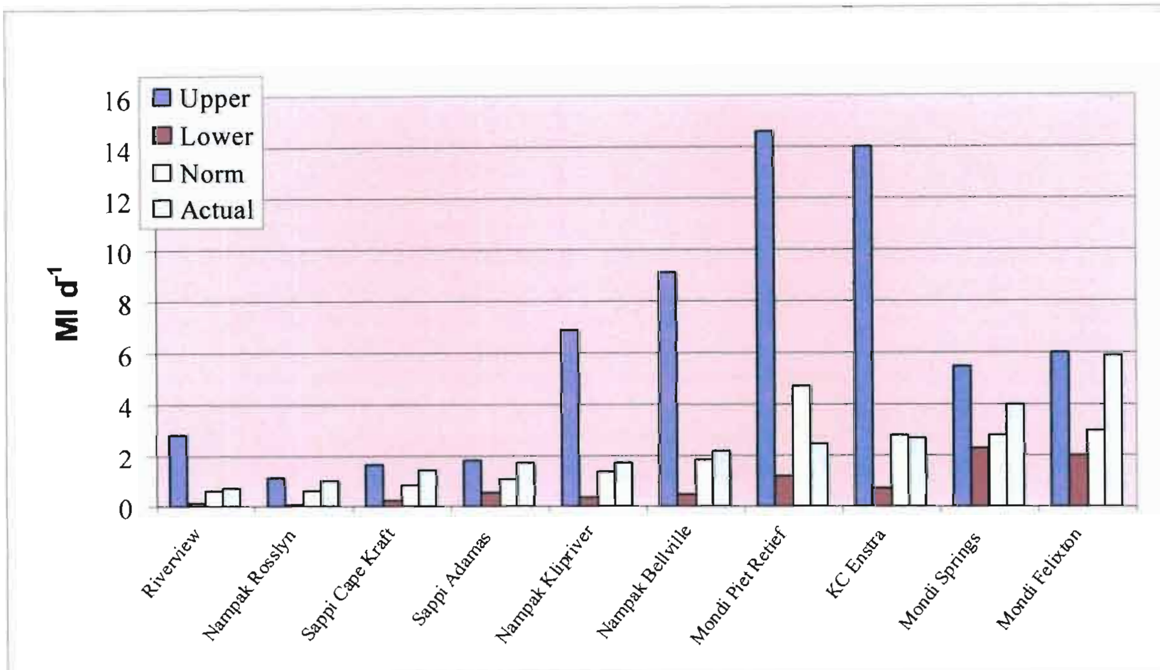


Figure 6.4 Smaller water users showing upper, lower, normal and actual usage

Smaller users are those which use less than 10 Ml day^{-1}, but the highest of these users is about 6 Ml day^{-1}. This group will include all the other mills in South Africa and not just those evaluated in this study. Again, mills will be evaluated in usage order, highest to lowest.

6.2.1 Discussion - Mondi Felixton

Mondi Felixton uses about double the amount of water than the estimated norm value. As with Sappi Stanger, the effect of bagasse processing is expected to be the main cause and will be analysed later (see Chapter 6.4.3).

6.2.2 Discussion – Mondi Springs

Although the water usage is moderate, there is some opportunity to reduce water usage by about half.

6.2.3 Discussion – Kimberly Clark Enstra

The usage at Kimberly Clark Enstra is very close to standard usage and reductions would require some additional effort which is probably not warranted for a mill which is well established for nearly forty years. This is the best usage for a tissue mill in South Africa.

6.2.4 Discussion – Mondi Piet Retief

Mondi Piet Retief is the mill which has gone furthest in reducing water consumption in South Africa and holds the lowest specific consumption at 7,3 kl t^{-1}. There is probably not a lot more the mill can do without intensive capital investment.

6.2.5 Discussion - Nampak Tissue Mills, Bellville, Klipriver and Riverview

Each of these mills has a specific consumption of around 25 kl t^{-1}. This figure is probably 5+ kl t^{-1} too much.

6.2.6 Discussion - Sappi Adamas

For one of the oldest mills in South Africa, the attention to water usage reduction is remarkable. The mill recycles water through a dissolved air flotation unit to remove fines and other trash before recycling the water back to the paper machines.

6.2.7 Discussion - Sappi Cape Kraft

This mill was designed to work on zero effluent which would represent about 4 kl t^{-1} usage rate. Clearly the mill is not operating in the design mode and could make some effort to reduce consumption.

6.2.8 Discussion – Nampak Rosslyn

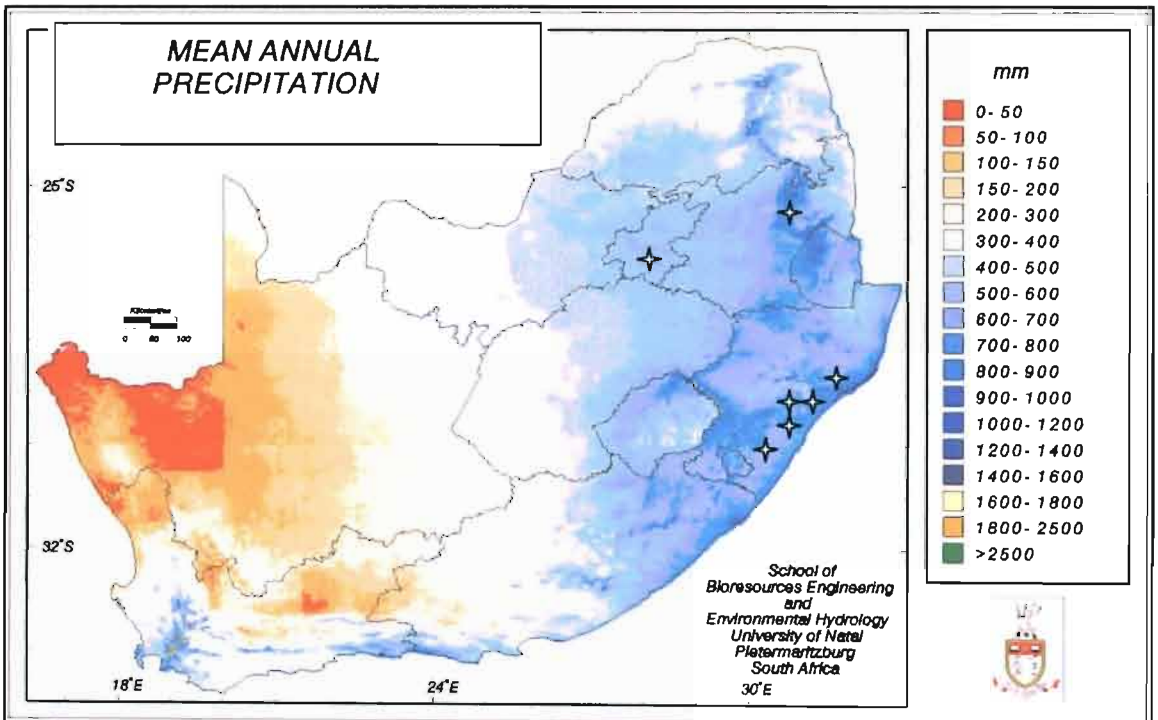
Nampak Rosslyn mill uses very little water and has carried out a number of water reduction projects and has the ability to operate off boreholes in times of water shortage.

6.3 Location of mills with respect to water usage

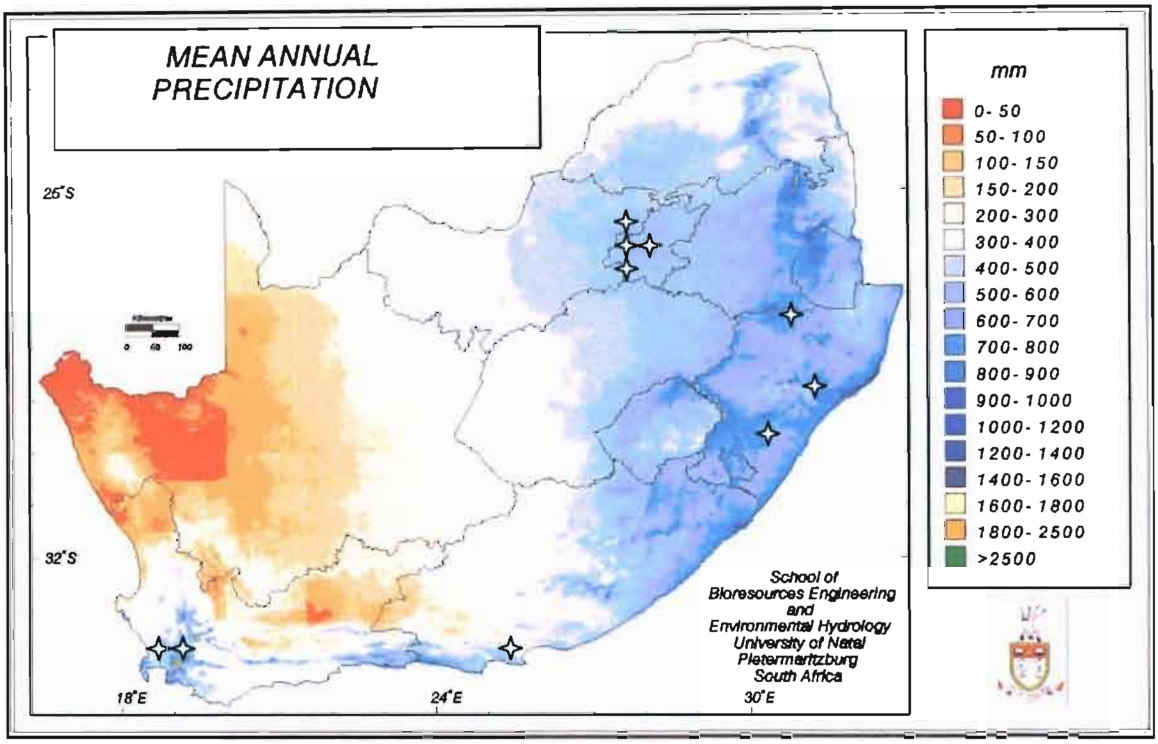
Clearly water usage has a major impact on location of larger pulp and paper mills. This requirement for water and the related requirement to dispose of effluent means that each mill must be located near a substantial supply of water for mill use and have a *water sink* to absorb its effluent.

The five large coastal mills all have different water supplies and effluent disposal methods.

Mondi Richards Bay draws water from the Umhlatuze Water Board and disposes its effluent to sea via pipeline. Sappi Tugela draws from the Tugela and disposes to the Tugela. Sappi Stanger draws from the Umvoti and disposes back to the Umvoti. Mondi Merebank previously drew metropolitan water from Umgeni Water Board but has converted 90% of its demand to recycled sewerage from Durban's Southern Sewerage Works. The mill effluent is passed to the outfall of the same sewerage works. Sappi Saiccor draws from the Umkomaas river and disposes to sea. Sappi Ngodwana draws from Ngodwana dam and irrigates effluent. Sappi Enstra draws half of its water requirement from Rand Water Board and the balance from recycled sewerage; the effluent is disposed to the Blesbokspruit.



[UKZN, School of Bioresources Engineering and Environmental Hydrology, web address]
Figure 6.5 Mean annual precipitation with large water using mills inserted (✧)



[UKZN, School of Bioresources Engineering and Environmental Hydrology, web address]
Figure 6.6 Mean annual precipitation with small water using mills inserted (✧)

Smaller mills tend to be based on recycled fibre and hence are located near the industrial centres of Gauteng, Cape Town, Port Elizabeth and Durban. The water requirements for these mills tend to be metropolitan water and effluent will be disposed to municipal sewerage. The cost of the water supply and effluent disposal tend to cause the mills to focus on water consumption. This certainly applies to Nampak Bellville, Klipriver, Riverview and Rosslyn, Kimberly Clark Enstra, Mondi Springs, Sappi Adamas and Sappi Cape Kraft. The anomalies are the two Mondi mills, Piet Retief and Felixton. Both use some recycled fibre but are essentially chemical pulp packaging mills. Mondi Felixton disposes effluent through the same line as Mondi Richards Bay. Mondi Piet Retief disposes effluent by irrigation but is under pressure to eliminate this method of disposal.

6.4 Discussion on groups of mills

Groups which merit special discussion are the bleached pulp mills and the recycled fibre mills.

6.4.1 Bleaching mills

Bleach effluent is the biggest problem facing the paper industry. If the bleach plant discharge contains significant chlorides (ie if chlorine, chlorine dioxide or hypochlorite bleaching agents are used), it is not feasible to use the stream internally and it must be disposed as effluent. Because the organic content is essentially lignin monomer – phenyl propane based, it is not easily digested in effluent treatment processes. Totally chlorine free (TCF) bleach effluent can be used as *wash water* for the pulping process and then treated by the recovery process. The two disadvantages of this treatment are that the liquor being partially oxidised in the bleaching process is more difficult to combust and the recovery furnace will require extra capacity. There being no TCF chemical pulp mills in South Africa, all bleach plant effluent is sewered. This means that water usage will be increased by 20 to 35 kl t^{-1}.

It is significant that the five bleaching mills feature in the top seven users in South Africa. Mondi Richards Bay and Sappi Saiccor effluent is discharged to sea without treatment. Sappi Stanger discharges to the Umvoti river after primary and secondary effluent treatment. Sappi Enstra discharges to the Blesbokspruit after primary and secondary treatment. Sappi Ngodwana irrigates mill effluent on farmlands.

6.4.2 Total recycled fibre mills

This group of mills (Nampak Rosslyn, Bellville, Klipriver and Riverview, Mondi Springs, Kimberly Clark Enstra, Sappi Cape Kraft and Adamas) use only 15,5 Ml d^{-1}. This usage is less than any of the larger usage mills.

6.4.3 Bagasse Mills

The discussion in paragraphs 6.1.7 and 6.2.1 indicates that the bagasse mills each use about double the norm of water. This arises as no consideration was given to bagasse fibre pre-pulp processing in terms of water usage. The treatment of bagasse requires water for depithing. Depithing is necessary prior to pulping to reduce the process cost. Part of this water remains in the bagasse fed to the digester, approximately 6 kl t^{-1} of pulp, and is transferred to the black liquor and can be recovered from evaporator condensate. Another 6 kl t^{-1} of pulp may be required to dispose of the pith to effluent.

6.5 Potential for reduction

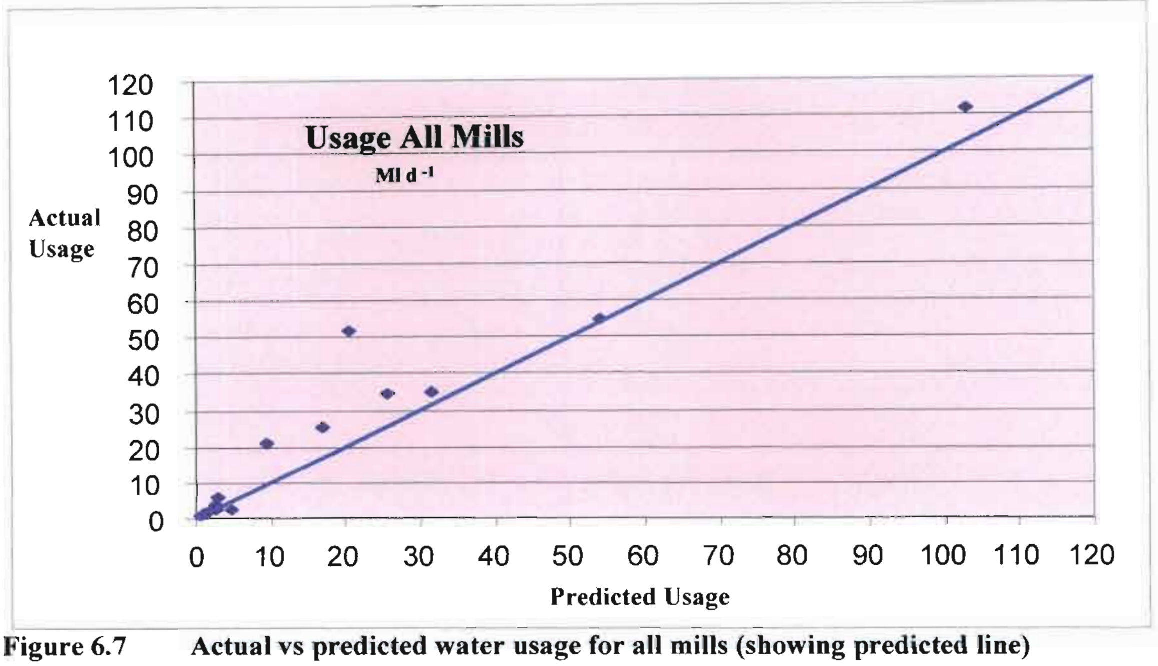


Figure 6.7 Actual vs predicted water usage for all mills (showing predicted line)

Looking at Figure 6.7, it is clear that the larger mills, except for Mondi Richards Bay, are all well above the predicted line whilst the smaller mills are located near the line with Mondi Piet Retief standing out as the only mill well below the line. Industry specific consumption is 31,6 kl t^{-1}.

As a starting point, if all the mills were on the predicted line the water reduction would be at least 20% or nearly 80 Ml d^{-1}. This could be achieved by all the large users reducing to the predicted line. The industry usage would be 280 Ml d^{-1}. This represents an all mill specific consumption of

24,7 kl t^{-1} A further 10% reduction would bring the usage to 250 Ml d^{-1}. This is an all-mill specific consumption of 22 kl t^{-1}.

The specific consumption of 31,7 kl t^{-1} could be reduced simply to 25 kl t^{-1} and with a little more investment to 22 kl t^{-1}. These fall between the approximately 50 kl t^{-1} of Canada and the 11,3 kl t^{-1} of Central Europe [Zippel, 2001].

6.6 Total usage by the industry

The usage rate of 358 Ml d^{-1} may be difficult to comprehend. To put it in perspective, if the industry used only Midmar Dam (235 Gl) [pers. comm. Lusignea, 2004] and if inflow balanced evaporation on the dam, then it would take the industry 660 days or 1,8 years to empty the dam. Whilst this is not practical, it does give a perspective to the amount of water consumed. Usage at the norm level of 280 Ml d^{-1} would take 840 days or 2,3 years to empty Midmar dam.

6.7 Impact of growth in the industry

As discussed in the earlier part of this dissertation, South Africa is a water-scarce country. The only area with excess water is the eastern region of KwaZulu-Natal. Increase in bleached chemical pulping capacity would have to take place in this region with definite consideration given to water saving and effluent reduction practices.

Chapter 7 Conclusion and Recommendations

In this chapter, the results, opportunities and way forward are discussed.

7.1 The relationship between processes employed by the pulp and paper industry and water used within those processes.

The investigations in Chapter 3 show that by analysing the unit operations in each pulp and paper making process it is possible to determine how much water a process requires. This analysis also highlighted the best applied technology to reduce the requirement of water and the direct implications on water usage.

In this analysis the usage of other process waters is discussed. The following transfers of process water streams were highlighted:

The use of evaporator condensates from the recovery process where contaminated condensates are used for wood washing, clean condensate is used for washing pulps in the pulp mill and cleaned blow condensates can be used for various purposes.

Closed screening circuits in pulp mills contribute significantly to water saving despite added salt cake loss.

Diversion of chloride-free filtrates from bleaching processes to pulp washing and back to the recovery process saves considerable water, at least 15 kl t^{-1}, despite some detrimental effect on the recovery furnace because of the additional organic and inorganic load which is also imbalanced as the additional organic fraction is partially oxidised.

Recycling of bleach filtrates in counter processes has been the most significant reduction in water usage in bleached pulp mills. The reduction from an open 5 stage bleach process by recycling filtrates is about 80% from 75 kl t^{-1} to 15 kl t^{-1}.

In papermaking the extensive use of machine backwater in pulping, stock preparation and in transfer of pulps from the pulp mill have significantly contributed to water usage reduction.

Important practices for paper machine water reduction include processing heated water from the vacuum pumps and the steam condensers through cooling towers and hence recycling the waters. The use of clarified machine backwater for wire and felt cleaning is a much debated water reduction process. As there are numerous pumps in the wet end, the sealing of these pumps requires the application of advanced sealing techniques which do not require too much water.

The estimated water consumption was analysed in terms of a lower value which represents the best attainable, the upper value which represents the worst or oldest mill and a norm value which represents a mode value where the highest number of mills operate. Some of the norm values were not available in the literature and an interpolation was made from the position of the norm value between the upper and lower values in given norm values.

7.2 South African pulp and paper mills, their capacities, processes employed and water consumption.

Each mill selected was covered by machine and by product. The estimated overall daily upper, lower and norm water consumptions were derived and compared to the actual usage. Only one mill operates below the norm level. Most of the smaller mills operate close to the norm level. Five of the larger mills need to apply techniques discussed in this dissertation to reduce their water usage to at least the norm level. As shown in the discussion this will reduce industry usage by $80 Ml\ d^{-1}$.

On of the reasons given for excessive usage is the fixation by the Department of Water Affairs and Forestry that discharges should be managed by concentration as opposed to total load. It is recommended that the effect of this should be investigated.

The pulp and paper industry should make an attempt to operate below the norm line. An initial target could be set at 5% below followed with a program to target 10% and then more.

7.3 Discussion on the implications of the hypothesis

The approximation of mill water usage to the norm value clearly supports the hypothesis and shows that water usage can be predicted by analysing process and capacity. The only problem is the range between upper and lower level being so large. This large range allows all the mills in South Africa to be within range except for Sappi Tugela.

Mill management would do well to manage the water consumption between a lower level of half way between the norm and the lower limit and the norm.

7.4 The way forward

Having examined the water usage of South African pulp and paper mills, the following could also be investigated:

- volume of effluent discharged by South African pulp and paper mills
- quality of effluent discharged by South African pulp and paper mills
- opportunities for further internal recycling at South African pulp and paper mills

A study of future availability of water for pulp and paper mills would be of benefit for the operating companies.

Appendix 1 Conversion of consistency to mass fraction

Consistency of a pulp suspension is measured in grams of pulp per 100 ml of suspension by definition. The densities of wood pulp and water are very similar; wood pulp having a density slightly higher than water, at 1070 kg m^{-3}. Hence, it is common practice to assume they are the same at ~1000 kg m^{-3}.

To convert consistency to mass fraction, divide consistency by 100

ie if the consistency is given by c and the mass fraction is x, then

$x = c/100$

So a consistency of 3% will give a mass fraction of 0,03 kg kg^{-1}.

Appendix 2 Application of mass balance to water dilution of pulp

In a hypothetical mix, say streams 1 and 2 mix to form stream 3, then stream 1 has a volumetric flow rate of F_1 and stream 2 a volumetric flow rate of F_2, and stream 1 has a consistency of c_1 and stream 2 a consistency of c_2, then:

To convert the consistencies to mass fraction: $x_1 = c_1/100$, and $x_2 = c_2/100$
For a mass balance: $\Sigma F_i = 0$ and $\Sigma F_i x_i = 0$

For example:

Mixing 100 l s^{-1} at 4% consistency with 1000 l s^{-1} at 0,1% consistency; to calculate the resultant stream:

$F_1 + F_2 - F_3 = 0$ Eq 1
$100 + 1000 - F_3 = 0$, therefore $F_3 = 1100$
$F_1x_1 + F_2x_2 - F_3x_3 = 0$ Eq 2
$100*4/100 + 1000*.1/100 - F_3x_3 = 0$
$4+1 - F_3x_3 = 0$, therefore $F_3x_3 = 5$ and $x_3 = 5/1100 = 0,0045$

The consistency of stream 3 is 0,0045*100 =0,45%

Appendix 3 Calculation of dilution factor

Dilution factor is the specific volume of *wash water* which ends up in the filtrate (black liquor, normally)

Basically, it is the difference in the specific volume of *wash water* added and the part of the *wash water* which is carried with the pulp.

If the specific *wash water* applied is 13 kl t^{-1} pulp, and the consistency of the pulp leaving the washer is say 10%, then the amount of *wash water* in the pulp leaving the washer per ton of pulp is:

Mass fraction is 10/100 = 0,1 so the specific mass of the pulp stream is 10 t (1/0,1) and by implication the mass of *wash water* associated with the pulp is 9 t or kl.

Therefore the specific *wash water* which ended in the filtrate is (13 – 9) = 4 t or kl

This is the **dilution factor**.

Appendix 4 Calculation of displacement ratio

Displacement ratio is the ratio of the volume of wash water applied to the volume which remains in the pulp

ie using the figures for dilution factor

Displacement Ratio = 13/9 = 1,444

Appendix 5 Bleaching Sequences

The bleaching agents and their symbols

Chlorine	C
Caustic Extraction	E
Sodium or Calcium Hypochlorite	H
Chlorine Dioxide	D
Hydrogen Peroxide	P
Oxygen	O
Hydrosulphite	R
Ozone	Z
Peracetic Acid	Pa
Acid Treatment	A
Chelating Agent	Q
Pressurised peroxide	PO
Enzyme treatment	X

Combinations

Chlorine followed by Chlorine Dioxide	C/D
Chlorine Dioxide followed by Chlorine	D/C
Chlorine partially replaced by Chlorine Dioxide	C_D
Oxygen enriched Extraction	E_O
Peroxide enriched Extraction	E_P

Sequences

Conventional Sequences
C
C-E-H
C-E-H-D
C-E-H-D-E-D
C-E-D-E-D
C-E_O-D-E-D
C-E_P-D-E-D
D/C-E-D-E-D

Elemental Chlorine Free
D-E-D-E-D
X-D-E-D
O-D-E-D
O-Z-E-D
O-D-E-P
OO-D-E-D
OO-D-E-P

Totally Chlorine Free
O-Z-E-P
A-QX-O-E_{OP}-PO-PO

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