APPLICATION OF WATER PINCH TO AN INTEGRATED PULP AND PAPER KRAFT MILL WITH AN ALREADY HIGHLY CLOSED WATER SYSTEM

Eric Slabbert
BIng Chem (UP)

Submitted in the fulfilment of the academic requirements for the degree of

Master of Science in Engineering.

in the Department of Chemical Engineering,

University of KwaZulu Natal, Durban

Abstract

Sappi's Ngodwana integrated Kraft pulp and paper mill was used as case study for the application and evaluation of the water pinch technique. The technique of water pinch originates from energy pinch, but uses mass flow and contaminant concentration to identify water and effluent reduction opportunities. The classical meaning of pinch, as defined by energy pinch has however been changed to a more modern meaning. Historically the terms water or energy pinch was used to refer to the points where two composite curves touched on energy or water graphs. This graphical meaning of pinch is gradually being replaced to refer to the optimal point proposed by a numerical solver beyond which improvement of the water network is no longer possible for the given inputs. The water pinch technique was applied by means of a numerical solver that used mixed integer non-linear programming to optimise to the minimum cost for running the water network under investigation. The problem definition was defined in terms of costs associated with the use of utilities, raw material, treatment facilities and process units. It was also possible to define factors such as environmental impact, corrosion, fouling, scaling, cooling tower treatment cost, legal risk etc in terms of a penalty cost. The water pinch technique has been refined in software packages that are user friendly, capable of handling multi-contaminants and suitable for varying flows. The software package WaterPinch™ by Linnhoff March was used. The case study was applied on Ngodwana mill that has an already highly closed water system with effluent generation rates as low 20 kL per ton of pulp and paper. The pinch study included sodium, chloride, calcium, suspended solids and COD as contaminants. The study investigated different applications of the pinch technique. The following was concluded:

- The mill's understanding of its current restrictions, or pinch points, of its water network was confirmed. No new pinch points have been identified of which the mill was not aware. This indicates that the mill was already highly knowledgeable about its water system. This was expected of a mill that has a very low specific-effluent-generation rate. Water pinch was unable to significantly improve on the effluent generation rate of the mill.
- The pinch analysis has identified opportunities of mixing small quantities of waste streams into process water streams to replace fresh water. These changes can introduce minor water savings and new risks to the process that have to be understood better before implementation.
- The mill has progressed far with the design and costing of a proposed effluent treatment plant (ERP1). The integration of this treatment plant into the water network was investigated using the pinch technique. The pinch solver suggested a totally different approach to the integration of the ERP1 plant compared to design of the mill. The mill's design revolves around the treatment of low chloride streams in the ERP1 plant and using of the treated water as make-up to the cooling towers. Sodium was recovered as raw material from the cooling towers' blow-down. Pinch proposed treatment of the high chloride containing streams and returning the streams to users suitable of using high chloride water. The network proposed by mill's design generates 8.2 ML/day effluent less than the pinch proposal, and recovers sodium as raw material. The proposal presented by pinch is not recommended and points to the difficulty in simulating factors, such as raw material recovery, in a pinch analysis.
- Users for the excess storm water were identified using water pinch and will be suitable for implementation. The mill has however decided on alternative sinks for the storm water based on considerations such as process inter-dependency, risks associated with contamination and general management philosophy for the different systems in the mill. These considerations could have been included into the pinch solver, but were not because it was of interest what the second best option would be.
- The pinch investigation proved useful to confirm certain understandings of the mill. The investigation confirmed the difficulty of improving the water systems of the mill due to the fact that Ngodwana is already a highly closed and integrated mill. Numerous smaller process changes have

been identified by the pinch solver and could be investigated further for smaller process improvements.

- It is recommended that pinch technology be applied again when the mill plans to make major process changes or expansions. It is also recommended to use water pinch on a more frequent basis in smaller sections of the mill or for other evaluations in the mill. As a group Sappi could benefit from the use of water pinch, especially in situations where the water network of the mill is not already water efficient.
- The recommendations and conclusions in this report have not been subjected to technical and economical feasibility studies. Extensive further studies must be conducted before implementation of any of the results. Further studies must include impacts from process dynamics, long term effects, impacts from other contaminants that have not been simulated, etc.

Keywords: Water pinch, energy pinch, water network, composite curves, kraft pulp and paper mill

I, Eric Slabbert, declare that unless indicated, this dissertation is my own work and that it has not been submitted, in whole or part, for a degree at another University or Institution.

The opinions expressed in this dissertation are that of the author, and not necessarily that of Sappi.

………………………………………………..
Eric Slabbert

Abbreviations

ADt	: Air-dried ton i.e. pulp with 10 percent moisture.
BDt	: Bone-dry ton i.e. pulp with no moisture.
BOC	: Bought Out Chip
BOD	: Biological Oxygen Demand
BPT	: Best Practicable Control Technology
BSW	: Brown Stock Washer
Caust	: Causticising
CMA	: Catchment Management Agencies
COD	: Chemical oxygen demand, indication of how much oxygen is required to oxidise a sample, measured in mg/L.
Conc	...............: Concentration. Usually refers to concentration in liquor or liquor part of pulp stream.
CRF	: Chemical Recovery Furnace. CRF1 and CRF2 signifies chemical recovery furnace #1 and #2 respectively.
CT	: Cooling tower
D	: Chlorine dioxide. Abbreviation is used to indicate the D-tower in the bleach plant.
DAF	: Dissolved Air Flotation
DC	: Indicates that a mixture of chlorine dioxide and chlorine gas is used.
Demin	: Demineralisation or demineralised
E	: Caustic. Abbreviation is used to indicate the E-tower, i.e. the bleaching process unit where caustic is used.
ECF	: Elemental Chlorine Free Bleaching.
EPA	: Environmental Protection Agency
ERP1	: Effluent Reduction Project #1
Evaps	: Evaporator set
FBHW	: Fully bleached hardwood
FBSW	: Fully bleached softwood
GAMS	: General Algebraic Modelling System
GE	: General Effluent
HEN	: Heat Exchange Network
IDE	: Integrated Development Environment
IWMP	: Integrated Water Management Plan.
KLB	: Kraft Liner Board, paper machine producing liner board.
LP	: Linear Programming
Lpm	: Litres per minute, indicates a volumetric flow.
MC	: Medium consistency
MEN	: Mass Exchange Network
MILP	: Mixed Integer Linear Programming
MINLP	: Mixed Integer Non-Linear Programming
MIM	: Minimum Impact Mill
MSA	: Mass Separating Agents
MW	: Mega watt
NLP	: Non-linear Programming
NP	: Newsprint machine, paper machine producing newspaper.
NPE's	: Non Process Elements. See Glossary.
NWRS	: National Water Resource Strategy
O	: Oxygen
OHSAS	: Occupational Health and Safety System

PE	: Process Engineer
PF	: Pulverised Fuel Boiler
R	: South African monetary unit in Rands.
SBL	: Strong black liquor. Weak black liquor is concentrated in the evaporators to strong black liquor. Consist of sodium carbonate, sodium sulphate and organics. SBL is incinerated in the CRF's.
SDT	: Smelt dissolving tank, tank into which the chemical recovery furnace discharges.
SWL	: Strong white liquor, cooking chemical used to dissolve lignin from fibre.
TA	: Total alkali
TCF	: Total Chlorine Free. Term used to indicate that at bleach sequence uses no chlorine or chloride containing chemicals.
TG2	: Turbine generator #2
TRS	: Total Reduced Sulphurs, odorous gaseous mixture.
Tpa	: Ton per annum
TWP	*: Twin wire press, same as double wire press*
UBHW	: Unbleached hardwood
UBSW	: Unbleached softwood
Ubt	: Unbleached ton
Upt	: Uptake to refer to Uptake machines #1, #2 or #3.
WBL	: Weak black liquor, spent cooking liquor containing dissolved lignin.
WDCS	: Waste Discharge Charge System
WTL	: White top line.
WWL	: Weak white liquor. Strong white liquor that has been diluted with condensates is weak white liquor. Typical composition is caustic and sodium sulphide in concentrations one fifth of strong white liquor.
Z	: Ozone
ZLE	: Zero liquid Effluent

Glossary

Note: where equipment is described with a number in brackets i.e. (A1) it refers to the grid location on the water network schematic as indicated in Mill Water Network Schematic for easy reference.

Back water	: In the uptake and paper machines this term is used to describe water originating from the uptake of paper machines. Because the water is returned back to source from which the pulp was collected the term "back water" is used. This water contains contaminants such as fibre and chemicals associated with the pulp.
Bleach plant	: Pulp is whitened or bleached in the bleach plant through a sequence of process units. Oxygen, chlorine gas (Cl_2), chloride dioxide (ClO_2), caustic (NaOH) and sulphuric acid are used in the bleach plant. The bleaching process that was used for this thesis is conventional bleaching.
Bleach plant wash press	: (U14) Wire type of press used in bleach plant to press pulp dry before the pulp enters the oxygen reactor.
Bottleneck	: See *Water pinch point.*
Brown stock washer	: Each digester has a brown stock washer. The brown stock washer is a drum filter where a pulp slurry is fed into a vat. The pulp is extracted by vacuum onto a drum from the slurry. The pulp and filtrate is separated to produce dry pulp with a consistency of 10%.
Caustic	: Sodium hydroxide (NaOH)
Causticising	: Describes the chemical reaction of sodium carbonate with lime to form

caustic. This reaction takes place partially in the slaker and the causticisers.

Chemical Recovery Furnace : Spent liquor from the digesters, i.e. weak black liquor is concentrated in the evaporators to form strong black liquor. The strong black liquor is incinerated in the chemical recovery furnace. In the furnace the organic material in the strong black liquor supplies the energy to burn while the chemicals in the strong black liquor are converted from sodium sulphate to sodium sulphite in the reduction zone of the furnace bed. The mill has two chemical recovery furnaces, which except for capacity are very similar.

Chips : Wood logs are cut into small pieces, i.e. chips in the chipper to facilitate the cooking process in the digester.

ClO_2 Plant : The plant where the ClO_2 chemical is produced used for bleaching.

Condensates : Different types of condensate are generated in a pulp and paper mill. Condensates can broadly be divided into two types – steam condensate and evaporator condensate. Steam condensates have conductivities lower than 20 mS/cm and are returned to the boilers as boiler water. Evaporator condensates typically have conductivities between 100 and 10 000 uS/cm. The cleaner fraction of the condensates is used for washing while the dirtier fraction of the condensates is recovered in the evaporators.

Connectivity Matrix : A matrix of ones and zeros which correspond to the logical possibility of a connection between a particular source and a particular sink with the process system. This is used in the GAMS modelling to eliminate inappropriate matches from the superstructure considered by the optimisation [30].

Consistency : Term used in the pulp and paper industry to indicate the percentage of dry pulp in a pulp slurry. For example, if the consistency of a pulp slurry is 10%, it means that 10% of the slurry is dried pulp.

Conventional bleaching : Bleaching process that uses chlorine gas as one of the bleaching chemicals.

D36 : (GG13) Bleached pulp storage chest in the bleach plant used to store pulp

D37 : (HH14) Pulp storage chest in Uptake #3 plant used to store bleached pulp at a consistency of 10%.

Delignification : The process of removing lignin from wood, i.e. dissolving the lignin between the wood fibres. This is done either in the digester or the bleach plant.

Diffusion washer : (Q22, Y13) 2 and 3 stage diffusion washers are used in the pulp plant. These are long vertical process units with the pulp inlet at the bottom of the tower. The pulp flows upwards in the tower-like washer while wash water is added and removed through special mechanisms at the top of the washer. Depending on the number of these washing regimes in the washer, the washer is either referred to as a 2 or 3 stage diffusion washer.

Digester : (X23, M20) Pulp, cooking liquor and steam are fed into a digester to allow the chemical to separate the fibre and the lignin from each other. The digesters are continuous digesters and the wood chips and cooking liquor are fed into the top of the digester, and the cooked chips are discharged from the bottom of the digester. The mill has two digesters that are, except for their capacities, very similar. These are referred to as digester #1 and digester #2.

D1 and D2 Towers : (AA13, EE13) Displacement bleaching towers that use chlorine dioxide and bleaching chemical. D1 and D2 signify towers #1 and #2 respectively.

DC Tower : Bleaching tower where a mixture of chlorine dioxide and chlorine gas is used for bleaching.

Displacement tower : Process unit where pulp is fed from the bottom of the tower with the bleaching chemicals. The spent chemicals are then displaced from the pulp at the top of the tower through special screens that displaces the chemicals with wash water and which also removes the wash water from the process.

E-Tower : (CC13) Indicates the displacement bleaching tower that uses caustic as part of the bleaching sequence

Evaporators : (B16, I16) Long tube vertical rising film evaporator sets. Evaporator #1 has four effects, and Evaporator #2 has five effects and two concentrators. Weak black liquor is fed into the evaporators and water is evaporated concentrating the weak black liquor into strong black liquor.

Evaps Cooling towers : (E22, H21) Integral to the working of the evaporators are the evaporator cooling towers. Evaporator #1 and #2 each have their own set of cooling towers. Evaps #1 cooling tower has only one cooling fan and evaps #2 has four cooling fans. The cooling water is used to condense vapour from the evaporator sets. This cooling water circuit can handle dirty water as make-up.

Eyes : Spring or fountain

Excess hot water cooling tower : (Q13) Cooling tower that forms part of the warm and hot water system. Water circuit has a quality of water similar to that of fresh water.

Fibre Line : A production line that processes fibre, i.e. wood, to produce pulp is referred to as a fibre line. Ngodwana has two fibre lines, #1 fibre line includes digester #1 and uptake #1. Fibre line #2 includes digester #2, bleach plant, uptake #2 and uptake #3.

Flume : Concrete or metal structure with known geometry that is placed in a channel with flow water/effluent/liquor. The resistance of the water to flow over this restriction is measured and the measurement is translated to a flow indication. Flumes are used in the effluent trenches to measure the effluent volumetric flow.

Forming section : The uptake #1, #2, #3, KLB and NP machines each have a forming section. The forming section is part section of each machine where the pulp is spread out and formed in preparation of the press sections that presses water out of the pulp. Dewatering and sheet formation are the primary functions of the forming sections.

Fourdrinier : Type of paper machine where a headbox is used to spray the pulp mixture onto a moving wire. Sheets are formed through drying and pressing.

Green liquor : Molten salts or smelt from the chemical recovery furnaces are dissolved in weak white liquor to form green liquor. Green liquor (Na_2CO_3 and Na_2S) is used in the causticising section to react with lime (CaO) to form strong white liquor ($NaOH$ and Na_2S).

Groundwood : Softwood logs are mechanically ground to form pulp. In the groundwood process, logs are pushed against turning stone grinders. The stone grinders have a rough surface and this disintegrates the wood log into pulp fibres. The mill has ten grinders.

Gum wood/tree : See *hardwood*.

Hardwood : Tree species with short fibres and less lignin than softwood. Typically from the tree family Eucalyptus, also known as gum wood. See *softwood*.

Hi-Kappa cooling tower: (AA26) Cooling tower in the digester #1 plant.

Hot/Warm water system : (M16) Fresh water is used as cooling water for condensors in the bleach plant and digester area. This water of varying temperature is stored in the warm and hot water tanks. From this system hot water is distributed to numerous users throughout the mill. The water must be of a high quality.

Irrigation fields : The mill has 514 hectares of land used to irrigate its effluent on.

Kraft Liner Board : Thick brown box paper that is produced from Kraft pulp. Abbreviated as *KLB*.

Lime : Calcium oxide (CaO)

Lime mud : Calcium carbonate ($CaCO_3$)

Lime mud washer : (D24) Clarifier in the causticising section where the lime mud is mixed and then separated from condensate in order to wash out sodium by means of dilution.

Liner board : Description used to indicate paper that is used to line-out either the inside or outside of a paper product.

Lube oil cooling towers : Cooling towers used in the Utilities plant to supply substations with cooling water.

Marginal value : Is the amount by which the objective function would change if the equation level were moved one unit. Often called reduced cost or dual values. Contain information about the rate at which the objective value will change if the associated bound or right hand side is changed [37].

Mixed stock chest : (KK13) Tank used for storing pulp in the Uptake #3 plant.

Non Process Elements : NPE's include heavy metals such as iron, cobalt, copper etc. These elements enter the chemical and recovery circuit via the wood and raw material and have a negative impact on the pulping process in many respects. A major consideration of the chemical and recovery circuit is the management and removal of these elements from the chemical circuit.

Noodle : (LL24) Pulp that has been pressed dry in a screw press into noodle textured format

033Blend chest : Chest in which pulp and filtrate is mixed to prepare the pulp consistency for the bleaching process.

Oxygen reactor : (V13) Bleaching process unit where pulp is bleached using oxygen.

Pinch point : See *Water pinch point*

Plies : The final paper product from the paper machine typically composes of more than one layer of "paper" to form a sheet of paper. These different layers are referred to as plies. Typically the brown paper (KLB) compose of three plies (layers) to form the sheet.

Pulp : Wood that has been digested to a slurry and of which the fibre and lignin are separated from each other

Reels : Pulp that has been dried as a sheet is rolled-up to form a roll or reel

Reel slab : Pulp reels/rolls are stored on a concrete slab known as the reel slab

Relaxing concentrations: When the maximum allowable concentration permitted into a sink is increased so that a higher concentration is permitted it is implied that the concentration limit is relaxed. A relaxed concentration means that higher concentrations of contaminants, with associated increase in risk, are permitted into the sink.

Repulpers : (V7) Noodle, reels and bales are dried pulp stored for later usage or for transportation purposes. When this pulp is re-used, water is added to the noodle, reels or bales and the mixture is mechanically slurried to form pulp. This process of turning dried noodle, reels or bales into pulp is called repulping. This is done in the repulpers.

Service Cooling tower #2 : Cooling tower used to supply numerous substations' air conditioners with cooling water. This water network spreads over the whole mill and the water has a quality requirement.

Slaker : Tank with screw conveyor and overflow weir used in the chemical plant to allow for the reaction of lime with green liquor.

Smelt dissolving tanks : Each of the chemical recovery furnaces has a smelt dissolving tank. Smelt or molten salts from the chemical recovery furnace falls into the smelt dissolving tank. Weak white liquor is used as make-up to the smelt dissolving tanks to dissolve the molten salts. The dissolved salts are pumped to the causticising section as green liquor.

Softwood : Tree species with longer fibres and more lignin. Typically from the tree family Pinus or better known as pine trees/wood. Also see *hardwood.*

Sticky temperature : Terminology used for the recovery boiler to indicate the temperature at which the ash in the boiler starts melting. The ash in the boiler is a mixture of sodium carbonate and sodium sulphate with other compounds in smaller quantities. In its molten form this ash sticks to the boiler tubes and starts plugging the boiler. The sticky/molten ash is difficult to blow or remove from the boiler tubes. Of particular importance is the chloride and potassium concentration of the ash. The higher the chloride and potassium levels the lower the melting point or sticky temperature of the ash. This means that the ash will become sticky in a region of the furnace where it is undesired for the ash to be sticky – a lower sticky temperature increases the risk of boiler plugging.

Strong Black Liquor : Produced in the evaporator plants when weak black liquor is evaporated to concentrate-up to strong black liquor. Strong black liquor is a mixture of organic material and inorganic spent cooking liquor.

Strong White Liquor : Mixture of caustic (NaOH) and sodium hydrogen sulphide (Na_2S) used in the digesters as cooking liquor.

TG2 Cooling tower : (H9) The mill has two turbine generators. Generator #2 is used for the prime purpose of generating electricity while generator #1 is also used for steam generation. The steam from generator #2 is condensed and the condensate returned to the boiler. The TG2 cooling tower supplies the cooling water
to cool and condense the steam from turbine generator #2.

Thickener : (LL13) Drum washer used for the primary purpose to dry pulp. Filtrate is removed from the pulp slurry to dry the pulp to a consistency of about 10%.

Uptake #1, #2 and #3 : (JJ22, U27, PP16) Pulp drying machines. Mechanical pressure and heat is used to press pulp dry into sheets that are rolled-up into rolls (or reels). Steam is not used on uptake #1. Uptake #3 is used only for bleached pulp.

Uptake #1 White water tank : (Z21) Tank in the Uptake #1 plant used to collect filtrate from different sources within the Uptake #1 plant.

White top line : Brown paper with a white or bleached side. The paper is bleached on one side and brown on the other side.

Waste plant : Plant that uses waste paper/recycled fibre to produce pulp which is used in the Kraft Liner board machine. Used paper bales are fed into the plant, slurried with water and screened to remove impurities and stickies.

Water Pinch point : The inlet or outlet concentration that limits the reuse/recycle of water the most. Otherwise known as the pinch point, this identifies the area within the water-using system where further engineering effort should be focused [36]

WaterPinch™ : WaterPinch™ is a systematic technique for analysing water networks and reducing water costs for processes. It uses advanced algorithms to identify and optimise the best water re-use, re-generation and effluent treatment opportunities [45].

Weak White Liquor : A weak solution of caustic (NaOH) that results from washing the lime mud. This liquor is used in the chemical recovery furnace for diluting smelt to produce green liquor.

Chapter 1 Introduction

Sappi's integrated Kraft pulp and paper mill, Ngodwana, is continuously seeking to improve its environmental performance. Already the mill has a highly closed water circuit resulting in a very low specific water-use-ratio. Ngodwana generates only about 17 000 litre of effluent for every ton of product produced [1]. This rates the mill as a water efficient mill. However, with the increased demands on fresh water consumption in the province and more stringent environmental legislation, it was necessary to evaluate all possible technologies to improve the water use of the mill even further. It was for this reason that the technique of water pinch was used to either optimise the water use of Ngodwana or to prove that the water network of the mill was already optimised. Internationally the focus on environmental impact is being raised with concepts such as sustainable development. The increasing necessity of implementing formal environmental management systems according to standards such as ISO14001 is further motivation for improving the water consumption of the mill.

1.1 Sustainable development

The concept of sustainability is more than just a buzzword; it is part of South Africa's legislation. The concept of sustainability was introduced in the 1980's and the Brundtland Commission first moved it from obscurity to the prominence of an internationally accepted important concept in environmental management. It is incorporated in the South African legislation, section 2 of the Environmental Conservation Act 73 of 1989. This act states that *"the concept of sustainable development is accepted as the guiding principle for environmental management"*. This definition was later replaced by the National Environmental Management Act 107 of 1998 in section 2(3) where it is stated that *"development must be socially, environmentally and economically sustainable"* [2]. South Africa has also signed Agenda 21, which is the international plan for sustainable development [3]. It is with this in mind that Ngodwana and the authorities have to find a sustainable solution for the future of Ngodwana. This solution must consider the economical side of sustainability as equally important to the environmental and social responsibilities. Figure 1 graphically depicts the concept of sustainability. In this thesis the technique of pinch was applied with cost being the variable used for optimisation. The impact on the environment was expressed in a monetary value, i.e. Rands (R).

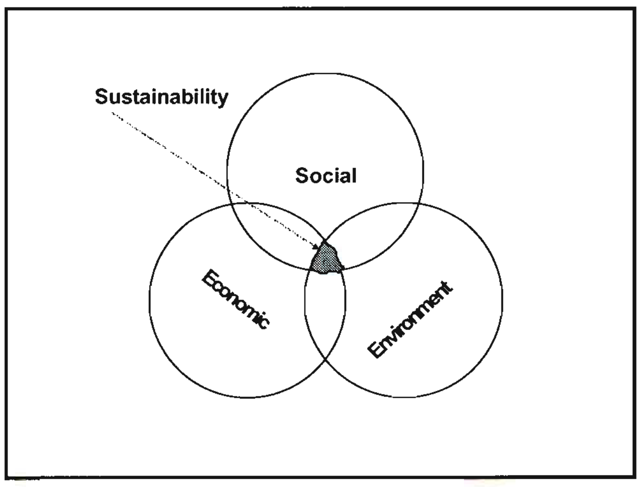


Figure 1: Sustainability

1.2 Water resources in South Africa and Mpumalanga

South Africa is a dry country. The country's average rainfall is about 450 mm per year. This is much less than the world average of about 860 mm per year. The rainfall also differs greatly from year-to-year, which makes the management even so much more difficult. The country is also prone to droughts. South Africa's rivers are small when compared to rivers of other countries. The Orange River carries only about 10% of the water in the Zambezi River. All South Africa's rivers together have less than half the water of that in the Zambezi River. A study by the Department of Water Affairs showed that 11 of the 19 water management areas in the country have a water problem. In these areas, people use so much water that the environment is under severe stress, and other users cannot rely on getting their fair share of water. Ngodwana mill falls within the Inkomati catchment, this catchment has the following features that make water management even more important:

- The main river of the catchment, the Nkomati, leaves the county. The river is thus of international importance and certain agreements between South Africa and Mozambique exist,
- The catchment borders the Kruger National Park which is a nature conservation area of international importance,
- Water demand for the catchment exceeds its water resources,
- The catchment has a positive population growth and
- Groundwater is not abundant [3].

These factors put additional pressure on Ngodwana to ensure that its water network is as efficient as is possible while ensuring sustainability.

1.3 Legislation Development

With South Africa's entry into the world trade arena, considerable focus, and development has gone into the improvement and generation of legislation that governs the environmental impact of industry. With the proclamation of the new National Water Act 36 of 1998, initiatives such as the National Water Resources Strategy (NWRS), Waste Discharge Charge System (WDCS) and Catchment Management Agencies (CMA's) have been established or are in the process of being established. The implementation of these initiatives impact on Ngodwana:

- The National Water Resource Strategy will determine the quality and quantity of water available in the different catchments,
- The Catchment Management Agencies will allocate the available water and
- Through the Waste Discharge Charge System Ngodwana will be charged with discharging water and contaminants to the environment [4].

The implementation of these initiatives has considerable economic implications for Ngodwana and must be considered when doing a pinch analysis.

1.4 ISO 14001

Ngodwana is also an ISO14001 certified mill. This means that Ngodwana has an environmental management plan that complies to an international standard, i.e. ISO14001. The essence of this standard is to show continuous improvement of the environmental aspects the mill considers significant. Aspects include any direct or indirect impact that any activity of the mill has. The irrigation of effluent and the release of storm water have been identified as two of Ngodwana's significant environmental aspects. To demonstrate continuous improvement on these activities, a water pinch analysis has been done either to identify improvement opportunities or to indicate that improvement was not sustainable.

1.5 The Pulp and Paper industry

This thesis was concerned with the application of water pinch on the Ngodwana Kraft Pulp and Paper mill. In a Kraft Pulp and Paper mill, wood is used to produce pulp and paper. The term "Kraft" is a German word meaning strong. This indicates that a specific sodium sulphide based process is used to remove the lignin from the wood fibres. From the wood fibres pulp is produced, and the pulp is used to produce paper. Throughout the pulp and paper making process water is used to:

- transfer chemicals,
- dilute chemicals,
- wash or remove chemicals or impurities and
- cool down processes or equipment.

The extensive use of water in the pulp and paper industry and the high degree of contamination resulting from pulp and paper effluent has put a lot of focus on the water use of this industrial section. The pulp and paper industry is faced with ever increasing pressure to improve its efficiency. Being one of a few water based industries and the only industry where the final product is about 10% water [5], every water related issue has a direct effect on the industry's performance.

1.6 Water Pinch

The application of **energy pinch** technology had been used and proven in industry since 1988 to optimise energy usage in industrial and process applications [6]. The term stems from the fact that in a plot of the system temperatures versus heat transferred, a pinch usually occurs between the hot stream and cold stream curves. For energy pinch it has been shown that the pinch represents a distinct thermodynamic break in the system and that, for minimum energy requirements, heat should not be transferred across the pinch [7]. Similarly, a technique had been developed to apply the heat pinch theories to achieve minimal water use (compared to minimal energy use). This technique, called **water pinch**, involves the identification of a particular constraint, or set of constraints, which ultimately limits any further improvement in water use by the system. Similar to heat pinch curves, the maximum allowable concentrations in different process streams were plotted against the mass load of contaminant being removed. In doing this the water pinch was identified which indicates the point across which it is not recommended to transfer mass when the objective is to minimise water usage.

The concept of determining a pinch point has been extended to include mathematical optimisation of water networks. This mathematical optimisation process uses minimum cost as the target objective for the optimised water network. By assigning costs to factors such as corrosion, fouling, treatment cost, fresh water cost, effluent discharge cost etc it was possible to incorporate social, economical and environmental cost into one solution description. The concept of using cost as the optimisation target brings the industry closer to finding water use solutions that are sustainable.

1.7 Objectives of this thesis

The **objective** of this thesis was to evaluate the practical application of the water pinch technique to an integrated pulp and paper mill with an already highly closed water circuit. The applicability of the pinch technique was rated against successes achieved in investigating the following primary objectives:

1. **What is the optimal recommended water network for the mill without adding new technology?**
2. **How must the ERP1 treatment plant be configured into the water network?**
3. **Where can the storm water of the mill be used?**

It was beyond the scope of this thesis to investigate the feasibility of implementation. The objective of the thesis was to identify improvement opportunities, rather than designing the final implementation and detailed evaluation of the proposed opportunities. Proposals that were made from this study that must be investigated further include cycling-up effects, dynamic process relations and the impacts of other process contaminants.

As a secondary objective the thesis also:

4. Discusses the suitability of using the WaterTarget Suite software [8] as a tool to achieve the main objectives.

Chapter 2 Literature Review

2.1 Water Consumption in Pulp and Paper Mills [1]

An extensive literature study [1] has been done by Ngodwana mill, as part of its Integrated Water Management Plan (IWMP), to benchmark Ngodwana mill against other mills in the world - some of the findings of this study are given. The Environmental Protection Agency (EPA) of the United States of America have put guidelines together [9] to outline the expected performance of different types of mills. Limitations have been identified for:

- organic material (measured as BOD),
- suspended solids,
- pH and
- absorbable organic halogens (for bleach effluents).

It was interesting to note that EPA has no significant interest in effluent flow, or dissolved inorganic solids, whereas the latter two effluent characteristics are the principal interest of the South African regulators.

The EPA has a very extensive approach to identifying the required performance levels for pulp and paper industries. The regulation of the pulp and paper industries is controlled by not only setting out performance levels, but by also identifying technologies that should be in place. Ngodwana is an integrated mill, which means it is a combination of different types of mills. To be able to compare Ngodwana's performance to the different types of mills identified by the EPA, Ngodwana is divided into the following mills (see **Figure 2**):

- Bleached paper grade kraft,
- Unbleached kraft,
- Integrated Secondary fibre and kraft linerboard and
- Integrated mechanical pulping with Newsprint mill.

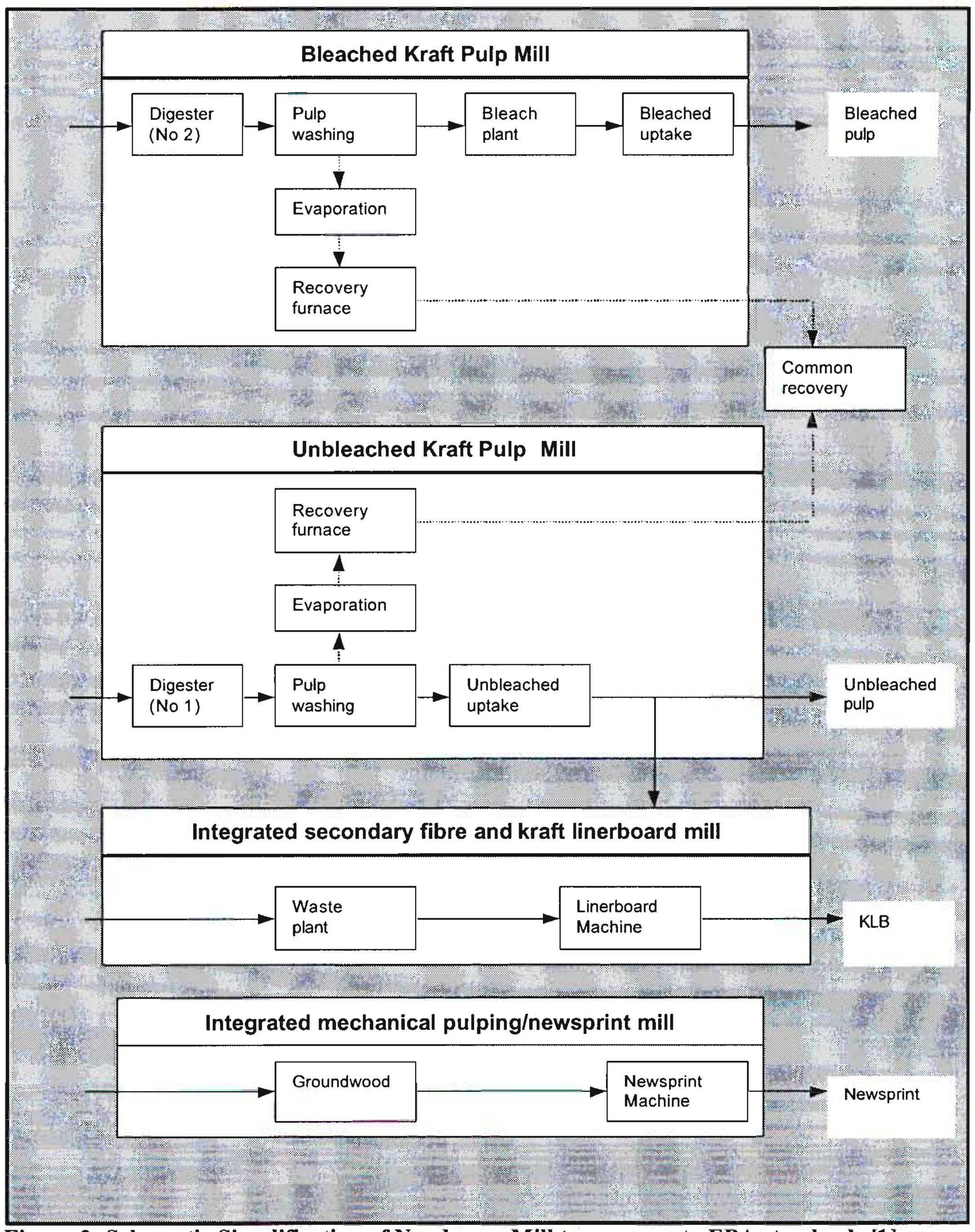


Figure 2: Schematic Simplification of Ngodwana Mill to compare to EPA standards [1]

The EPA has a set of baseline requirements that must be adhered to, and advanced technology tiers as additional incentive for mills that have already implemented the baseline technology. The main incentive for the industry to select the stricter limits associated with the advanced technology tiers is a longer period within which they must meet the set limits. Effluent discharge limits (including specific effluent generation rate) have been set for each tier of advanced technology (refer to Table 1):

- **Tier I** require that mills have advanced fiberlines (extended cooking and/or oxygen delignification). Bleach effluents and evaporator condensates are sewered. Tier I is applicable to mills which currently do not have oxygen delignification and/or extended cooking. In addition to installing either of those technologies, the water systems before bleaching have to be closed, i.e. closed screening and effluent free reject handling.
- **Tier II** represents an additional step for mills that already have an advanced fiberline. In order to meet the proposed effluent volume limit (10 m3/ton) for Tier II, advanced technologies are required which enable at-source reduction in effluent generation, and/or reuse of bleach filtrates.
- **Tier III** requires, in addition, the reuse (after steam stripping) of evaporator condensates.

Tiers II and III tie the need to recycle digester and evaporator condensates, as a water conservation measure into the picture by specifying a limit for the sum of the effluents that can be discharged from the bleaching and with these condensates. The subsequent pulp drier or paper machine was not included. The AOX limits are also very low (0.05 - 0.1 kg/t), meaning that bleach plant effluent recovery or special treatment would be necessary in ECF mills.

Table 1: EPA Advanced Technology Tiers [**1**]

	Unit	Tier I	Tier II	Tier III
Technology				
Advanced Fibre line[1]		Yes	Yes	yes
Kappa to Bleaching: - Softwood - Hardwood	 4 4	 20 13		
Closed water cycles before bleaching		Yes	Yes	yes
Limitations				
Process Effluent[2]	m^3/Ubt		10	5
Final Effluent AOX	kg/Ubt	0.3	0.1	0.05

[1]Advanced fibre line includes extended cooking and/or oxygen delignification
[2]Includes bleach plant effluent and digester + evaporator condensates to sewer.
[4]Dimensionless

Effluent discharge limits proposed by the US EPA are compared with effluent discharges from the Sappi Ngodwana mill in Table 2. The EPA limits for one of the baseline requirements, i.e. BPT (best practicable control technology currently available) have been adjusted to reflect values before biological treatment.

Table 2: Specific contaminant generation Rates – Ngodwana vs. EPA kg/ton) [**1**]

Parameter	Bleached kraft		Unbleached kraft		Kraft Linerboard		Integrated Newsprint	
	EPA[1]	Ngodw.	EPA[1]	Ngodw.	EPA[1]	Ngodw.	EPA[1]	Ngodw.
BOD	81	39.7	28	27.5		6.2	39	15.8
COD	-	57.6		38.2	-	8.0	-	18.9
TSS	164	7.5	60	3.7		14.8	69	28.5
AOX	0.9	1.3[2]	-	-	-	-	-	-
Chloride	-	40.0	-	0.3	-	0.5	-	0.2
Sodium	-	27.1	-	7.0	-	2.3	-	1.5
Sulphate	-	4.1	-	2.2	-	11.6	-	1.4

1. Adjusted to reflect untreated values
2. Conventional (chlorine) bleaching

A detailed case study [10] has been conducted on three (an old mill, a modernised mill and a new mill) mills in the USA to determine the feasibility of implementing Tier I, II and III technology. The conclusions of the study are listed:

- There was not a single bleached Kraft mill in North America or the Nordic countries that would meet the effluent flow limits proposed for Tier II or Tier III. Most industries operate at 5 - 10 times higher effluent discharge levels than proposed by EPA.
- Several new mills have established effluent flow goals comparable to Tier II and III levels, but in practice these levels have proven difficult to achieve. Plugging and scaling of equipment, as well as corrosion, have been major concerns.
- Recovery of bleach plant effluents disturbs the chemical balance and causes an increase in solid waste discharge, which was being experienced in many mills attempting closed cycle operation.
- Internal regeneration and re-use of bleach chemicals to reduce the waste was technically known, but not used in practice yet.
- Conversion of an existing mill to meet Tier I level requirements was technically feasible and may be an attractive option when taking into account the cost benefit and the incentives offered. For an existing mill the modifications required to reach Tier II or III may be very costly. Especially an old mill with high water use will certainly accomplish some savings in energy, fibre and chemicals in reducing water use. The savings are not nearly enough to justify the investments if and old mill attempts to reach Tier III level performance.
- While conversion of an existing old mill to Tier II or III level performance may not be justified economically today, the Advanced Technology program may be of interest for the mills that, because of age and condition, see it necessary to build a new fiberline within the next 5 - 15 years. Depending on the final form of the Advanced Technology program, it may offer an opportunity to the mills to carry out a staged modernisation program that will lead to low effluent at the end.
- The old mill that has already gone through a modernisation program may benefit from the Advanced Technology program. Achieving Tier I level may be possible without any additional investments for both modernised old mill and especially for a new modern mill.
- Tier II levels should be achievable in a new mill with moderate investments.
- Tier III level performance requires that practically all bleach plant effluent be recovered. While interesting development was going on in this area, there was not enough mill scale experience on Tier III level operation that decision to go for Tier III level would be easy on any existing mill, whether old or new.
- Some of the Tier II and III technologies, such as the pulping and bleaching technologies are proven in the industry. Some others, such as reduction of the process effluent flow to 10 (Tier II) or 5 (Tier III) m3/ADt have not yet been proven in practice. The costs and risks related to these technologies are not well known today, and therefore a commitment to these effluent levels may not be an easy decision.

2.1.1 Fresh Water Usage [1]

In terms of specific water usage, all areas of the Ngodwana mill use significantly less water (up to 60% less) than mills of similar design and vintage. In all cases specific water usage was less than that achieved by newer mills, but not as low as that achieved by current designs.

Table 3: Fresh Water Usage Rate Comparison

Type of mill	Fresh water utilisation rate (m^3/AD ton pulp)			
	Old mill	New mill	Current design	Ngodwana
Bleached Kraft	78	44	12	40.4
Unbleached Kraft	22	13	2	8.7
Kraft linerboard	25	10	1	4.6
Integrated newsprint	40	20	6	8.5

2.1.2 Effluent Generation Rate [1]

The specific effluent-generation-rates were significantly less than mills of similar design and vintage. In all cases specific effluent-generation-rate was less than that achieved by newer mills, but not as low as that achieved by currently designs. The US EPA does not have guidelines for effluent generation rates for baseline technologies, however, limits of 10 m^3/ton for Tier II, and 5 m^3/ton for Tier III advanced technology kraft bleach mills are given.

Table 4: Comparison of specific effluent generation rates [1]

Type of mill	Effluent generation rate (m^3/AD ton pulp)			
	Old mill	New mill	Current design	Ngodwana
Bleached Kraft	75	40	18	29.4
Unbleached Kraft	22	13	2	8.7
Kraft linerboard	22	8	0.6	6.4
Integrated newsprint	45	18	10	11.0

Defining, comparing and evaluating a mill's performance with regards to effluent and effluent discharges was complex and dependent on the mill type and the different processes the mill consists of. A *Best Practice Review* report by Leske [1] outlines, quantifies and relates the waste generation rates of the Sappi Ngodwana mill with literature and other mills in the world. The following conclusions related to this study are listed from the report:

- Ngodwana was comparable with modern mills worldwide, although the technology employed at the mill was 15 years old, and in some parts of the mill, older than 30 years.
- The US EPA presents the most extensive and applicable guidelines and recommendations for the pulp and paper industry.
- In terms of technology employed, the Sappi Ngodwana bleached kraft mill falls between a Tier I and Tier II advanced technology mill.
- The Sappi Ngodwana mill has implemented either by design and/or by process modifications the vast majority of waste minimisation technologies and practices quoted in the literature. This has been achieved mainly by the implementation of water conservation and reuse technologies and practices.
- Opportunities quoted in the *Best Practice Review* report as having the potential for further significant reduction of water usage and contaminant release include:
    - Upgrade of the black liquor evaporators, condensate splitting and installation of steam strippers. Ngodwana has implemented this in 2005.
    - Replace the bleach plant diffusion washers with new technology (wash presses). Ngodwana has implemented this.
    - Implement integrated or separate bleach effluent recovery processes
    - Install external effluent treatment processes for recycling

- Apart from implementing the majority of best technologies mentioned, Ngodwana has implemented the majority of best practices. A detailed list on the implemented best practices is presented in paragraph 3.1 *Details of Ngodwana Mill.*

2.2 Process Integration Techniques

Traditionally freshwater use and wastewater generation has been reduced by considering design improvements in individual unit operations or by identifying water reuse opportunities across unit operations without systematic consideration of the overall process or the total site. Approaches that are more systematic have been developed over the years to tackle the integration of different process units with each other and to consider larger systems or whole plants when optimising [11].

Four engineering tools or techniques that are available to industry are discussed by Buehner and Rossiter [11]. These are:

- Thermal pinch
- Water pinch
- Knowledge based approaches
- Numerical and graphical approaches

Each of the techniques has somewhat different areas of application and tends to yield different yet complimentary results. When tackling a process or environmental improvement project each of the techniques must be considered and evaluated to decide on the most appropriate tool for the specific requirement. In many instances, several methods are often used together when addressing a design problem [11]. These techniques are discussed.

2.2.1 Thermal Pinch Analysis [11]

Thermal pinch analysis is based on rigorous thermodynamic principles used to construct plots and perform simple calculations that yield insights into heat flows through processes. The technique is widely used to determine the scope of energy savings in industrial operations. Thermal pinch has been used during the past 25 years for identifying a wide range of process improvement options, including optimal plant utility systems and co-generation schemes, heat exchanger networks, capacity increase, yield improvements and emission reduction. Other important technical developments made with the use of pinch analysis include pressure drop optimisation, multiple-base-case design, distillation column thermal profile analysis, low temperature process design, batch process design, total site integration and emission targeting. The pinch technique produces a graphical representation of the proposed network. This provides targets (i.e. realistically attainable goals based on thermodynamic and economical principles) to the designer. This allows the designer to explore various options without the added time and expense of carrying out detailed simulations and costing. Pinch analyses were performed as early as the mid-1980's, for example BASF's Ludwigshafen (a German factory) saved 790 MW with significant reductions in air emissions. The reductions in air emissions were realised as a result of the saving that was made in improving the efficiency of energy of the processes. More recently the German giant Bayer conducted a systematic study of CO_2 emission reduction using a total-site pinch. The maximum theoretical scope for CO_2 reduction was 28%. However, if only projects with an incremental payback of fewer than three years were implemented, this percentage decreased to 8%. For many energy integration projects, short payback times can exclude potentially large energy reduction projects. More detail of the thermal pinch technique and its similarities to water pinch is given in paragraph 2.4.

2.2.2 Water Pinch Analysis [11]

Similarly to energy pinch that uses temperature and enthalpy as the design parameters, the technique of water pinch was developed. Water pinch uses contaminant concentration (or purity) and flow as the design parameters. Different permutations of applying the technique exist ranging from approaches that were developed for varying or constant flow, single or multiple contaminants and graphical or numerical. More detail is given in 2.3 to 2.5. Unilever (Vinamul) applied this technique. This factory produces more than 200 products including paints, glues and adhesives. Savings in freshwater demand and wastewater production were 50% and 65% respectively. The Monsanto Chemical factory in Newport (Wales) also applied water pinch to their site, this study resulted in reducing the estimated project cost from $15 million to $3.5 million and an operating cost saving of $1 million annually. This project also won *The Chemical Engineer's* Excellence in Safety and Environment Award in 1995.

The energy and water pinch approaches are good for identifying fundamental insights into heat and mass transfer problems, which can result in step-change design improvements.

2.2.3 Knowledge Based Approaches [11]

Knowledge based approaches were founded on the many universal features common to almost all industrial processes. An accumulated knowledge base of proven ideas exist for processing steps for material conversion, material separations, material recycling and energy utilisation. Typically, the knowledge base includes unit processes like different types of reactors, crystallisation, digestion, separation processes such as distillation, fractional crystallisation, filters, centrifuges, and hydro-cyclones. For each different discipline in industry such as waste product treatment for example mutual unit processes exist such as membranes, biological treatments, drying, agglomeration etc.

Another common denominator for all industrial processes is energy. Thermal energy is typically supplied by steam, reaction, electrical heating and various types of heat exchangers can be used to exchange heat between process streams. Energy my also be removed by air cooling or forced cooling using compressors, heat exchangers or cooling towers. Mechanical energy generated from steam or gas turbines or from electricity from power stations can be used to drive pumps, compressors, and other items of process equipment. Although the exact application of each of the process units might be unique, the similarities in the application of the process units are far greater than their difference for the different industries. It is this premise that forms the foundation of the knowledge-based methodologies for new designs and retrofits. With this in mind artificial intelligence is used to configure, apply, organise and arrange process units into a sequence or flow sheet of process units that would achieve the desired objective. Typically a few possible designs can be configured and with more detailed investigation, research and costing exercises the best design can be identified. Amoco (Yorktown, VA) used this methodology on their fluid catalytic cracker and sour-water system to identify improvements. Applying a hierarchical approach whereby more and more detail was involved, the project identified savings in surplus water, 30% reduction in desalter brine, recovering raw material, savings in firing fuel and recovering energy in fuel gas.

When processes are complex with multiple variants the knowledge based approach is needed to narrow the scope of the problem.

2.2.4 Numerical and Graphical Optimisation Approaches [11]

Although numerical and graphical techniques form part of thermal or water pinch or knowledge based approaches, there are also approaches that do not fall purely into these categories. There are also a variety of numerical optimisation approaches, from simulation using simplified mathematical models of the process to sophisticated mathematical programming methods. These approaches were often combined with cost equations to quantify the impact of design decisions on process economics. Graphs can provide a visual representation of the effect of varying design and/or operating parameters and often enhance the usefulness of the results. Sophisticated programming techniques such as linear and non-linear programming, with and without mixed integers have been used in many different applications.

The numerical optimisation approach is most appropriate when only a few well-defined design options require evaluation.

2.3 History and Development of Water Pinch

The historical development of pinch is described:

- Hendry et al [12], Hlavacek [13] and Nishida et al [14] focussed on the problem of **separation-system synthesis** with the main focus being on energy-separating-agent processes such as distillation, crystallisation and evaporation. This was due to the significant capital and operating costs associated with the separation processes used in chemical plants. Little attention was directed toward the other important category of separation-system synthesis, i.e. mass-separating agents (MSA) such as solvents, adsorbents, washing liquor etc. A definition of separation-system synthesis is the synthesis of a separation sequence that can separate a given set of multicomponent feed streams of know conditions into several multicomponent product streams of known conditions at a minimum cost [15].
- Various attempts by different authors such as Siirola [16], Stephanopoulos [17] up to Muraki and Hayakawa [18] were made to do separation-system synthesis for MSA's. Despite the considerable contributions accomplished by the MSA's synthesis methods, all these procedures had a common limitation: they have not addressed the problem of minimising the cost of MSA's subject to the thermodynamic constraints imposed by the phase-equilibrium relations. These serious limitations can be mitigated by introducing the notion of mass-exchange network (MEN) synthesis [15].
- The problem of optimal water use was first addressed by Takama et al [19]. Their approach first generated a superstructure of all possible re-use and regeneration opportunities. This superstructure was then optimised and uneconomic features of the design removed.
- Linnhoff and Hindmarsh [20] made significant contribution to the development of and optimisation of heat exchange networks (HEN).
- El-Halwagi and Manousiouthakis [15] adapted the methodology developed by Linnhoff and Hindmarsh to address the more general problem of mass exchange between a rich process stream and a process lean stream. A minimum allowable concentration difference was defined and applied throughout the mass exchange network. The method only applied to a single contaminant. The concept of a mass exchange network (MEN) was developed. MEN synthesis is the systematic generation of a cost-effective network of mass exchangers with the purpose of preferentially transferring certain species from a set of rich streams to a set of lean streams. The concepts developed by Linnhoff and Hindmarsh for HEN were explored to gain insights into their applicability for MEN's. The concept of pinch and a graphical representation of the pinch is presented in paragraph 2.5.1
- Later El-Halwagi and Manousiouthakis [21] automated the MEN approach and included regeneration. In the first stage of their automated approach, thermodynamic constraints were used to formulate a linear programming (LP) problem of which the solution determined the minimum cost and pinch points that limit the mass exchange between rich and lean streams. Then in the second stage a mixed integer linear program (MILP) transhipment problem was solved to identify the minimum number of mass exchange units.
- An alternative approach to water minimisation was developed by Wang and Smith (1994) [22, 23] which used the concept of the limiting water profile to represent rich stream and driving force

information together with process constraints. They specifically addressed the water minimisation problem by considering it a contaminant-transfer problem from process streams to water streams [23]. This allowed minimum water use through maximum reuse to be targeted. Design methods were used to allow targets to be achieved in practice. The method can be applied graphically. This approach has a number of draw-backs:

- In a few cases the method fails to give the best target when the pinch for the problem moves to a different position after regeneration has been introduced,
- Required operations to be split which are not practical to split and
- It is difficult to apply to cases involving multiple contaminants

- A similar approach was used by Rossiter and Nath [25]. Rossiter and Nath used non-linear optimisation techniques to optimise the superstructure.
- The graphical approach by Wang and Smith was improved on by Dhole et al [24]. This approach overcomes the shortfalls of Wang and Smith. The approach involves a combination of new graphical and mathematical techniques, and is trademarked WaterPinch™.
- Doyle and Smith [26] presented a method for targeting reuse for multiple contaminants based on mathematical programming. This allowed the targeting methods of Wang and Smith [23] to be extended to deal with both complex constraints and more complex mass transfer models.
- Kuo and Smith [27] improved on the graphical method for water pinch by introducing techniques that allow for the change in the pinch position with the introduction of regeneration processes.

2.4 Relation between Thermal and Water Pinch

Energy pinch has been applied successfully to the pulp and paper industry for improving thermal efficiency [28, 5]. These principles used in energy pinch have been extended to water/material pinch techniques. Material pinch analysis uses the analogy between heat and mass transfer. The mass exchange network is categorised by donor streams (those with high concentrations of contaminants, equivalent to the hot streams in heat transfer networks) and receptor streams (those with low concentrations, equivalent to the cold streams). The implementation of energy pinch start by identifying and defining the energy load and temperatures of each individual process' heating and cooling duty. Hot and cold "composite curves" are thereby generated, representing overall process heating and cooling profiles as heat flow versus temperature (see Figure 3). Similarly with water pinch, source and sink composite curves are generated for a single contaminant. Water flow rate (quantity) is represented on the horizontal axis and water purity (quality) on the vertical axis. Hence the source and sink curves are also referred to as purity profiles or composite curves. The horizontal overlap of the source and sink curves indicates the scope for water re-use, it is limited by the pinch point where the two curves touch. The open parts to either side of the overlap represent target for minimum freshwater consumption (on the right) and minimum waste water discharge (on the left). Maximising the re-use of water within the shaded area will automatically result in minimum fresh water make-up and wastewater discharge [5].

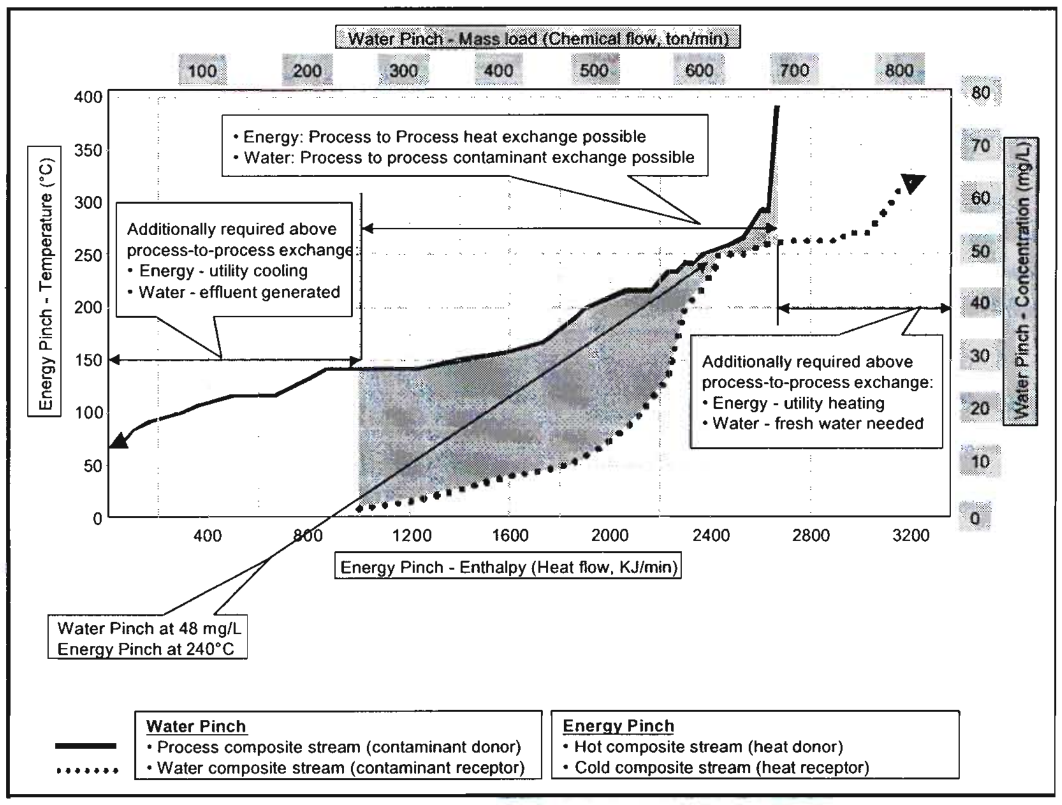


Figure 3: Relationship between Water Pinch and Energy Pinch*

*This Figure was compiled by integrating information from different references [5, 11]

The relationship between energy and water pinch described in Figure 3 shows the composite curves for the hot and cold streams. In other words it show that a specific hot stream will reduce heat as heat is loss, similarly it indicates the temperature increase of a cold stream as heat is taken up by the cold stream. Heat recovery between hot and cold streams is feasible in regions where the hot composite curve lies above the cold composite curve (shaded area), i.e. where the available heat is above the temperature at which it is required. Maximum heat recovery occurs when the composites are drawn to touch at the pinch. In the majority of cases this leaves additional heating and cooling required to carry out the remaining duties that cannot be satisfied by process-to-process heat recovery. This means that however good the heat recovery system is, there is still a minimum amount of utility heating and cooling necessary.

Similarly for water pinch, it can be seen from Figure 3 that the same principles can be applied. Process and water composite streams are shown. For a specific process, the process composite curve indicates how the concentration of the stream decreases with mass of contaminant transferred (for a constant flow rate). The shaded area presents opportunity for mass flow of contaminant from a stream with high concentrations of the contaminant to streams with lower concentrations of the contaminant. The portions where the curves do not overlap represent additional fresh water requirements and the quantity of effluent that will be generated also.

2.5 Different Water Pinch Techniques

Literature indicates different techniques for applying water pinch in industry [8, 27]. The three techniques are described:

- Graphical technique for constant flows and single contaminants,
- Graphical technique for varying and constant flows and single contaminants,
- Numerical technique for varying and constant flows and multi-contaminants.

The technique used in this investigation was a combination of the graphical technique for varying and constant flow for single contaminants and the numerical technique.

2.5.1 Graphical Water profiles – Constant Flows

This method was based on work done by Wang and Smith in 1994 [22, 23].

This method assumes the following [29]:

1. Only a single contaminant is considered at a time
2. The process runs counter-currently to the water stream
3. The direction of mass transfer is from the process stream to the water stream
4. There is no flow rate change throughout the process for both the process stream and the water stream, i.e. mixing of stream for consistency control etc.

This method is particularly well suited to processes in which the donor and receptor streams are non-miscible which is the case, for example, for wash-water networks in the petrochemical industry where an organic phase and aqueous phases are concerned. On the other hand, its application to miscible networks such as the water-water systems encountered in the pulp and paper, in which the streams are losing their identities as they are mixed at various process steps, poses a particular problem.

An example could be a petroleum refiner desalter in which crude oil is mixed with water to extract salt from emulsified water in the oil. The oil and water are then allowed to settle with the assistance of an electrical field and are separated into two phases. In the example there are two sink and two sources (see Figure 4). This example would be represented using only two lines (and not four lines compared to the technique followed in paragraph 2.5.2, see Figure 5). The process line would be a declining line indicating the start concentration (C1) and the finishing concentration (C2) as the salt load is transferred to the water stream. The water stream would be at an incline to indicate the starting (F1) and finishing concentration (F2) of the water as the salt dissolves in the water stream. This process assumes that the total mass flow rate of the streams change so little that it could be assumed to remain constant.

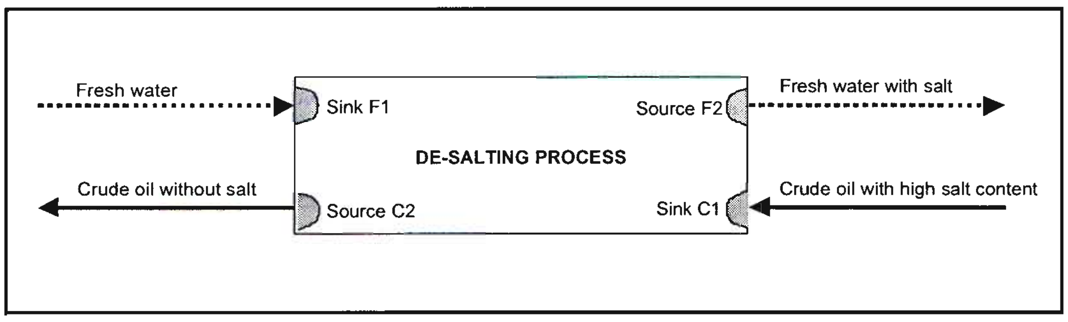


Figure 4: De-salting example [23]

In Figure 5 the example flow composite curves for the desalter are illustrated. Again, it must be noted that when the technique for constant flow is used, only two lines are used to represent the four sources and sinks. This curve can be compared to Figure 6 that indicates the composite curve when the technique for varying flow is used. The technique for varying flow uses four lines to represent the four sources and sinks, more detail on this technique is discussed in paragraph 2.5.2.

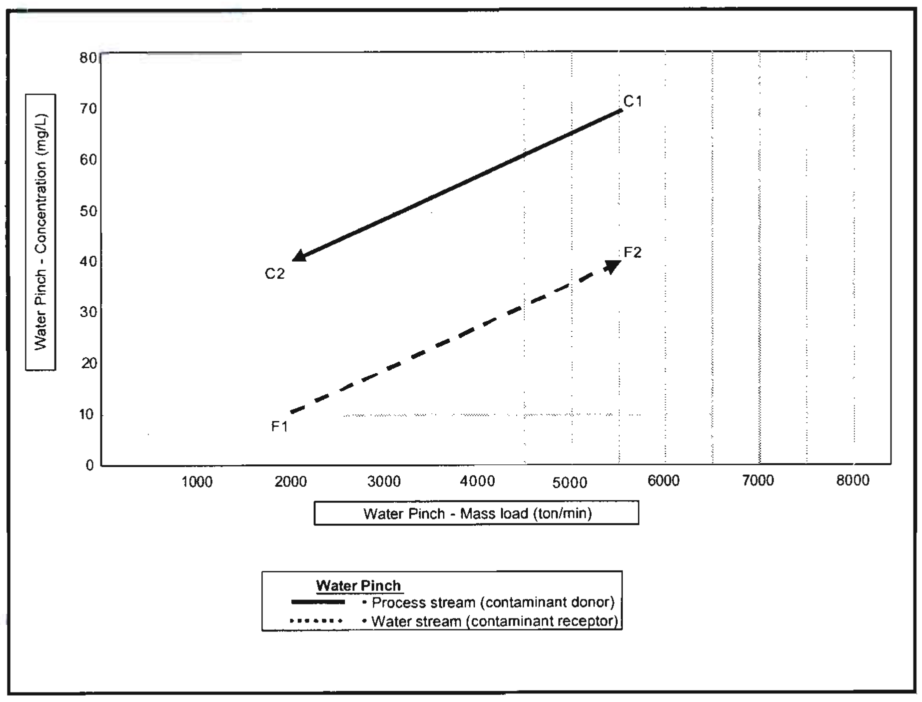


Figure 5: Example constant flow curves for de-salter [23]

The detail of the technique for constant flows were not discussed in detail in this thesis because of the limited use for this technique and also because better techniques are making this technique redundant. The developments of techniques that cater for constant and varying flow and those using numerical solutions are becoming more favourable. The main steps followed and the disadvantages of the constant flow technique are discussed. For more detail references 29, 22, 23 and 24 can be used.

The steps followed are described shortly [24]:

1. Develop a limiting water profile for each water-using process operation, based on maximum inlet and outlet concentrations for the water stream for each operation
2. Combine the limiting water-stream concentrations of all the process units together to construct the limiting composite curve for the overall plant
3. The minimum fresh water demand for the overall plant is determined by constructing a fresh water line that has the zero concentration point and an intermediate concentration as a point on the line. The intermediate point is called the pinch point
4. Develop the water-reuse network to achieve the minimum fresh water demand. Different network-design methodologies can be used.
5. The designed water network then must go through a simplification step

This method has the following drawbacks [24]:

1. Deals with one contaminant only. Through a very tedious iterative process more contaminants can be addressed, but integration of the different solutions into one solution is difficult.

2. The approach uses contaminant mass transfer as the basis for modelling. Many process units such as cooling towers, boilers, consistency/dilution control and heat exchangers can not readily be described as contaminant mass transfer units.
3. It is difficult to model situations, not uncommon to process plants, in which several water-based streams enter and leave a process unit at different concentrations.
4. The approach does not directly address practical constraints such as geographical distances (long pipes layouts), environmental factors, corrosion, scaling etc that my forbid re-use of water from one unit to another.

The graphical approach for a single contaminant will apply to multiple contaminants if only one contaminant is key, providing the other contaminants do not interfere with the transfer of the key contaminant. It will most often be necessary to take account of several (if not all) contaminants in targeting and design [23].

2.5.2 Graphical Demand and Source composite curves – Varying Flows [24]

Because of the limited application possibilities associated with the assumption of constant flow made in the water profile approach, a custom methodology has been developed that also suits the specific needs of the pulp and paper industry. In this approach, each relevant process or utility was considered as having aqueous input and output streams. There can be several of each, at different purities, in a single operation. The demand and source composite curves are an extension of the water profile curves, but are adopted for sources and sinks with varying flows. Figure 6 indicates the composite demand and source curves for the de-salter example (see Figure 4) constructed in a manner applicable to varying flow. The following is noted from Figure 6:

- Water flow rate (quantity) is represented on the horizontal axis and water purity (quality) on the vertical axis.
- The purity numbers on the vertical axis increase downward, not upward – thus purity is measured in terms of the amount of contaminant present. Hence, the composite curves are also referred to as source and sink curves or purity profiles.
- Each curve on the composite curves is made up of horizontal segments representing different water qualities, with connecting vertical lines. Only the horizontal segments have meaning.
- The length of each horizontal segment represents the flow of water at the purity indicated.
- Comparing Figure 5 to Figure 6, which has only two lines to represent the process, the approach for varying flow has four lines to represent the process.
- It can be seen that overlap F1 represents the flow of fresh water required.
- F2 presents the flow of effluent (fresh water contaminate with the salt) that will be generated.
- The shaded area indicates the scope for water re-use.
- The pinch point where the two curves touch limits the degree of re-use.

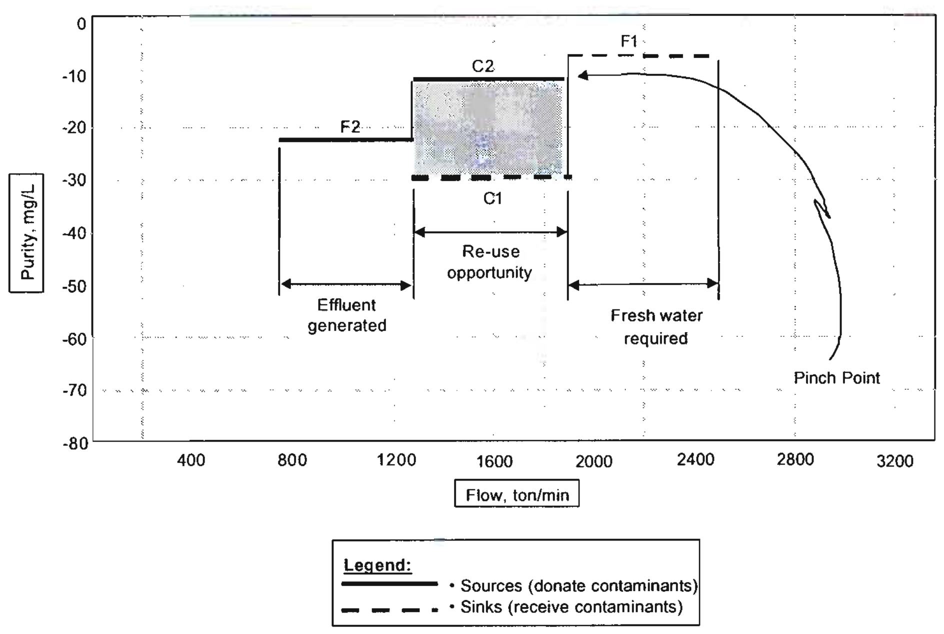


Figure 6: Example of a Demand-and-source composite [24, 11]* *Note that a negative sign is used to indicate the "purity" on the y-axis. This is because "purity" rather than "contaminant concentration" is used.

A more detailed example was used to show how the process network was developed from the composite curve and how the relaxation of the pinch point improves water usage [24, 11]. Figure 7 indicates the composite curve for process units A, B, C, D and E. The pinch point is what determines the degree to which the process can be closed. Looking at the pinch point of a particular flow system, typically the following information would be provided:

1. Optimal location of an extraction step
2. Minimum flow-rate to be treated
3. Minimum quantity of contaminant to be extracted
4. Which streams could be mixed to improve the quality of a stream? Typically mixing two streams can improve the quality of one of the streams that result in higher purity, this can result in moving the pinch point.
5. Which sources can be mixed with which sinks. Any source(s) of higher purity than a particular sink can be supplied to the source.
6. Sources should provide water to demands on the same side of the pinch (also see paragraph 4.3.4). Flow of water from a source above the pinch to a demand below the pinch will increase the consumption beyond the target. Using fresh water to satisfy demands below the pinch, or sending water from sources above the pinch to waste treatment, will have the same effect.

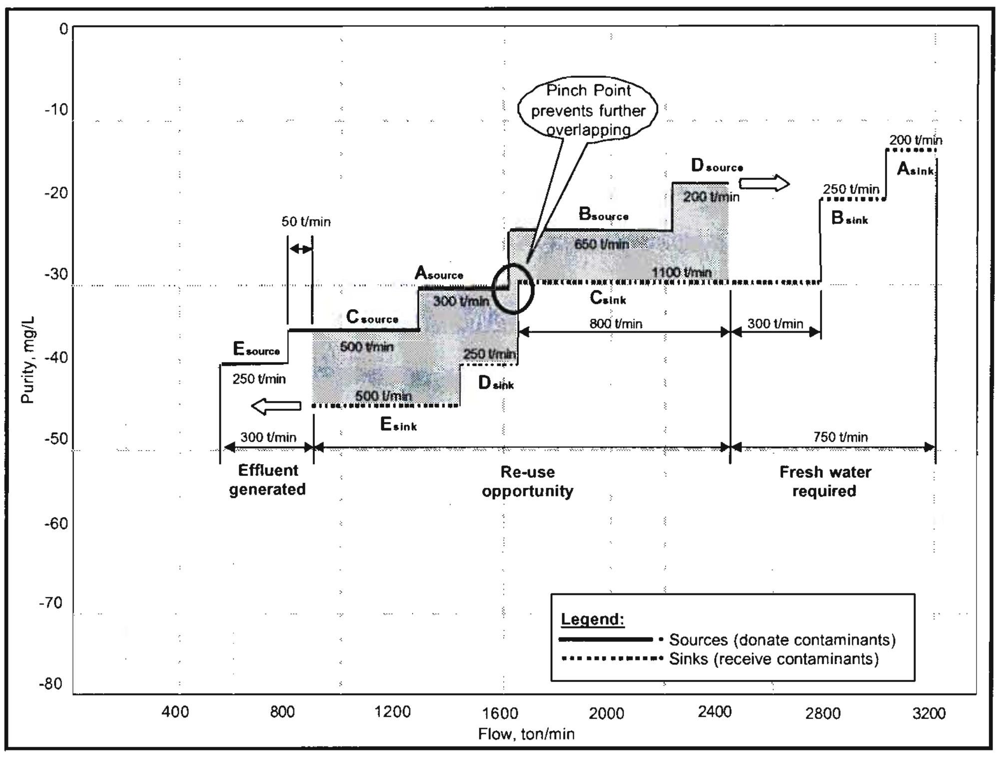


Figure 7: Example Composite curve for Varying flows Before Pinch Relaxation [24, 11]

The following can be seen from Figure 7:

- Fresh water flow of 750 t/min is required as make-up to process units A, B and C.
- Effluent flow of 350 t/min is generated from processes C and E.
- Because the quality of water from process A_{SOURCE} is too dirty (un-pure), it is not possible to overlap the two curves further. Only when the quality of stream A improves will it be possible to make the two curves overlaps further, i.e. relax the pinch.
- Alternatively the pinch can be relaxed if the purity requirement for C_{SINK} is relaxed. If it is possible for process C to receive water of a poorer quality (poorer purity), the reuse of water can be further increased (i.e. the pinch can be further relaxed).
- The composite curves indicate where opportunities are to:
  - Use different processes that have a higher tolerance for using water of a poorer quality. For example if C_{SINK} can be replaced with a process that can use poorer quality water, it would be possible to use water from A_{SOURCE} as feed.
  - Install effluent treatment process. For example if A_{SOURCE} can be treated to be cleaner, it would be possible to use A_{SOURCE} as make-up to C_{SINK}.

Figure 8 indicates how it is possible to shift (or relax) the pinch point thus making it possible for the two demand and source curves to overlap even further and thus reducing effluent generation and fresh water usage. The following can be seen from Figure 8:

- By mixing the water streams from A_{SOURCE} and B_{SOURCE} a mixed stream results. The purity of A_{SOURCE} improves when it is mixed with B_{SOURCE}. This mixed steam is suitable to use as feed to C_{SINK}.

- Mixing of A_{SOURCE} and B_{SOURCE} results in a water stream with a quality that is suitable for use in C_{SINK}.
- Only 450 t/min of fresh water is required as make-up.
- No effluent is generated by this process configuration.

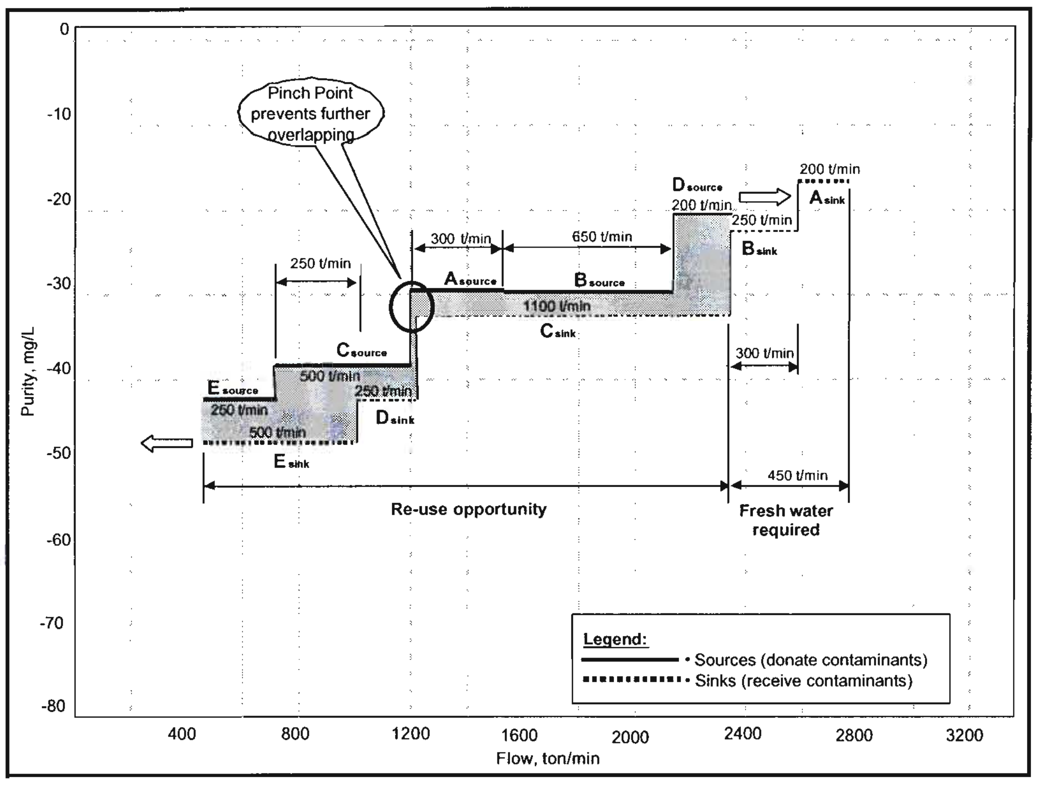


Figure 8: Example Composite curve for Varying flows After Pinch Relaxation [24, 11]

The composite curves in Figure 7 and Figure 8 were used to construct the process flow networks before and after relaxing the pinch respectively. The different process flow networks are depicted in Figure 9. From the composite curves, it is possible to see how much flow from the different sources must be supplied to the different sinks. It is evident that the as much as possible water from the dirtiest source must be supplied to the sink that can use the most of the dirtier water. For example, looking at Figure 7 it can be concluded that if water from the very clean source D_{SOURCE} is used as make-up to D_{SINK}, it would be necessary to add additional fresh water as make-up to C_{SINK}. Because only water with a high purity can be used in C_{SINK}, more fresh water is required. This also means that less of A_{SOURCE} can be used as make-up to D_{SINK}, and this means that more effluent is generated. The general rule is that mass must not be transferred across the pinch since this will always lead to more fresh water being used and/or more effluent being created. A similar rule applies for heat pinch techniques.

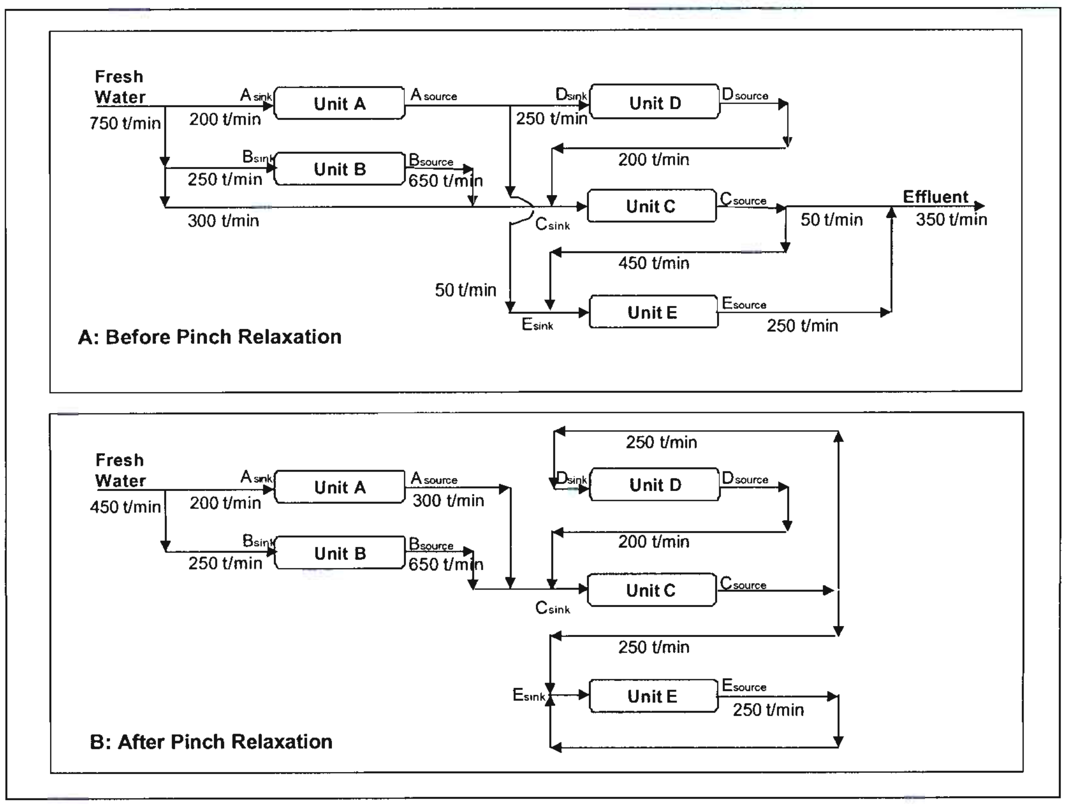


Figure 9: Process Flow Networks Constructed from Example Composite Curves[24, 11]

The example described in Figure 7 was done for a single component. When working with a process where more than one component is of interest, the technique is similar to the extent that composite curves and block flow diagrams have to be generated. Theoretically, composite curves have to be developed for every contaminant. Each contaminant will have an ideal design that meets its specific flow rate targets and concentration limitations. However, these targets will all be different and so will the designs needed to achieve them. In practicality, the various independent designs have to be merged into a common piping network that performs well for all contaminants. Achieving this optimal design configuration using graphical techniques can become tedious and extremely iterative so, a mathematical programming formulation using advanced algorithms must be used [5].

2.5.3 Numerical Solutions – Constant and Varying Flows

It is described in paragraph 2.5.2 that the graphical approaches were tedious iterative processes and do not always reach the optimal solution since the different problems are solved consecutively rather than simultaneously. The graphical approaches are limited to two dimensions that can only address one contaminant at a time. By expressing the problem numerically, more than one contaminant can be addressed at the same time. A wide range of approaches can be used to set-up the numerical equations that are either linear, non-linear, mixed integers etc.

Gianadda [30] describes the differences between linear and non-linear optimisation problems as follows: Depending on the nature of the constraints and the types of variable involved in the optimisation problem, different algorithms are required to solve the different optimisation problems which may arise. Linear programming (LP) problems contain only continuous variable and the constraints and objective functions are all linear. The solution techniques available for LP problems are guaranteed to find the global (as opposed to the local) optimal solution (see **Figure 30**). Mixed-integer linear programming (MILP) problems contain both discrete and continuous variable but the objective function and the constraint equations remain linear. Solution algorithms for MILP problems are similarly guaranteed to converge to the global optima. Should any of the constraint equations or the objective function of either the LP or MILP problems be non-linear, these problems are designated as non-linear programming (NLP) and mixed-integer non-linear programming (MINLP) problems respectively. Solution methods for both NLP and MINLP problems are likely to converge to local optima which may or may not coincide with the global optima; the exception to this the case of convex NLP problems for which any local optima is also the global optima. Despite not being able to determine the global optima with certainty, achieving solutions which are seemingly coincidental, or in the vicinity of the global optima remain an important aspect of the use of mathematical programming for water system design.

Jacob et al [31] formulated linear relationships between fines reduction and fresh water use. These relationships were solved using generic software. Argáez [32] on the other hand formulated a mixed integer non-linear (MINLP) relationship between different parameters and used cost as the target to optimise.

Figure 10 shows a superstructure model for two water-using operations and one single treatment unit. The following basic features of the model can be highlighted:

- Each fresh water stream entering the network is split towards all operations, including water-using and treatment options
- All the effluent streams generated from each operation are mixed in final discharge points, where the environmental limitations must hold
- Prior to each operation a mixer is considered, where the flow from the freshwater splitters and re-use flow from all other operations are merged into a flow towards the operation
- After each operation a splitter is considered, from which potential flows are driven towards the final mixer and the other operations in the system.

The superstructure enables the exploration of the complex trade-offs that may arise between the minimum water demand and effluent treatment and between network cost and environmental performance, when cost is used as target objective.

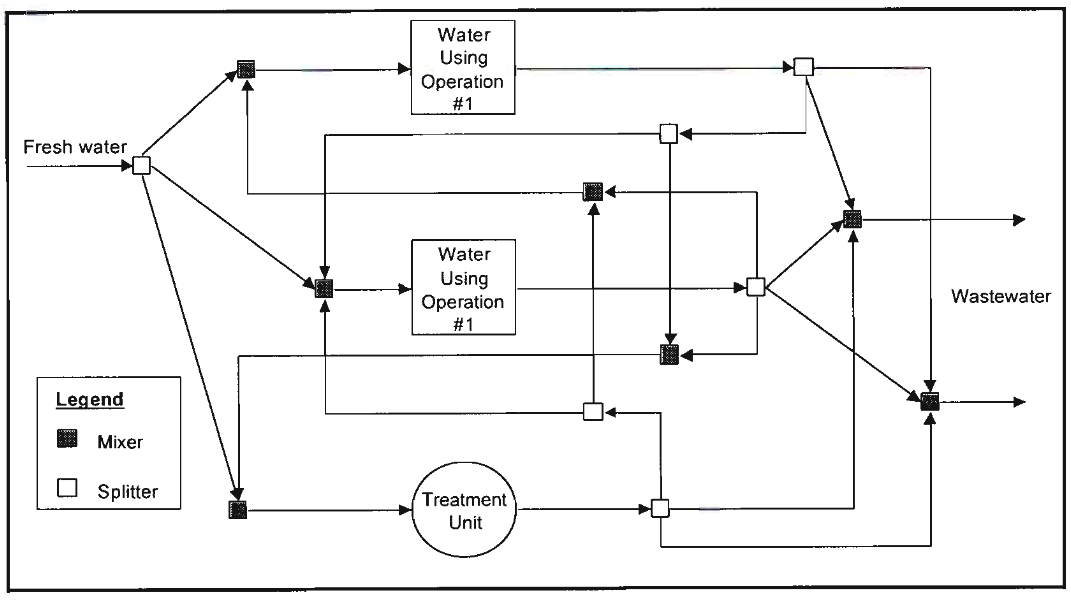


Figure 10: Superstructure representation [32]

Doing mass balances around the operations, mixers and splitters of the superstructure, and including capacity constraints, design equations, cost calculations and logical statements concludes the following objective function (See reference 32 for details to equation symbols):

$$Cost^{TAC} = \left(\sum_{j \in J} Cost_j^{supp} \right) + \left(\sum_{j \in J} \sum_{i \in I} Cost_{j,i}^{pipeFw} + \sum_{i \in I} \sum_{i' \in I} Cost_{i,i'}^{pipeP} + \sum_{e \in E} \sum_{i \in I} Cost_{i,e}^{pipeOUT} \right) + \left(\sum_{i \in I_{TR}} Cost_i^{T} \right) + \left(\sum_{i \in I_{ME}} Cost_i^{ME} \right)$$

In the objection function the different mass balances and constraints were expressed as a cost, thus the objection function is the minimisation of the sum of freshwater costs, piping costs, treatment costs and mass exchanger costs.

The solution to this mixed integer non-linear programming optimisation problem gives a proposed optimal structure for the water network, as well as operating flows and concentrations of contaminants in each connection. To solve mixed integer non-linear program equations, various solvers such as GAMS can be used [33]. Caution must however be taken with numerical solutions due to the nature of numerical solvers. Certain approaches often find a local optima far away from the global optimal solution [26]. Depending on the initial values given to a numerical solver, different local optimal solutions can be reached. Initial values for the variables which satisfy most the constraints and which, if possible, are located in the same region of space as the global optima are more likely to converge to the global optima [34, 35].

2.5.4 Combination of Graphical and Numerical Techniques [11]

Isolated use of the graphical or numerical techniques prevents having the advantages associated with both techniques. When the two techniques are used in conjunction, the following advantages are realised:

- Graphical visualisation of the problem provides better insight and interaction with the engineer. This makes decision making, screening of solutions and adjustments to the problem definition easier and quicker.
- Numerical solutions provides for a more systematic approach, making it possible to investigate numerous solutions and

The software used (WaterPinch™) in this thesis provides for both the numerical and graphical approaches. The numerical approach was used to reach the different solutions and the solutions were then represented in numerical and graphical format. The graphical side of the software does not participate in arriving at a solution, but was merely used to represent results obtained from the numerical computations.

The WaterPinch™ software determines the configuration of the water-using network that minimises the cost associated with the water usage. In addition it determines the areas of the system where further engineering effort should be focused by means of the sensitivity analysis [36].

2.6 General Algebraic Modelling System (GAMS)

It is common practice to use a computer-based approach for the solution of mathematical programming problems. Aside from the task of formulating the problem in the mathematical sense, some effort is required to convert the problem into a format which can be handled by the specific optimisation algorithm chosen to solve the problem, an activity which can prove time-consuming. Circumventing this step has been one of the primary motivations in the development of the software language GAMS. GAMS is a high-level language for the compact representation of large and complex optimisation problems [30]. The WaterPinch™ software makes use of GAMS to solve the equations generated by the user of the software through the user interface environment.

The problem is formulated using consistent notation within a common development environment, termed the Integrated Development Environment (IDE), which is independent of the nature of the problem. This implies that whether the problem conforms to an LP, MILP, NLP or MINLP problem, it is independent of the solution algorithm required to solve the problem. Logical operators available within the IDE can be used to eliminate terms from the model as it is constructed for the optimisation algorithm, should certain criteria for term inclusion not be met. Hence, the introduction of a connectivity matrix of ones and zeros, which correspond to the logical possibility of a connection between a particular source and a particular sink with in the process system, inappropriate matches can be eliminated from the superstructure from the outset [30]. This connectivity matrix is populated via the bounds editor table in the WaterPinch™ software.

The directional search procedure of a feasible path algorithm is based on the strategy of first finding an initial and feasible point, that is, one that satisfies all of the model constraints, and then using the derivatives of the objective function at this feasible point to determine the search direction that should be followed such that a better feasible point is found. This new point is used in the succeeding search step. Given that the progress of the optimisation algorithm towards the optimal solution is via a series of feasible solutions, each one better than the previous, the whole procedure relies on the initial feasible solution and the derivatives at this point. In addition, given that non-convexities are present in the model, multiple local optima may be present within the search space and thus an initial point in the vicinity of the global optimal solution is more likely to converge to the global optimal solution [30, 35].

According to Gianadda [30] the sensitivity graphs generated by WaterPinch™ are a carried forward from the GAMS marginal values. Not all marginal values from GAMS are carried through. The meaning of the marginal value in terms of the objective value is discussed in detail in most texts on mathematical programming (see paragraph 2.7). The crude but useful definition is that it is the amount by which the objective function would change if the equation level were moved one unit, this is often called reduced cost or dual values. The values, which are meaningful only for non-basic rows or columns in optimal solution, contain information about the rate at which the objective value will change if the associated bound or right hand side is changed [37].

Gianadda proved that the sensitivities provided by WaterPinch™ sometimes agrees with the sensitivities provided by GAMS when doing problem formulations using WaterPinch™ compared to formulating the problem in GAMS without the aid of the WaterPinch™ user interface [30]. Software packages such as WaterPinch™ selectively highlight marginal values from GAMS and present the values in sensitivity graphs. These sensitivity graphs are special cases of the marginal values and include concentration and flow [according to WaterPinch™ help file 8]. Gianadda continues to conclude that in the absence of more advanced approaches, it is still possible to identify substantial savings using the standard approaches utilised by WaterPinch™.

Gianadda concluded that if it is assumed that all the parameters associated with the design and performance of the plant under study and the regeneration procedure are correct, that is, that the model for the system is representative of the actual design and performance of the operation concerned, then the sensitivities (marginal values) reported by the optimisation algorithm must correspond to the quantity and the quality associated with the raw water being treated by the plant. If it is assumed further that the quantity of water processed by the plant is unable to change, then the sensitivities arise purely from the quality of the water entering the plant. The sensitivities thus generated for concentration represent the economic saving per unit change in the mass fraction of the species in the effluent water [30].

Gianadda used marginal values provided by the GAMS optimisation algorithm to identify pinch constraints and process interventions [30].

2.7 Definition of the Pinch Point

The definition of the pinch point is given by different references as:

- Numerous references indicate the pinch graphically as the point where limiting composite curve and the water supply line touch [29, 22]
- "In this context, the 'pinch' refers to the particular constraint, or set of constraints, which ultimately limits any further improvement in water use by the system. In general the pinch will be a function of the particular choice of technology used in the system, and the particular set of environmental constraints arising out of its location." [38].
- Brouckaert et al had the following to say about the use of sensitivity graphs in WaterPinch™ – "A feature of the WaterPinch™ software is a sensitivity analysis tool that calculates the effect of relaxing limiting concentration constraints of the water-using network and hence, determines scope for further improvement. This sensitivity analysis is equivalent to determining the pinch point for the system: the constraint with the greatest sensitivity coefficient can be viewed as constituting the pinch" [38].
- Brouckaert says: In the Linnhoff-March framework, these concentration sensitivities *[marginal values generated by GAMS]* take the place of the pinch concentration in the simple graphical approach [39].
- Argaez had the following to say regarding the development of a numerical optimiser – "Former limitations of the water pinch method to address multiple contaminants are now overcome as there are, in principle, no limits to the number of components or the number of fresh water sources" [32].
- Brouckaert says that in that in the past water pinch analysis has largely focussed on concentration constraints, and has developed various elegant techniques for handling them. This is particular true

of the graphical pinch analysis techniques, and it is notable that, in the current water pinch analysis literature, the "pinch" itself refers to a concentration limit. This emphasis on concentration limits has been carried over into the versions of pinch analyses that are based on the use of general-purpose optimisation algorithms, such as the version of the Linnhoff-March WaterPinch™ software [39].

- Gianadda reports that the use of mathematical programming has made it possible to do targeting and design simultaneously, thus making the identification of the pinch for design purposes obsolete. However, from the perspective of gaining insight into the system, the identification of the pinch point remains the key element in reported studies [30].

Gianadda gives a comprehensive literature summary of the pinch concept, some of the concepts and definitions are given [30]:

- The first applications of Pinch analysis occurred in the area of heat integration in the late 1970's [40]. For heat pinch the identification of the pinch point for the system served as an indication that the maximum level of heat integration between two sets of streams had been achieved. The pinch point further served as a significant point around which a design procedure was developed. In this context the pinch point corresponded to a temperature.
- Oleson and Polley [41] consider the pinch point as a significant concentration relative to which process operations should be placed in achieving a network design which meets the predicted target.
- Dhole et al [24] define the pinch point as the point where the source and demand composite curves overlap, which is representative of the level of reuse in the system. This is limited by the pinch point.
- Sorin and Bédard [42] comment that the Two-Composite methodology produces a number of local pinch points where the source and demand composite curves touch each other and that this leads to an obscuring of the concept of the pinch point. The global pinch point is introduced by these authors to provide consistency between the pinch point defined by Wang and Smith [23] and the pinch point defined by Dhole et al [24]. The global pinch point corresponds to the species concentration of the purest source for which a portion is diverted to effluent without there being an increase in the freshwater consumption by the system.
- Other researchers identify two different pinch points. Kuo and Smith [27] identify both freshwater and regeneration pinch points, as do Castro et al [43] and Mann and Liu [44].
- Gianadda [30] notes that the general interpretations of the pinch point presented by these researchers is that the pinch is a mass-transfer or mass-balance concept. It identifies a thermodynamic limit that prevents a further reduction in the amount of freshwater used by the system.
- Gianadda [30] comments that for systems involving only a single contaminant, it is possible to identify the pinch point using a graphical approach, as has been shown by these researchers. This is because the optimisation problem is one-dimensional. When the system involves more than one contaminant, the optimisation problem becomes multidimensional and the identification of the pinch point is more difficult using a graphical approach.
- In addressing the problem of more than one contaminant, Wang and Smith [23]) introduced a concentration shifting procedure such that it is possible to identify the pinch point for a system involving multiple contaminants using a graphical approach.
- Gianadda [30] continues to note that a further problem with the graphical approach is that it involves the minimisation of a single freshwater resource only. While multiple sources of freshwater were considered by Wang and Smith [22], the incorporation of the different costs associated with these resources remained implicit.
- Gianadda [30] also notes that the graphical approaches presented thus far only considered non-reactive contaminants. The current approaches of weighting systems have uncertainty in their usefulness, given that the motivation for his type of problem would most likely involve the minimisation of cost.

- Gianadda [30] notes that contrary to the graphical approaches, mathematical programming allows problems involving multiple species and multiple resources to be solved. Constraints such as enforced and forbidden matches between process operations and minimum flow rates through process operation may be incorporated in the problem statement. In providing a weighting system to represent the relative significance of the different resources in the problem, economic cost may be used, although other weighting systems, such as environmental impact or the suggested thermodynamic weighting system, could be used.
- Gianadda [30] asks the question of how the pinch should be interpreted in the mathematical situation? With mathematical programming economic considerations may lead to a design optima that does not observe the pinch restrictions of no-cross pinch use of a resource. The reuse of resources may further be limited by an enforced match or a minimum flow rate to an operation, the nature of the pinch is thus no longer thermodynamically based.
- Gianadda [30] concludes that the mathematical definition of a pinch is measured in terms of cost of resources, rather than a thermodynamic basis. The pinch relates to a constraint or set of constraints rather than a pinch point.
- According to Gianadda [30] there are two basic approaches to define the pinch in mathematical programming:
  - **Approach 1:** It is a trend in at least two of the commercially available water-reuse network design packages to construct composite curves from the data provided by the optimisation algorithm (Dhole et al., [24]; Tainsh and Rudman, [45]; Koufos and Retsina, [5]). These composite curves correspond to those of the two-composite methodology and for problems involving multiple contaminants, the curves are plotted separately for each contaminant. Doyle and Smith [26] propose a methodology for the construction of a composite curve for a system of mass-exchange type operation involving multiple contaminants from the solution provided by an optimisation algorithm. A shifting procedure similar to that proposed by Wang and Smith [23] is used to account for the multiple contaminant nature of the problem. It is noted by these authors that the construction includes flow and forbidden match constraints in addition to concentration constraints. While this statement does apply to both cases in that these constraints are incorporated into the mathematical programming problem, the composite curves do not provide complete insight into why the pinch arises. In plotting the solution on the concentration versus water flow axes, only the contaminant concentration constraints are represented. The pinch, as it is defined above, may however result from an enforced match or may be due to a minimum flow rate requirement constraint associated with some operation in the process system. These constraints are however not explicitly evident from the concentration composite curves.
  - **Approach 2:** The second approach for identifying process interventions for water-reuse networks is the use of marginal values which are available from the solution provided by the mathematical software. These measures identify which are the most significant constraints in the problem and provide and indication of what the incentives are if these constraints are relaxed (Rossiter and Nath, [25]). The use of these values as a means of identifying process interventions is noted by Mann and Liu [44] and implemented in the WaterPinch™ software (Linnhoff March Limited, [8]). Some insight into these values is now provided: The set of constraints associated with an optimisation problem is divided into a set of equality constraints and a set of inequality constraints. The inequality constraints are of the form:

    $$g(x) \leq 0 \quad \text{.......} 2.7a$$

    where g(x) is an arbitrary constraint and x represents the set of variable adjusted during the course of the optimisation. When the left-hand side of the Equation 2.7a is equal to the right-hand side, that is, the equality is active, the objective variable in a minimisation problem will be prevented from decreasing further by this constraint. As such, there is a sensitivity associated with the objective variable with respect to this (equality) constraint and the marginal value associated with this constraint is a manifestation of this sensitivity. The constraint functions g(x) will have parameters which are considered as constant during the optimisation. The marginal values associated with a constraint provide a quantification of the effect on the objective variable should one of the constants within the constraint equation change by an infinitesimal amount. Mathematically, should the (equality) constraint g(x) change by an infinitesimal amount ε such that:

$$g(x) - \varepsilon = 0 \quad \text{.......................................2.7b}$$

then the marginal value λ associated with the constraint corresponds to:

$$\frac{\partial Z}{\partial \varepsilon} = \lambda \quad \text{.......................................2.7c}$$

where Z is the constrained objective function for the problem as evaluated at the optima. The derivation of Equation 2.7c is part of basic optimisation theory and is available in standard optimisation texts such as Wilde and Beightler [46] and Edgar et al. [34].

Marginal values are reported for all active constraints, that is, equalities and inequalities which have reached their bounds. Marginal values thus represent the sensitivity of the system to all constraints rather than only certain constraints, for example, such as concentration constraints. As such they direct attention to those areas of the system for which interventions will have the greatest impact. Unfortunately they are only valid in a very limited range around the current optimal point and there is no indication as to the size of this range. In terms of the definition of the pinch, it will be a particular constraint or set of constraints which prevents a further reduction in the cost associated with the system. In relaxing these constraints, that is, adjusting their values such that they become less restrictive, a point will be reached where another constraint or set of constraints becomes active. This constraint or set of constraints corresponds to a new pinch and different marginal values will be reported by the optimisation algorithm for this set of active constraints.

- As an illustration of these concepts, the example of a system of mass-exchange operation of the type considered by Wang and Smith [23] is used. For this system the set of pinch constraints will include a concentration limit associated with the inlet or outlet of one of the mass-exchange operations. This problem is described in terms of a fixed mass-load addit ion as shown in Equation 2.7d.

  $$\Delta m = F_W * (C_w^{out} - C_w^{in}) \quad \text{.......................................2.7d}$$

  where Δm is the mass-load of contaminant transferred from the process stream to the water stream in a particular operation, F_W is the water flow rate through that operation, and C_W^{in} and C_W^{out} are the contaminant concentrations at the inlet and outlet to the operation respectively. In this situation, the pinch arises due to a combination of these factors rather than only the concentration limits, only the flow rate through the operation or only the mass-load of contaminant transferred to the water stream. Thus, in identifying interventions which will reduce the flow rate target of the network, an intervention which achieves an adjustment to any one of these variable may be effective in reducing the water demand of the process; some factors are of course more easily adjusted than others. It is however noted that all variables cannot vary independently since they are related by Equation 2.7d. Given the variety of constraints associa ted with the problem, the use of information derived from the marginal values is favoured in identifying the significant areas of the problem that should be explored as candidates for process interventions.
- The term water pinch analysis itself has become popularised through the availability of Linnhoff March's commercial software package WaterTarget™ with its pinch analysis module

WaterPinch^{TM}. Academically too, the use of mathematical programming in conjunction with insights from pinch analysis is gaining recognition as water pinch analysis [30].

2.8 Application of Water Pinch in the Pulp and Paper industry

Literature references for the application of water pinch in the pulp and paper industry is limited. Numerous papers on the theory of pinch, development of pinch and descriptions on hybrid pinch methods are available. By hybrid pinch applications reference was made to different graphical and numerical methods applied to that being used in this investigation, i.e. WaterPinch^{TM}. Listed below are examples of the application of WaterPinch^{TM}.

- The following example is not from the paper industry, but is cited to indicate how a single contaminant, i.e. COD, is used to represent more than one contaminant. The same principle can be applied in the pulp and paper industry. At Monsanto Chemical (Newport, Wales) effluent from seven process units at Monsanto's site were collected together and adjusted for pH before being discharged into the River Severn estuary. A WaterPinch^{TM} realised the following benefits:
  - Fresh water could be reduced by 30%
  - Reduced COD load by 76% in effluent stream
  - Final effluent volume to be treated was reduced by 95%
  - Gained an operating cost saving of $1 million annually
- Jacob et al [31] applied the graphical pinch on the alkaline and acid loops of a de-inking plant in Quebec. The pinch analyses did not produce any significant improvements for the acid loop because the process was already well closed and the proposed network was similar to the existing one. The alkaline loop also did not provide any water savings but indicated that it was possible to dispense of a filtration step thus reducing operating cost, but may reduce operation flexibility. A graphical pinch was also performed on the whitewater network of a Thermo-mechanical pulping Newsprint machine, this produced no water savings and confirmed the existing network configuration. Applying the numerical pinch to an integrated thermo-mechanical pulp and Newsprint mill yielded a two third reduction of the fresh water consumption.
- Brouckaert et al [38] applied WaterPinch^{TM} on the Sappi Tugela mill in South Africa to demonstrate that both the river and the mill would benefit from changing the effluent concentration limits to load based limits. The benefit to the mill was that it could treat and recycle effluent at a lower treatment cost, without exceeding the load discharge limit. The recommendations from this investigation was not final and needed further detailed studies.
- The Parenco paper mill in Holland produces newsprint from recycled waste paper. Fresh water is obtained from on-site wells at 55°F, and used for once through cooling before it is sent to the process. The main water pinch project involved re-routing relatively clean DAF effluent from the de-inking pulper and reducing the white water overflow to sewer. The potential savings were 111 ton/hour of fresh water, or a 23% saving [45].

It is concluded that some case studies do exist for the successful application of WaterPinch^{TM}, although its application in the pulp and paper industry has been limited.

2.9 Conclusions on Literature study

The following comments and summaries on the literature search are present as additional clarification:

- Various definitions and jargon are used to describe the approaches followed to optimise mills, terms such as "zero liquid effluent" (ZLE) and "minimum impact mill" (MIM). Other concepts such as Best Available Technology (BAT) and Best Practice (BP) were also mentioned and discussed in the quest to achieve a sustainable mill. Ultimately none of the approaches defines the final and best solution. In other words, many of the approaches were dependent on the legislation, politics and environment in which the mill is embedded. For one mill it might be sustainable to close-up the mill, with all the associated heavy capital investment and high variable production cost, while another mill might not consider it feasible. To find the best solution for any mill is ultimately too complex and unique to be captured by any one approach only. Each mill has to take the best of each approach, philosophy and technical suggestions to reach a sustainable solution. What was however evident from literature was that it was very well understood how good the environmental performance of different types of mills could be.

- It was concluded that Ngodwana was a realistic representation of an Integrated Pulp and Paper Kraft Mill with an already highly closed water system, when comparing the mill's water use with EPA standards.
- The important developments in the pinch technique are summarised as:
  1. Development of heat pinch for energy saving
  2. The heat pinch concept was extended to the water pinch technique for constant flow systems. This is a graphical technique with limited application opportunity and for single contaminants only.
  3. The graphical technique for constant flows was adjusted to also cater for varying flow processes. This is also a graphical technique with fewer limitations than the constant flow technique, but is also limited to a single contaminant system.
  4. The limitations of single contaminants and tedious iterations of the graphical techniques were engineered out with the development of numerical optimisers. GAMS is used as a solver for optimising equations and also presents marginal values which are an indication of sensitivity of parameters to change. GAMS calculates marginal values for all variables. Off-the-shelf software packages such as WaterPinch™ serves as a user-friendly interface between GAMS and the user. Marginal values from GAMS are selectively presented to the user as sensitivity values. Assuming that flows are constant to the different sinks and from the different sources, and assuming that all other variables are correct and constant, it is practical to assume that concentrations are the only variables. WaterPinch™ presents the sensitivity of the network to concentrations. This technique combines the graphical approach for varying flow (see 2.5.2) and mathematical solutions. This technique handles multiple contaminants and was applied in this investigation.
- Numerical and graphical methods were used in water pinch. The numerical approach has certain advantage and disadvantages compared to the graphical approach, these are listed:
  - The advantages associated with the numerical technique are:
    - More than one contaminant can be handled at the same time. An integrated solution was achieved.
    - Various factors can be included in the problem statement for consideration in achieving the final solution. This includes raw material cost, treatment costs, environmental impacts, geographical layout of the plant, solid waste disposal and many more.
    - The use of PC's and formulation of integrated problem statements make it possible to cover a wide range of solutions and options
  - The disadvantages associated with the numerical technique are:
    - More information is required to formulate the problem statement accurately
    - Complicated and involved solvers have to be used to solve the equations generated in the problem statement. These solvers require understanding, computing power and basic engineering and mathematical understanding.
    - The number of solutions given from numerical solvers could be confusing and difficult to interpret.
- Water pinch is part of toolbox of process improvement techniques or approaches that can be used. With the increased levels of process complexity, more competitive profit margins between companies, stricter legislation or permit requirements and more power to communities to put

pressure on industry; it has become necessary to develop engineering tools that could help to meet these requirements.

- Considerable development has gone into the graphical determination of the pinch point, but due to the limitation of being restricted to a single contaminant it has very little to no scope for application in the pulp and paper industry.
- The classical method of presenting the pinch as a two dimensional graph has proved to be outdated and of very little use for multi-contaminant systems.
- Some numerical solvers generate a superstructure representation of the design problem where all the elements of the total water system are considered. The **sources** comprise of internal and external sources. External sources comprise streams from outside the boundary of the studied process and typically include fresh water. Internal sources are streams generated from the process units in the process and include streams like effluent streams, filter filtrate, condensates etc. **Sinks** also include internal and external sinks. External sinks normally have an environmental or cost penalties associated with them and are outside the boundary of the process being studied. Typically, external sinks include municipal treatment facilities or the environment (i.e. rivers and irrigation fields). The last component to any water system is the bounds imposed on it. When connecting sources with sinks to find the optimal network, certain bounds have to be adhered to. Numerical approaches generate a variety of possible networks by linking the sources and sinks while complying with the bounds imposed on the network. One way to generate possible networks is to generate equations that cover all possible connections, this superstructure is then optimised to find the optimal solution based on the bounds imposed. Different criteria can be used as optimisation parameter, one such parameter is cost.
- Figure 11 indicates that any water system comprise of three component, these are:
  - Sources,
  - Nodes or Bounds and
  - Sinks

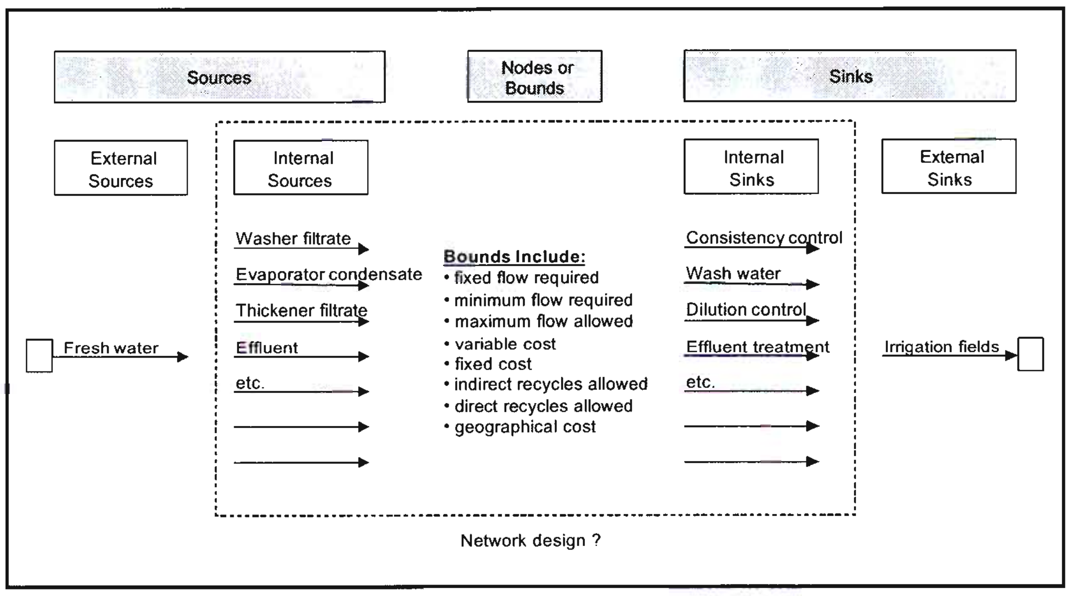


Figure 11: Elements of total water system design

Chapter 3 Background

3.1 Details of Ngodwana Mill

3.1.1 Background

The mill is situated approximately 45 kilometres west of Nelspruit next to the main road that links the larger highveld cities of South Africa to Maputo via the 'Maputo Corridor'. The mill is situated at the confluence of the Elands River and the smaller Ngodwana River. Apart from being situated inland next to small rivers the mill is also situated in a scenic valley where conservation, tobacco farming and tourism are of high importance. This sensitive geographical location of the mill necessitates high environmental focus and continual improvement in terms of reducing environmental impact. The mill is one of the lowest effluent producing mills of its type in the world, at only about 17 kL per ton of product produced. Apart from heavy capital investment in technology to improve the fresh water use and effluent generation volumes, the mill also has advanced and mature management systems. Ngodwana mill is ISO 9000:2000, ISO14001 and OHSAS 18000 certified, which provides an essential basis for quality, environmental and safety management respectively. Within the guidelines of these standards the mill runs a paperless integrated system to ensure that best operating practices, specifications, procedures, preventative and corrective action systems and maintenance practices are up to date and easily accessible to mill personnel.

3.1.2 History

1966: Ngodwana mill commissioning #1 fibre line unbleached softwood at 217 ton per day.
1983: Newsprint and Groundwood plant commissioned
1984: #2 Fibre line with conventional bleach plant commissioned
1985: Kraft Liner Board machine commissioned
1986/1988: Two turbines were installed at 117 MW
1995: Installation of the ozone bleaching facility at the Ngodwana mill was completed.

The excavation work at Ngodwana started in February 1964 with the first pulp produced (from the No. 1 Fiberline) in 1966. The Mill was officially opened in 1967 [1]. Plans to expand Ngodwana Mill were approved in 1981 and construction began in August of the same year. The first part of the three phase expansion saw the installation of a 150 000 ton per annum Newsprint machine, which started production in September 1983. Next came a pulping and bleaching plant with a capacity of 300 000 tpa, the first pulp being produced in August 1984. The third phase the 220 000 tpa Kraft Linerboard machine, came on line in March 1985. Other milestones include the commissioning of the 45-Megawatt generator in July 1986 and the second generator in August 1988.

3.1.3 Core Business

Ngodwana produces pulp and a paper from the Kraft pulping process. Over half of Ngodwana's output is for local consumption and the rest is exported to countries all over the world. The mill has the following production capacities (ton per annum):

• Unbleached pulp (from digester #1 and #2)	= 220 000
• Bleached pulp (from ECF bleach plant)	= 240 000
• Mechanical Stone Groundwood pulp (used on Newsprint)	= 110 000
• Newsprint and other mechanical grades paper (from paper machine #2)	= 150 000
• Kraft and White Top Liner board paper (from paper machine #1 and waste plant)	= 250 000
	970 000

3.1.4 Manufacturing Modes

The mill has various production modes it can operate and alternate between to produce products for specific markets. The following permutations of manufacturing modes exist in the pulp and paper mills:

- In the pulp mill the digester #1 and #2 can alternate between hardwood (gum or eucalyptus) and softwood (pine or pinus) production. At any stage any of the two digesters can produce either hardwood or softwood pulp. Typically the following production ratios are maintained on the two digesters between hardwood and softwood:
  - No. 1 Digester : - Unbleached 31 % hardwood
    - 69 % softwood
  - No. 2 Digester - Bleached 22 % hardwood
    - 78 % softwood
  - Digesters' production capacities:
    - Digester #1 = 350 t/d
    - Digester #2 = 850 t/d
  - 75% of the mill's production is as softwood
- The bleach plant can alternate between producing bleached pulp with either conventional bleaching or ozone (elemental chlorine free, ECF) bleaching. The wood type being bleached changes as digester #2 alternates between hardwood and softwood. The mill currently does not use the conventional bleaching capabilities of the bleach plant for environmental reasons. Approximately 20 ton per day of chloride (as Cl^-) is produced from conventional bleaching, whilst only about 9 ton per day is produced with ECF bleaching.
- Paper machine #1 can change between producing Kraft Liner board (KLB) or White top line (WTL) paper. The KLB paper does not include bleached pulp, whereas the WTL paper includes bleached pulp as the top layer.

3.1.5 Mill Layout and Fibre Processes

The mill is divided into the pulp mill, the paper mill and a storage area (pulp, noodle and reel slab) between the two sections. The storage area allows the pulp and paper mill to run independently of each other for short periods. This means that the paper mill can run while the pulp mill is shut down. Figure 12 shows the general layout of the mill, indicating that the mill consists of the pulp and the paper mill, separated by a storage area in between. The figure also indicates that the mill is composed of twenty-three sections.

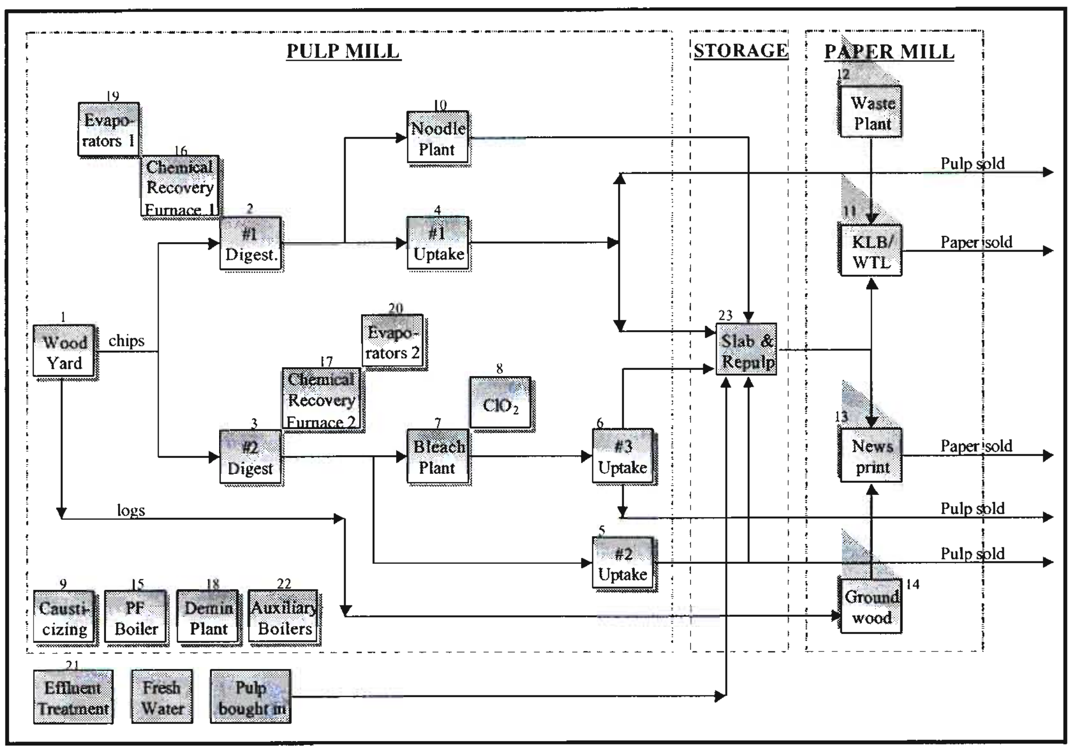


Figure 12: General Fibre Flow Schematic

Following the schematic from left to right wood enters the woodyard as logs and as chips. Some of the logs are debarked, chipped, screened and stored on the hardwood and softwood chip piles respectively. The remainder of the logs are used in the groundwood plant for mechanical pulping, and is not chipped. From the woodyard chip storage piles (hardwood and/or softwood), the two continuous digesters are supplied. The #1 digester has a capacity of approximately 340 ADt/d and is the older digester of two. The #2 digester has a capacity of approximately 950 ADt/d. The two digesters are the starting points of what is referred to as the two fibre lines. #1 Digester with the noodle plant and Uptake #1 machine is known as the #1 fibre line, while the #2 digester, the bleach plant, the Uptake #2 and the Uptake #3 are known as the #2 fibre line. Both digesters have their own dedicated chemical recovery circuit with a shared causticising section. The two recovery systems complement each other, meaning that if the #1 digester is running at low rates, then the #1 chemical recovery furnace and #1 evaporator set can be put off-line. Chemical recovery #2 and evaporator #2 can receive liquor from recovery #1 when it is off line, to run at an increased rate. The Uptake machines are pulp-drying machines. Uptake #1 and #2 are dedicated to drying unbleached pulp while #3 uptake is a dedicated bleached pulp drying machine. The noodle plant presses the pulp dry to be stored in a noodle form, ready for repulping as the need arises in the paper mill. The bleach plant has a capacity of about 620 ADt/d and has the option to bleach according to two different bleaching sequences. The conventional bleaching sequence involves the utilisation of chlorine, this sequence is the O-D/C-E-D (oxygen, chlorine dioxide with some chlorine, a caustic extraction stage and a final chlorine dioxide bleaching stage) sequence. The practice of running conventional bleaching has been stopped by the mill due to environmental reasons. Alternatively the bleach plant can run an elemental chlorine free (ECF) sequence that uses ozone instead of chlorine, the sequence is O-Z-D-E-D. The causticising section has one kiln with a production capacity of approximately 340 t/d (as pure CaO), the other usual process units are slaker, with three causticising reactors, clarifiers and drum dregs filter. The pulverised fuel boiler burns pulverised coal and also waste bark and sawdust as fuel. From the pulverised fuel boiler and the #2 chemical recovery furnace the mill is supplied with steam. The mill also generates about 40% of its own power from two turbines (45 and 55 MW).

Bleached and unbleached pulp from the pulp plant is either sold or stored on the pulp slab to be repulped and used by the paper mill. From the pulp slab (or pulp storage) the pulp is repulped in four repulpers from which two paper machines are fed. The one paper machine is a three-ply fourdrinier, and uses recycled paper for the middle ply. This machine is used interchangeably for kraft linerboard or white top line production. The second paper machine is a newsprint machine. The newsprint machine also receives pulp from the groundwood plant. The groundwood plant has eight atmospheric stone grinders and two pressure stone grinders.

Figure 13 depicts the general mill layout. The irrigation fields are approximately 4 kilometres west (left of Figure 13) of the mill and all effluent generated in the mill has to be pumped to irrigation fields for irrigation purposes.

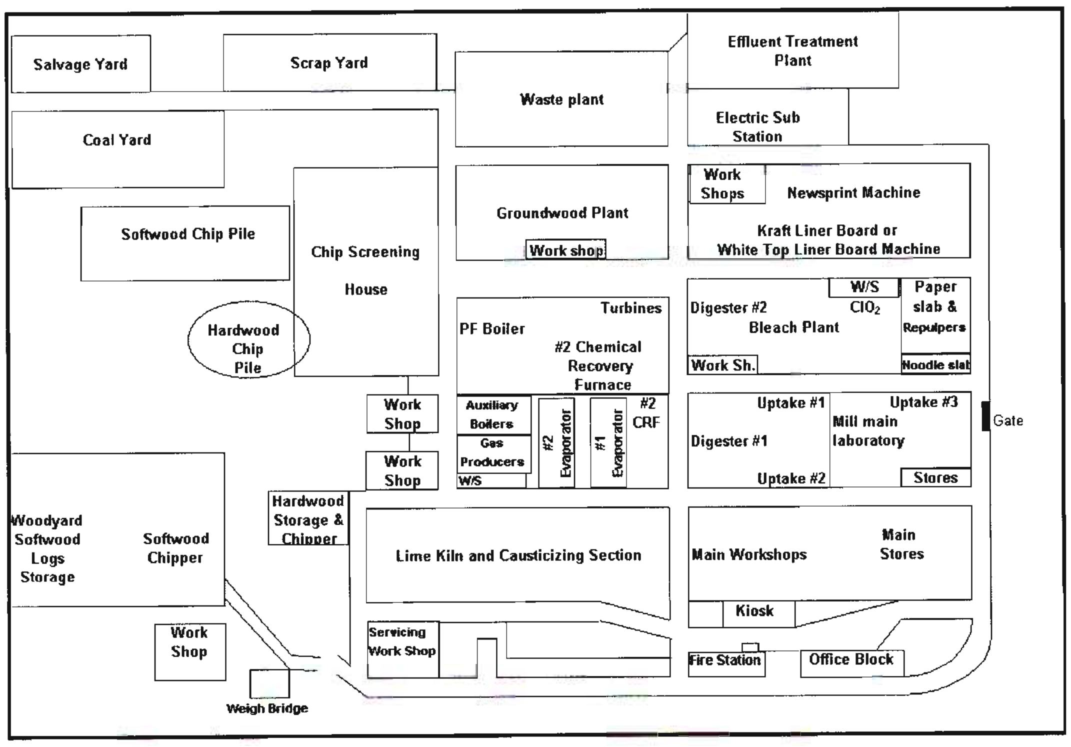


Figure 13: General Mill Layout (not to scale)

3.1.6 Mill Chemical Processes

Kraft pulp mills are known for the different nomenclature used to describe the different chemical streams involved in the chemical circuit and Ngodwana is no exception. A schematic explanation of the chemistry is given in **Figure 14**. A summary of the processes are given and detailed process flow schematic is given in Appendix 8.6:

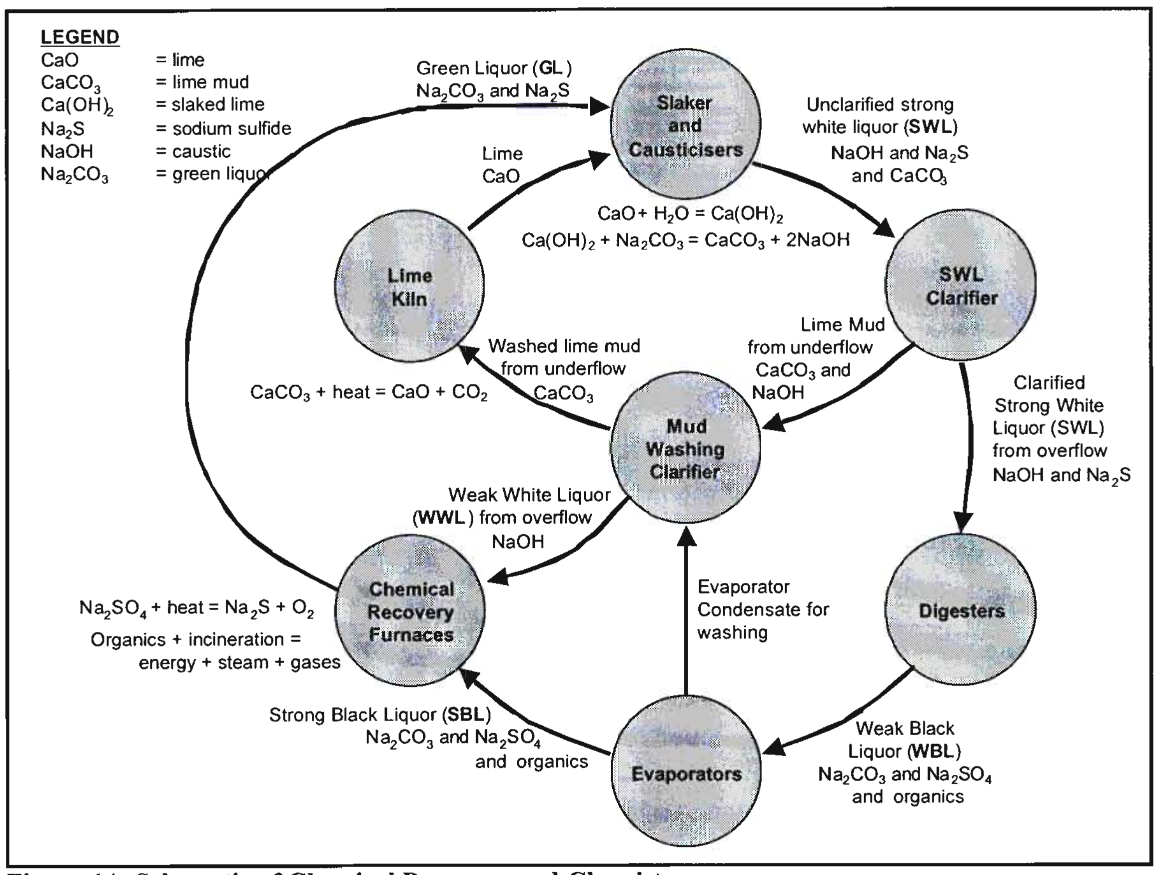


Figure 14: Schematic of Chemical Processes and Chemistry

- In the slaker green liquor (GL) consisting of sodium carbonate and sodium sulphide, is mixed with lime (powder – calcium oxide). This is a violent exothermic reaction that releases carbon dioxide. The green liquor and lime react to form sodium hydroxide and lime mud (calcium carbonate). This mixture of sodium carbonate, calcium carbonate, sodium sulphide and sodium hydroxide is referred to as unclarified strong white liquor (SWL). SWL overflows from the slaker into the three consecutive causticiser tanks to allow the reactions time to complete. After about 85% reaction completion the mixture consisting mainly out of sodium hydroxide, sodium sulphide and calcium carbonate is pumped to the SWL clarifier.
- In the SWL clarifier the lime mud (calcium carbonate) is separated by means of sedimentation from the sodium hydroxide and sodium sulphide. The underflow from the clarifier contains mainly calcium carbonate (lime mud) while the overflow is known as clarified strong white liquor (SWL). The clarified SWL is the cooking liquor and is pumped to the digesters to be used for digesting wood.
- The digesters charge the SWL with wood into the digester. Through steam the temperature and reaction is controlled in the digester to allow the SWL to dissolve the lignin between the wood fibres. The pulp mixture from the digester is passed over a drum filter to separate the pulp and the spent cooking liquor from each other. The spent cooking liquor contains the dissolved lignin and organics and the sodium hydroxide and sodium sulphide have been changed into sodium carbonate and sodium sulphate in the digester. This mixture of organics and spent liquor is referred to weak black liquor (WBL).

- The WBL is pumped to the evaporator plants where the WBL is heated by means of steam to concentrate the WBL by evaporating water from the WBL. The WBL is evaporated from a strength of 13% solids to 65% solids. The concentrated mixture from the evaporators is known as strong black liquor (SBL). SBL consists out of the same components as WBL but less water. From the evaporators the SBL is pumped to the recovery furnaces. The evaporators also produce condensate, from the evaporation of the WBL that is used in the lime mud clarifier for washing the lime mud.
- In the chemical recovery furnaces (CRF's) the SBL is sprayed into the furnace to form fine droplets, the droplets evaporate further while falling to the bottom of the furnace. The droplets are evaporated to the point that only organic and inorganic remain. The organics are incinerated to provide energy as fuel and the inorganics melt to form a molten bed on the furnace floor. The molten bed, smelt bed, allows further reactions – oxidation as well as reduction reactions to take place. The smelt bed chemicals run out of the furnace through the smelt spouts into the smelt dissolving tank (SDT) where weak white liquor (WWL) is added to dilute the smelt. The diluted mixture of smelt and WWL is referred to as green liquor. In the furnace the sodium sulphate is reduced to sodium sulphide, the organics are burnt as fuel and the sodium carbonate passes through unchanged. The green liquor mixture (GL) contains sodium carbonate and sodium sulphide. The green liquor is pumped to the slaker, as described previously and the cycle of reactions start again.
- From the SWL clarifier underflow the lime mud is pumped to the lime mud clarifier for washing. Through a process of dilution and separation the lime mud and caustic mixture is diluted with condensate from the evaporator plants. The mixture of lime mud, condensate and weak sodium hydroxide is extracted from the clarifier underflow and separated from the clarifier overflow. The clarifier overflow is a weak mixture of sodium hydroxide and condensate and is referred to as weak white liquor (WWL). WWL is pumped to the chemical recovery furnaces smelt dissolving tank (SDT), as described previously to form green liquor (GL).
- The mud underflow from the lime mud clarifier is pumped to drum filters that separate the lime mud and the water. The dry lime mud (30%) moisture is fed into the limekiln. Producer gas and off-gases from the different sections in the plant are used as a heat source in the kiln. The lime mud, calcium carbonate, is transformed into lime (calcium oxide) in the limekiln. The lime is fed into the slaker, as described previously, to generate SWL again.

3.1.7 Chloride issue and Tobacco Farming

Figure 15 indicates some features of the geographical location of Ngodwana mill. It shows that the mill is situated at the confluence of the Ngodwana and Elands River. The Ngodwana River has a flow typically between 0.5 – 1 m^3/s, the Elands River flow is typically 4 m^3/s. About 15 kilometres to the east on the N4 national road, the Elands River joins up with the Crocodile River. The Houtbosloop River joins the Crocodile River about 25 kilometres from the mill. This is just before the sampling point at Rivulets. The Rivulets sampling point is specified in the mill's effluent permit as the point at which the measured chloride concentration should not exceed certain set limits. The concentration limits are flow related and higher flow permits a higher concentration limit, typically if the river flow is between three and four cubic meters per second the chloride concentration may not exceed 25 mg/L at Rivulets. The chloride limit is to protect the tobacco farming industry east of the mill that irrigates their tobacco from the Crocodile River. The figure also shows the location of three important eyes (or springs) that contribute to the chloride load. The Ngodwana dam, from which the mill draws and treats its fresh water, is also shown. Decreasing the chloride load that originates from the mill is of very high importance in order to stay within the legal compliance set by Water Affairs in terms of the chloride concentration limit at Rivulets. Reduction in the chloride load was the main reason for converting the bleach plant from conventional bleaching to ECF bleaching.

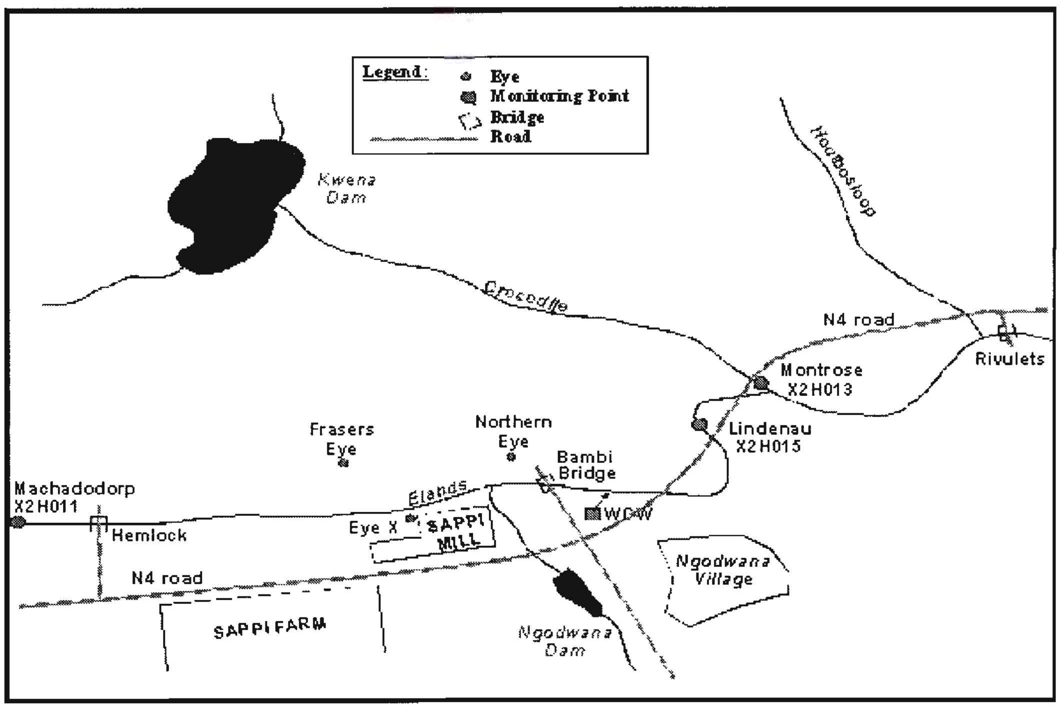


Figure 15: Aerial View of Ngodwana Mill's Geographical Position

3.1.8 Mill Effluent Network Layout

A schematic depicting the general collection and handling of effluent is given in Figure 16. Effluent collection is broadly divided into two types of effluent, the general effluent stream, and the bleach effluent stream. The general effluent stream is a combination of streams with low chloride concentrations, whereas the bleach effluent streams have high chloride concentrations. The bleach plant floor drain and the #3 uptake effluent streams, currently going into the general effluent stream, are however also high chloride containing streams. Effluent flow measurement is extensive, a daily effluent report is generated, and effluent volumes are managed to effluent budgets on a daily basis. The schematic shows the flow measuring points, some of the flows are measured via a flume, other flows are measured using a magnetic flow meter and other flows are calculated. The general and bleach effluents are fed separately into the effluent treatment plant. In the effluent treatment plant the effluent streams are clarified separately after which the two streams are combined and pumped to the irrigation dams. The irrigation dams are about four kilometres from the treatment plant (4100 meter of pipe length, 3 000 meter in a straight line). The effluent treatment plant also has storage facility in order to cope with peak flows. The under-flows of the clarifiers are dried to a consistency of about 18% (solids) on a belt filter press and in a centrifuge. From the irrigation dams, the effluent is irrigated on 514 hectares of kikuju grass.

A storm water system, that is separate from the effluent systems, collects run-off during downpours in the storm water ponds. The quality of the water in the storm water ponds is tested. Storm water that does not comply with General Standards is added to the effluent treatment process, otherwise it is discharged to the Elands river.

During periods when the flow in the Elands river is low, and the chloride concentration at Rivulets is high, the chloride load from the fountains (see Figure 15) are intercepted via boreholes and pumped back into irrigation dams for irrigation. This way the high chloride load to the Elands River is literally 'kept in the air' until the river flow is high again. This is notified as the 'chloride abstraction well' stream in Figure 16.

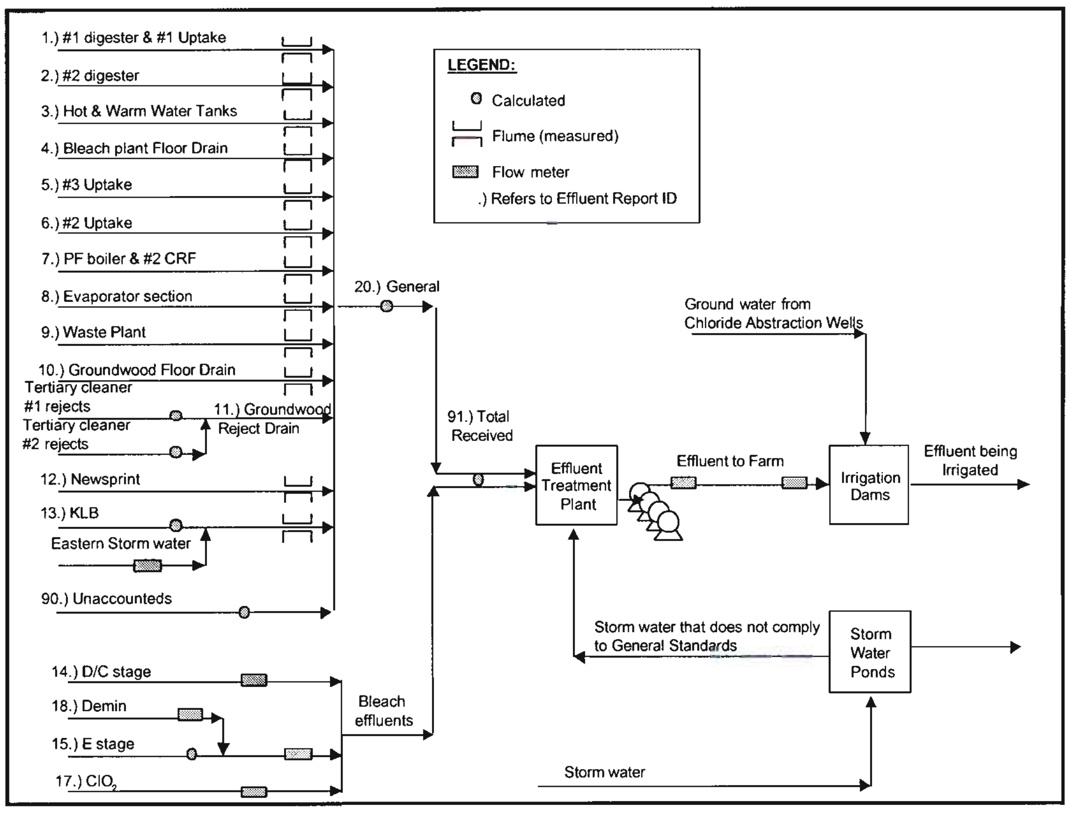


Figure 16: Mill Effluent Sources and Monitoring Schematic

3.1.9 Water System Description

Some prominent features of the hydraulic system of Ngodwana are highlighted, a representation of the current water network is also given in Figure 17:

- **Pulp and Paper Mill not integrally connected:** The pulp and paper mill water circuits are not integrally linked. The only links between the pulp and paper mill are via the pulp going from the pulp mill to the paper mill and via the hot water system. These two streams are currently the only hydraulic link between the pulp and paper mill. This makes it currently easier to do problem solving between the pulp and paper mill when there is a problem with water circuits.
- **Hot water system – pulp mill wide connected:** A central hot water system supplies the mill with its hot water requirements. Fresh water is used for cooling and the resulting hot water is then discharged into the hot water system. Part of the hot water system is a cooling tower, used to reduce the temperature of the hot water, the temperature is however only reduced to about 40°C. The hot water is distributed through most of the pulp mill. The boiler supplies hotwater into the hotwater system at the digester.
- **Service Cooling tower – mill wide connected:** The service cooling water system consists of a cooling tower and an integrated water network throughout the pulp and paper mill. Water is supplied through this system to air conditioners, seal water systems, and substations. Service water

from the air conditioners and substations are returned to the service water system. This connection could lead to contamination of the cooling water system that links the whole mill.

- **Evaporator condensate – connected to Bleach:** The clean condensate from the evaporators is used as washing water in the bleach plant on the three-stage diffusion washer. This condensate becomes part of the recovery circuit, i.e. weak black liquor.
- **Evaporator condensate – as make-up to cooling towers:** Condensate from the evaporators is used as make-up to the evaporator cooling towers. Blow down from the cooling towers becomes effluent.
- **Evaporator condensate - Lime mud washing:** Foul condensate from the evaporator plant is used for washing the lime mud before it enters the kiln. The quality of the wash water determines the washing efficiency that in turn determines the slaking time of lime produced. This condensate generates weak white liquor.
- **Counter current flow in pulp plant:** Wash water and pulp flow counter current in the pulp plant. The pulp plant has three counter current water/pulp flow systems:
  - From digester #1 unbleached pulp is supplied to Uptake #1 and/or the Noodle plant. This pulp contains high volumes of water (i.e. low consistency). The water is removed at the pulp plant and noodle plant and returned to the digester for wash water. Fresh water and hot water is added to the return water to be used as wash water.
  - From digester #2 low consistency pulp (i.e. high water content) is supplied to uptake #2 and/or the bleach plant.
    - At uptake #2 the pulp is dewatered, the filtrate is mixed with fresh and hot water, and the mix of water and filtrate is returned to the digester as wash water.
    - The water system in the bleach plant is very important for the pulp plant. Water and pulp flow in the bleach plant is also counter current, but the three-stage diffusion washer splits this counter current flow into two systems. The bleach plant is the point of chloride generation, and the ingress of this chloride into the recovery circuit must be controlled. Counter current wash water flows from the 3-stage diffusion washer to the wash press, to the brown stock washer. Weak black liquor (WBL) from the brown stock washer enters the chemical recovery circuit. High chloride ingress into the WBL can result in furnace plugging and corrosion.
- Paper machine #1 is the Kraft Liner Board (KLB) and White Top Liner (WTL) machine. The PM1 joins three sheets together to form the KLB paper. The compositions of the different plies are made-up by combining unbleached pulp and recycled fibre pulp. The waste plant and PM1 plant water system are interlinked. Fresh and hot water were made up to the paper machine for use as seal water, chemical dilution/make-up etc. The water ends up in the filtrate water that is used in the waste plant for pulp dilution and transportation. The PM1 can also be used to produce WTL, this means that the paper machine must be shut, cleaned out and started again with a different pulp mix. For WTL bleached pulp is used as the top layer.
- Paper machine #2 is the Newsprint (NP) machine. Pulp from the Groundwood plant and bleached pulp is mixed to produce newsprint paper. Fresh water is used as make-up water to the NP machine, filtrate from the NP machine is recycled to the groundwood plant.

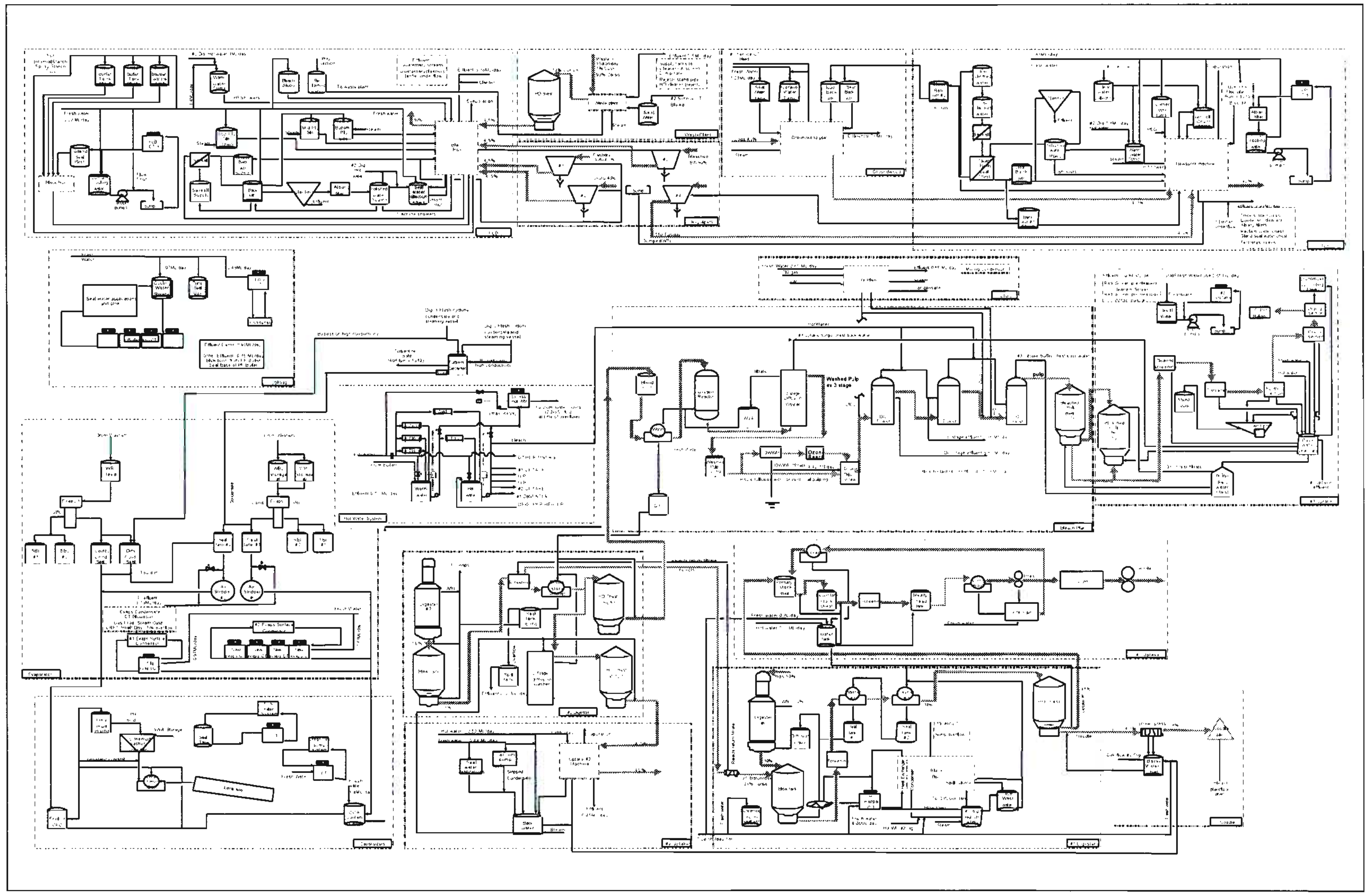


Figure 17: Mill Water System Representation (Acknowledgement to J van Breda for schematic contribution)

Ngodwana has implemented most of the water saving techniques and technologies mentioned in literature. Table 5 compares and lists the water saving techniques and technologies [1], it is also indicates whether the activity is conservation, recycle or re-use initiative (see Figure 18).

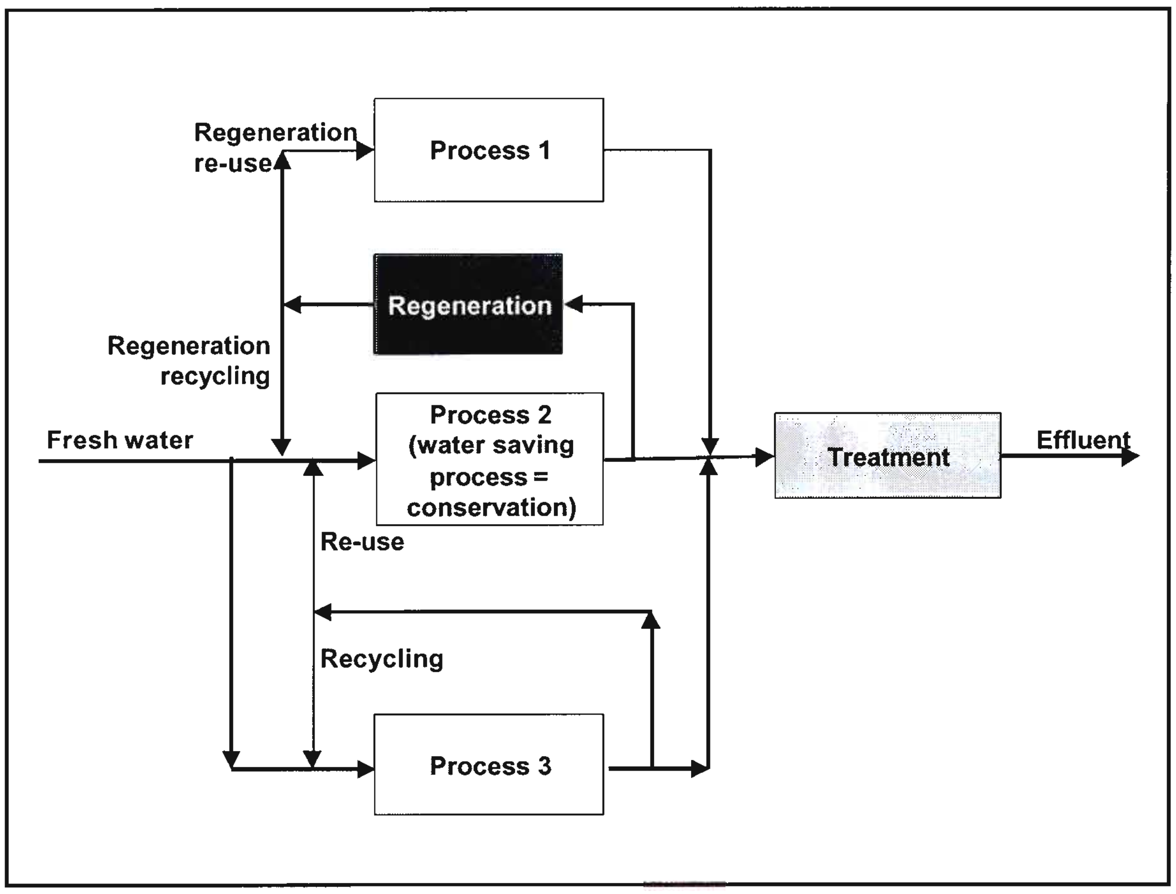


Figure 18: Re-use and recycling of water

Table 5: Waste minimisation techniques and technologies (literature vs. Ngodwana) [1]

Mill Section	Minimisation technique/technology		Type
	Published	Ngodwana	
Woodyard	Use of residual chips	✔ (Use 20% BOC)	Conservation
	Dry drum debarking	✔	Conservation
	Belt or chain conveyors to replace flumes	✔	Conservation
Digestion	Oxygen delignification	✔	Conservation
	Extended delignification		Conservation
	Medium consistency pulping, or	✔	
	Lo-solids cooking, or	✔ (No 1 Digester)	
	Isothermal cooking	X	
	Pulping additives	X	Conservation
	Pre-steam chip bin with flash steam	X	Reuse
	Use of relief and flash steam condensate	✔	Reuse
	Spill collection system	✔	Reuse
Pulp washing	Upgrade to pressurised knotting and screening systems	✔	Conservation
	Increase washer discharge consistency Eliminate sweetener flows and fresh water make ups	✔ (pressure diffusers operate at design) ✔	Conservation Conservation
	Spill recovery	✔	Conservation
	Use of filtrates for wire cleaning (self cleaning nozzles)	✔	Reuse
	Increase the number of wash stages	X	Conservation
	Use washing aids	✔	Conservation
	Use of filtrates in hood blowers/vacuum seals	✔	Reuse
Bleaching	Increase washer discharge consistencies Implement flow control on washer showers	✔ (at design) ✔	Conservation Conservation
	Seal tank level control	✔	Conservation
	Use of wash presses rather than diffusion washers	One installed	Conservation
	Use filtrates on wire cleaning showers	N/A to diffusion washers	Reuse
	Use filtrates on MC pump dilution	✔	Reuse
	Use evaporator condensate for washing	✔	Reuse
	ECF or TCF bleaching	ECF	Conservation
	Bleach filtrate recycle processes	X	Recycle
	Counter current washing	✔	Reuse
Chlorine dioxide	Increase concentration of ClO_2 solution	✔ (at maximum safe limit)	Conservation
Pulp drying/ uptakes	Use of machine water in place of fresh water	✔ (Partial)	Reuse
	Collection and use of cooling water	✔	Reuse

Table 5: Waste minimisation techniques and technologies (literature vs. Ngodwana) (continue)

Mill Section	Minimisation technique/technology		Type
	Published	Ngodwana	
Chemical recovery	Countercurrent condensing in plate-type falling film evaporators	Countercurrent, rising film, tube evaporators	Conservation
	Split evaporator condensates for re-use	✔	Reuse
	Use weak white liquor on lime kiln scrubber	✔	Reuse
	Spill recovery	✔ (not optimal)	Reuse
	Evaporation of condensate	✔ (partial)	Recycle
	Use evaporator condensates for mud washing	✔	Reuse
	Steam stripping of evaporator condensates	Air stripping	Recycle
	Turpentine condensate to foul condensate system	✔	Reuse
	Replace white- and green liquor clarifiers with pressure disc filters and Ahlstrom X filters respectively	X	Conservation
	Steam condensate return	✔ (not optimal)	Reuse
Groundwood	Use pressurised grinders	2 out of 10	Conservation
	Clarify the decker filtrate for reuse (with a small purge stream)	✔	Recycle
	Install limiting orifices in gland seal lines	✔ (most grinders have waterless packing)	Conservation
	Divert the rejects from screening into a reject refiner and return the filtrate to the process, just ahead of the fine screen	✔	Reuse
	Replace gland seals with mechanical seals	✔	Conservation
Paper mill	Closed white water system	✔	Conservation
	Vacuum pump recirculation system	✔ (cooling towers)	
	Use of high pressure (low volume) felt showers Replace gland seals with mechanical seals	✔ ✔ (majority)	Conservation Conservation
	Use saveall water for wash-up	✔ (majority)	Reuse
	Chemically aided settling	✔	Recycle

✔ Indicates implementation

Table 6 below shows the waste minimisation technologies and techniques that have been implemented at the Ngodwana mill (either by design and/or due to modifications made), that were not typically cited in the literature.

Table 6: Minimisation activities at Ngodwana (not cited in the literature) [1]

Mill section	Technology/Technique	Type
No 2 Fiberline	Turpentine decanter and storage condensates used in evaporator cooling towers	Reuse
	Backwater from No 1 Fiberline used on tertiary screens (countercurrent)	Reuse
	Thickener underflow is dewatered and returned to tertiary screen	Recycle
	Backwater from No 3 Uptake reused to wash on the second ClO_2 stage and post oxygen wash	Reuse
	Backwater from No 3 Uptake used for washing in the 3 stage diffusion washer	Reuse
	Backwater from No 2 uptake used for brownstock washing	Reuse
	Turpentine recovery for sale	Recycle
	Mechanical seals on 70 % of medium consistency pumps	Conservation
	Operation at low displacement ratios (1.2)	Conservation
	Brownstock washing dilution factor of 2.5	Conservation
	Good management of synchronicity between plants	Conservation
Chlorine dioxide	Condensate from condensers used on vent scrubber	Reuse
No 1 Fiberline	Screening rejects from No 2 Fiberline reclaimed in blow tank	Reuse
	Uptake No. 1 backwater used on No 2 wash filter	Reuse
	Noodle backwater used on No 2 wash filter and HD chest	Reuse
	Hi Kappa delignification	Conservation
	Turpentine recovery	Reuse
Newsprint	Recovery of air conditioner water	Reuse
	Cloudy backwater used at repulpers	Reuse
	Condensate return	Reuse
	Water from pressure relief valves on high pressure pumps recovered	Reuse
	Rejects from contaminated water chest recovered into reclaimed water chest	Reuse
Groundwood	Newsprint cloudy backwater reused in Groundwood	Reuse
	Grinder heat exchanger condensate used as seal water	Reuse
	Clear backwater used on thickener showers and refined rejects screen	Reuse
	Cloudy backwater used in stock mixer and grinder showers and reject refiners	Reuse
	Cooling tower No 2 blowdown used for log washing	Reuse
	Grinder leak recovery and waterless packing	Reuse
	Laboratory sampling water recovered	Reuse
	Excess hot water used during start-ups and shut-downs	Reuse
	Installation of dynamic seals	Conservation
Waste plant	Cloudy backwater from KLB used on drum thickener	Reuse
	Spill recovery	Reuse

Table 6 :Minimisation activities at Ngodwana (not cited in the literature) (continued) [1]

Mill section	Technology/Technique	Type
KLB	Clarifier underflow diverted to spill stock chest	Reuse
	Cloudy backwater used on size press repulper, dry end repulper and winder repulper	Reuse
	Cloudy backwater used at Noodle repulpers	Reuse
	Polished backwater filtered and used for gland seals	Recycle
	Air conditioner water recovered	Reuse
	Hot water make-up into fresh water	Conservation
	Increased capacity of bleach dilution chest	Conservation
	Back-water used for chemical make-up	Intermittent
Chemical Recovery	Weak white liquor used on lime kiln scrubber	Reuse
	Evaporator condensate split and reused	Reuse
	Evaporator condensate evaporated in cooling towers	Reuse
	Tar water used on mud washers	Reuse
Boilers	Boiler blowdown recovered into warm water system	Reuse

3.1.10 Environmental Permit requirements

A prominent feature of Ngodwana mill was the low specific-effluent generation rate. The mill's effluent permit specifies an annual irrigated effluent limit of 10 000 mega-liters. This means that on average the mill is not allowed to irrigate more than about 27.4 Mega -litres per day. The permit also stipulates the maximum ton of soda, chloride and COD that may be irrigated per day. Ngodwana places high focus on managing effluent losses to the permit requirements. Effluent volume and soda losses from individual plants are measured and reported daily. The effluent layout system of the mill is depicted in Figure 16. A summary of the mill's permit requirements are given in

Table 7: Ngodwana Mill Effluent permit requirements

Parameter	Permit Limit
Volume	10 000 000 m^3/annum (yearly total) 30 000 m^3/day (daily maximum)
Chloride (as Cl)	10 ton per day (monthly average)
Sodium (as Na)	22.2 ton per day (monthly average)
Sulphate (as SO_4)	14.7 ton per day (monthly average)
COD	60 ton per day (monthly average)

3.2 Application of Water Pinch to Ngodwana

Water pinch was applied to Ngodwana mill to achieve different objectives, the different objectives are described in paragraphs 3.2.1 to 3.2.3.

3.2.1 What is the optimal water network for the mill without adding technology?

WaterPinch™ was used to determine if the current fresh water usage or effluent generation rates could be reduced without having to add new technology. This analysis suggests improvements that involve piping changes only and not new treatment facilities. There are two approaches to optimising the network:

- Changes without relaxing concentrations and
- Changes while relaxing the concentrations

Relaxing a concentration limit implies that the maximum allowed concentration that a sink can accept is increased, i.e. the stringent criteria of allowing a certain maximum concentration only were relaxed. When a network is optimised without relaxing concentrations, it implies that only network changes are allowed that do not put any additional quality constraints/risks onto the water network. This means for example that if the maximum allowed suspended solids in the seal water are 10 mg/L currently, then it will not be allowed to receive water with higher suspended solids. The network that is achieved from relaxing the maximum allowed concentrations into a sink has more risks and puts more strain on quality. For example, if the maximum allowed suspended solids concentration into the seal water is relaxed from 10 to of 15 mg/L it could mean that less effluent is generated because more condensate instead of fresh water can be used. It could however mean higher risk and maintenance on the seals used for the pumps. This resultant network could save water but would definitely come at either a higher maintenance cost, more down time due to cleaning and descaling work, possible quality impacts etc.

3.2.2 How must the ERP1 treatment plant be configured into the water network?

At the time of doing the pinch study, the mill was in the late design phase of adding new effluent treatment facilities to the water network of the mill. The implementation was planned to happen in two phases:

1. Effluent Reduction Project (ERP 1) involves a comprehensive biological-treatment facility for the organic and sodium rich streams that have low chloride concentrations. The treated water from the facility (C3 water) would be re-used in the mill.
2. Effluent Reduction Project (ERP 2) involves a membrane facility to treat the chloride rich streams with planned re-use of treated water.

The pinch analyses was used to determine where the ERP1 treatment plant must be located in the water network of the mill and also how the treated water from the ERP1 plant must be re-used. This was intended to either confirm the current suggested location of the treatment facility and re-use opportunities or to give new insight into configuring the ERP1 plant into the mill's network.

3.2.3 Where can the storm water be used?

The mill has a storm-water collection system that collects rainwater in two ponds. Before discharging the water to the Ngodwana River, the quality is tested. This storm water system has however gained water sources that were not related to rain water. During non-raining days approximately 2 ML/day of water is collected in the storm water ponds. A water pinch analysis was done to determine suitable sinks or users for this water.

3.3 General Approach to Doing a Pinch analysis

Figure 19 outlines the steps that comprise a Pinch analysis until the point of implementation. The process involves the following steps:

- **Step 1:** Do a mass and contaminant balance of the section or process for which the pinch analysis is required. For this investigation a detailed mass and contaminant balance for the whole Ngodwana process during conventional bleaching of softwood was developed using the WinGEMS software [49]. Key features and considerations for this step were:
  - Identify the contaminants of interest
  - Identify the boundary of the pinch investigation
  - Decide on the level of detail of the balance required
- **Step 2:** Identify the elements in the mass balance that should be considered in the pinch analysis. Not all elements of a mass balance should be transferred to the pinch analysis. Typically, it would not

always be desirable to consider product streams that enter and exit reactors or unit processes for changes in the pinch analysis. During this step, the mass balance was reduced to a "pinch-balance".

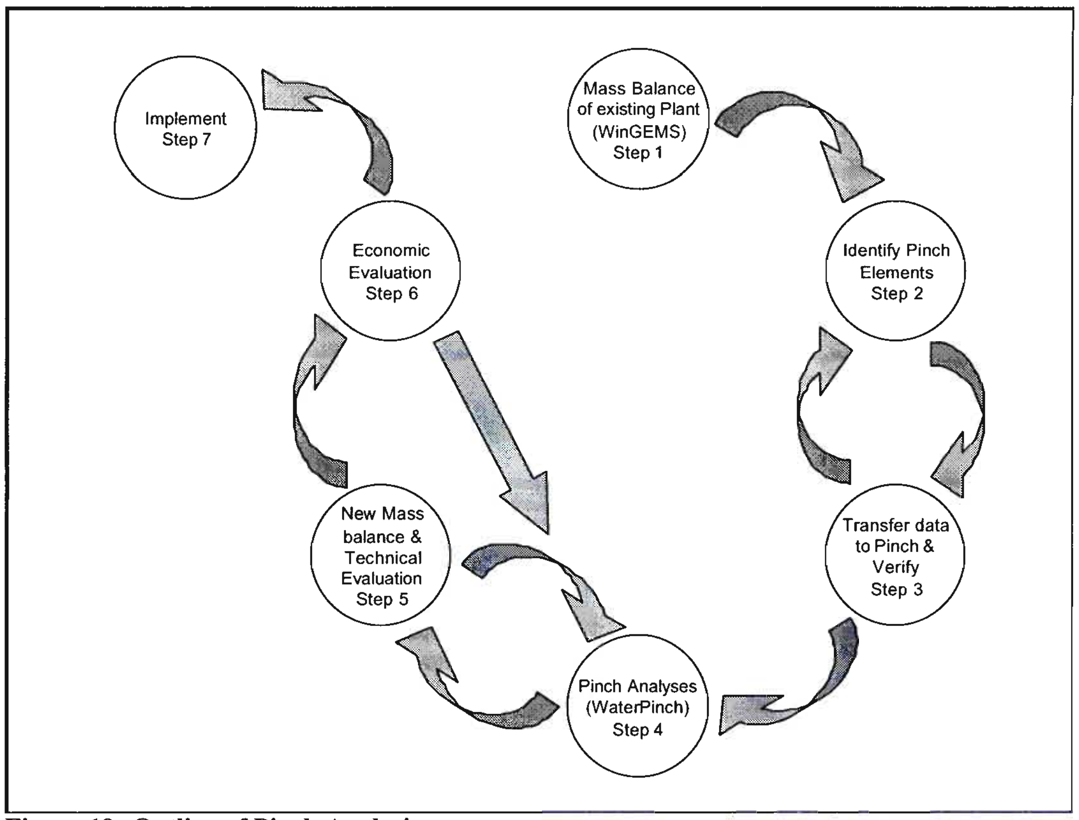


Figure 19: Outline of Pinch Analysis

- **Step 3:** The data in the pinch-balance is transferred to the pinch software. An important feature of this step is to verify that the data had been transferred correctly to the pinch software, since it is possible to either double account or misrepresent certain sources and sinks in the pinch software. The solver used by the pinch software should be able to achieve the pinch-balance in order to verify that the data had been presented and input correctly into the pinch software.
- **Step 4:** The actual pinch analysis was done.
- **Step 5:** The system network proposed by the pinch analysis must be evaluated for technical feasibility. This is done by mass balance simulations, literature studies, pilot plant work, conceptual design etc. Steps 4 and 5 are an iterative process until a technically feasible option is identified.
- **Step 6:** The final feasibility test would be to evaluate the economics of the proposed network. Again this is an iterative process between steps 4, 5 and 6 to find a technically and economically feasible network.
- **Step 7:** Finally the plant construction or network changes must be implemented.

For purposes of this thesis the analysis was done as far as step 4. Improvement opportunities were identified, but it was beyond the scope of this thesis to complete the technical evaluation for final implementation.

Chapter 4 Methodology Considerations

In this chapter clarification is given on the issues considered in the case study, information is also presented on the working of the software and terms used in the case study. Two software packages were used for this study:

- WaterTarget™ [8] consisting of WaterPinch™ and WaterTracker™
- WinGEMS 4.5 [55].

4.1 Mass Balance software WinGEMS™ and WaterTracker™

Very early in the pinch study it was necessary to have mass balance information of the process that was being studied. As part of the WaterTarget™ software, the mass balanc e package WaterTracker™ was presented. This mass balance package has the following useful features:

- It interfaces with WaterPinch™, making it possible to transfer mass balance information directly into the water pinch software,
- Data balancing. The objective of the balancing calculations was to find those flow rates (and concentration) values that give the lowest sum of 'relative-deviations-from-typical-values', while maintaining a mass balance around each node. Where there were unknown contaminant losses or gains, the optimisation will try to keep those to a minimum. Where it has the freedom, it will attempt to distribute flow rates and contaminant loads evenly between outlet streams of a node. WaterTracker firstly solves for the total mass balance, then fixes this mass balance before attempting to achieve contaminant balances.
- Metering analyses. The metering analysis lists the most strategic measurements for achieving a better balance quality and also lists any 'loops' or 'paths' that were detected in the network data structure.

WaterTracker™ can be used to do a mass balance. For this investigation however, it was opted to rather use WinGEMS™ for the mass balance. WinGEMS™ has the following advantages for this investigation:

- The author was already familiar with the use of WinGEMS™,
- WinGEMS™ has been custom-made for the pulp and paper industry. The packages has over 30 different pre-programmed blocks related to the pulp and paper industry, for example causticisers, digesters, chemical recovery furnaces etc.
- This study's focus was on handling a large, integrated and detailed mill's water network. WinGEMS™ has been proven by the author to handle large and complicated mass balance networks without having any computational bugs or size restrictions. It was not known how well WaterTracker™ handles large networks. WinGEMS™ makes use of compound blocks that can be used to group mass balance elements together. This feature of WinGEMS™ was used to group different plant section (i.e. causticising, KLB, NP etc) together which allows the model to develop the different sections of the mill to higher levels of detail in future.
- WinGEMS™ is very user friendly in indicating the level of convergence of the mass balance and in debugging the network.

It was possible to use WaterTracker™ as a mass balance package in conjunction with WaterPinch™. WinGEMS™ (by Pacsim) was however, the preferred mass balance software package that was used for this investigation. The following is noted for completeness sake regarding the WinGEMS™ software package:

- The stream components that a user intends to use must be pre-defined for each project, should a user then later want to simulate additional components, it would not always be possible to add these additional components without great effort. To overcome this problem, dummy elements were defined which could be used to simulate additional components without great effort.
- To interpret the WinGEMS flow sheets it is important to understand that a WinGEMS diagram gives six types of information [see Figure 20]. Of the six types of information shown on a WinGEMS diagram only the stream number and block number are of importance. The stream and block numbers

are referred to in the resulting report that WinGEMS generates (see Appendix 8.8). WinGEMS starts the stream and block numbering at zero again for each different level (i.e. the different sections KLB, NP etc are each on different levels which means that stream numbering will re-start at zero each time)

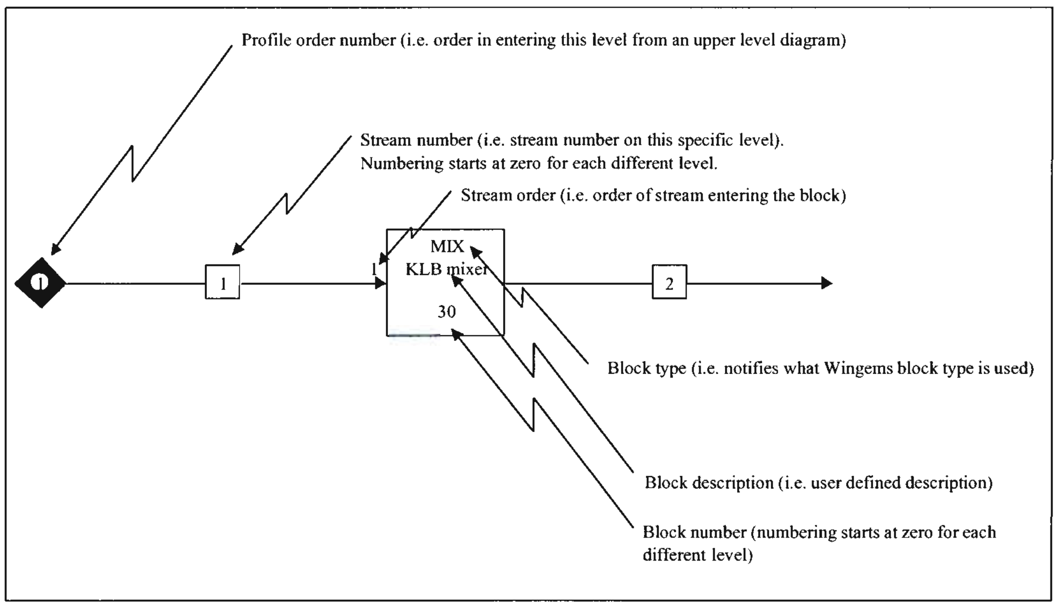


Figure 20: WinGEMS Conventions

4.2 WaterPinch™ Software

With the mass balance complete, it was then necessary to decide on the water pinch technique to be used. As was discussed in the literature review of this document, there are numerous methods with which to do a water pinch. These techniques included graphical, numerical and a combination of graphical and numerical. The following was concluded when selecting a water pinch technique:

- A combination of numerical and graphical methods have to be used to realise the advantages associated with each method,
- The method has to be automated. With modern PC's and software it was possible to automate the method to the extent that numerous different problem definitions, different initial values and other boundaries can be investigated to reach a range of different possible solutions.

These features form part of the software package WaterPinch™ by Linnhoff March [8]. This was the software used for this investigation to do the water pinch. Another feature that makes WaterPinch™ very suitable for this application was that a monetary value was used for optimisation. The use of water, effluent treatment, environmental impact etc can all be expressed in terms of a monetary value, the proposed solution was then the solution with the lowest cost. Data can be input into WaterPinch™ manually or the data can be imported from the mass balance software WaterTracker™. The software was user friendly and powerful to handle the computations required for a large network. The solver uses GAMS software to solve the solutions. One disadvantage of the software was that it had some nuisance software bugs related to the input of initial concentrations and concentration relationship equations. These bugs were merely a nuisance and do not affect the integrity of the solution. The main features and important terms used in WaterPinch™ are presented in the following paragraphs.

4.2.1 Sources and Sinks

A water network is comprised of sources and sinks. During the pinch analyses, sources and sinks are connected in a manner that yields the lowest objective function value for which all the process constraints applicable to the network are satisfied. The following definitions were used:

- **Source** = The point at which supply of water is available or generated.
- **Sink** = The point at which water is consumed.

Figure 21 indicates the difference and meanings of a source and sink.

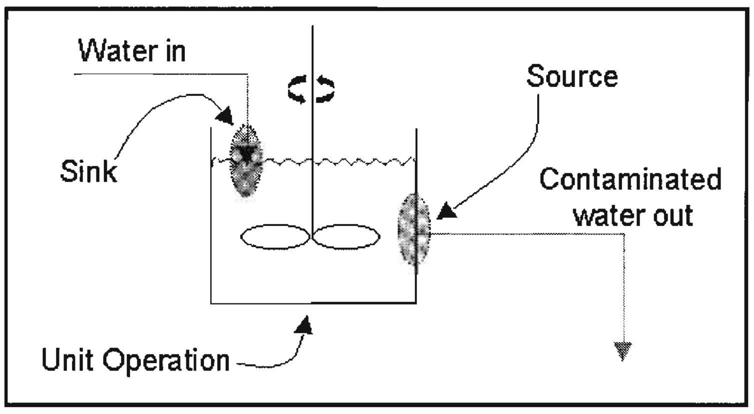


Figure 21: Graphical Representation of a Source and Sink [8]

4.2.2 Unit operations

A unit operation in WaterPinch™ represents a piece of equipment or a processing unit that acts as both a source and a sink for water. In addition, a unit operation will normally change the contaminant load of the water flowing through it. When entering a unit operation into WaterPinch™ the are two choices:

1. Design a **generic** unit operation or
2. Use **pre-defined** standard WaterPinch™ units.

Both the generic and the pre-defined units can be divided into one of two types, either a **process** unit or a **utility** unit operation. The differences between a process and utility unit are listed in Table 8.

Table 8: Comparison between Process Unit and Utility Unit operation

	Process Unit Operation	Utility Unit Operation
1.	1 to 5 sinks.	1 sink
2.	1 to 5 sources.	1 or 2 sources
3.	Total flow entering sink does **not** have to equal the total flow leaving the sources.	Total flow entering sink **has to** equal total flow leaving sources.
4.	Outlet concentration can be linked to inlet concentration.	Outlet concentration can be linked to inlet concentration.
5.	The water flows entering and leaving are always fixed at the value specified by user. WaterPinch must keep flow constant during analysis.	Flow is variable between lower and upper limit specified by user and WaterPinch can vary the flow during the analysis.
6.	Can not provide a fixed or variable cost.	Can provide a fixed cost and a variable cost.
7.	For example: supply of water to a reactor or to a wash tank.	For example: • Sources: fresh water • Sinks: effluent discharge • Unit operations: filters

4.2.3 Environmental Limits

It was mentioned in previous paragraphs that WaterPinch™ uses a monetary based objective function. The network configuration with the lowest cost was the proposed solution. With WaterPinch™ the engineer has the option to incorporate environmental limits into the problem definition by assigning a cost to the environmental impact. For example if the mill's effluent permit stipulates a maximum allowed concentration for sodium to be discharged with the effluent, a cost for exceeding this limit can be assigned to incorporate this limitation into the problem definition. Apart from assigning a cost, environmental limits applicable to the mill can be factored into WaterPinch™ in one of the following ways:

- As a strict concentration limit. A maximum allowed concentration could be stipulated, for example a maximum sodium concentration of 1000 mg/L was allowed.
- As a mass-load limit. For example, a load of 1000 g/day of sodium was allowed.
- As a concentration-load cost for a utility sink. For example, R0.50/(mg/L) sodium

This was a powerful and essential tool in defining the water network of a pulp and paper mill. The impacts associated with bad publicity, environmental impact and long term impacts can also be taken into account by manipulating the mentioned limits to reflect the risks that the mill are willing to take. For example, it might cost the mill only R1000/ton of chloride that is irrigated, but the poor public relationship associated with the irrigated chloride load might pose a much greater risk. This risk can be incorporated into the problem definition by assigning a greater cost then R1000/ton of chloride to the irrigated chloride load. An additional cost burden associated with these poor public relationships can be gradually increased in consecutive solver runs until an acceptable chloride load is achieved.

4.2.4 Bound limits

Bounds were used to guide the optimised network design solver– the bounds act on the optimisation algorithm to restrict, forbid, encourage or discourage individual matches. A bound matrix of the sources and sinks were provided in WaterPinch™ that makes it easy for the engineer to define bounds. Different types of bounds can be defined:

- **Flow** bounds force the solver to achieve the specified flow between the source and sink.
- **Flow max** bounds restricts the flow between sources and sinks to the set maximum flow.

- **Flow min** bounds specifies the minimum flow that must be achieved between a source and sink.
- **Existing flow** connections indicate that there is an existing connection between the source and sink and this connection can be freely used up to its stated maximum capacity. Any additional flow between the source and sink has to flow through a new connection.
- **Ztol** indicates the minimum flow required before a new connection can be made. For example, of the Ztol between a sink and source is 30 t/hr, it implies that the solver may not allow a flow between that source and sink if the flow is not greater than 30 t/hr.
- **Fixed costs** are those that do not change as the production levels increase or decrease. The engineer can assign the fixed cost incurred when a new connection is made, this is a fixed once-off charge.
- **Variable costs** are those which vary directly with production. In WaterPinch™ it is easy to assign a cost per unit flow when new connection is used.

4.2.5 Recycles

WaterPinch™ also makes it easy to forbid the recycling of flow between sources and sinks. A matrix was supplied at the end of each problem solution indicating the direct and indirect recycles. The following definitions apply:

- A **direct recycle** occurs when a unit operation supplies itself with water by connecting one of its outlets to its own inlet.
- An **indirect recycle** occurs when a unit operation supplies itself by sending water on a circular route through one or more other unit operations.

The engineer can forbid direct and indirect recycles by selecting the recycle node and forbidding it.

The recycle editor presents the results from the solution by indicating the direct and indirect recycles. The recycle editor also provides a platform for the engineer to forbid the recycling of streams. A direct recycle is when the effluent (or source stream) from a process is recycled as feed to the same process without having the stream pass through any treatment or another process. An indirect recycle is when the effluent stream from a process is recycled back to the same process after passing through treatment or other processes. Figure 22 is a screen shot from the WaterPinch™ recycle editor. The recycle editor gives a description of the flow route, flow volume and indicates whether the engineer forbade the recycle or not.

From...	...to	Flow kg/min	Forbid?
Direct, 0			
Indirect, 9			
bleach - wash press out	dig 2 - brown stock washer in	4249.41	No
dig 2 - brown stock washer out	bleach - wash press in	682.11	
dig 2 - hot and warm water tanks out	dig 2 - WBL cooler, T20/21 and T11 - simplified in	4619.24	No
dig 2 - WBL cooler, T20/21 and T11 - simplified out	dig 2 - hot and warm water tanks in	5372.00	
CT - excess hot water out 1	dig 2 - hot and warm water tanks in	171.00	No
dig 2 - hot and warm water tanks out	CT - excess hot water in	4988.00	
CT - excess hot water out 2	dig 2 - hot and warm water tanks in	4541.00	No
dig 2 - hot and warm water tanks out	CT - excess hot water in	4988.00	
bleach - DC tower out	bleach - E tower in	1581.73	No
bleach - E tower out	bleach - DC tower in	1131.58	
bleach - 3 stage out	evaps - New evaps inlet	124.51	
evaps - New evaps clean	evap - New evaps foul/cont inlet	4735.00	No
evap - New evaps foul/cont clean	bleach - 3 stage in	560.15	
ERP 2 clean	ERP 1 inlet	2285.17	
ERP 1 clean	bleach - 3 stage in	389.97	
bleach - 3 stage out	evaps - New evaps inlet	124.51	
evaps - New evaps clean	evap - New evaps foul/cont inlet	4735.00	No
evap - New evaps foul/cont clean	dig 1 - wsh filter 2 in	355.67	
dig 1 - wsh filter 2 out	dig 2 - two stage washer in	12.95	
dig 2 - two stage washer out	ERP 2 inlet	925.66	
ERP 1 clean	bleach - 3 stage in	389.97	
bleach - 3 stage out	evaps - New evaps inlet	124.51	No
evaps - New evaps clean	evap - New evaps foul/cont inlet	4735.00	
evap - New evaps foul/cont clean	ERP 1 inlet	2712.89	
ERP 2 clean	ERP 1 inlet	2285.17	
ERP 1 clean	bleach - 3 stage in	389.97	
bleach - 3 stage out	evaps - New evaps inlet	124.51	No
evaps - New evaps clean	evap - New evaps foul/cont inlet	4735.00	
evap - New evaps foul/cont dirty	ERP 2 inlet	284.10	

Figure 22: Example Screen shot of Recycle Editor from WaterPinch™

4.2.6 Geographical costs

WaterPinch has the facility to specify the location of sources, sinks and unit operations together with piping costs. The locations of the sources and sinks can be entered using a graphical grid or table indicating the X and Y co-ordinates. Pipe lengths were calculated from geographical positions as follow:

- If no position is entered for a source or a sink the pipe length between them will be taken as zero and
- If both source and sink positions were supplied, then the pipe length is the orthogonal distance between them (this implies that pipes were laid out on a rectangular grid).

From the geographical positions, the distance between sources and sinks were calculated. This distance is used to calculate the capital and operating cost.

Capital costs

Capital cost is applied only to new connections. Existing flow bounds can be used to indicate the capacity of existing connections. The following formula is used for capital cost calculations:

$$\text{Capital Cost} = k.d^{n}.\text{Distance}$$

Where k = constant
d = pipe inside diameter

Operating cost

$$O_c = OP.\ Flow.\ Distance$$

Where : Q_c = Operating cost (R/min)
: OP = constant (R/kg/m)
: Flow = flow to be pumped (kg/min)
: Distance = distance that liquor must be pumped (m)

4.3 Outputs from a Pinch Analysis

The WaterPinch™ package has an extensive range of graphs and tables to present the inputs into and the results from the pinch analyses. The manners in which these were presented were a critical part of pinch analyses. The different graphs and tables used are briefly discussed with more detailed information being presented on the composite curves which are used more extensively.

4.3.1 Pinch Solver Summary

At the end of each problem solution, WaterPinch™ presented a summary. This gives a summary of the integrity of the solver solution, the objective cost obtained etc. The information from the summary is described in Figure 23.

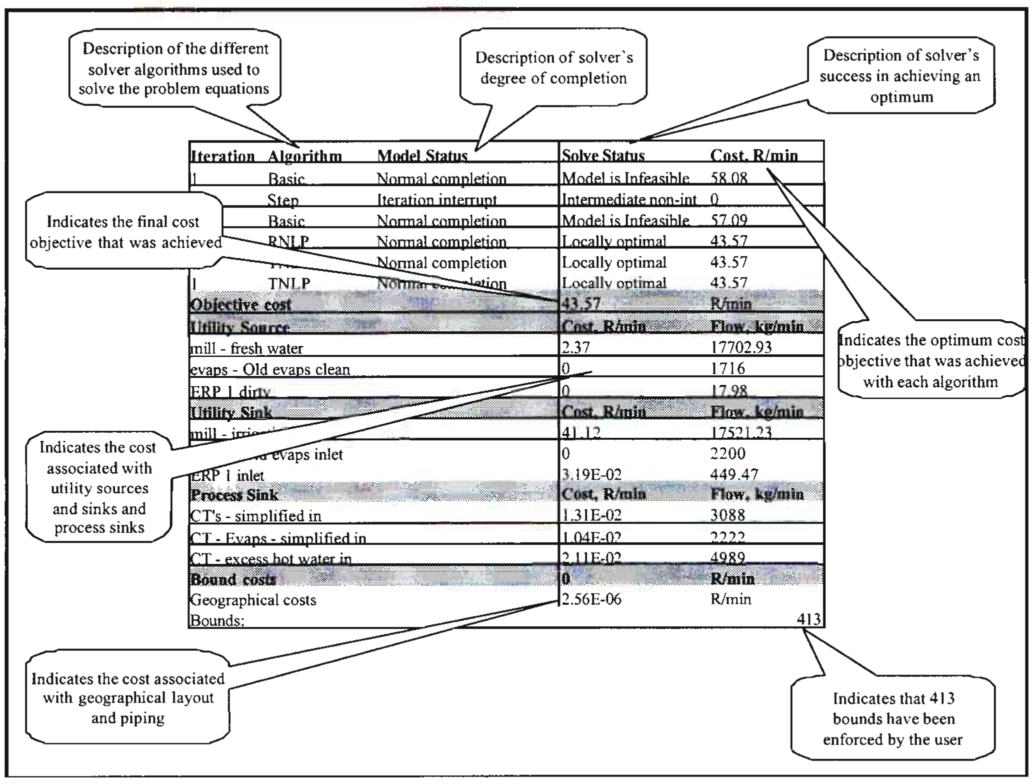


Figure 23: Pinch Solver Summary

4.3.2 Network Configuration Results

The resultant proposed network from WaterPinch™ is presented in tabular format (see Table 9). This presented some difficulty to the engineer since it was cumbersome interpreting the results for a large network. Typically the results from the table have to be transferred into a mass balance package, another drawing software package or they have to be redrawn by hand to understand the full scope of the proposed tabled results. However it was possible to scan through the results, looking at the high flow streams' connections, to decide if the proposed solution has merit for further investigation or not. The results table indicates the sources and sinks that were linked and the flow volume interchange between the two. The results can be sorted to group different sources or different sinks together or it can be sorted according to flow volume.

Table 9: Example of WaterPinch™ Network Configuration Results

From Process...	...to	Flow kg/min
bleach - wash press out	upt 3 - thickener wash water	134.7
bleach - DC tower out	evaps - New evaps inlet	100.96
newsprint - cloudy back water	dig 1 - uptake feed consistency control	1363.88
upt 3 - effluent out	mill - irrigation fields	800
upt 2 - presses out	mill - irrigation fields	582.58
noodle - effluent	bleach - D2 tower in	52
ClO2 effluent	mill - irrigation fields	455
From Utility...		
mill - fresh water	upt 3 - effluent in	98.16
mill - fresh water	upt 1 - fresh water applications	60.66
mill - fresh water	caust - dust control on lime dump	40.22
mill - fresh water	caust - lme mud wash water	155.89
evaps - Old evaps clean	dig 1 - dil wash filter 1	10.56
evaps - New evaps clean	evap - New evaps foul/cont inlet	4735
evaps - New evaps dirty	CRF1 - SBL incineration	570
evaps - New evaps dirty	CRF2 - SBL incineration	765.51
evap - New evaps foul/cont clean	dig 2 - T11 condenser in	300
dig 2 - hot and warm water tanks out	upt 3 - cleaning consist control	331.27
dig 2 - hot and warm water tanks out	upt 2 - effluent in	20.95

4.3.3 Source and Sink compositions

The concentration results from the WaterPinch™ solver are also presented in tabular format. The example Table 10 shows the presentation of sink and source results. The sink or source is indicate and the flow volume to or from the respective sink or source. The concentration at which the sink or source converged is also indicated. For the sink report an asterisk (*) by a concentration value indicates that the contaminant has not reached the maximum concentration allowed for the sink. The marginal cost is also shown, marginal cost indicates the objective cost change that would occur if the sink or source flow could be changed by a small amount. The marginal cost information is used to compose the sensitivity results.

Table 10: Example of WaterPinch™ Sources and Sinks Results

Name	Flow kg/min	Marginal R/kg	Chloride (Cl) ppm wt	Sodium (Na) ppm wt	COD ppm wt	Calcium (Ca) ppm wt	Solids ppm wt
Sink							
bleach - wash press in	2196	-1.25E-02	426.31	3884.46*	17983.93*	46.87*	89.59*
bleach - DC tower in	3909	-2.73E-03	1123.93*	622.73	2385.56*	16.91*	450
bleach - E tower in	4027	-1.41E-03	526.31*	534.45	743.34*	22.01*	115.96*
bleach - D2 tower in	3656	-2.71E-03	1067	620	1932.76*	12.61*	366.77*
bleach - 3 stage in	4087	-1.11E-03	322	202	880	18	142.09*
bleach - D36 consistency	6948	-2.71E-03	1075	620	1939.63*	12.68*	367.31*
Sources							
bleach - wash press out	8329	1.29E-02	278.09	4066.55	18752.88	22.8	45.23
bleach - DC tower out	4353	2.06E-03	2111.98	375.43	2440.88	40.46	445.45
bleach - E tower out	4161	1.98E-03	869.85	1106.04	911.66	42.93	121.84
dig 1 - wash filter 1 out	12864	1.44E-02	169.18	4223.26	21176.47	49.37	39.77
evaps - New evaps clean	4735	-0.00052	18.6	25.72	2047.45	0	0
evaps - New evaps dirty	1335.51	0.00134	4161.33	116836.4	708631.3	209.56	133.99

*Indicates concentrations that solver has hit a constraint and would not be able to make the concentration higher in order to improve the solution

4.3.4 Interpretation of the Pinch Point in WaterPinch™

It was discussed in detail in paragraphs 2.6 and 2.7 how the definition of the pinch point has changed over the past years, starting from a clear-cut graphical definition referring to the point where two composite curves meet to a more complex definition for the numerical approach to water network optimisation.

The classical meaning of the pinch and the first pinch techniques are limited to one contaminant and only considers flow and concentration of a single contaminant at a time. The development of more advanced techniques have allowed to bring other factors such as corrosion, fouling, environmental impact, costs etc into consideration. Newer techniques also allow for more than one contaminant. The newer techniques are based on numerical optimisation and this has transformed the classical meaning of the pinch. The numerical pinch indicates a point identified by a numerical solver beyond which further improvement of the water network is not possible based on the information supplied to the solver. With WaterPinch™ software this pinch point is described by means of the sensitivity graphs. This sensitivity analysis is equivalent to determining the pinch point for the system: the constraint with the greatest sensitivity coefficient can be viewed as constituting the pinch [38]. Sensitivities are a graphical interpretation of pinch point for mathematical programming [36].

WaterPinch™ extracts the sensitivities from the marginal values calculated from the GAMS numerical solver. The GAMS solver calculates marginal values for all variables in the problem definition, WaterPinch™ however, only extracts the concentration marginal values to display it on the sensitivity graphs. These sensitivities presented by WaterPinch™ are function of [8]:

- Flow into the sink. Usually large flow sinks are more sensitive
- The availability and cost of "clean enough" sources. If there is not enough clean, cheap water to fully supply a sink, it will be sensitive
- The existence and cost of sources that are "too dirty". If the available "dirty" sources of water are only slightly too dirty, then the sink will be sensitive.

Gianadda [30] concluded that this selective extraction of marginal values from GAMS could still identify substantial savings compared to using all variable sensitivities generated in GAMS. Gianadda further noted that because most other variables are normally fixed in a plant and because the quantity of water processed by the plant is unable to change, sensitivities arise purely from the quality of the water entering the plant in any case. Gianadda also illustrated the use of the sensitivities by indicating that for a portion of plant investigated, the WaterPinch™ sensitivities agreed with the basic GAMS sensitivities. Gianadda also used concentration sensitivity graphs to present results from the GAMS solver. For the purposes of this investigation the sensitivity graphs presented by the WaterPinch™ are considered as indicating or describing the pinch point, i.e. variables that constrain further improvement. It must however be noted that due to the selective extraction of variables from GAMS insight into the performance of the system is not as useful as when considering all the GAMS marginal values [30]. It is beyond the scope of this thesis to investigate the use of marginal values generated from the GAMS solver, the sensitivities displayed by the WaterPinch™ software are used instead.

4.3.5 Sensitivity analysis

A very useful and user-friendly feature of WaterPinch™ is the sensitivity analysis. The solver optimises to achieve the lowest overall cost for the problem statement. The engineer defining the problem definition expresses the problem by assigning costs to bounds, raw material usage, treatment facilities, environmental impact, chemical losses, piping cost, geographical cost etc. Sensitivity values were calculated and used to give directions to the user with regards to the manipulation of the problem statement and also guidance on the relaxation of concentrations limits in order to identify opportunities for re-use or treatment opportunities. Two different types of sensitivities were calculated, they are inlet and outlet sensitivities. The results from a sensitivity calculation can be presented either graphically (see Figure 24) or numerically in table format.

Inlet Sensitivity is the amount of decreased cost when a maximum inlet concentration is increased. The inlet sensitivity values normally indicate opportunities for re-use.
For example: An inlet sensitivity value reported as +R82/min/(mg/L) means that a saving of R82 can be realised per minute when the maximum allowable concentration is increased by one mg/L, i.e. increased from say 50 to 51 ppm.
A reported value of –R82/min/(change in concentration) means that a cost of R82/min will be incurred if the maximum allowed concentration is increased say from 50 to 51 ppm. This is because the outlet concentration would increase (which could lead to higher treatment cost) if the allowed maximum inlet concentration is increased.
The inlet sensitivity values are a function of:

- The flow into the sink. Usually large flow sinks are more sensitive.
- The availability and cost of "clean enough" sources. If there is not enough clean, cheap, water to fully supply a sink, it will be sensitive.
- The existence and cost of sources that are "too dirty". If the available "dirty" sources of water are only slightly too dirty, then the sink will be sensitive.

Outlet Sensitivity means the amount of decreased cost when an outlet concentration is decreased. The outlet sensitivity usually identifies opportunities for the installation of treatment plants/processes.
For example: A outlet sensitivity of +R82/min/(mg/L) would mean that a saving of R82/min would be realised if the outlet concentration was decreased from say 50 to 49 ppm. A negative outlet sensitivity of say –R82/min/(mg/L) will mean that the overall cost would increase by R82/min if the outlet concentration would decrease from say 50 to 49 ppm. This can be because the dirtier stream, that has to be disposed at a cost, is generated to clean the stream from 50 to 49 ppm.

Figure 24 is an example of the results from a sensitivity analysis. The highest sensitivity value indicates the best or most probable opportunity for a saving, these are the processes where engineering should be concentrated. Sensitivities are shown for each sink and source and also for the different contaminants that were considered in the problem.

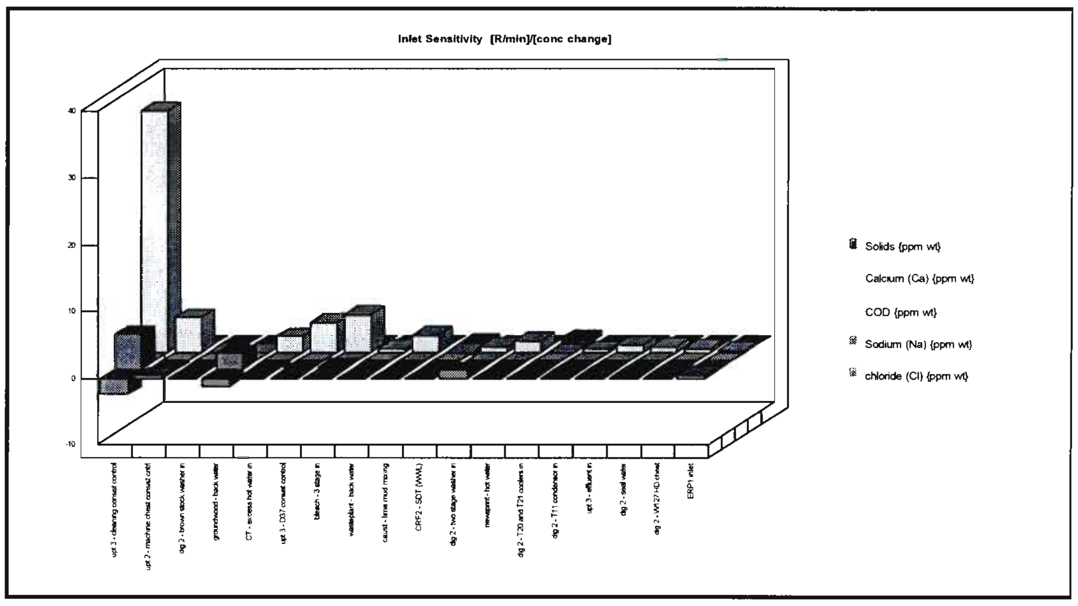


Figure 24: Example Graphical representation of sensitivity analysis [8]

4.3.6 Composite curves

In paragraph 2.5.2 the graphical representation of pinch results were explained with the aid of an example. WaterPinch™ has refined this graphical approach by introducing four different types of graphs to represent the results from the pinch study. The use of these composite curves is best explained by means of another example. A small section of the bleach plant was used for this example to do a pinch analysis on.

The network proposed by the pinch solution is depicted in Figure 25, flow is indicated in ton/hr and the concentration is mg/L. The solution presented by the pinch solver is identical to the current water network configuration, this implies that the current bleach plant flow network is optimised for the given constraints, i.e. system boundary, maximum allowed concentrations etc. WaterPinch™ presents the results from the solver by means of four different types of composite curves, these are:

- Unblended Process Composite Curves,
- Blended Process Composite Curves,
- Balanced Composite Curves and
- Grand Composite Curves.

The example mass balance was done for four different contaminants. The composite curves for only one of the four contaminants are shown to describe the functionality of the curves. Curves for the other contaminants (16 curves) are not necessary to understand the functionality of the composite curves for the example.

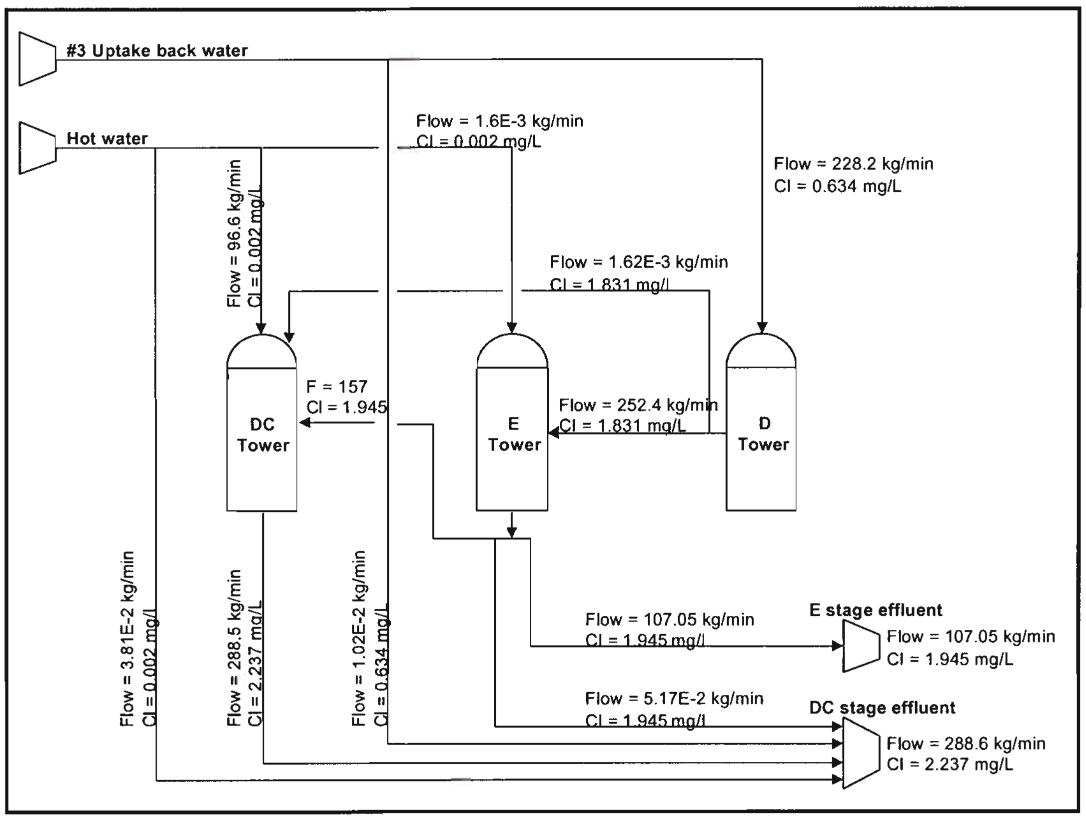


Figure 25: Bleach plant pinch solution from WaterPinch™ Proposed Solution

It is important to emphasise that the example was done considering four different contaminants. This means that the solver provides the lowest overall cost solution considering four contaminants. Once the numerical solver has reached a solution, the composite curves are generated from the results of the numerical solver. The composite curves are not used in determining the optimal network or do not form part of the solving process. The composite curves are merely a graphical method to display the results from the numerical solver. The composite curves can also only represent one contaminant at a time. For this example the composite curves for chloride only were presented. Similar composite curves were also generated for the other three contaminants, but those are not presented in this example for this thesis.

4.3.6.1 Un-blended Process Composite Curves

The description of the "unblended process composite curve" is best explained by means of the example presented in Figure 26.

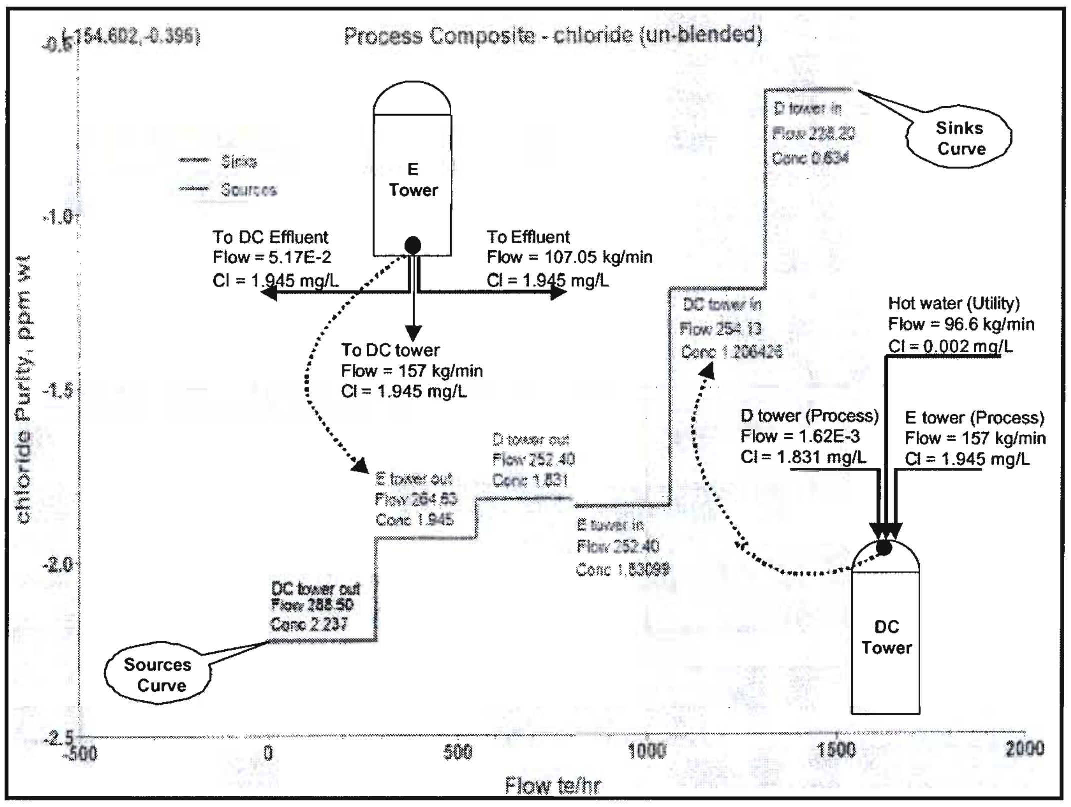


Figure 26: Un-blended Process composite curve for chloride

The **un-blended process composite curve** (see Figure 26) shows the following:

- Concentration and flow results from the solver solution were used to generate the curves. The concentrations and flows of the various sinks and sources were as determined by the solver.
- Sinks and sources of process units are shown. Sinks and sources of Utility units are not shown, however the influence of Utility sources and sinks on Process sources and sinks were incorporated into the results. The DC tower sink indicates a flow of 253 kg/min that includes the flow from the Hotwater utility stream (96.6 kg/min).
- The sink curve represents the sink concentration and total flow of all streams entering the sink. The concentration is not the maximum concentration as defined by the user, but the concentration resulting from the pinch solution is used.

4.3.6.2 Blended Process composite Curves

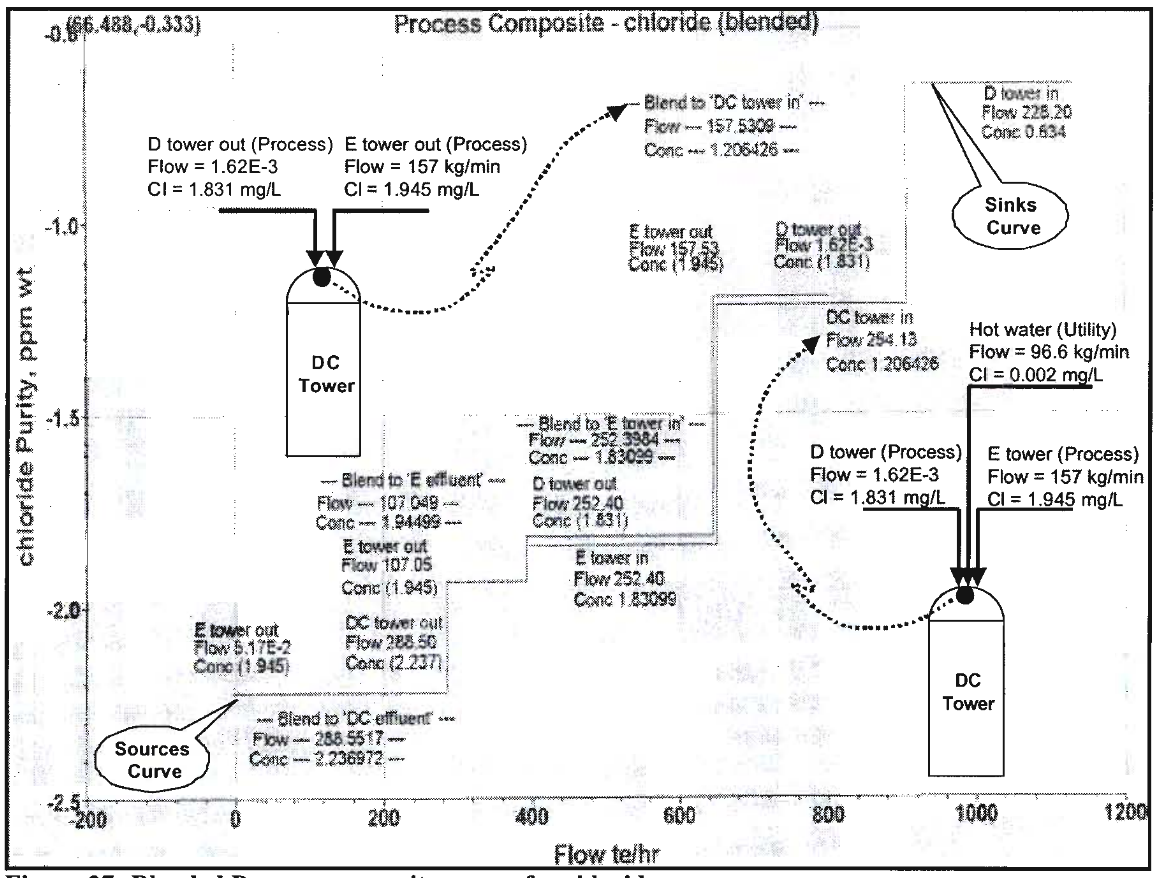


Figure 27: Blended Process composite curves for chloride

The **blended process composite curve** (see Figure 27) shows the following:

- Utility sources and sinks were not shown
- The sink curve is identical to the un-blended process composite curve.
- Sinks and sources with the same concentrations were displayed as overlapping. A small offset is used between the curves to make them visible.
- Grouping or blending the sources together that supply the same sinks constituted the source curve segments.

4.3.6.3 Balanced Composite Curves

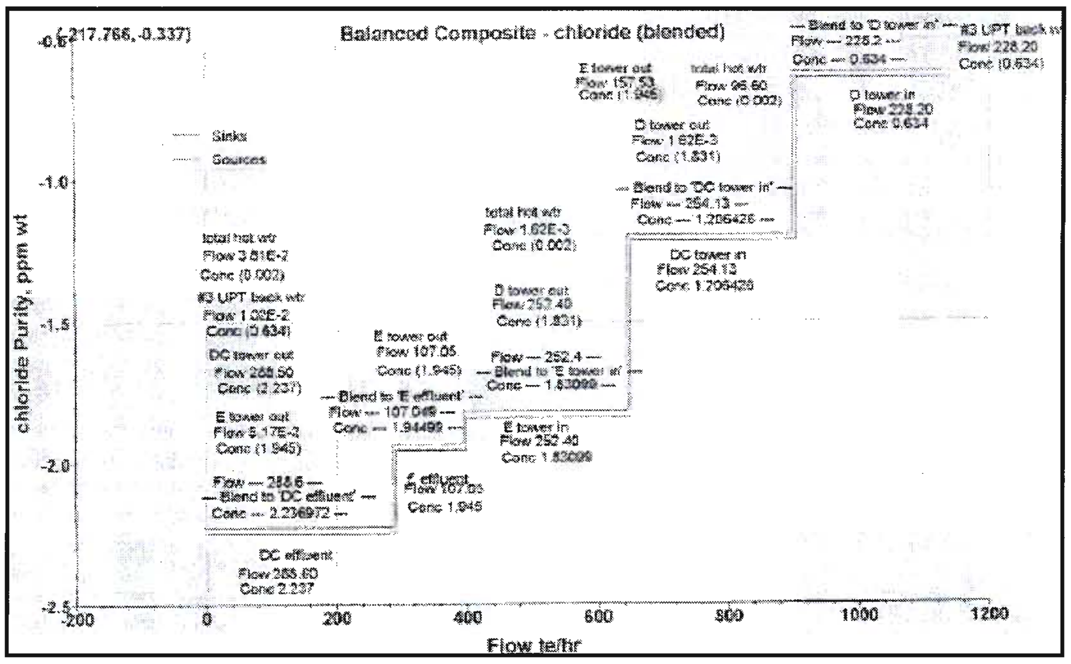


Figure 28: Balanced Composite curves (blended) for chloride (screen print from WaterPinch™)

The balanced composite curve (see Figure 28) shows the following:

- Utility sources and sinks are also shown
- The sink curve is identical to the un-blended and blended process curves except for the fact that the utility sources and sinks were also displayed.
- Source curves are exactly the same at the blended composite curves except for the fact that the utility sources are included

4.3.6.4 Grand Composite Curves

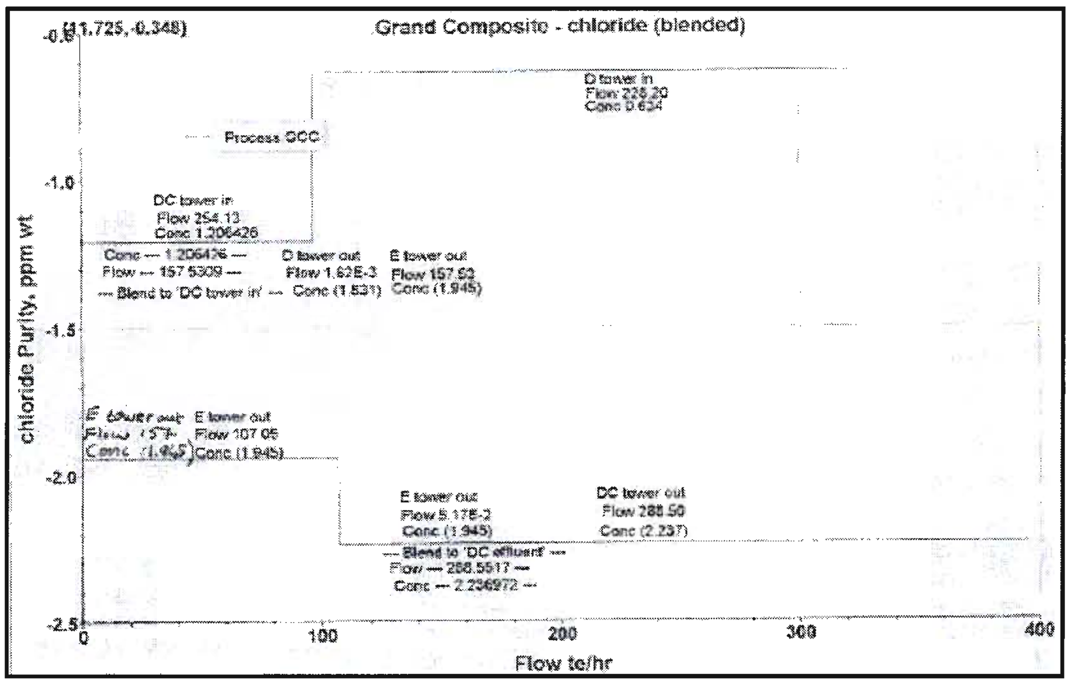


Figure 29: Grand composite curve for chloride (screen print from WaterPinch™)

The grand composite curve (see Figure 29) shows the following:

- Only process streams and not Utility streams were shown.
- Grand composite curves represent the design resulting from the WaterPinch analysis.
- At each level of purity the flow into sinks and from sources were indicated. Flows into sinks were indicated as a net flow to the right of the graph. Flows from sources were indicated as a flow to the left of the graph.
- The grand composite curve gives a visual indication of purity levels and the flow quantity ranges of which the network is composed. It can be seen that most of the sources and sinks were at a concentration of less than 500 mg/L chloride

Only the unblended composite curves were used in this investigation, since these are the only curves that give a possible indication of where pinch point might be. The other curves provide a graphical representation without highlighting or identifying new information that could be of use to the engineer.

4.4 Selecting streams

When doing a water pinch it is important to know which streams to include and which streams to exclude from the analyses. The simplest rule of thumb is that if you could change either the source or sink connection for a water stream and still make the same quality product, then the source and sink should be included in the analysis. This implies that pulp streams and other chemicals charged (i.e. bleaching chemicals) should not be included in the analysis. It was almost never possible to change the source or sink of a pulp stream and still make the same quality pulp. This will involve a totally new process, whereas pinch firstly tries to optimise water usage without changing the manufacturing process. The following were given as guidelines for excluding or including a stream:

- Streams that contribute significantly to the contaminant load should be included.

- Stream with significant flow rate should be included.
- Steam users that return clean steam condensate that is returned to generate steam again are not included. This closed system does not need optimisation in terms of water.
- Steam users that do not return clean condensate for re-use should be included.
- Streams which can not be changed (i.e. product from reactor A can and must only go to reactor B) must be excluded. These types of streams obviously have no room for improvement except if a different manufacturing process is an option.
- Atmospheric losses to atmosphere from cooling towers, vent etc should be excluded.

A large portion of the time and effort involved in the pinch analyses was to reduce the water balance to a "pinch balance". A pinch balance is derived from the water balance but includes only the streams that should be included in the water pinch.

4.5 Selecting Unit operations

If at least one sink and one source from a unit operation were included in the pinch analyses, a rough guide is to include that unit operation into the pinch analyses. The relationship between the inlet and outlet concentrations must also be defined for the different unit operations. Paragraph 4.2.2 explains the difference between a utility and process unit. WaterPinch^{TM} gave the option to select different types of process and utility units with different characteristics. The user also has the choice to select between different relationships between the inlet and outlet concentrations. A straight-line correlation between inlet and outlet concentrations was used the most frequently in this thesis.

4.6 Selecting process Boundaries

When considering the boundaries of the section to do the analysis on the following was considered:

- Selecting too large a system might make the simulation very complex leading to not fully understanding the problem,
- Selecting too small a system will reduce the opportunities for water saving,
- Take distance into account, processes that are too far apart from each other might not be feasible to integrate and
- The chemistry must be considered too, it was for example not feasible to mix black liquor condensates into the paper machine.

If only a small system, such as the evaporators was selected for the pinch balance, a benefit such as using the condensate in the bleach plant would not be identified.

4.7 Selecting Contaminants

During the selection of contaminants the following must be considered:

- The contaminant must be a conserved specie, i.e. not pH or conductivity or temperature
- If re-use of a contaminant in streams was a problem anywhere in the process, then the contaminant was considered for inclusion,
- If the contaminant was not allowed to go to waste, it was considered for inclusion,
- Will re-use of the contaminant cause down stream problems like corrosion, bio-fouling, plugging etc? If 'yes' the contaminant must be selected.
- If the contaminant was a problem in one part of the system only, it was not necessary to select the contaminant as a component that must be simulated. However, through the use of the bounds editor it was possible to direct streams to and from preferred and forbidden sinks respectively were applicable to this contaminant,

- Selecting between two to five contaminants yields good results. If too many contaminants were selected, the solver may take very long to converge. Too many contaminants can also make it difficult to define a sensible problem statement.
- Contaminants with similar characteristics can be grouped together. For example, it might not be necessary to simulate the impact of heavy metals by including iron, cobalt, copper and nickel into the problem definition. Iron can be used to represent heavy metals since the source, impact and restrictions related to iron were similar for the other heavy metals.

4.8 Selection and Relaxation of Concentration Limits

Apart from selecting the boundary, streams, unit processes and contaminants, it was also necessary to decide on the concentration values that must be assigned to sinks. It is recommended to start with the concentrations as extracted from the mass balance. The mass balance can be done by taking average concentration or by taking instantaneous concentrations. The concentrations in the mass balance can be used as a starting point, and based on the results from the pinch analyses can be relaxed. The sensitivity analyses (see paragraph 4.3.5) indicated the stream and concentration that would provide the greatest benefit if relaxed. With guidance from the sensitivity analyses the engineer can decide to increase, the maximum allowed concentration that a sink can receive. Relaxing a concentration constraint must be done carefully and scientifically, it was no use permitting a calcium concentration level into the bleach plant that would scale up the bleach plant.

4.9 Mass and Contaminant Balance

The starting point of doing a water pinch is a mass balance. The mass balance supplies information on the flow, contaminants and identifies the sources and sinks that exist in the current system configuration. The mass balance also identifies and quantifies mass load transfers that occur. WinGEMS 4.5 [55] was used for the mass balance due to the powerful mass balance capabilities of the software package. During the mass balance the following must be considered:

- The mass balance was done for the plant under steady state. The impacts of dynamic changes were considered later during the Technical evaluation phase (see **Figure 19**).
- Where is the *boundary* of the mass balance? The boundary of the mass balance also determines the boundary of the pinch analysis. The larger the boundary, the better the chance of achieving a more optimal system, but also the more belaboured the mass balance becomes and the more complex the pinch solution needs to be. The solution can become so complex that the solver can not solve it.
- Which *contaminants* must be considered in the pinch analysis? Selecting contaminants is a play-off between creating a solution too complex to solve for the solver and between considering too few contaminants. Contaminants should be included that represent the different physical-chemical restraints that govern the water circuit.
- How does the data from the mass balance get *transferred* into the water pinch software? Mass balance software exists from which the mass balance data can automatically be transferred into the water pinch. This type of software however might only be powerful enough to do a basic mass balance that might not be adequate. For this thesis the sink and source data were transferred manually from the mass balance software to the pinch software package.
- How much *time* is available to do the pinch? Generating a mass balance can constitute the major part of the time, effort and money when doing a pinch analysis.
- Lastly it is important to decide how the results from the pinch analysis will be *simulated* to verify the feasibility of the proposed pinch network. To simulate the proposed pinch solution requires a mass balance that has sufficient detail; and software that is powerful enough to accurately simulate the proposed network changes.

The different considerations for doing the mass balance are discussed.

4.9.1 Mass balance boundaries

Ngodwana is a highly closed mill with a specific effluent generation rate lower than 20 kL/ton of product [1]. This means that the boundary of the mass balance and pinch investigation should be as encompassing as was practical in order to identify reduction opportunities [24]. This highly closed water system also required a more detailed mass balance compared to when an open water circuit was evaluated, for the following reasons:

1. Improvements to the process was not that obvious any longer, thus even the smaller volume streams needed to be considered in order to come up with a more optimised process and
2. The circuit was much more sensitive to changes in the process flow configuration and qualities of streams due to increased concentrations due to recycling. This means that it became more important to have a detailed mass balance to evaluate the impact of proposed pinch process changes.

Of particular importance to the mass balance for an integrated pulp and paper kraft mill were the separation or saddle points. Throughout the Ngodwana mill process flow there were points or instances where it was critical to know how much of what components were removed or passed down or up-stream. This point or instance is referred to as a saddle point, implying that a component or contaminant has the 'opportunity' of following one of two process streams. As a saddle allows a rider to fall to two sides, likewise a saddle point provides a contaminant the "opportunity" to follow one of two streams or water systems. Due to the counter-current flow nature between pulp and wash water of Ngodwana mill's pulp plant, and because of the already closed nature of the process, it was important to evaluate these saddle points correctly. The product streams from these saddle points also qualify as process sinks and sources during the pinch analysis. The most prominent saddle points identified for Ngodwana are:

1. #1 Chemical recovery furnace stack and smelt dissolving tank emission,
2. #2 Chemical recovery furnace stack and smelt dissolving tank emission,
3. #1 Digester brown stock washers,
4. #2 Digester brown stock washers,
5. 3 stage diffusion washer in bleach plant,
6. 2 stage diffusion washer in digester #2 area,
7. wash press in bleach plant,
8. dregs filter,
9. Demineralisation plant,

The mass balance includes the whole pulp and paper mill. Sections that were excluded, but which have very limited opportunity for improvement, were the sewage and fresh water treatment plants. The mass balance was very detailed and includes stream flows as low as 10 litres per minute for certain sections of the mill. The pulp mill details include almost every individual process unit, while the paper mill was not simulated to include unit process. The paper mill portion of the balance was done by assuming ratios between the inlet and outlet streams. In Appendix 8.10 hardcopies of the mass balance flow diagrams are provided. Different sections of the mill were done to different levels of detail. The detail to which the balance is done can be described using three levels:

- **Level 1:** the fence around the mill is the boundary, only inputs and outputs that leave Ngodwana or enter the mill are considered. The mass balance will be only one block with inputs and outputs representing Ngodwana mill.
- **Level 2:** the boundary is around the different sections, for example the inputs and outputs from say Newsprint section are considered. For this level of detail there will be 21 blocks needed to represent Ngodwana mill, showing KLB, NP, groundwood, causticizing etc. A level 2 balance is typically a mixing block into which all incoming streams are mixed, and then a number of split blocks that split out/off in fixed ratio's the flow and contaminants.
- **Level 3:** sections are broken up into process units, i.e. inputs and outputs from process units within a section are considered. That means that intermediate stream qualities within sections are

considered. For this level of detail each of the 21 sections mentioned in the previous bullet have numerous blocks to present process units.

The mass balance was done to **at least** a level 2 for the whole mill, meaning that for each section in the mill the inputs and outputs to that section can be qualified and quantified, it does not however mean that the section's internal streams can be qualified or quantified. The following sections were done to a level 3 detail. These section were done to level 3 detail either because it required very little time to get to level 3 or because of anticipated high impact of water re-use and recycling changes in these sections:

- Digester #1 and #2
- Uptake #1, #2 and #3
- Bleach plant
- Causticising section
- Woodyard
- Utilities and recovery boilers
- Effluent treatment plant
- Pulp slab
- Noodle plant

4.9.2 Selecting Contaminants to Include into Mass Balance

Selecting the contaminants to use in the pinch analysis was crucial to the success of the pinch analysis. Selecting too few contaminants for the analyses can result in solutions that are not feasible in practice due to other contaminants that were not selected. On the other hand, selecting too many contaminants will impact on the time and effort required in getting a balance done and will also result in the solver taking very long to get to a solution. With too many contaminants there might even be instances where the solver was unable to find a solution. The contaminants selected must represent the chemical and physical constraints that must be considered in the solution. The following contaminants were chosen for the balance and pinch analysis:

Chloride: Chloride has many important physical, chemical and socially important impacts which makes it an important contaminant to include. Chloride is an indication of corrosion and impacts on the sticky temperature of the ash in the recovery boiler that could result in plugging the boiler [73]. Apart from these the factors, chloride also impacts on the tobacco crops that are being irrigated from the Elands River downstream of the mill. The current water license for the mill has a maximum limit of 20 mg/L of chloride (as Cl^-) in the Elands. This means that the mill must control their release of chloride into the river so that the chloride concentration in the river is never higher than 20 mg/L (as Cl^-). Chloride results mainly from three sources: the incoming wood, saltcake (raw material) and from the bleaching chemicals that were used in the bleach plant. By including chloride, the impact of potassium was also catered for since the two contaminants have the same characteristics and impacts on the system.

Sodium: Two properties make sodium an important element to include in the balance. Sodium is a cooking chemical that must be retained in the cooking circuit. One of the major raw material make-up streams into the mill is saltcake (Na_2SO_4) which is added to replenish the sodium stocks in the chemical circuit. Secondly, because sodium was easy to model in a mass balance and because it was the most abundant element in the circuit, it can effectively be used to represent total dissolved solids (TDS). Thus sodium was an indication of the TDS of a stream and also an indication of whether the stream must be retained in the liquor circuit or not. Sodium can also be used as an indication of the foaming tendency of a stream. Sodium is also an indication of pH, high sodium content is associated with high pH. Thus by including sodium as a component the following was catered for: cooking chemical recovery, TDS, foaming tendency and pH.

Calcium: The scaling potential of the calcium ion makes it an important contaminant to include in the pinch analyses. The precipitation or scaling properties of calcium carbonate and calcium oxalate limits the closure extent of the bleach plant [73]. Precipitation of calcium carbonate often occurs in washing operations and leads to plugging of the washing equipment, which in turns leads to poor pulp washing and further build-up of contaminants. Plant downtime due to calcium build-up that has to be removed also poses a significant risk in terms of productivity. The precipitation of calcium oxalate predominates in a pH range from 3 to 8, whereas calcium carbonate precipitation occurs at a pH higher than 8. The solubility of calcium oxalate increases with increased temperature and increased organic contents, whereas the solubility of calcium carbonate decreases with increased temperature. Calcium oxalate occurs in acidic bleaching stages. One of the main sources of calcium into the mill is the wood that is used as raw material. The use of calcium carbonate as raw material in the causticising section results in calcium contamination when calcium carry-over occurs in the strong white liquor clarifier. In an open cycle mill the principle source of calcium in the black liquor is the wood. Under highly acidic conditions ($pH<3$) calcium becomes soluble. The soluble calcium re-precipitates on fibre and/or process equipment under alkaline conditions. For this reason, direct counter current recycle between acid and alkali stages is not recommended due to scale formation.

Suspended Solids or Fibre: Fibre is the main component of the suspended solid matter. Wherever pulp is washed or pulp has to be screened, cleaned or during dewatering on the paper machine wires and felts fibre contamination results. The fibre poses a particular risk where nozzles are used since it can block nozzles and wires. The fibre is also a valuable component for certain sinks since it can be included in the pulp or the paper that is sold. Thus suspended solid mainly cater for suspended solids represented as fibre, but this represents most of the scenarios within the mill. Where suspended solids need a different interpretation the engineer bounds or forces the solver to encourage or prohibit connections between sources and sinks.

Chemical Oxygen Demand (COD): The organic content of a stream is an indication of properties such as the foaming tendency, bio-fouling and also of the chemical consumption of that particular stream. The chemical oxygen demand (COD) is an indication of the organic content of a stream. A stream with a high COD will require more bleaching chemicals than a stream with a lower COD, this is because the bleaching chemicals must first oxidise the COD before it can bleach the pulp. The COD is also an indication of complex compounds that can form between organic and inorganic compounds that can result in scaling or plugging. The main source of COD in a pulp and paper mill is the lignin that is removed in the pulping process. This dissolved lignin is distributed throughout the mill via the pulp streams, condensate streams, weak black liquor, strong black liquor and effluent. Only a very small portion of the COD originates from additives such as starch being added in the paper mill.

Chloride, sodium, calcium, COD and suspended solids were the five contaminants used in the pinch analyses. These five contaminants catered for the majority of the chemical properties that were necessary to consider in the pinch analysis. By including these five contaminants other properties or contaminants were also indirectly considered.

The concept of using a property such as COD to represent a family of other contaminants or physically characteristics in pinch analyses is supported by literature. Buehner et al [11] quotes the use of COD as a contaminant using WaterPinch™ on Unilever (Vinamul, Warrington, England). This factory produces more than 200 products including paints, glues and adhesives. Here it was possible to treat all product compounds in water as a single contaminant without significant loss of accuracy [11].

Other chemical contaminants and physical parameters:

The following contaminants or physical parameters have not been included as a "contaminant" input into the analyses but their impact or contribution to the analyses has been considered. The impact of these contaminants or physical parameters were included either through the inclusion of other contaminants that represent them or by means of the engineer's input using the bounds editor or in defining the cost problem. The contaminants and properties that were not directly included in the pinch analysis contaminant list are discussed:

- **High and Low Temperatures:** Temperature was an important parameter to consider in the pinch analysis, however it can not taken into account by the same method as for contaminants. Temperature is not a conservative contaminant, but a thermodynamic property. Where contaminants were defined in the individual sources and sinks as an integral part of the pinch analysis, the temperature could not be done in the same manner. With the other contaminants the general trend was that as long as a source concentration was lower than the specified maximum sink concentration the stream was suitable for use, the same does not hold for temperature. In many instances, a stream was not permitted to receive temperatures less than a specific temperature. The impact that temperature had on the pinch analysis was controlled by the user via the bound editor. The user's input forbids and encourages certain connection based on the user's understanding of the temperature requirements of the network. Because of the high level of closure the mill already has it was also assumed that the impact of temperature was secondary to improving the effluent and fresh water flow rates. It was assumed that with capital investment, i.e. heat exchangers or cooling towers the effect of temperature could be overcome to realise an effluent or fresh water saving.
- **pH:** pH was treated in the same manner as temperature. Since pH is not necessarily a contaminant/property that becomes undesired at higher values for all sinks, it cannot be treated in the same manner as contaminants. Certain sinks require high pH. As with temperature, the user guides the pinch analysis by defining bounds, thus preventing and or encouraging connections. Contaminants such as sodium also give a certain degree of indication of the pH. High sodium content is always associated with high pH in a Kraft pulp and paper mill.
- **Salts and/or Non-Process Elements (NPE) or heavy metals:** Non process elements are one of the important factors influencing mill closure. The controlling of NPE is one of the important factors in mill closure. Irrespective of the water network or water saving techniques employed, the mill must have system or processes where the NPE are removed, i.e. must have NPE "kidney". Non process elements are inorganic, or they are intermediates in the chemical recovery process, and they are not active pulping chemicals. NPE's include Potassium (K), Aluminium (Al), Phosphorus (P), Silicon (Si), Magnesium (Mg), Calcium (Ca), Manganese (Mn), Chloride (Cl) and Iron (Fe)

The major sources of these NPE's are:

- Wood (Ca, K, Mn, Si, Cl),
- Make-up lime/limestone (Al, Mg, Fe, Si) and
- Water (Al, Fe, Si, Cl).

The NPE's are discussed:

- **Potassium:** In open cycle mills, potassium generally does not present any problems, except when the mill liquors also have a high chloride ion concentration or the liquor cycle losses are very low. Potassium, in combination with chloride, reduces the melting point of sodium salts in the dust that deposits on the tubes of the recovery boiler. This results in a stickier dust that more readily clings to, and accumulates in the tube banks and leads to eventual plugging of the furnace. Relative to sodium there is some enrichment of potassium in the dust collected by the recovery boiler electrostatic precipitator. Including chloride in the pinch analyses represented the impact of potassium.
- **Magnesium and Phosphorus:** These chemical elements accumulate in the calcium cycle of the mill and result in a variety of operating problems such as increased dead load and reduced settling

rates in clarifiers and filterability over filters. Most of the magnesium precipitates from the green liquor and is removed with the green liquor dregs thereby preventing it from entering the calcium cycle. However a portion does get through green liquor clarification and can precipitate out during the subsequent slaking and causticising operations, carrying forward to the calcium cycle. Likewise, phosphorus transfers to the calcium-cycle during causticising due to the very low solubility of calcium hydroxy-phosphates in sodium hydroxide. Discharging a portion of the lime mud can control concentrations of magnesium and phosphorus in the calcium cycle. The impact of phosphorus and magnesium was catered for in the pinch analyses through the inclusion of calcium.

- **Aluminium and Silica:** The presence of these elements in the sodium cycle of a kraft mill can result in the formation of a very hard, glassy sodium aluminosilicate (NaAlSi) scale on heat transfer surfaces. This scale is very resistant to normal washing and mechanical cleaning and has a low heat transfer coefficient and can severely reduce evaporator capacity. Aluminium and silica were not included in the pinch analyses. The impact of these contaminants was assumed to be negligible at the early stages of pinch analyses. During the implementation phase more detailed investigations can evaluate their impact.
- **Iron:** Wood supply again is the primary source for this trace element. Control of iron is not a concern in an open cycle mill but for the closed cycle option, conscious removal with dregs and lime mud must be achieved. The impact of this contaminant was assumed to be negligible at the early stages of pinch analyses. During the implementation phase more detailed investigations can evaluate its impact.
- **Manganese:** Manganese entering with the wood is particularly detrimental to any open or closed TCF bleach sequences. Special chelation (Q) stages are necessary to achieve acceptable final pulp brightness, particularly when using hydrogen peroxide bleaching stages. Controlled lime mud purging and efficient dregs removal operation can accomplish control of manganese. The impact of this contaminant was assumed to be negligible at the early stages of pinch analyses. During the implementation phase more detailed investigations can evaluate its impact.
- **Sulphate:** Sulphate, like sodium is a process element that is fundamental to kraft pulping. The impact of sulphur was catered for to a certain extend through the inclusion of sodium. During the implementation phase more detailed investigations can evaluate their impact.

Five contaminants were included in the pinch analyses i.e. sodium, calcium, suspended solids, COD and chloride. Other contaminants and physical parameters were taken into account because their properties were similar to an included parameter. The engineer also considers the impact of other contaminants and physical parameters by means of the bound editor and cost assignments.

4.9.3 Data collection

To complete the mass balance a detailed and extensive sampling and analyses exercise was done. Over a year period, approximately 600 samples were taken. Each of these samples were analysed for temperature, pH, conductivity, sodium, calcium, magnesium, chloride, sulphate, COD, potassium, total suspended solids, total dissolved solids, iron, manganese and silica. The important sample points (approximately 60 different sample points) and streams were identified for sampling and approximately 10 samples were taken over a one-year period at each of these sample points. The majority of the samples were taken during periods when the plants were running stable, while some samples were taken during upset conditions. Data was also collected from the laboratory history database of the mill. The collated database was used to calibrate the mass balance. This data is given in Appendix 8.7. It was not possible to clearly determine if samples were taken under stable operating conditions due to the high dead times, lack of on-line measurements of process and also because it is difficult to clearly define when is the process (or point of sampling) representing a stable process. Sampling was not done during obvious unstable process conditions (i.e. plant shut or shortly after start-up or shut), but some of the samples could have been taken that represent unstable process conditions. In the next paragraph, "4.9.4 Mass balance Assumptions, it is explained how this data was used.

4.9.4 Mass balance Assumptions

The assumptions that are applicable for the mass balance in general are given. More detailed and section specific assumptions are stated later when discussing each section individually.

1. To satisfy both requirements of determining the impact on the environment and on the composition of internal streams, calibrating the mass balance had to be a trade off between simulating **instantaneous** conditions versus **average** conditions. With instantaneous conditions the impact on internal stream quality can be determined, i.e. chemical charges, dilution ratios, different stream's flow ratios and other operating parameters are exactly at the values as when operating the plant. Calibrating the mass balance on instantaneous rates only though would not have taken into account events such as spillage, drainage of tanks, shut conditions, inaccurate operating to control parameters, start-up and shut down or tolerance in measurements. For example, a certain plant may instantaneously discharge say 10 ton per day of chloride, due to events that only occur periodically, like washing or routine maintenance for example. At other times the plant might discharge no chloride. It would however be inaccurate, when looking at long term environmental impact, to say that the plant is discharging 10 ton per day or to assume that the plant discharges zero ton. Seen over a longer term the plant in actual fact only discharges, say on average 8 ton per day of chloride if the average is calculated over a year. The mass balance was done for average conditions, but instantaneous values were used to describe process correlations, i.e. reject rates, chemical charges, etc, where possible. The average values of effluent rates and environmental losses were incorporated by including averages from data collected over a longer time span. Yearly average production figures were used, assuming that the mill only produced softwood (75% of mill's production).
2. The balance was done with both digesters on softwood only, since information for softwood pulping was more readily available due to the mill running mostly softwood. Softwood pulping also resulted in higher effluent rates than hardwood.
3. Any hardwood that was needed in the paper mill, while the pulp mill is only producing softwood, were assumed to be inputs into the mill via the pulp slab before the re-pulpers.
4. Calcium, magnesium, manganese and sodium are assumed to have adsorption/de-sorption properties that have to be accounted for. These properties result in losses of these chemicals via the pulp, paper and with the solids in the effluent stream [1]. The details of these assumptions are given Appendix 8.4.
5. The different plants were assumed to have the production rates as depicted in Table 11. It was assumed that the digesters only produced softwood.

Table 11: Average productions [Sales Manager 1999]

Section	Production	
	ADt per day	BD* kg per minute
No 2 digester total	700	437.5 / 440
Into bleach plant	485	303 / 332
Out of bleach plant	432	270 / 302
Ex #2 Dig to #2 Uptake	168	105 / 108
No 1 Digester	310	194 / 208
Ex. #1 Dig to Noodle	186	116 / 122
Ex. #1 Dig to #1 Uptake	124	77.5 / 83
Waste	105	66 / 76
KLB	570	356 / 396
Groundwood	240	150 / 169
Newsprint	312	195 / 198

*The grey-scaled values are from the mass balance

6. The mass balance was done for a dry season, meaning that the rainfall was assumed to be zero.
7. Twelve sections in the pulp mill were done to a level 3 (see paragraph 4.9.1 for a list of the sections) detail due to the probable high impact on the sections when implementing effluent reduction options. The causticizing and bleach plant section were done to a level 3 detail because of the high risks associated with these sections when implementing effluent reduction projects. The paper mill mass balance was done to a level 2 detail only.

4.9.5 Verifying the Mass balance

The validity of the mass balance was verified by means of four different checks:

1. Different mill scenarios were modelled to determine the response of the model to these different scenarios. The results from the balance for these different scenarios were compared to mill actual measured data. If the results from various different mill scenarios compare well with mill actual data, it could be used as an indication of accuracy and credibility of the mass balance. See paragraph 4.9.5.1.
2. Mass balance concentration values obtained in different critical streams were compared to the 50-percentile value from the laboratory analyses. See paragraph 4.9.5.2.
3. Mass balance concentration values obtained were also compared to the minimum and maximum value range. See paragraph 4.9.5.3.
4. Mass balance flows from different critical streams were compared to measured flows. See paragraph 4.9.5.4.

Results for the different checks are discussed. It must be noted that COD and suspended solids were not included in all the verification checks to validate the balance since it was only later decided to include COD and suspended solids as contaminants. These two contaminants were added later on into the investigation when the solver proved to be able to handle more contaminants simultaneously.

4.9.5.1 Check 1: Modelling Different Mill scenarios

The validity of the model was confirmed by simulating various different mill scenarios and by making changes to assumptions, variables and operating conditions in the model. Results from these simulations were compared to the results from the model with mill data. The results from simulating a range of different mill scenarios were compared to the measured effluent quality. If simulating a range of different assumptions and scenarios did not yield values that were outside of the normal range of measured data, and if the modelling results agreed with the minimum and maximum values measured it can assist in concluding that the model is an accurate representation of the mill. During this scenario testing investigation a sensitivity analysis was also done to determine the model's sensitivity for the different assumptions and parameters. The results from this sensitivity analysis were available to give a better understanding into the importance and criticality of certain parameters. Although it was outside the scope of this report to investigate the technical feasibility of proposals from this report, the sensitivity investigation proved the model's suitability for use later to investigate the technical feasibility of implementing these proposed changes. The sensitivity analysis was done for volume, sodium, chloride and calcium. COD and suspended solids was not included in the sensitivity investigation since it was only later decided to include them as contaminants.

Because it was not possible to simulate all the different mill scenarios, the method of factorial analyses, based on the technique by Taguchi, was used to decide which different scenarios had to be simulated. A brief description of the Taguchi method is given. For a detailed description of the Taguchi method, refer to Roy et al [47]. Factorial design is the technique of defining and investigating all possible conditions in an array of scenarios involving multiple factors. This method helps an engineer to determine all the possible combinations of scenario variables and to identify the best combination for a required result. An indication of the model's sensitivity to different variables is also generated [47]. More detail on the Taguchi method is presented in Appendix 8.3, only the results are presented in this chapter.
The general approach that was followed is outlined:

1. Decide on a Taguchi L_{64} array for the conventional bleaching scenario. This means that only 64 different mill scenarios had to be run which fitted in with the time allowed for this project.
2. From all the assumptions that were made during the formulation of the mass balance (see reference 51) 63 parameters and assumptions were selected that were considered important in the mass balance. These parameters were selected based on experience and literature references. The selected parameters are presented in Table 38 in Appendix 8.3. For each parameter low and high values are also listed.
3. A Taguchi sensitivity analysis was done. This means that 64 mass balance runs were done and the results from the different mass balance runs were input into the Taguchi software. From the software the sensitivity of the mass balance to the parameters are given and their importance ranked. The parameters are listed in order of significance in Table 40 in Appendix 8.3.
4. A second sensitivity was done to determine the impact of plant up- and down time. A L_{12} Taguchi array was used for the second sensitivity, which allowed a maximum of 11 factors to be included in the analysis. It also meant that only 12 different mass balance scenarios had to be run. The results from Table 40 were used to select a smaller set of assumptions for the second sensitivity, in addition assumptions were made to cluster some of the original factors together. This clustering was used to include as many factors as possible within the limitations of the Taguchi array, and was selected to simulate extreme conditions within the mill. For example, the type of wood used in the digesters (hard wood or softwood) will influence a whole range of operation and plant performance parameters, as shown in Table 41.
5. The ranges for effluent quality and quantity generated by these two sensitivity analyses were compared to actual mill data. The results were correlated to the measured effluent values for the fraction of time that the effluent occurred at less than or equal to those specific values. The results from these comparisons are summarised in Table 12.
6. The minimum and maximum values obtained during the 12 mass balance runs were also compared to measured data. See Table 13.

Table 12: Correlation between WinGEMS model predicted ranges and measured mill values.

Response	Units	Sensitivity Analyse response range[1]		Actual Data Time percentile[2]	
		Min	Max	Min (%)	Max (%)
Irrigated volume	Ml/d	7.96	30.95	0	98
Irrigated chloride	t/d	0.07	23.14	0	78
Irrigated sodium	t/d	5.13	21.61	1	60
Irrigated calcium	t/d	0.371	3.92	0	20

Note 1: Refer to reference 51 for data. This is data generated from the sensitivity analyses
Note 2: Actual measured mill data was used to determine the percentile compliance

From Table 12 it can be seen that the predicted response ranges for the irrigated effluent volume, sodium load and chloride load was in reasonable agreement with the measured values. The predicted response ranges for the irrigated calcium loads were somewhat lower than the measured values. This can be attributed in part to the fact that the WinGEMS model only predicts the effluent quality up to before gypsum ($CaSO_4$) addition to the effluent prior to irrigation, whereas the measured effluent values were from after gypsum addition. The WinGEMS model was corrected after this sensitivity analyses to include the calcium that was added to the effluent. This means that calcium's correlation to actual data would be better than indicated in Table 12, however the sensitivity analysis was not repeated after the correction was made because the sensitivity analysis had already served its purpose, i.e. to highlight calcium as a the least accurate. The amount of work and time associated with calculating the new sensitivity value was beyond the scope of this investigation. Should more detailed technical studies highlight this as a concern, this issue can be re-visited. The sensitivity analyses has highlighted calcium as the least accurate, improvements have been made to the calcium simulation and for the purposes of this report it is adequate to continue with that knowledge. Table 12 indicates that the model can be used to simulate different mill scenarios, with certain assumptions ranging between minimum and maximum values of their typical range while the irrigated effluent properties are still in agreement with the typical measured values. It also indicates that up- and down time simulations of certain plants can be simulated. The table shows that the effluent volume generated with the mass balance for different scenarios and variable assumptions will be within typical mill measured values for 98% of the time.

Table 13 compares the percentage error when comparing the minimum and maximum values generated by the mass balance simulations with the actual minimum and maximum values measured in the plant.

Table 13: Correlation between WinGEMS model predicted Minima and Maxims

Response description	Units	Sensitivity Analyses minimum[1]	Mass Balance minimum	Percentage Error (%)[2]	Sensitivity Analyses maximum[1]	Mass Balance maximum	Percentage Error (%)[2]
Irrigated effluent flow rate	ML/d	7.96	10.92	-37	30.95	26.04	16
Irrigated effluent chloride load	t/d	0.07	0.82	-1071	23.14	21.78	6
Irrigated effluent sodium load	t/d	5.13	6.48	-26	21.61	20.69	4
Irrigated effluent calcium load	t/d	0.371	0.405	-9	3.92	2.753	30

Note 1: Refer to reference 51 for data

Note 2: Percentage error = 100 - 26.04/30.95*100

From Table 12 and Table 13 the following can be concluded:

- Effluent volume, chloride and sodium are in good agreement with the actual measured values.
- Modelling of calcium needed improvement and this has been done after this sensitivity analysis.
- Prediction of contaminant concentrations at the lower scale, i.e. at lower concentrations is not as accurate as when concentrations are modelled at high concentrations. This means that when concentration values are used that are at the lower range of typical values, these concentrations should be used with caution. However, the risks associated with these contaminants at the lower concentration levels are not significant and negligible. The higher level of inaccuracy at the lower level was thus not considered to be a significant problem with regards to the objectives of this thesis.
- The sensitivity analysis also gave an indication of the mass balance's sensitivity to certain parameters and assumptions. See Table 40 in Appendix for results.
- It is interesting to note that digester yield is the most sensitive parameter in the balance. This is in agreement with the mill's current understanding of the importance of digester yield. Although the range over which digester yield can change is low, changes in yield impact on:
  - The volume of weak black liquor being generated,
  - COD content of the weak black liquor,
  - Volume of cooking liquor (i.e. strong white liquor),
  - Residual cooking liquor,
  - Inorganic to organic ratio in the weak black liquor,
  - Pulp productions,
  - Volume of wash water used to wash the pulp and
  - Volume of condensate being generated at evaporator plants.

4.9.5.2 Check 2: Compare Mass Balance concentrations with Measured Data

The concentrations of the different contaminants in various streams were compared to laboratory analyses. The 50-percentile value (and not the average) of the laboratory analyses were used for comparison. For a reference to the laboratory data refer to Appendix 8.7. The comparisons are presented in Table 15. The comparison was done for chloride, sodium, COD and calcium. The difference between the mass balance concentration and the laboratory analyses is expressed as a percentage difference. This percentage difference is positive for certain contaminants (where the mass balance values are lower than the laboratory values) and negative for others (where the mass balance values are higher than the laboratory values). From Table 15 the following can be concluded:

- The contaminants in order of decreasing accuracy are listed:
  - Sodium = 37% (average), 28% (percentile) error
  - Chloride = 57% (average), 35% (percentile) error
  - Calcium = 91% (average), 44% (percentile) error
  - COD = 93% (average), 53% (percentile) error
- The above-calculated accuracy implies that, for example, a sodium concentration could be 28% higher or lower than the mass balance calculated value.
- COD has the lowest accuracy and this is probably due to the high variability of COD in streams. See paragraph 4.9.5.3 on the range of contaminant concentrations.

Laboratory results that are orders of magnitude higher than other data points were not excluded for the following reasons:

1. The water pinch technique requires the typical maximum concentrations. These results that are order of magnitude higher make an important contribution when deciding on the final maximum value to be used in the water pinch analysis
2. It was not clear-cut to define unstable plant conditions, i.e. it is not clear-cut to conclude that a value was an out flyer or whether it is normal process variability
3. The 50-percentile value rather than average values were used. When the 50-percentile value is used, the contribution from out flyer results becomes less significant, but the advantage is that the out flyer results were still considered. In Table 14 example results are presented to explain the use of percentile. Except for one result (500), all the example analyses are all within a certain range. The average calculated for this data is 82 and the 50-percentile is 12. The percentile value is a more realistic representation of typical values for this particular example while the out flyer (500) is still considered. If this particular stream comes up in the sensitivity analyses as being limiting, then the user can evaluate that stream for relaxation of the maximum allowed concentration. By using the percentile value the user have to spend less time up-front to evaluate data from all stream while the conservative solution is provided. Only streams that are then limiting should receive more detailed user focus.

Table 14: Average vs Percentile example

Example	Result
Analysis #1	10
Analysis #2	12
Analysis #3	15
Analysis #4	17
Analysis #5	10
Analysis #6	11
Analysis #7	500
Average	**82**
50-percentile	**12**

Table 15: Mass Balance Concentration Verification

	Mass Balance Stream Number	Chloride			Sodium			COD			Calcium		
		Lab analysis (mg/L)	Mass balance (mg/L)	Diff. (%)	Lab analysis (mg/L)	Mass balance (mg/L)	Diff. (%)	Lab analysis (mg/L)	Mass balance (mg/L)	Diff. (%)	Lab analysis (mg/L)	Mass balance (mg/L)	Diff. (%)
#3 uptake surge chest back water	222	345	403	-14	350	251	39	508	737	-31	46	22	109[9]
#3 uptake buffer back water chest	232	701	1067	-34	550	619	-11	760	1935	-61[6]	71	12	492[6]
#2 uptake back water to #2 fibre line	741	104	70	49	775	992	-22	6787	4671	45	24	18	33
#1 uptake back water to #1 fibre line	726	22	15	47	700	921	-24	5200	1638	217[7]	116	67	73[7]
hot water tank	156	4	2	100[1]	6	4	50	13	15	-13	18	13	38
weak white liquor	313	718	657	9	16500	19000	-13		1708			12	
newsprint effluent	600	19	30	-37	118	153	-23	440	746	-41	53	59	-10
KLB effluent	604	81	83	-2	275	505	-46	920	1506	-39	103	131	-21
Waste plant effluent	106	70	25	180[2]	425	261	63[2]	2400	2429	-1	153	67	128[2]
Strong white liquor	165	3294	3314	-1	122500	96205	27		1807		12	12	0
Weak black liquor from #1 digester	120	1041	1157	-10	33000	32112	3	152000			39	37	5
Weak black liquor from #2 digester	356	840	849	-1	32500	22776	43	144000			51	50	2
Contaminated condensate	344	2	0		10	8	25	1360	1360	0	0	0	
backwater from noodle plant	3	58	15	287[3]	640	1355	-53[3]	8133	1648	394[3]	119	35	240[3]
Groundwood rejects effluent	90	20	19	5	197	264	-25	1391	3249	-57[4]	72	48	50
Groundwood floor drain effluent	465	39	18	117[4]	80	176	-55[4]	640	1455	-56[4]	39	54	-28
Backwater from KLB to repulper	264	152	101	50	620	610	2	1320	785	68[8]	141	134	5
Backwater from NP to repulper	236	21	17	24	35	52	-33	660	1064	-38	10	33	-70[10]
Reclaimed water from KLB to Wasteplant	96	157	101	55[5]	570	613	-7	1260	808	56[5]	153	143	7
#2 uptake effluent	201	93	70	33	713	992	-28	6000	4673	28	81	18	350[4]
#1 digester effluent	145	39	25	56[4]	1188	631	88[4]	5000	3096	61[4]	24	14	71[4]
Evaporators effluent	401	9	37	-76[4]	206	999	-79[4]		8784	-100[4]	14	5	180[4]
E stage effluent	550	877	2089	-58[4]	1070	1524	-30	780	3329	-77[4]	142	47	202[4]
DC stage effluent	552	1538	2453	-37	720	803	-10	1120	2389	-53[4]	91	61	49
ClO_2 Plant effluent	645	839	1068	-21	575	2542	-77[4]	680	62	997[4]	18	14	29
#3 uptake effluent	201	280	70	300[4]	228	992	-77[4]	173	4673	-96[4]	20	18	11
#2 Digester floor drain	534	178	188	-5	2939	3853	-24	3544	17420	-80[4]	166	49	239[4]
Hot water effluent	544	2	2	0	5	4	25		15		11	14	-21
Bleach plant floor drain	553	494	763	-35	550	2739	-80[4]	292	8488	-97	71	39	82[4]
Absolute Average Difference (%)				**57**			**37**			**93**			**91**
Absolute 50 Percentile Difference (%)				**35**			**28**			**53**			**44**

Notes: See next page for notes

Notes on Table 15

Large differences between the mass balance results and the measured results are discussed according to the superscript numbers.

Note 1: The percentage difference is small because the concentrations are very low. These orders of magnitude difference for these low concentrations were acceptable for the purpose of this investigation. The quality is comparable to fresh water quality and fresh water could be used almost at any sink in the mill. With such high quality water, the differences are only significant when they are a few order of magnitudes different.

Note 2: The waste plant was only done to a level 2 detail balance because the plant is a small plant with a effluent stream flow of only 80 litres per minute. This lower level of detail and focus on this plant resulted the quality parameter's prediction being less accurate. The size of the plant and the type of streams (i.e. very similar to the paper machines) made inaccuracy in this plant acceptable for this study to be able to identify saving opportunities.

Note 3: Only three samples were taken of this stream which could have contributed to the laboratory analyses not be being representative. However, apart from the chloride the noodle plant concentrations were not limiting in the pinch analyses. The chloride concentration was relaxed from 15 mg/L to 30 mg/L. The accuracy of the mass balance for the noodle plant could be improved in future for a second round of analyses once the recommendations from this thesis have been implemented.

Note 4: Except for KLB and Newsprint effluent streams, all the other effluent streams have high variability in flows and concentrations. The majority of the effluent streams have zero flow for a high percentage of the time and then spikes of instantaneous high flows and high concentrations. This made it difficult to have a high level of accuracy on all streams. The impact of instantaneous versus average flows and concentrations were accounted for through deviations in the effluent streams that have the highest variability. The impact of this variability will have to be accounted for in the next phase of the study (not included in the scope of this thesis) where process dynamics will have be catered for, i.e. typically the installation of dumping or storage facilities.

Note 5, 6, 7: Only three samples were taken for this stream and the mass balance value is within the minimum and maximum values measured. More detailed mass balancing could be done in future to improve this. For the purposes of this study the accuracy is adequate.

Note 8, 9, 10: This accuracy could be improved for further technical studies. The mass balance value does however still fall within the measured range. The accuracy is considered suitable for this thesis.

4.9.5.3 Check 3: Mass Balance Concentration Comparison with Minima and Maximums

In this check the mass balance concentrations for different streams were compared to the minimum and maximum concentrations measured from the laboratory analyses. If the mass balance value was not within the minimum and maximum range, it was noted and marked in grey scale in Table 16. The percentage of times the different concentrations were outside of the allowed minimum to maximum range was noted and a percentage of time out of specification was calculated. The following results were obtained:

- Number of stream concentrations outside of allowed specification are:
  - Chloride = 4%
  - Sodium = 7%
  - Calcium = 14%
  - COD = 35%
- The above-calculated accuracy implies that for example, mass balance calculated chloride concentration has 4% chance of being outside of the measured minimum and maximum range.
- COD is again the most inaccurate, and as can be seen from the Table 16 has a very wide range of concentration spans.

Table 16: Mass Balance Concentration Range Verification

	Mass Balance Stream Number	Chloride			Sodium (mg/L)			COD (mg/L)			Calcium (mg/L)		
		Min. (mg/L)	Max. (mg/L)	Mass balance (mg/L)	Min. (mg/L)	Max. (mg/L)	Mass balance (mg/L)	Min. (mg/L)	Max. (mg/L)	Mass balance (mg/L)	Min. (mg/L)	Max. (mg/L)	Mass balance (mg/L)
#3 uptake surge chest back water	222	198	618	403	83	2825	251	172	2000	737	10	62	22
#3 uptake buffer back water chest	232	267	1077	1067	120	1800	619	256	2800	1935	18	413	12
#2 uptake back water to #2 fibre line	741	31	1260	70	80	1600	992	160	16400	4671	4	800	18
#1 uptake back water to #1 fibre line	726	13	23	15	550	1200	921	800	8400	1638	20	674	67
hot water tank	156	4	5	2	5	8	4	4	40	15	13	24	13
weak white liquor	313	526	1032	657	6850	25000	19000	2800	16320	1708	0	0	12
newsprint effluent	600	13	44	30	60	510	153	22	1180	746	11	71	59
KLB effluent	604	12	217	83	100	1700	505	22	1880	1506	64	146	131
Waste plant effluent	106	37	187	25	250	650	261	1680	3120	2429	71	470	67
Strong white liquor	165	920	6519	3314	10600	217500	96205			1807	4	75	12
Weak black liquor from #1 digester	120	706	1521	1157	27500	42500	32112				10	134	37
Weak black liquor from #2 digester	356	610	1586	849	18000	37750	22776				8	85	50
backwater from noodle plant	3	23	94	15	600	1700	1355	4000	14400	1648	22	119	35
Groundwood rejects effluent	90	11	44	19	33	885	264	15	2340	3249	12	320	48
Groundwood floor drain effluent	465	6	20	18	20	137	176	18	800	1455	26	1068	54
Backwater from KLB to repulper	264	75	163	101	510	932	610	22	1540	785	56	218	134
Backwater from NP to repulper	236	9	43	17	21	140	52	22	1450	1064	5	49	33
Reclaimed water from KLB to Wasteplant	96	64	177	101	500	700	613	22	1560	808	111	191	143
#2 uptake effluent	201	32	295	70	325	1900	992	4800	7200	4673	36	882	18
#1 digester effluent	145	14	212	25	675	2900	631	4800	5200	3096	10	712	14
Evaporators effluent	401	3	114	37	88	4000	999			8784	6	17	5
E stage effluent	550	1	5899	2089	7	2600	1524			3329	15	672	47
DC stage effluent	552	141	2918	2453	60	1260	803	124	2400	2389	14	284	61
ClO_2 Plant effluent	645	12	8994	1068	6	15000	2542	4	3160	62	0	25	14
#3 uptake effluent	201	31	865	70	77	1680	992	4	704	4673	7	89	18
#2 Digester floor drain	534	60	329	188	300	6875	3853	3120	5000	17420	20	656	49
Hot water effluent	544	2	7	2	3	11	4			15	7	18	14
Bleach plant floor drain	553	14	2404	763	140	130000	2739	15	6400	8488	13	1068	39
Percentage of sample out of range (%)				**4**			**7**			**35**			**14**

4.9.5.4 Check 4: Compare Mass Balance Volumes to Actual Measure Volumes

In this check the volumes calculated in the mass balance were compared to the measured volumes. It can be seen from Table 17 that the model has a high accuracy for calculating volumes. The percentage difference between the mass balance calculated volume and actual measured volume were calculated and is indicated in the Table.

Table 17: Mass Balance Flow Verification

	Plant Actual Flow	Balance Result Flow	Error Difference
	(kg/min)		(%)
PF and CRF #2 Effluent flume	438	438.4	0
Demin Effluent flume	583	584.8	0
Evaporators Effluent flume	2100	2343	-12
#2 Digester Hot water flume	56	56.3	-1
#2 Digester Floor drain flume	570	553	3
Wasteplant Effluent flume	85	87	-2
Groundwood Reject flume	250	254.3	-2
Groundwood Floor flume	180	184	-2
#1 Digester and Uptake Effluent flume	100	100.5	-1
DC Effluent	4500	4245	6
E stage Effluent	1400	1365	3
Bleach Plant Floor Drain flume	430	411	4
ClO_2 Plant Effluent flume	455	455	0
#2 Uptake Effluent flume	500	464	7
#3 Uptake Effluent flume	800	799	0
KLB Effluent flume	2500	2551	-2
Newsprint Effluent flume	2450	2426	1
General Effluent flume	11659	11970	-3
Effluent to Farm	18597	18557	0

4.9.6 Mass Balance Conclusions

- The mass balance validity was verified doing four different checks. None of the checks provide a final and conclusive result, but the combined results from the four different checks provide an adequate indication of the mass balance validity and accuracy.
- Three of the checks focused on the accuracy of the contaminant concentrations, the results from these three concentration checks are given in Table 18.

Table 18: Mass Balance Contaminant Concentration Accuracy Summary Table

	Check 1: Taguchi		Check 2	Check 3
Criteria used	**Time Percentile**	**Maximum**	**50 Percentile**	**Min/Max**
Most Accurate contaminant	Chloride (78%)	Sodium (99%)	Sodium (72%)	Chloride (96%)
Second Most Accurate Contaminant	Sodium (60%)	Chloride (94%)	Chloride (65%)	Sodium (93%)
Third Most Accurate Contaminant	Calcium (20%)[1]	Calcium (58%)[1]	Calcium (62%)	Calcium (86%)
Least Accurate contaminant	Note 2	Note 2	COD (47%)	COD (65%)

Note 1: The accuracy of calcium was improved after the analysis, but the analysis was not repeated.
Note 2: COD was not simulated due to time constraints. COD was only identified at a later stage for inclusion.

- The contaminants sodium, chloride and calcium have a level of accuracy that is adequate for the purpose of this study. COD has a lower accuracy due to the wide variations observed in the concentrations, but the level of accuracy as also deemed adequate for the purpose of this study.
- The fourth check that was used as a measure of the accuracy of the balance in terms of volume proved that the balance is adequately accurate for the purposes of this study. Flow from the Evaporator flume was the most inaccurate, but this is understandable and acceptable for this study. The Evaporator flume is known to have very extreme sporadic flows which makes it more difficult to simulate with a steady state balance.
- Studies done with the Taguchi analysis also proved that the balance could be used for later technical studies to simulate proposals from this thesis. With the Taguchi analyses different scenarios, plant up- and down time, changes to variables and changes to assumptions were imposed on the model. The results proved to be within the minimum and maximum measure ranges for the effluent steam.
- The mass balance was done for a steady state condition and not the dynamic state of the plant. The dynamic state of the plant would have been difficult to simulate and would not yield sensible results, for example certain streams have zero flow for a great percentage of time, and then for short periods have high flows. These streams would have been noted as zero flow and would not have featured in the pinch analysis. With the steady state approach, an average flow was taken for streams, meaning that the extreme and zero flows would have featured in the pinch analysis. Practical implementation of the pinch results thus has to be investigated further through further technical studies that would include looking at process dynamics.

4.10 Setting up the Pinch software

The following paragraphs outline the considerations and methods of setting up the pinch software, verifying the input data and highlights important tips when executing the solver.

4.10.1 Identifying Pinch elements

For the pinch balance the following elements were identified and input into WatePinch™:

- **Process sources** = **43** – these included sources that generate a fixed flow, i.e. weak white liquor from causticising, Demin plant effluent, sub station cooling water, KLB back water etc.

- **Process sinks** = **46** – these included sinks that must receive a fixed flow, i.e. seal water requirements for pumps, ID fan cooling water, smelt dissolving tank vent scrubbers, lime mud clarifier, consistency control in pulp streams etc.
- **Process unit operations** = **28** – unit operations that must receive a defined quantity of water include, the D/C tower, brown stock washer, heat exchangers, cooling towers etc. A user defined relationship exists between the input and output streams of a process unit operation. The brown stock washer for example must receive a defined volume and quality of water to which a defined mass load of contaminants was added to generate a filtrate stream. Each of the process units have at least one sink and one source associated with it.
- **Utility sources** = **2** – utility sources supply water at a defined fixed quality, but the user do not define the flow. The pinch simulation draws water from the utility source as required. Fresh water was defined as a utility source. A dummy utility source was also defined to assist the solver in deriving an answer and to indicate to the designer where the solver was hampered by strict criteria. The dummy source was defined as an unlimited source of very clean water at a cost at least ten times the cost of fresh water. Thus the solver will not use the dummy source except if it has difficulties finding a solution using fresh water which does contain some contaminants.
- **Utility sinks** = **5** – utility sinks have a user defined maximum allowed quality that it can accept. The user also defines a maximum allowed volume that the sink can accept, it does however not mean that the utility sink must receive this volume of water. A certain cost was assigned to the utility sink, and during the pinch analysis the sink can be used until the maximum allowed volume of quality of the sink was reached. The utility sink does not have to reach the user-defined maximum allowed volume. Five utility sinks were defined:
  - Irrigation fields - from the effluent treatment plant the effluent is pumped about 4 kilometres to the irrigation fields from where it is irrigated.
  - Solid waste - effluent sludge is disposed on the solid waste disposal site
  - Dummy sink - the dummy sink is an imaginary user defined sink that can accept liquor or effluent that is very dirty, but at an excessively high cost. The main purpose of the dummy sink is to ensure that a solution does exist for the configuration. The user can also use the dummy sink to trouble shoot the pinch balance and criteria that was defined by the user. Due to the high cost of the dummy sink the solver will only use the dummy sink if no other option exists.
  - #1 CRF SBL incineration – The chemical recovery furnaces were an integral part of the process and it would not be possible to change the function of the furnace in the chemical recovery circuit. However, the furnace was included in the pinch analyses as a sink as a means of controlling the flows into the evaporators. The product stream from the evaporators feed into the chemical recovery furnace. This means the solver will not allow streams into the evaporators that would prevent meeting the concentration requirements of the recovery furnace.
  - #2 CRF SBL incineration – see #1 CRF.
- **Unit operations** = **5 –** Unit operations differ from process unit operations in the sense that a fixed volume of liquor/effluent don't have to pass through the unit operation. The unit operation can have user defined minimum or maximum flows, maximum allowed inlet qualities and can also execute operations that would simulate screens, cleaners, membranes, biological removal etc. Four unit operations have been defined:
  - Evaporators #1
  - Evaporators #2
  - Evaporators #2 condensate splitter - two different types of condensate are generated from Evaporators #2. This block simulates the splitting of the condensate from Evaporators #2.
  - Effluent treatment plant

A total of 146 sources and sinks were identified and transferred into the WaterPinch™ software. A list of the sources and sinks are listed in Appendix A in Table 30 and **Table 31**.

4.10.2 Dummy Sinks and Sources

An important tool used in the water pinch solver was the dummy sinks and sources. Especially with complicated and large pinch networks it was important to use a dummy source and sink that provides the solver with a way to correct tight bounds and incorrect or unknown limitations. For example, if the user or engineer prohibits connections that should be permitted in order to reach a solution, the solver will come up with an error message stating that a solution was not possible. This leaves the engineer without a reason or indication as to why the solution was not feasible. If a dummy sink or dummy source were available, the solver would reach a solution by using the dummy sink or source. This solution indicates the use of the dummy sink or source that in turn allows the user to investigate the reasons for using the dummy. The dummy source was configured to supply an infinite volume of clean water, while the dummy sink was configured to receive an infinite volume at infinitely high concentrations. Both the dummy sink and source were assigned a very heavy cost penalty to use.

4.10.3 Pinch set-up Verification

During the process of identifying and transferring of pinch data into the pinch software there were various mistakes that could have been made. It was thus essential to verify that the solver could solve the pinch data to achieve at least the existing mass balance network. Thus before the pinch analysis could be done it was necessary to verify that a solution did exist for the information that was entered into the WaterPinch™ software.

One way of verifying the pinch data was to extensively bound the pinch simulation to force the pinch solver to achieve the existing mass balance without utilising the dummy sources and sinks, while calculating the correct sink concentrations. The results obtained are summarised in Table 32 and Table 33 in Results from Pinch Set-up Verification. Negligible volumes of water were used from the dummy source and negligible volumes were discharged to the dummy sink. The concentrations calculated by the solver differ on average 8.1% or 0.7 mg/L from the actual concentrations.

Thus by extensively bounding the solution to achieve the original mass balance network configuration without using the dummy sinks and sources, and by calculating the sink concentrations correctly, it was proven that the pinch set-up was correct. This technique **proves**:

- Sinks and sources have not been doubly accounted for
- Sinks and sources have not been omitted
- Sink and source properties are correct. The concentrations specified for the sources and sinks should at least achieve the original mass-balance network as a solution.
- Process and Utility units operations have been configured correctly.

This technique **does not prove** that:

- Costs assigned to sources, sinks and operations are correct. It was not possible to verify costs assigned in the problem definition, these costs were confirmed by engineer and accountant's verifications.
- The proposed water network was the optimal network.

To bound the pinch set up to achieve the existing mass balance network 4,568 bounds were used. The resultant pinch network achieved through this check is given in Table 34 in Appendix 8.2.

4.10.4 Simplification of Pinch Analyses

The number of sources and sinks transferred from the mass balance into the pinch balance amounted to 146 initially. Apart from this being a very large number of sinks and sources that complicated the interpretation of results there were also sinks and sources that were similar. The solver had difficulty reaching a solution when sinks or sources were identical. If sinks or sources have the same cost implication the solver does not have a criteria for using the one sink or source above the other. Due to this open-ended problem definition the solver had difficulty reaching an optimal solution.

Reducing the size of the problem definition and removing identical sources or sink significantly improved the frequency of achieving feasible solutions and also improved the time the solver needed to reach a solution. By reducing the number of sources and sinks it was also possible to include more contaminants into the problem definition, i.e. five contaminants. By sacrificing one complexity in the problem definition, i.e. number of sources and sinks another complexity that was more beneficial, i.e. more contaminants were introduced. The number of sources and sinks were reduced from 146 to 92.
The problem definition was simplified by means of three methods:

1. Sources and sinks with the same properties were grouped together to represent one source or one sink. For example the different sources of storm water were combined to form one higher volume source of storm water. Sources and sinks that have been simplified by combining with other sources or sinks have been indicated with the words "simplified". For the detailed list refer to Table 19.
2. the sink and sources with flows smaller than 500 lpm were left out from the problem definition f they were not critical streams (refer to Table 35). The experience and understanding of the engineer was used to evaluate the criticality of the sink or source
3. sinks and sources with the same concentrations were changed slightly to ensure that the qualities were not exactly the same. Normally when two streams have the same quality, one of the contaminants of the stream can be either cleaner or dirtier under different conditions. The contaminants were changed slightly to represent either a dirtier or cleaner scenario for that stream to ensure a difference between the two similar streams.

Table 19: Simplification and Combining of Sources and Sinks

#	Sources and Sink Combined
1.	Combining of all storm water sources – numerous plants had fresh water that was discharged to the storm water system even when it was not raining. The discharges from these plants were combined: JT boilers, gas producers, evaporators sub station, lime kiln substation cooling water, screening house, compressor room
2.	Warm water from the CRF #1 and #2 and the PF boiler were combined.
3.	Scrubbing water used at the CRF #1 and #2 smelt dissolving tanks were combined
4.	Weak white liquor requirement of CRF #1 and #2 were combined
5.	Strong black liquor requirements of CRF #1 and #2 were combined
6.	Filtrate generated at different sources in the Uptake #3 area was combined – thickener filtrate, forming section A and B, press section A and B.
7.	Make-up requirements for cooling towers at Evaporators #1 and #2 were combined.
8.	Make-up requirements for cooling towers that have clean water circuits were combined – hi-kappa cooling tower, Lube oil cooling tower, TG2 cooling tower and service cooling tower.
9.	Digester #1 dilution control and screening consistency control were combined
10.	Causticizing sinks were combined that used the same quality wash water – dregs filter, lime mud washer and dust suppression sprayers
11.	Hot and fresh water sinks at KLB
12.	Uptake #1 sinks – secondary stock chest consistency control, primary screen supply pump consistency control, steady head tank and dry-end repulper.
13.	Uptake #3 filtrates – D37 consistency control, cleaning consistency control, thickener wash water, mixed stock chest consistency water
14.	Hot and fresh water sinks at NP
15.	Digester #2 dilution and blow tank consistency control
16.	Digester #2 WBL cooler water, T20, T11 and T21 heat exchanger cooling water
17.	Hot and fresh water from Uptake #1
18.	Dilution water used at repulpers #1 and #2
19.	Uptake #2 seal water and vacuum pump water

4.10.5 Cost Assignment

The minimum total cost for the water network is used by WaterPinch™ for optimisation. The solver optimises the network through optimising the cost of the network. Although it was important to try and assign accurate costs to the different utilities and process units as a start, it was also not that critical to have an exact cost. The importance of the cost assignment lies rather in the relative cost assigned to one sink or source compared to another. Apart from rand-and-cents that a utility might cost the mill when looking at the accounting books, it was also important to express other factors in terms of cost. Other factors include:

- Environmental impact and constraints,
- Public image,
- Legal compliance and relationships with authorities,
- Permit restrictions,
- Corrosion, scaling and quality impacts,
- Production impacts,
- Geographical constraints and
- Future planning of the mill etc.

Ngodwana mill has been in negotiation with the authorities regarding its irrigation permit, this means that the cost of irrigating effluent was not only a matter of including the variable and fixed cost, but additional motivation must be included in the cost to deter the solver from using the irrigation fields. A penalty factor of 10 was imposed on the irrigation fields to account for indirect cost associated with using the irrigation fields. A summary of costs used in the problem definition is given in Table 20. The table also indicates the penalty factor imposed and the reason for the factor.

Table 20: Assignment of Cost to different Process and Utility units

Variable cost (R/kg)				
Process description	**Actual Cost**	**Penalty factor**	**Reason for penalty factor**	**Adjusted cost**
Fresh water treatment plant	1.34×10^{-5}	10	High permit focus to reduce this intake. Usage was also directly related to effluent volume generated.	1.34×10^{-4}
Effluent treatment plant	6.51E-05	1		6.51×10^{-5}
Irrigation of effluent	2.1×10^{-3}	10	High permit and legal focus.	2.1×10^{-3}
Dummy source	10 times more costly than most expensive source		This source must be the last resort	1.34×10^{-3}
ERP 1 treatment plant	6.51×10^{-5}	1		6.51×10^{-5}
ERP 2 treatment plant	2.32×10^{-5}	1		2.32×10^{-5}
Evaps cooling tower treatment	3.99×10^{-6}	1		3.99×10^{-6}
Dummy sink	10 times more costly than most expensive source		This sink must be the last resort	2.1×10^{-2}

Geographical cost was not considered in this investigation since the cost related to geographical layout become negligible when working with a plant that was already highly closed. The engineer does not want the solver to reject saving opportunities just because of geographical layout. When a connection was proposed that was geographically not feasible, that connection was prevented by using the bound editor.

Penalty factors and controlling the cost assignments were very dependent on the skills and understanding of the engineer. However, through trial and error the cost penalty factors can be adjusted between high and low cost extremes. The approach followed was to set the penalty factors equal to 1 and then gradually increase the penalty factors until the solver could not find a solution due to the factor being too high. This concept is best explained by describing how the irrigation penalty factor was determined:

Initially the cost associated with irrigating effluent was purely the fixed and variable operating costs as determined from the accounting department. The penalty factor was one. This resulted in a solution that provided too much effluent to the irrigation fields, meaning that the proposed solution was worse than the current actual mill network. This penalty factor was then gradually increased and after each increase the proposed solution was evaluated. This was continued until the solver was unable to find a solution or started using the dummy source or dummy sink. Once this point was reached it was known that the penalty factor has been adjusted to adequately compensate for factors such as environmental permit requirement, social importance, future planning of mill etc.

For this thesis it was not necessary to consider corrosion, biofouling, scaling etc by means to assigning penalty factors to different sources and sinks. These impacts were accounted for simply by either preventing certain connections, and/or by the introduction of penalty factors into the irrigation field sink and fresh water source. More attention to these factors can be given once the solver has proposed solutions that have potential for further investigation.

It must be noted that for this thesis the concept of relative costs were used, but it is possible to apply the concept of actual cost to sinks and sources. This would then mean that the total cost provided by the solver could have some practical implications and significance. For this thesis the total cost calculated from the network is only relative cost between different solutions.

The dummy sources and sinks were assigned a cost that is at least ten times higher than the most expensive source and sink respectively. The costs of the dummy sinks and sources must just as expensive as possible to limit the use of the dummy source and sink, but must be "affordable" enough to ensure that a solution is achieved when the solver is unable to use the process sources and sinks.

4.10.6 Pinch Solver Solutions

- *Optimal water network* is the best possible water network that can be achieved for a certain water system. The optimal water network is not dependent on the type of mathematical solver being used, starting conditions, constraints imposed by engineer or any other factor or technique used by the engineer to identify the optimal water network. The ultimate goal of any water optimisation investigation is to achieve the optimal water network. The optimal water network is a network that is normally difficult to achieve due to limitations in solver capabilities or due to the fact that incorrect information was given to the solver. It is also difficult to prove that the optimal network has actually been achieved.
- *Global and local optimal networks* are different types of optimal solutions that can be achieved within numerical solvers. Numerical solvers are a function on the starting conditions, bounds, constraints and other factors designed into the problem statement by the engineer to achieve a global or local optima. Depending on these factors either the global optima or the local optima of a solution could be the actual optimal water network. This concept is depicted in **Figure 30**. The figure indicates that for a certain defined problem a global optima and numerous local optima exist. Depending on the starting conditions provided to the solver, constraints specified by the user, type of mathematical solver used etc either a local or global optima could be achieved.

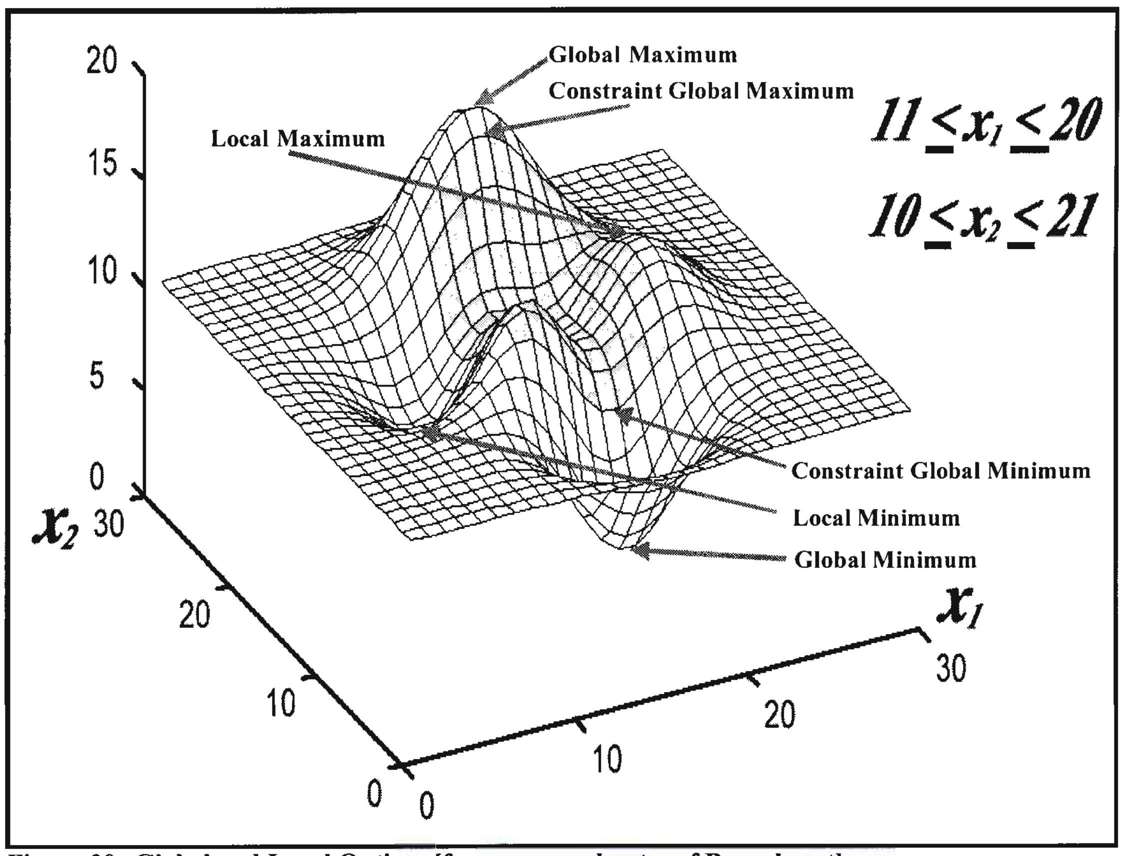


Figure 30: Global and Local Optima [from personal notes of Brouckaert]

This optimal water network is difficult to obtain due to the following reasons:

- Thousands of different starting configurations, i.e. initial concentrations, initial flows are possible and these starting conditions impact on the final solution achieved. The probability of reaching a local optimum is higher than that of reaching a global optimum, because there are normally many local optima but only one global optima.
- It is very difficult to impossible to define a network so accurately that the ideal network is achieved.

For the reasons stated above, careful consideration was given to the approach used to identify the optimal water network. Two different approaches for achieving the optimal water network are indicated in **Figure** 31 in arrow blocks. Using WaterPinch^{TM}, optimisation can be approached from two directions [31]:

1. **By adding bounds:** Taking a completely open process as starting configuration, i.e. a configuration with minimum bounds imposed on it. Typically the following degrees of freedom were allowed: fresh water was permitted to almost all sinks and minimum bounds were enforced. The optimised solution was achieved by a series of optimisation runs. After each run bounds were added where necessary to prohibit the connection of certain sinks and sources until the optimised network was achieved.
2. **By removing bounds:** Taking the actual configuration of the mill, in its current state of closure, as starting configuration. In this case, the optimal configuration was reached through an iterative process by removing bounds that prohibit the connection of certain sinks and sources after each subsequent run.

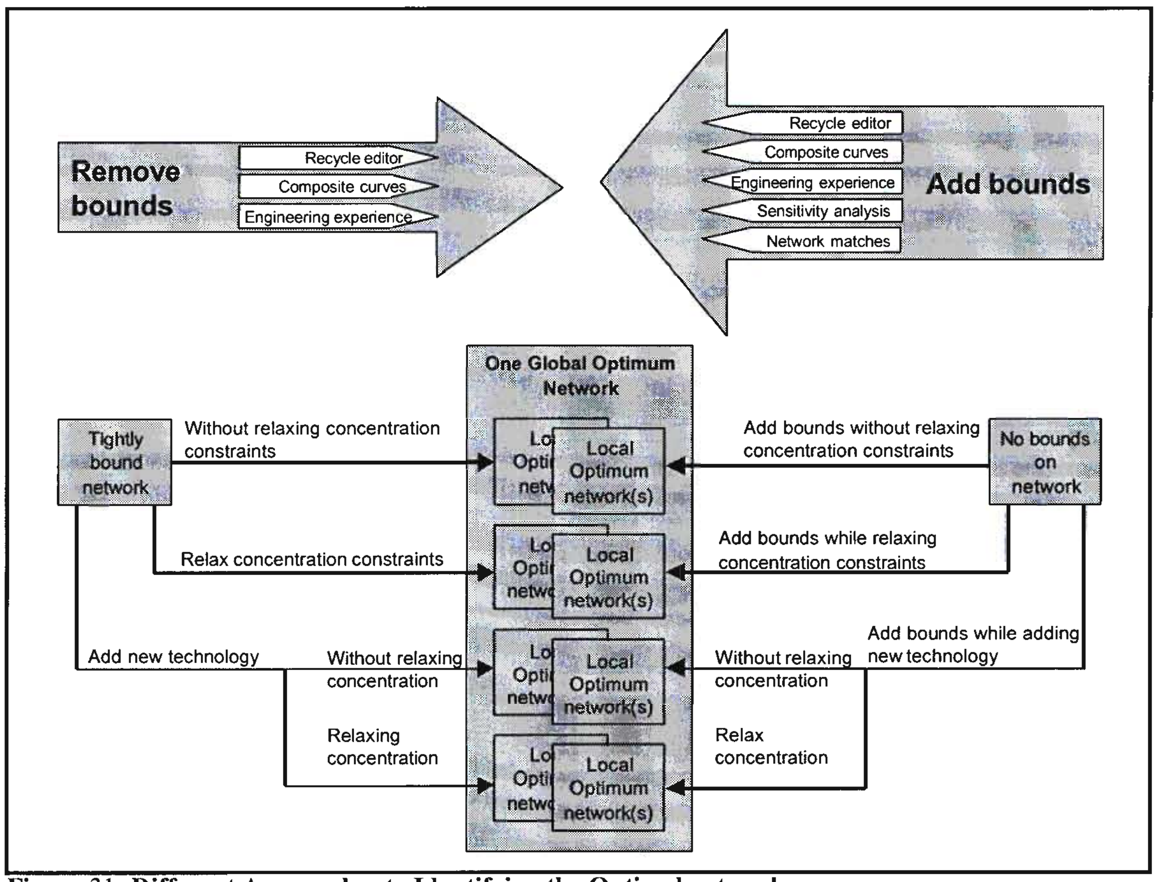


Figure 31: Different Approaches to Identifying the Optimal network

The two different approaches can be applied in four different ways with increasing degree of change to the original network. **Figure** 31 indicates the hierarchy of optimisation:

1. Without relaxation of concentration constraints. This implies that the network was not able to take additional risks in terms of using water with higher levels of contamination. The network was optimised without compromising on the quality of water used at the different sinks in the network. See section 5.2.1. Projects identified in this way were low-cost opportunities involving only pipe-work modifications.
2. With relaxation of concentration constraints. This was the next level of change permitted. This implies that the network was allowing water with an inferior quality to be used at certain sinks. This increases risks such as scaling, corrosion, fouling, deterioration of product quality etc. See section 5.2.2.
3. Once re-routing of pipes and the relaxation of concentration constraints could not improve the network any more, it was necessary to consider the introduction of treatment facilities. The pinch analysis gives guidance on where the most improvement to optimisation was possible with the addition of a treatment facility. The addition of treatment facilities can be considered without relaxing concentration constraints.
4. Addition of treatment facilities can be done while also considering the relaxation of concentration constraints. See section 5.3. For this investigation the option of relaxing concentrations was done.

The advantages and disadvantages of the different approaches are listed in Table 21.

Table 21: Advantages and Disadvantages of different approaches to optimised network*

	Adding bounds	Removing bounds
1.	**A:** The chance of reaching the optimal network is better since all degrees of freedom (i.e. options) were allowed.	**D:** The optimal network may not be reached. The degrees of freedom may restrict the solver to achieve the optimal network.
2.	**A:** The sensitivity graphs in WaterPinch can be used to assist in the optimisatio n process. The sensitivity graphs only evaluates the sensitivity of contaminants for the available degrees of freedom.	**D:** The sensitivity graphs can not be used effectively, since the graphs only indicate the sensitivities within the available degrees of freedom. Connections that are forbidden that might have potential for improving the network are not indicated in the sensitivity graphs.
3.	**D:** The proposed solution can differ to a great extent with the existing water network. This means that the proposed changes can be more difficult to implement because they are so much different from the existing water network. Getting capital approved and convincing management to implement the changes can more tedious.	**A:** The proposed solution does not differ too much from the existing water network. The suggested network changes are easier, and probably less capital intensive, to implement.
4.	**A:** The technique of adding bounds , i.e. prohibiting connections, between sources and sinks was systematic. The "matches" output from the pinch solver can be used effectively.	**D:** The technique of removing unwanted bounds between sources and sinks was not systematic. The decision to remove a bound depends on the user's engineering/technical skills. It was not evident from the pinch output results which bounds must be removed and which not.
5.	**D:** Computational time required reaching a solution could be a constraint depending on the exact network set-up.	

*A = Advantage, D = Disadvantage

For this thesis, the approach followed was to start with the unbound network and to add bounds. This process was repeated for a fixed and relaxed water quality configuration. The option of starting with a bound solution and then removing bounds were not explored due to the disadvantages lis ted in Table 21.

4.11 Assumptions and Limitations of Pinch analyses

The main assumptions and limitation related to the pinch analyses are listed:

1. The mass balance and pinch analyses were done for the mill operating with conventional bleaching. This was the predominant bleaching sequence during the time of the analyses. During the time of the investigation in excess of 90% of the bleaching was done with conventional bleaching.
2. The analysis was done for softwood only since the mill produces mostly softwood (75% softwood production). The difference between softwood and hardwood can be allowed for, or can be investigated during the technical evaluation of proposals. During the time of the investigation the mill was also investigating the possibility of either producing either softwood or hardwood only.
3. Sources and sinks with flows lower than 500 litres per minutes were omitted from the analysis to reduce the complexity of the problem definition so that more contaminants can be included (see Table 35 for a list of the removed sources and sinks)
4. The impact of temperature was included by means of preventing connections using the bound editor. The water pinch technique does not have an integrated method of allowing for temperature impacts.

5. The concept of penalty factors was used to include factors such as environmental impact, legal requirements etc into the problem definition
6. Typical of all optimisers, the success of finding the final solution was a function of the initial or starting point. This means that the starting concentrations can influence the final proposed solution, which might be a local optimum rather than the desired global optimum. The best approach was to start at the current known concentrations. When other starting conditions were tried the solver failed to reach a solution.
7. It was not possible to simulate when a component was valuable or beneficial to the water network. The pinch analyses works on the basis that all chemicals are contaminants, and not a product or a beneficial chemical. It was also not possible to define negative costs to sink or source that would imply a cost saving. Only maximum concentrations were permitted for specification. It was not possible to specify a minimum allowed or requested contaminant concentration. These limitations or problem defining information was imposed onto the solver by means of the bound editor only.

Chapter 5 Results

Note: Refer to Mill Water Network Schematic for clarity on sources and sinks descriptions. The source or sink is indicated on this schematic by reference to the grid number of the source or sink. The grid reference is indicated in brackets i.e. (A3) refers to a source or sink in column A row 3 on the network schematic.

5.1 Composite Curves for Existing Mill Network

In paragraph 4.10.3 the pinch problem was tightly bound to force the solver to achieve the existing mill network. From this solution composite curves were generated. As was described in paragraphs 2.6 and 2.7 the composite curves can not definitively describe the pinch point when a system with multi-contaminants is analysed, however the insight and information obtained from the curves could be used to understand the system better. These curves could also be used as comparison between composite curves generated by other pinch solutions. The results of the composite curves generated from this tightly bound problem are presented here for comparison with other composite curves generated in paragraphs 5.2.1 and 5.2.2. The conclusions from the composite curves are (see Figure 32 to Figure 35):

- The composite curves indicated that the sink and source composite curves for the contaminants chloride, calcium and solids were close to touching. The contaminants COD and sodium were not close to touching each other. The COD and sodium source and sink curves can be moved even closer to each other to overlap more, but the chloride, calcium and/or solids concentration constraints prevent this.
- The composite curves indicate that the sources and sinks closest to the point of touching are:

  Sources
  - Upt 3 – forming section B (Chloride, Calcium) (NN13)
  - Upt 3 – thickener filtrate (Chloride, Calcium) (LL13)
  - Bleach – E tower out (Solids) (CC13)
  - Bleach – D2 tower out (Solids) (EE13)
  - Upt 3 – D37 filtrate (Solids) (HH14)
  - KLB – back water to waste plant (Solids) (J3)

  Sinks
  - Upt 3 – cleaning consistency control (Chloride, Calcium) (KK12)
  - Bleach – wash press in (Chloride) (U14)
  - Bleach – oxygen reactor dilution (Chloride) (V13)
  - Upt 3 – D37 consistency control (Sodium, COD, Calcium) (HH14)
  - Bleach – E tower in (Solids) (CC13)
  - Bleach – D36 consistency (Solids) (GG13)
  - Upt 2 – machine chest consistency control (Solids)
- From the different composite curves, for the different contaminants, the minimum volume of fresh water required for this operation ranges between 17,000 kg/min to 52,000 kg/min (or 24.7 – 74.9 ML/day) [24]. This means that for these network sinks, sources and contaminants, 24.7 – 74.9 ML/day of fresh water was the minimum water target range that could probably be achieved. It is however not possible to definitely conclude that only 24.7 ML/day of fresh water was required with five contaminants to consider. The minimum volumes are only targets that could be targeted for during design, it might however not be possible to achieve a design that could achieve these volumes [23].

- With Ngodwana's current fresh water consumption being 36 ML/day it can be concluded that the mill water system of Ngodwana was very close to being optimised with the current technology being installed
- The minimum target effluent volumes indicated by the composite curves are between 27.4 and 79 ML/day.
- Ngodwana's current effluent generation volume is 27.5 ML/day, which means that the mill's water system is optimised.

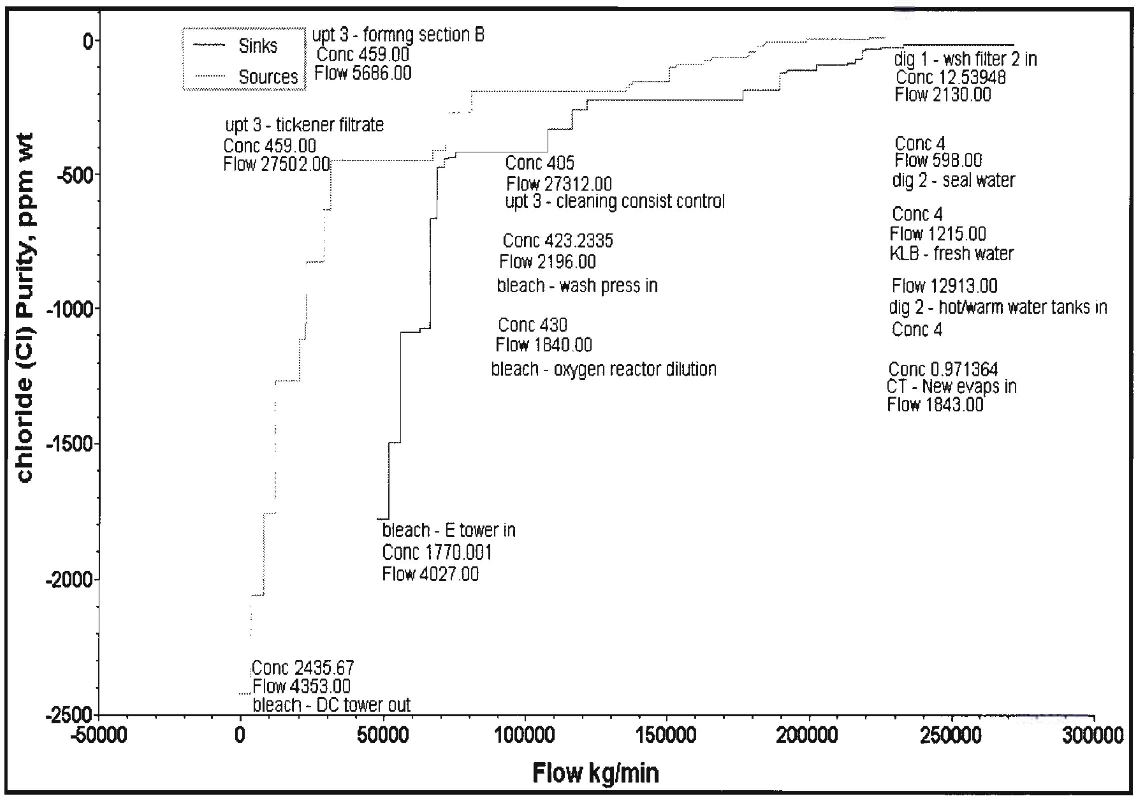


Figure 32: Process Composite – Chloride (un-blended)

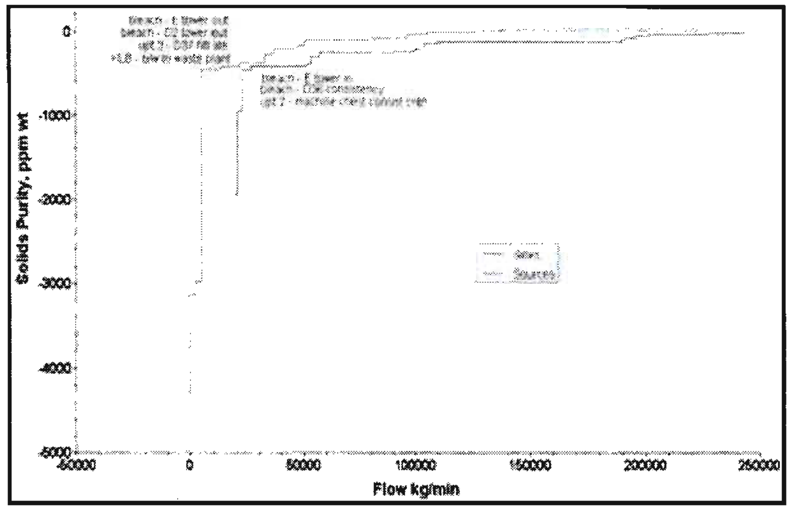


Figure 33: Process Composite – Solids (un-blended)

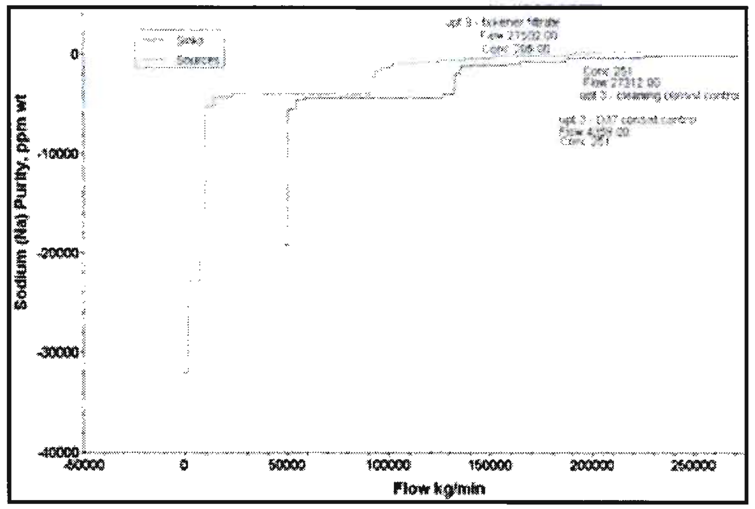


Figure 34: Process Composite - Sodium (un-blended)

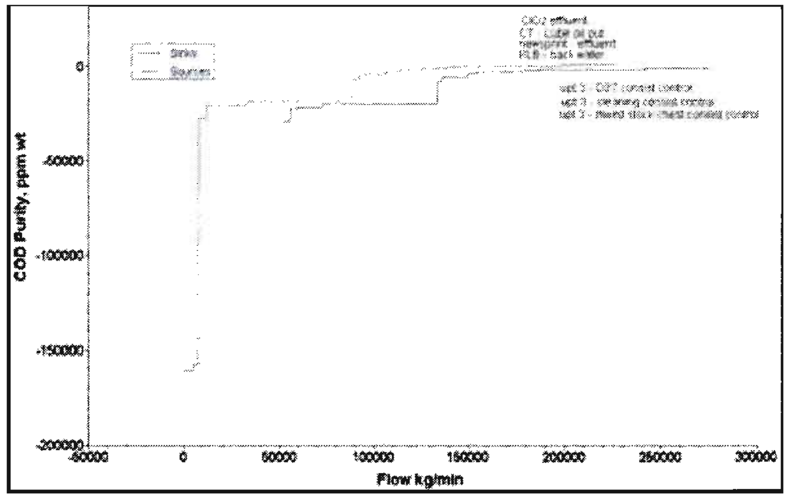


Figure 35: Process Composite – COD (un-blended)

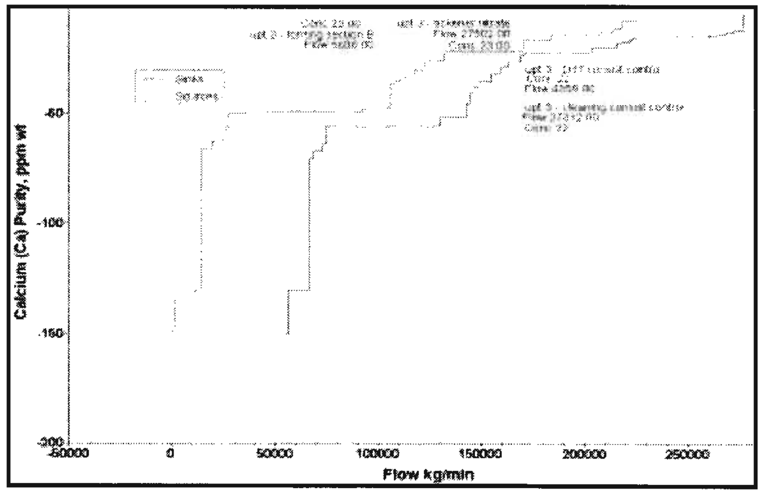


Figure36: Process Composite – Calcium (un-blended)

5.2 Proposed Mill water network Improvements (without adding technology)

Ngodwana is already very water efficient, as was evident from literature surveys where Ngodwana was compared to other mills of the same vintage. This thesis attempted to either improve on this efficiency of the mill or to conclude that Ngodwana's water network can not easily be improved. Improvements to the system were investigated under two different scenarios:

1. In the first scenario the concentration limits were not relaxed, i.e. no additional quality risks were brought into the water network. See paragraph 5.2.1.
2. In the second scenario certain concentration limits were relaxed, implying that if the mill was willing to take additional quality risks what water savings could be realised. See paragraph 5.2.2.

5.2.1 Fixed Water Quality Analysis

The pinch analysis was done by starting with an unbound network allowing the solver maximum degrees of freedom. After each solver run bounds were placed on those connections that were not permitted. Concentration limits were not relaxed. This means that improvements involved mainly pipe changes and that the intention was to not introduce additional risks associated with using water with lower quality compared to current qualities. Only 406 bounds were imposed on the solver.

From the matches table, sensitivity graphs and the composite curves improvement opportunities were identified and conclusions made. The pinch analysis confirmed certain current practices and suggested improvements or changes. The suggested changes have to be evaluated for technical and economical feasibility before implementation. The following was concluded and confirmed from the pinch analysis:

- The proposed network solution generated from the water pinch solution did not make improvements to the existing network. The ultimate measure of improvement was to compare the quantity and quality of the effluent generated from the mill. Table 22 compares the effluent volume, chloride, sodium, COD, calcium and suspended solids from the pinch solution with the actual mill performance. A negative (-) change signifies an improvement. It can be seen that mill's current performance was better or just slightly worse compared to the pinch network.
- There were no major changes identified in the pinch analysis that were significantly different from the current water network. This suggests that without relaxing the concentration constraints, the current mill water network was optimised. But with the implementation of numerous smaller improvements it might be possible to save 1.3 ML/day of effluent. This saving might however not be achieved when taking process dynamics into account and when the technical implications of these changes are investigated in detail.

Table 22: Effluent Comparison between Proposed vs. Actual Water Network

Variable	Mill Actual	Pinch Proposed Network[1]	Pinch Saving[2]
Effluent (ML/day)	26.6	25.3	-1.3
Chloride (kg/min)	16	31	+25
Sodium (kg/min)	16	22	+6
COD (kg/min)	63	92	+29
Calcium (kg/min)	4	2	-2
Suspended solids (kg/min)	21	25	+4

Note 1: Without adding new technology and without relaxing the concentration limits

Note 2: A negative (-) change indicates a reduction or improvement in the effluent discharge

Various small flow connections were made in the pinch solution that could have merit for further investigation. These changes could however result in only small water savings and could introduce significant risks. This was in agreement with the current understanding of the water network of the mill, i.e. to improve the water usage and to reduce effluent it is necessary to make various smaller flow connections that might not be technically and economically practical. The water pinch solution also confirmed current process connections. This is also useful information that the mill can use to its benefit as prove of a sensible connection. **The following practises already implemented at Ngodwana were confirmed with this analysis. These confirmations are also important to indicate to the mill good water network configurations :**

- Filtrate from E tower was used by the solver as wash water on the DC tower (3760 kg/min) (AA13) counter current flow. This flow configuration agrees with the flow configuration of the existing mill.
- The filtrate from the bleach wash press was still recommended (i.e. similar to existing mill network) for use in the O33 blend chest (3615 kg/min) (T13)
- Filtrate from the 3 stage diffusion washer was still recommended (i.e. similar to existing mill network) for use in the oxygen reactor for dilution (1840 kg/min) (Y13).
- The blow down from the Evaps cooling towers (E22, H21) was still recommended (i.e. similar to existing mill network) to be dumped to effluent. Clean condensate with some fresh water was still (i.e. similar to existing mill network) recommended as make-up to the cooling towers.
- Weak white liquor was still recommended (i.e. similar to existing mill network) for use as density control in the CRF #1 and #2 smelt dissolving tanks.
- The Demin acidic effluent was still (i.e. similar to existing mill network) recommended for discharge to effluent treatment to be irrigated.
- KLB backwater (J4) was still recommended (i.e. similar to existing mill network) for use in the waste plant and the repulpers (V7).
- KLB effluent was still recommended (i.e. similar to existing mill network) mostly for discharge to effluent, with small volumes being used in the bleach plant and uptake #2.
- Newsprint backwater (FF7) was still recommended (i.e. similar to existing mill network) for use mainly in the repulpers and the groundwood section.
- The bulk of the Newsprint effluent was still (i.e. similar to existing mill network) being discharged to effluent with smaller volumes being used in the bleach plant and the digester #2.
- Uptake #1 (Z1) backwater utilisation remains the same as the current mill usage.
- Uptake #2 (Q27) backwater utilisation remains the same as the current mill usage.
- It is worthy to note that the pinch results confirm that there is no significant water link between the pulp and paper mill. Apart from the existing water link with the hotwater system between pulp and paper, only a few other minor water flows were suggested.

The following low risk and low capital changes to Ngodwana's current water network were identified in the pinch analyses:

- An interesting connection from the pinch solution was the use of D37 filtrate (HH14) on the bleach E tower (2381 kg/min) (CC13). The difference in quality of D37 filtrate vs. the quality of the filtrate from the backwater chest was something that can be investigated further.

The following high risk and low capital changes to Ngodwana's current water network were identified in the pinch analyses. These changes could be considered for implementation without having to spend considerable capital, after more technical evaluations have been done:

- The Demin caustic effluent has some scope for re-use in the dig #1, uptake #1 (Z1) and the repulpers (V7), however further technical studies might indicate that the heavy metal content and silica content would pose an unacceptable high risk.

The following low risk but high capital changes to Ngodwana's current water network were identified in the pinch analyses:

- Newsprint effluent for wash water on the 3-stage diffusion washer (46 kg/min) (Y13), bleach E tower (169 kg/min) (CC13) and on dig #2 two stage diffusion washer (50 kg/min) (Q22). This is not currently done in the mill, and would also not be implemented because the flow benefit is too small in comparison to the piping and process dynamics complexity. These connections would link the paper mill water network with that of the pulp mill network. Such a connection would only be beneficial when the saving is great.
- Newsprint cloudy backwater (FF7) for wash water on the bleach D2 tower (142 kg/min) (EE13) and consistency control on D36 tower (87 kg/min) (GG13). Same comment as for previous point.
- Fresh water was used as make-up to all other cooling towers, with the blow downs being proposed as make-up to the upt #3 back water system. This was probably a worthwhile connection to implement, the blow downs from the cooling towers TG2 (H9), Hi-kappa (AA26), Lube oil and #2 service cooling tower can be used to replace the fresh water make-up at #3 uptake (941 kg/min). The blow down was also used to replace fresh water use on the repulpers (143 kg/min) (V7).
- The effluent from the hot water system (N16) should be recovered back into the hot water system. In this instance, storage and control are required to ensure that the tanks do not overflow. When it does overflow, the effluent should be stored so that it can be reclaimed back into the hot water system at a later stage.

The following high risk or high capital changes to Ngodwana's current water network were identified in the pinch analyses:

- Use of DC (182 kg/min) (AA13) and E stage (372 kg/min) (CC13) effluent for wash water on the 3-stage diffusion washer (Y13) was identified in the solver. This is a valid option that has been considered in the past by the mill (in ERP1 studies) but is not currently implemented. Although a certain load of chloride into the 3-stage washer is tolerated, chlorides into this sink increase the risk of damage to the recovery furnace. It would thus be advantageous to attempt to decrease the chloride ingress into this sink so the proposal to use DC effluent into this sink would only be considered in practice if an additional chloride removal process were installed. This approach is also followed in other mills.
- Use of fresh water (3159 kg/min) on the 3-stage diffusion washer (Y13) instead of uptake backwater and clean condensate. The clean condensate that is currently used on the 3 stage diffusion washer would then be used on the D2 stage (2190 kg/min) (EE13). These are valid connections, but would not be implemented since they do not result in savings compared to the mill's current water network.
- DC (AA13) and D bleach towers' (EE13) filtrate was still recommended for discharge to effluent (i.e. similar to existing mill network), while all the filtrate from E stage was used for washing on DC tower. The suggested bleach plant was not a pure counter-current flow configuration. Upt #3 filtrate could be used for washing on E stage tower (CC13), this would make it possible to recycle all of the filtrate from the E stage onto the DC tower for washing.
- Storm water was used as make-up to replace fresh water into the hot and warm-water tank (M16) system. This is also a connection that has been considered by the mill in a project to reduce storm water. The mill did however decide against this option due to the risks associated with the storm water getting contaminated under abnormal conditions.
- ClO_2 effluent (EE10) was suggested as wash water on the digester #2 brown stock washer (R19) at a rate of 356 kg/min. Although a certain maximum load of chloride is permitted into this sink, there is a risk associated with it, i.e. plugging of the recovery furnace. The mill would only consider this option with the installation of a process unit to remove the chlorides from the ClO_2 stream.

Apart from the information obtained by analysing the proposed network, additional insight into the proposed network can be obtained by studying the sensitivity graphs. The sensitivity graphs obtained for this pinch analysis are given in Figure 37 and Figure 38. Assuming that all other process variables are not changeable, i.e. flows, mass balance assumptions etc, the only changeable variables are the concentrations. This implies that the sensitivity graphs are a description of the pinch point of the relevant network (see paragraph 2.7).

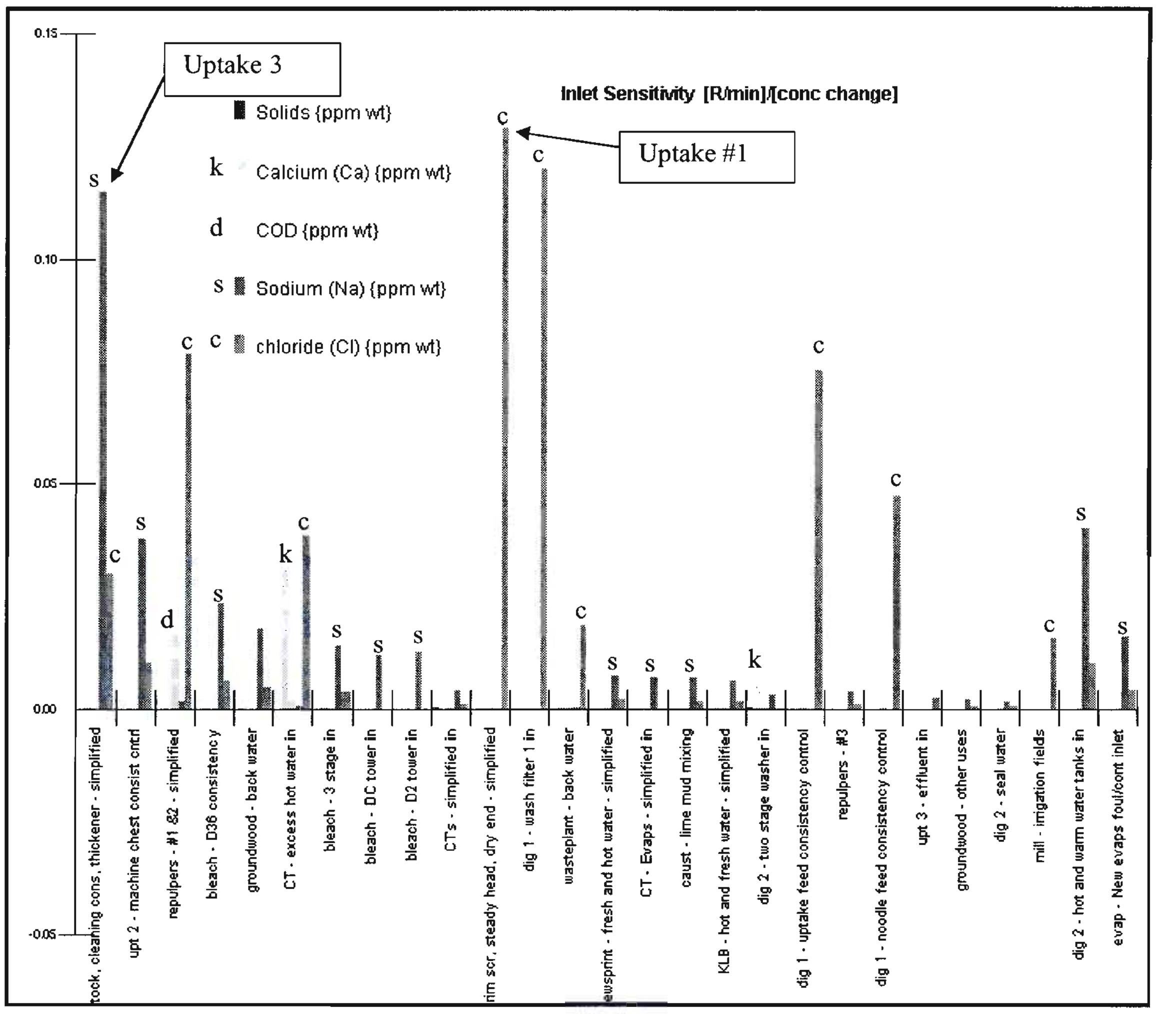


Figure 37: Inlet Sensitivity without Relaxing Concentrations and without new Technology (screen print from WaterPinch™)

From Figure 37 the following can be observed:

- At first glance it is evident that chloride has the highest overall sensitivity for most of the sinks with sodium the second highest overall sensitivity.
- This profile of sensitivities differs from the mill's understanding of its current water network limitations. Most of the improvement opportunities for the new network lie in the uptake plants and the fibre line #1. Studies done by the mill to identify improvement opportunities identified sodium content in the weak white liquor, chloride ingress into the 3-stage diffusion washer and calcium in the bleach plant as restrictions [1].

Observation from the outlet sensitivity graph (see Figure 38) is:

- This sensitivity profile indicates that if the sodium concentration from the evaporator condensates can be reduced, it could lead to water savings. This is a concept that is also known in the mill and is part of the mill's daily management issues, i.e. to ensure low sodium content in the evaporator condensate or else the mill has high effluent rates.

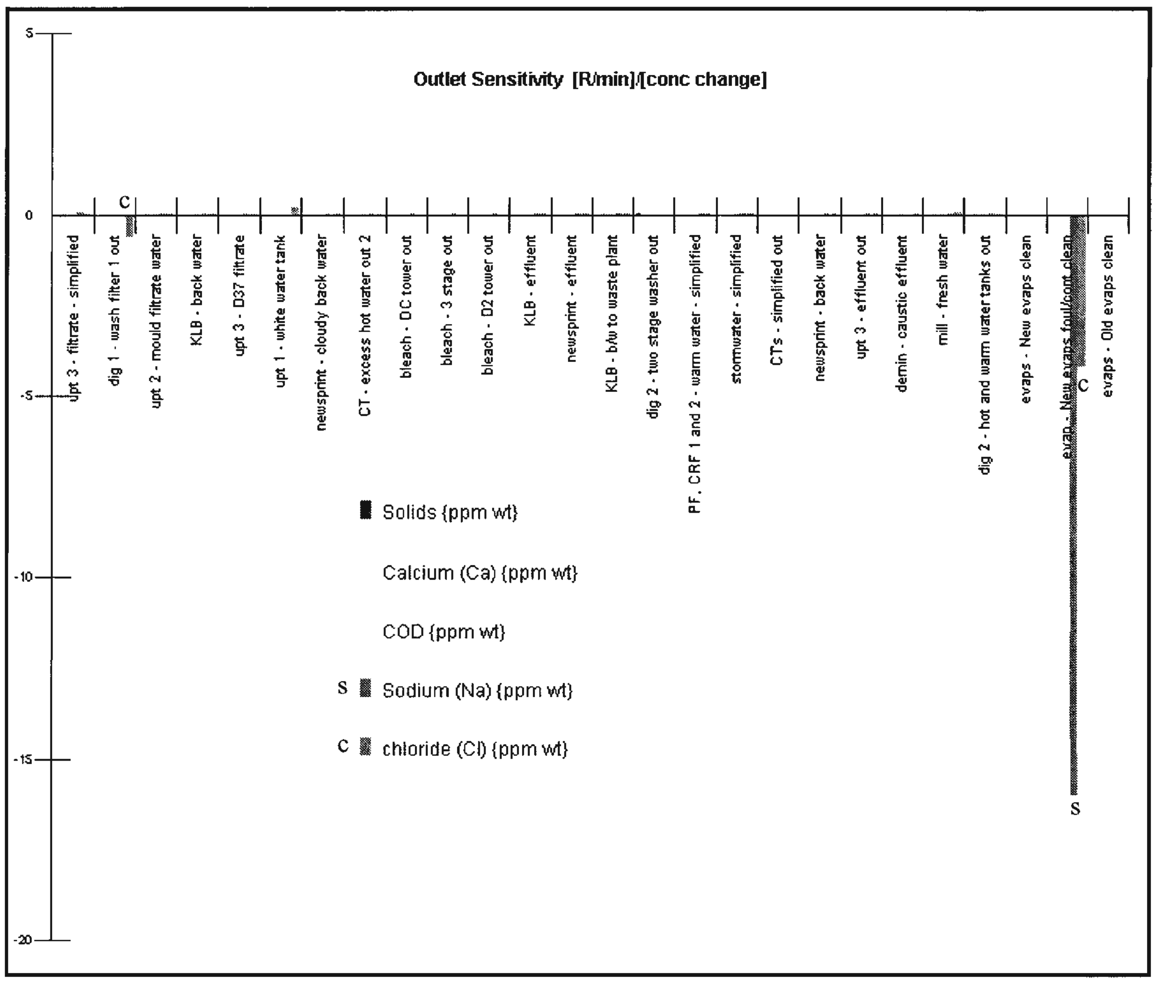


Figure 38: Outlet Sensitivity without Relaxing Concentrations and without new Technology Technology (screen print from WaterPinch^{TM})

The unblended process composite curves also presented insight into the newly proposed water network. Comparing Figure 39 to Figure 32 it can be seen that the chloride composite curve is in agreement with the existing mill's composite profile. It is interesting to note that the composite curves for the mill agrees with composite curves for resultant solver network although the sensitivity graphs do not reflect the mill's current concentration limitations.

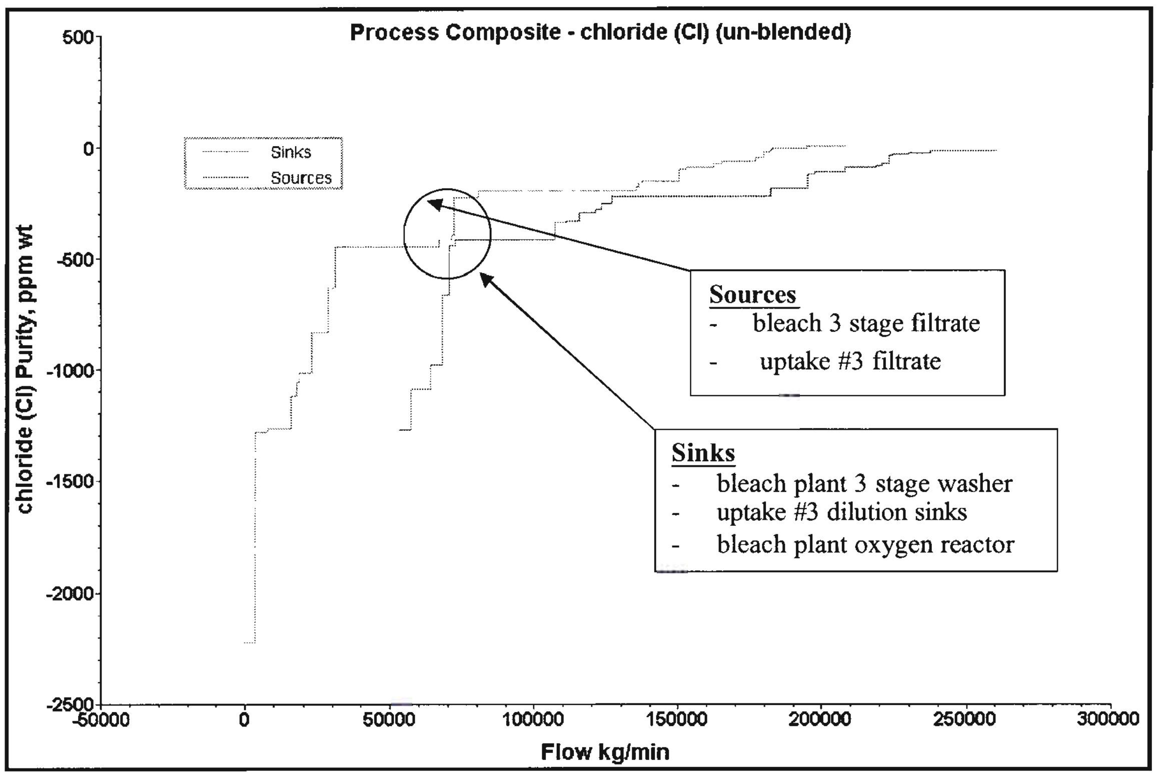


Figure 39: Composite Curve for Newly proposed water network – without relaxing concentrations Technology (screen print from WaterPinch™)

It was concluded that the resultant optimum water network, without relaxing the concentration constraints, was very close to the existing water network, with minor stream changes that could be investigated further. As a rough estimate it might be possible to save a maximum of 1.4 ML/day of effluent and fresh water with the implementation of all the proposed changes from this result. The general interpretation of the results is that the pinch solver could not suggest a water network that is significantly better than the mill's current water network. Small savings could maybe be realised but would require additional study, capital and would introduce new risks into the process. Compared to this solver water network the mill is optimised already. To evaluate the full impact on variable cost the proposed changes identified in the pinch analyses need to be technically investigated further (refer to **Figure 19**).

5.2.2 Relaxed water Quality Analysis

The minimisation of fresh water usage and generation of effluent can further be improved by relaxing certain concentration requirements. The sensitivity graphs were used to identify the sinks that would have the highest impact when they were relaxed. After each solver run the sensitivity graphs were used to determine which concentrations should be considered for relaxation. Those sinks with the highest sensitivities were considered and if possible, a relaxed concentration was imposed on the sink(s). The solver was then run again after the concentrations have been relaxed. These steps were repeated until it was no longer possible to relax concentration restrictions due to the risks becoming too high for the mill to accept.

Figure 43 indicates the final sensitivity profile after all possible and necessary concentrations have been relaxed. Figure 40, Figure 41 and **Figure 42** indicate the intermediate sensitivity graphs that were used to decide which concentrations had to be relaxed after each solver run Careful consideration must be given before relaxing concentration constraints. By relaxing concentration constraints, it was implied that the sinks could accept water of a poorer quality. This means that corrosion, scaling, fouling, foaming and product quality could worsen. The concentration can be relaxed until the risk of these factors was too high to be acceptable. Once the network concentrations have been relaxed to the maximum, further improvement can only be achieved with the implementation of treatment facility(ies). Note: The implementation of treatment facilities was not considered in this part of the study.

To decide how far a particular concentration can be relaxed it was necessary to use experimental data, literature references, and experience. For this thesis, an extensive monitoring program was implemented to build up a database of the current range of contaminant concentrations. This was done for all the sinks and sources. The information from this database was used to determine how much a concentration can be relaxed. In general concentrations were not relaxed to concentrations higher than was measured during the data base analyses – see Appendix 8.7. Information from other technical studies was also used [51].

From the starting configuration, depicted in Figure 40, it can be seen that chloride and sodium were restricting the network from further improvement. After about five iterative steps of evaluating and relaxing concentrations and running the solver a final proposed network was proposed. The final sensitivity profile is given in Figure 43 and the concentrations that were relaxed are given in Table 23.

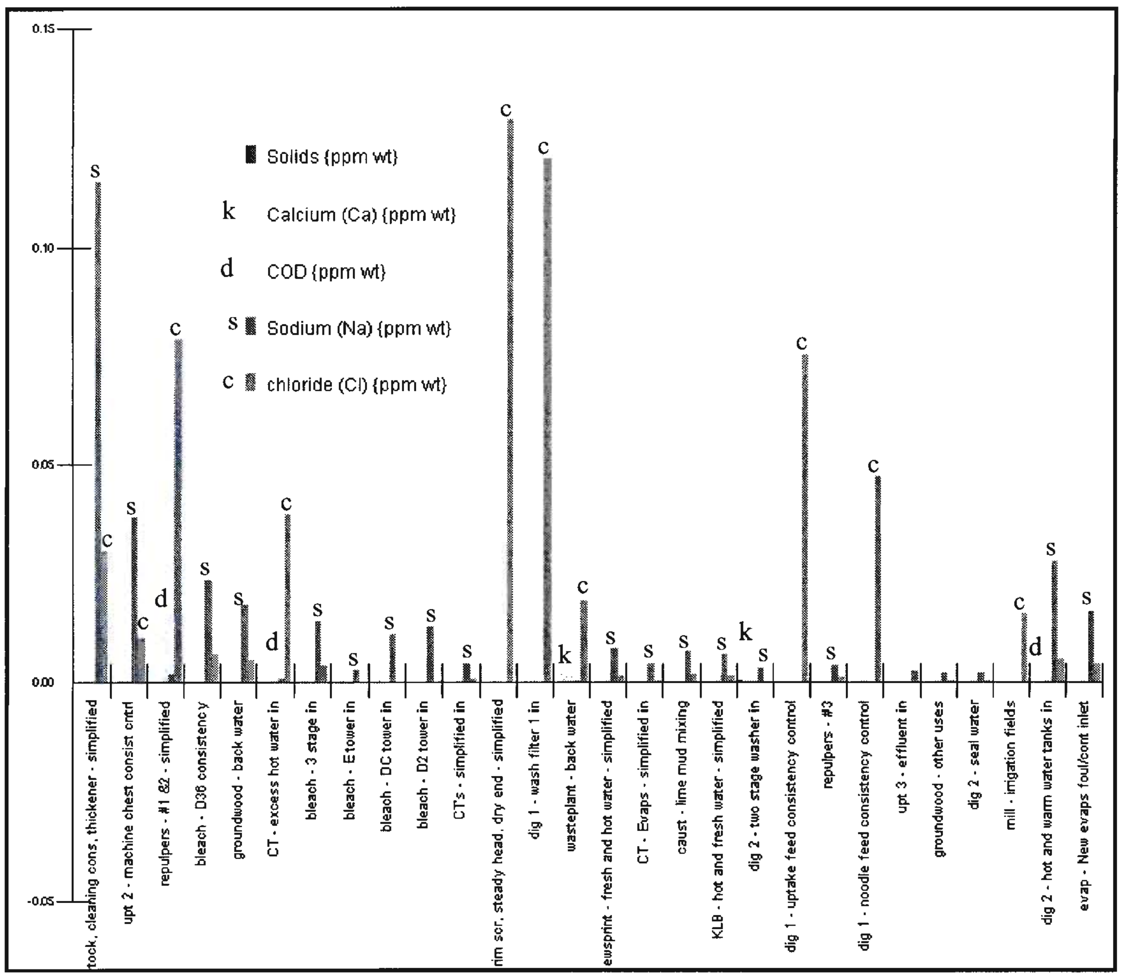


Figure 40: Inlet sensitivity round 1 (screen print from WaterPinch™)

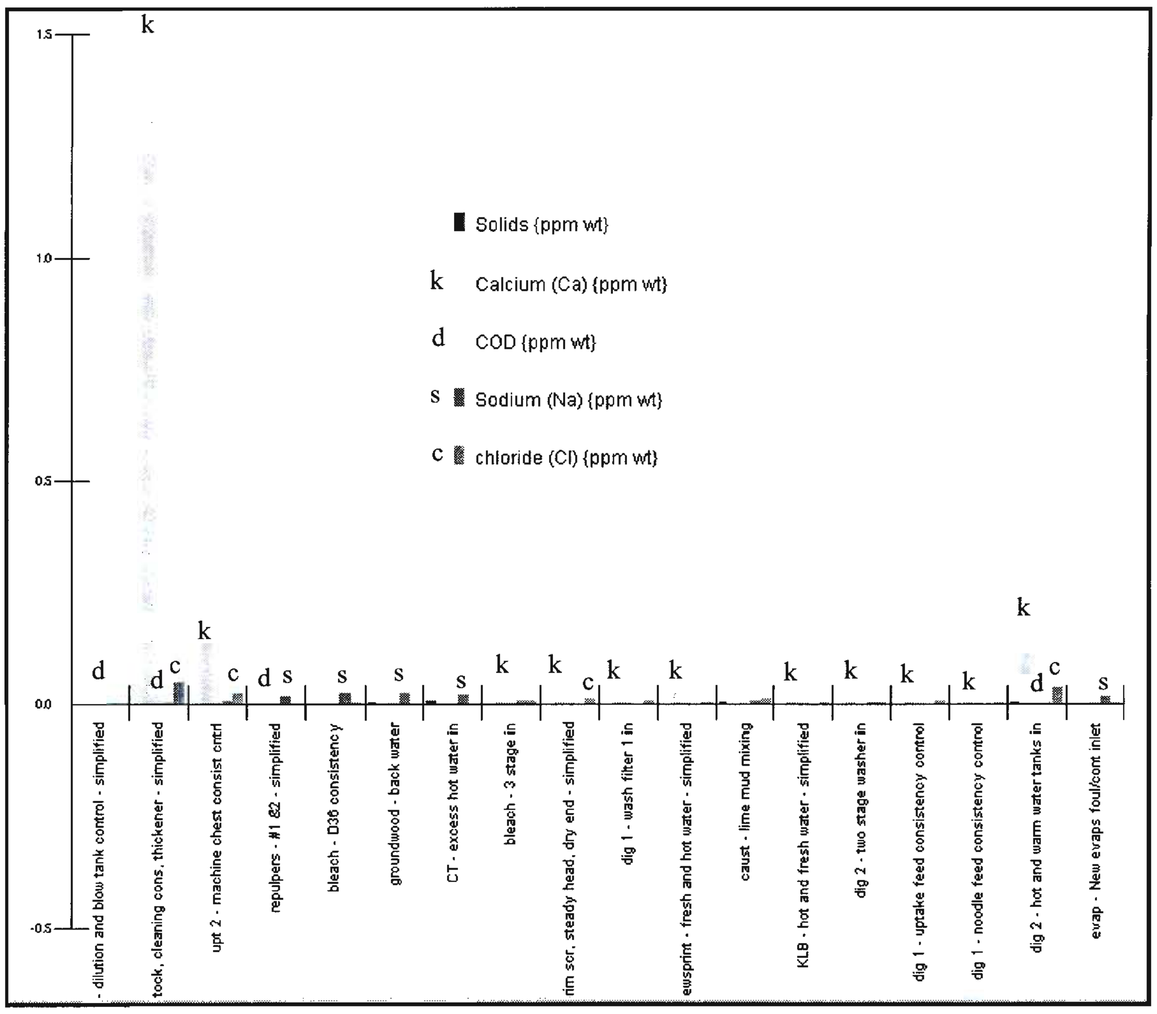


Figure 41: Inlet sensitivity round 2 (screen print from WaterPinch™)

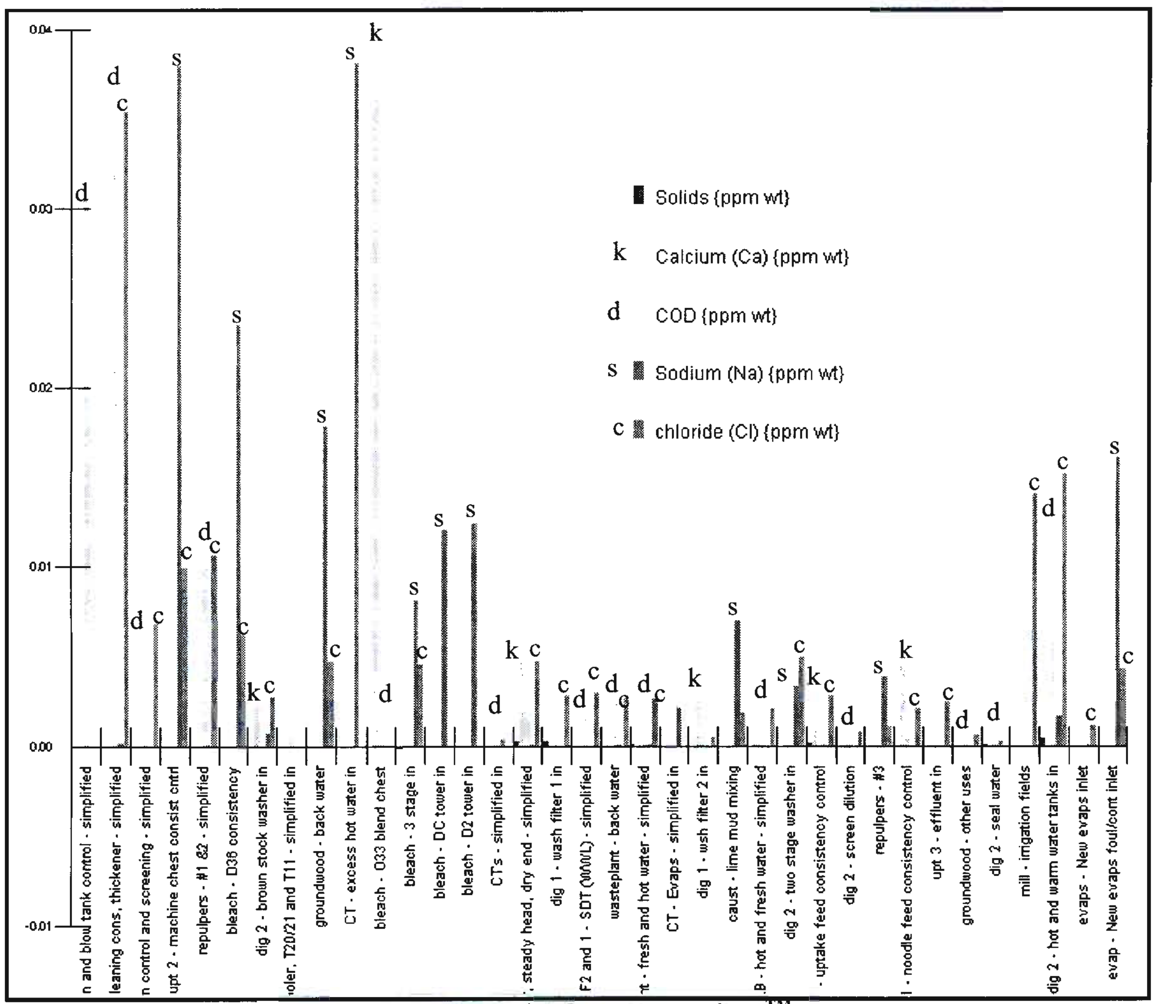


Figure 42: Inlet sensitivity round 3 (screen print from WaterPinch™)

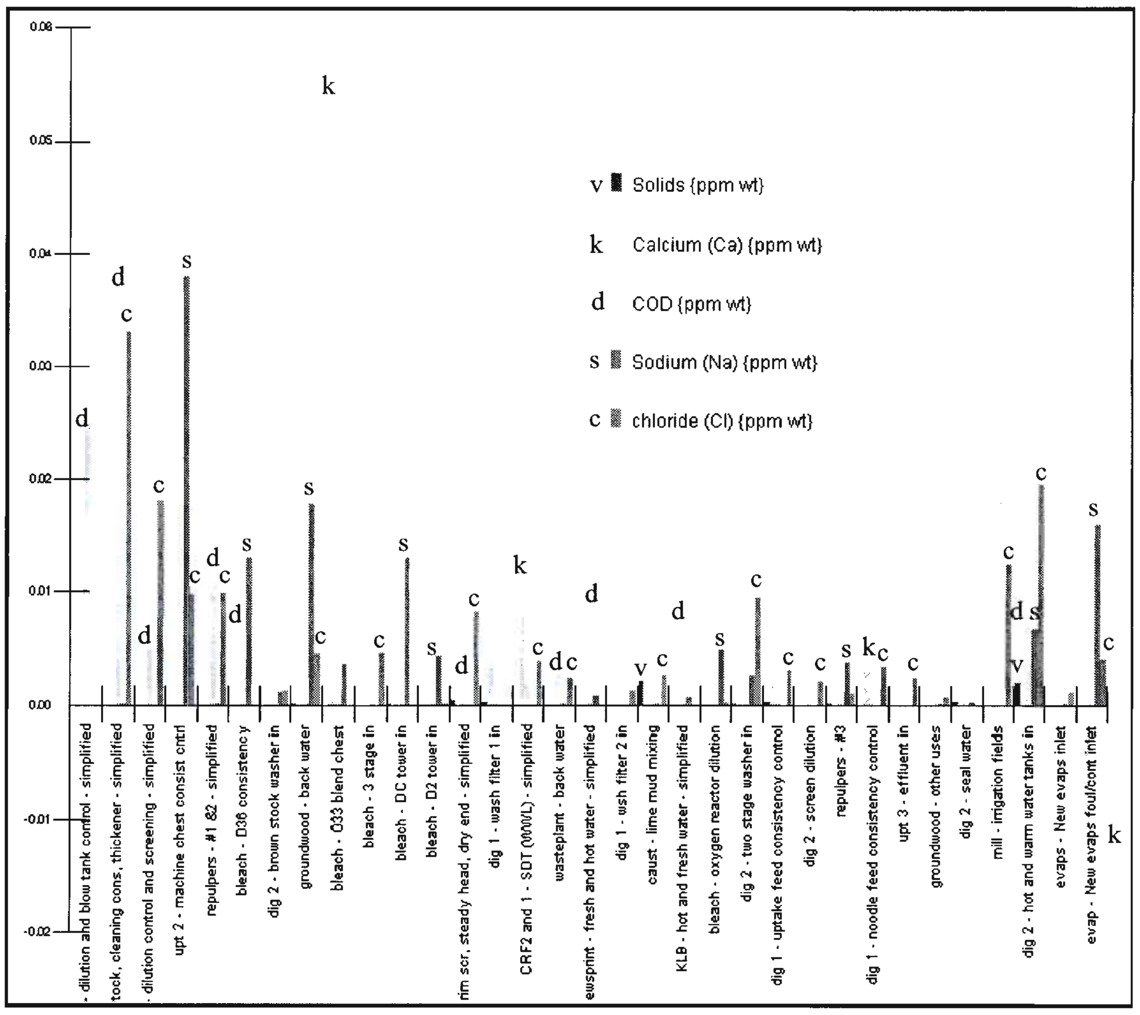


Figure 43: Inlet sensitivity after Relaxing concentrations (screen print from WaterPinch™)

Table 23: Summary of relaxed concentrations

Sink	Contaminant	Initial Conc. (mg/L)	Relaxed Conc. (mg/L)	Change in Conc. (%)			
				Cl	Na	Ca	COD
Dig 1 wash filter #1(Z23)	Cl	59	70	18.6			
Dig 1 wash filter #2 (BB23)	Ca	50	55			10.0	
Upt 1 sec stock chest (Z19)	Cl	15	25	66.7			
	Ca	67	120			79.1	
Upt 3 filtrate sinks (D37..) (HH14)	Na	251	360		43.4		
	Cl	405	450	11.1			
	Ca	22	50			127	
	COD	740	800				8.1
Repulpers 1 and 2 (R6, S7)	Cl	97	160	64.9			
	Na	575	650		13.0		
Dig 1 uptake feed consist. Cntrl (GG23)	Cl	15	25	66.7			
	Ca	67	70			4.5	
Dig 1 noodle feed consist. Cntrl (GG24)	Cl	15	30	100			
Cooling tower excess hot wtr (Q13)	Cl	4	5	25.0			
	COD	16	25				56.3
	Na	6	10		66.7		
Dig 2 hot water system (N16)	Na	6	10		66.7		
	COD	16	25				56.3
	Ca	15	20			33.3	
	Cl	4	6	50.0			
Upt 2 machine chest (R25)	Ca	20	30			50.0	
	Na	*	1000				
	Cl	*	75				
Bleach 3 stage washer (Y13)	Ca	18	25			38.9	
	Na	202	500		148		
Dig 2 two stage washer (Q22)	Ca	20	30			50.0	
	Cl	*	71				
	Na	*	922				
Bleach O33 blend chest (T13)	Ca	31	35			12.9	
	COD	21530	22000				2.2
Bleach D36 consistency (GG13)	Na	*	626				
	Cl	*	1075				
Bleach DC tower (AA13)	Na	1091	1200		10.0		
Bleach D2 tower (EE13)	Na	620	1000		61.3		
Groundwood back water (Z3)	Na	*	50				
	Cl	20	30	50.0			
Cooling towers (TG2, lube,...)	Na	6	575		9483		
Waste plant back water (V5)	Cl	110	160	45.5			
	Ca	150	190			26.7	
Newsprint and KLB fresh water use (FF2, B4)	Na	6	15		150		
	Cl	4	10	150			
Causticising foul tank (B27)	Na	42	1427		3298		
	Cl	1	67	6600			
Relative percentage changes (%)**				34.5	63.1	2.0	0.3
Number of individual changes				13	10	10	3

*See next page

** See next page

Notes on **Table 23**
*Starting values not on record
**The percentage change of the different contaminants relative to each other was calculated. For example if the concentration was relaxed from 110 mg/L to 160 mg/L, the percentage change is (160-110)/110*100 = 45.5%. As a further note, the averaging of concentrations is considered an unconventional method of interpreting the relaxation of concentrations. The information from these average concentrations should be used as information only and be applied with caution when used in future investigations.

The solver water network connections are presented in Appendix 8.9 in Table 118. The following improvement opportunities and conclusions are made from the pinch analysis for the final relaxed network configuration:

- Table 24 compares the effluent quantity and quality generated by the mill currently with that of the pinch water network. A negative (-) performance indicates an improvement. From this table it can be seen that the proposed pinch water network has improved on the mill's current water network in terms of quantity and quality. These savings come however at an increased risk to the mill, and can only be considered once more detailed studies have investigated the impact of non process elements (NPE's). Table 23 indicates the extent of the concentration relaxation.

Table 24: Effluent Comparison between Proposed vs. Actual Water Network

Variable	Mill Actual	Pinch Proposed Network[1]	Pinch Saving[2]
Effluent (ML/day)	26.7	20.6	-6.1
Chloride (kg/min)	16	12	-3.4
Sodium (kg/min)	16	5	-11
COD (kg/min)	63	41	-21.7
Calcium (kg/min)	4	0.4	-4.0
Suspended solids (kg/min)	21	12	-9.7

Note 1: Without adding new technology and with relaxing the concentration limits
Note 2: A negative (-) change indicates a reduction or improvement in the effluent discharge

The following practises already implemented at Ngodwana were confirmed with this analysis:

- Uptake #3 filtrate (2723 kg/min from D37 (HH14) and 924 kg/min from uptake) was used as wash water on D2 bleach tower (EE13). A small volume of KLB effluent (P3) can also be used as wash water on the D2 tower (7 kg/min) (EE13). Except for the use of a small volume of KLB effluent this was similar to the mill's current water network.
- D36 consistency control (GG13) remains the same as current water network with uptake #3 filtrate being used.
- All the filtrate from the DC tower (AA13) was dumped to effluent, this is also the current mill practice.
- The bleach plant wash press filtrate (U14) are used on the digester #2 brown stock wash for washing (4507 kg/min) (R19) and the O33 blend chest (3152 kg/min) (T12) – similarly to the mill's current water network.
- The hot water system (N16) make-up remains largely the same with fresh water make-up and return from the excess hot water cooling tower (Q13). However, some of the blow down from the cooling towers (189 kg/min) and the evaps cooling towers (401 kg/min) (E22, H21) were also used as make-up. The feasibility of using the evaps-cooling tower's blow-down as make-up has to be confirmed with energy balances.
- WWL liquor from the mud washer (E24) is used for dilution at the smelt dissolving tanks (2401 kg/min). This is similar to the mill's current water network.

The following high risk and low capital changes to Ngodwana's current water network were identified in the pinch analyses. These changes could be considered for implementation without having to spend considerable capital, after more technical evaluations have been done:

- ClO_2 effluent (BB9) was used on E tower (CC13) for washing (51 kg/min) – this is not the same as the mill's current water network. For both networks proposed by the pinch solver (i.e. without relaxing the concentration and with relaxation of concentration limits) the ClO_2 effluent was used in small volumes in different parts of the plant. This is an option that could be looked at, however the ClO_2 effluent stream is known to have variable pH, volume and quality.

The following low risk but high capital changes to Ngodwana's current water network were identified in the pinch analyses:

- For lime mud mixing (C23), the blow down from the cooling towers were used (871 kg/min) (E22, H21) – only fresh water was used as make-up to the cooling towers. This was in agreement with the planning for future improvements with the ERP1 project, but is however not currently done since the implementation of project ERP1 has been put on hold. Fresh water (815 kg/min) and weak white liquor (140 kg/min) (E24) were also used as make-up to the lime mud mixing tank (C23).
- The KLB effluent (P3) was used in small volumes at different sinks in the pulp mill. Table 21 summarises the sinks where KLB effluent can be used.

Table 25: KLB effluent usage

Sinks	Flow (kg/min)
upt 2 - machine chest consist cntrl (U27)	873
upt 3 - D37, mixed stock, cleaning cons, thickener – simplified (PP16)	841
mill – irrigation fields	500
dig 1 - noodle feed consistency control (GG24)	155
upt 1 - sec stock chest, prim scr, steady head, dry end – simplified (JJ21)	56
dig 1 - wsh filter 2 in (BB23)	55
dig 1 - uptake feed consistency control (GG23)	33
wasteplant - back water (V5)	28
dig 1 - wash filter 1 in (Z23)	22
CRF2 and 1 - SDT (WWL) – simplified	22

- The suggested supply of wash water into the 3-stage diffusion washer (Y12) is presented in Table 26. The supply into the 3-stage diffusion washer differs considerable from the mill's current water network. The mill uses only uptake #3 back water and evaporator condensate as wash water.

Table 26: Supplies to 3 Stage Washer

From Source	Flow (kg/min)
upt 2 - mould filtrate water (U27)	242
upt 3 - D37 filtrate (HH14)	193
upt 3 - filtrate – simplified (NN13)	1577
KLB - effluent	12
upt 3 - effluent out	800
mill - fresh water	1261

The following high risk or high capital changes to Ngodwana's current water network were identified in the pinch analyses:

- Uptake #3 filtrate (193 kg/min from D37 (HH14) and 1577 kg/min from uptake), uptake #3 effluent (800 kg/min) and fresh water (1261 kg/min) was used on the 3 stage diffusion washer. A small volume of uptake #2 mould filtrate (242 kg/min) (Q27) and KLB effluent (12 kg/min) (P3) was also used as wash water on the 3-stage diffusion washer (Y13). This is almost in agreement to the mill's current water network, however the use of the 800 kg/min of uptake #3 effluent was a new proposal. The uptake #3 effluent replaces the use of evaporator condensate, and the evaporator condensate was used as wash water on the DC tower (AA13).
- The flow suggestions around the bleach towers were different from the current flow configuration. Filtrate from the D2 tower (EE13) was used on the DC tower (2286 kg/min) (AA13) and clean condensate from the evaps (H18) was also used on the DC tower (883 kg/min) (AA13). Again a small volume of Newsprint effluent (300 kg/min) (MM7) was used on the DC tower (AA13).
- Instead of counter current flow with filtrate D2 filtrate (EE13) onto the E tower (CC13), uptake #3 filtrate (LL16) was used on the E tower (3908 kg/min) (CC13). The filtrate from E tower (3715 kg/min) (CC13) was returned to the uptake #3 plant for use. This is considerably different to the current mill arrangement and could be investigated further.
- Fresh water only was used as make-up to the evaporators cooling towers (2222 kg/min) (E22, H21) with the blow down from these cooling towers going to the hot and warm water tanks (401 kg/min) (N16). The use of only fresh water on all cooling towers was in agreement with the current focus that was experienced on improving the cooling tower's water circuits. More detailed energy balances are however required confirming the feasibility of the proposed connections.
- Storm water was used in the uptake #3 section (PP16) to replace fresh water make-up (1233 kg/min).

Apart from the observations made from the match table, sensitivity graphs were also generated. The final sensitivity analysis for the proposed network is given in Figure 43 and Figure 44. The figures show that:

- Calcium, COD, sodium, and chloride were all sensitive to change which means that the network was close to optimisation in more than one respect. A large number of sinks were indicated as having a high sensitivity, again that points to a network that was close to being at the optima.
- The sensitivity of the bleach plant to high calcium concentration confirms that the mill has been focussing its attention in the correct areas to try and improve the mill water network.
- D37, mixed stock, cleaning consistency control and thickener were sinks in the uptake #3 plant (PP16). These sink's high sensitivity to COD and chloride are high on the sensitivity scale and would need attention in future if further improvement has to be made.
- From the outlet sensitivity graph it was shown that the calcium concentration in the clean condensate was limiting further improvement. In this analysis it was interesting to note that the clean condensate was disposed to effluent and was not used on the 3-stage diffusion washer (Y13). The outlet sensitivity again confirms the sensitivity of the network to supplying chlorides into the SBL stream, i.e. reducing chloride in the evaps clean condensate. The necessity for a chloride removal process was thus confirmed again.

Table 23 indicates the relaxed concentrations. The following interesting observations were made:

- A total of 63.1% changes were made to sodium concentrations, 34.5% to chloride, 2% to calcium and 0.3% change in the COD concentrations. This means that the in order to derive at a new water network with relaxed concentrations, the greatest changes in the mill can be expected due to sodium and chloride concentrations that will increase at different sinks in the new proposed water network. This was in agreement with other detailed technical studies around the ERP1 project.
- Although the biggest changes will be in the sodium concentration, more sinks will be affected by chloride changes. 13 sinks will have their chloride concentrations relaxed, 10 sinks will have their sodium and calcium concentrations relaxed.

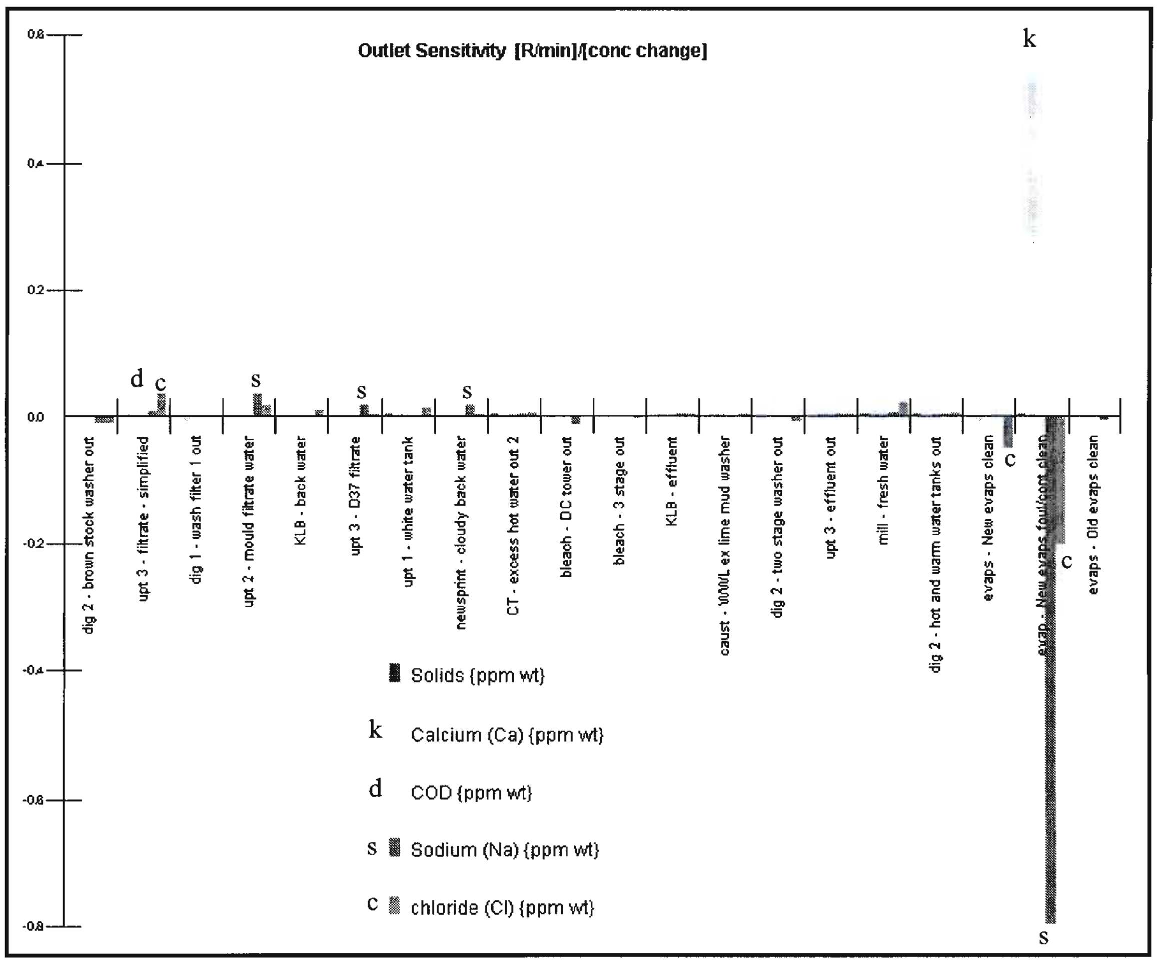


Figure 44: Outlet sensitivity after Relaxing concentrations (after relaxing concentration limits) (screen print from WaterPinch™)

5.3 Proposed Configuration for ERP1 plant

The pinch solver can also be used to determine the best location in the water network to use treatment technologies. The proposed new ERP1 (effluent reduction project phase 1) was simulated in order for the pinch solver to determine which sources should be treated in the facility. The solver also indicates where the treated water can be used. From pilot plant studies [61] it was determined that the ERP1 plant can remove 85% COD and 95% of the suspended solids, 96% of the flow was recovered. A treatment block was added to simulate the ERP1 plant. The cost of using the ERP1 treatment plant was set to zero cost, this was to encourage the solver to use the ERP1 plant to its maximum. By doing this it was determined what the best use for the ERP1 plant was if cost was not a concern. This approach demonstrated the principle use of the ERP1 treatment plant without the possibility of incorrect cost penalty factors distorting the ERP1 application. When costs were assigned to the ERP1 plant the solver did not use the ERP1 plant. The proposed water pinch network had the following features:

- The feed streams into the water pinch ERP1 plant were different to the mill's feed streams planned for the new ERP1 plant. The mill's planning is to put the low chloride containing streams through the

ERP1 plant. The treated water from the ERP1 plant would then be used as make-up to evaporator cooling towers. In the evaporator cooling towers the low chloride containing streams would get concentrated from where the blow down would be used in the causticising section from where sodium can be recovered. See Figure 45 for a layout of the mill's plan for the ERP1 treatment plant.

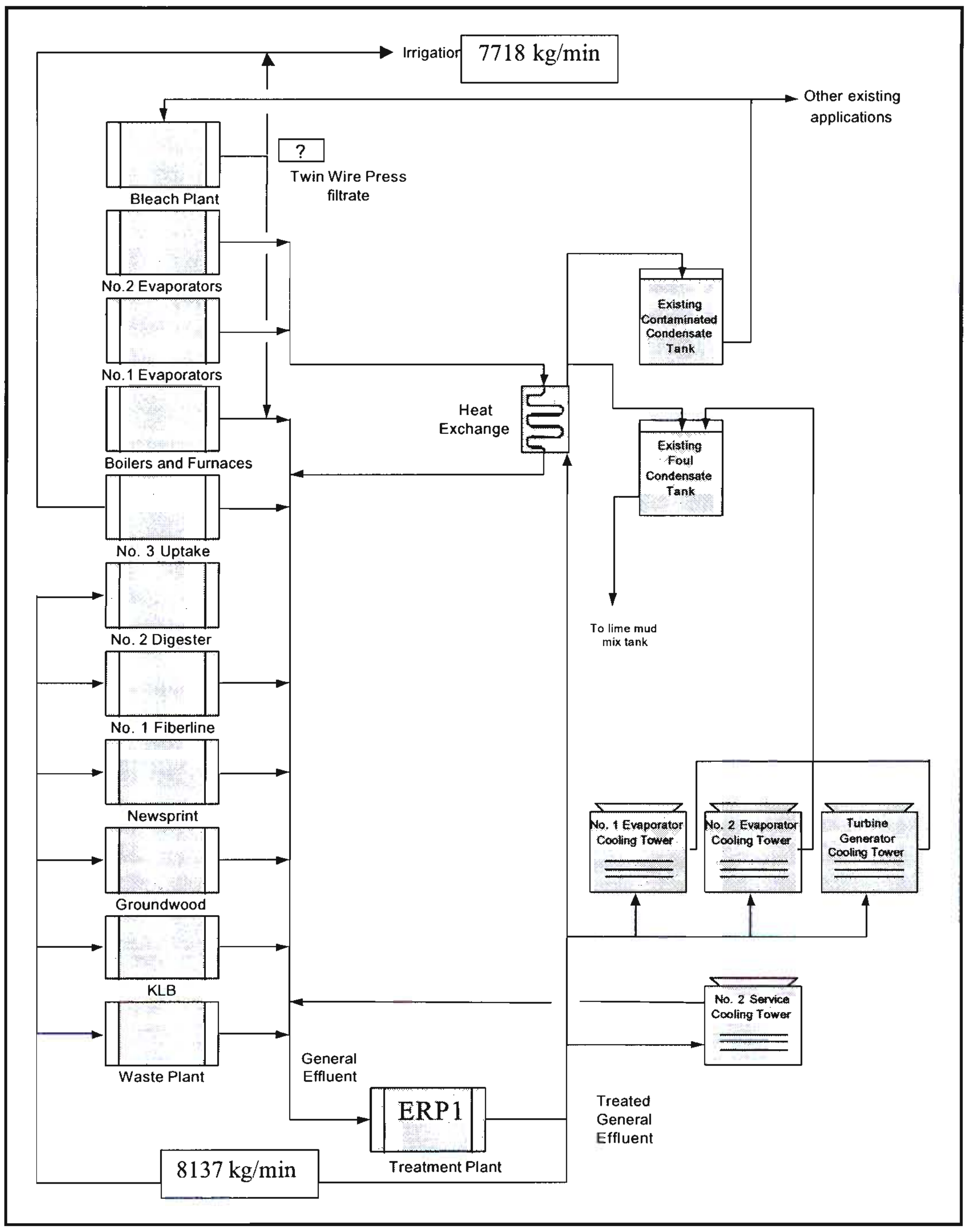


Figure 45: Mill's Proposed water network for planned ERP1 plant

The pinch solver however, proposed treating the high chloride containing streams, as opposed to the mill's plan of using the low chloride containing streams. The network proposed by the solver treats more effluent in the ERP1 treatment plant compared to the mill's planned ERP1 network. The pinch solver treats 47765 kg/min of water as opposed to the mill's proposed network that only treats 8137 kg/min. The streams treated in the ERP1 plant as suggested by the pinch solver are list in Table 27.

Table 27: Feed streams into ERP1 plant

Sources into ERP1	Flow (kg/min)
upt 3 - filtrate – simplified (PP16)	35101
upt 3 - D37 filtrate (HH14)	3784
bleach - D2 tower out (EE13)	3599
bleach - E tower out (CC13)	3518
upt 3 - effluent out (PP16)	800
bleach - DC tower out (AA13)	656
evap - New evaps foul/cont dirty (G18)	151
newsprint – effluent (MM7)	124
groundwood – effluent (rejects and floor) – simplified (AA4)	32

The possible sinks for use of the treated ERP1 water is given in Table 28. It was noticeable that the proposed sinks were sinks capable of handling high chloride concentrations. This was again in contradiction with the mills current approach to use the treated water in sinks capable of handling low chloride and high sodium concentrations. The sinks identified by the mill for re-use of the low chloride containing streams are indicated in Table 29.

Table 28: Uses of ERP1 treated water according to Pinch Analyses

Sinks where ERP1 treated water was used	Flow (kg/min)
upt 3 - D37, mixed stock, cleaning cons, thickener – simplified (HH14)	22459
mill – irrigation fields	8216
bleach - DC tower in (AA13)	3909
bleach - D2 tower in (EE13)	3558
bleach - E tower in (CC13)	2881
bleach - D36 consistency (GG13)	2272
bleach - 3 stage in (Y13)	1811
upt 2 - machine chest consist cntrl (R25)	537
wasteplant - back water (V5)	111
groundwood - back water (Z3)	81
repulpers - #3 (U5)	14
CT's - simplified in	3
caust - lime mud mixing (C23)	2

- The effluent being irrigated from the proposed pinch result was 13904 kg/min (20.2 ML/day), this flow was much higher than the flow proposed by the ERP1 project team. The technical team of the mill proposes a water network with a final irrigated flow of only 12 ML/day.
- Clean condensate from evaporators was still (i.e. similar to existing mill network) recommended for use in the causticising section for lime mud washing.
- The concept of using high sodium streams in the cooling towers as make-up, and reclaiming that sodium as blowdown from the cooling towers as wash water in the causticising section are not proposed by the simulation. This was because the pinch solver does not have the capability of simulating a saving due to product reclaiming, it can only simulate a cost due to contamination.
- The solution proposed with the pinch solver was not more elegant and was not more feasible compared to the solution proposed by the technical team, however concepts of the proposed solution can be evaluated and investigated further for conceptual ideas. In particular the idea of treating the high chloride containing streams and re-using of the treated water could be investigated for partial implementation.
- Note that the ERP1 plant proposed by the pinch solver was still treating high COD streams and was still conceptually the same as the mill's ERP1 plant (apart from the volume being treated). The difference in chloride concentration does not influence the type of treatment plant, i.e. oxygen activated sludge, bio-filters etc. The difference in chloride only influenced the sinks that could re-use the treated water.

Table 29 Other Applications of ERP1 treated water according to Mill's Design

Stream	Application	Flow (ML/day)	Plant where water is used
Recycled GE	Replace CC as make-up to CC tank and also additional flow to account for condensate not discharged into the foul tank (recycled water to 3-stage diffusion washer accounted for here).	5.63	Chemical recovery section
5*Recycled water (cooling tower blowdown)	Cooling tower blowdown used as make-up to foul tank instead of condensate, and additional recycled water	1.01	
Recycled GE	To replace fresh and hot water	0.47	Uptake #1
Recycled GE	To replace dumped TWP filtrate and also make-up to ozone cooling tower (also to replace CC on 3 stage washer, but the volume is accounted for in the make-up to the CC tank at causticising)	6.00	Bleach plant
Recycled GE	To replace fresh and hot water	2.2	Digester #1
Recycled GE	Replace fresh water and CC	3.50	Evaporator #2 cooling tower
Recycled GE	Replace fresh water	3.43	TG 2 cooling tower
Recycled GE	Replace fresh water	1.02	#2 Service cooling tower
Recycled GE	Replace fresh water	0.69	Evaporator #1 cooling tower
Recycled GE		1.23	Groundwood
Recycled GE	Showers and seal water	0.35	NP
Recycled GE	Replace fresh water	0.34	Wasteplant
Recycled GE	Seal water and some showers	1.97	KLB

5.4 Proposed Uses for Storm water

The mill currently has high flow rates in the storm water system even when it is not raining due to the discharge of clean once-through cooling water from various sources (i.e. substations, air conditioners etc) into the storm water system. This storm water must be used in the mill so that it is not necessary to discharge the storm water from the mill. The pinch solver proposed the following users/sinks:

- Uptake #3 area – D37, mixed stock chest, cleaning and thickener (HH14)
- Hot water system (N16)

These sinks are a possibility for re-use of the storm water, and in the absence of any better suggestions would have been suitable users, however the mill has suggested its own solution to the problem [76]. The mill proposed returning the once-through water to the #2 service cooling tower system. The mill prefers the proposal of returning the water to the #2 service cooling water system for three reasons:

1. this is the system that the water is supposed to be used in. All other substations and air conditioners form part of the #2 service cooling tower system
2. if it is part of the #2 service cooling tower system, it reduces the inter-dependency of process units (i.e. uptake #3 and hot water system) on an auxiliary system for water supply
3. there are chances of the storm water sources getting contaminated with leaking heat exchangers etc, and it would be a higher risk to use this water in process sinks (i.e. uptake #3 or hot water system).

The proposal suggested by the pinch solver does have merit and can be implemented; however the mill's proposal is the preferred option. The water pinch solver might have also suggested that use of the #2 service cooling if any process connections were prohibited in the bounds editor, however it was not done because the second best options (i.e. process sinks) were of interest.

5.5 Technical Evaluation and Implementation of Pinch results

In **Figure 19** an outline is given on the steps followed during a pinch analyses. It was beyond the scope of this thesis to take any of the recommendations or findings to the level where they were investigated technically or economically for final implementation. The findings and recommendations of this thesis must not be accepted as final since the impact of the findings have to be evaluated by doing more detailed mass balances and technical studies before final implementation.

Chapter 6 Conclusions and Recommendations

6.1 General

- Ngodwana mill is under pressure to improve the environmental impact of the mill. This must however be done in a sustainable manner. Environmental as well as social and economical issues must be considered. No improvement can be made without considering all three segments of sustainability.
- The fact that Ngodwana mill has its geographical location in Mpumalanga, i.e. small rivers, high water demand in province and nearby internationally renowned Kruger National Park, has contributed to the mill's high focus on managing effluent from the mill. Ngodwana can be classified as a low effluent generating mill with a high degree of closure.
- Considerable effort from the mill technical team has already gone into reducing effluent and fresh water volumes at the mill. The majority of effluent reducing technologies and best practices cited in literature have been implemented at the mill. The mill has a specific-effluent generation rate of less than 20 kL/ton of pulp and paper produced. Ngodwana presented a highly closed integrated pulp and paper Kraft mill.

6.2 Mass Balance

- Extensive knowledge, analyses, and information were required to do the mass balance. Considerable time, effort and resources have to be allowed when doing the mass balance of an already highly closed water network system.
- Comparing results with measured analysis results also validated the mass balance. Chloride and sodium were the most accurately simulated then calcium and lastly COD.

6.3 Water pinch Analyses

- The software combines the advantages associated with numerical as well as graphical techniques. The software solves for the optimal solution numerically, but also represents the results graphically. Match tables, sensitivity and composite graphs were used to represent the answers from the solver.
- The principle of the software was that sources, sinks, utilities, process units and treatment facilities were defined in terms of a cost in a monetary value. Costs for using facilities, using resources, environmental impact, losses or any other factor were incorporated into the problem definition. This makes it possible for the engineer to include almost any factor in terms of cost into the problem definition. The solver then optimises the network by optimising costs. The water network with the lowest cost was the proposed network.
- The solver does have some draw-backs (which could be related to the WaterPinch interface also):
  - Negative mass load costs were not allowed. The problem definition was based on the concept of contaminants, or unwanted elements in the water rather than wanted elements. It was not easy to define the problem solution in a manner that indicates that it was advantageous to retain certain contaminants as products or raw materials.
  - The solution presented by the solver indicates the proposed network in table format. This makes visualisation of the network tedious since no graphical network was shown.
  - The composite curves presented in the software were not user friendly and have very limited application. Only the unblended composite graph was used in this analysis.
- Water pinch initially started as a graphical technique with a clearly defined pinch point where the sink and source composite curves approached each other. This approach considers concentration and flow

only, no other allowance was made for environmental impact, legal requirement, corrosion, fouling etc.

- Apart from the graphical approach not being able to consider other important factors, it is also limited to one contaminant only. The graphical approach and concept of water pinch has limited application and a better technique, i.e. that of the numerical approach was used for this investigation.
- With the development of the numerical approach, the term "water pinch" has lost its classical meaning of a pinch. The pinch was no longer a pinch point between two lines on a composite curve, but rather the pinch refers to the optimal point identified by a numerical solver beyond which further improvement was restricted.
- Case studies do exist for the application of the numerical pinch in industry, however different solvers and different software was used.
- Although the software makes it possible to include geographical location of sources and sinks, these were not considered in the pinch analysis. With the mill water network already being highly closed, any restrictions due to geographical location were considered secondary to finding a better water network.
- The scope of the pinch analysis was the whole pulp and paper mill. The whole mill was considered in the pinch analysis thus making the possibility of finding integrated improvements for the whole mill better.

6.4 Results

- Results from the pinch analyses were not investigated in this thesis for technical and economical feasibility. This document evaluated the technique of water pinch through the identification of possible improvements and by verifying existing knowledge about the water network of the mill. The recommendations have to be investigated in more detailed studies for detailed technical and economical feasibility.
- Two approaches can be followed in applying water pinch to derive at an optimal water network (refer to **Figure** 31), the one approach is to start with an open network and gradually add bounds to prevent illegal connections. The second approach is to start with the existing mill network and gradually remove bounds to identify opportunities. For this report the first approach was followed to allow the maximum degrees of freedom to identify saving opportunities. This also identified networks that were considerably different to the mill's current network, and this makes implementation of the water pinch network changes difficult due to the great difference between the water pinch network and the mill's current water network.
- Composite curves for the mill's current water network were generated by tightly bounding the problem until the mill's current water network was achieved. These composite curves do not define the pinch, but do however give an indication of where source-sink concentration curves are approaching each other. The observations from these curves are:
  - High chlorides in the uptake #3 plant and forming section were close to touching sinks such as the bleach plant wash press, and the oxygen reactor dilution water and uptake #3 consistency control.
  - Solids generated from the bleach E tower, bleach D2 tower and uptake #3 D37 filtrate are close to the limiting concentrations for the sink bleach E tower sink and also the bleach D36 consistency control
  - Sodium and COD concentrations for sources and sinks are not close to touching.
  - Calcium concentrations from the uptake #3 thickener were close to the concentrations required for the uptake #3 D37 consistency control and cleaning consistency control on uptake #3.
- The mill water network can be improved by making piping changes, without adding new technology and without relaxing maximum allowed concentration limits. This means that theoretically the effluent generation rate can be reduced by 1.3 ML/day by making numerous piping changes. These

changes will entail capital cost for making piping changes and will introduce many new risks. In conclusion the pinch analyses have not been able to make significant improvements to the current mill water network without relaxing the maximum allowed concentration limits.

- The pinch analyses that allowed relaxing of concentration restrictions without adding new technology again presented numerous piping changes. Some of these changes can be looked at in more detail for partial implementation. However, the network proposed differs considerably from the current water network and would be very costly to implement. The proposed network amounted to 20.6 ML/day of effluent, 6.8 ML/day less than the current effluent volumes generated. The achieving of this proposed network in its entirety was however not recommended since it would introduce significant new risks apart from the capital costs.
- The number of sinks that had concentration changes as well as the percentage of change in the different contaminant concentrations was an indication of the risk profiles that future closure might have. The percentage relaxation in concentrations were as follow:
  - Sodium = 63%, number of sinks changed = 10 sinks
  - Chloride = 35% = 13 sinks
  - Calcium = 2% = 10 sinks
  - COD = 1% = 3 sinks
- The mill did an independent technical study for the implementation of a biological treatment plant in future (ERP1 plant). The pinch technique was used to confirm or investigate the location of such a treatment plant. The pinch investigation predicts concepts different to the approach planned by the mill. The pinch technique proposes the treatment of the chloride containing streams, and the return of the streams to sinks that can handle high chloride concentrations. The technical team of the mill propose treating low chloride containing streams in the ERP1, returning the treated water to the cooling towers and recovering sodium via the cooling tower blow down. The network proposed by the pinch analyses generates 20.2 ML/day of effluent. The network proposed by the ERP1 team generates only 12 ML/day effluent and recovers valuable sodium as raw material. The pinch solver was unable to suggest a better water network configuration than the technical team of the mill.
- The ability of the pinch analyses to simulate or consider the recovery of valuable raw material or product was limited and care should be taken when using the results from the pinch solution. The simulation and inclusion of treatment plants were more complex to simulate.
- The pinch technique was used to identify possible sinks for the use of excess storm water, the following two sinks were identified and need further technical investigation:
  - Uptake #3 area – D37, mixed stock chest, cleaning and thickener
  - Hot water system.
- The storm water network recommended by the pinch solution is feasible, but the mill has designed its own water network for handling of the storm water. The mill's system is more practical to implement. The fact that the mill's proposal is more practical could have been simulated with the solver, but the solver was used to find an alternative approach to the mill's conventional proposed water network. It was thus not a matter of the pinch technique failing to arrive at the same practical network, as was designed by the mill, but rather the pinch solver was unable to find a network better than the mills' proposal.
- This study did however prove that even if the mill's water network would be redesigned (i.e. maximum allowed degrees of freedom were given to solver), water pinch was unable to achieve a better water network. The 1.3 ML/day saving is small and would probably only be partially realised if dynamics and process-upset conditions are taken into account.

6.5 Recommendations

- The differences between the mill's current water network and the network proposed by water pinch (without relaxing the concentrations) can be investigated further through technical studies and mass balance simulations. This might provide insight and generate technical questions and answers that might give insight and identify practical water savings.
- Further study into applying the water pinch starting with a tightly bound solution, that simulates the mill's current water network, is needed. There is currently not a systematic way to decide which bounds to remove when starting with a tightly bound solution without going deeper into the workings of the GAMS solver. It is recommended to repeat part of this exercise starting with the tightly bound solution and trying to use the marginal values generated from GAMS. By starting with a tightly bound solution improvement opportunities will be identified that might be easier to implement.
- Water pinch could be applied in other studies in the mill that are section or project specific. It is recommended that the mill or Sappi group, look into purchasing the WaterPinch™ software or develop its own water pinch package from first principles.

6.6 Final Conclusion

The application of water pinch to Sappi Ngodwana, an integrated kraft pulp and paper mill with an already highly closed water circuit, was successful and provided the following information of benefit to the mill:

- It was proved that the mill water network could not be improved without adding technology, meaning that Ngodwana's water network is already optimised for the current technology,
- The effluent reduction project, i.e. ERP1 is a well designed water network – water pinch could not improve on the use of the ERP1 treatment plant,
- Verified that the mill's design for the storm water excess water is a well designed water network – water pinch could not improve on the design and
- Numerous small water savings were identified that can be investigated further for smaller water savings.

Chapter 7 References

1 Leske A, *Integrated Water Management Plan – Best Practice Review*, Report 3928-2137-14-W Rep B10, Sappi, Ngodwana Mill, October 2000.

2 Barnard, D, *Environmental law for all*, Impact books, Pretoria, 1999.

3 *Using Water Wisely - A National water resource strategy for South Africa*, Information document on the proposed National Water Resource Strategy for comment by the people of South Africa, August 2002, Department of Water Affairs and Forestry.

4 *Development of a Charge System for discharging wastewater into water resources*, Newsletter No.4 and workshop slides issued by the Department of Water Affairs and Forestry.

5 Koufos D and Retsina T, *Practical energy and water management through pinch analysis for the pulp and paper industry*, Water Science and Technology, Vol. 42 no 2 pp 327 – 332, 2001, IWA Publishing and the authors.

6 Sinnott R.K, *Coulson & Richardson's Chemical Engineering*, Department of Chemical Engineering, University College of Swansea, Volume 6, Pergamon Press, 1993.

7 Townsend D and Linnhoff B, *Designing total Energy Systems by Systematic* Methods, Chem. Engr., London, No. 378 (March) 91, 1982.

8 WaterTarget version 2.1.03, WaterPinch version 2.1.02 and WaterTracker version 2.1.03 software by Linnhoff March Ltd, Software Support +44 (0)1606 815 100, **techsupport@linnhoffmarch.com**, **www.linnhoffmarch.com**, 1999.

9 US Environmental Protection Agency, Development Documentation for Interim Final and Proposed Effluent Limitations Guidelines and Proposed New Source Performance Standards for the Bleach Kraft, Groundwood, Sulfite, Soda, Deink and Nonintergrated Paper mills segment of the Pulp and Paper, Paper and Paperboard Mill Point Source Catergory, EPA 440/1-76/047-A, EPA, Washington, DC, January 1976.

10 Mannisto E., Mannisto H. and Roos K., *Feasibility of EPA's Advanced Technology Tiers*, TAPPI Proceedings 1997, 1997 Environmental Conference & Exhibit, Book 1, page 229, May 5-7, 1997, Minneapolis Convention Centre.

11 Buehner F.W and Rossiter A.P, *Minimise waste by Managing Process Design*, Chemtech, April 1996, p. 64 – 72.

12 Hendry J.E, Rudd D.F and Seader J.D, *Synthesis in the Design of Chemical Processes*, 19(1), 1 (1973).

13 Hlavacek V, *Synthesis in the Design of Chemical Proc esses*, Comp. Chem. Eng., 2, 67 (1978).

14 Nishida N, Stephanopoulos G and Westerberg A.W, *A review of Process Synthesis*, AIChe J., 27(3), 321, May 1981.

15 El-Halwagi M. M and Manousiouthakis V, *Synthesis of Mass Exchange Networks*, AIChE Journal, Vol 35, No 8, August 1989.

16 Siirola J.J, Powers G.J and Rudd D.F, *Synthesis of System Designs II: Toward a Process Concept Generator*, AIChe J., 17(4), 677, July 1971.

17 Stephanopoulos G and Westerberg A.W, *Studies of Process Synthesis, II: Evolutionary Synthesis of Optimal Process Flowsheets*, Chem. Eng. Sci., 31, 195 (1976).

18 Muraki M and Hayakawa T, *Synthesis of a Multicomponent Multi-Product Separation Process with Nonsharp Separators*, Chem. Eng. Sci. 43 (2), 259, 1988.

19 Takama N, Kuriyama T, Shiroko S and Umeda T, *Optimal planning of water allocation in a petroleum refinery*, Computers and Chem. Eng. 4 (4) 251 – 258, 1980.

20 Linhoff B and Hindmarsh E, *The pinch design method for Heat Exchanger Networks*, Chem. Eng. Sci., 38 (5), 745, 1983.

21 El-Halwagi MM and Manousiouthakis V, *Simultaneous synthesis of mass-exchange and regeneration networks*, AIChe Journal 36 (8) 1209 – 1219, 1990.

22 Wang Y.P and Smith R, *Wastewater minimisation with flow rate constraints*, Trans IchemE, Vol 73, Part A, November 1995.

23 Wang Y.P and Smith R, *Waste water minimisation*, Chemical Engineering Science, Vol 49, No 7, 1994.

24 Dhole V.R, Ramchandani N, Tainsh R.A and Wasilewski M, *Make your process water pay for itself*, Chemical Engineering, 103, January 1996, p. 100 –103.

25 Rossiter A.P and Nath R, *Chapter 17. Wasterwater minimisation using nonlinear programming.* In *Waste minimisation through process design*, Rossiter A.P, ed., McGraw-Hill, New York, ISBN: 0-07-053957-X, 225 – 243, 1995.

26 Doyle S,J and Smith R, *Targeting water reuse with multiple contaminants*, Trans IchemE, Vol 75, Part B, August 1997.

27 Kuo W.-C.J and Smith R, *Design of water-using systems involving regeneration*, Institution of chemical engineers, Trans IchemE, Vol 76, Part B, May 1998.

28 Kuo W.J, *A combined approach to water minimisation and effluent system design*, A thesis submitted to the University of Manchester Institute of Science and Technology, Department of Process Integration, Sackville Street, PO Box 88, Manchester M60 1QD, June 1996.

29 Wang Y, *Wastewater minimisation and the design of distributed wastewater treatment systems*, A thesis submitted to the Victoria University of Manchester, Department of Process Integration, September 1993.

30 Gianadda P, *The Development and Application of Combined water and materials pinch analysis to a Chlor-alkali plant*, PhD Dissertation, School of Chemical Engineering, University of Natal, December 2002.

31 Jacob J, Kaipe H, Couderc F and Paris J, *Water Network analysis in pulp and paper processes by Pinch and Linear programming*, Chem. Eng. Comm., 2002, Vol 189(2), pp. 184 – 206.

32 Argaez A.A, *Integrated Design of Water Systems*, A thesis submitted to the University of Manchester Institute fo Science and Technology, Department of Process Integration, February 1999.

33 Grossmann I.E, Caballero J, A and Yeomans H, *Advances in Mathematical Programming for Automated Design, Integration and Operation of Chemical Processes*, Department of Chemical Engineering, Carnegie Mellon University, Pittsburg, PA 1521, 1999.

34 Edgar T.F, Himmelblau D.M and Lasdon LS, *Optimisation of chemical processes*, 2nd Edition, McGraw-Hill, New York, 2001, ISBN; 0-07-039359-1.

35 Gams Development Corporation, *GAMS – The Solver Manuals*, GAMS Development Corporation, Accessed on 5 October 2001 at **http://www.gams.com/docs/solver_man.pdf**.

36 Brouckaert C.J and Fraser D.M, *Water Pinch Analysis – A Pre-Conference Workshop of the WISA Biennial Conference and Exhibition,* Cape Town, 2ND May 2004.

37 GAMS Development Corporation, *GAMS – A User's Guide*, Tutorial by Richard E. Rosenthal, GAMS Development Corporation, Washington, DC, 2006.

38 Brouckaert C.J, Schneider J, Mansfield M and Buckley C.A, *Water Pinch Analysis as a transparent tool for the co-regulation of industrial processes*, Pollution Research Group, School of Chemical Engineering, University of Natal, Durban 4041, 2002.

39 Brouckaert C.J, Gianadda P, Schneider J.P.Z, Naylor G.M and Buckley C.A, *Report to the Water Research Commission – The Application of Pinch Analysis for Water and Effluent Management,* Pollution Research Group, University of Natal, February 2005.

40 Linnhoff B and Flower J.R, *Synthesis of heat exchanger networks:I. Systematic generation of energy optimal networks*, AIChe Journal 24 (4), 633 – 642, 1978.

41 Oleson S.G and Polley G.T, *A simple methodology for the design of water networks handling single contaminants*, Trans IchemE 75 (A4) 420 – 426, 1997.

42 Sorin M and Bédard S, *The global pinch point in water reuse networks*, Trans IchemE 77 (B5) 305 – 308, 1999.

43 Castro P, Matos H, Fernandes M.C and Pedro Nunes C, *Improvements in mass-exchange networks design*, Chem Eng. Sci 54, 1649 – 1665, 1999.

44 Mann J.H and Liu Y.A, *Industrial water reuse and wastewater minimisation*, McGraw-Hill, New York, ISBN: 0-07-134855-7, 1999.

45 Tainsh R.A and Rudman A.R, *Practical Techniques and Methods to develop an efficient water management strategy*, Paper presented at the IQPC Conference – "Water Recycling and Effluent Re-use", 26th and 27th April 1999, Linnhoff March International, Targeting House, Gadbrook Park, Northwich.

46 Wilde D.J and Beightler C.S, *Foundations of Optimisation*, Prentice-Hall Inc. Englewood Cliffs, New Jersey, Library of Congress Catalog Card Number: 67-10755, 1967.

47 Roy R.K, *A Primer on the Taguchi Method*, Competitive Manufacturing Series, Van Nostrand Reinhold, 115 Fifth Avenue New York, New York 10003, 1990.

48 Knobel A.N; *Material and Energy balances of Ngodwana's Kraft Circuits and some resulting observations;* Sappi Research and Development, Report number: R&D 97/009, 15 October 1997.

49 Bosman H,L and Slabbert E, *Mill Water and Contaminant Mass Balance Report*, Sappi Ngodwana, May 2000.

50 Software Package, *Design-Expert version 6.0.0*, Stat-Ease Inc., 2021 East Hennepin Avenue, Suite 191, Minneapolis, MN, 55413, 2000.

51 Bosman H, L and Slabbert E; *Mass and Contaminant Balance Report: Treatment of General Effluent for Re-use (ERP1),* Sappi Ngodwana report, May 2000.

52 Slabbert E, *Solid waste Handling – Environmental Requirements*, Sappi Ngodwana, 07/01/99, reference number 'solidwas.doc', 1999.

53 Slabbert E; Environmental Engineer; Sappi Ngodwana; *Investigation into the Non Condensable gas Collection System at Sappi Ngodwana,* 1999-03-11.

54 Eriksson G and Gren U, Department of Chemical Engineering Design, Chalmers University of Technology, Gothenburg, Sweden; *Pulp washing: Sorption equilibria of metal ions on Kraft pulps*; Nordic Pulp and Paper Research Journal no. 3/1996.

55 Software Packge, *WinGEMS™ 4.5*, Pacific Simulation; 1187 Alturas Drive Avenue, Moscow, ID 83843, www.pacsim.com, 1998.

56 Fosteras N and Evert B, *Investigation into Performance and Piping configurations of the lime kiln venturi scrubber*, report done at Ngodwana mill, document reference STD92/001, 20/05/1992.

57 Magnusson H, Mork K and Warnqvist B; Swedish Forest Products Research Laboratory; Stockholm; Sweden; *Non-Process Chemical Elements in the Kraft Recovery System*, (??)

58 Cornell C.F; Marketing Manager; Green Bay Packing, Inc; Goslin-Birmingham Division, Post Office Box 398, Birmingham; AL 35201; *Current Recausticising Practice Part 2 – Principles*, (??)

59 Wingems software package example, *Fullmill.wg.*, 1998

60 Fitzsimmons E.J; *Ngodwana Mill Expansion Project Recommended Mill Water Balance*, Zululand Construction (PTY) LTD, 25 June 1982, Sappi Ngodwana library reference RP10/13.

61 Slabbert, E; *Pilot Plant Report for treating Condensates*, Sappi Ngodwana, 1997.

62 Raubenheimer, S.J; *The Effect of Sulphur Addition to Kraft White Liquor of Varying sulphidity*, Sappi Research and Development Report, M82/253, November 1982.

63 *Sappi Technical Report: Monthly Report*; Monthly laboratory report summarising Sappi Ngdowana qualities, June 1999.

64 Bosman H, L and Slabbert E; *Mass and Contaminant Balance Report: Effluent Reduction Technologies*, Sappi Ngodwana report, May 2000.

65 Knobel A; *Revised Model for Predicting Sodium Levels in Kiln Feed*; Sappi Research and Development, M99/133, 18 June 1999.

66 Pekkanen M and Norden H.V; *Review of Pulp washing Models*; No. 11, Paperi ja Puu – Paper och Tra., 1985

67 Bryant P.S and Edwards L.L; *The effects of dissolved organic carry-over on pulp bound metals when closing the bleach plant*; 1996 Pulping Conference 802.

68 Baldus R, Edwards L and Warqvist B; *Application of washing models to general material balance calculations including sorption*, Transactions of the Technical section 3 (2):TR56, June 1977, CPPA Con/231A.

69 Grace T.M and Malcolm E.W; *Pulp and Paper Manufacture: Volume 5 Alkaline Pulping*; Published by the Joint Textbook Committee of the Paper Industry, TAPPI 1989.

70 Slabbert, E; *Investigation into Solid Waste Management at Sappi Ngodwana*, June 1996.

71 Leske T, Slabbert E and Bosman H, *Integrated Water Management Plan – Pre-screening report*, March 2000 (Draft), Sappi, Ngodwana Mill.

72 McLeary F, *Accounting and its Business environment*, Juta, Fifth Edition 1999.

73 KAM Report A32, *Ecocyclic pulp*, Final report KAM1, 1996-1999, English version

74 Smith R and Klemes J, *Introduction and Basic Energy Pinch concepts*, An international seminar on advanced achievements in pinch technology, 18 – 20 November 2002, South Africa

75 Brouckaert C.J and Buckley C.A, *Report to the Water Research Commission on The Application of Pinch Technology to the Rational Management of Water and Wasterwater in an Industrial Complex*, Pollution Research Group, University of Natal, Durban, WRC Report No 851/1/03, ISBN No 1-77005-028-0, May 2003.

76 Slabbert, Eric, *Design of Storm water Handling System*, Sappi Ngodwana internal report, 2004.

Chapter 8 Appendixes

8.1 Sources and Sinks of Pinch Analyses

Sources and sinks were identified from the mass balance. In Table 30 and **Table 31** the sources and sinks respectively are tabled. These were the sources and sink before simplifying the pinch problem definition by ignoring the lower flow sources and sinks. The source table indicates the fixed concentrations and flows specified by the user. These flows and concentrations were the same as the flows and concentrations from the solver solution. The concentrations with an asterisk (*) indicates sources from variable sources. The variable sources' concentrations and flows were not necessarily the same as the solution results.

Table 30: Total Sources Identified from Mass Balance

#	Source	Unit	Flow kg/min	chloride (Cl) ppm wt	Sodium (Na) ppm wt	COD ppm wt	Calcium (Ca) ppm wt	Solids ppm wt
1	bleach - wash press out	'bleach - wash press'	8329	278*	4463*	21528*	27*	47*
2	bleach - DC tower out	'bleach - DC tower'	4353	2443*	795*	2440*	51*	304*
3	bleach - E tower out	'bleach - E tower'	4161	2079*	1514*	3320*	35*	405*
4	bleach - D2 tower out	'bleach - D2 tower'	4027	1048*	954*	3229*	13*	408*
5	bleach - 3 stage out	'bleach - 3 stage'	4290	425*	5388*	28512*	64*	49*
6	bleach - bleach plant scrubber out	'bleach - bleach plant scrubber'	196	13*	2453*	27*	12*	3*
7	bleach - OWL cooler out	'bleach - OWL cooler'	129	4	6	16	15	3
8	dig 1 - extraction liquor		2309	1128	32130	157917	36	50
9	dig 1 - wash filter 1 out	'dig 1 - wash filter 1'	12864	165*	4217*	21176*	49*	36*
10	dig 1 - wsh filter 2 out	'dig 1 - wsh filter 2'	2634	56*	1837*	7360*	37*	62*
11	dig 1 - effluent		146	25	633	3094	15	3
12	CT - Hi kappa out	'CT - Hi kappa'	29	3*	6*	19*	18*	2*
13	CT - Lube oil out	'CT - Lube oil'	653	3*	6*	16*	15*	2*
14	CT - TG2 out	'CT - TG2'	289	16*	29*	93*	84*	3*
15	CT - Old evaps out	'CT - Old evaps'	69	19*	38*	141*	65*	7*
16	CT - Service out	'CT - Service'	114	8*	11*	36*	33*	3*
17	CT - New evaps out	'CT - New evaps'	343	22*	20*	5117*	28*	10*
18	CRF2 - floor drain sump		10	19	440	2609	16	10
19	PF and CRF2 - effluent		100	4	6	16	15	10
20	Storm water - CRF1 - ID fan cooling water out	'Storm water - CRF1 - ID fan cooling water'	474	3	5	15	14	2
21	PF - warm water		658	4	6	16	15	10
22	CRF1 - warm water		67	4	6	16	15	3
23	CRF2 - warm water		511	4	6	16	12	3
24	CRF1 - effluent		78	4	8	931	10	3
25	demin - acidic effluent		468	22	61	16	25	3
26	demin - caustic effluent		117	22	4622	16	15	3
27	PF - scraper conveyor out	'PF - scraper conveyor'	174	4	6	23	15	9
28	caust - WWL ex lime mud washer		2541	644	19085	1721	15	3

Table 30: Total Sources Identified from Mass Balance (continue)

#	Source	Unit	Flow kg/min	chloride (Cl) ppm wt	Sodium (Na) ppm wt	COD ppm wt	Calcium (Ca) ppm wt	Solids ppm wt
29	upt 1 - white water tank		5420	15	921	1638	67	20
30	upt 2 - seal water out	'upt 2 - seal water'	80	4	6	16	15	3
31	upt 2 - vacuum pump out	'upt 2 - vacuum pump'	100	4	6	16	15	3
32	upt 2 - mould filtrate water		11735	75	1061	5016	18	111
33	upt 2 - effluent out	'upt 2 - effluent'	464	70	992	4680	18	434
34	upt 3 - D37 filtrate		8056	1276	735	2312	9	447
35	upt 3 - thickener filtrate		27502	459	285	828	23	130
36	upt 3 - forming section A		1895	459	285	838	23	480
37	upt 3 - formng section B		5686	459	285	828	23	475
38	upt 3 - press section A		504	459	285	828	23	475
39	upt 3 - pres section B		216	459	285	838	23	475
40	woodyard - hardwood washing water		171	4	6	16	15	3
41	groundwood - effluent (rejects)		254	19	264	3249	48	4610
42	groundwod - effluent (floor)		184	18	176	1455	54	1980
43	wasteplant - effluent		87	58	417	2100	149	62
44	newsprint - effluent		2481	30	153	746	59	3170
45	newsprint - back water		1058	17	52	1064	33	104
46	KLB - back water		9700	101	586	785	134	230
47	KLB - effluent		2613	83	485	1507	131	3011
48	stormwater - JT boilers		83	4	6	16	15	3
49	stormwater - gas producers sub station		121	4	6	16	15	3
50	stormwater - evaps subs station		91	4	6	16	15	3
51	stormwater - lime kiln cooling water		255	4	6	16	15	3
52	stormwater - screening house		100	4	6	16	15	3
53	stormwater - compressor room drain		46	4	6	16	15	3
54	stormwater - turbine room drains		63	4	6	16	15	3
55	dig 2 - extraction WBL		5837	839	22910	161442	51	19
56	dig 2 - brown stock washer out	'dig 2 - brown stock washer'	55135	202.43*	4159.73*	19085.00*	50.17*	2.00*
57	dig 2 - two stage washer out	'dig 2 - two stage washer'	1363	176.00*	2542.00*	12133.00*	24.68*	0.00*
58	dig 2 - WBL cooler out	'dig 2 - WBL cooler'	3700	3.43*	6.00*	16.00*	14.42*	2.00*
59	dig 2 - T20 and T21 coolers out	'dig 2 - T20 and T21 coolers'	1000	3.43*	6.00*	16.00*	14.42*	3
60	dig 2 - T11 condensor out	'dig 2 - T11 condensor'	972	4.00*	6.00*	16.00*	15.00*	2.00*
61	dig 2 - turpentine underflow		66	815	22921	112841	26	3

Table 30: Total Sources Identified from Mass Balance (continue)

#	Source	Unit	Flow kg/min	chloride (Cl) ppm wt	Sodium (Na) ppm wt	COD ppm wt	Calcium (Ca) ppm wt	Solids ppm wt
62	dig 2 - effluent		558	187	3878	17439	49	160
63	dig 2 - hot water effluent		56	4	6	16	15	3
64	noodle - filtrate		1746	15	1355	1648	35	200
65	CT - excess hot water out 1	'CT - excess hot water'	171	4	6	16	15	3
66	CT - excess hot water out 2	'CT - excess hot water'	4541	4	6	16	15	3
67	KLB - b/w to waste plant		2431	110	620	820	150	400
68	newsprint - cloudy back water		5259	16	49	1296	31	120
69	upt 3 - effluent out	'upt 3 - effluent'	800	403	251	737	22	230
70	upt 2 - presses out	'upt 2 - presses'	1070	73*	1024*	4837*	17*	198*
71	noodle - effluent		52	15	1355	1648	35	200
72	ClO2 effluent		455	1068	2542	62	14	2

*Indicates contaminants that are limiting to the further improvement.

Table 31: Total Sinks Identified from Mass Balance

	Sink	Unit	Flow kg/min	Max chloride (Cl) ppm wt	Max Sodium (Na) ppm wt	Max COD ppm wt	Max Calcium (Ca) ppm wt	Max Solids ppm wt
1	bleach - wash press in	'bleach - wash press'	2196	427	5391	28513	66	100
2	bleach - DC tower in	'bleach - DC tower'	3909	1495	1091	2386	38	450
3	bleach - E tower in	'bleach - E tower'	4027	1785	957	3233	25	450
4	bleach - D2 tower in	'bleach - D2 tower'	3656	1067	620	1935	23	450
5	bleach - 3 stage in	'bleach - 3 stage'	4087	322	202	880	18	184
6	bleach - D36 consistency	Advanced	6948	1075	620	1940	15	400
7	bleach - bleach plant scrubber in	'bleach - bleach plant scrubber'	165	4	6	16	15	3
8	bleach - NaOH dilution	Advanced	150	4	6	16	15	3
9	bleach - OWL cooler in	'bleach - OWL cooler'	129	4	6	16	15	3
10	dig 1 - dilution control on digester 1	Advanced	2450	170	4230	21200	51	100
11	dig 1 - screening dilution	Advanced	9090	170	4230	21200	51	100
12	dig 1 - wash filter 1 in	'dig 1 - wash filter 1'	2634	59	1866	7385	46	100
13	dig 1 - wsh filter 2 in	'dig 1 - wsh filter 2'	2130	15	880	1310	50	100
14	dig 1 - uptake feed consistency control	Advanced	1650	15	921	1640	67	100
15	dig 1 - noodle feed consistency control	Advanced	1032	15	1356	1650	35	1920
16	dig 1 - seal water	Advanced	460	4	6	16	15	3
17	CT - Hi kappa in	'CT - Hi kappa'	39	4	6	16	15	3
18	CT - Lube oil in	'CT - Lube oil'	746	4	6	16	15	3
19	CT - TG2 in	'CT - TG2'	1789	4	6	16	15	3
20	CT - Old evaps in	'CT - Old evaps'	379	4	8	1494	15	3
21	CT - Service in	'CT - Service'	514	4	6	16	15	3
22	CT - New evaps in	'CT - New evaps'	1843	4	8	1494	15	3
23	CRF2 - SDT (WWL)	Advanced	1890	650	19090	1730	16	5
24	Storm water - CRF1 - ID fan cooling water in	'Storm water - CRF1 – ID fan cooling water'	474	3	5	15	14	2

Table 31: **Total Sinks Identified from Mass Balance**

	Sink	Unit	Flow kg/min	Max chloride (Cl) ppm wt	Max Sodium (Na) ppm wt	Max COD ppm wt	Max Calcium (Ca) ppm wt	Max Solids ppm wt
25	CRF2 - SDT vent scrubbing	Advanced	150	4	64	4020	15	3
26	CRF1 - SDT vent scrubbing	Advanced	150	4	64	4020	15	3
27	CRF1 - SDT (WWL)	Advanced	670	650	19090	1730	16	5
28	PF - scraper conveyor in	'PF - scraper conveyor'	174	4	6	23	15	20
29	caust - lime mud mixing	Advanced	2040	4	43	1650	15	5
30	caust - dregs filter wash water	Advanced	10	4	6	1370	15	5
31	caust - lme mud wash water	Advanced	280	4	8	1370	15	5
32	caust - dust control on lime dump	Advanced	41	4	8	1370	15	5
33	upt 1 - fresh water applications	Advanced	260	4	8	16	15	3
34	upt 1 - hot water to w/w tank	Advanced	75	4	8	16	15	3
35	upt 1 - sec stock chest consist control	Advanced	843	15	921	1640	67	100
36	upt 1 - prim scr suply pmp consist control	Advanced	588	15	921	1640	67	100
37	upt 1 - steady head tank	Advanced	1276	15	921	1640	67	100
38	upt 1 - dry end repulper	Advanced	119	15	921	1640	67	100
39	upt 2 - seal water in	'upt 2 - seal water'	80	4	6	16	15	2
40	upt 2 - vacuum pump in	'upt 2 - vacuum pump'	100	4	6	16	15	2
41	upt 2 - effluent in	'upt 2 - effluent'	464	70	992	4680	18	434
42	upt 3 - D37 consist control	Advanced	4359	405	251	740	22	230
43	upt 3 - mixed stock chest consist control	Advanced	2111	459	286	839	23	930
44	upt 3 - cleaning consist control	Advanced	27312	405	251	740	22	230
45	upt 3 - thickener wash water	Advanced	175	405	250	740	22	230
46	repulpers - #1	Advanced	7320	97	575	740	130	220
47	repulpers - #2	Advanced	2934	97	575	740	130	220
48	repulpers - #3	Advanced	1109	23	80	1055	40	110
49	groundwood - back water	Advanced	5259	20	50	1300	35	120
50	groundwood - other uses	Advanced	618	4	6	16	15	2
51	wasteplant - back water	Advanced	2431	110	620	820	150	400
52	wasteplant - other uses	Advanced	226	4	6	16	15	2
53	newsprint - fresh water	Advanced	1111	4	6	16	15	2
54	newsprint - hot water	Advanced	1266	4	6	16	15	2

Table 31: **Total Sinks Identified from Mass Balance**

	Sink	Unit	Flow kg/min	Max chloride (Cl) ppm wt	Max Sodium (Na) ppm wt	Max COD ppm wt	Max Calcium (Ca) ppm wt	Max Solids ppm wt
55	KLB - fresh water	Advanced	1215	4	6	16	15	2
56	KLB - hot water	Advanced	779	4	6	16	15	2
57	dig 2 - dilution control	Advanced	3402	210	4200	19100	55	100
58	dig 2 - blow tank consist control	Advanced	51765	210	4200	19100	55	100
59	dig 2 - screen dilution	Advanced	1308	170	4230	21200	51	100
60	dig 2 - brown stock washer in	'dig 2 - brown stock washer'	5526	280	4000	19165	30	100
61	dig 2 - two stage washer in	'dig 2 - two stage washer'	1669.7	71	992	4680	20	380
62	dig 2 - W127 HD chest	Advanced	374.9	71	992	4680	20	380
63	dig 2 - WBL cooler in	'dig 2 - WBL cooler'	3700	4	6	16	15	2
64	dig 2 - T20 and T21 coolers in	'dig 2 - T20 and T21 coolers'	1000	4	6	16	15	2
65	dig 2 - seal water	Advanced	598	4	6	16	15	2
66	dig 2 - T11 condensor in	'dig 2 - T11 condensor'	972	4	6	16	15	3
67	noodle - washing (H)?	Advanced	273	4	6	16	15	2
68	bleach - O33 blend chest	Advanced	4313	320	4510	21530	31	100
69	CT - excess hot water in	'CT - excess hot water'	4989	4	6	16	15	3
70	bleach - oxygen reactor dilution	Advanced	1840	430	5391	28600	70	100
71	upt 2 - machine chest consist cntrl	Advanced	11204	75	1000	4700	20	400
72	upt 3 - effluent in	'upt 3 - effluent'	800	403	251	737	22	230
73	upt 2 - presses in	'upt 2 - presses'	60	4	8	16	15	3
74	dig 1 - dil wash filter 1	Advanced	16.1	170	4230	21200	51	100

8.2 Results from Pinch Set-up Verification

Table 32: Pinch Set-up Verification

Iteration	Algorithm	Model Status	Solve Status	Cost, R/min
1	Basic	Normal completion	Model is Infeasible	40.95
1	Step	Normal completion	Model is Infeasible	55.37
1	Basic	Normal completion	Model is Infeasible	1916
1	RNLP	Normal completion	Locally optimal	18.99
1	TNLP	Normal completion	Locally optimal	18.99
1	TNLP	Normal completion	Locally optimal	18.99
Objective cost	18.99	R/min		
Utility Source	Cost, R/min	Flow, kg/min		
mill - fresh water	2.58	19226.82		
evaps - Old evaps clean	0	1716		
evaps - Old evaps dirty	0	484		
evaps - New evaps clean	0	4735		
evaps - New evaps dirty	0	1335.51		
evap - New evaps foul/cont clean	0	4450.9		
evap - New evaps foul/cont dirty	0	284.1		
mill - effluent treatment clean	0	18377.78		
mill - effluent treatment dirty	0	138.87		
dummy source	2.78E-02	20.73		
Utility Sink	Cost, R/min	Flow, kg/min		
mill - irrigation fields	10.45	18402.84		
evaps - Old evaps inlet	0	2200		
evaps - New evaps inlet	0	6070.51		
evap - New evaps foul/cont inlet	0	4735		
CRF2 - SBL incineration	0	1300		
CRF1 - SBL incineration	0	519.51		
mill - effluent treatment inlet	1.21	18516.65		
mill - solid waste	4.58	138.87		
dummy sink	1.46E-01	25.63		
storm water ponds	0	1518		
Bound costs	0	R/min		
Geographical costs	-4.01E-07	R/min		
Bounds:	4568			

Table 33: Pinch Set-up Verification – Concentration Difference

Sink Description	Percentage Difference Between Model results and Actual (%) See Note *	Absolute Difference Between Model results and Actual (mg/L) See note **
bleach - wash press in (Chloride)	0.9	3.8
bleach - wash press in (Sodium)	0.2	0.8
bleach - wash press in (COD)	0.0	0.0
bleach - wash press in (Calcium)	3.9	25.7
bleach - wash press in (Susp. Sol.)	50.9	5.1
CT - TG2 in (Chloride)	0.7	10.6
CT - TG2 in (Sodium)	0.9	1.0
CT - TG2 in (COD)	0.7	0.2
CT - TG2 in (Calcium)	25.3	96.1
CT - TG2 in (Susp. Sol.)	37.0	16.7
caust - lime mud mixing (Chloride)	0.8	15.0
caust - lime mud mixing (Sodium)	0.7	0.7
caust - lime mud mixing (COD)	0.5	0.2
caust - lime mud mixing (Calcium)	47.8	119.4
caust - lime mud mixing (Susp. Sol.)	11.3	5.1
upt 2 - seal water in (Chloride)	0.6	6.3
upt 2 - seal water in (Sodium)	0.7	0.4
upt 2 - seal water in (COD)	0.7	0.1
upt 2 - seal water in (Calcium)	47.0	108.0
upt 2 - seal water in (Susp. Sol.)	2.3	1.0
groundwood - back water (Chloride)	0.7	2.3
groundwood - back water (Sodium)	1.6	0.3
groundwood - back water (COD)	0.6	0.0
groundwood - back water (Calcium)	3.2	5.7
groundwood - back water (Susp. Sol.)	0.2	0.0
CT - excess hot water in (Chloride)	34.1	1.4
CT - excess hot water in (Sodium)	18.7	0.1
CT - excess hot water in (COD)	0.0	0.0
CT - excess hot water in (Calcium)	9.3	13.9
CT - excess hot water in (Susp. Sol.)	80.3	0.2

Table 33: Pinch Set-up Verification – Concentration Difference - continued

Sink Description	Percentage Difference Between Model results and Actual (%) See Note *	Absolute Difference Between Model results and Actual (mg/L) See note **
bleach - wash press in (Chloride) stream 1	5.6	3.3
bleach - wash press in (Sodium) steam 1	1.5	2.9
bleach - wash press in (COD) stream 1	0.6	0.5
bleach - wash press in (Calcium) stream 1	19.0	87.3
bleach - wash press in (Susp. Sol.) stream 1	38.1	3.8
bleach - wash press in (Chloride) stream 2	16.4	2.5
bleach - wash press in (Sodium) stream 2	1.9	1.6
bleach - wash press in (COD) stream 2	2.1	0.3
bleach - wash press in (Calcium) stream 2	10.5	52.3
bleach - wash press in (Susp. Sol.) stream 2	23.5	2.3
bleach - wash press in (Chloride) stream 3	34.5	1.4
bleach - wash press in (Sodium) stream 3	23.0	0.1
bleach - wash press in (COD) stream 3	8.1	0.0
bleach - wash press in (Calcium) stream 3	9.3	14.0
bleach - wash press in (Susp. Sol.) stream 3	81.0	0.2
CT - Lube oil in (Chloride)	34.5	1.4
CT - Lube oil in (Sodium)	21.8	0.1
CT - Lube oil in (COD)	5.6	0.0
CT - Lube oil in (Calcium)	9.3	14.0
CT - Lube oil in (Susp. Sol.)	81.0	0.2
CT - TG2 in (Chloride)	34.5	1.4
CT - TG2 in (Sodium)	21.8	0.1
CT - TG2 in (COD)	5.6	0.0
CT - TG2 in (Calcium)	9.3	14.0
CT - TG2 in (Susp. Sol.)	81.0	0.2
CT - Old evaps in (Chloride)	51.9	2.1
CT - Old evaps in (Sodium)	0.0	0.0
CT - Old evaps in (COD)	64.5	9.6
CT - Old evaps in (Calcium)	39.5	59.3
CT - Old evaps in (Susp. Sol.)	87.3	0.3
CT - Service in (Chloride)	34.1	1.4
CT - Service in (Sodium)	18.7	0.1
CT - Service in (COD)	0.0	0.0
CT - Service in (Calcium)	9.3	13.9
CT - Service in (Susp. Sol.)	80.3	0.2
CT - New evaps in (Chloride)	75.7	3.0
CT - New evaps in (Sodium)	78.4	0.6
CT - New evaps in (COD)	36.5	5.5
CT - New evaps in (Calcium)	66.8	100.2
CT - New evaps in (Susp. Sol.)	93.0	0.3

Table 33: Pinch Set-up Verification – Concentration Difference - continued

Sink Description	Percentage Difference Between Model results and Actual (%) See Note *	Absolute Difference Between Model results and Actual (mg/L) See note **
dig 2 - brown stock washer in (Chloride)	12.2	34.2
dig 2 - brown stock washer in (Sodium)	2.7	10.8
dig 2 - brown stock washer in (COD)	2.2	4.2
dig 2 - brown stock washer in (Calcium)	13.9	41.8
dig 2 - brown stock washer in (Susp. Sol.)	74.8	7.5
dig 2 - two stage washer in (Chloride)	0.5	0.3
dig 2 - two stage washer in (Sodium)	0.1	0.1
dig 2 - two stage washer in (COD)	0.0	0.0
dig 2 - two stage washer in (Calcium)	11.7	23.5
dig 2 - two stage washer in (Susp. Sol.)	2.9	1.1
dig 2 - WBL cooler in (Chloride)	14.2	0.6
dig 2 - WBL cooler in (Sodium)	9.0	0.1
dig 2 - WBL cooler in (COD)	2.5	0.0
dig 2 - WBL cooler in (Calcium)	3.8	5.8
dig 2 - WBL cooler in (Susp. Sol.)	0.0	0.0
dig 2 - T20 and T21 coolers in (Chloride)	14.2	0.6
dig 2 - T20 and T21 coolers in (Sodium)	9.0	0.1
dig 2 - T20 and T21 coolers in (COD)	2.5	0.0
dig 2 - T20 and T21 coolers in (Calcium)	3.8	5.8
dig 2 - T11 condensor in (Chloride)	0.0	0.0
dig 2 - T11 condensor in (Sodium)	0.0	0.0
dig 2 - T11 condensor in (COD)	0.0	0.0
dig 2 - T11 condensor in (Calcium)	0.0	0.0
dig 2 - T11 condensor in (Susp. Sol.)	0.0	0.0
dig 1 - dil wash filter 1 (Chloride)	0.0	0.0
dig 1 - dil wash filter 1 (Sodium)	25.0	0.2
dig 1 - dil wash filter 1 (COD)	0.0	0.0
dig 1 - dil wash filter 1 (Calcium)	0.0	0.0
dig 1 - dil wash filter 1 (Susp. Sol.)	0.0	0.0
Average	**8.1**	**0.7**

* Indicates the difference between the mass balance input concentration of the sink and the calculated value of the pinch solution expressed in percentage difference (%)

** Indicates the same as noted in (*), but expressed as absolute difference in concentration as “mg/L”.

Table 34: Pinch Set-up Verification Matches Table

From...	...to	Flow (kg/min)
dig 2 - brown stock washer out	dig 2 - blow tank consist control	51735
upt 3 - tickener filtrate	upt 3 - cleaning consist control	21386
mill - effluent treatment clean	mill - irrigation fields	18378
upt 2 - mould filtrate water	upt 2 - machine chest consist cntrl	10428
dig 1 - wash filter 1 out	dig 1 - screening dilution	9090
KLB - back water	repulpers - #1	6886
upt 3 - D37 filtrate	bleach - D36 consistency	5302
newsprint - cloudy back water	groundwood - back water	5259
dig 2 - hot/warm water tanks out	CT - excess hot water in	4989
evaps - New evaps clean	evap - New evaps foul/cont inlet	4735
CT - excess hot water out 2	dig 2 - hot/warm water tanks in	4541
bleach - DC tower out	mill - effluent treatment inlet	4353
bleach - wash press out	bleach - O33 blend chest	4313
bleach - D2 tower out	bleach - E tower in	4027
bleach - wash press out	dig 2 - brown stock washer in	4016
dig 2 - WBL cooler out	dig 2 - hot/warm water tanks in	3700
dig 2 - extraction WBL	evaps - New evaps inlet	3674
dig 2 - brown stock washer out	dig 2 - dilution control	3400
bleach - E tower out	bleach - DC tower in	2797
KLB - back water	repulpers - #2	2763
upt 3 - D37 filtrate	bleach - D2 tower in	2754
dig 1 - wsh filter 2 out	dig 1 - wash filter 1 in	2634
KLB - effluent	mill - effluent treatment inlet	2613
upt 3 - formng section B	upt 3 - cleaning consist control	2537
newsprint - effluent	mill - effluent treatment inlet	2481
dig 1 - wash filter 1 out	dig 1 - dilution control on digester 1	2450
KLB - b/w to waste plant	wasteplant - back water	2431
upt 3 - tickener filtrate	upt 3 - D37 consist control	2354
dig 1 - extraction liquor	evaps - New evaps inlet	2272
bleach - 3 stage out	bleach - wash press in	2195
dig 2 - hot/warm water tanks out	dig 2 - WBL cooler in	2177
dig 2 - extraction WBL	evaps - Old evaps inlet	2163
upt 3 - forming section A	upt 3 - mixed stock chest consist control	1895
caust - WWL ex lime mud washer	CRF2 - SDT (WWL)	1871
dig 2 - hot/warm water tanks out	upt 3 - cleaning consist control	1862
bleach - 3 stage out	bleach - oxygen reactor dilution	1840
evap - New evaps foul/cont clean	caust - lime mud mixing	1833
mill - fresh water	CT - TG2 in	1789
upt 3 - tickener filtrate	bleach - 3 stage in	1741
upt 1 - white water tank	dig 1 - uptake feed consistency control	1650
evaps - Old evaps clean	mill - effluent treatment inlet	1568

Table 34: Pinch Set-up Verification Matches Table - continued

From...	...to	Flow (kg/min)
mill - fresh water	upt 3 - cleaning consist control	1527
mill - fresh water	dig 2 - WBL cooler in	1523
upt 3 - formng section B	upt 3 - D37 consist control	1464
upt 3 - tickener filtrate	bleach - D36 consistency	1437
bleach - E tower out	mill - effluent treatment inlet	1364
dig 2 - two stage washer out	dig 2 - brown stock washer in	1363
mill - fresh water	dig 2 - hot/warm water tanks in	1335
dig 1 - wash filter 1 out	dig 2 - screen dilution	1308
evaps - New evaps dirty	CRF2 - SBL incineration	1300
upt 1 - white water tank	upt 1 - steady head tank	1276
mill - fresh water	newsprint - hot water	1266
mill - fresh water	KLB - fresh water	1215
evap - New evaps foul/cont clean	CT - New evaps in	1168
mill - fresh water	bleach - DC tower in	1112
upt 3 - formng section B	bleach - 3 stage in	1102
upt 2 - presses out	dig 2 - two stage washer in	1070
newsprint - back water	repulpers - #3	1058
noodle - filtrate	dig 1 - noodle feed consistency control	1032
dig 2 - T20 and T21 coolers out	dig 2 - hot/warm water tanks in	1000
dig 2 - T11 condensor out	dig 2 - hot/warm water tanks in	972
dig 2 - hot/warm water tanks out	dig 2 - T11 condensor in	972
upt 1 - white water tank	dig 1 - wsh filter 2 in	944
mill - fresh water	newsprint - fresh water	863
upt 1 - white water tank	upt 1 - sec stock chest consist control	843
evap - New evaps foul/cont clean	bleach - 3 stage in	817
upt 3 - effluent out	mill - effluent treatment inlet	800
mill - fresh water	KLB - hot water	779
mill - fresh water	CT - Lube oil in	746
noodle - filtrate	dig 1 - wsh filter 2 in	714
mill - fresh water	CT - New evaps in	675
caust - WWL ex lime mud washer	CRF1 - SDT (WWL)	670
PF - warm water	dig 2 - hot/warm water tanks in	658
mill - fresh water	groundwood - other uses	618
mill - fresh water	dig 2 - seal water	598
dig 2 - hot/warm water tanks out	dig 2 - T20 and T21 coolers in	589
upt 1 - white water tank	upt 1 - prim scr suply pmp consist control	588
dig 2 - effluent	mill - effluent treatment inlet	558
CT - Lube oil out	mill - effluent treatment inlet	528
upt 2 - mould filtrate water	dig 2 - two stage washer in	526
CRF2 - warm water	dig 2 - hot/warm water tanks in	511
mill - fresh water	CT - Service in	510
upt 3 - press section A	bleach - D2 tower in	504

Table 34: Pinch Set-up Verification Matches Table - continued

From...	...to	Flow (kg/min)
evaps - Old evaps dirty	CRF1 - SBL incineration	484
CRF1 - ID fan cooling water out	storm water ponds	474
mill - fresh water	CRF1 - ID fan cooling water in	474
demin - acidic effluent	mill - effluent treatment inlet	468
upt 2 - effluent out	mill - effluent treatment inlet	463
dig 2 - hot/warm water tanks out	dig 1 - seal water	460
ClO2 effluent	mill - effluent treatment inlet	455
mill - fresh water	repulpers - #1	434
upt 2 - mould filtrate water	upt 2 - effluent in	432
upt 3 - tickener filtrate	upt 3 - effluent in	431
dig 2 - hot/warm water tanks out	dig 1 - wsh filter 2 in	420
mill - fresh water	upt 2 - machine chest consist cntrl	413
mill - fresh water	dig 2 - T20 and T21 coolers in	411
upt 2 - mould filtrate water	dig 2 - W127 HD chest	350
CT - New evaps out	mill - effluent treatment inlet	343
dig 2 - hot/warm water tanks out	upt 3 - D37 consist control	297
CT - TG2 out	mill - effluent treatment inlet	289
upt 3 - formng section B	bleach - D2 tower in	288
evap - New evaps foul/cont dirty	mill - effluent treatment inlet	284
mill - fresh water	noodle - washing (H)?	273
upt 3 - formng section B	upt 3 - effluent in	269
dig 2 - hot/warm water tanks out	upt 2 - machine chest consist cntrl	260
mill - fresh water	upt 1 - fresh water applications	260
bleach - 3 stage out	mill - effluent treatment inlet	255
stormwater - lime kiln cooling water	storm water ponds	255
groundwood - effluent (rejects)	mill - effluent treatment inlet	254
mill - fresh water	CT - Old evaps in	253
dig 2 - hot/warm water tanks out	newsprint - fresh water	248
mill - fresh water	upt 3 - D37 consist control	244
mill - fresh water	wasteplant - other uses	226
dig 2 - hot/warm water tanks out	bleach - 3 stage in	223
upt 3 - pres section B	upt 3 - mixed stock chest consist control	216
bleach - bleach plant scrubber out	mill - effluent treatment inlet	196
groundwod - effluent (floor)	mill - effluent treatment inlet	184
mill - fresh water	bleach - 3 stage in	183
evap - New evaps foul/cont clean	caust - lme mud wash water	180
PF - scraper conveyor out	mill - effluent treatment inlet	174
mill - fresh water	PF - scraper conveyor in	174
mill - fresh water	repulpers - #2	171
woodyard - hardwood washing water	mill - effluent treatment inlet	171
CT - excess hot water out 1	storm water ponds	171
mill - fresh water	bleach - bleach plant scrubber in	164

Table 34: Pinch Set-up Verification Matches Table- continued

From...	...to	Flow (kg/min)
upt 3 - tickener filtrate	upt 3 - thickener wash water	153
mill - fresh water	bleach - NaOH dilution	150
evap - New evaps foul/cont clean	CRF1 - SDT vent scrubbing	150
evap - New evaps foul/cont clean	CRF2 - SDT vent scrubbing	150
dig 1 - effluent	mill - effluent treatment inlet	146
mill - fresh water	dig 2 - brown stock washer in	141
mill - effluent treatment dirty	mill - solid waste	139
bleach - OWL cooler out	dig 2 - hot/warm water tanks in	129
mill - fresh water	bleach - OWL cooler in	129
evap - New evaps foul/cont clean	CT - Old evaps in	126
CT - Lube oil out	evaps - New evaps inlet	125
stormwater - gas producers sub station	storm water ponds	121
upt 1 - white water tank	upt 1 - dry end repulper	119
demin - caustic effluent	mill - effluent treatment inlet	117
evaps - Old evaps clean	caust - lime mud mixing	117
CT - Service out	storm water ponds	114
dig 2 - hot/warm water tanks out	bleach - D36 consistency	114
PF and CRF2 - effluent	mill - effluent treatment inlet	100
upt 2 - vacuum pump out	upt 2 - machine chest consist cntrl	100
stormwater - screening house	storm water ponds	100
mill - fresh water	upt 2 - vacuum pump in	100

Table 35: Simplification of Pinch Balance (removed sources and sinks)

Sources	Flow (kg/min)
CT - New evaps out	343
CT - TG2 out	289
bleach - bleach plant scrubber out	196
PF - scraper conveyor out	174
woodyard - hardwood washing water	171
CT - excess hot water out 1	171
dig 1 - effluent	146
bleach - OWL cooler out	129
CT - Service out PF and CRF2 - effluent	114 100
upt 2 - vacuum pump out	100
upt 2 - seal water out	80
CRF1 - effluent	78
CT - Old evaps out	69
CRF1 - warm water	67
dig 2 - turpentine underflow	66
CT - Hi kappa out	29
CRF2 - floor drain sump	10
Sinks	**Flow (kg/min)**
dig 1 - seal water	460
CT - Old evaps in	379
dig 2 - W127 HD chest	375
caust - lme mud wash water	280
noodle - washing (H)?	273
upt 1 - fresh water applications	260
wasteplant - other uses	226
PF - scraper conveyor in	174
bleach - bleach plant scrubber in	165
bleach - NaOH dilution	150
CRF2 - SDT vent scrubbing	150
CRF1 - SDT vent scrubbing	150
bleach - OWL cooler in	129
upt 1 - dry end repulper	119
upt 2 - vacuum pump in	100
upt 2 - seal water in	80
upt 1 - hot water to w/w tank	75
upt 2 - presses in	60
caust - dust control on lime dump	41
CT - Hi kappa in	39
dig 1 - dil wash filter 1	16
caust - dregs filter wash water	10

8.3 Verification of Mass Balance – Taguchi Factorial Analyses

Factorial Design [49]

Because it was not possible to simulate all the different mill scenarios, the method of factorial analyses, based on the technique by Taguchi, was used to decide which different scenarios had to be simulated. A brief description of the Taguchi method is given. For detail on the Taguchi method, refer to Roy et al [47]. Factorial design is the technique of defining and investigating all possible conditions in an array of scenarios involving multiple factors. This method helps an engineer to determine all the possible combinations of scenario variables and to identify the best combination for a required result [47].

The nomenclature commonly used to describe factorial designs is described below:

- *Factor* refers to the input or user defined variable being investigated, e.g. the chlorine charge in the bleach plant, or the type of wood used in the digester.
- *Level* refers to the value assigned to the factor. Each factor can be evaluated at two or more levels, e.g. a chlorine charge of 1%, 2% or 3%, or the digester being run on either hardwood or softwood.
- *Response* refers to the output or dependent variable being investigated, e.g. the total volume of effluent generated by the mill, or the chloride load in the effluent.

If, for example, a scenario array depends on three factors A, B and C, and each of these factors has to be investigated at two discrete levels, the total number of scenarios are:

$$\text{No. of experiments} = 2^3 = 8$$

This three factor (A, B and C), two level (1 and 2) scenario array is depicted Table 36, which shows the 8 different combinations that make up the total factorial experiment.

Table 36: Matrix with three factors at two levels.

	A1		A2	
	B1	**B2**	**B1**	**B2**
C1	A1,B1,C1	A1,B2,C1	A2,B1,C1	A2,B2,C1
C2	A1,B1,C2	A1,B2,C2	A2,B1,C2	A2,B2,C2

Fractional Factorial Design [49]

When either the number of factors or the number of levels of a scenario array become large, the full factorial design becomes very cumbersome and exorbitant in terms of time, cost and effort. Fractional factorial design techniques have subsequently been developed to simplify such scenario arrays. With fractional factorial design only a fraction of all the possible combinations from the full factorial design are investigated. This approach requires substantially less time and effort than the full factorial design, but requires a rigorous mathematical treatment both in the design of the array and in the analysis of the results [47].

Taguchi method [49]

When setting up a fractional factorial design the engineer must determine how many scenarios to simulate in order for the analysis of the results to be meaningful, and also which combinations of factor levels to test. The Taguchi method simplifies and standardises this procedure in such a way that engineers will always use similar arrays and trends to get similar results. Taguchi constructed a special set of orthogonal arrays to facilitate the scenario design process. To design an scenario simulation the most suitable array has to be selected from the several pre-defined arrays available, depending on the number of factors and levels used in the particular design. A typical orthogonal array for a three factor, two level scenario array is shown Table 37. In this array, designated by the symbol L_4, each row corresponds to a trial condition with factor levels indicated by the numbers in the row.

Table 37: Orthogonal array L_4

Trial number	Factors			Response
	A	B	C	
1	1	1	1	R1
2	1	2	2	R2
3	2	1	2	R3
4	2	2	1	R4

It can therefor be seen that the eight scenarios required for a full factorial design are reduced to only 4 by using the Taguchi method.

Statistical analysis of results [49]

The results of the fractional factorial design can be analysed once the scenarios recommended by the Taguchi array have been completed and the required response data collected for each scenario. In general, a model of the following kind is fitted to each response:

$$f(\text{Response}) = a_0 + a_1X_1 + a_2X_2 + \ldots a_nX_n$$

where a_0, a_1 ... a_n are constants determined by the statistical analysis of the response data, and X_1, X_2 ... X_n are the factors considered in the scenario. The Taguchi method [47] guides the user through the different steps in the analysis of the response data. The principles used in this analysis are described in standard texts on statistics, and are briefly described below.

Transformation [49]

Transformation is the application of a mathematical function to the response data. This may be needed if the error (difference between the actual and predicted values) is a function of the magnitude of the predicted values. The transformation can take on the form of a power function (inverse, square root, etc.) or a logarithmic function. The Taguchi method [47] provides extensive diagnostic capabilities further on in the analysis to test the validity of the selected transformation.

Factor effects [49]

Significant factors have to be identified and separated from insignificant factors to best analyse the fractional factorial design. The Taguchi method [47] calculates the effects of all the factors on the given response, and produces statistics for comparing the factors. The factor effects can be viewed on either normal or half-normal probability plots, which simplifies the selection of significant factors for the statistical model.

Analysis of variance [49]

Once the significant factors have been selected, the analysis of variance (ANOVA) can be done. The ANOVA evaluates the significance of each individual factor included in the statistical model, as well as the significance or accuracy of the model itself. Definitions used in the ANOVA are given below:

- *Sum of squares*: the sum of the squared distances from the response mean to the average responses of a factor at its low value and its high value.
- *Total sum of squares*: the sum of the squared differences between the overall mean and the response values of the individual runs in the experimental design.
- *Residual sum of squares*: the sum of squares after the model sum of squares is subtracted from the total sum of squares.
- *Degrees of freedom*: the number of independent comparisons available to estimate a parameter.
- *Mean square*: the sum of squares divided by the degrees of freedom.
- *F-distribution*: a probability distribution used in the analysis of variance.
- *F-value*: the ratio of the mean square of a factor to the residual mean square.
- *Prob > F*: probability of a larger F-value. If this probability is small, then the factor is judged to be significant in terms of the statistical model.

Design-Expert [50] suggests that factors with a 'Prob>F' value smaller than 0.05 should be regarded as significant in terms of the statistical model, while factors with values larger than 0.1 are not significant and should be taken out of the model. The Taguchi method [47] ANOVA generates case statistics such as the R^2-value, signal-to-noise ratio and outlier t-values which aids the engineer in interpreting the results of the statistical analysis. It also generates a Box Cox plot that provides a guideline for selecting the most appropriate mathematical transformation for the original response data.

Predicting minimum and maximum responses [49]

The statistical model fitted to the response data describes how each factor in the model influences the response, e.g. the higher the value of factor A the higher the value of the response, or vice versa. This information can be used to predict the combination of factor levels where the response will respectively be at a minimum or maximum. The model itself may also be used to predict the minimum and maximum values of the response. However, these predicted responses should be used with caution and ideally the experiment should be repeated at the combination of factor levels used to predict the minimum or maximum responses.

8.3.1 Sensitivity analysis excluding downtime assumptions

A sensitivity analyses was done firstly without taking the fact into account that some plants might be off-line while others are on-line.

Planning

The L_{64} Taguchi array was used to set up the initial sensitivity analysis for the conventional bleaching WINGEMS model. This array allows a maximum of 63 factors at two levels each, and requires 64 factor level combinations to be run (as opposed to the 9.22×10^{18} runs required by the full factorial design). The first step in setting up the sensitivity analysis was selecting the factors to be investigated. For the full list of assumptions made in setting up the conventional bleaching WinGEMS model, refer to reference 50. From this full list 63 assumptions were selected for the sensitivity analysis (excluding production rates and plant on line assumptions), with the main criteria for selection being the possible impact on effluent quality and quantity. For each assumption, high and low values were determined based on historical plant data, WinGEMS mass balance values and literature data. These assumptions and values are presented in Table 38.

Table 38: Factors and levels for the conventional bleaching sensitivity analysis.

Factor	Factor description	Units	Low	High
A	Waste plant fresh water feed	kg/kg BD bales	2.36	2.88
B	Groundwood fresh water feed	kg/kg logs	1.889	2.389
C	Groundwood evaporation	% of incoming liquor	11.2	18.4
D	Softwood logs to groundwood: moisture	%	60.8	63.5
E	Softwood logs to groundwood: Na	g/kg wood liquor	0.004	0.067
F	Softwood logs to groundwood: Cl	g/kg wood liquor	0.03	0.061
G	Softwood logs to groundwood: SO_4	g/kg wood liquor	0.072	0.12
H	Softwood logs to groundwood: Ca	g/kg wood liquor	0.237	0.523
J	Softwood logs to groundwood: Mg	g/kg wood liquor	0.052	0.146
K	Softwood logs to chipper: moisture	%	55	58.1
L	Softwood logs to chipper: Na	g/kg wood liquor	0.005	0.085
M	Softwood logs to chipper: Cl	g/kg wood liquor	0.038	0.077
'n	Softwood logs to chipper: SO_4	g/kg wood liquor	0.04	0.091
O	Softwood logs to chipper: Ca	g/kg wood liquor	0.299	0.659
P	Softwood logs to chipper: Mg	g/kg wood liquor	0.065	0.184
Q	Softwood bought out chips: moisture	%	48.6	52.7

Table 38: Factors and levels for the conventional bleaching sensitivity analysis - continued

Factor	Factor description	Units	Low	High
R	Softwood bought out chips: Na	g/kg wood liquor	0.006	0.104
S	Softwood bought out chips: Cl	g/kg wood liquor	0.047	0.099
T	Softwood bought out chips: SO_4	g/kg wood liquor	0.04	0.117
U	Softwood bought out chips: Ca	g/kg wood liquor	0.387	0.853
V	Softwood bought out chips: Mg	g/kg wood liquor	0.084	0.238
W	#2 Service cooling tower evaporation rate	kg/min	300	493
X	TG2 cooling tower evaporation rate	kg/min	1536	2090
Y	#1 Evaporators cooling tower evaporation rate	kg/min	277	400
Z	#2 Evaporators cooling tower evaporation rate	kg/min	1618	2090
A'	Cooled warm water from w/water cooling tower to #2 Fibre line	kg/min	2826	4541
B'	Demin plant H_2SO_4 use	kg/kg fresh water treated	0.0002424	0.000267
C'	Demin plant Caustic use	kg/kg fresh water treated	0.000319	0.00037
D'	SWL TA	g/kg as Na_2O	125	130
E'	SWL Ca concentration	g/kg liquor	0.012	0.026
F'	SWL Mg concentration	g/kg liquor	0.00024	0.026
G'	SWL caustic make-up	kg/min	2	4
H'	Na_2SO_4 in saltcake	%	44.4	65.7
J'	NaCl in saltcake	%	1.2	2
K'	Recovery furnace Cl removal efficiency	%	10	25
L'	Soap skimmings	kg/min	6.7	28.7
M'	Combined condensate to foul condensate tank	kg/min	225.3	925.7
N'	Dirty condensate to foul condensate tank	kg/min	38.1	925.7
O'	Foul condensate to foul condensate tank	kg/min	198.3	776.8
P'	Fresh water make up to CCA tank	kg/min	1330	1942
Q'	#2 Digester yield	%	45.2	49.2
R'	#2 Digester SWL charge	% EA on dry wood	11	16
S'	#2 Digester fresh water ingress	kg/min	1560	1910
T'	#1 Digester yield	%	47	49
U'	#1 Digester SWL charge	% EA on dry wood	13	17
V'	D/C stage Cl_2 charge	kg/100kg BD pulp	2.2	2.61
W'	D/C stage ClO_2 charge	kg/100kg BD pulp	1.51	2.5
X'	D2 stage ClO_2 charge	kg/100kg BD pulp	0.97	1
Y'	E stage caustic charge	kg/100kg BD pulp	2.5	3
Z'	#1 Uptake fresh water feed	kg/kg BD pulp	1.2	2
A"	#1 Uptake hot water feed	kg/kg BD pulp	1.2	1.76
B"	ClO_2 plant effluent Cl load	t/d	0.5	2
C"	#2 Uptake fresh water feed	kg/kg BD pulp	2.4	2.64
D"	#2 Uptake hot water feed	kg/kg BD pulp	3.76	4.16

Table 38: Factors and levels for the conventional bleaching sensitivity analysis - continued

Factor	Factor description	Units	Low	High
E"	#3 Uptake fresh water feed	kg/kg BD pulp	6.41	6.62
F"	#3 Uptake hot water feed	kg/kg BD pulp	4.06	7.69
G"	#3 Uptake buffer chest back water	kg/min	9174.4	9669.4
H"	#3 Uptake surge chest back water	kg/min	1100	1400
J"	Newsprint fresh water feed	kg/kg BD pulp	3.98	5
K"	Newsprint hot water feed	kg/kg BD pulp	3.71	4.64
L"	Newsprint steam feed	kg/kg BD pulp	1.57	3.12
M"	KLB alum addition	kg/kg BD pulp	0.0146	0.015
N"	KLB PAC addition	kg/kg BD pulp	0.001	0.003

Sensitivity Analyses Results

The 'Observed minimum' and 'Observed maximum' columns in Table 39 refer to the minimum and maximum response values that were actually obtained in the 64 runs of the Taguchi design.

Table 39: Predicted minimum and maximum response values.

Response	Units	Predicted minimum	Observed minimum	Predicted maximum	Observed maximum
Irrigated effluent flow rate	Ml/d	23.78	25.10	30.95	30.11
Irrigated effluent chloride load	t/d	16.25	16.40	22.61	22.45
Irrigated effluent sodium load	t/d	16.82	17.33	21.61	21.40
Irrigated effluent sulphate load	t/d	10.11	10.36	11.41	11.22
Irrigated effluent magnesium load	t/d	0.844	0.881	1.158	1.088
Irrigated effluent calcium load	t/d	1.330	1.389	2.617	2.542

The results of the first sensitivity were used to weed out insignificant assumptions. This process involved assigning weights to the ten most important factors for the effluent quality responses from the first sensitivity. For example, the most important factor that influenced the irrigated effluent sodium load was awarded a weight of 10, the second most important factor a weight of 9, etc. The top 3 factors influencing the irrigated effluent chloride load were awarded double weights. These weights were subsequently summed to determine an overall ranking of the most important factors in the sensitivity analysis, as shown in Table 40.

Table 40: Prioritising the factors used in the first sensitivity analysis.

Factor	Factor description	Cl	Na	SO4	Ca	Mg	Σ
Q'	#2 Digester yield		7	3	6	6	22
R'	#2 Digester SWL charge		9	8	3	1	21
W'	D/C stage ClO2 charge	20					20
V'	D/C stage Cl2 charge	18					18
H"	#3 Uptake surge chest back water	6	4	4		4	18
U'	#1 Digester SWL charge		8	9			17
N"	KLB PAC addition	7			10		17
B"	ClO2 plant effluent Cl load	16					16
Q	Softwood bought out chips: moisture		3		5	5	13
R	Softwood bought out chips: Na		6	6			12
S'	#2 Digester fresh water ingress		5	5			10
P	Softwood logs to chipper: Mg					10	10
Y'	E stage caustic charge		10				10
M"	KLB alum addition			10			10
O	Softwood logs to chipper: Ca				9		9
F'	SWL Mg concentration					9	9
H	Softwood logs to groundwood: Ca				8		8
J	Softwood logs to groundwood: Mg					8	8
U	Softwood bought out chips: Ca				7		7
V	Softwood bought out chips: Mg					7	7
B'	Demin plant H2SO4 use			7			7
F"	#3 Uptake hot water feed	5			1		6
K	Softwood logs to chipper: moisture				4	2	6
G"	#3 Uptake buffer chest back water	2				3	5
X'	D2 stage ClO2 charge	4					4
J'	NaCl in saltcake	3					3
E'	SWL Ca concentration				2		2
H'	Na2SO4 in saltcake			2			2
M'	Combined condensate to foul condensate tank		2				2
K'	Recovery furnace Cl removal efficiency	1					1
N'	Dirty condensate to foul condensate tank		1				1
L"	Newsprint steam feed			1			1
P'	Fresh water make up to CCA tank						0
C	Groundwood evaporation						0
Z	#2 Evaporators cooling tower evaporation rate						0
B	Groundwood fresh water feed						0
J"	Newsprint fresh water feed						0
K"	Newsprint hot water feed						0
Y	#1 Evaporators cooling tower evaporation rate						0
A	Waste plant fresh water feed						0
D	Softwood logs to groundwood: moisture						0
E	Softwood logs to groundwood: Na						0
F	Softwood logs to groundwood: Cl						0

Table 40: Prioritising the factors used in the first sensitivity analysis.

Factor	Factor description	Cl	Na	SO4	Ca	Mg	Σ
G	Softwood logs to groundwood: SO4						0
L	Softwood logs to chipper: Na						0
M	Softwood logs to chipper: Cl						0
'n	Softwood logs to chipper: SO4						0
S	Softwood bought out chips: Cl						0
T	Softwood bought out chips: SO4						0
W	#2 Service cooilng tower evaporation rate						0
X	TG2 cooling tower evaporation rate						0
A'	Cooled warm water from w/water cooling tower						0
C'	Demin plant Caustic use						0
G'	SWL caustic make-up						0
L'	Soap skimmings						0
O'	Foul condensate to foul condensate tank						0
T'	#1 Digester yield						0
Z'	#1 Uptake fresh water feed						0
A"	#1 Uptake hot water feed						0
C"	#2 Uptake fresh water feed						0
D"	#2 Uptake hot water feed						0
E"	#3 Uptake fresh water feed						0

8.3.2 Sensitivity analysis including downtime assumptions

The second sensitivity analysis included downtime assumptions. A L_{12} Taguchi array was used for the second sensitivity, which allowed a maximum of 11 factors to be included in the experimental design. The results of the analysis done in Table 40 were used to select the smaller set of assumptions that were tested in the second sensitivity. In addition, simplifying assumptions were made to cluster some of the original factors together. This clustering was used to include as many factors as possible within the limitations of the Taguchi array, and was selected to simulate extreme conditions within the mill. For example, the type of wood used in the digesters (hard wood or soft wood) will influence a whole range of operation and plant performance parameters, as shown in Table 41.

Table 41: Factors used in the second sensitivity analysis.

Factor	Factor description	Cluster	Units	Low	High
A	Wood type to digesters		-	SW	HW
		#1 Digester SWL charge	%EA on dry wood	17*	13
		#1 Digester yield	%	45.2	49.2
		#2 Digester SWL charge	%EA on dry wood	16*	11
		#2 Digester yield	%	45.2	49.2
		D/C Cl2 charge	kg/100 kg BD pulp	2.61*	0.99
		D/C ClO2 charge	kg/100 kg BD pulp	2.5*	1.19
		D2 ClO2 charge	kg/100 kg BD pulp	1*	0.57

*Higher and lower values are swopped around to coincide with when softwood (SW) is selected

Table 41: Factors used in the second sensitivity analysis.

Factor	Factor description	Cluster	Units	Low	High
B	#3 Uptake surge chest backwater	-	kg/min	1000	2000
C	KLB chemical addition		-	low	High
		KLB alum addition	kg/kg BD total feed	0.001	0.003
		KLB PAC addition	kg/kg BD total feed	0.0146	0.015
D	ClO2 plant effluent chloride load	-	t/d	0.5	2
E	Wood sodium content		-	low	High
		SW groundwood logs	g/kg wood liquor	0.004	0.067
		SW logs to chipper	g/kg wood liquor	0.005	0.085
		SW bought out chips	g/kg wood liquor	0.006	0.1
		HW logs to chipper	g/kg wood liquor	0.2457	0.3003
		HW bought out chips	g/kg wood liquor	0.1953	0.2387
F	Wood magnesium content		-	low	High
		SW groundwood logs	g/kg wood liquor	0.052	0.15
		SW logs to chipper	g/kg wood liquor	0.065	0.18
		SW bought out chips	g/kg wood liquor	0.084	0.24
		HW logs to chipper	g/kg wood liquor	0.2844	0.3476
		HW bought out chips	g/kg wood liquor	0.2259	0.2761
G	E-stage caustic charge	-	kg/100 kg BD pulp	2.5	3
H	Wood calcium content		-	low	High
		SW groundwood logs	g/kg wood liquor	0.24	0.52
		SW logs to chipper	G/kg wood liquor	0.3	0.66
		SW bought out chips HW logs to chipper	G/kg wood liquor G/kg wood liquor	0.39 1.1907	0.85 1.4553
		HW bought out chips	G/kg wood liquor	0.945	1.155
J	KLB /waste plant on line assumption	-	-	Up	Down
K	Newsprint/groundwood on line assumption	-	-	Up	Down
L	Bleach plant/ClO2 plant/#3 uptake on line assumption	-	-	Up	Down

Sensitivity Analyses with Down Time Results

This statistical analysis was used to predict the maximum and minimum values of the responses listed in Table 13. The 'Observed minimum' and 'Observed maximum' columns in Table 13 refer to the minimum and maximum response values that were actually obtained in the 12 runs of the Taguchi design.

8.4 Data Tables and Other Data to which the mass balance was Calibrated [51]

8.4.1 Wood yard

The woodyard receives wood in the form of chips and logs, either as hardwood or as softwood, via rail and road. All logs are debarked and some of the logs are chipped for chemical pulping and the remaining logs are used in groundwood for mechanical pulping. In the woodyard the chips are screened to remove chips that are under and over size. Bark, from debarking the logs, as well as the over- and under size chips are either burnt in the pulverised fuel boiler as fuel or are dumped on the macro dump. Chips are stored in the woodyard on two separate chip piles, one pile for hardwood and another pile for softwood.

The assumptions that are made in the woodyard are listed Table 42. The assumptions are listed in such a way as to explain or point out also the control logic followed in building the mass balance simulation.

Table 42: Woodyard Assumptions and Mass Balance Control Logic

#	Assumption	Comment or Reference
1.	The woodyard balance is done to a level between level 2 and level 3. This means that the quality and quantity of the most prominent intermediate streams in the woodyard are available, although not all intermediate streams and process units are seen on the balance.	It is assumed that a detailed level 3 balance is not required due to the fact that very little liquor streams are involved in the woodyard.
2.	The quantity of incoming wood is user defined, should any additional wood be required in excess to the quantity specified by the user, this additional wood would then be accessed from the hardwood and softwood chip pile storage's respectively. Should the user specify more wood into the woodyard than are required by the digesters, that excess of wood will go onto the wood chip piles. The following wood feed rates are assumed: • SW logs to GWD debarker = 782 t/d • SW chemical logs = 3 600 t/d • SW BOC = 1 030 t/d • HW chemical logs = 438 t/d • HW BOC = 160 t/d	To see wood quantities used refer to Table 50 page 171. This assumptions is necessary to cater for scenario's where the woodyard is on-line, but the digesters are off-line and vice versa. A buffer storage is thus simulated here.
3.	The quality of the incoming wood logs and chips are user defined. The user states what the concentration of the components is in the different wood types being fed. The qualities assumed are given in Table 43	Refer to Table 46page 170, Table 48 page 170, Table 9 page 170.
4.	It is assumed that the chemical components that are in the wood are mostly dissolved in the liquor/moisture that are in the wood. This means that the chemical components are not absorbed/adsorbed onto the wood at this stage.	Provision is however made for adsorbing sodium onto pulp after the digesters #1 and #2.
5.	The quality of the chips from the chip piles is of the same quality as the chips going onto the pile. That means that no provision is made for the fact that the chip quality, i.e. moisture content, change over time when stored on the chip piles	No data is available to improve the balance to this level of detail. See Table 43
6.	0.086 kg bark is generated for every kg of softwood that is debarked in the debarker.	This is close to the general perception that 10% of the log is bark.
7.	0.086 kg groundwood logs are rejected on the 'Lilly pad' per kg logs fed to groundwood. The logs are rejected to chemical pulping.	
8.	Assume that only 180 Lpm of fresh water is used in the woodyard, of which 171 Lpm is used for washing at the hardwood chipper. All fresh water ends up in the storm water system.	Washing on logs was measured by G Nxasana to be 171 Lpm.
9.	Moisture content of the bark is assumed to be 50%.	
10.	126.6 t/d bark is sold.	Figure 46page 172.

Table 42: Woodyard Assumptions and Mass Balance Control Logic - continued

#	Assumption	Comment or Refe rence
11.	75 t/d bark and sawdust burnt. Assume that the split is 50% bark and 50% sawdust burnt.	Driver that loads bark and sawdust says he loads one load bark, one load sawdust. Figure 46page 172. Also see assumptions regarding PF boiler for determining bark quantities Table 90 page 217.
12.	If not enough logs are fed to into the woodyard to satisfy the groundwood wood requirement, it is assumed that any short fall of logs are reclaimed from the '24 hour' day storage of groundwood. Logs from this storage have the same quality as groundwood logs into woodyard.	Table 43 for qualities,
13.	Enough logs are fed either from the groundwood debarker directly, or from the groundwood day storage to achieve the groundwood pulp production.	
14.	Enough chips (HW and/or SW) are fed to the digesters #1 and #2 respectively, either directly from the chipper or from the hard- and/or softwood chip piles to satisfy the productions specified.	
15.	The three storage's (i.e. hardwood chip pile, softwood chip pile and groundwood storage) either have a positive value or a negative value. Positive indicating that the storage pile is increasing at that rate, and a negative indicating that the storage pile is decreasing.	• GWD storage = +1.2 t/d • SW chip pile = - 106 t/d • HW chip pile = + 598 t/d
16.	0.038 kg oversize is generated per kg harwood screened.	Table 45
17.	0.0061 kg oversize is generated per kg softwood screened.	Table 45
18.	0.0132 kg sawdust is generated per kg hardwood screened.	Table 45
19.	0.0132 kg sawdust is generated per kg softwood screened.	Table 45

Table 43: Quality of Wood Commodities into mill

	Unit	SW Logs	HW Logs	SW BOC	HW BOC	SW GWD Logs	SW chips ex pile	HW chips ex pile
Moisture	% of total sample	56.6 56.6	34.7 34.7	51.5 51.5	40.1 40.1	62.2 62.2	55.5 55.5	37.8 NA
Pulp	% of dried sample	N/D 99.3	N/D 99.2	N/D 99.3	N/D 99.2	N/D 99.2	N/D 99.3	N/D 99.6
Inerts/Ash	% of dried sample	0.7 0.7	0.5 0.8	0.7 0.7	0.5 0.8	0.8 0.8	0.7 0.7	0.4 0.4
Chloride	mg/L moisture	38.4 38.4	30.4 30.4	47.0 47.0	30.4 30.4	30.4 30.4	40.0 40.0	18.0 18.0
Sodium	mg/L moisture	85.0 85.0	67.0 67.0	104 104	67.0 67.0	67.0 67.0	88.9 88.9	39.4 39.4
Calcium	mg/L moisture	297 297	236 236	365 365	236 236	236 236	311 311	139 139
Magnesium	mg/L moisture	125 125	99.0 99.0	154 154	99.0 99.0	99.0 99.0	131 131	58.0 58.0
Manganese	g/kg liquor	59 59	46.9 46.9	73.0 73.0	46.9 46.9	469 469	62 62	26.4 26.4
Sulphate	g/kg liquor	N/D 40.0	120 120	N/D 40.0	120 120	N/D 120	N/D 41.0	71.0 71.0
Iron	g/kg liquor	5.1 5.1	4.0 4.0	6.3 6.3	4.0 4.0	4.0 4.0	5.3 5.3	2.3 2.3

Table 44 gives a summary of the wood input into the mill, the table also gives the actual Wingems values in gray scale.

Table 44: Wood Input

Commodity	Average (ton/month)	Average (kg/min)
HW BOC chips	4 623	106 / 111
HW logs	14 372	328 / 304
SW BOC chips SW logs	18 685 85 334	427 / 900 1 948 / 2 500
SW GWD logs	22 281	509 / 570
Total	**145 297**	**3 317 / 4 385**

Table 45: Solid waste from Wood yard [weigh bridge history]

Solid waste	AD ton/day	AD kg/min
Bark generated	312.5	216.7 / 262
• **Bark burnt***	75.7	52.5 / 26
• **Bark sold**	131.2	91.1 / 88
• **Bark to macro dump**	105.6	73.3 / 148
Sawdust generated	87.2	60.5 / 41
• **Sawdust burnt***	75.7	52.5 / 26
• **Sawdust to macro dump**	11.5	6.9 / 15
• **Sawdust sold**	0	0 / 0
Oversize generated/dumped	33.1	23 / 19

The woodyard receives timber in various forms (i.e. logs or chips) with varying quality requirements (in terms of moisture content, specie and age). The following terms are used when discussing timber input into the woodyard:

- Softwood (SW) : pinus specy wood, this can enter the mill either as logs or as chips. Two main groups of softwood logs are of importance, namely the wood used for chemical pulping (chemical logs), or logs used for mechanical pulping in the groundwood plant (groundwood or Newsprint logs). The logs used for mechanical pulping have higher quality specifications than the chemical logs, i.e. should be fresher (thus higher moisture content). The softwood logs have a high bark content and needs to be debarked before being chipped.
- Hardwood (HW) : eucalyptus specy wood, can also enter the mill either as a log that must still be chipped or as chips bought from outside suppliers. The hardwood logs have very little bark and does not need to be debarked.
- Bought out chips (BOC): are chips received from outside suppliers. These chips are stored on the same piles as the chips that originate from the logs which had been chipped on-site.

User defined wood quantities, at user defined qualities, enter the woodyard as softwood logs for groundwood, softwood logs for chemical pulping, softwood bought out chips, hardwood logs to be chipped and also hardwood bought out chips. Should this input of wood be more than required by the digesters, the wood would be stored on the hardwood and softwood chip piles, as well as on the groundwood day storage for logs. Should the user-defined quantities of input be less than that required by the digesters, additional chips or logs from the chip piles and groundwood day storage respectively would be made up. In the woodyard the softwood logs are debarked and also screened. Chips feed rates as well as bark/sawdust required for burning in PF boiler are read from the digester and boiler sections and enough chips and sawdust/bark are fed.

Any excess bark and sawdust are send to the macro dump. Oversize is also being sent to the macro dump. The woodyard section thus has three storage facilities that can act as an input or output, depending on whether the storage piles are growing or decreasing. This helps to simulate different actual mill operating modes easier, for example, say the woodyard is processing hardwood, although both digesters are on softwood, the model will show that the hardwood pile is increasing. It can also simulate the scenario where the woodyard is down, i.e. no bark, sawdust or oversize is being generated, while both digesters are actually running on chips from the chip piles.

Currently the chips coming from the chip storage pile, as well as the groundwood logs from the groundwood day storage, have the same properties (quality) as the chips and/or logs coming into the woodyard. It is however possible to define different qualities for chips coming from the chip storage compared to chips coming off fresh from the chipper, this way the influence of using older chips (or older groundwood logs) coming from the respective storage's can be evaluated.

The feed rate of groundwood logs from the woodyard to the groundwood is controlled so the required pulp rate from groundwood (as specified by Newsprint) to Newsprint is achieved. In other words, based on user inputs at Newsprint it is calculated how much mechanical pulp is needed, the rate of logs from woodyard to groundwood then increases incremental until the pulp production rate of groundwood satisfies Newsprint's requirements for mechanical pulp.

Table 46: Chip moisture content [Karel Boon, financial year 1999]

	Unit	SW LOGS	HW LOGS	SW BOC	HW BOC	NP LOGS
Moisture from chipper/supplier	%	56.6	34.7	51.5	40.1	62.2
Moisture from chip pile	%	54.1	37.8	--	--	--

Table 47: Wood Quality [analyses done 27 March 1992]

	Unit	Wattle	CTE	Grandis
Moisture	%	24.05	37.77	31.89
Ash	%	0.29	0.29	0.38
Chloride	% dry wood	0.0008*	0.0008*	0.0008*
Sodium	% dry wood	0.00390	0.0125	0.0165
Calcium	% dry wood	0.07300	0.039	0.0988
Magnesium	% dry wood	0.01800	0.014	0.0184
Manganese	% dry wood	<0.000006	0.009	0.0027
Sulphur	% dry wood	0.00240	0.0042	0.00291
Iron	% dry wood	0.00086	0.0028	0.0014

*estimate from Volkmar Böhmer

Table 48: Ngodwana Pinus Patula Wood quality

	Unit	Pinus Patula [analyses done]	Scandinavian Pine [1]
Moisture	%	--	--
Ash	%	--	--
Chloride	ppm on dry sample	50*	Max 100
Sodium	ppm on dry sample	110.52	6
Calcium	ppm on dry sample	387.6	390-860
Magnesium	ppm on dry sample	163.5	85-240
Manganese	ppm on dry sample	77.21	51-112
Sulphate	ppm on dry sample	--	--
Sulphur	ppm on dry sample	39.36	--
Iron	ppm on dry sample	6.66	135

*estimate from Volkmar Bohmer

Table 49: BOC moisture content [Sappi Logistics]

Month	YTD BOC Pine Chip moisture %	YTD BOC Gum Chip moisture %
Oct-98	50.8	35.9
Nov-98	51.2	37.2
Dec-98	51.3	36.4
Jan-99	51.7	39.0
Feb-99	52.2	40.4
Mar-99	52.1	38.9
Apr-99	51.9	36.7
May-99	51.9	36.7
Jun-99	**50.2**	**36.68**

Table 50: Input Wood Quantities [Sappi Logistics]

DATE	Total Gum Chips	Total Gum Pulp	Total Pine Chips	Total Pine Logs	Pine Newsprint
1999	**BOC**	**round logs**	**BOC**	**round logs**	**Groundwood**
JAN	3.553	13.056	10.092	79.627	21.296
FEB	5.119	12.004	15.952	81.322	20.215
MAR	4.811	17.427	24.740	109.700	24.199
APR	4.052	18.873	16.191	68.388	19.436
MAY	4.910	11.283	19.831	63.600	22.462
JUN	5.294	13.594	25.309	109.369	26.079
Average (ton/month)	4623.2	14372.8	18685.8	85334.3	22281.2
(kg/min)	105.6	328.1	426.6	1948.3	508.7

Table 51: Rejection of Groundwood logs at Groundwood log checker (LillyPad) [PE investigation results - 1999]

Sample No.	Knots		Log						Tot. Logs Rej /100 Logs	Sample Size
	Too Many	Too Big	Too Big	Too Small	Too Short	Too Long	Bark	Splitting		
1	1	1	2	2	1	0	0	4	11	100
2	2	2	1	0	1	0	1	2	9	100
3	4	2	1	1	1	0	0	2	11	100
4	1	0	0	2	4	0	2	2	11	100
5	3	3	0	1	0	0	1	0	8	100
6	3	0	0	2	2	0	2	1	10	100
7	1	1	0	0	4	0	0	1	7	100
8	4	1	0	1	0	0	0	0	6	100
9	1	0	1	1	1	0	1	1	6	100
10	2	1	0	0	2	1	0	1	7	100
TOTAL	**22**	**11**	**5**	**10**	**16**	**1**	**7**	**14**	**86**	**1000**
AVG.	**25.58**	**12.8**	**5.81**	**11.63**	**18.60**	**1.16**	**8.14**	**16.28**	**8.6**	**100**

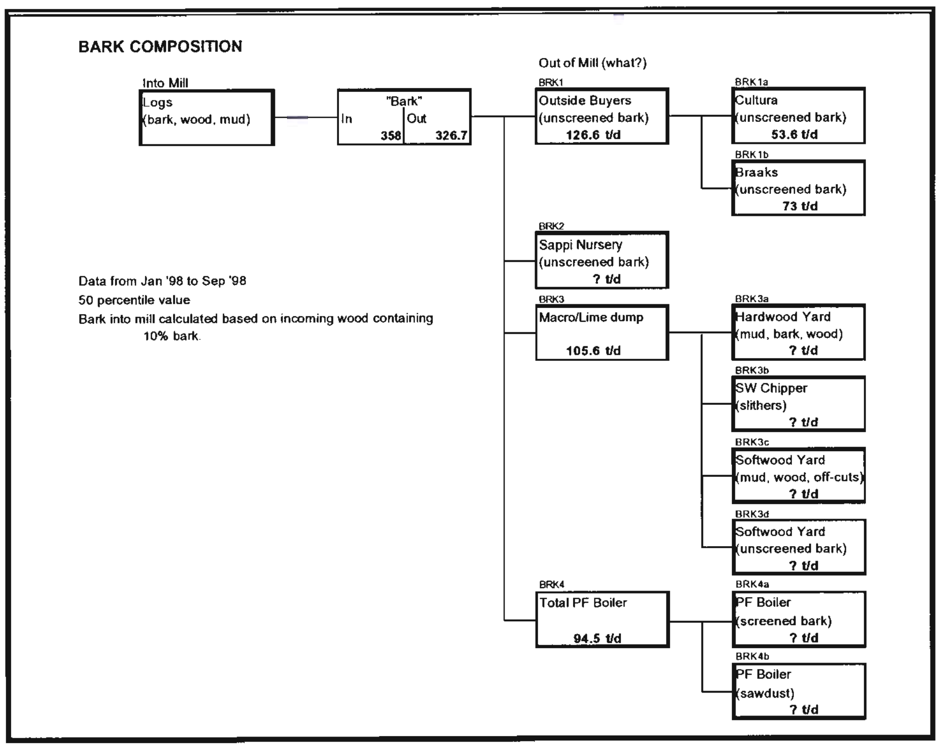


Figure 46: Bark Quantities

Figure 47: Oversize Quantities

Figure 48: Sawdust Quantities [52]

8.4.2 Digester #1

The digester is a continuous digester that can pulp hardwood and softwood. For the calibration of the model softwood data was used as basis for the calibration. Strong white liquor from the causticizing section is used as cooking liquor and the spent cooking liquor (weak black liquor) is returned the evaporators. The cooked pulp is screened and washed to be processed further in the noodle plant or uptake #1. Fresh water and hot water is used for washing of pulp, seal water and in the digester diffusion washer. Screen rejects from #2 digester can also be processed with the pulp from the #2 digester when both digesters are on softwood. The ingress of liquor with the received screen rejects from #2 fibre line is balanced by returning the liquor to #2 fibre line. #1 Digester can do low solids cooking as well as hi-kappa cooking, the balance was done for conventional cooking. A cooling tower (the hi-kappa cooling tower) is associated with the #1 digester operation. A more detailed description of this section is given by Leske [1].
The #1 digester mass balance is done to a level 3.

Table 52: Woodyard Assumptions and Mass Balance Control Logic

#	Assumption	Comment or Reference
1.	The user defines the required pulp production rate. Assume a pulp production rate of 332 ADt/d.	Table 11 page 88, also discussions with PE. Production record (24/05/2000) give year average as 311 ADt/d and month record of 391 ADt/d.
2.	The user also specifies whether the digester is processing hardwood or softwood. For calibration of the model softwood was considered, but allowing different yields and strong white liquor charges when hardwood is used.	See assumption 3 and 4.
3.	Strong white liquor charges for pulping softwood = 0.17 fraction as EA on BD wood..	PE = 0.16
4.	Strong white liquor charges for pulping hardwood = 0.13 fraction as EA on BD wood..	PE = 0.13

Table 52: Woodyard Assumptions and Mass Balance Control Logic - continued

#	Assumption	Comment or Reference
5.	The same yield over the digester is assumed for hardwood and softwood = 0.48. The wood is converted to COD.	
6.	0.8264 kg steam is required for every kg of BD chips fed into the digester.	PE balance = 0.674
7.	1.20841 kg fresh water is required for every kg of BD chips fed into the digester.	PE balance = 0.607
8.	The user defines whether rejects from #2 digester is being utilized. For calibration purposes with both digesters on softwood the rejects were utilized.	
9.	2.5596 kg hot water is required for every kg of BD chips fed into digester.	PE balance = 1.822
10.	40.6% of the total production from the digester is process via the uptake #1 and the remaining pulp via the noodle presses.	PE balance = 50.6%. Ratio changed based on production requirements in noodle press and uptake #1.
11.	White water returned from uptake #1 is 1.134 kg back water returned for every kg of pulp to uptake #1	PE balance = 1.03
12.	Noodle back water return from noodle presses is 0.875 kg filtrate returned for every kg pulp to noodle presses.	PE balance = 0.80
13. 14.	Hi kappa cooling tower blow down rate is 29 Lpm and blows down into the hot water system. Sodium, calcium and magnesium adsorps onto the pulp in the digester. • Sodium = 1.4 g/kg BD pulp • Magnesium = 0.4 g/kg BD pulp • Calcium = 0.9 g/kg BD pulp	PE balance = 20 Lpm
15.	0.0252 kg water (H_2O) is evaporated for every kg of BD chips fed = 9.9 Lpm = 0.014 ML/d.	
16.	0.235 kg turpentine containing condensate is generated for every kg of BD chips fed = 92.3 Lpm = 0.13 ML/d. The composition of the condensate is assumed to be: • Sodium = 5 mg/L • Chloride = 20 mg/L • Sulphate = 17 mg/L • COD = 19 654 mg/L • Ca = 1 mg/L • Mg = 2 mg/L • SS = 0 mg/L	PE balance = 0.202

Table 52: Woodyard Assumptions and Mass Balance Control Logic - continued

#	Assumption	Comment or Reference
17.	7.38 kg weak black liquor is generated for every kg of BD chips fed = 2 900 Lpm = 4.2 ML/d. The WBL is assumed to have the following composition: • Sodium = 25 409 mg/L • Chloride = 1 390 mg/L • Sulphate = 2 424 mg/L • COD = 133 312 mg/L • Ca = 31 mg/L • Mg = 11 mg/L • SS = 25 mg/L • TDS = 12.9% • HS^- = 2 595 mg/L • OH^- = 126 mg/L • CO_3^{2-} = 979 mg/L	• PE balance = 6.68 • Table 54page 177. • 1.7 ton SBL solids generated for every ton BD pulp produced [P Merensky] for unbleached pine and O_2 bleach • 1.5 ton SBL solids generated for every ton BD pulp produced [P Merensky] unbleached HW.
18.	0.529 kg BD pulp is produced for every kg of BD chips fed.	PE = 0.5
19.	Pulp is at a consistency of 12%.	
20.	0.001 kg screen rejects for every kg of BD chips fed are produced at a consistency of 10% = 5.5 t/d	PE = not indicated See page 177
22.	The reject liquor that is returned to #2 fibre line is 99% of the amount of pulp rejects received = 1 271 Lpm = 1.8 ML/d.	
23.	The composition assumed for the return reject liquor is: • Sodium = 22 582 mg/L • Chloride = 17 mg/L • Sulphate = 1 795 mg/L • COD = 1 266 mg/L • Ca = 5 mg/L • Mg = 0 mg/L • SS = 100 mg/L	
24.	Any excess liquor and components that did not form part of the above mentioned streams will report to the effluent stream. Any upsets or excess will thus be seen in the effluent.	
25.	Because COD is rather a property than a mass, and because the evaporators section works with dissolved wood solids rather than COD, the COD in the WBL is converted to dissolved wood solids before it enters the evaporators. After the evaporators the COD is corrected again. 0.695 kg dissolved wood solids are formed for every kg of COD.	See section 8.4.8 page 203 for a more detailed description on how COD vs dissolved wood solids are handled.

Table 52: Woodyard Assumptions and Mass Balance Control Logic - continued

#	Assumption	Comment or Reference
26.	Although the effluent stream is the excess of all the input streams, which have not be split off to the various output streams, a certain quality and volume flow has still been assumed for the digester to assist in calibrating the #1 digester. In other words, the model is programmed so that any process upset or excesses report to the effluent stream, but in calibrating the model, in order to help define inputs, it was assumed that the #1 digester effluent, excluding #1 uptake, has the following properties: • Flow = 0.28 ML/d • SS = 2 587 mg/L • Sodium = 2 643 mg/L • Chloride = 37 mg/L • Sulphate = 102 mg/L • COD = 4 477 mg/L • Magnesium = 0 mg/L • Calcium = 107 mg/L	
27.	The LVHC system flow is estimated at 1.12 kg/min where the TRS concentration is at 667 g/kg and the moisture concentration at 333 g/kg.	[53]
28.	The HVLC system flow is estimated at 106.2 kg/min where the TRS concentration is 8.7 g/kg and moisture concentration is the remainder of the flow.	[53]

- A typical weak black liquor sample from a single line southern market bleach kraft pulp mill that runs campaigns of softwood and hardwood are given in Table 54.

Table 53: Metal content measured in three WBL samples

Metal	mg/litre of liquor
Na	141 000
Mg	73.6
Al	76.6
Ca	196
Mn	55.1
Fe	30.7

Table 54: Weak Black Liquor Properties of Digester #1

Date[3]	EC(uS)	Na	Ca	Mg	Cl	SO4	COD	Fe	Mn	SS	Total Solids
		g / kg liquor									
1/11/99[1]	19280	41.8	0.094	0.055	1.17	1.80	152	0.012	0.032	2.63	160
3/11/99[1]	18020	42.5	0.082	0.078	1.39	0.45	176	0.010	0.029	5.38	135
4/11/99[1]	17570	29.3	0.134	0.062	1.20	2.13	150	0.016	0.025	3.86	93
Wingems[2]		28.25				2.20					

1. Sample taken of Ngodwana weak black liquor for conventional bleaching
2. Taken from WinGEMS example of a total mill balance – "fullmill.wg"
3. No ozone ran during sampling [De Wet Brandt]

Calculating Rejected Quantities to solid waste Dump:

- #1 digester + #2 digester + uptake #3 rejects = 24.6 t/d @ 10% consistency [52].
- Uptake #3 only = 4 t/d, thus digester #1 with digester #2 = 24.6 – 4 = 20.6 t/d
- Dividing the 20.6 t/d according to the digester productions:
  - #1 digester = 5.6 t/d
  - #2 digester = 15.0 t/d

8.4.3 Digester #2

The wood chips fed to no.2 digester first pass through the steaming vessel, where the temperature is raised, and through the impregnation vessel where the cooking chemicals are added. Brown stock washer filtrate is used for pulp washing in the digester. Pulp leaves the digester at 10% consistency, and is diluted further in the blow tank to 3.3% consistency using brown stock washer filtrate. The pulp then passes through the screening section and enters the brown stock washer at 1.2% consistency.

The brown stock washer (BSW) uses backwater from the bleach plant wash press as well as two stage diffusion washer filtrate for pulp washing. Pulp leaves the BSW at 10% consistency, and is split between the two-stage diffusion washer and the high density pulp storage chest (SU53). Bleach plant backwater is used to dilute the pulp in SU53 to 5.5% consistency, before it is sent to the bleach plant.

The two-stage diffusion washer uses backwater from no.2 uptake for pulp washing. Pulp exits the washer at 10% consistency, and is diluted to 3% consistency (again using no.2 uptake backwater) before being sent to no.2 uptake, which produces unbleached pulp.

Weak black liquor (WBL) from no.2 digester passes through two flash cyclones (C50 and C51) and the WBL cooler. Vapour from the first flash cyclone (C50) is used in the steaming vessel; vapour from the steaming vessel joins the second flash cyclone vapour, and this stream is condensed to produce turpentine. The turpentine is fed to the turpentine decanter along with the turpentine produced by no.1 digester.

Hot water from the turpentine condensers and WBL cooler is collected in the hot water tank, from where it is distributed to various users in the mill.

The assumptions that are made in no.2 fibre line are listed in Table 55. The assumptions are listed in such a way as to explain or point out also the control logic followed in building the mass balance simulation.

Table 55: No.2 Fibre Line Assumptions and Mass Balance Control Logic

#	Assumption	Comment or Reference
1.	A level 3 balance is used to simulate no.2 fibre line. All major process units and relevant intermediary streams are shown in detail	
2.	The most important parameters used to calibrate the no.2 fibre line model were: • No.2 digester production = 630 BDton/day • WBL flow rate and composition as described in Table 56 • No.2 digester effluent flow rate and composition as described in Table 56 • Hot water effluent flow rate and composition as described in Table 56	Emphasis was placed on the WBL because it influences the operation and effluent generation of the Evaporators and Chemical Recovery sections of the WinGEMS model.
3.	Steaming vessel: • Chips heated to 110°C • No change in moisture of chips	
4.	Tramp material separator: • No loss of wood chips • No SWL addition	
5.	HP feeder: • All incoming SWL is fed to the HP feeder • 90% of the total feed to the HP feeder is split to the impregnation vessel, the balance to the sand separator	
6.	Sand separator: • Brown stock washer filtrate used = 10 kg/min • 99% of the total feed is split to the In-line drainer, the balance is split out as waste	
7.	In line drainer: • All of the feed is split out to the Tramp material separator	
8.	Impregnation vessel: • No chemical reactions, no yield loss • 70% of the total feed is split to the digester, the balance is recycled to the HP feeder.	
9.	Digester: • HP steam added to heat incoming pulp to 175°C • Softwood run: Digester yield = 45.6% SWL charge = 16% EA on dry wood • Hardwood run: Digester yield = 49.2% SWL charge = 11% EA on dry wood • The pulp is washed at the bottom of the digester with brownstock washer filtrate; Dilution Factor = 3.1 • Pulp exits the digester at 10% consistency	The WinGEMS model was calibrated for a softwood run.
10.	Blow tank: • Brown stock washer filtrate used to dilute the pulp to 3% consistency = 8973 kg/min	

Table 55: No.2 Fibre Line Assumptions and Mass Balance Control Logic - continued

#	Assumption	Comment or Reference
11.	Knotters: • 84% of incoming pulp goes out to the Primary screen supply chest (SU45) at 2.6% consistency • BSW filtrate used for washing = 6693 kg/min (50% of the incoming pulp stream)	
12.	Primary screens: • Rejects = 11% of incoming pulp at 0.6% consistency • BSW filtrate used to control pulp accepts consistency at 1.21% = 10240 kg/min	
13.	Secondary screens: • Accepts = 50% of incoming pulp at 1.1% consistency • BSW filtrate used for washing = 945 kg/min (2.16 kg/BD kg pulp produced by the digester) • BSW filtrate used as make up to the Secondary screen supply chest (SU47) = 2441 kg/min (5.58kg/BD kg pulp produced by the digester)	
14.	Tertiary screens: • Accepts = 28% of incoming pulp at 1.8% consistency • BSW filtrate used for washing = 354 kg/min (0.81 kg/BD kg pulp produced by the digester) • BSW filtrate used as make up to the Tertiary screen supply chest (SU48) = 79 kg/min (0.18 kg/BD kg pulp produced by the digester) • No.1 fibre line back water to the Tertiary screen supply chest = 1271 kg/min at 0.077% consistency • Of the Tertiary screens rejects stream, 11.4% is split to no.1 fibre line blow tank.	
15.	Stocker: • BSW filtrate to stocker = 1181 kg/min (2.7 kg/BD kg pulp produced by the digester) • Rejects from stocker = 0	
16.	SU26: • BSW filtrate to SU26 = 1181 kg/min (2.7 kg/BD kg pulp produced by the digester) • Rejects from SU26 = 0	
17.	Brown stock washer: • Bleach plant back water (5229 kg/min) and two stage diffusion washer filtrate (1254 kg/min) used as wash water; Dilution Factor = 5.7 • Pulp exits the BSW at 10% consistency	The WinGEMS model first satisfies the water requirements of the screening section, before sending

Table 55: No.2 Fibre Line Assumptions and Mass Balance Control Logic - continued

#	Assumption	Comment or Reference
18.	Brown stock washer seal tank: • BSW seal tank fresh water make up = 1734 kg/min (approximately 2.5 Ml/d) to simulate seal water, leaks, etc. • The WinGEMS model first satisfies the water requirements of the screening section, before sending water to the digester. • 220 kg/min is assumed lost to the spill tank	The fresh water make up is required to satisfy the hydraulic requirements of the screening section and the digester.
19.	Spill tank: • Noodle back water to spill tank = 20 kg/min • Spill tank water to blow tank = 20 kg/min • Spill tank water to effluent flume = 220 kg/min	
20.	High density pulp storage chest SU53: • Enough pulp is split to SU53 to ensure a bleach plant production rate of 482.7 ADton/day • Bleach plant back water (2716 kg/min) is used to dilute the pulp to 5.5% consistency	
21.	Two stage diffusion washer: • No.2 uptake back water (1276 kg/min) is used as wash water to give an overall DF = 2.5 • Pulp exits the washer at 10% consistency • The pulp is diluted with no.2 uptake back water (2738 kg/min) to 3% consistency	
22.	Sorption of sodium, magnesium and calcium onto the pulp (at high pH's) was simulated, using literature values.	[54]
23.	Flash cyclones (for WBL): • First flash (C50) vapour = 80 kg/min (constant) • Second flash (C51) vapour = 4.3% of incoming liquor	
24. 25.	WBL cooler: • WBL feed = 5114 kg/min • Cooling water usage = 3700 kg/min (constant) BSW filtrate added to WBL = 2637.5 kg/min (equal to half of the volume of BSW filtrate used for washing on the digester)	
27.	A portion of the WBL stream (120 kg/min) was assumed lost to the no.2 digester effluent stream.	The 'lost' WBL was used to simulate overflows, plant upsets, tank washing etc.

Table 55: No.2 Fibre Line Assumptions and Mass Balance Control Logic - continued

#	Assumption	Comment or Reference
28.	Turpentine recovery assumptions: • Turpentine recovered (No.1 and 2 digesters) = 1.4 kg/min (2 ton/day) at 0.2% moisture content • Turpentine decanter underflow/condensate = 378 kg/min • LVHC gas from turpentine decanter = 1.7 kg/min with 49% TRS content • Cooling water used by turpentine condensers T20 and T21 = 1000 kg/min (500 kg/min per condensor) • Warm water used in turpentine condenser T11 = 958 kg/min	

Table 56: WBL and no.2 digester effluent streams used for calibrating the WinGEMS model.

	Units	No.2 digester WBL	No.2 digester effluent	Hot water effluent
Flow	ton/d	10 989	490	120
Sodium	mg/l	23 254	2 811	4
Chloride	mg/l	1 353	157	2
Sulphate	mg/l	2 957	504	8
Calcium	mg/l	8	9	13
Magnesium	mg/l	7	7	5
COD	mg/l	-	3 398	15
Dissolved wood solids	mg/l	94 232	-	-
TSS	mg/l	77	1 817	0.6

8.4.4 Bleach plant

The bleach plant operates on a O-D/C-E-D bleaching sequence, and receives its pulp from the no.2 fibre line high density pulp storage chest. The pulp passes through a wash press, used for pulp washing and consistency control, prior to the oxygen delignification stage. The pulp subsequently passes through a three-stage diffusion washer prior to entering the D/C-E-D bleaching stages.

Wash water passes through the bleach plant in a counter-current fashion. The D/C-E-D bleaching stages use backwater from the no.3 uptake buffer chest. Approximately 40% of this wash water is dumped after the E-stage washing and replaced with an equivalent amount of hot water. The D/C stage effluent is dumped to effluent. The three-stage diffusion washer uses both back water from the no.3 uptake surge chest and contaminated condensate (in a 1:3 ratio) for washing. The filtrate is used for consistency control on the pulp exiting the oxygen bleaching stage, and as wash water on the wash press. The wash press filtrate is again used for consistency control, and as wash water on the brown stock washer.

The ozone (Z) bleaching stage, between the three-stage diffusion washer and the D/C stage, can be used to replace the elemental chlorine used for bleaching on the D/C stage. The Z-stage is however not used for the current (status quo) simulation, and is only included for future reference.

The assumptions that are made in the bleach plant are listed in Table 57. The assumptions are listed in such a way as to explain or point out also the control logic followed in building the mass balance simulation. The composition and flow rates of the D/C, E-stage and bleach plant floor drain used to calibrate the bleach plant model are given in Table 58.

Table 57: Bleach Plant Assumptions and Mass Balance Control Logic

#	Assumption	Comment or Reference
1.	A level 3 balance is used to simulate the bleach plant. All major process units and relevant intermediary streams are shown in detail	A level 3 balance is required due to the significant impact of the bleach effluents on the overall effluent quality and quantity.
2.	The model was calibrated according to the yearly average values for the following streams: • Production of 482.7 ADt/day of fully bleached pulp • E-stage effluent quality and quantity as described in Table 58 • D/C-stage effluent quality and quantity as described in Table 58 • Bleach plant floor drain quality and quantity as described in Table 58	For lab analyses of the bleach plant effluent streams, refer to Table 58
3.	Pulp enters the bleach plant at 332 BDkg/min and 5.5% consistency, and is diluted in the blend chest (033) with wash press filtrate to 5% consistency.	
4.	The pulp is washed in the wash press with three stage diffusion washer filtrate at a dilution factor (DF) = 5.6; the pulp exits at 28% consistency. Backwater from no.3 uptake surge chest is used as make up to the wash press filtrate tank at 376.7 lpm (0.54 Ml/d).	The model has a higher DF than the actual plant value (DF=2) in order to satisfy the water balance on no.2 fibre line, where the wash press filtrate is used as wash water on the brown stock washer.
5.	Oxidised White Liquor charge = 50 kg/ton BD pulp (mixed with pulp prior to oxygen reactor); it is assumed that the amount of fresh water used in the OWL cooler is twice the OWL flow rate.	
6.	The $MgSO_4$ is dissolved to approximately 200 g/l and is charged to the pulp at 6.5 kg/ton BD pulp, prior to the oxygen reactor.	
7.	HP steam charged at 380 kg/ton BD pulp, prior to oxygen reactor.	
8.	Assumptions for the oxygen bleaching stage: • Yield loss = 6% • Pulp outlet consistency = 11%	

Table 57: Bleach Plant Assumptions and Mass Balance Control Logic

#	Assumption	Comment or Reference
9.	The three stage diffusion washer has an overall DF = 3.2, and uses the following wash water: • 852.1 lpm backwater from no.3 uptake surge chest • 2556.4 lpm contaminated condensate The following streams are used as make up for the three stage diffusion washer filtrate tank (W24): • 170.4 lpm backwater from no.3 uptake surge chest • 619.6 lpm contaminated condensate	The high DF used in the model (opposed to the plant DF = 2.5), as well as the make up streams to the filtrate tank, are necessary to satisfy the water balance of no.2 fibre line.
10.	Pulp exits the three stage diffusion washer at 11.5% consistency.	
11.	A constant seal water ingress of 10 lpm is assumed, and is added to the pulp stream exiting the three stage washer.	
12.	H_2SO_4 enters at 98%, gets diluted to 10%, and is charged to the washed pulp tank at 8kg H_2SO_4/ton BD pulp.	For ozone bleaching only – not used in current simulation.
13.	Fresh water to ozone cooling tower = 400 kg/min	For ozone bleaching only – not used in current simulation.
14.	TWP outlet consistency = 80%	For ozone bleaching only – not used in current simulation.
15.	D/C-stage assumptions: • Cl_2 charge = 8.7 kg/min (23.5 kg/ton AD pulp) • ClO_2 strength = 8.5 g/l • ClO_2 charge = 929.7 kg/min (22.5 kg/ton AD pulp) • DF = 4.7 • Pulp outlet consistency = 10% • Yield loss = 1%	The high DF (compared to the plant DF = 1.2) is necessary to achieve the required D/C effluent flow (yearly average value). The plant values for Cl_2 and ClO_2 were increased in order to reach the required chloride levels in the bleach effluents.
16.	Caustic charge prior to E-stage = 27.03 kg/ton BD pulp	NaOH enters at 40% strength and is diluted to 5% before being charged; used for pH control.
17.	E-stage assumptions: • DF = 4.7 • Pulp outlet consistency = 10% • Yield loss = 1%	The high DF (compared to the plant DF = 1.4) is necessary to achieve the required E-stage effluent flow (yearly average).
18.	Hot water make up to E-stage filtrate tank = 1610 lpm	
19.	Chemicals used for pH control prior to D2-stage: • Caustic = 0.9 kg/min (0.1365kg/ton BD pulp) • HCl = 0 kg/min	Caustic strength = 5% HCl strength = 5%

Table 57: Bleach Plant Assumptions and Mass Balance Control Logic

#	Assumption	Comment or Reference
20.	D2-stage assumptions: • ClO_2 strength = 8.5 g/l • ClO_2 charge = 372.6 kg/min (9 kg/ton AD pulp) • DF = 3.6 • Pulp outlet consistency = 10% • Yield loss = 1%	The high DF (compared to the plant DF = 1.2) is necessary to achieve the required D/C and E-stage effluent flows. The plant values for ClO_2 charge were increased in order to reach the required chloride levels in the bleach effluents.
21.	Fully bleached pulp is stored in storage tank D36, where it is diluted with no.3 uptake buffer chest back water to 3.4% consistency.	
22.	A portion of the three stage diffusion washer filtrate (3.5% of the total flow = 151 lpm) is split to the bleach plant floor drain.	To compensate for spillages, tanks that overflow, etc.
23.	A portion of the ClO2 charge to the D/C-stage (0.2% of the total flow = 2 lpm) is split to the bleach plant floor drain.	To compensate for spillages, tanks that overflow, etc.
24.	A portion of the D/C-stage effluent (0.57% of the total flow = 28 lpm) is split to the bleach plant floor drain.	To compensate for spillages, tanks that overflow, etc.
25.	A portion of the E-stage effluent (0.5% of the total flow = 9 lpm) is split to the bleach plant floor drain.	To compensate for spillage, tanks that overflow, etc.
26.	Vent losses per bleaching stage = 10 kg/min (average) for the D/C, E and D2 bleaching stages; Chloride loss per bleaching stage = 0.01 kg/min (average).	
27.	The vent gases are scrubbed with 129 lpm fresh water and 0.9 lpm caustic (at 5% strength); 100% contaminant removal is assumed, and the scrubber effluent is added to the bleach plant floor drain.	The amount of fresh water used on the scrubber was calibrated to give the required bleach plant floor drain flow rate.
28.	Sorption and desorption of sodium, magnesium and calcium onto the pulp (at high and low pH's respectively) was simulated. Literature values were used where available, else sorption values were calibrated to yield the desired effluent qualities.	

Table 58: Bleach effluent specifications.

	Units	D/C effluent	E-stage effluent	Bleach plant floor drain
Flow	Ml/d	6.89	2.56	0.485
Sodium	mg/l	863.3	1145.9	409.2
Chloride	mg/l	2237.2	1425.7	436.8
Sulphate	mg/l	77.8	42.3	337.6
Calcium	mg/l	82.2	51.7	16.7
Magnesium	mg/l	92.1	65.8	17.0
COD	mg/l	1430.6	1174.0	1107.2
TSS	mg/l	116.2	162.4	1115.3

The following procedure was used to determine the amount of chlorine gas and chlorine dioxide charged to the bleach plant for the WinGEMS mass balance.

<u>Cl_2 into bleach plant:</u>
Charge aim = 22 kg Cl_2/ADton at a production of 584 ADton/day
= 12.8 ton Cl_2/day
The amount of chlorine gas into the bleach plant in the WinGEMS model is 12.6 ton/day, and was changed slightly from the calculated value to reach the desired chloride concentrations in the bleach effluents.

<u>ClO_2 into bleach plant</u>
Charge aim = 18.5 kg ClO_2/ADton at a production of 584 ADton/day
= 10.8 ton ClO_2/day
MM(Cl^-) = 35.5 g/mol; MM(ClO_2) = 67.5 g/mol
Chloride equivalent = 10.8*(35.5/67.5)/0.71
= 8 ton Cl/day

The WinGEMS model is calibrated to give a chloride input of 8 ton/day into the bleach plant with the ClO_2 stream. The ClO_2 is split approximately in a 70:30 ratio between the D/C and D2 bleaching stages respectively. The chemical charges on the bleach plant are depicted Table 59.

Table 59: Bleach Plant Charges [PE]

Point of addition	ClO_2 (%) (kg ClO_2 / ton BD pulp)	Cl_2 (%) (kg Cl_2 / ton BD pulp)
D/C stage	1.35 13.5	2.2 – 2.4 22
D stage	0.8 – 0.9 8	-- --

8.4.5 Chlorine Dioxide plant (ClO_2 plant)

The chlorine dioxide plant has two very distinct sets of operating conditions. Chilled water is used on the separator at approx. 0.5 ml/d during running conditions. As soon as the plant is stopped the product must be dumped to prevent dilution for approx. 4 hours at 1.35 ML/D [PE = De Wet Brandt], or until no more gases are picked up in the ClO2 generator before the chilled water can be stopped

Table 60: Chlorine Dioxide Plant Assumptions and Mass Balance Control Logic

#	Assumption	Comment or Reference
1.	Fresh water to ClO2 plant = 1578 kg/min (calibrated to give measured yearly average effluent flow)	
2.	HCl production = 0 kg/min	
3.	Cl2 consumption = 6.2 kg/min (calibrated to give 1 tpd Cl loss in effluent)	
4.	SWL to scrubber = 12 kg/min (calibrated to give 4g/l Na in effluent)	

Table 61: ClO_2 effluent flume Quality to which model is calibrated to [T Leske]

	Flow		Cl	Na	SO4	COD	TSS	TDS	Mg	Ca
	Ml/d	kg/min	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
ClO2	0.412	286.1	4017	4000	160	10	5	15000	5	13
	0.412	285.8	2429	3917	160	26	2		6	14

No accurate quantity of chlorine dosed to the chlorine dioxide plant is available. Thus enough chlorine is fed into the chlorine dioxide plant so that the outputs (which are more accurately measured than the input) are satisfied in terms of the required chloride concentration.

The chloride loss via the scrubber is calculated assuming a chloride concentration of 30 ppm [PE = De Wet Brandt]. The chloride load from the chlorine dioxide plant to the bleach plant is based on a charge of 18.5 kgClO_2/ADt at a rate of 584 ADt/d. Because the mass balance is calibrated with information taking into account instantaneous and average conditions, i.e. average production rates and instantaneous flow, the charges are not exactly the same as used by the plant. Thus the chloride input, in mass per time unit, is used. Using 18.5 kgClO_2/ADt at a rate of 584 ADt/d, means that 8 000 (7 993) kg Cl^- per day [Shift Foreman = M Meiring] must enter the bleach plant as ClO_2 coming from the ClO_2 plant.

Table 62: ClO_2 samples taken by laboratory

Date	Chlorides mg/l	Cond uS/cm	Flow ML/d	Load mg/d
02.12.99	703	3810	0.52	365560000
03.12.99	887	3530	0.52	461240000
06.12.99	1000	18200	0.55	550000000
07.12.99	474	3370	0.61	289140000
08.12.99	749	3810	1	749000000
09.12.99	2426	10580	0.86	2086360000
10.12.99	186	1350	0.53	98580000
14.12.99	3318	12240	0.51	1692180000
15.12.99	1367	3200	0.51	697170000
17.12.99	906	4910	0.53	480180000
20.12.99	492	3340	0.6	295200000
21.12.99	271	1301	0.55	149050000
04.01.2000	186	945	0.62	115320000
05.01.2000	1094	7320	0.67	732980000
06.01.2000	295	359	0.55	162250000
07.01.2000	908	425	0.56	508480000
10.01.2000	629	4760	0.52	327080000
11.01.2000	807	5760	0.51	411570000
12.01.2000	720	5530	0.51	367200000
13.01.2000	2253	1381	0.48	1081440000
14.01.2000	657	256	0.46	302220000
SUM =			**12.17**	**11922200000**
Concentration	979.6	**mg/L**		

Table 63: ClO_2 samples taken for mass balance purposes

DATE	Cl (mg/l)
21-Jun	8881
22-Jun	19258
23-Jun	11.7
24-Jun	50784
25-Jun	23.9
30-Jun	2142
1-Jul	15.7
2-Jul	838.7
Average	**10244.38**

8.4.6 Causticizing and Lime kiln section

In the causticizing section green liquor reacts with lime to form strong white liquor. The converted lime, slaked lime, is washed with foul condensates, from the CFC tank, which is then clarified in the lime mud washer (clarifier). The clarifier separates the slaked lime slurry into weak white liquor and lime mud. The weak white liquor is used for total alkali control and density control at the chemical recovery furnaces on the smelt. The lime mud is fed into the lime kiln and re-generated into lime. The strong white liquor is used as cooking chemical at the digesters and any excess strong white liquor is stored. The causticizing section is done to a level three balance.

It is necessary to do the causticizing section to a level three detail, in order to simulate the property changes that could result from implementing the different effluent reduction projects. Also of high importance is the quality change in the lime mud being fed into the kiln. The assumptions made in programming the causticizing section are listed in Table 64.

Table 64: Causticizing Assumptions and Mass Balance Control Logic

#	Assumptions	Comment or Reference
1.	The user defines the TA to which the green liquor must be controlled. The chemical recovery furnaces burn all SBL (i.e. no WBL storage, thus all WBL generated by digesters, of which the user specified the production rates and to which a specific WBL generation rate is linked are burned). The smelt flow rate from the furnaces thus is in fact determined by the production rates the user specify at the digesters.	Actual plant control logic to control the green liquor's TA.
2.	Adding weak white liquor controls the green liquor TA. More weak white liquor to the smelt dissolving tanks result in lower green liquor TA.	
3.	To maintain the hydraulic balance in the causticizing section, CFC condensates are used as make-up/wash water into the lime mud-mixing tank, which feeds into the lime mud washer (clarifier).	
4.	Should there not be enough CFC condensates, then CCA condensate makes up the additional condensate.	Actual plant control logic.
5.	2.9 ML/d of fresh water is made up into the CCA tank. This is only practiced under abnormal conditions at much higher rates, the yearly average though is assumed to be 2.9 ML/d.	W Henning estimated that fresh water is made up about 30% of time on yearly average. Thus from an actual measured CFC flow of about 4 ML/d [G Nxasana – dopler], 30% = 1.2 ML/d.

Table 64: Causticizing Assumptions and Mass Balance Control Logic

#	Assumptions	Comment or Reference
6.	Although the green liquor properties are the result of many other factors, in calibrating these many other factors it was assumed that green liquor from SDT #1 had the following properties: • Flow = 1 102 Lpm • SS = 1 743 mg/L • Inerts = 30.6% of solids • $CaCO_3$ = 59.2% of solids • CaO = 10.2% of solids • Chloride = 4 791 mg/L • Sodium = 88 780 mg/L • Sulphate = 7 476 mg/L • Magnesium = 23.6 mg/L • HS^- = 15 773 mg/L • OH^- = 14 649 mg/L • CO_3^{2-} = 64 511 mg/L • COD = 2 073 mg/L • Ca = 41.3 mg/L • AA = 45.9 g/L as Na_2O • EA = 29.5 g/L as Na_2O • Sulphidity = 71.3% • TTA = 119.6 g/L as Na_2O	Table 66page 194 Table 75page 199.
7.	Although the green liquor properties are the result of many other factors, in calibrating these many other factors it was assumed that green liquor from SDT #2 had the following properties: • Flow = 2 475 Lpm • SS = 1 705 mg/L • Inerts = 30.0% of solids • $CaCO_3$ = 59.9% of solids • CaO = 10.0% of solids • Chloride = 4 783 mg/L • Sodium = 88 569 mg/L • Sulphate = 7 714 mg/L • Magnesium = 22.8 mg/L • HS^- = 16 140 mg/L • OH^- = 15 488 mg/L • CO_3^{2-} = 62 710 mg/L • COD = 1 830 mg/L • Ca = 40.1 mg/L • AA = 47.9 g/L as Na_2O • EA = 31.2 g/L as Na_2O • Sulphidity = 69.8% • TTA = 119.6 g/L as Na_2O	Table 66page 194. Table 74page 199.

Table 64: Causticizing Assumptions and Mass Balance Control Logic

#	Assumptions	Comment or Reference
8.	A constant caustic make-up of 2 Lpm at 48% pure NaOH is added to the strong white liquor clarifier.	
9.	Green liquor clarifier is operated at 2% consistency in the underflow.	
10.	Green liquor clarifier overflow suspended solid content is 100 ppm.	
11.	The slaker is operated at the following conditions: • Lime charge = 0.85* • $CaSO_4$ being dissolved = 100% • Pressure in slaker and causticizer = 101.325 kPa • Volume of slaker = 48 + 139 = 187 m^3 • Volume of two causticizers = 139*2 = 278 m^3 • White liquor causticity = 81.1% • Rate constant for slaking 0.18 ^{1}/min. • Rate constant for causticizing = 1.9 L/min mol.	• *units of charge are (mole CaO + $Ca(OH)_2$ of lime)/(mole CO_3 in green liquor) • the first causticizers is seen as continuation of the slaker. • The slaker and its reactions are handled by a pre-programmed Wingems block [55]. • Table 75page 199.
12.	0.00436 kg dregs is generated for every liter of green liquor going into the green liquor clarifier. The dregs is at a consistency of 47%. 22.5 t/d of dregs are generated and is trucked down to the effluent treatment plant for pH control in the general effluent.	
13.	Calibrating the model it was assumed that the dregs has the following properties: • Inerts = 25.3% of solids • $CaCO_3$ = 65.2% of solids • CaO = 8% of solids • Chloride = 4 315 mg/L • Sodium = 79 914 mg/L • Sulphate = 6 943 mg/L • TTA = 106.8 g/L as Na_2O	
14.	Strong white liquor clarifier underflow consistency is 34.5%	Table 69 page 195.
15.	Strong white liquor clarifier overflow solids is 100 ppm.	
16.	The ECO filter is 75% efficient in removing solids from the strong white liquor.	
17.	The user specifies how much strong white liquor must be produced, and then model then makes-up enough saltcake to achieve the required strong white liquor quantity. Any excess strong white liquor that is not used by the digesters is indicated as an excess stream that leaves the mill (i.e. storage).	

Table 64: Causticizing Assumptions and Mass Balance Control Logic

#	Assumptions	Comment or Reference
18.	In calibrating the model to give just enough strong white liquor to satisfy the digesters' requirements, it was assumed that 56.4 t/d of saltcake are required. The saltcake composition is: • 62.3% Na_2SO_4 • 34.1% Na_2CO_3 • 3.6% Chloride.	Table 65
19.	2% of the lime exiting the kiln are assumed to be lost the environment = 7.5 t/d.	
20.	70 t/d of lime mud is reclaimed from the lime dump using weak white liquor for dilution. The lime on the lime dump is assumed to have the following composition; • Flow = 101 t/d • Consistency = 95% • Inerts = 9% of solids • $CaCO_3$ = 80% of solids • CaO = 1% of solids • CaOH = 10% of solids	
21.	52.4 t/d lime is sold.	Table 73 page 197.
22.	The calcium and magnesium in the strong white liquor feeding into the SWL clarifier and the WWL feeding into lime mud washer is precipitated to have a concentration of : • Calcium = 12 mg/L in SWL and WWL • Magnesium = 0.24 mg/L in SWL and WWL.	
23.	The lime mud washer (WWL clarifier) has an underflow consistency of 35%.	Table 69page 195.
24.	The lime mud washer overflow suspended solid content is 200 ppm.	
25.	0.25 kg CCA is used for washing each kg of mud onto the lime mud filers = 325 Lpm to wash 1 300 Lpm mud.	
26.	The lime mud filters are assumed to work at the following conditions [55]: • Displacement ratio = 0.536 • Outlet pulp consistency = 72% • Dilution factor = 0.325	The washing efficiency of the lime mud washer was determined/set to achieve sodium level of 0.433% Na_2O on BD solids into lime kiln. Table 75 page 199.

Table 64: Causticizing Assumptions and Mass Balance Control Logic

#	Assumptions	Comment or Reference
27.	Lime kiln operating conditions are [55]: • Production rate of lime = 373 t/d • Consistency of lime = 97.6% • CaO = 82.7% of solids • $CaCO_3$ = 0% of solids • $CaSO_4$ = 5.7% of solids • Excess air = 10% • Exit lime temperature = 600°C • Exit gas temperature = 260°C • Heat loss = 12% • Total $CaCO_3$ not converted to CaO = 0% • Availability of lime = 87% • Total CaO, $Ca(OH)_2$ and $CaCO_3$ converted to $CaSO_4$ if S available = 5% • Incoming SS solids in dust leaving kiln 11.5% by weight • Incoming Na vaporized = 0% by weight.	Table 72 page 197. Table 75 page 199.
28.	Although the lime in the lime kiln quality is determined by many factors, these factors were calibrated by assuming the following lime quality from the lime kiln: • Sodium = 0.433% Na_2O	Table 65
29.	Although the strong white liquor properties is a result of many factors, it was assumed that the strong white liquor had the following properties when calibrating these many factors: • Flow = 2 682 Lpm • SS = 25 mg/L • Inerts = 6.4% of solids • $CaCO_3$ = 87.4% of solids • CaO = 0.04% of solids • $Ca(OH)_2$ = 5.9% of solids • Chloride = 5 149 mg/L • Sodium = 95 526 mg/L • Sulphate = 10 772 mg/L • Magnesium = 0.24 mg/L • HS^- = 17 177 mg/L • OH^- = 45 701 mg/L • CO_3^{2-} = 15 024 mg/L • COD = 2 112 mg/L • Ca = 12 mg/L • AA = 109.7 g/L as Na_2O • EA = 91.9 g/L as Na_2O • Sulphidity = 32.4% • TTA = 126.8 g/L as Na_2O	Table 66 page 194. Table 70 page 196. Table 75 page 199.

Table 64: Causticizing Assumptions and Mass Balance Control Logic

#	Assumptions	Comment or Reference
30.	Although the WWL quality is the result of many factors, the following WWL qualities were assumed in calibrating these many factors: • Flow to SDT #1 = 850 Lpm • Flow to SDT #2 = 2 262 Lpm • SS = 200 mg/L • AA = 19.2 g/L as Na_2O • EA = 16.0 g/L as Na_2O • TTA = 22.3 g/L as Na_2O • Sulphidity = 33.3%	Table 71 page 196. Table 75 page 199.
31.	Information regarding flow around the scrubber are very vague since flow and control around this system is poor	Table 67 page 195. Table 74 page 198.

From the logic of Table 64 it can be summarised that the user specifies the excess strong white liquor flow (in excess to the digesters' requirements), and the model then automatically make-ups with saltcake to achieve the desired strong white liquor flow. The excess of strong white liquor leaves the mill as a product (storage). The user also specifies the required green liquor TA, and the model then controls the WWL liquor flow to achieve this green liquor TA. Make up into this section are via the CFC tank and CCA tank. The CCA tank also receives fresh water as make-up.

Chemistry and Definitions

Wingems uses the following definitions in the causticising section active alkali (AA), effective alkali (EA) and total titratable alkali (TTA). All three are calcualted in gram per liter as NaOH but are reported as Na_2O:

AA = NaOH + Na_2S = f(EA, HS^-)...........................equation 1

EA = NaOH +0.5 Na_2S = f(OH^-).............................equation 2

TTA = NaOH + Na_2S + Na_2CO_3 = f(AA, CO_3^{2-})..........equation 3

A definition used in practice but which is not used by Wingems is the total chemical or total alkali (TA):
TA = NaOH + Na_2S + Na_2CO_3 + Na_2SO_4 + $NaSO_3$ + $Na_2S_2O_3$......eq 4

The definition used for sulphidity is:

$$sulphidity = 2\frac{AA - EA}{AA} = f(OH^-, HS^-) \text{..................equation 5}$$

Make-up Chemicals

Sulphur is used as a make-up chemical to control the sulphidity in cooking chemicals.

Table 65: Chloride Concentrations of stream in Causticizing

Date	Sample	Chlorides
		% as Cl
18/11/99	Lime ex kiln	15.1
18/11/99	Lime mud	3.9
99/09/11	Salt cake ex day silo	1.8
27/10/99	Salt cake ex day silo	1.2
25/11/99	Salt cake ex day silo	1.8
	Average	**1.6**
26/11/99	Salt cake ex Tugela	2
26/11/99	Salt cake ex Tugela **Average**	1.9 **1.95**
15/11/99	Delta sodium sulphate solution	1

Green and White Liquor Properties

Typical compositions of the dissolved components in green and white liquor are given Table 66.

Table 66: Green and White liquor properties

Dissolved solid	Green Liquor (g/kg liquor)		White Liquor (g/kg liqour)	
	Wingems[1]	58	Wingems[1]	58
Ca		$< 4*10^{-5}$		$< 4*10^{-5}$
Mg		$< 2.4*10^{-7}$		$< 2.4*10^{-6}$
Mn		$5.5*10^{-4}$		--
OH^-	13.7	4.25	42.5	39.1
HS^-	13.0	23.1	13.4	23.1
CO_3^{2-}	54.7	72	8.7	10.8
SO_4^{2-}	4.8	4.8	6.0	4.8
Na^+ Cl^-	73.0	80.5	77.7 (96.6)[2] (4.08)[3] 2.45	80.5
TTA (as Na_2O)	100.8		106	
EA (as Na_2O)	27.0		83	
AA (as Na_2O)				
Sulphidity	0.653		0.28	

1. Wingems example of a total mill balance, example "fullmill.wg"
2. Calculated from laboratory TA, AA, EA
3. Calculated from laboratory TA, AA, EA and Na:Cl ratio as reported in technical report

Lime Kiln Scrubber

Due to the difficult nature of measurements around the lime kiln scrubber configuration (i.e. gaseous measurements at stack, gaseous measurements before scrubber and the influence of combustion reaction products) there is a wide range within which data are thought, by different parties, to vary.

Table 67: Operation parameters around the Lime Kiln scrubber

Parameter	Value
Liquor loss out with stack from scrubbing medium (kg/min)	75.7[1]
Liquor loss out with stack due to combustion and mud drying (kg/min)	625[1]
Total liquor loss out of stack (kg/min)	262[3]
Bleed from slurry tank circulation to maintain consistency (kg/min)	419[2]
Make-up flow rate into slurry tank (kg/min)	104[2] 612[3]

1. S Howlet (process engineer) in agreement with Turbosonic audit
2. Measured by G Nxasana 1999
3. [56]

Table 68: Densities of streams in Causticizing section [G Nxasana analyse 1999]

Sample #	Description	Temp. (C)	pH	Density (kg/l)
1	Green liquor from CRF going into G.L.clarifier	92	11.93	1.150
2	G.L. from G.L clarifier going into the slaker	85	13	1.134
3	G.L from the slaker	93	11.67	1.114
4	Strong white liquor going to standpipe	93	11.62	1.102
5	SWL from SWL clarifier	86	11.72	1.130[1]
6	SWL from polisher	88	11.67	1.117
7	SWL to digesters(to #2 Dig. only, #1 Dig. was offline)	38	12.95	1.053
8	Weak white liquor going to smelt dissolving tank	56	12.53	1.003
9	Liquor from lime mud mix tank to lime mud washer	55	12.54	1.016

1. Reference 11 quotes a typical value of 1.164 g/L

Table 69: Strong White Liquor- and Mud washer Clarifier Underflow Consistency

Analyses requested by (when)	Strong White liquor Clarifier underflow consistency (%)	Mud washer Clarifier underflow consistency (%)
G Buisson-Street (93)	47	59
E Slabbert (16/09/99)	55	70
E Slabbert (20/09/99)	56.3	54.1
E Slabbert (06/09/99)	53.4	45.7
E Slabbert (20/10/99)	47	59
Reference 8	40	45
A Knobel (1999)	--	38
Average	**49.8**	**53.0**

Table 70: Strong white liquor Chloride concentration [laboratory analyses]

Year 1999	Strong white liquor	
	g/L NaCl	mg/L Cl
01-Nov	6.8	4125
02-Nov	8.8	5338
03-Nov	8	4853
04-Nov	7.8	4732
05-Nov	6.6	4004
08-Nov	9.1	5520
10-Nov	7.6	4610
11-Nov	7.9	4792
15-Nov	8	4853
16-Nov	7.9	4792
17-Nov	9.5	5763
18-Nov	8.8	5338
19-Nov	7.8	4732
22-Nov	8.2	4974
23-Nov	9.7	5884
24-Nov	9.3	5642
26-Nov	8.4	5096
Average	**8.2**	**5003.0**

Table 71: Weak white liquor properties

	Analyses #1 20/01/93	**Analyses #2 19/01/93**
TA (g/L as Na_2O)	18.9	21.5
AA (g/L as Na_2O)	16.7	18.3
EA (g/L as Na_2O)	14.0	15.0
Sulphidity (%)	33.4	35.5
Suspended solids (mg/L)	62 (H_2O) 12 (HCl)	326 (?)
Reduction (%)	68	67

Table 72: Lime production [causticizing process engineer]

Year 1999	ton/month	ton/day	kg/min
Jan	7940	256.1	177.9
Feb	8267	295.3	205.0
Mar	9729	313.8	217.9
Apr	8561	285.4	198.2
May	7349	237.1	164.6
Jun	10463	348.8	242.2
Jul	7837	252.8	175.6
Aug	7772	250.7	174.1
Sep	8940	298.0	206.9
Oct	8304	267.9	186.0
Average	**8516.2**	**280.6**	**194.8**

Table 73: Lime Sales [causticising process engineer]

Year 1999	ton/month	ton/day	kg/min
Jan			
Feb			
Mar	239.2	7.7	5.4
Apr	937.5	31.2	21.7
May	473.6	15.3	10.6
Jun	703.0	23.4	16.3
Jul	1265.6	40.8	28.4
Aug	895.1	28.9	20.1
Sep	333.4	11.1	7.7
Oct	1553.6	50.1	34.8
Average	**640.1**	**26.1**	**18.1**

Table 74: Lime Kiln scrubber system Conditions

	R&D[1]	Turbo sonic	N Fosteras [13]	F Grobler[3]	G Nxasana[2]
Gas flow into scrubber • **Flow rate (m^3/s, NTPD)** • **Moisture/Liquor content (g/m^3, NTPD)** • **Particulate content**				22.4 64.3	
Gas flow out of scrubber • **Flow rate (m^3/s, NTPD)** • **Moisture/Liquor content** • **Particulate content (mg/Nm^3)**	40.5 168			19.1	
Make-up rate into scrubber slurry tank (kg/min)			712		104
Bleed-off rate from scrubber system			422		419
Consistency to which scrubber liquor is controlled			Recommends 10%		
• **Liquor formed from reactions and mud drying (kg/min)** • **Liquor evaporated from scrubbing medium (kg/min)** • **Total liquor from stack (kg/min)**	694 666[4]	75.7	290	240	
Recycling flow rate (kg/min)	3 400		4 000 design = 5 930		
Scrubber efficiency in removing particulate matter					

1. Sappi Research and Development mass balance done by A Knobel on the causticizing section
2. Measurement done by G Nxasana, close bleed and calculate volume change of tank, close WWL make-up and calculate volume change.
3. Measurements done F Grobler (process engineer) 1999/11/11.
4. Measurements done by H Coppens, Sappi R&D

Table 75: Properties of streams in Causticizing Section [process engineer F Grobler]

Stream	Property	Units	Reference 1[1]	
Green liquor ex recovery furnace	TA	g/L as Na_2O	124.6	
	AA	g/L as Na_2O	45.3	
	Sulphidity (TA)	%	25.2	
Green liquor ex green liquor clarifier	TA	g/L as Na_2O	127.6	
	Suspended solids	mg/L	120	
Slaker	TA	g/L as Na_2O	131.8	
	AA	g/L as Na_2O	105.4	
	EA	g/L as Na_2O	88.4	
	Na_2CO_3		27.3	
	CE	%	72.4	
SWL @ standpipe	TA	g/L as Na_2O	133.2	
	AA	g/L as Na_2O	115.3	
	EA	g/L as Na_2O	98.2	
	Na_2CO_3		17.1	
	CE	%	83.0	
SWL ex clarifier	TA	g/L as Na_2O	131.4	
	EA	g/L as Na_2O	97	
	CE	%	81.7	
	Suspended solids	mg/L	84	
SWL ex polisher	Suspended solids	mg/L	22	
SWL ex storage to fibre lines	TA	g/L as Na_2O	126.5	
	AA	g/L as Na_2O	108.7	
	EA	g/L as Na_2O	93.6	
	Na_2CO_3		17.5	
	CE	%	81.7	
	Sulphidity (AA)	%	28.2	
WWL ex mud washer	TA	g/L as Na_2O	21.7	
	Suspended solids	mg/L	200	
Mud mix slurry tank	TA		21.7	
Mud entering kiln	Na	% Na_2O on BD solids g Na per kg liquor	0.413 7.7	
	Solids	%	71.7	
Lime ex kiln	CaO	%	86.6	
	$CaCO_3$	%	0.4	
Dregs ex filter	Na	% Na_2O on BD solids	6.05	

1. Process engineer of causticizing – F Grobler 1999

Other relationships and Information used in Mass Balance

- Chemical elements maybe grouped into two classes. One class, including Ca, Mg, P and Mn, may be almost completely removed from the liquor system by green and white liquor clarification, i.e. dregs, lime mud and grits. The other class, including K, Cl, Al and (with some reservations) Si, is not so removed and will tend to build-up in the liquor system with increased closure [57].
- A typical value given for purged lime mud from a well operated lime circuit, in order to purge inert material, is 7.5 – 10 kg lime mud per metric ton of pulp [58].

- The washing efficiency on a mud pre-coat filter is about 65% [11], this means that at a single wash displacement, the amount of soda remaining after washing is 35% of the amount in the mud prior to washing.
- Typical dregs and grits generation rates are given as 7.72 kg/min @ 80% consistency and 5.12 kg/min @ 60% consistency respectively at a green liquor feed to green liquor clarifier of 2 763 Lpm [59]. Thus the following generation rates apply:
  - Dregs = 2.794 grams dregs per liter green liquor feed
  - Grits = 1.853 grams grits per liter green liquor feed
- The total weak white liquor flow from the lime mud washer was measured as 3 211 lpm (3 909) (average of 3 448, 3078 and 3108 measured with Dopler) [G Nxasana]. Of this approximately 1 435 lpm (2 320) goes to the #2 smelt dissolving tank [dopler measurement by G Nxasana].
- Flow from the foul condensate tank to the lime mud mixer was measured at 2 800 lpm (2 617) [dopler measurement by G Nxasana, 21/9/99].
- The lime mud pre-coat filters use wash water at a flow rate of 146*2 = 292 (335) lpm [56].

8.4.7 Gas producers

In the gas producers (two reactors) coal is burnt to generate hydro-carbon gas which is used as fuel in the lime kiln. Air is used as oxidising agent. Steam is generated when cooling off the combustion reaction, and the steam is also used to control the temperature of the gas to the lime kiln. Steam from the utilities is used on various miscellaneous uses like line tracing etc. Coarse ash, tar and phenolic water are by-products from the gas producers. The phenolic water is dumped in the lime mud washer, the tar is sold and the coarse ash is used for road maintenance and building applications. The gas producer section is done to between a level two and three detail. The effluent reduction projects will have a low impact on the inputs into the gas producers and also on the outputs from the gas producers. To only significant impact of the gas producers relate to the quality and quantity of fuel (or gas producers gas) feeding into the lime kiln.

Table 76: Gas Producer Assumptions and Mass Balance Control Logic

#	Assumption	Comment or Reference
1.	0.869344 kg coal is fed for every kg of CaO produced in lime kiln 262 t/d.	• Table 77 page 203, states an average of 171 t/d for 1999. • Design documentation 0.364 kg coal per kg CaO produced [design documentation].
2.	8.5 kg air is fed for every kg of coal fed 2 224 t/d.	
3.	The air compose of 21% oxygen and 79% nitrogen.	

Table 76: Gas Producer Assumptions and Mass Balance Control Logic (continue)

#	Assumption	Comment or Reference
4.	0.0287288 kg tar is produced for every kg coal fed = 5.1 Lpm. The tar composition is assumed to be: • SS = 1 008 mg/L • Inerts = 100% of solids • Other components are taken as the same as the air stream from which the tar stream is split (i.e. gaseous components like nitrogen and oxygen etc.)	• Because the tar stream is split from a gaseous stream with typical components like nitrogen and oxygen, and because the level of detail for this section's mass balance is low, the composition of the tar stream is not well defined. • At an average tar sold rate of 3.39 kg/min [production declaration PE for Jan '97 – Dec '97] and an average coal consumption rate of 118.8 kg/min [Table 77] a tar production rate of 0.0285 kg tar per kg coal consumed results.
5.	0.01 kg fresh water is required for every kg of coal fed = 1.8 Lpm..	
6.	0.0774194 kg steam is required for every kg of coal fed = 14 Lpm.	a rate of 12 ton per day [1986 mill water balance, 60] at a coal consumption rate of 171.1 ton per day, i.e. 0.070 kg steam consumed per kg coal burnt.
7.	0.658 kg hotwater from boiler hotwell is required for every kg of coal fed = 120 Lpm.	Demin water (from the hotwell) is fed to gas producers to generate steam, the demin feed rate is 204 ton per day [1986 mill water balance, 60]. This means that a specific rate of 204/171.1 = 1.192 kg demin water (hotwell) is used for each kg coal fed.
8.	0.2174 kg coarse ash is produced for every kg of coal burnt = 56.9 t/d at a consistency of 69%.	• Monthly solid waste report states 23.3 t/d (Feb '98 – Jan '99). • 70 states 28.5 t/d at 69%

Table 76: Gas Producer Assumptions and Mass Balance Control Logic (continue)

#	Assumption	Comment or Reference
9.	Combustion of the coal is calibrated to give a fuel gas to lime kiln at a rate and composition of: • Flow = 2 430 t/d • SS = 1 005 mg/L • Temperature = 567.5 °C • Inerts = 100% of solids • Carbon = 7.6% • CO_2 = 18.6% • H_2 = 0.95 • Oxygen = 0.4% • SO_2 = 0.32% • Nitrogen = 71.6%	
10.	0.0011 kg phenolic water is generated for every kg coal burnt = 0.2 Lpm.	Phenolic water from the gas producers is drained about once per month, this amounts to a continuous flow of approximately 0.10 liters per minute. The drained phenolic water is discharged into the kiln mud washer [W Henning].
11.	0.5377 kg water is evaporated for every kg of coal burnt = 97.7 Lpm = 0.14 ML/d.	
12.	0.1772 liter effluent is generated for every kg of coal burnt = 32.2 Lpm = 0.046 ML/d.	Two types of effluent result from the gas producers, blow down due to steam and blow or overflows. Steam blow down is taken as 4 ton per day and other water discharges are taken as 48 ton per day. Thus 52 ton per day of effluent results for every 171.1 ton per day of coal burnt, i.e 0.304 kg effluent for every kg of coal burnt.
13.	The coal compose fed into the gas producers compose off: • Consistency = 99.1% • Inerts = 97% • Sulphur = 3%	Typical moisture composition of coal fed to gas producers is 0.95% [special sample analyses].

1. Sulphate enters the gas producers as sulphur in the coal.
2. The sulphate in the coal is converted to SO_2 of which a certain portion will be converted to $CaSO_4$ in the lime kiln. The lime kiln states that 5% of the calcium in the lime kiln will react to form $CaSO_4$ if there is enough sulphur available.
3. Sulphate enters the gas producers as sulphur in the coal.
4. The sulphate in the coal is converted to SO_2 of which a certain portion will be converted to $CaSO_4$ in the lime kiln. The lime kiln states that 5% of the calcium in the lime kiln will react to form $CaSO_4$ if there is enough sulphur available.

The control of the gasproducers is thus linked to the lime production rate of the kiln. A direct relationship is assumed between the amount of coal that must be burnt in the gasproducers compared to the lime production rate. Other feeds into the gasproducers are in turn directly related to the amount of coal that is burnt.

Table 77: Gas Coal Useage [causticizing process engineer]

1999	Gas Coal Useage	
	ton/day	kg/min
January	150	104.2
February	212	147.2
March	215	149.3
April	117	81.3
May	108	75.0
June	200	138.9
July	192	133.3
August	178	123.6
September	189	131.3
October	150	104.2
Average	**171.1**	**118.8**

8.4.8 Evaporator section

The evaporator section receives weak black liquor from the #1 and #2 digester. The weak black liquor goes through two evaporator trains to concentrate the weak liquor up to a strong black liquor. The #1 evaporator train is the older of the two trains, it has a lower capacity than the #2 evaporator and is also less efficient in concentrating the weak black liquor up. The two types of condensates received from the #1 evaporator train are of a poor quality and are used as washing water in the causticizing section's lime mud washer. The #2 evaporator also has two types of condensates, the contaminated condensate is the cleaner of the two and is used as make-up water in the #1 and #2 Evaps cooling towers. The other condensate stream from the #2 evaporator is of a poor quality and is used with the condensate from #1 evaporators as washing water in the causticizing section. Steam is used as energy to evaporate the weak black liquor, and a small portion of the steam is also used to generate vacuum in the steam ejectors which drives the evaporated liquor through the condensers.

The evaporators' balance is done to between a level 2 and a level 3 detail. The intermediate stream qualities within the section is not essential for this stage (although burkeite scaling must be investigated for intermediate streams in the evaporator section at a later stage), but the qualities and quantities have a significant impact on the mill balance.

Table 78: Evaporator set #1 and #2 Assumptions and Mass Balance Control Logic

#	Assumption	Comment or Reference
1.	0.2087 kg steam is used to evaporate every kg of WBL from the #1 digester = 605 Lpm = 871 t/d.	PE = 0.2087 kg/kg = 583 Lpm PE = 850 Lp,
2.	0.1621 kg steam is used to evaporate every kg of WBL from the #2 digester = 1 237 Lpm = 1 781 t/d.	PE = 1 258 Lpm PE = 1 417 Lpm
3.	Of the steam in assumption 2, 52 Lpm steam is used to drive ejectors on #2 evaporator train. This steam CCA and foul condensate.	
4.	Of the steam in assumption 1, 19 Lpm steam is used to drive ejectors on #1 evaporator train. This steam becomes dirty condensate.	
5.	Steam used in the #1 evaporator set is returned as return steam condensate to the hotwell = 605 Lpm	PE = 571 Lpm
6.	Steam used in the #2 evaporator set is returned as return steam condensate the return steam condensate receiver = 1 166 Lpm.	PE = 1 006 Lpm.
7.	No water losses occur from the #1 evaporator cooling tower cooling water circuit which cools the #1 evaporator condensor and surface condensor.	
8.	The #2 chemical recovery floor drain sump pump delivers 656 Lpm =0.94 ML/d into the spill collection tank.	
9.	Of the contents of the spill collection tank (0.94 ML/d) only 10% is returned the SBL, the remainder goes to effluent.	
10.	0.04662 kg soap skimmings is recovered from the WBL for every kg of softwood produced. In calibrating the model it is assumed that the soap has the following composition: • Flow = 22.1 Lpm • SS = 62 mg/L • Chloride = 1 355 mg/L • Sodium = 23 703 mg/L • Sulphate = 2 793 mg/L • Magnesium = 8 mg/L • COD = 0.1 mg/L • TA = 5 g/L as Na_2O.	Table 84 page 211.
11.	0 kg soap skimmings is recovered from the WBL for every kg of hardwood produced.	
12.	25.6% of the total WBL received from #1 and #2 digesters are assumed to be evaporated in #1 evaporator train, the remaining 75% in evaporator #2..	
13.	Many factors contribute to the composition of the WBL, but in calibrating these factors, the combined WBL from #1 and #2 digester has a TDS content of 13.1%.	

Table 78: Evaporator set #1 and #2 Assumptions and Mass Balance Control Logic

#	Assumption	Comment or Reference
14.	The following operating conditions are assumed for evaporator set #1: • Outlet TDS of SBL = 65% • Condensate temperature = 60°C • Concentrated SBL temperature = 112°C • Incoming Chloride split to condensate = 0.58% • Incoming Sodium split to condensate = 0.26% • Incoming Sulphate split to condensate = 0.51% • Incoming Magnesium split to condensate = 0.01% • Incoming Calcium split to condensate = 1.87%	
15.	The following operating conditions are assumed for evaporator set #2: • Outlet TDS of SBL = 65% • Condensate temperature = 60°C • Concentrated SBL temperature = 112°C • Incoming Chloride split to condensate = 0.15% • Incoming Sodium split to condensate = 0.03% • Incoming Sulphate split to condensate = 0.61% • Incoming Magnesium split to condensate = 0.7% • Incoming Calcium split to condensate = 2.31%	
16.	Many factors contribute to the quantity of condensate from #1 evaporator set, but in calibrating these factors it was assumed that the total condensate (i.e. dirty and combined condensate) flow is = 2 161 Lpm = 3.1 ML/d.	PE = 2 370 Lpm A Knobel = 2 546 Lpm
17.	Many factors contribute to the quantity of condensate from #2 evaporator set, but in calibrating these factors it was assumed that the total condensate (i.e. CCA and foul) flow is = 6 285 Lpm = 9.1 ML/d.	PE = 5 880 Lpm A Knobel = 6 785 Lpm
18.	Many factors contribute to the quantity and quality of the combined condensate from #1 evaporator set, but in calibrating these factors it was assumed to be as follow: • Flow = 51.9% of total condensate from #1 evaporator set = 1 122 Lpm = 1.62 ML/d • SS = 0 mg/L • Chloride = 9.9 mg/L • Sodium = 77.9 mg/L • Sulphate = 17.8 mg/L • Magnesium = 0 mg/L • COD = 4 025 mg/L • Calcium = 0.03 mg/L • TTA = 0.03 g/L as Na_2O.	Table 83 page 210.

Table 78: Evaporator set #1 and #2 Assumptions and Mass Balance Control Logic

#	Assumption	Comment or Reference
19.	Many factors contribute to the quantity and quality of the dirty condensate from #1 evaporator set, but in calibrating these factors it was assumed to be as follow: • Flow = remainder of total condensate from #1 evaporator set = 1 040 Lpm = 1.5 ML/d • SS = 0 mg/L • Chloride = 9.9 mg/L • Sodium = 77.9 mg/L • Sulphate = 17.8 mg/L • Magnesium = 0 mg/L • COD = 4 025 mg/L • Calcium = 0.03 mg/L • TTA = 0.03 g/L as Na_2O.	
20.	Because the evaporators evaporate to a defined TDS, and because COD complicates the interpretation of TDS, the COD is converted to dissolved wood solids before it enters the evaporators. After the evaporators however, the dissolved wood solids are converted back to COD using a direct relationship to the what the COD was before entering the evaporators.	Figure 49
21.	Because the chemical recovery furnace needs the component 'total dissolved wood solids' rather than COD for its calculation purposes, the dissolved wood solid fraction is only corrected to COD after the chemical recovery furnaces.	Section 8.4.9 and 8.4.10 page 213. Figure 49
22.	Many factors contribute to the quantity and quality of the foul condensate from #2 evaporator set, but in calibrating these factors it was assumed to be as follow: • Flow = 5.9% of total condensate from #2 evaporator set = 374 Lpm = 0.54 ML/d • SS = 0 mg/L • Chloride = 3.3 mg/L • Sodium = 5.2 mg/L • Sulphate = 8.5 mg/L • Magnesium = 0.0 mg/L • COD = 11 026 mg/L • Calcium = 0.0 mg/L • TTA = 0.0 g/L as Na_2O.	

Table 78: Evaporator set #1 and #2 Assumptions and Mass Balance Control Logic

#	Assumption	Comment or Reference
23.	Many factors contribute to the quantity and quality of the CCA condensate from #2 evaporator set, but in calibrating these factors it was assumed to be as follow: • Flow = remainder of total conductivityensate from #2 evaporator set = 5 910 Lpm = 8.5 ML/d • SS = 0 mg/L • Chloride = 2.5 mg/L • Sodium = 10 mg/L • Sulphate = 22.2 mg/L • Magnesium = 0.0 mg/L • COD = 1 553 mg/L • Calcium = 0.0 mg/L • TTA = 0.0 g/L as Na_2O.	PE = 5 530 Lpm Table 81 page 209.
24.	Combined condensate flow to CFC tank = 62.6 Lpm = 0.09 ML/d	
25.	Combined condensate contributing to effluent = 1 059 Lpm = 1.5 ML/d.	
26.	Dirty condensate to CFC tank = 45.1 Lpm.	
27.	Dirty condensate to #1 CRF SDT vent scrubber = 150 Lpm	PE = 150 Lpm
28.	Dirty condensate contributing to effluent = 864 Lpm = 1.2 ML/d.	
29.	Foul condensate to CFC tank = 216 Lpm = 0.3 ML/d.	
30.	Foul contributing to effluent = 562 Lpm = 0.8 ML/d.	
31.	CCA contributing to effluent = 537 Lpm = 0.8 ML/d.	
32.	CCA to CFC tank = 3 585 Lpm = 5.2 ML/d.	
33.	CCA make-up to evaporator #1 CT = 56 Lpm.	A Knobel = 1 410 Lpm 1986 Balance = 493 Lpm
34.	CCA make-up to evaporator #2 CT = 1 758 Lpm = 2.5 ML/d.	1986 Balance = 2 643 Lpm
35.	The turpentine decanter under flow and sump discharge into the foul condensate tank at a rate of 378 Lpm = 0.5 ML/d.	
36.	No losses from or ingress into the #2 evaporator cooling tower cooling water circuit are assumed.	
37.	20 Lpm of fresh water ingress into the effluent system of the evaporators.	
38.	SBL from #1 and #2 evaporators are mixed, only to split 31.5% of the SBL to #1 chemical recovery furnace. • #1 CRF SBL feed = 667 Lpm • #2 CRF SBL feed = 1 449 Lpm.	
39.	0.65% of the total SBL from both evaporators are lost to effluent = 14 Lpm.	

Table 78: Evaporator set #1 and #2 Assumptions and Mass Balance Control Logic

#	Assumption	Comment or Reference
40.	Although the evaporator effluent flume is the result of many factors, these factors were calibrated assuming the evaporator effluent flume had the following properties: • Flow = 3 243 Lpm = 4.67 ML/d • Contribution to unaccounted effluent = 1.4 ML/d • SS = 2.2 mg/L • Chloride = 35.5 mg/L • Sodium = 503 mg/L • Sulphate = 79.7 mg/L • Magnesium = 2.6 mg/L • COD = 4 639 mg/L • Calcium = 6.9 mg/L • TTA = 0.54 g/L as Na_2O	

The evaporators section receives weak black liquor from the digester which it evaporates. The evaporation process generates condensate streams and strong black liquor. The condensate stream flows are controlled to maintain the CFC tank requirement and also the make-up to the evaporator cooling towers.

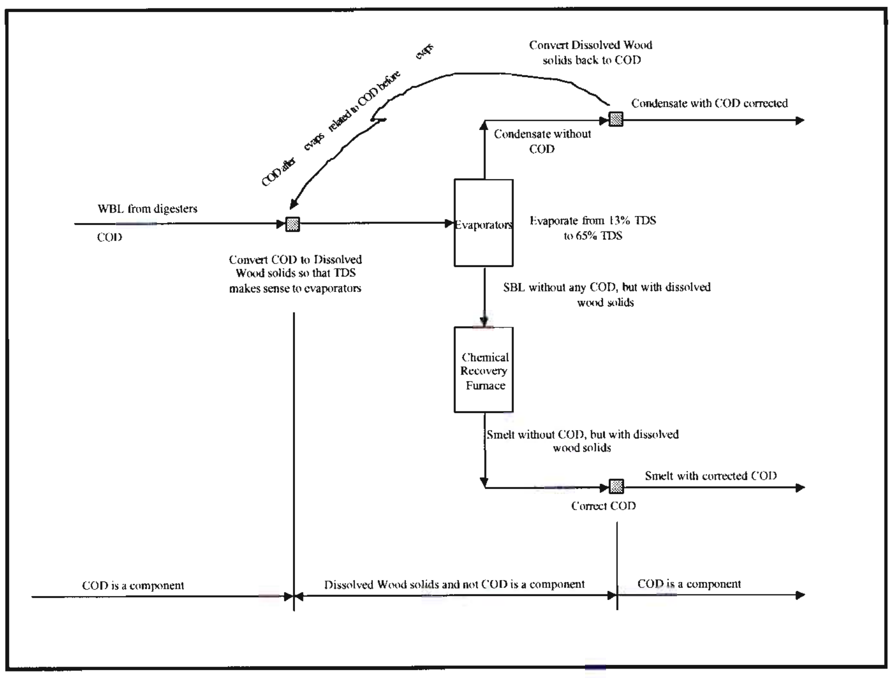


Figure 49: Relationships between Dissolved wood Solids and COD

Table 79: Evaps #1 Miscellaneous Users [PE]

Evaps 1 Misc streams	
Instrumentation	0.004977
Steam trap from CRF 2.	
seal water	0.008986
Line from control room.air con?	0.015264
Total flow (ML/d)	**0.029226**

Table 80: Evaps #2 Miscellaneous Users [PE]

Evaps 2 Miscel streams	
Sample pot near SBL TF pump	0.011664
Drain from #1 spill tnk	0.015533
SBL product sample pot	0.012044
WBL sample pot	0.00432
# 2 CRF sump to spil tnk.	0
Effect 2?? sample pot	0.015552
Total flow (ML/d)	**0.03924**

Table 81: Contaminated Condensate Quality [61].

	CC									
	pH	**Conduct**	**Color**	**SS**	**COD**	**TDS**	**NO_3**	**NH_4**	**PO_4**	**BOD**
		uS/cm	**HCU**	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**
min.	8.3	113	61	0	320	4	0	7	0	
5%	8.63	138	126	2	960	11.5	0.003	13	0	
50%	8.98	170	252	14	1360	69.5	0.24	19.5	0	
95%	9.59	476	992	49.4	1896	534.9	0.55	24.9	0.6	
max.	12.5	14500	10610	105	26800	25049	2.6	33.5	22.9	
data	168	168	168	167	104	156	127	165	160	
	Na	**Ca**	**Mg**	**Al**	**Fe**	**Mn**	**Cu**	**Cl**	**SO_4**	
	mg/l	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**	
min.	2	0	0	0	0	0	0	0.7	3.21	
5%	4.45	0	0	0.07	0	0	0	0.82	5.7	
50%	10	0.4	0.02	0.3	0	0	0	1.81	19.2	
95%	69	6.0	0.27	0.54	0.09	0.05	0.02	47.5	96.8	
max.	175	6.1	0.5	0.9	0.19	0.22	0.07	92	347	
data	31	20	35	34	34	34	34	34	34	

Table 82: Foul Condensate Quality [61]

	FC									
	pH	**Conduct**	**Color**	**SS**	**COD**	**TDS**	**NO_3**	**NH_4**	**PO_4**	**BOD**
		uS/cm	**HCU**	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**
min.	8.9	0	346	2	3200	2	0	8	0	
5%	9.8	0	435	4	5400	13.2	0.12	55	0	
50%	10	445	1134	15	10750	63	0.37	235	0	
95%	10.5	682	2338	52	13865	268.2	1.69	319	3.3	
max.	11.2	2030	3513	65	14800	2435	4.0	365	9.5	
data	94	100	94	92	90	85	76	93	81	
	Na	**Ca**	**Mg**	**Al**	**Fe**	**Mn**	**Cu**	**Cl**	**SO_4**	
	mg/l	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**	
min.	3.0	-	0	0	0	0	0	1.0	2.0	
5%	3.9	-	0.08	0	0	0	0	1.0	2.1	
50%	5.0	-	0.19	0.3	0.01	0	0	2.4	7.4	
95%	94.6	-	0.33	0.8	0.08	0.1	0	7.4	27.8	
max.	540	-	0.3	0.8	0.1	0.1	0	11.3	31.5	
data	18	0	19	18	19	19	19	19	18	

Table 83: Combined Foul Condensate Quality [61]

	CFC									
	pH	**Conduct**	**Color**	**SS**	**COD**	**TDS**	**NO_3**	**NH_4**	**PO_4**	**BOD**
		uS/cm	**HCU**	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**
min.	9.5	200	286	0	500	45	0	5.5	0	
5%	9.7	333	914	10	1396	256	0	35	0	
50%	10.1	751	1988	28	3900	895	0.1	100	0	
95%	10.9	1323	3158	165	7420	1833	0.3	154	1.0	
max.	11.1	2050	4894	218	10200	2490	0.5	170	2.7	
data	43	43	43	43	40	43	39	43	43	
	Na	**Ca**	**Mg**	**Al**	**Fe**	**Mn**	**Cu**	**Cl**	**SO_4**	
	mg/l	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**	
min.	16.0	1.1	0	0	0	0	0	3.2	8.5	
5%	27.9	1.1	0	0	0	0	0	3.9	8.7	
50%	75.5	1.12	0.3	0.2	0	0	0	7.2	15.6	
95%	175.8	1.12	0.5	0.4	0.2	0.1	0	13.5	29.7	
max.	195.0	1.1	0.5	0.4	0.2	0.1	0	14.4	30.0	
data	8	1	9	9	9	9	9	10	10	

Table 84: Evaporator Soap Skimmings [G Nxasana]

Month	Soap Despatch	SW Production	
	t/month	t/month	Kg/ADT
Jan-97	1016	27988	36.30
Feb-97	1098	27655	39.70
Mar-97	1001	38822	25.78
Apr-97	828	26718	30.99
May-97	1387	25859	53.64
Jun-97	1084	35253	30.75
Jul-97	1266	23476	53.93
Aug-97	1167	28634	40.76
Sep-97	1466	30747	47.68
Oct-97	1248	28917	43.16
Nov-97	245	18071	13.56
Dec-97	1217	30211	40.28
Jan-98	843	24095	34.99
Feb-98	244	25289	9.65
Mar-98	1015	17688	57.38
Apr-98	967	19981	48.40
May-98	1441	15245	94.52
Jun-98	1278	25974	49.20
Jul-98	977	14825	65.90
Aug-98	1420	16879	84.13
Sep-98	270		
Oct-98	870		
Nov-98	644		
Dec-98	1244		
Jan-99	829		
Feb-99	967		
Mar-99	1137		
Apr-99	838		
May-99	943		
Jun-99	1448		
	1013.27	**25116.35**	**45.03**

8.4.9 #1 Chemical Recovery Furnace

The #1 chemical recovery furnace is the older furnace of two chemical recovery furnaces in the mill. Strong black liquor is used as fuel while Na_2SO_4, a spent cooking chemical, is regenerate to form the active cooking chemical Na_2S. Weak white liquor from the causticizing section is used for density (in fact TA) control on the smelt discharging from the furnace. The smelt diluted with the weak white liquor, known as green liquor, feeds to the green liquor clarifier in the causticizing section. When necessary, salt cake is made up into the mixing tank of the #1 chemical recovery furnace. Sulphur can also be made up into the green liquor to maintain the strong white liquor sulphidity.

Table 85: #1 Chemical Recovery Furnace Assumptions and Mass Balance Control Logic

#	Assumption	Comment or Reference
1.	3.68339 kg demin (and return steam condensate) is required for every kg SBL solids fired.	
2.	24.4% of the feed water in the #1 CRF steam tubes are returned steam condensate from hotwell, the remainder of water is demin water.	
3.	31.5% of the total strong black liquor from the evaporators are burnt in the #1 chemical recovery furnace.	
4.	The #1 CRF blows down 29.4 Lpm, which contributes to the evaporator effluent flow.	
5.	5% of the feed water into the boiler (excluding blow down) contributes to the flow to the warm water holding = 78 Lpm.	
6.	#1 CRF produces 2 143 t/d of steam	
7.	524 Lpm = 0.75 ML/d fresh water is utilised around the #1 CRF of which a 100 Lpm contributes to the evaporator effluent flume flow, and 423 Lpm is used for #1 ID fan cooling water which goes to #1 evaporator cooling tower as make-up.	
8.	18.6 t/d of salt cake is made up into the mixing tank with the strong black liquor that feeds into the furnace. Salt cake composition: • Na_2SO_4 = 62.3% • Na_2CO_3 = 34.0% • NaCl = 1.3% • NaOH = 2.4%	
9.	0 t/d sulphur is made up, but if there should be a make-up of sulphur then it would be added after the smelt dissolving tank.	
10.	In calibrating the model it is assumed that the weak white liquor is at a flow of 850 Lpm = 1.22 ML/d into the smelt dissolving tank.	

Table 85: #1 Chemical Recovery Furnace Assumptions and Mass Balance Control Logic

#	Assumption	Comment or Reference

11.	Wingems pre-programmed block is used to simulate the furnace operation, the following conditions are assumed:
	• 10% excess air
	• Entering chloride leaving in stack as NaCl = 10%
	• Loading factor = 0.9
	• Dregs per solids entering furnace = 3.5 g/kg
	• Reduction ratio = 0.86652
	• Smelt temperature = 1 040°C
	• Gas temperature after economizer = 150°C
	• Dissolved wood weight percent composition:
	  • Carbon = 53%
	  • Hydrogen = 6%
	  • Oxygen =- 41%
	• For sodium and sulphur calculations the empirical STFI model is used	

12.	The following removal efficiencies are assumed for the precipitator dust remover: • Na_2SO_4 = 97% • Na_2CO_3 = 97% • NaCl = 97%	
13.	After the furnace, the COD is corrected again, since the furnace works with dissolved wood solids. It is assumed that the green liquor has a COD of 2 073 mg/L.	Figure 49 page 208.
14.	Because the composition/break-up fractions of solids had not been calibrated throughout the model to the detail required to simulate the causticizing section's chemistry, a correction for solid composition is build into the model after the chemical recovery furnace. In other words, after the chemical recovery furnace the make-up of the solids in the green liquor is defined. In calibrating the green liquor solid fraction composition it is assumed that the solids are made as follow: • SS = 1 743 mg/L • Inerts = 30.6% • $CaCO_3$ = 59.2% • CaO = 10.2%	

8.4.10 #2 Chemical Recovery Furnace

This furnace is the more modern furnace of the two chemical recovery furnaces and most of the black liquor is burnt in this furnace. Steam is generated which contributes to the 8 965 kPa header to generate electricity.

Table 86: #2 Chemical Recovery Furnace Assumptions and Mass Balance Control Logic

#	Assumption	Comment or Reference
1.	3.41771 kg demin (and return steam condensate) is required for every kg SBL solids fired.	
2.	0 kg fresh water is used per kg SBL solids fired.	
3.	57.7% of the feed water in the #1 CRF steam tubes are returned steam condensate from RCR, the remainder of water is demin water.	
4. 5.	19.3% of the feed water into the boiler is lost to effluent and to the warm water holding tank (excluding blow down) = 0.89 ML/d. Boiler is running at 70 cycles of concentration, resulting in a blow down of 37 Lpm.	
6.	68.5% of the total strong black liquor from the evaporators are burnt in the #2 chemical recovery furnace = 1 449 Lpm = 2 087 t/d.	
7.	3 678 t/d steam is produced at 8 965 kPa.	
8.	48 t/d steam is produced at 415 kPa.	
9.	Of the water losses from the boiler feed water, 46 Lpm contribute to the warm water holding tank and 622 Lpm contribute to boiler effluent flume flow.	
10.	653 Lpm of water from the lube oil cooling tower contribute to the #2 CRF floor drain which is pumped to the evaporator spill collection system.	
11.	0.2% of the strong black liquor fed to the furnace are lost the spill collection sump which pumps to spill collection system at the evaporators.	
12.	In calibrating the #2 CRF it was assumed that the flow from the spill collection sump the to the evaporator spill collection tank is = 656 Lpm = 0.84 ML/d.	
13.	37.9 t/d of salt cake is made up into the mixing tank with the strong black liquor that feeds into the furnace. Salt cake composition: • Na_2SO_4 = 62.3% • Na_2CO_3 = 34.0% • NaCl = 1.3% • NaOH = 2.4%	
14.	The following removal efficiencies are assumed for the precipitator dust remover: • Na_2SO_4 = 97% • Na_2CO_3 = 97% • NaCl = 97%	

Table 86: #2 Chemical Recovery Furnace Assumptions and Mass Balance Control Logic

#	Assumption	Comment or Reference

15.	Wingems pre-programmed block is used to simulate the furnace operation, the following conditions are assumed:
	• 10% excess air
	• Entering chloride leaving in stack as NaCl = 10%
	• Loading factor = 0.9
	• Dregs per solids entering furnace = 3.5 g/kg
	• Reduction ratio = 0.862
	• Smelt temperature = 1 040°C
	• Gas temperature after economizer = 150°C
	• Dissolved wood weight percent composition:
	  • Carbon = 53%
	  • Hydrogen = 6%
	  • Oxygen =- 41%
	• For sodium and sulphur calculations the empirical STFI model is used	

16.	1.7 t/d of sulphur is made-up into the SDT.	
17.	In calibrating the model it is assumed that the weak white liquor is at a flow of 2 262 Lpm = 3.26 ML/d into the smelt dissolving tank.	
18.	After the furnace, the COD is corrected again, since the furnace works with dissolved wood solids. It is assumed that the green liquor has a COD of 1 831 mg/L.	
19.	Because the composition/break-up fractions of solids had not been calibrated throughout the model to the detail required to simulate the causticizing section's chemistry, a correction for solid composition is build into the model after the chemical recovery furnace. In other words, after the chemical recovery furnace the make-up of the solids in the green liquor is 'correctd'. In calibrating the green liquor solid fraction composition it is assumed that the solids are made as follow: • SS = 1 743 mg/L • Inerts = 30.0% • $CaCO_3$ = 60.0% • CaO = 10.0% • CaOH = 0%	Figure 49page 208.

Table 87: Smelt Chloride concentration [laboratory analyses]

Year 1999	Smelt	
	g/kg as NaCl	**mg/kg as Cl**
01-Nov	2.1	1274
02-Nov	2.8	1699
03-Nov	2.4	1456
04-Nov	2.3	1395
05-Nov	2.1	1274
08-Nov	2.4	1456
10-Nov	2	1213
11-Nov	1.8	1092
12-Nov	2.1	1274
15-Nov	2.7	1638
16-Nov	2.4	1456
17-Nov	2.2	1335
18-Nov	2.4	1456
19-Nov	2.6	1577
22-Nov	2.3	1395
23-Nov	4.1	2487
24-Nov	3.8	2305
26-Nov	3.3	2002
Average	**2.5**	**1543.5**

Table 88: Smelt Compostion

Component	**Units**	**WinGEMS reference[1]**	**WinGEMS reference[2]**
Green liquor: smelt flow	kg/kg		
Suspended solids	%	0.94	0.84
Inerts	fraction	1	1
$CaCO_3$	fraction		
CaO	fraction		
CaOH	fraction		
Cl	g/kg liq.		
Na	g/kg liq.	465.3	472.1
SO_4^{2-}	g/kg liq.	29.2	36.1
HS	g/kg liq.	87.6	108.3
OH	g/kg liq.	8.6	8.7
CO_3^{2-}	g/kg liq.	409.3	374.8
TA	g/L as Na_2O	935.5	
AA	g/L as Na_2O		
EA	g/L as Na_2O	28.2	
Sulphidity	fraction	1.67	

1. WinGEMS example, *fullmill.wg*
2. WinGEMS example, *kfurn.wg*

8.4.11 Auxiliary Boilers

These boilers are used during shuts or abnormal conditions, and include the John Thomspon oil fired boiler, and two other smaller boilers. The impact that these boilers have on the operation of the mill is estimated to be small.

Table 89: Auxiliary Boilers Assumptions and Mass Balance Control Logic

#	Assumption	Comment or Reference
1.	The impact of these boilers on the operation of the mill in terms of effluent qualities and quantities are small, especially due to the fact that they are being utilised very rarely. For the pre-feasibility stage considerations it is assumed that these boiler are off 100% of the time.	
2.	Seal water from pumps contributes to unaccounteds effluent at a rate of 36.4 Lpm.	

8.4.12 PF Boiler

The pulverised fuel boiler is used to generate the largest part of the mill's internally generated electricity. Bark, sawdust and coal are used as fuel, the steam contributes to the 8 965 kPa header that is common to the #2 CRF header. Two turbines are used to generate steam.

Table 90: PF Boiler Assumptions and Mass Balance Control Logic

#	Assumption	Comment or Reference
1.	Enough steam is generated by the PF boiler to satisfy the steam and energy requirements of the mill. Thus the amount of steam that is required from the PF boiler is calculated and this steam quantity is then used as the basis for all other PF boiler parameters, i.e. coal requirements etc. See comments.	Paragraph 8.4.13 page 218 explains the complicated/detailed assumptions used to calculate PF boiler steam requirement ito total plant steam requirement, losses and energy generation.
2.	The following specific steam generation rates are assumed for different fuels (ton steam generated for every kg of fuel fired): • 8 kg/kg coal fired • 3.5 kg steam/kg bark fired • 3.5 kg steam/kg sawdust fired	
3.	The following fuel feeding ratio's (on weight) are fed into PF boiler: • Coal = 96% = 781 t/d • Bark = 2% = 37 t/d • Sawdust = 2% = 37 t/d	
4.	5.2% of the fuel fed into the boiler becomes wet ash = 45 t/d at 64.7% consistency.	
5.	24.2% of the fuel fed into the boiler becomes fly ash = 207 t/d at 74.6% consistency.	

Table 90: PF Boiler Assumptions and Mass Balance Control Logic - continued

#	Assumption	Comment or Reference
6.	128 Lpm fresh water is used for washing and seal water and other uses around the boiler.	
7.	1 Lpm foul condensate is used on the submerged scraper conveyor for seal water. This contributes to the effluent flume flow.	
8.	14.3% of the feed water into the boiler is demin water, the remaining feed water is return steam condensate from the RCR.	
9.	The boiler runs at 70 cycles of concentration to give a blow down rate of 65.5 Lpm.	
10.	6 511 t/d of steam at 8 965 kPa is generated,	
11.	1 t/d of steam a 415 kPa is generated.	
12.	443 LPm of boiler water is lost the warm water holding tank that contributes to the warm water system at the #2 digester.	

8.4.13 Steam and Electricity Balance

The total steam generation required from the boilers is function of steam demand of the plants, but also of the electricity requirement of the plants. The PF boiler and the #2 CRF feeds steam into a common header at 8 965 kPa, from this header a fraction of the steam goes through turbine generator #2 and the condensate is returned to the return steam condensate receiver. Enough steam is put through turbine generated #2 to run the turbine at its maximum rate. Another fraction of the steam is put through turbine generator #1 to supply the steam demand. The steam through generator #1 feeds into the lower pressure steam header, which supplies the plants. Due to the integrated nature of the steam supply and handling system of the PF boiler and the two chemical recovery furnaces, this system is handled/calibrated as a stand alone system 'outside' the balances of the boiler and furnaces. It is done to between a level 2 and 3 detail, the block name is referred to as 'to sort' in the Wingems simulation.

Table 91: Steam and Electricity Assumptions and Mass Balance Control Logic

#	Assumption	Comment or Reference
1.	6 511 t/d of steam from the PF boiler and 3 678 t/d of steam from the #2 CRF feeds into the 8965 kPa header.	
2. 3.	9.3% of the steam feeding into the 8 965 kPa header is lost to lower pressure steam system, i.e. do not contribute to electricity generation =950 t/d. 7 ton steam generates 1 MW steam in turbine #1	
4.	3.5 ton steam generates 1 MW steam in turbine #2.	
5.	30 MW of steam is generated in turbine #1, and the resulting lower pressure steam supplies to the mill plants = 5 040 t/d.	
6.	50 MW of steam is generated in turbine #2, and the resulting condensate is returned the RCR = 4 200 t/d.	
7.	2 143 t/d of low pressure steam is supplied from #1 CRF.	

Table 91: Steam and Electricity Assumptions and Mass Balance Control Logic - continued

#	Assumption	Comment or Reference
8.	988 t/d of steam from the low pressure header is assumed to be loss	

8.4.14 Demineralisation Plant

The demineralisation plant receives fresh water from the fresh water treatment plant and demineralises the water through cation and anion resin beds. These ion beds are regenerated using caustic and sulphuric acid. The spent regeneration liquor is discharged into the same tank, to allow for neutralisation, before being discharged into the bleach effluent.

Table 92: Demineralization Assumptions and Mass Balance Control Logic

#	Assumption	Comment or Reference
1.	Enough fresh water is fed into the demin plant to supply the boilers with the demin feed water requirements = 5.3 ML/d	
2.	0.000267044 kg sulphuric acid is required for every kg of fresh water feed into the demin plant = 1 Lpm	
3.	0.000369983 kg caustic is required for every kg of fresh water feed into the demin plant = 1.3 Lpm	
4.	The sand filter backwash flow is 1% of the fresh water feed through it = 37 Lpm.	
5.	The sulphuric acid used for regeneration is at 98% concentration.	
6.	The caustic used for regeneration is at 48% concentration.	
7.	The model was calibrated assuming the following demin flow rates required for the different boilers (excluding the return steam condensate to the boilers): • PF boiler = 1 021 t/d • #1 CRF = 1 735 t/d • #2 CRF = 1 959 t/d • Auxiliary boilers = 0 t/d	
8.	Many factors contribute to the flow and composition of the caustic effluent, but in calibrating these factors it is assumed that 20% of the total demin effluent is caustic demin effluent with the following properties: • Flow = 68 Lpm = 0.10 Ml/d • Chloride = 25 mg/L • Sodium = 5 329 mg/L • Sulphate = 2 804 mg/L • Magnesium = 2 mg/L • COD = 15 mg/L • Calcium = 6 mg/L • pH = 8.9	

Table 92: Demineralization Assumptions and Mass Balance Control Logic - continued

#	Assumption	Comment or Reference
9.	Many factors contribute to the flow and composition of the acid demin effluent, but in calibrating these factors it is assumed that 80% of the total demin effluent is acid demin effluent with the following properties: • Flow = 272 Lpm = 0.40 Ml/d • Chloride = 25 mg/L • Sodium = 70 mg/L • Sulphate = 2 804 mg/L • Magnesium = 9.6 mg/L • COD = 15 mg/L • Calcium = 29 mg/L • pH = 0	
10.	The anion-cation bed separates out 9.344% of the fresh water during the regeneration process. The following components/compounds are also selectively split out: • 90% of incoming chloride • 90% of incoming sodium • 90% of incoming sulphate • 15% of incoming magnesium • 17% of incoming calcium	

8.4.15 Uptake #1 or Pulp Drying #1

Uptake #1 gets its pulp from digester #1, the pulp is pressed dry and the filtrate is returned to #1 digester. #1 Digester and Uptake #1 uses the same effluent flume, which makes it difficult to determine exactly how much of the measured '#1 digester' effluent flume effluent is from digester #1 and how much is from #1 Uptake. The filtrate from #1 uptake white water tank is returned to the #2 wash filter of #1 digester. The uptake #1 is done to a level 3 detail.

Table 93: #1 Uptake Assumptions and Mass Balance Control Logic

#	Assumption	Comment or Reference
1.	Fresh water usage = 2 kg/kg BD pulp feed = 0.24 ML/d.	
2.	Hot water usage = 1.76 kg/kg BD pulp feed = 0.21 ML/d.	
3.	Steam usage = 0.88 kg/kg BD pulp feed = 0.107 ML/d.	
4.	0.372 kg steam is generated for every BD kg of pulp inot the uptake = 31.4 kg/min	

Table 93: #1 Uptake Assumptions and Mass Balance Control Logic - continued

#	Assumption	Comment or Reference
5.	9.454 kg back water is return to #1 digester for every BD kg of pulp feed. Although the back water is the result of many factors, in calibrating these factors it was assumed to have the following properties: • Flow = 797 kg/min = 1.15 ML/d • SS = 1 290 mg/L • Pulp = 98.3 % of total solids • Sorbed sodium = 0.13% of total solids • Inerts = 1.5% of total solids • Chloride = 23.2 mg/L • Sodium = 1 438 mg/L • Sulphate = 355 mg/L • Magnesium = 20.7 mg/L • COD = 4 237 mg/L • Calcium = 56.6 mg/L • TTA = 9.70 g/L as Na_2O	
6.	Fraction of reels sold = 0.39 kg sold for every kg produced = 85 t/d. The remaining reels are stored on pulp slab for re-pulping = 133 t/d.	
7.	Dried pulp consistency = 55%.	
8.	A total pulp production of 133 ADt/d is assumed.	
9.	98.6% of the pulp fed into the uptake ends up as reels.	
10.	The liquor in the dried pulp is assumed to have the following composition: • Pulp = 98.6% of total solids • Sorb sodium = 0.12% of total solids • Inerts = 1.3% of total solids • Chloride = 23 mg/L • Sodium = 1 714 mg/L • Sulphate = 467 mg/L • Magnesium = 0 mg/L • COD = 2 774 mg/L • Calcium = 10 mg/L • TTA = 9.70 g/L as Na_2O	

Table 93: #1 Uptake Assumptions and Mass Balance Control Logic - continued

#	Assumption	Comment or Reference
11.	Although the effluent composition and flow is the result of many factors and also the 'excess' stream from the uptake, in calibrating the uptake the effluent was assumed to have the following properties: • Flow = 64.7 kg/min = 0.09 ML/d • SS = 2 336 mg/L • Pulp = 100 % of total solids • Sorbed sodium = 0% of total solids • Inerts = 0% of total solids • Chloride = 8.8 mg/L • Sodium = 3 009 mg/L • Sulphate = 89 mg/L • Magnesium = 85 mg/L • COD = 4 577 mg/L • Calcium = 376 mg/L • TTA = 9.70 g/L as Na_2O	
12.	Desorption is assumed to place at the following rate; • 20% of all incoming sorbed sodium desorps • 100% of all incoming sorbed magnesium desorps • 100% of all incoming sorbed calcium compounds desorp.	

8.4.16 Uptake #2 or Pulp Drying #2

#2 Uptake receives pulp mainly from #2 digester at a consistency of approximately 3% and returns the backwater to the two-stage diffusion washer at #2 digester. The pulp leaves the uptake in a reel form at a consistency of approximately 45%. #2 Uptake is done to a level 3 detail, meaning that all inputs are combined in one mixing block and from this mixing block the different outputs are split off.

Table 94: #2 Uptake Assumptions and Mass Balance Control Logic

#	Assumption	Comment or Reference
1.	Fresh water usage = 2.6424 kg/kg BD feed = 0.438 ML/d.	
2.	Hot water usage = 4.16 kg/kg BD feed = 0.69 ML/d.	
3.	Steam usage = 0 kg/kg BD feed.	
4.	Contaminated condensate usage = 0 kg/min	
5.	0.00122 kg evaporation takes place for every kg of pulp feed = 4.7 kg/min	
6.	50% of the reels produced are sold, and the remainder is stored on the pulp slab for further re-use.	
7.	A total pulp production rate of 172 ADt/d reels is used.	
8.	93.2% of the pulp that enters the uptake #2 ends/contributes to the pulp being produced.	
9.	The pulp is at a consistency of 44%.	

Table 94: #2 Uptake Assumptions and Mass Balance Control Logic - continued

#	Assumption	Comment or Reference
10.	The liquor in the dried pulp is assumed to have the following composition: • Pulp = 98.5% of total solids • Sorb sodium = 0.03% of total solids • Inerts = 1.5% of total solids • Chloride = 51 mg/L • Sodium = 245 mg/L • Sulphate = 2 mg/L • Magnesium = 0 mg/L • COD = 27 mg/L • Calcium = 7 mg/L • TTA = 0.80 g/L as Na_2O	
11.	34.8 kg back water is return to #2 digester for every BD kg of pulp feed. Although the back water is the result of many factors, in calibrating these factors it was assumed to have the following properties: • Flow = 4 013 kg/min = 5.78 ML/d • SS = 1 707 mg/L • Pulp = 98.4 % of total solids • Sorbed sodium = 0.13% of total solids • Inerts = 1.7% of total solids • Chloride = 95 mg/L • Sodium = 444 mg/L • Sulphate = 55 mg/L • Magnesium = 6 mg/L • COD = 383 mg/L • Calcium = 9 mg/L • TTA = 0.80 g/L as Na_2O	
12.	Although the effluent composition and flow is the result of many factors and also the 'excess' stream from the uptake, in calibrating the uptake the effluent was assumed to have the following properties: • Flow = 367 kg/min = 0.53 ML/d • SS = 1 702 mg/L • Pulp = 100 % of total solids • Sorbed sodium = 0% of total solids • Inerts = 0% of total solids • Chloride = 55 mg/L • Sodium = 1 140 mg/L • Sulphate = 259 mg/L • Magnesium = 148 mg/L • COD = 5 790 mg/L • Calcium = 390 mg/L • TTA = 0.80 g/L as Na_2O	

Table 94: #2 Uptake Assumptions and Mass Balance Control Logic - continued

#	Assumption	Comment or Reference
13.	Desorption is assumed to place at the following rate; • 80% of all incoming sorbed sodium desorps • 100% of all incoming sorbed magnesium desorps • 100% of all incoming sorbed calcium compounds desorp.	

8.4.17 Uptake #3 or Pulp Drying #3

Uptake #3 receives pulp from bleach plant at a consistency of approximately 3.4% that it converts into bales at a consistency of approximately 90%. Two qualities of filtrate are generated which are returned to the bleach plant's three stage diffusion washer and D2 stage displacement tower respectively. The balance is done to a level 3.

Table 95: #3 Uptake Assumptions and Mass Balance Control Logic

#	Assumption	Comment or Reference
1.	Fresh water usage = 6.40596 kg/kg BD feed = 2.78 ML/d	
2.	Hot water usage = 4.06 kg/kg BD feed = 1.76 ML/d.	
3.	Steam usage = 1.62 kg/kg BD feed = 0.71 ML/d.	
4.	0.0345 kg water is evaporated for every kg of liquor fed with the pulp = 296 kg/min	
5.	32 kg buffer back water is return to the bleach plant for every BD kg of pulp feed. Although the back water is the result of many factors, in calibrating these factors it was assumed to have the following properties: • Flow = 9 668 kg/min = 13.9 ML/d • SS = 101 mg/L • Pulp = 98.4 % of total solids • Sorbed sodium = 0.03% of total solids • Inerts = 1.7% of total solids • Chloride = 634 mg/L • Sodium = 257 mg/L • Sulphate = 16 mg/L • Magnesium = 94 mg/L • COD = 238 mg/L • Calcium = 61 mg/L • TTA = 0.007 g/L as Na_2O	

Table 95: #3 Uptake Assumptions and Mass Balance Control Logic - continued

#	Assumption	Comment or Reference
6.	4.637 kg surge chest back water is return to the bleach plant for every BD kg of pulp feed. Although the back water is the result of many factors, in calibrating these factors it was assumed to have the following properties: • Flow = 1 399 kg/min = 2.0 ML/d • SS = 211 mg/L • Pulp = 98.4 % of total solids • Sorbed sodium = 0.03% of total solids • Inerts = 1.7% of total solids • Chloride = 885 mg/L • Sodium = 211 mg/L • Sulphate = 10 mg/L • Magnesium = 48 mg/L • COD = 247 mg/L • Calcium = 14 mg/L • TTA = 0.007 g/L as Na_2O	
7.	88.3% of the bales produced are sold and the remaining fraction of bales are stored on the pulp slab to be repulpoed.	
8.	0.0855 kg screen rejects is produced for every BD kg of pulp feed. Although the screen rejects is the result of many factors, in calibrating these factors it was assumed to have the following properties: • Flow = 26 kg/min = 37 t/d • Consistency = 9% • Pulp = 98.4 % of total solids • Sorbed sodium = 0.03% of total solids • Inerts = 1.7% of total solids • Chloride = 442 mg/L • Sodium = 94 mg/L • Sulphate = 17 mg/L • Magnesium = 77 mg/L • COD = 181 mg/L • Calcium = 0.4 mg/L • TTA = 0.007 g/L as Na_2O	
9. 10.	A total pulp production rate of 476 ADt/d is assumed. 98.5% of the pulp fed into the uptake #3 ends up in the pulp bales.	
11.	0 kg HCl from ClO_2 plant is used.	

Table 95: #3 Uptake Assumptions and Mass Balance Control Logic - continued

#	Assumption	Comment or Reference
13.	Although the effluent composition and flow is the result of many factors and also the 'excess' stream from the uptake, in calibrating the uptake the effluent was assumed to have the following properties: • Flow = 451 kg/min = 0.65 ML/d • SS = 2 000 mg/L • Pulp = 99.5 % of total solids • Sorbed sodium = 0% of total solids • Inerts = 0.5% of total solids • Chloride = 267 mg/L • Sodium = 320 mg/L • Sulphate = 24 mg/L • Magnesium = 7 mg/L • COD = 100 mg/L • Calcium = 20 mg/L • TTA = 0.80 g/L as Na_2O	
	Desorption is assumed to place at the following rate; • 0% of all incoming sorbed sodium desorps • 0% of all incoming sorbed magnesium desorps • 100% of all incoming sorbed calcium compounds desorp.	

8.4.18 Noodle Presses

The noodle press consists of a screw press that presses pulp from #2 digester. The noodle is stored on the pulp slab. The noodle section balance is done to a level 3 detail.

Table 96: Noodle Plant Assumptions and Mass Balance Control Logic

#	Assumption	Comment or Reference
1.	Noodle consistency 30%.	
2.	Noodle press filtrate suspended solids = 2 260 mg/L.	
3.	0.87488 kg filtrate is returned to #1 digester for every kg of pulp pressed = 899 kg/min = 1.30 ML/d.	
4.	2.40984 kg hot water is required for every BD kg of pulp feed = 297 kg/min = 0.43 ML/d	
5.	0 kg fresh water is generated for every BD kg fresh water produced.	
6.	All back water that is not returned is assumed to contribute #2 digester effluent. In the calibration process the flow was assumed to be 20 kg/min.	

8.4.19 Pulp Slab

Between the pulp and paper mill there is a storage area called the pulp slab. This storage area enables the pulp and paper mill to run out of synchronisation for short periods without impacting on one anther. This buffer capacity is required in the model to allow the paper machines to run (using softwood and hardwood) while both digesters are in actual fact producing only softwood. The pulp slab is done to a level three detail and shows storage piles for the different pulp types stored. A positive storage quantity indicates that the storage is increasing, while a negative storage value indicate the storage pile is decreasing, i.e. pulp is taken from the storage pile.

Table 97: Pulp Slab Assumptions and Mass Balance Control Logic

#	Assumption	Comment or Reference
1.	It is assumed that the pulp from the slab are of the same quality of the pulp feeding onto the slab. That means that rain and drying of pulp due to evaporation is not considered.	
2.	The user, based on required production rates and fibre furnishes, defines pulp requirements for the KLB and NP machine. The required pulp feed rates (i.e. hardwood, softwood, unbleahed or bleached) are supplied from the slab. Should the feed of a specific pulp type not be sufficient to supply the need, then pulp is taken from a 'storage pile' that has the same quality as the specific pulp.	
3.	The UBSW noodle is assumed to have the following pulp quality: • Consistency = 29% • Pulp = 98% of total solids • Sorbed sodium = 0.14% of total solids • Inerts = 1.3% of total solids • Chloride in liquor = 102 mg/L • Sodium in liquor = 586 mg/L • Sulphate in liquor = 521 mg/L • Magnesium in liquor = 0.5 mg/L • COD in liquor = 5 141 mg/L • Calcium in liquor = 54 mg/L • TTA in liquor = 14.8 g/L as Na_2O	

Table 97: Pulp Slab Assumptions and Mass Balance Control Logic - continued

#	Assumption	Comment or Reference
4.	The UBHW noodle is assumed to have the following pulp quality: • Consistency = 28% • Pulp = 98% of total solids • Sorbed sodium = 0.14% of total solids • Inerts = 1.3% of total solids • Chloride in liquor = 102 mg/L • Sodium in liquor = 586 mg/L • Sulphate in liquor = 521 mg/L • Magnesium in liquor = 0.5 mg/L • COD in liquor = 5 141 mg/L • Calcium in liquor = 54 mg/L • TTA in liquor = 14.8 g/L as Na_2O	
5.	The UBSW Uptake #1 reels is assumed to have the following pulp quality: • Consistency = 52% • Pulp = 99% of total solids • Sorbed sodium = 0.12% of total solids • Inerts = 1.3% of total solids • Chloride in liquor = 23 mg/L • Sodium in liquor = 1 714mg/L • Sulphate in liquor = 467 mg/L • Magnesium in liquor = 0.0 mg/L • COD in liquor = 2 774 mg/L • Calcium in liquor = 10 mg/L • TTA in liquor = 9.7g/L as Na_2O	
6.	The UBHW Uptake #1 reels is assumed to have the following pulp quality: • Consistency = 40% • Pulp = 99% of total solids • Sorbed sodium = 0.12% of total solids • Inerts = 1.3% of total solids • Chloride in liquor = 23 mg/L • Sodium in liquor = 1 714mg/L • Sulphate in liquor = 467 mg/L • Magnesium in liquor = 0.0 mg/L • COD in liquor = 2 774 mg/L • Calcium in liquor = 10 mg/L • TTA in liquor = 9.7g/L as Na_2O	

Table 97: Pulp Slab Assumptions and Mass Balance Control Logic - continued

#	Assumption	Comment or Reference
7.	The UBSW Uptake #2 reels is assumed to have the following pulp quality: • Consistency = 44% • Pulp = 98% of total solids • Sorbed sodium = 0.03% of total solids • Inerts = 1.5% of total solids • Chloride in liquor = 51 mg/L • Sodium in liquor = 245 mg/L • Sulphate in liquor = 2 mg/L • Magnesium in liquor = 0.0 mg/L • COD in liquor = 27 mg/L • Calcium in liquor = 7 mg/L • TTA in liquor = 0.8g/L as Na_2O	
8.	The UBHW Uptake #2 reels is assumed to have the following pulp quality: • Consistency = 40% • Pulp = 98% of total solids • Sorbed sodium = 0.03% of total solids • Inerts = 1.5% of total solids • Chloride in liquor = 51 mg/L • Sodium in liquor = 245 mg/L • Sulphate in liquor = 2 mg/L • Magnesium in liquor = 0.0 mg/L • COD in liquor = 27 mg/L • Calcium in liquor = 7 mg/L • TTA in liquor = 0.8g/L as Na_2O	
9.	The FBSW Uptake #3 bales is assumed to have the following pulp quality: • Consistency = 90% • Pulp = 98% of total solids • Sorbed sodium = 0.03% of total solids • Inerts = 1.7% of total solids • Chloride in liquor = 4 135 mg/L • Sodium in liquor = 179 mg/L • Sulphate in liquor = 23 mg/L • Magnesium in liquor = 48 mg/L • COD in liquor = 62 mg/L • Calcium in liquor = 11 mg/L • TTA in liquor = 0 g/L as Na_2O	

Table 97: Pulp Slab Assumptions and Mass Balance Control Logic - continued

#	Assumption	Comment or Reference
10.	The FBHW Uptake #3 bales is assumed to have the following pulp quality: • Consistency = 80% • Pulp = 98% of total solids • Sorbed sodium = 0.03% of total solids • Inerts = 1.7% of total solids • Chloride in liquor = 4 135 mg/L • Sodium in liquor = 179 mg/L • Sulphate in liquor = 23 mg/L • Magnesium in liquor = 48 mg/L • COD in liquor = 62 mg/L • Calcium in liquor = 11 mg/L • TTA in liquor = 0 g/L as Na_2O	

8.4.20 Re-pulpers

The re-pulper section is four re-pulpers where pulp from the pulp slab are fed and repulped to supply the Kraft Liner Board and Newsprint machine of pulp. The user specifies the pulp mix ratios. Backwater from the two paper machines is used in the re-pulp and dilutes the pulp to the user defined consistency. Some fresh water are also used for re-pulping. The re-pulpers are done to between a level 3 detail.

Table 98: Re-pulpers Assumptions and Mass Balance Control Logic

#	Assumption	Comment or Reference
1.	Consistency of unbleached softwood to KLB = 3.5%	
2.	Consistency of unbleached hardwood to KLB= 3.5%	
3.	Consistency of fully bleached softwood to NP = 4%	
4.	Consistency of fully bleached hardwood to WTL = 3.5%	
5.	2.58127 kg fresh water is used for every kg of BD pulp feed, with a minimum set at 623 Lpm = 0.9 ML/d.	

8.4.21 Newsprint

The newsprint machine receives pulp from the re-pulpers and also from the groundwood plant to produce newspaper. The newsprint machine is done to a level 3 detail.

Table 99: Newsprint Assumptions and Mass Balance Control Logic

#	Assumption	Comment or Reference
1.	Fresh water usage = 5 kg/kg BD total feed = 1 019 Lpm = 1.46 ML/d.	
2.	Hot water usage = 4.64 kg/kg BD total feed = 945 Lpm = 1.36 ML/d.	
3.	Steam usage = 3.12 kg/kg BD total feed = 635 kg/min = 0.91 ML/d.	

Table 99: Newsprint Assumptions and Mass Balance Control Logic - continued

#	Assumption	Comment or Reference
4.	3.756% of all incoming liquor is evaporated to atmosphere = 263 kg/min	
5.	Assume a production rate of 317 ADt/d.	
6.	The fraction of pulp from the groundwood plant make-up the total pulp feed is specified by the user = 83% = 270 ADt/d.	
7.	Pulp consistency from groundwood is specified by the user = 0.04%	
8.	0 kg/min of water is assumed to ingress from the #2 service cooling tower system into the Newsprint water system.	
9.	0 kg/min of water is assumed to overflow from KLB clean water collection tank to the Newsprint effluent.	
10.	Desorption is assumed to place at the following rate; • 99% of all incoming sorbed sodium desorps • 0% of all incoming sorbed magnesium desorps • 100% of all incoming sorbed calcium compounds desorp.	
11. 12.	97.2% of all incoming pulp ends up in the paper produced. Although the paper composition and production is the result of many factors, in calibrating the model the liquor in the paper is assumed to have the following properties: • Production = 308 t/d • Consistency = 92.7% • Pulp = 99.7 % of total solids • Sorbed sodium = 0% of total solids • Inerts = 1.3% of total solids • Chloride = 4 mg/L • Sodium = 35 mg/L • Sulphate = 3 mg/L • Magnesium = 0 mg/L • COD = 611 mg/L • Calcium = 120 mg/L • TTA = 0.03 g/L as Na_2O	

Table 99: Newsprint Assumptions and Mass Balance Control Logic - continued

#	Assumption	Comment or Reference
13.	Although the composition of the back water to #3 re-pulper and flow is the result of many factors, in calibrating the model the back water was assumed to have the following properties: • Flow = 792 kg/min = 1.14 ML/d • SS = 108 mg/L • Pulp = 88.6 % of total solids • Sorbed sodium = 0% of total solids • Inerts = 11.2% of total solids • Chloride = 9 mg/L • Sodium = 55 mg/L • Sulphate = 40 mg/L • Magnesium = 4 mg/L • COD = 1 384 mg/L • Calcium = 23 mg/L • TTA = 0.03 g/L as Na_2O	
14.	Although the composition of the back water to the groundwood plant and flow is the result of many factors, in calibrating the model the back water was assumed to have the following properties: • Flow = 4 176 kg/min = 6.0 ML/d • SS = 116 mg/L • Pulp = 98.7 % of total solids • Sorbed sodium = 0% of total solids • Inerts = 1% of total solids • Chloride = 8 mg/L • Sodium = 49 mg/L • Sulphate = 47 mg/L • Magnesium = 11 mg/L • COD = 1 253 mg/L • Calcium = 20 mg/L • TTA = 0.03 g/L as Na_2O	

Table 99: Newsprint Assumptions and Mass Balance Control Logic - continued

#	Assumption	Comment or Reference
15.	Although the effluent composition and flow is the result of many factors and also the 'excess' stream from the Newsprint, in calibrating the Newsprint balance the effluent was assumed to have the following properties: • Flow = 1 752 kg/min = 2.52 ML/d • SS = 3 331 mg/L • Pulp = 98.9 % of total solids • Sorbed sodium = 0% of total solids • Inerts = 1.1 % of total solids • Chloride = 17 mg/L • Sodium = 170 mg/L • Sulphate = 154 mg/L • Magnesium = 18 mg/L • COD = 1 837 mg/L • Calcium = 46 mg/L • TTA = 0.80 g/L as Na_2O	
16.	0.01368 kg dye is required for every BD kg of pulp feed = 2.8 Lpm • Inerts = 100% of solids • COD = 60 000 mgL.	
17.	0.0706 kg organopol is required for every BD kg of pulp feed = 14.4 Lpm • Inerts = 100% of solids • COD = 60 000 mgL.	
18.	0.06289 kg organosorb is required for every BD kg of pulp feed = 12.8 Lpm • Inerts = 100% of solids • COD = 60 000 mgL.	
19.	0.00121 kg aquamol is required for every BD kg of pulp feed = 0.25 Lpm • Inerts = 100% of solids • COD = 60 000 mgL.	
20. 21.	0.0007 kg magnafloc is required for every BD kg of pulp feed = 0.14 Lpm • Inerts = 100% of solids • COD = 60 000 mgL. 0.00032 kg cathol is required for every BD kg of pulp feed = 0.07 Lpm • Inerts = 100% of solids • COD = 60 000 mgL.	
22.	0.0051 kg biocide is required for every BD kg of pulp feed = 1.04 Lpm • Inerts = 100% of solids • COD = 60 000 mgL.	

8.4.22 Groundwood

The groundwood plant has ten stone grinders of which two are pressure grinders. Logs are washed and ground to a pulp after which the pulp is screened and stored for use on the Newsprint machine.

Table 100: Groundwood Assumptions and Mass Balance Control Logic

#	Assumption	Comment or Reference
1.	EDTA usage is 0.000513 kg per kg logs (as is, i.e. with moisture) fed, and with COD =60 000 mg/L. The EDTA flow is at 0.2 kg/min.	
2.	Hydrogen peroxide usage is zero kg/min.	
3.	0.000217 kg caustic is used per kg logs fed, and at 1 000 000 mg/kg sodium concentration and zero hydroxide concentration. The flow is 0.1 kg/min.	
4.	0.0015481 kg hydrosulfite is consumed per kg logs fed, and a sodium concentration of 262 000 mg/L and sulphate concentration at 220 000 g/L. The flow is 0.7 kg/min.	
5. 6.	1.889 kg fresh water used per kg logs fed. The fresh water used is 855.4 kg/min. Assume that the steam consumption is zero kg per kg logs fed.	
7.	11.2% of all incoming liquor (i.e. fresh water, steam, back water, liquor in wood etc) evaporates. This will give a flow rate of 598 kg/min.	
8.	99.8% of all fibre entering groundwood (i.e. from logs, return back water etc) leaves groundwood as pulp to Newsprint, and at a consistency of 4%. Assume that 86% of all liquor entering groundwood leaves in the pulp to Newsprint. This will give a total pulp flow of 4 227 kg/min = 270 ADt/d.	
9.	The rejects effluent stream is at 326.8 kg/min with a composition of: • Suspended solids = 600 mg/L • Na = 47 mg/L • Cl^- = 12 mg/L • SO_4 = 60 mg/L • Ca = 30 mg/L • Mg = 17 mg/L • COD = 2 084 mg/L	

Table 100: Groundwood Assumptions and Mass Balance Control Logic - continued

#	Assumption	Comment or Reference
10.	The floor drain effluent stream is at 318.9 kg/min with a composition of: • Suspended solids = 500 mg/L • Na = 45 mg/L • Cl^- = 7 mg/L • SO_4 = 40 mg/L • Ca = 38 mg/L • Mg = 17 mg/L • COD = 730 mg/L	
11.	Assume that the rejects effluent flume contributes 2.1% to unaccounteds. That is a flow of 7.1 kg/min.	
12.	Assume that the floor drain flume contributes 2.1% to unaccounteds. That is a flow of 7.1 kg/min.	

8.4.23 Kraft Liner Board (KLB)

The Kraft Liner Board machine utilizes pulp from the waste plant (recycled fibre) and from the re-pulpers to produce box paper or white top liner. The KLB machine is done to between a level 2 and level 3 detail.

Table 101: Kraft Liner Board Assumptions and Mass Balance Control Logic

#	Assumption	Comment or Reference
1.	The user defines whether KLB or WTL is produced. The furnishes for KLB and WTL is user defined. Although the model is calibrated to adjust the furnish depending on whether KLB or WTL is selected, the model is however not calibrated for WTL in terms of stream qualities and flows.	
2.	The production required is used defined and the model was calibrated using a production rate of 633 ADt/d.	
3.	Machine uptime is user defined and impacts on what rate the paper machine must run to achieve the user defined production rate. The uptime is taken as 10%.	
4.	Shrinkage is assumed to be 10%.	
5.	Unbleached hardwood reels from uptake #1 is user defined as 50% of the hardwood make-up. The remaining unbleached hardwood is made up from #2 uptake reels.	
6.	Unbleached softwood reels from uptake #1 is user defined as 50% of the softwood make-up. The remaining unbleached softwood is made up from #2 uptake reels.	
7.	3.37976 kg fresh water is required for every BD kg of pulp fed.	
8.	1.58132 kg hot water is required for every BD kg of pulp fed.	

Table 101: Kraft Liner Board Assumptions and Mass Balance Control Logic - continued

#	Assumption	Comment or Reference
9.	0.0035 kg size is used for every BD kg of pulp fed. • COD = 800 000 mg/L	
10.	0.0146 kg alum is used for every BD kg of pulp fed. • Sulphate = 842 mg/L	
11.	0.001 kg PAC is used for every BD kg of pulp fed. • Chloride = 200 000 mg/L	
12.	0.0004 kg PAM is used for every BD kg of pulp fed.	
13.	0.0003 kg Buckman 5031 is used for every BD kg of pulp fed.	
14.	0.0021 kg BMA is used for every BD kg of pulp fed.	
15.	1.7417 kg steam is used for every BD kg of pulp fed.	
16.	The user defined stock furnish on which the model is calibrated when feeding KLB is: • UBHW = 23.5% • UBSW = 58.5% • FBHW = 0% • FBSW = 0% • Secondary fibre from waste plant = 18%	
17.	The composition for HW furnish is further defined by pulp supplier: • 50% HW reels • 50% HW noodle	
18.	The composition for SW furnish is further defined by pulp supplier: • 50% SW reels • 50% SW noodle	
19.	Desorption is assumed to place at the following rate; • 100% of all incoming sorbed sodium desorps • 0% of all incoming sorbed magnesium desorps • 100% of all incoming sorbed calcium compounds desorp.	

Table 101: Kraft Liner Board Assumptions and Mass Balance Control Logic - continued

#	Assumption	Comment or Reference
20.	Although the composition of the back water to repulpers and flow are the result of many factors, in calibrating the model the back water was assumed to have the following properties: • Flow = 7 866 kg/min = 11.3 ML/d • SS = 1 243 mg/L • Pulp = 89.1 % of total solids • Sorbed sodium = 10.8% of total solids • Inerts = 11.2% of total solids • Chloride = 66 mg/L • Sodium = 180 mg/L • Sulphate = 2 880 mg/L • Magnesium = 16 mg/L • COD = 1 209 mg/L • Calcium = 40 mg/L • TTA = 2.012 g/L as Na_2O	
21.	Although the composition of the back water to waste plant repulper and flow is the result of many factors, in calibrating the model the back water was assumed to have the following properties: • Flow = 1 906 kg/min = 2.74 ML/d • SS = 345 mg/L • Pulp = 96.1 % of total solids • Sorbed sodium = 0% of total solids • Inerts = 3.9 % of total solids • Chloride = 52 mg/L • Sodium = 219 mg/L • Sulphate = 1 612 mg/L • Magnesium = 16 mg/L • COD = 1 209 mg/L • Calc ium = 82 mg/L • TTA = 2.01 g/L as Na_2O	

Table 101: Kraft Liner Board Assumptions and Mass Balance Control Logic - continued

#	Assumption	Comment or Reference
22.	Although the composition of the effluent and flow is the result of many factors, in calibrating the model the effluent was assumed to have the following properties: • Flow = 2 739 kg/min = 3.9 ML/d • SS = 2 346 mg/L • Pulp = 99.4 % of total solids • Sorbed sodium = 0% of total solids • Inerts = 6 % of total solids • Chloride = 74 mg/L • Sodium = 346 mg/L • Sulphate = 1 826 mg/L • Magnesium = 16 mg/L • COD = 1 209 mg/L • Calcium = 114 mg/L • TTA = 2.01 g/L as Na_2O	
23.	Although the composition of the liquor in the paper product and flow is the result of many factors, in calibrating the model the liquor in the product paper is assumed to have the following properties: • Consistency = 92.4% • Pulp = 97.9 % of total solids • Sorbed sodium = 0% of total solids • Inerts = 2 % of total solids • Chloride = 128 mg/L • Sodium = 130 mg/L • Sulphate = 2 147 mg/L • Magnesium = 28 mg/L • COD = 3 747 mg/L • Calcium = 181 mg/L • TTA = 37.8 g/L as Na_2O	

8.4.24 Waste plant

The waste plant is the secondary fibre re-pulping plant. Secondary fibre bales (class K4) are re-pulped, screened and stored.

Table 102: Waste Plant Assumptions and Mass Balance Control Logic

#	Assumption	Comment or Reference
1.	Assume waste bales into the waste plant have the following composition: • Consistency 90% • Na =20 000 mg/L • Cl^- = 8 000 mg/L • SO_4 = 0 mg/L • Ca = 10 000 mg/L • Mg = 3 000 mg/L • COD = 20 000 mg/L	
2.	Assume that only 84% of the bone dry pulp in the waste bales go to KLB, the other 16% of bone dry pulp ends up in the waste plant effluent and solid waste rejects.	
3.	Assume that 0.29 kg steam is used for every kg BD bales fed = 27 Lpm.	
4.	Assume that 2.62 kg fresh water is used for every kg BD bales fed = 237 Lpm = 0.34 ML/d.	
5.	Assume that 95.6% of the liquor feeding into the waste plant (fresh water, steam and moisture in bales) contribute to KLB–waste plant backwater loop. The remaining water is discharged via the effluent and solid waste rejects.	
6.	Assume a 41% consistency for the waste plant rejects going to the macro dump.	

Table 102: Waste Plant Assumptions and Mass Balance Control Logic - continued

#	Assumption	Comment or Reference
7.	Although the pulp flow and composition to KLB depends on many factors, in calibrating these factors it is assumed that the pulp to KLB has the following composition: • Flow = 1 906 Lpm = 2.7 ML/d • Consistency 3.5% • Pulp = 95% of total solids • Sorbed sodium = 0.01% of total solids • Inerts = 5% of total solids • Na =279 mg/L • Cl^- = 82 mg/L • SO_4 = 1 429 mg/L • Ca = 115 mg/L • Mg = 28 mg/L • COD = 1 082 mg/L	
8.	Although the effluent composition and flow depends on many factors, in calibrating these factors it is assumed that the effluent stream has the following composition: • Flow = 69 Lpm = 0.10 ML/d • Suspended solids = 63 mg/L • Pulp = 0% of total solids • Sorbed sodium = 0.01% of total solids • Inerts = 99% of total solids • Na = 523 mg/L • Cl^- = 127 mg/L • SO_4 = 1 080 mg/L • Ca = 149 mg/L • Mg = 16 mg/L • COD = 2 742 mg/L	

8.4.25 Fresh water Treatment Plant

Fresh water supply is from the fresh water treatment plant, which treats water originating from the Ngodwana dam. Fresh water is supplied to the mill, the shopping center, Ngodwana village, Jabulani hostel and also to Mbokodo village.

Table 103: Fresh water Treatment Plant Assumptions and Mass Balance Control Logic

#	Assumption	Comment or Reference
1.	The fresh water into the mill is assumed to have the following user defined quality: • SS = 0.6 mg/L • Inerts = 100% of total solids • Chloride = 2.6 mg/L • Sodium = 3.8 mg/L • Sulphate = 8.3 mg/L • Magnesium = 5.1 mg/L • COD = 15 mg/L • Calcium = 13.6 mg/L • TTA = 0 g/L as Na_2O.	
2.	The fresh water quantity is the result of many factors, but in calibrating these factors it was assumed that 39.8 ML/d of fresh water into the mill is correct.	
3.	The fresh water treatment plant balance was not done to a level 2 detail, only sufficient detail was considered to identify flow quantities. The fresh water feed quality into the mill for example is independent on the raw dam water feed into the fresh water treatment plant. The fresh water feed quality into the mill is user defined.	This is because apart from the quality of the fresh water, the fresh water treatment plant plays an insignificant role on the mill operation. The fresh water quality is user defined.
4.	The sand filter back wash and darifier under flow that discharge to the effluent treatment plant is assumed to have the following flow and properties: • Flow = 29 Lpm • SS = 787 mg/L • Inerts = 100% of total solids • Chloride = 8 mg/L • Sodium = 3.8 mg/L • Sulphate = 36 mg/L • Magnesium = 8 mg/L • COD = 15 mg/L • Calcium = 28 mg/L • TTA = 0 g/L as Na_2O.	

Table 104: Fresh water users [W Henning, B Thom]

User	Flow (m^3/hr)	Flow (kg/min)
Jabulani hostel	40	667
Mbokodo	4.5	75
Sewerage treatment plant and shopping centre	4.5	75
Ngodwana Village	19	322[1]
Total	**68**	**1 139**

1. Calculated from literature figures for consumption per capita and info from housing on inhabitants

Table 105: Treated fresh water Quality [laboratory technical report Oct – Jun 1999]

Property	Units	Value
pH		8.3
Calcium	mg/L as $CaCO_3$ mg/L as Ca	33.9 13.6 / 13.6
Magnesium	mg/L as $CaCO_3$ mg/L as Mg	21.1 5.1 / 5.1
Carbonate alkalinity	mg/L as $CaCO_3$ mg/L as CO_3^{2-}	0.079 0.047 / 28.5
Suspended solids	mg/L	0.62 / 0.62
Manganese	mg/L	0.014
Iron	mg/L	0.089
Chlorides	mg/L	2.61 / 2.61
Sodium	mg/L	3.8 / 3.8
Sulphate	mg/L	8.3 / 8.3

Table 106: Chemical Useage on Fresh water treatment plant [B Thom history 99]

Chemical	Units	Value
Fresh water treated	kg/min	25 556
Alum @ 50%	1000 kg/kg fresh water	0.039012
Hydrated lime @ 50%	1000 kg/kg fresh water	0.02731
Poly-electrolyte	1000 kg/kg fresh water	0.0002
Chlorine	1000 kg/kg fresh water	0.0017

8.4.26 Storm water Ponds

Two storm water ponds receive run-off after rain. The storm water ponds also receive water from the mill on non-raining days, this includes water seal water and cooling water which are almost the same quality as fresh water. As the one storm water pond is being filled, the water in the other pond is checked to see if the quality complies to general standard qualities, and if so it is discharged to the Ngodwana river. Should the quality not adhere to general standards, the storm water is then discharged to effluent.

Table 107: Storm Water Ponds Assumptions and Mass Balance Control Logic

#	Assumption	Comment or Reference
1.	Zero mega liters per day of storm water is discharged to effluent treatment.	
2.	The ponds receive 585 Lpm = 0.84 ML/d of storm water and all of it is discharged to the Ngodwana river.	

8.4.27 Effluent treatment Plant

The effluent treatment plant receives two types of effluent, the general effluent and the bleach effluents. The general effluent consist of mainly the non-chloride containing effluents, where as the bleach effluents have the high chloride containing streams. The two streams go through separate clarifiers to remove the suspended solids, after which the two streams are combined and pumped to the irrigation fields for irrigation. Two large emergency dams (ED's) are used to buffer out peaks in the effluent flows.

Table 108: Effluent Treatment Plant Assumptions and Mass Balance Control Logic

#	Assumption	Comment or Reference
1.	0.01 kg de-foamer and other chemicals are used for every kg of bleach chemical received = 72 Lpm but only contributing to total mass and not individual components, i.e. no sodium, chloride or COD etc in the chemicals added.	
2. 3.	2.5 Lpm of scum is removed from the bleach plant clarifier and is dumped to solid waste. The composition of the scum is: • Consistency = 1% • Pulp = 98% of total solids • Inerts = 2% of total solids • Chloride = 1 920 mg/L • Sodium = 1 060 mg/L • Sulphate = 200 mg/L • Magnesium = 77 mg/L • COD = 1 232 mg/L • Calcium = 69 mg/L • TTA = 0.2 g/L as Na_2O The bleach plant clarifier is operated at: • Overflow suspended solid content = 83 mg/L • Consistency = 2.5%	
4.	No fresh water is used on the effluent treatment plant.	
5.	No chemical or de-foamer are assumed to be used on the general effluent clarifier.	
6.	The sand filter back wash and clarifier under flow from the fresh water treatment plant is added to the general effluent before the general effluent clarifier.	
7.	Dregs is added to the general effluent clarifier. The dregs have the following composition: • Flow = 22.5 t/d • Consistency = 47% • Pulp = 0% of total solids • Inerts = 25% of total solids • $CaCO_3$ = 65% of total solids • CaO = 8% of total solids • CaOH = 1.4% • $CaSO_4$ = 0% • Chloride = 4 315 mg/L • Sodium = 79 914 mg/L • Sulphate = 6 943 mg/L • Magnesium = 77 mg/L • COD = 1 910 mg/L • Calcium = 36 mg/L • TTA = 107 g/L as Na_2O	

Table 108: Effluent Treatment Plant Assumptions and Mass Balance Control Logic

#	Assumption	Comment or Reference
8.	2.5 Lpm of scum is removed from the general effluent clarifier and is dumped to solid waste. The composition of the scum is: • Consistency = 1% • Pulp = 98% of total solids • Inerts = 2% of total solids • Chloride = 1 920 mg/L • Sodium = 1 060 mg/L • Sulphate = 200 mg/L • Magnesium = 77 mg/L • COD = 1 232 mg/L • Calcium = 69 mg/L • TTA = 0.2 g/L as Na_2O	
9. 10.	The general effluent clarifier is operated at: • Overflow suspended solid content = 350 mg/L • Consistency = 2.5% The under flow from the bleach and general effluent clarifiers are dried in the centrifuge and belt filter press. No distinction is made between the two presses and it is assumed the underflow is pressed to: • Outlet consistency = 18% • Filtrate suspended solids = 100 mg/L	
11.	The press filtrate is returned to the general effluent clarifier.	
12.	0.1% of the effluent is assumed to be evaporated from the effluent treatment plant = 15 Lpm.	

Table 108: Effluent Treatment Plant Assumptions and Mass Balance Control Logic - continued

#	Assumption	Comment or Reference
13.	The irrigated effluent quality is the result of many factors, but in calibrating these factors it was assumed that the irrigated effluent had the following flow and quality: • Flow = 19 270 Lpm = 27.7 ML/d • SS = 250 mg/L • Pulp = 71% of total solids • Sorbed sodium = 0% of total solids • Inerts = 8% of total solids • $CaCO_3$ = 18% of total solids • CaO = 2% of total solids • CaOH = 4% • $CaSO_4$ = 0% • Chloride = 761 mg/L • Sodium = 732 mg/L • Sulphate = 395 mg/L • Magnesium = 39 mg/L • COD = 2 122 mg/L • Calcium = 62 mg/L • TTA = 2.2 g/L as Na_2O	
14.	The solid waste stream flow and quality is the result of many factors, but in calibrating these factors it was assumed that the solid waste to dump had the following flow and quality: • Flow = 106 kg/min = 153 t/d • Consistency = 18% • Pulp = 68% of total solids • Sorbed sodium = 0% of total solids • Inerts = 9% of total solids • $CaCO_3$ = 20% of total solids • CaO = 3% of total solids • CaOH = 0% • $CaSO_4$ = 0% • Chloride = 711 mg/L • Sodium = 541 mg/L • Sulphate = 510 mg/L • Magnesium = 16 mg/L • COD = 2 647 mg/L • Calcium = 58 mg/L • TTA = 3.4 g/L as Na_2O	
15.	No dissolving effect of dregs solids had been accounted for.	
16.	In calibrating the effluent treatment plant, it was assumed that the effluent flows and unaccounted flows, and qualities, are as depicted by each individual plant.	

Table 109: Effluent flume data [averages from daily effluent report period 01/01/99-31/12/99]

Effluent flume	Flow		Soda loss[1]	Solid loss
	ML/d	kg/min	t Na_2SO_4/day	ton / day
No 1 digester and uptake	0.22	153	1.2	0.5
No 2 digester	0.53	368	2.4	0.3
No 2 digester (hot water tank)	0.1	69		
Bleach plant floor drain	0.82	569		
No 3 Uptake	0.71	493	0.5	0.6
No 2 Uptake	0.51	354	1.3	0.7
PF boiler and CRF 2	0.73	507	1.2	
Evaporators	4.52	3 139	6.8	
Waste plant	0.11	76		
Groundwood floor	0.47	326		
Groundwood reject drain	0.45	313		
Newsprint	2.65	1 840	1	8.7
Kraft Liner board	3.66	2 542	4	7.3
D/C stage	6.58	4 569	16.7	0.5
E stage	2.34	1 625	8.9	0.3
Chlorine dioxide plant	0.5	347		
Demin	0.58	403		
Irrigated	27.76	19 278	60.6	
Unaccounteds			9.2	8.1
• **Pulp mill (85%)**	**1.93**	**1 340**		
Evaporators (67%)	1.53	1 063		
#1 fibre line (5%)	0.11	76		
#2 fibre line (5%)	0.11	76		
TG 2 cooling tower (5%)	0.12	84		
Auxiliary boilers (3%)	0.06	42[2]		
• **Paper mill (15%)**	**0.34**	**236**		
Kraft liner board (7%)	0.16	111		
Newsprint (7%)	0.16	111		
Groundwood rejects (0.5%)	0.01	7		
Groundwood floor (0.5%)	0.01	7		
• **Total**	**2.27**	**1 576**		

1. Soda excludes soda absorbed onto fibre
2. Measured

8.4.28 Cooling Towers

The cooling towers have a very prominent and important role in at least one of the proposed effluent reduction projects. The ERP1 option uses recycled water as make-up in certain cooling towers and the blow down is then discharged to the causticizing section. Some of the cooling towers form part of one section only, but other cooling towers are shared by different users.

#1 Service or New Evaporators' Cooling Tower

This cooling tower receives contaminated condensate (CCA) as make-up water, and is manually blown down occasionally. The cooling water is used to cool down the new evaporator's vapour from the final condensate.

Table 110: #1 Service Cooling Tower/New Evaps Cooling Tower Assumptions and Mass Balance Control Logic

#	Assumption	Comment or Reference
1.	Assume the evaporation rate is 2 090 kg/min of pure H_2O	
2.	Assume that 108 647 kg/min of cooling water is used on the surface condensor and after cooler, and that there is no losses or ingress of water into this cooling loop.	
3.	Assume that blow down rate is 343 kg/min.	
4.	Assume that 1 758 kg/min contaminated condensate is used as make-up in addition to the constant fresh water make-up.	
5.	Assume that 675 kg/min of fresh water is used as make-up.	

Old Evaporator's Cooling Tower

The cooling tower also receives contaminated condensate as make-up and is also manually blown down. The cooling water is used to cool the vapour from the #1 evaporator set's final effect.

Table 111: Old Evaps Cooling Tower Assumptions and Mass Balance Control Logic

#	Assumption	Comment or Reference
1.	Assume the evaporation rate is 400 kg/min of pure H_2O	
2.	Assume that 1000 kg/min of water is used to cool tower #1 smelt dissolving spout, and that only 990 kg/min water returns. I.e. 10 kg/min of losses from the spout cooling loop.	
3.	Assume that 41 523 kg/min of cooling water is used for #1 evaporator's surface condensor and condensor. Also that all of this water returns, i.e. no ingress or losses from the cooling loop.	
4.	Assume that #1 CRF ID fan cooling water is used as make-up at a rate of 423 kg/min.	
5.	Assume that the contaminated condensate make-up rate is 56 kg/min.	
6.	Assume that blow down rate is 69 kg/min.	

#2 Service Cooling Tower

This cooling water is shared/used by almost the whole mill for cooling of compressors, air conditioners, seal water and many other heat exchangers.

Table 112: #2 Service Cooling Tower Assumptions and Mass Balance Control Logic

#	Assumption	Comment or Reference
1.	Assume the evaporation rate is 493 kg/min of pure H_2O	
2.	Assume that 100 kg/min of the cooling water is used in the ClO_2 plant, i.e. except for the 100 kg/min all cooling water from the cooling tower returns to the cooling tower.	
3.	Only fresh water is used as make-up at a rate of 707 kg/min to account for evaporation, blow down and losses from return cooling water.	
4.	Assume that blow down rate is 114 kg/min.	

Turbine Generator #2 or TG2 Cooling Tower

This cooling tower is used to cooling down the turbine generators and requires a high quality water.

Table 113: TG2 Cooling Tower Assumptions and Mass Balance Control Logic

#	Assumption	Comment or Reference
1.	Assume the evaporation rate is 2 090 kg/min of pure H_2O	
2. 3.	Assume that all 16 302.5 kg/min of cooling water to TG2 returns to TG2 cooling tower. I.e. no losses or ingress into cooling loop. Assume that blow down rate is 289 kg/min.	
4.	Assume that the blow down stream contributes to unaccounteds effluent.	
5.	Assume that enough fresh water is made up to account for losses via the blow down and evaporation.	

Lube Oil Cooling Tower (old TG1 Cooling Tower)

Table 114: Lube Oil Cooling Tower Assumptions and Mass Balance Control Logic

#	Assumption	Comment or Reference
1.	Assume the evaporation rate is 92.7 kg/min of pure H_2O	
2.	Assume that only fresh water is used as make-up to account for blow down and evaporation losses.	
3.	Assume that blow down rate is 653 kg/min.	

Excess Hot water Cooling Tower

The hotwater system takes fresh water in, the fresh water is used in the C61, T20 and T21 condensers at the #2 digester (flashed WBL vapour cooling). The water going through these heat exchangers is then discharged as warm water into the warm water tank. From the warm water tank the water is used again in the T11 heat exchanger which heats the water up from about 40°C to 82°C and discharges the water into the hot water system. From the hot water system, different users take-off hot water, any excess hot water goes through the excess hot water cooling tower and is returned to the warm water-cooling tower.

Table 115: Excess Hot water Cooling Tower Assumptions and Mass Balance Control Logic

#	Assumption	Comment or Reference
1.	Assume the evaporation rate is 277 kg/min of pure H_2O	
2.	Cooled warm water to #2 fibre line warm water tank = 4541 kg/min	
3.	Assume that blow down rate is 191 kg/min.	
4.	Assume that 0 kg/min of fresh water is used as make-up.	

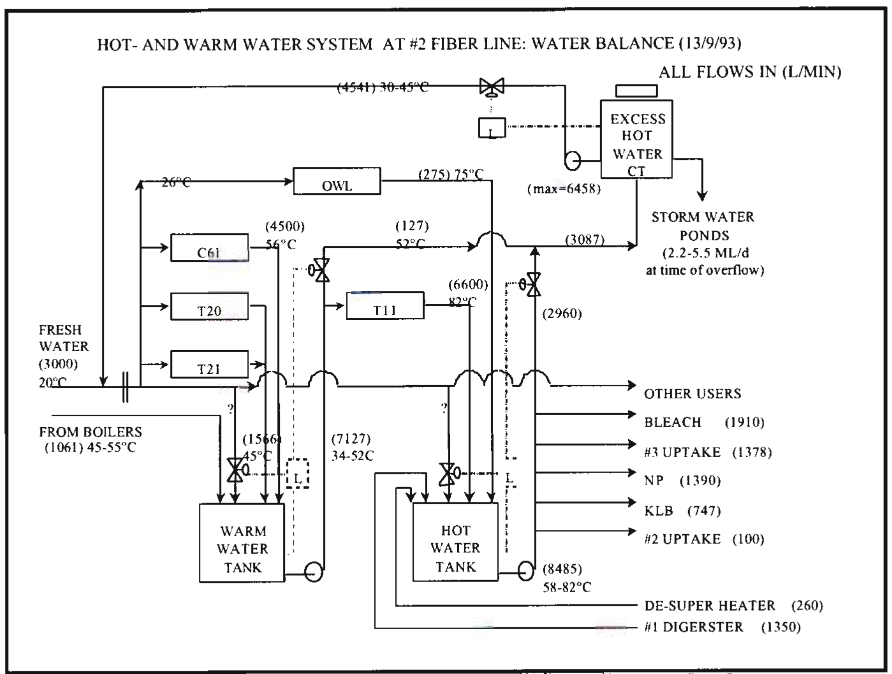


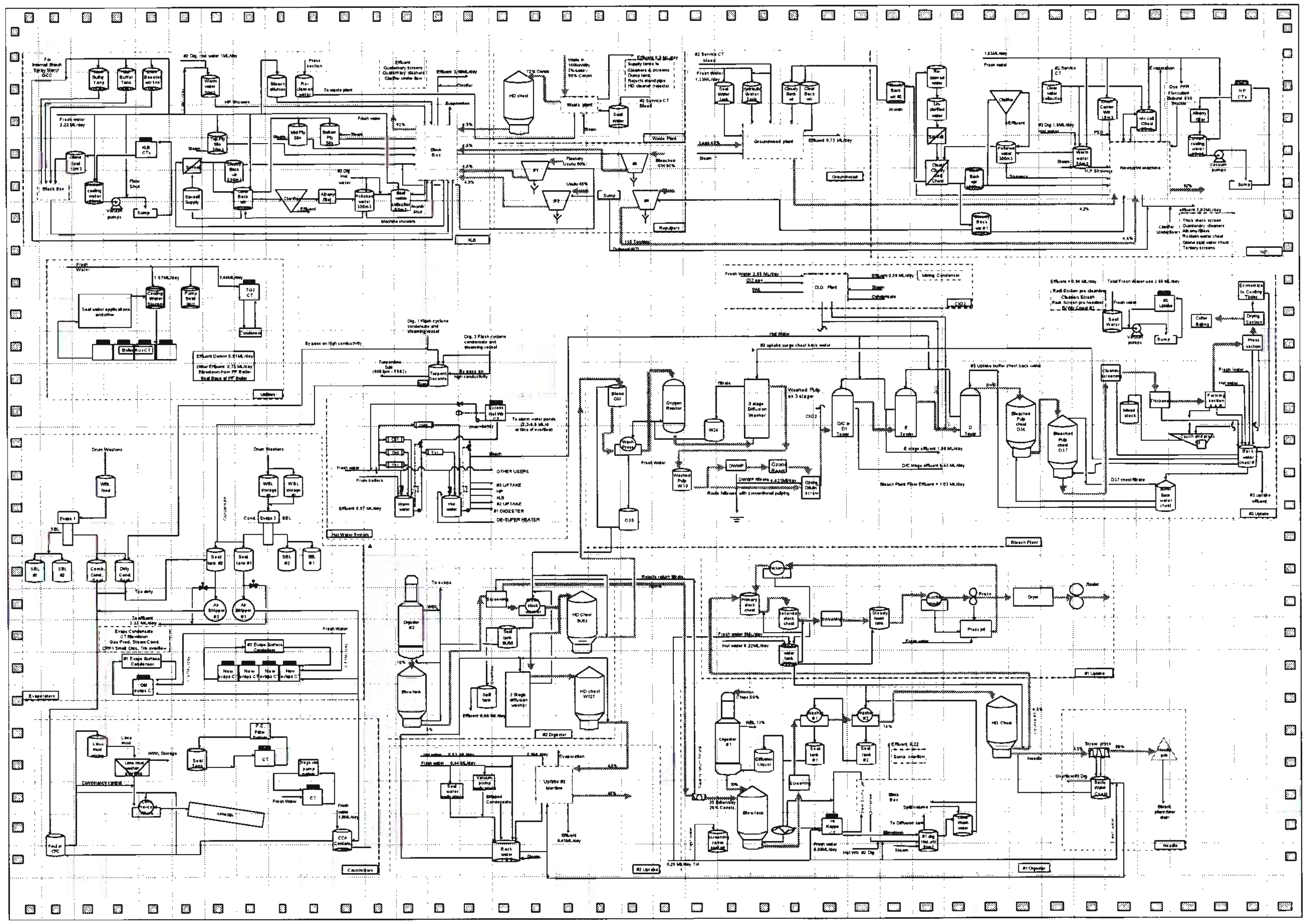
Figure 8-50: Hot and Warm water system Block flow diagram [PE]

Hi-Kappa Cooling Tower

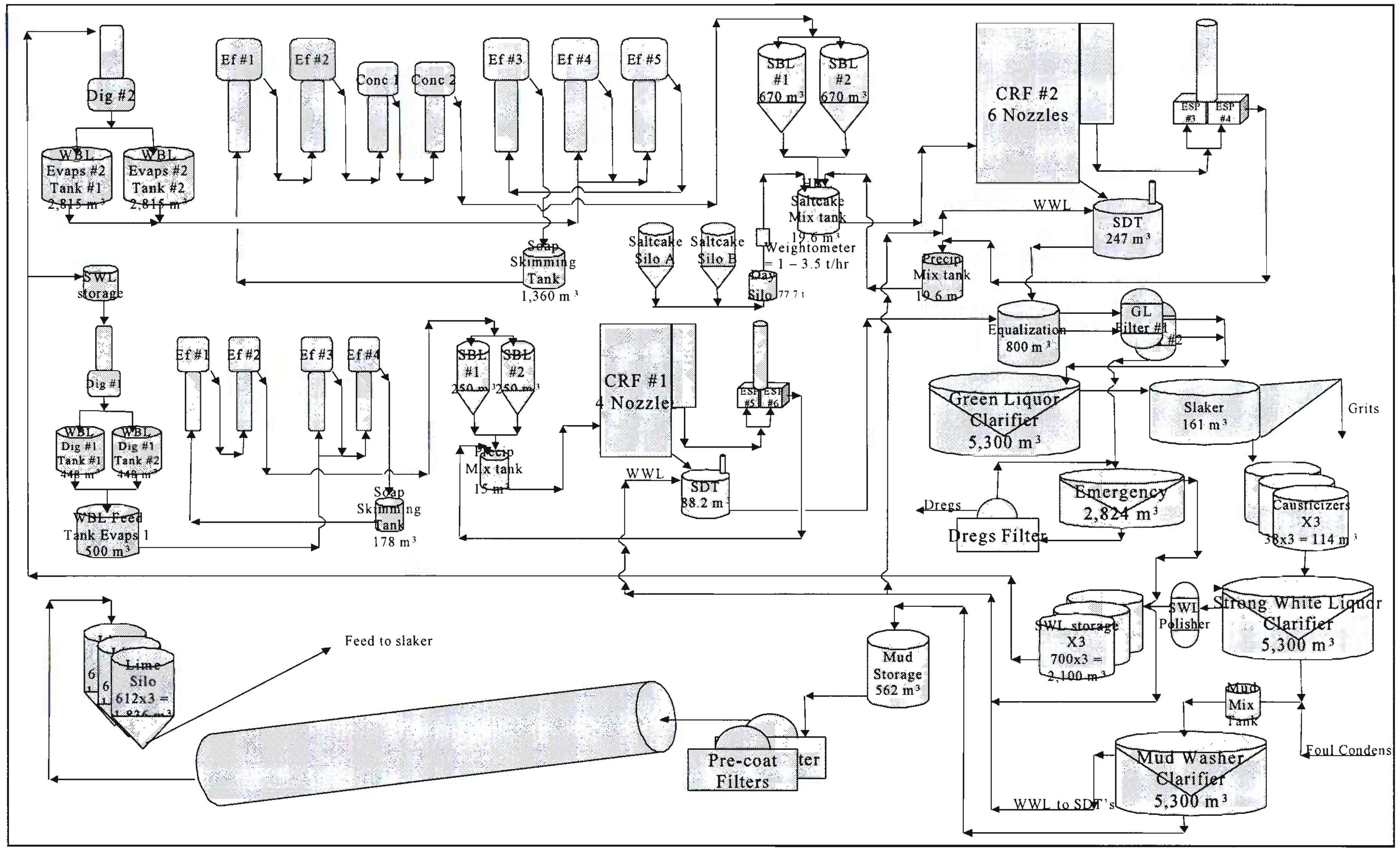
Table 116: Hi Kappa Cooling Tower Assumptions and Mass Balance Control Logic

#	Assumption	Comment or Reference
1.	Assume the evaporation rate is 10 kg/min of pure H_2O	
2.	Cooled warm water to #2 fibre line warm water tank = 1000 kg/min	
3.	Assume that blow down rate is 29.2 kg/min.	
	Assume that 39.2 kg/min of fresh water is used as make-up.	

8.5 Mill Water Network Schematic



8.6 Chemical Process Flow Schematic



8.7 Mill Laboratory Analyses Data base

8.8 Proposed Mill Network (without relaxing concentration limits)

(without adding technology and without relaxing concentrations limits)

Table 117: Match Table (without relaxing concentrations)

Source	Unit	Flow (kg/min)
bleach - 3 stage out	bleach - oxygen reactor dilution	1840
	dig 2 - dilution and blow tank control - simplified	938
	bleach - O33 blend chest	688
	bleach - wash press in	676
	dig 1 - dilution control and screening - simplified	130
	dig 2 - screen dilution	18
bleach - D2 tower out	mill - irrigation fields	4022
	upt 3 - D37, mixed stock, cleaning cons, thickener - simplified	5
bleach - DC tower out	mill - irrigation fields	3852
	bleach - 3 stage in	182
	bleach - D36 consistency	138
	bleach - E tower in	129
	upt 3 - D37, mixed stock, cleaning cons, thickener - simplified	50
	dig 2 - hot and warm water tanks in	2
	CT's - simplified in	1
	dig 2 - seal water	0
bleach - E tower out	bleach - DC tower in	3760
	bleach - 3 stage in	372
	upt 2 - machine chest consist cntrl	29
	dig 2 - hot and warm water tanks in	0
	CT's - simplified in	0
	dig 2 - seal water	0
bleach - wash press out	dig 2 - brown stock washer in	4190
	bleach - O33 blend chest	3615
	dig 2 - dilution and blow tank control - simplified	311
	dig 1 - dilution control and screening - simplified	212
caust - WWL ex lime mud washer	CRF2 and 1 - SDT (WWL) - simplified	2541

Table 117: Match Table (without relaxing concentrations) - continued

Source	Unit	Flow (kg/min)
ClO2 effluent	dig 2 - brown stock washer in	356
	dig 2 - dilution and blow tank control - simplified	64
	repulpers - #1 &2 - simplified	16
	CRF2 and 1 - SDT (WWL) - simplified	16
	dig 2 - hot and warm water tanks in	2
	CT's - simplified in	1
	dig 2 - seal water	0
	CT - excess hot water in	0
CT - Evaps - simplified out	mill - irrigation fields	412
CT - excess hot water out 1	dig 2 - hot and warm water tanks in	171
CT - excess hot water out 2	dig 2 - hot and warm water tanks in	4541
CT's - simplified out	upt 3 - D37, mixed stock, cleaning cons, thickener - simplified	941
CT's - simplified out	repulpers - #3	144
demin - caustic effluent	repulpers - #1 &2 - simplified	42
	upt 1 - sec stock chest, prim scr, steady head, dry end - simplified	29
	dig 1 - noodle feed consistency control	26
	dig 1 - uptake feed consistency control	20
dig 1 - extraction liquor	evaps - New evaps inlet	2227
	evaps - Old evaps inlet	71
	bleach - O33 blend chest	11
	dig 2 - brown stock washer in	0
dig 1 - wash filter 1 out	dig 1 - dilution control and screening - simplified	11037
	dig 2 - screen dilution	1249
	bleach - wash press in	443
	evaps - New evaps inlet	135
dig 1 - wsh filter 2 out	dig 1 - wash filter 1 in	2489
	dig 1 - uptake feed consistency control	145
dig 1 & 2 - effluent - simplified	dig 2 - brown stock washer in	704

Table 117: Match Table (without relaxing concentrations) - continued

Source	Unit	Flow (kg/min)
dig 2 - brown stock washer out	dig 2 - dilution and blow tank control - simplified	53853
	bleach - wash press in	1076
	dig 1 - dilution control and screening - simplified	161
	dig 2 - screen dilution	42
	CRF2 and 1 - SDT (WWL) - simplified	3
dig 2 - extraction WBL	evaps - New evaps inlet	3708
	evaps - Old evaps inlet	2129
	bleach - oxygen reactor dilution	0
dig 2 - hot and warm water tanks out	CT - excess hot water in	4988
	newsprint - fresh and hot water - simplified	2377
	KLB - hot and fresh water - simplified	1994
	CT's - simplified in	1625
	dig 2 - WBL cooler, T20/21 and T11 - simplified in	1083
	groundwood - other uses	618
	dig 2 - seal water	315
dig 2 - hot water effluent	dig 2 - hot and warm water tanks in	56
dig 2 - two stage washer out	mill - irrigation fields	776
	dig 2 - brown stock washer in	275
	upt 2 - machine chest consist cntrl	97
	dig 1 - wash filter 1 in	93
	dig 1 - noodle feed consistency control	41
	dig 1 - wsh filter 2 in	34
	caust - lime mud mixing	24
	repulpers - #3	13
	upt 1 - sec stock chest, prim scr, steady head, dry end - simplified	11

Table 117: Match Table (without relaxing concentrations) - continued

Source	Unit	Flow (kg/min)
dig 2 - WBL cooler, T20/21 and T11 - simplified out	dig 2 – hot and warm water tanks in	4854
	CT - Evaps - simplified in	518
dummy source	CRF1 and 2 - SBL incineration - simplified	45
evap - New evaps foul/cont clean	caust - lime mud mixing	1965
	bleach - D2 tower in	1426
	dig 1 - noodle feed consistency control	282
	groundwood - back water	263
	upt 3 - D37, mixed stock, cleaning cons, thickener - simplified	246
	dig 1 - wsh filter 2 in	162
	upt 1 - sec stock chest, prim scr, steady head, dry end - simplified	107
evap - New evaps foul/cont dirty	mill - irrigation fields	284
evaps - New evaps clean	evap - New evaps foul/cont inlet	4735
evaps - New evaps dirty	CRF1 and 2 - SBL incineration - simplified	1336
evaps - Old evaps clean	mill - irrigation fields	944
	bleach - D2 tower in	764
	groundwood - back water	8
evaps - Old evaps dirty	CRF1 and 2 - SBL incineration - simplified	484
From Utility...		
groundwood – effluent (rejects and floor) – simplified	mill - irrigation fields	387
	dig 2 - two stage washer in	51
KLB - b/w to waste plant	wasteplant - back water	2431
KLB - back water	repulpers - #1 &2 - simplified	9654
	upt 2 - machine chest consist cntrl	46
	CT - excess hot water in	0

Table 117: Match Table (without relaxing concentrations) - continued

Source	Unit	Flow (kg/min)
KLB – effluent	mill - irrigation fields	2334
	upt 2 - machine chest consist cntrl	165
	bleach - D36 consistency	84
	bleach - DC tower in	14
	groundwood - back water	10
	repulpers - #3	7
mill - fresh water	dig 2 - WBL cooler, T20/21 and T11 - simplified in	4289
	bleach - 3 stage in	3159
	upt 3 - D37, mixed stock, cleaning cons, thickener - simplified	2952
	CT - Evaps - simplified in	1704
	CT's - simplified in	1462
	dig 2 - hot and warm water tanks in	905
	upt 2 - machine chest consist cntrl	670
	dig 1 - wsh filter 2 in	634
	repulpers - #1 &2 - simplified	542
	dig 1 - uptake feed consistency control	491
	dig 2 - seal water	283
	dig 1 - noodle feed consistency control	208
	bleach - E tower in	152
	upt 3 - effluent in	98
	dig 1 - wash filter 1 in	52
	dig 2 - two stage washer in	52
	upt 1 - sec stock chest, prim scr, steady head, dry end - simplified	29
	CT - excess hot water in	1
	groundwood - back water	0
newsprint - back water	repulpers - #3	933
	groundwood - back water	125

Table 117: Match Table (without relaxing concentrations) - continued

Source	Unit	Flow (kg/min)
newsprint - cloudy back water	groundwood - back water	4796
	mill - irrigation fields	216
	bleach - D2 tower in	142
	bleach - D36 consistency	87
	caust - lime mud mixing	19
newsprint - effluent	mill - irrigation fields	2199
	bleach - E tower in	169
	dig 2 - two stage washer in	50
	bleach - 3 stage in	46
	bleach - DC tower in	9
	caust - lime mud mixing	8
	groundwood - back water	1
PF, CRF 1 and 2 - warm water simplified	dig 2 - hot and warm water tanks in	1236
stormwater - simplified	dig 2 - hot and warm water tanks in	1233
upt 1 - white water tank	upt 1 - sec stock chest, prim scr, steady head, dry end - simplified	2651
	dig 1 - wsh filter 2 in	1300
	dig 1 - uptake feed consistency control	994
	dig 1 - noodle feed consistency control	475
upt 2 - mould filtrate water	upt 2 - machine chest consist cntrl	10195
	dig 2 - two stage washer in	1518
	caust - lime mud mixing	23
upt 3 - D37 filtrate	bleach - D36 consistency	5024
	bleach - E tower in	2381
	bleach - 3 stage in	329
	bleach - D2 tower in	313
	upt 3 - D37, mixed stock, cleaning cons, thickener - simplified	7
	caust - lime mud mixing	1
upt 3 - effluent out	upt 3 - D37, mixed stock, cleaning cons, thickener - simplified	800
upt 3 - filtrate – simplified	upt 3 - D37, mixed stock, cleaning cons, thickener - simplified	28954
	mill - irrigation fields	2127
	bleach - D36 consistency	1616
	bleach - E tower in	1196
	bleach - D2 tower in	1011
	upt 3 - effluent in	702
	bleach - DC tower in	126
	groundwood - back water	55
	repulpers - #3	13
	upt 2 - machine chest consist cntrl	3

8.9 Proposed Mill Network (with relaxing concentration limits)
(without adding technology and with relaxing concentrations limits)

Table 118: Match Table (with relaxing concentrations)

Source	Unit	Flow (kg/min)
bleach - 3 stage out	bleach - oxygen reactor dilution	1812
	bleach - O33 blend chest	1161
	bleach - wash press in	736
	dig 2 - dilution and blow tank control - simplified	312
	dig 1 - dilution control and screening - simplified	129
	evaps - Old evaps inlet	125
	dig 2 - screen dilution	15
	CT - excess hot water in	1
bleach - D2 tower out	bleach - DC tower in	2287
	mill - irrigation fields	1423
	dig 2 - brown stock washer in	128
	bleach - wash press in	108
	bleach - D36 consistency	68
	bleach - oxygen reactor dilution	9
	repulpers - #3	4
bleach - DC tower out	mill - irrigation fields	4289
	groundwood - back water	37
	bleach - D36 consistency	26
	upt 2 - machine chest consist cntrl	1
bleach - E tower out	upt 3 - D37, mixed stock, cleaning cons, thickener - simplified	3715
	repulpers - #1 &2 - simplified	409
	wasteplant - back water	37
	dig 2 - seal water	0
bleach - wash press out	dig 2 - brown stock washer in	4507
	bleach - O33 blend chest	3152
	dig 2 - dilution and blow tank control - simplified	670

Table 118: Match Table (with relaxing concentrations) – continued

Source	Unit	Flow (kg/min)
caust - WWL ex lime mud washer	CRF2 and 1 - SDT (WWL) - simplified	2401
	caust - lime mud mixing	140
ClO2 effluent	repulpers - #1 &2 - simplified	362
	bleach - E tower in	51
	wasteplant - back water	25
	newsprint - fresh and hot water - simplified	9
	KLB - hot and fresh water - simplified	7
	dig 2 - seal water	0
CT - Evaps - simplified out	dig 2 - hot and warm water tanks in	401
	dig 2 - WBL cooler, T20/21 and T11 - simplified in	11
CT - excess hot water out 1	dig 2 - hot and warm water tanks in	171
CT - excess hot water out 2	dig 2 - hot and warm water tanks in	4541
CT's - simplified out	caust - lime mud mixing	871
	dig 2 - hot and warm water tanks in	190
	dig 2 - WBL cooler, T20/21 and T11 - simplified in	24
demin - caustic effluent	upt 3 - D37, mixed stock, cleaning cons, thickener - simplified	83
	caust - lime mud mixing	22
	repulpers - #1 &2 - simplified	6
	wasteplant - back water	5
dig 1 - extraction liquor	evaps - New evaps inlet	1911
	evaps - Old evaps inlet	398
dig 1 - wash filter 1 out	dig 1 - dilution control and screening - simplified	11094
	dig 2 - screen dilution	1257
	bleach - wash press in	512
dig 1 - wsh filter 2 out	dig 1 - wash filter 1 in	2489
	dig 1 - noodle feed consistency control	103
	upt 1 - sec stock chest, prim scr, steady head, dry end - simplified	42
dig 1 & 2 - effluent - simplified	dig 2 - brown stock washer in	704

Table 118: Match Table (with relaxing concentrations) – continued

Source	Unit	Flow (kg/min)
dig 2 - brown stock washer out	dig 2 - dilution and blow tank control - simplified	54185
	bleach - wash press in	597
	dig 1 - dilution control and screening - simplified	317
	dig 2 - screen dilution	36
dig 2 - extraction WBL	evaps - New evaps inlet	4159
	evaps - Old evaps inlet	1678
dig 2 - hot and warm water tanks out	CT - excess hot water in	4988
	dig 2 - WBL cooler, T20/21 and T11 - simplified in	3169
	newsprint - fresh and hot water - simplified	1925
	KLB - hot and fresh water - simplified	1283
	upt 3 - D37, mixed stock, cleaning cons, thickener - simplified	726
	groundwood - other uses	618
	dig 2 - seal water	290
dig 2 - hot water effluent	dig 2 - seal water	56
dig 2 - two stage washer out	mill - irrigation fields	637
	bleach - wash press in	243
	upt 2 - machine chest consist cntrl	193
	dig 2 - brown stock washer in	187
	dig 1 - wash filter 1 in	85
	bleach - oxygen reactor dilution	19
dig 2 - WBL cooler, T20/21 and T11 - simplified out	dig 2 - hot and warm water tanks in	5372
dummy source	CRF1 and 2 - SBL incineration - simplified	45
evap - New evaps foul/cont clean	mill - irrigation fields	3232
	bleach - DC tower in	883
	upt 2 - machine chest consist cntrl	228
	groundwood - back water	109
evap - New evaps foul/cont dirty	mill - irrigation fields	284
evaps - New evaps clean	evap - New evaps foul/cont inlet	4735
evaps - New evaps dirty	CRF1 and 2 - SBL incineration - simplified	1336

Table 118: Match Table (with relaxing concentrations) – continued

Source	Unit	Flow (kg/min)
evaps - Old evaps clean	mill - irrigation fields	1716
evaps - Old evaps dirty	CRF1 and 2 - SBL incineration - simplified	484
groundwood - effluent (rejects and floor) - simplified	mill - irrigation fields	438
KLB - b/w to waste plant	wasteplant - back water	2119
	repulpers - #1 &2 - simplified	245
	bleach - E tower in	67
KLB - back water	repulpers - #1 &2 - simplified	8862
	upt 3 - D37, mixed stock, cleaning cons, thickener - simplified	313
	upt 1 - sec stock chest, prim scr, steady head, dry end - simplified	263
	dig 1 - uptake feed consistency control	130
	dig 2 - hot and warm water tanks in	59
	caust - lime mud mixing	49
	dig 1 - wash filter 1 in	23
KLB - effluent	upt 2 - machine chest consist cntrl	873
	upt 3 - D37, mixed stock, cleaning cons, thickener - simplified	841
	mill - irrigation fields	500
	dig 1 - noodle feed consistency control	155
	upt 1 - sec stock chest, prim scr, steady head, dry end - simplified	56
	dig 1 - wsh filter 2 in	55
	dig 1 - uptake feed consistency control	33
	wasteplant - back water	28
	dig 1 - wash filter 1 in	22
	CRF2 and 1 - SDT (WWL) - simplified	22
	bleach - 3 stage in	12
	bleach - D2 tower in	7
	repulpers - #3	7
	dig 2 - hot and warm water tanks in	0

Table 118: Match Table (with relaxing concentrations) – continued

Source	Unit	Flow (kg/min)
mill - fresh water	CT's – simplified in	3088
	CT - Evaps - simplified in	2222
	dig 2 - hot and warm water tanks in	2217
	dig 2 - WBL cooler, T20/21 and T11 - simplified in	2168
	bleach - 3 stage in	1261
	caust - lime mud mixing	815
	dig 1 - noodle feed consistency control	634
	dig 1 - wsh filter 2 in	520
	newsprint - fresh and hot water - simplified	443
	KLB - hot and fresh water - simplified	372
	dig 2 - seal water	252
	bleach - DC tower in	152
	repulpers - #3	137
	upt 3 - effluent in	98
	dig 1 - uptake feed consistency control	55
	dig 2 - two stage washer in	16
	groundwood - back water	12
newsprint - back water	repulpers - #3	931
	groundwood - back water	127
newsprint - cloudy back water	groundwood - back water	4972
	bleach - DC tower in	287
newsprint - effluent	mill - irrigation fields	1810
	bleach - DC tower in	301
	upt 2 - machine chest consist cntrl	246
	dig 2 - two stage washer in	123
	groundwood - back water	1
PF, CRF 1 and 2 - warm water - simplified	upt 3 - D37, mixed stock, cleaning cons, thickener - simplified	529
	repulpers - #1 &2 - simplified	370
	KLB - hot and fresh water - simplified	332
	wasteplant - back water	5

Table 118: Match Table (with relaxing concentrations) – continued

Source	Unit	Flow (kg/min)
stormwater - simplified	upt 3 - D37, mixed stock, cleaning cons, thickener - simplified	1233
upt 1 - white water tank	upt 1 - sec stock chest, prim scr, steady head, dry end - simplified	2465
upt 1 - white water tank	dig 1 - wsh filter 2 in	1511
	dig 1 - uptake feed consistency control	1370
upt 2 - mould filtrate water	caust - lime mud mixing	75
	upt 2 - machine chest consist cntrl	9663
	dig 2 - two stage washer in	1531
	bleach - 3 stage in	242
	dig 1 - noodle feed consistency control	140
	dig 1 - uptake feed consistency control	61
	dig 1 - wsh filter 2 in	45
	repulpers - #3	31
	CRF2 and 1 - SDT (WWL) - simplified	11
	dig 1 - wash filter 1 in	9
	dig 2 - hot and warm water tanks in	1
	dig 2 - WBL cooler, T20/21 and T11 - simplified in	0
upt 3 - D37 filtrate	bleach - D36 consistency	5069
	bleach - D2 tower in	2724
	bleach - 3 stage in	193
	CRF2 and 1 - SDT (WWL) - simplified	70
	bleach - 3 stage in	800
upt 3 - effluent out	upt 3 - D37, mixed stock, cleaning cons, thickener - simplified	26516
upt 3 - filtrate - simplified	bleach - E tower in	39[illegible]
	bleach - D36 consistency	1[illegible]
	bleach - 3 stage in	[illegible]
	bleach - D2 tower in	[illegible]
	upt 3 - effluent in	[illegible]
	wasteplant - back water	[illegible]
	caust - lime mud mixing	[illegible]
	CRF2 and 1 - SDT (WWL) - simplified	[illegible]
	dig 2 - hot and warm water tanks in	[illegible]
	dig 1 - wash filter 1 in	[illegible]

8.10 Mill Mass Balance Diagrams

ERP REF #	SAMPLE DESCRIPTION	DATE	WINGEMS STREA	WINGEMS DIAGRAM HEADING	FLOW RATE (kg/min)	TEMP (°C)	pH	EC (uS/cm)	Na (mg/l)	Ca (mg/l)	Mg (mg/l)	Cl (mg/l)	SO4 (mg/l)	COD (mg/l)	K (mg/l)	TSS (mg/l)	TDS (mg/l)	Fe (mg/l)	Mn (mg/l)	OMMENT [redacted]
1	Fresh water	Jan 99 - Jun 99	61	TOPLEVEL		21.1	8.3	108.3	3.809	13.6	5.1	2.6	8.28			0.619	97.4	0.089	0.015	Ngodwana Technical Dept Mont
2	Process water	11-Oct-99	66	FIBRELINE#2		20	7.39	150	23.8	14.21	5.06	7.4	11	36		237		0.23	0.05	pine running
3	Process water	28-Sep-99	66	FIBRELINE#2		18	7.43	152.4	7			5.6	8.9	48		136.7		0.36	0.26	gum running
4	#3 Upt. Surge Chest Backwater to Bl. Plant	22-Jun-99	222	TOPLEVEL			7.9	444	83	15.6	6.72	115.9	29.7	172		340	40			
5	#3 Upt. Surge Chest Backwater to Bl. Plant	05-Jul-99	222	TOPLEVEL		53	5.3	1424	435	21.6	11.3	618.6	22.8	720		185	1305			
6	#3 Upt. Surge Chest Backwater to Bl. Plant	23-Aug-99	222	TOPLEVEL		53	6	1718	400	10	2.8	500	81	2000		136	1413	1.1	1.24	
7	#3 Upt. Surge Chest Backwater to Bl. Plant	28-Sep-99	222	TOPLEVEL		48	7.38	1095	100			370	17.6	208		636.7		0.78	0.18	gum running
8	#3 Upt. Surge Chest Backwater to Bl. Plant	11-Oct-99	222	TOPLEVEL		49	3.12	3700	780	31.98	24.22	1664	80	508		2923		0.33	2.6	pine running
9	#3 Upt. Surge Chest Backwater to Bl. Plant	14-Feb-00	222	TOPLEVEL					350	1335	0	404	53.5							
10	#3 Upt. Surge Chest Backwater to Bl. Plant	15-Feb-00	222	TOPLEVEL					2825	46	107	343.5	42.5							
11	#3 Upt. Surge Chest Backwater to Bl. Plant	16-Feb-00	222	TOPLEVEL					200	57	64	346.7	31.7							
12	#3 Upt. Surge Chest Backwater to Bl. Plant	17-Feb-00	222	TOPLEVEL					280	135	356	341	36.4							
13	#3 Upt. Surge Chest Backwater to Bl. Plant	18-Feb-00	222	TOPLEVEL					380	71	114	551	40.6							
14	#3 Upt. Surge Chest Backwater to Bl. Plant	21-Feb-00	222	TOPLEVEL					460	62.3	204.7	519.9	29.9							
15	#3 Upt. Surge Chest Backwater to Bl. Plant	22-Feb-00	222	TOPLEVEL					220	39.16	103.2	229.3	25.4							
16	#3 Upt. Surge Chest Backwater to Bl. Plant	23-Feb-00	222	TOPLEVEL					650	46.3	131.7	294.5	26.8							
17	#3 Upt. Surge Chest Backwater to Bl. Plant	24-Feb-00	222	TOPLEVEL					290	53.4	131.7	290.3	33.4							
18	#3 Upt. Surge Chest Backwater to Bl. Plant	25-Feb-00	222	TOPLEVEL					110	32	35.6	198.2	28.6							
AVERAGE						50.8	5.9	1676.2	504.2	139.7	92.4	452.5	38.7	721.6		844.1	919.3	0.7	1.3	#DIV/0!
percentile						51.0	6.0	1424.0	350.0	46.2	83.6	346.7	31.7	508.0		340.0	1305.0	0.8	1.2	#NUM!
19	#3 Upt. Buffer Chest B/W to Bleach Pl.	22-Jun-99	232	TOPLEVEL			6.9	993	475	15.2	5.28	267.3	56.5	256		178	70			
20	#3 Upt. Buffer Chest B/W to Bleach Pl.	05-Jul-99	232	TOPLEVEL		46	4.3	1823	575	24.8	13.4	838.7	28.5	760		105	1620			
21	#3 Upt. Buffer Chest B/W to Bleach Pl.	23-Aug-99	232	TOPLEVEL		47	3.3	2870	750	18	5.2	901	1331	2800		32	2267	1.42	2.29	
22	#3 Upt. Buffer Chest B/W to Bleach Pl	14-Feb-00	232	TOPLEVEL					1800	413	85	614	44.8							
23	#3 Upt. Buffer Chest B/W to Bleach Pl.	15-Feb-00	232	TOPLEVEL					437.5	64	64	520.8	40.7							
24	#3 Upt. Buffer Chest B/W to Bleach Pl	16-Feb-00	232	TOPLEVEL					520	150	135	767.4	52							
25	#3 Upt. Buffer Chest B/W to Bleach Pl.	17-Feb-00	232	TOPLEVEL					600	303	71	730	62.2							
26	#3 Upt. Buffer Chest B/W to Bleach Pl.	18-Feb-00	232	TOPLEVEL					690	85	235	1077.3	66.1							
27	#3 Upt. Buffer Chest B/W to Bleach Pl.	21-Feb-00	232	TOPLEVEL					640	97.9	258.1	766.8	53.7							
28	#3 Upt. Buffer Chest B/W to Bleach Pl.	22-Feb-00	232	TOPLEVEL					550	71.2	242.1	577.3	32.1							
29	#3 Upt. Buffer Chest B/W to Bleach Pl	23-Feb-00	232	TOPLEVEL					270	85.4	274.2	701.2	44.6							
30	#3 Upt. Buffer Chest B/W to Bleach Pl.	24-Feb-00	232	TOPLEVEL					120	53.4	284.8	349.9	38.6							
31	#3 Upt. Buffer Chest B/W to Bleach Pl.	25-Feb-00	232	TOPLEVEL					220	67.6	78.4	497.9	46.7							
AVERAGE							4.83	1895.33	588.27	111.42	134.73	662.28	145.96	1272.00		105.00	1319.00			
						46.5	4.3	1823.0	550.0	71.2	85.0	701.2	46.7	760.0		105.0	1620.0	1.4	2.3	
32	Contaminated condensate to bleach plant	28-Sep-99	31	BLEACHPLNT		57	9.5	302	60	2.9	0.38	10.9	40.8	1680		153.70		3.6	0.005	gum running
33	Contaminated condensate to bleach plant	11-Oct-99	31	BLEACHPLNT		60	8.31	320.00	50.00	1.92	0.43	59.40	28.40	1760.00		230.00		0.34	0.12	pine running
34	#2 Upt. Backwater to #2 F/L	22-Jun-99	200	TOPLEVEL			11.5	2570	775	67.2	6.24	47.2	69.9	2000		4010	82			
35	#2 Upt. Backwater to #2 F/L	05-Jul-99	200	TOPLEVEL		19	8.7	311	80	23.6	12.7	31.3	32.4	160		60	245			
36	#2 Upt. Backwater to #2 F/L	23-Aug-99	200	TOPLEVEL		44	10.5	4110	1600	799	201.6	104	3492	16400		536	557	1.94	5.5	Sample strangle black, too muc
37	#2 Upt. Backwater to #2 F/L	28-Sep-99	200	TOPLEVEL		27	10.05	1506	375	4.3	9.7	1260	170	2500		1070		2.8	1.2	
38	#2 Upt. Backwater to #2 F/L	11-Oct-99	200	TOPLEVEL		40	9.22	2860	875	10.47	28.66	131	373	4000		4263		0.74	1.87	
AVERAGE							10.23	2330.33	818.33	296.60	73.51	80.83	1198.10	6186.67		1535.33	294.67			
						####	10.1	2570.0	775.0	23.6	12.7	104.0	170.0	######		######	245.0	1.9	1.9	
39	#1 Upt. Backwater to #1 F/L	22-Jun-99	143	TOPLEVEL			9.9	1434	700	19.6	2.16	21.7	153.9	800		1856	168			
40	#1 Upt. Backwater to #1 F/L	05-Jul-99	143	TOPLEVEL		51	11.1	1732	550	116	36.2	13.3	86.4	6400		500	2705			
41	#1 Upt. Backwater to #1 F/L	24-Aug-99	143	TOPLEVEL		54	10.41	3450	1200	674	119.8	22.7	746.2	8400		796	6313	2.1	2.35	
AVERAGE							10.47	2205.33	816.67	269.87	52.72	19.23	328.83	5200.00		1050.67	3062.00			
						####	10.4	1732.0	700.0	116.0	36.2	21.7	153.9	######	#NUM!	796.0	2705.0	2.1	2.4	
42	Backwater from Noodle Press to #1 F/L	22-Jun-99	3	TOPLEVEL			11	3390	640	119.2	7.2	94.2	116.8	4000		5364	188			
43	Backwater from Noodle Press to #1 F/L	05-Jul-99	3	TOPLEVEL		51	11.4	1873	600	672	237	57.8	103.3	6000		275	2785			
44	Backwater from Noodle Press to #1 F/L	25-Aug-99	3	TOPLEVEL		50	10.82	4480	1700	21.2	9	22.7	746.2	14400		1094	11993	1.61	2.8	
AVERAGE							11.07	3247.67	980.00	270.80	84.40	58.23	322.10	8133.33		2244.33	4988.67			
						####	11.0	3390.0	640.0	119.2	9.0	57.8	116.8	######	#NUM!	######	2785.0	1.6	2.8	
45	Bleached pulp fitrate from D36 (BL. Plant) to #	23-Jun-99	140	BLEACHPLNT		38	5.3	1050	268	16.6	6.44	377	56	224		20	660			
46	Bleached pulp fitrate from D36 (BL. Plant) to #	06-Jul-99	140	BLEACHPLNT		40	3.7	1960	620	28.4	15.4	735.8	46.6	560		25	1430			
47	Bleached pulp fitrate from D36 (BL. Plant) to #	24-Aug-99	140	BLEACHPLNT		44	3.32	2900	800	55.6	18.3	967.1	76.7	1600		536	2250	0.93	1.7	
48	Bleached pulp fitrate from D36 (BL. Plant) to #	28-Sep-99	140	BLEACHPLNT		37	3.5	2090	435	-	-	617.5	31.8	435				0.58	0.63	
49	Bleached pulp fitrate from D36 (BL. Plant) to #	11-Oct-99	140	BLEACHPLNT		42	2.98	4030	875	34.07	29.37	452	75	540				2.58	1.61	
AVERAGE							4.11	1970.00	562.67	33.53	13.38	693.30	59.77	794.67		193.67	1446.67			
						####	3.5	2090.0	620.0	31.2	16.9	617.5	56.0	540.0		25.0	1430.0	0.9	1.6	
50	Unbl. pulp filtr. from #2F/L to 2 stage diff. wash	23-Jun-99	181	FIBRELINE#2		42	11.7	5070	5070	18	7.12	453	638	400		205	3605			
51	Unbl. pulp filtr. from #2F/L to 2 stage diff. [illegible]	[illegible]	[illegible]	[illegible]																

REF #	SAMPLE DESCRIPTION	DATE	MS STREA	DIAGRAM HEADING	FLOW RATE (kg/min)	P (°C)	pH	EC (uS/cm)	Na (mg/l)	Ca (mg/l)	Mg (mg/l)	Cl (mg/l)	SO4 (mg/l)	COD (mg/l)	K (mg/l)	TSS (mg/l)	TDS (mg/l)	Fe (mg/l)	Mn (mg/l)	COMMENT
52	Unbl. pulp filtr. from #2F/L to 2 stage diff. wash	24-Aug-99	181	FIBRELINE#2		52	11.45	9890	5000	1111	232.1	377.5	1621	23600		226	2245	1.38	13.02	
AVERAGE							11.85	7540.00	4690.00	443.00	98.54	337.87	1045.00	#####		545.33	7356.67			
						49.0	11.7	7660.0	5000.0	200.0	56.4	377.5	876.0	14800.0		226.0	3605.0	1.4	13.0	
53	Pulp from 2-stage diffusion washer	28-Sep-99	141	FIBRELINE#2		35	10.6	4150	1250	8.4	21.2	49.2	1054	2000		7.5% cons		3	2.4	gum running
54	Pulp from 2-stage diffusion washer	11-Oct-99	141	FIBRELINE#2		50	7.68	6170	19000	16.9	18.06	-	-	19000		11.3% cons		4.91	6.14	pine running
						42.5	9.1	5160.0	10125.0	12.7	19.6	49.2	1054.0	10500.0	#NUM!	#NUM!	#NUM!	4.0	4.3	
55	Wash press in	11-Oct-99	6	BLEACHPLNT		46	9.73	9130	4600	20.4	27.99	-	-	14400		7.3% cons		3.03	6.57	
56	O2 reactor out	11-Oct-99	244	BLEACHPLNT		76	10.07	11220	9250	18.4	17.62	1659	3915	12000		9% cons		5.75	3.41	
57	3-Stage diffusion washer out	28-Sep-99	61	BLEACHPLNT		58	11.03	5010	475	4.93	9.3	86.7	17	2440		10.1% cons		2.5	0.7	gum running
58	3-Stage diffusion washer out	11-Oct-99	61	BLEACHPLNT		57	9	182.9	965	27.35	19.6	263	434	3000		10.2% cons		1.35	1.29	pine running
						57.5	10.02	2596.45	720	16.14	14.45	174.85	225.5	2720				1.925	0.995	
59	DC-stage pulp in	11-Oct-99	84	BLEACHPLNT		62	8.97	3110	800	27.31	17.46	186	295	1400		9.7% cons		1.61	1.52	pine running
60	DC-stage pulp out	28-Sep-99	111	BLEACHPLNT		56	2.65	2500	570	14.5	9.6	805	104	1040		7.4% cons		3.1	0.8	gum running
61	DC-stage pulp out	11-Oct-99	111	BLEACHPLNT		62	3.71	630	920	53.02	51.3	825	206	1360		9.1% cons		2.01	5.82	pine running
						59	3.18	1565	745	33.76	30.45	815	155	1200				2.555	3.31	
62	E-stage in	11-Oct-99	241	BLEACHPLNT		47	9.87	6820	2000	40.54	9.15	1808	250	12400		6630		0.62	0	
63	E-stage pulp out	28-Sep-99	126	BLEACHPLNT		69	9.35	3120	850	10	7.6	1043.5	41.2	860		9.2% cons		2.1	0.6	gum running
64	E-stage pulp out	11-Oct-99	126	BLEACHPLNT		68	6.31	290	1775	43.71	44.4	2756	138	4800		10.4% cons		1.12	4.86	pine running
						68.5	7.83	1705	1312.5	26.855	26	1899.75	89.6	2830				1.61	2.73	
65	D2-stage in	11-Oct-99	242	BLEACHPLNT		32	2.96	6190	-	-	-	-	-	-		5533		-	-	
66	D2- stage out	28-Sep-99	136	BLEACHPLNT		70	3.2	719	675	-	-	1110	86	600		10.6% cons		0.72	0.86	gum running
67	D2- stage out	11-Oct-99	136	BLEACHPLNT		64	2.88	4640	1500	38.4	36.08	2060	28.3	400		10.3% cons		1.53	4.1	pine running
						67	3.04	2679.5	1087.5	38.4	36.08	1585	57.15	500				1.125	2.48	
68	Pulp filtr. from the HD chest (#1 F/L) to #1 upt	23-Jun-99	14	FIBERLINE#1		30	10.9	234	2380	48.4	5.86	12.5	84.1	600		50	1395			
69	Pulp filtr. from the HD chest (#1 F/L) to #1 upt.	06-Jul-99	14	FIBERLINE#1		43	11.6	2440	1100	0	0	11.2	94.7	4800		130	4485			
70	Pulp filtr. from the HD chest (#1 F/L) to #1 upt	25-Aug-99	14	FIBERLINE#1		44	10.42	3550	1200			1934.1	153.5	10400		4.3% cons	8214	1.54	2.4	
AVERAGE							10.97	2074.67	1560.00	24.20	2.93	652.60	110.77	5266.67		90.00	4698.00			
						43	10.9	2440	1200	24.2	2.93	12.5	94.7	4800		90	4485	1.54	2.4	
71	Hotwater from hotwater tank #2 F/L	24-Jun-99	101	FIBRELINE#2		52	7.7	121	5	16	7.92	3.8	12	4		5	125			
72	Hotwater from hotwater tank #2 F/L	07-Jul-99	101	FIBRELINE#2		49	8	100	5	12.8	5.76	5.24	9.36	5.6		5	140			
73	Hotwater from hotwater tank #2 F/L	25-Aug-99	101	FIBRELINE#2		54	8.3	114	7.5	23.7	8.2	3.8	16.2	28		34	63.3	0.76	0	
74	Hotwater from cooling tower	28-Sep-99	70	FIBRELINE#2		28	5.85	131.8	6	-	-	3.09	7.2	40		73.3		0.32	0.06	
75	Hotwater from cooling tower	11-Oct-99	70	FIBRELINE#2		30	6	170	6.5	14.75	4.98	4.5	14.3	12		150		0.33	-	
AVERAGE							8.00	111.67	5.83	17.50	7.29	4.28	12.52	12.53		14.67	109.43			
						49	7.7	121	6	15.375	6.84	3.8	12	12	#NUM!	34	125	0.33	0.03	
76	Screen rejects filtrate from #1 F/L	24-Jun-99	233	TOPLEVEL		36	12.5	18560	23750	0	0	108	656	29200		1235	3490			
77	Screen rejects filtrate from #1 F/L	07-Jul-99	233	TOPLEVEL		30	12.8	15900	19300	0	0	2878	792	96000		320	92680			
78	Screen rejects filtrate from #1 F/L	25-Aug-99	233	TOPLEVEL		34	11.48	6450	4600	30.1	46.2	66601	55433	16000		1.6% cons	12790	2.12	2.4	
AVERAGE							12.26	13636.67	15883.33	10.03	15.40	23195.67	18960.33	#####		777.50	36320.00			
						34	12.5	15900	19300	0	0	2878	792	29200		777.5	12790	2.12	2.4	
79	Screen rejects filtrate from #2 F/L(from STOC	24-Jun-99	194	FIBRELINE#2		42	11.7	8760	4750	0	0	58	845	8000		1255	7885			
80	Screen rejects filtrate from #2 F/L(from STOC	26-Aug-99	194	FIBRELINE#2		40	10.93	10400	4600	9.71	115.1	88	2295.4	30000		668	26463			
81	Screen rejects filtrate from #2 F/L	28-Sep-99	174	FIBRELINE#2		57	11.18	10690	4500	31.7	92.6	26	1246	8000		18180		7.6	8.8	
AVERAGE							11.32	9580.00	4675.00	4.86	57.55	73.00	1570.20	#####		961.50	17174.00			
						42	11.18	10400	4600	9.71	92.6	58	1246	8000		1255	17174	7.6	8.8	
82	Screen rejects filtrate from #3 uptake	24-Jun-99	220	TOPLEVEL		48	7.7	872	220	13.2	7.2	255	34	188		115	540			
83	Screen rejects filtrate from #3 uptake	07-Jul-99	220	TOPLEVEL		50	6.6	465	105	10	3.12	129.8	12.1	320		1990	400			
84	Screen rejects filtrate from #3 uptake	26-Aug-99	220	TOPLEVEL		52	7.79	977	175	40.6	7.49	15.8	350	7200		260	1037	0.8	0.42	
AVERAGE							7.36	771.33	166.67	21.27	5.94	133.53	132.03	2569.33		788.33	659.00			
						50	7.7	872	175	13.2	7.2	129.8	34	320		260	540	0.8	0.42	
85	#1 Evaps cooling tower outlet water	25-Jun-99	355	TOPLEVEL		14	7.1	168	10	24	6.96	4.99	17.1	72		5	4			
86	#1 Evaps cooling tower outlet water	08-Jul-99	355	TOPLEVEL		15	7.7	382	75	35.2	14.2	22.3	82.7	400		80	265			
87	#1 Evaps cooling tower outlet water	26-Aug-99	355	TOPLEVEL		23	7.63	500	75	34.3	18.7	32.3	158.6	4800		305	607	1.12	0.24	
AVERAGE							7.48	350.00	53.33	31.17	13.29	19.86	86.13	1757.33		130.00	292.00			
						15	7.63	382	75	34.3	14.2	22.3	82.7	400		80	265	1.12	0.24	
88	#1 Service cooling tower outlet water	25-Jun-99				29	7.2	739	400	119	[illegible]	[illegible]	[illegible]	[illegible]						

REF #	SAMPLE DESCRIPTION	DATE	MS STREA	DIAGRAM HEADING	(kg/min)	P (°C)	pH	(uS/cm)	Na (mg/l)	Ca (mg/l)	Mg (mg/l)	Cl (mg/l)	(mg/l)	(mg/l)	K (mg/l)	(mg/l)	(mg/l)	(mg/l)	Mn (mg/l)	COMMEN
89	#1 Service cooling tower outlet water	08-Jul-99				30	7.5	556	125	58.8	11.3	19.9	233	3400		330	630			
90	#1 Service cooling tower outlet water	26-Aug-99				28	5.04	1760	337.5	17.5	4.5	494.1	33.8	292		1110	2217	0.12	1.12	
AVERAGE							6.58	1018.33	187.50	65.10	14.80	183.97	191.93	2830.67		536.67	1409.00			
						29	7.2	739	125	58.8	11.3	37.9	233	3400		330	1380	0.12	1.12	
91	WWL	19-Jan-93	31	CHEM_REC												326				Special analysis (LAB.93/C09)
92	WWL	20-Jan-93	31	CHEM_REC												62				Special analysis (LAB.93/C09)
93	Weak white liquor to CRF smelt dissolving tan	25-Jun-99	31	CHEM_REC		53	12.9	139000	25000	0	0	718	1169	16320		16320	49980			
94	Weak white liquor to CRF smelt dissolving tan	08-Jul-99	31	CHEM_REC		57	13.1	13660	16500	0	0	526	3274	12000		1645	32660			
95	WWL to smelt dissolving tank	25-Aug-99	31	CHEM_REC		56	12.43	O/R	6850	0	8.2	1031.6	295.3	2800		666	40827	1.62	0.83	
AVERAGE						55.3	12.8	76330.0	16116.7	0.0	2.7	758.5	1579.4	10373.3		3803.8	41155.7	1.6	0.8	
						56.0	12.9	76330.0	16500.0	0.0	0.0	718.0	1169.0	12000.0		666.0	40827.0	1.6	0.8	
96	Pumped water from warm water holding tank (	25-Jun-99	62	FIBRELINE#2		42	7.1	85	4.5	13.6	5.04	1.81	6.69	40		40	4			
97	Pumped water from warm water holding tank (	07-Jul-99	62	FIBRELINE#2		30	8	91	5	11.6	5.04	3.05	8.91	920		5	155			
98	Pumped water from warm water holding tank (	27-Aug-99	62	FIBRELINE#2		34	7.9	97	7	20.9	7.3	0.9	0.8	23.6		18	190	0.04	0.01	
99	Pumped water from warm water holding tank (	28-Sep-99	62	FIBRELINE#2		48	6.26	112.1	7	-	-	0.4	9.7	64		130		0.44	0.11	
100	Pumped water from warm water holding tank (	11-Oct-99	62	FIBRELINE#2		54	10	180	6	16.95	6.88	6.8	26	24		253		0.28	-	
AVERAGE							7.67	91.00	5.50	15.37	5.79	1.92	5.47	327.87		21.00	116.33			
						42.0	7.9	97.0	6.0	15.3	6.0	1.8	8.9	40.0		40.0	155.0	0.3	0.1	
101	Green liquor from G.L. clarifier to slaker (at the	28-Jun-99	11	CHEM_REC		85	13.4	163000	100000	0	0	2838	3342	43000		1800	116686			
102	Green liquor from G.L. clarifier to slaker (at the	30-Aug-99	11	CHEM_REC		86	13.3	0	58000	10	2.85	3086.9	1239.6	19.7		1675	220840	3.39	4	
103	Green liquor from G.L. clarifier to slaker (at the	24-Aug-98	11	CHEM_REC					78000	8.1	<2.4		73 g/l as S		7963			<0.5	<0.1	Lab data base (K Nisbet, 17/2/0
104	Green liquor from G.L. clarifier to slaker (at the	24-Aug-98	11	CHEM_REC					75900	8.3	<2.4		71.1 g/l as S		8527			<0.5	<0.1	Lab data base (K Nisbet, 17/2/0
AVERAGE							13.35	81500.00	79000.00	5.00	1.43	2962	2291	21510		1738	168763			
						85.5	13.4	81500.0	76950.0	8.2	1.4	2962.5	2290.8	21509.9	8245.0	1737.5	168763.0	3.4	4.0	
105	Newsprint effluent	29-Jun-99	296	TOPLEVEL		48	5.8	353	60	26	10.8	19	128	1180		10	478			
106	Newsprint effluent	08-Jul-99	296	TOPLEVEL		57	5.7	298	60	11.2	5.76	12.7	103	440		1790	390			
107	Newsprint effluent	27-Aug-99	296	TOPLEVEL		54	6.76	1920	460	28.7	15.3	35.8	279	21.6		2325	8433	0.44	2.22	
108	Newsprint effluent	15-Feb-00	296	TOPLEVEL					145	107	160	16.7	389.6							
109	Newsprint effluent	16-Feb-00	296	TOPLEVEL					100	57	43	21.8	282.3							
110	Newsprint effluent	17-Feb-00	296	TOPLEVEL					510	99.7	42.7	13.7	414.1							
111	Newsprint effluent	18-Feb-00	296	TOPLEVEL					230	71	50	22	470							
112	Newsprint effluent	21-Feb-00	296	TOPLEVEL					155	71.2	26.7	15.9	320.5							
113	Newsprint effluent	22-Feb-00	296	TOPLEVEL					110	44.5	17.8	17.5	187.3							
114	Newsprint effluent	23-Feb-00	296	TOPLEVEL					90	40.1	40	18.7	153.4							
115	Newsprint effluent	24-Feb-00	296	TOPLEVEL					90	49.8	21.4	18.5	483.4							
116	Newsprint effluent	25-Feb-00	296	TOPLEVEL					125	71.2	0	43.8	256.4							
VERAGE							6.09	857.00	177.92	56.45	36.12	21.34	288.92	547.20		1375.00	3100.33			
						54.0	5.8	353.0	117.5	53.4	24.1	18.6	280.7	440.0	#NUM!	1790.0	478.0	0.4	2.2	
117	KLB effluent	29-Jun-99	500	TOPLEVEL		40	6.4	2070	688	146	21.1	147	1195	1880		24	440			
118	KLB effluent	08-Jul-99	500	TOPLEVEL		40	6.4	1562	380	105	11.3	76.9	1059	920		3040	1620			
119	KLB effluent	27-Aug-99	500	TOPLEVEL		42	4.77	681	130	107.3	15.7	33.9	348.6	22.3		5775	6503	3.68	2.78	
120	KLB effluent	15-Feb-00	500	TOPLEVEL					300	106.8	53.4	48.9	689.2							
121	KLB effluent	16-Feb-00	500	TOPLEVEL					1700	170	22	64.9	849.5							
122	KLB effluent	17-Feb-00	500	TOPLEVEL					100	71.2	64	11.6	304.8							
123	KLB effluent	18-Feb-00	500	TOPLEVEL					200	100	42	48.9	431.5							
124	KLB effluent	21-Feb-00	500	TOPLEVEL					200	89	89	84	310.2							
125	KLB effluent	22-Feb-00	500	TOPLEVEL					280	80.1	26.7	98.3	352.4							
126	KLB effluent	23-Feb-00	500	TOPLEVEL					240	64.1	49.8	86.6	296.1							
127	KLB effluent	24-Feb-00	500	TOPLEVEL					270	78.3	35.6	111	366.6							
128	KLB effluent	25-Feb-00	500	TOPLEVEL					380	113.9	64.1	217.5	835.7							
VERAGE							5.86	1437.87	405.67	102.64	41.23	85.79	586.55	940.77		2946.33	2854.33			
						40.0	6.4	1562.0	275.0	102.5	38.8	80.5	399.1	920.0	#NUM!	3040.0	1620.0	3.7	2.8	
129	Groundwood #1 rejects effluent (stainless stee	29-Jun-99	90	TOPLEVEL		45	4.9	318	55	25	10.1	18.4	92	2340		32	1308			
130	Groundwood #1 rejects effluent (stainless stee	09-Jul-99	90	TOPLEVEL		54	5.6	207	33	11.6	6.48	11.4	27.6	1820		585	925			
131	Groundwood #1 rejects effluent (stainless stee	27-Aug-99	90	TOPLEVEL		53	4.61	728	140	33.7	20.2	33.6	420.6	14.6		5220	2783	0.68	3.8	
132	Groundwood #1 rejects effluent (stainless stee	14-Feb-00	90	TOPLEVEL					155	320	71.2	21.7	25.9							
133	Groundwood #1 rejects effluent (stainless stee	15-Feb-00	90	TOPLEVEL					155	57	14	19	225							
134	Groundwood #1 rejects effluent (stainless stee	16-Feb-00	90	TOPLEVEL					145	71	64	16.2	307.6							
135	Groundwood #1 rejects effluent (stainless stee	17-Feb-00	90	TOPLEVEL					885	178	57	14.2	419.4							
136	Groundwood #1 rejects effluent (stainless stee	18-Feb-00	90	TOPLEVEL					155	64	36	12	267.8							
137	Groundwood #1 rejects effluent (stainless stee	21-Feb-00	90	TOPLEVEL					215	44.5	44.5	22.6	251.2							
138	Groundwood #1 rejects effluent (stainless stee	22-Feb-00	90	TOPLEVEL					155	53.4	71.2	15.3	162.5							
139	Groundwood #1 rejects effluent (stainless stee	23-Feb-00	90	TOPLEVEL					125	17.8	62.3	12.2	117.6							
140	Groundwood #1 rejects effluent (stainless stee	24-Feb-00	90	TOPLEVEL					140	42.7	14.2	15.3	109							
141	Groundwood #1 rejects effluent (stainless stee	25-Feb-00	90	TOPLEVEL					200	26.7	17.8	44	178.3							
VERAGE							5.04	417.67	196.77	72.72	37.61	19.68	200.35	1391.53		1945.67	1672.00			

REF #	SAMPLE DESCRIPTION	DATE	MS STREA	DIAGRAM HEADING	FLOW RATE (kg/min)	P (°C)	pH	EC (uS/cm)	Na (mg/l)	Ca (mg/l)	Mg (mg/l)	Cl (mg/l)	SO4 (mg/l)	COD (mg/l)	K (mg/l)	TSS (mg/l)	TDS (mg/l)	Fe (mg/l)	Mn (mg/l)	OMMENT 662
						53.0	4.9	318.0	155.0	44.5	36.0	16.2	178.3	1820.0	#NUM!	585.0	1308.0	0.7	3.8	
142	Groundwood #2 floor drain effluent	29-Jun-99	465	TOPLEVEL		22	5.4	188	23	26	10.3	6.3	35	640		20	364			
143	Groundwood #2 floor drain effluent	09-Jul-99	465	TOPLEVEL		23	6.6	242	20	26.4	10.3	10.5	44.9	800		960	255			
144	Groundwood #2 floor drain effluent	27-Aug-99	465	TOPLEVEL		26	5.97	409	80	32.4	15	18.5	538.4	18.3	Oil Contamin.		2900	0.88	1.38	
145	Groundwood #2 floor drain effluent	14-Feb-00	465	TOPLEVEL					150	1068	0	35	2375							
146	Groundwood #2 floor drain effluent	15-Feb-00	465	TOPLEVEL					77.5	35.6	42.4	12	135							
147	Groundwood #2 floor drain effluent	16-Feb-00	465	TOPLEVEL					60	50	71	11.92	95.8							
148	Groundwood #2 floor drain effluent	17-Feb-00	465	TOPLEVEL					132.5	121	57	11.2	330							
149	Groundwood #2 floor drain effluent	18-Feb-00	465	TOPLEVEL					22.5	43	28	11.9	37.9							
150	Groundwood #2 floor drain effluent	21-Feb-00	465	TOPLEVEL					137.5	44.5	44.5	14.8	163.4							
151	Groundwood #2 floor drain effluent	22-Feb-00	465	TOPLEVEL					80	44.5	89	10	87.8							
152	Groundwood #2 floor drain effluent	23-Feb-00	465	TOPLEVEL					80	35.6	57	9.6	76.5							
153	Groundwood #2 floor drain effluent	24-Feb-00	465	TOPLEVEL					115	35.6	24.9	15.1	116.2							
154	Groundwood #2 floor drain effluent	25-Feb-00	465	TOPLEVEL					67.5	39.2	107.7	20	67.3							
VERAGE							5.99	279.67	80.42	123.22	42.85	14.37	315.63	486.10		490.00	1173.00			
						23.0	6.0	242.0	80.0	39.2	42.4	11.9	95.8	640.0	#NUM!	490.0	364.0	0.9	1.4	
155	Backwater from KLB B/W chest to the repulpe	30-Jun-99	264	TOPLEVEL		39	5.3	2020	510	172	25	163	997	1540		165	2372			
156	Backwater from KLB B/W chest to the repulpe	09-Jul-99	264	TOPLEVEL		35	5.9	2350	700	141	25.7	152.6	1406	1320		60	3085			
157	Backwater from KLB B/W chest to the repulpe	30-Aug-99	264	TOPLEVEL		38	7.83	2360	520	102.3	17.2	74.6	1279.4	21.9		170	6580	0.32	2.95	
158	Backwater from KLB B/W chest to the repulpe	?	264	TOPLEVEL			7.03	2430	932	218	14	160	1400	1351		420	1216	0.8	6	Buckman analysis (CDJ, 4/8/99)
159	Backwater from KLB B/W chest to the repulpe	?	264	TOPLEVEL			7	1220	526	56	15	142	300	548		346	615	0.1	2	WTL, Buckman analysis (CDJ,
VERAGE							6.61	2076.00	657.60	137.86	19.38	138.44	1076.48	956.18		232.20	2773.60	0.4067	3.65	
						38.0	7.0	2350.0	620.0	141.0	17.2	152.6	1279.4	1320.0	#NUM!	170.0	2372.0	0.3	3.0	
160	Backwater from NP B/W chest to repulper #4	30-Jun-99	236	TOPLEVEL		40	6.4	178	30	20.8	10.3	9.2	43.6	1440		125	336			Newsprint down
161	Backwater from NP B/W chest to repulper #4	09-Jul-99	236	TOPLEVEL		52	6.5	159	35	10	4.56	14.5	59.2	660		150	425			
162	Backwater from NP B/W chest to repulper #4	30-Aug-99	236	TOPLEVEL		52	6.06	646	140	48.7	12	19.4	357.6	21.7		44	937	0.48	1.69	
163	Backwater from NP B/W chest to repulper #4		236	TOPLEVEL			5.02 (17	282 (177)	42 (28)	14 (51)	3.3 (33)	18.9 (33)	45.1 (35)	1450 (84)		68 (177)	1005 (176)	1.2 (32)	6.56 (32)	E Slabbert
164	Backwater from NP B/W chest to repulper #4	?	236	TOPLEVEL			7.74	185	21	5	3	21	24	882		273	92	0.3	2	Buckman analysis (CDJ, 4/8/99)
165	Backwater from NP B/W chest to repulper #4	?	236	TOPLEVEL			8.04	228	26	10	6	25	34	558		131	114	0.4	2	super mechanical run, Buckman
166	Backwater from NP B/W chest to G/W	?	80	TOPLEVEL			7.98	2410	38	10	7	43	37	634		189	1210	1	2	Buckman analysis (CDJ, 4/8/99)
167	Backwater from NP B/W chest to G/W	?	80	TOPLEVEL			6.83	1190	72	13	7	28	50	1069		172	590	0.6	3	super mechanical run, Buckman
VERAGE							7.08	713.74	51.71	16.79	7.12	22.87	86.49	752.10		154.86	529.14	0.556	2.138	
						52.0	6.8	228.0	35.0	10.0	7.0	21.0	43.6	660.0		150.0	425.0	0.5	2.0	
168	Back/Reclaimed-water from KLB to wasteplant	30-Jun-99	96	TOPLEVEL		42	5.6	2100	500	191	25.7	177	996	1560		360	3148			
169	Back/Reclaimed-water from KLB to wasteplant	09-Jul-99	96	TOPLEVEL		42	5.9	2390	700	153	17.8	157	1434	1260		445	3175			
170	Back/Reclaimed-water from KLB to wasteplant	30-Aug-99	96	TOPLEVEL		40	5.9	2360	570	111.1	23.2	64.2	1528.5	21.8		352	3037	0.32	2.93	
VERAGE							5.80	2283.33	590.00	151.70	22.23	132.73	1319.50	947.27		385.67	3120.00			
						42.0	5.9	2360.0	570.0	153.0	23.2	157.0	1434.0	1260.0	#NUM!	360.0	3148.0	0.3	2.9	
171	Waste plant effluent	01-Jul-99	110	TOPLEVEL		28	5	1827	550	153	23	121	920	1680		56	2330			
172	Waste plant effluent	12-Jul-99	110	TOPLEVEL		31	5.6	1773	550	128	12.5	109.2	936.6	3120		70	2805			
173	Waste plant effluent	15-Feb-00	110	TOPLEVEL					538	441	0	85	1118							
174	Waste plant effluent	16-Feb-00	110	TOPLEVEL					500	384	114	70	986.3							
175	Waste plant effluent	17-Feb-00	110	TOPLEVEL					425	470	384	57.8	903							
176	Waste plant effluent	18-Feb-00	110	TOPLEVEL					362.5	427	71	57.6	850.4							
177	Waste plant effluent	21-Feb-00	110	TOPLEVEL					275	275.9	142.4	37.4	482.6							
178	Waste plant effluent	22-Feb-00	110	TOPLEVEL					237.5	151.3	26.7	54.7	320.6							
179	Waste plant effluent	23-Feb-00	110	TOPLEVEL					250	124.6	53.4	60.5	266							
180	Waste plant effluent	24-Feb-00	110	TOPLEVEL					300	71.2	71.2	82.1	315							
181	Waste plant effluent	25-Feb-00	110	TOPLEVEL					650	149.5	106.8	186.8	427.4							
VERAGE							5.30	1800.00	421.64	252.32	91.36	83.83	684.17	2400.00		63.00	2567.50			
						29.5	5.3	1800.0	425.0	153.0	71.0	70.0	850.4	2400.0	#NUM!	63.0	2567.5	#NUM!	#NUM!	
182	#2 Uptake effluent	01-Jul-99	201	TOPLEVEL		30	11	3490	1600	882	176	79.7	464	4800		126	5460			
183	#2 Uptake effluent	12-Jul-99	201	TOPLEVEL		24	11.9	2100	730	382	70.6	31.7	84.1	7200		155	2615			
184	#2 Uptake effluent	14-Feb-00	201	TOPLEVEL					725	178	0	175	367							
185	#2 Uptake effluent	15-Feb-00	201	TOPLEVEL					563	35.6	35.6	90	157							
186	#2 Uptake effluent	16-Feb-00	201	TOPLEVEL					600	43	7	70.3	153							
187	#2 Uptake effluent	17-Feb-00	201	TOPLEVEL					1450	-	-	55	498							
188	#2 Uptake effluent	18-Feb-00	201	TOPLEVEL					1900	81	9	183	892.3							
189	#2 Uptake effluent	21-Feb-00	201	TOPLEVEL					325	178	71.2	175	93.4							
190	#2 Uptake effluent	22-Feb-00	201	TOPLEVEL					1075	267	534	295.1	324							
191	#2 Uptake effluent	23-Feb-00	201	TOPLEVEL					625	71.2	0	23.7	78.4							
192	#2 Uptake effluent	24-Feb-00	201	TOPLEVEL					1125	35.6	14.2	95.7	301.3							
193	#2 Uptake effluent	25-Feb-00	201	TOPLEVEL					400	71.2	106.8	290.8	340.2							
VERAGE							11.45	2795.00	924.00	202.24	93.13	130.42	312.73	6000.00		140.50	4037.50			
						27.0	11.5	2795.0	712.5	81.0	35.6	92.9	312.7	6000.0	#NUM!	140.5	4037.5	#NUM!	#NUM!	
194	#1 Digester effluent	01-Jul-99	621	TOPLEVEL		28	11.8	2640	1100	470	71	14	[illegible]	[illegible]		[illegible]	[illegible]			

REF #	SAMPLE DESCRIPTION	DATE	MS STREA	DIAGRAM HEADING	FLOW RATE (kg/min)	P (°C)	pH	EC (uS/cm)	Na (mg/l)	Ca (mg/l)	Mg (mg/l)	Cl (mg/l)	SO4 (mg/l)	COD (mg/l)	K (mg/l)	TSS (mg/l)	TDS (mg/l)	Fe (mg/l)	Mn (mg/l)	OMMENT
195	#1 Digester effluent	12-Jul-99	621	TOPLEVEL		23	10.8	2160	900	294	106	51.1	149.7	4800		4895	3365			
196	#1 Digester effluent	14-Feb-00	621	TOPLEVEL					2900	712	0	212	2734							
197	#1 Digester effluent	15-Feb-00	621	TOPLEVEL					800	142.4	0	21.6	44							
198	#1 Digester effluent	16-Feb-00	621	TOPLEVEL					1325	107	7	54.5	138.8							
199	#1 Digester effluent	17-Feb-00	621	TOPLEVEL					2175	sample too dark		39.1	141.1							
200	#1 Digester effluent	18-Feb-00	621	TOPLEVEL					675	17.1	5	26.4	98.1							
201	#1 Digester effluent	21-Feb-00	621	TOPLEVEL					1275	20.8	6.5	44.3	91.4							
202	#1 Digester effluent	22-Feb-00	621	TOPLEVEL					1225	20	5	39.2	131							
203	#1 Digester effluent	23-Feb-00	621	TOPLEVEL					875	23.5	6.1	36.6	74.2							
204	#1 Digester effluent	24-Feb-00	621	TOPLEVEL					1150	14.6	3.6	38.1	129.6							
205	#1 Digester effluent	25-Feb-00	621	TOPLEVEL					3200	14.2	5	95.3	155.3							
VERAGE							11.30	2400.00	1000.00	382.00	88.50	32.55	106.50	5000		2473.50	3627.50			
						25.5	11.3	2400.0	1187.5	23.5	5.0	39.2	130.3	5000.0	#NUM!	2473.5	3627.5	#NUM!	#NUM!	
206	Green liquor from CRF 2 to green liquor clarifie	10-Jan-97	3	CHEM_REC											7780					Lab data base (K Nisbet, 17/2/0
207	Green liquor from CRF 2 to green liquor clarifie	06-Jul-99	3	CHEM_REC		88	12.3	19400	50000	0	0	3277	4937	20000		3790	228885			
208	Green liquor from CRF 2 to green liquor clarifie	30-Aug-99	3	CHEM_REC		78	13.2	O/R	56500	2.4	1.78	3286.6	1902.1	19		1642	263047	4.2	3.59	
VERAGE							12.75	19400.00	53250.00	1.20	0.89	3281.80	3419.55	10010		2716.00	########			
						83.0	12.8	19400.0	53250.0	1.2	0.9	3281.8	3419.6	10009.5	7780.0	2716.0	245966.0	4.2	3.6	
209	Turpentine decanter filtrate	07-Jul-99	81	FIBRELINE#2		49	10.3	484	5	4.8	1.68	17.3	15.9	20000		15	70			
210	Condensate to evaporators	28-Sep-99	81	FIBRELINE#2		40	10.47	501	100	-	-	104	137.3	18400		130		2.5	-	
211	Condensate to evaporators	11-Oct-99	81	FIBRELINE#2		44	9.77	760	1670	2.6	1.76	1450	163	17200		130		0.23	-	
212	Condensate to evaporators	28-Sep-99	81	FIBRELINE#2		34	10.27	5620	100	-	-	22.7	168	35600		80		0.52	0.1	
213	Condensate to evaporators	11-Oct-99	81	FIBRELINE#2		42	9.78	800	150	0.15	2.06	104	465	15600		197		0.23	-	
VERAGE							10.30	484.00	5.00	4.80	1.68	17.30	15.90	21360		15.00	70.00			
						42.0	10.3	760.0	100.0	2.6	1.8	104.0	163.0	18400.0	#NUM!	130.0	70.0	0.4	0.1	
214	Turpentine sold	28-Sep-99	80	FIBRELINE#2		28	10.04	9.07	1775.00	-	-	0.20	-	88000		686.70		-	-	
215	Turpentine sold	11-Oct-99	80	FIBRELINE#2		39														
						33.5	10.0	9.1	1775.0	#NUM!	#NUM!	0.2	#NUM!	88000.0	#NUM!	686.7	#NUM!	#NUM!	#NUM!	
216	SWL ex polisher	23-Dec-96	23	CHEM_REC					10600	16	<0.48		41.9 g/l S		8776			5.9	2.5	Lab data base (K Nisbet, 17/2/0
217	SWL from SWL storage to the digesters	23-Dec-96	23	CHEM_REC					13500	18	<0.48		30.5 g/l S		6579			5.4	4.7	Lab data base (K Nisbet, 17/2/0
218	SWL ex polisher (filtered)	06-Jan-98	23	CHEM_REC					141000	<2.1	<2.4		20.3 g/l S		4551			<0.5	0.17	Lab data base (K Nisbet, 17/2/0
219	SWL ex polisher (unfiltered)	06-Jan-98	23	CHEM_REC					150000	3.1	<2.4		16.7 g/l S		4778			<0.5	0.12	Lab data base (K Nisbet, 17/2/0
220	SWL ex polisher	08-Dec-99	23	CHEM_REC								246								Lab data base (K Nisbet, 17/2/0
218	SWL from SWL storage to the digesters (filter	03-Apr-98	23	CHEM_REC					177000	10	<0.24		26.8 g/l S		7580			<0.05	2.6	Lab data base (K Nisbet, 17/2/0
219	SWL from SWL storage to the digesters (filter	14-May-98	23	CHEM_REC					178000	6.9	<2.4		31.8 g/l S		11800			<0.05	0.88	Lab data base (K Nisbet, 17/2/0
220	SWL from SWL storage to the digesters (filter	24-Aug-98	23	CHEM_REC					90300	5.8	<2.4		44.6 g/l S		8588			<0.05	<0.1	Lab data base (K Nisbet, 17/2/0
221	SWL from SWL storage to the digesters	10-Jan-97	23	CHEM_REC											8660					Lab data base (K Nisbet, 17/2/0
222	SWL from SWL storage to the digesters	24-Aug-99	23	CHEM_REC		80	12.62	O/R	130000	12.5	20.2			47200		1468	214217	8.1	3.16	
223	SWL from SWL storage to the digesters	28-Sep-99	23	CHEM_REC		76	12.71	-	217500	11	13.7	3294	3506.6	540000		244657		12.6	5.7	
224	SWL from SWL storage to the digesters	11-Oct-99	23	CHEM_REC		84	12.94	>20 000	96500	74.73	28.84	4284	6883	60000		259547		8.7	13.72	
225	SWL from SWL storage to the digesters	14-Feb-00	23	CHEM_REC							0	920	320							
226	SWL from SWL storage to the digesters	15-Feb-00	23	CHEM_REC					-	-	-	5333	-							
227	SWL from SWL storage to the digesters	16-Feb-00	23	CHEM_REC					100000	57		14137	9704							
228	SWL from SWL storage to the digesters	17-Feb-00	23	CHEM_REC					105000	-	-	2856	5718.3							
229	SWL from SWL storage to the digesters	18-Feb-00	23	CHEM_REC					107500	13	2	5993.3	7053.4							
230	SWL from SWL storage to the digesters	21-Feb-00	23	CHEM_REC					122500	12.3	1.8	3865.7	8298.8							
231	SWL from SWL storage to the digesters	22-Feb-00	23	CHEM_REC					122500	10.4	1.2	2805.8	7181.2							
232	SWL from SWL storage to the digesters	23-Feb-00	23	CHEM_REC					137500	16	2	3198.1	5534.2							
233	SWL from SWL storage to the digesters	24-Feb-00	23	CHEM_REC					37500	6.8	0	1269.1	2897.6							light yellow-green colour, low Na
234	SWL from SWL storage to the digesters	25-Feb-00	23	CHEM_REC					142500	3.8	0.4	6518.9	9165.9							
AVERAGE						80.0	12.8		115522.2	17.3	7.0	4209.3	6023.9	######	7664.0	######	214217.0	8.1	3.7	
						80.0	12.7		122500.0	11.7	1.9	3294.0	6883.0	60000.0	8084.0	######	214217.0	8.1	2.6	
235	Condensate from 3rd effect evaporator - #2 Ev	26-Aug-99	31	EVAPORAT		90	6.65	55	20	43.7	1.9	48.8	9.92	880		30	170	0.24	0.18	Gibson sampling
236	Contaminated condensate feed quality						8.98 (16	170 (168)	10 (31)	0.4 (20)	0.02 (35)	1.81 (34)	19.2 (34)	360 (104)		14 (167)	69.5 (156)	0 (34)	0 (34)	E Slabbert
237	Foul condensate feed quality						10 (94)	445 (100)	5 (18)	-	0.19 (19)	2.4 (19)	7.4 (18)	0750 (90)		15 (92)	63 (85)	0.01 (19)	0 (19)	E Slabbert
238	Combined foul condensate feed quality						10.1 (43	751 (43)	75.5 (8)	1.12 (1)	0.3 (9)	7.2 (10)	15.6 (10)	3900 (40)		28 (43)	895 (43)	0 (9)	0 (9)	E Slabbert
VERAGE							6.65	55.00	20.00	43.70	1.90	48.80	9.92	880.00		30.00	170.00			
239	SWL Clarifier Underflow	06-Sep-99	26	CHEM_REC		88														
VERAGE							#####	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		#DIV/0!	#DIV/0!			
240	Lime Mud Washer Underflow	06-Sep-99	34	CHEM_REC		54														
VERAGE							#####	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		#DIV/0!	#DIV/0!			
241	Ozone cooling tower blow down	25-Feb-00	612	TOPLEVEL					135	135.3	24.9	131.5	60							
242	Effluent to farm (irrigated)		596	TOPLEVEL					749	86	45	759	390	2200						
																				values for conventional bleachin

ERF REF #	SAMPLE DESCRIPTION	DATE	MS STREA	DIAGRAM HEADING	FLOW RATE (kg/min)	P (°C)	pH	EC (uS/cm)	Na (mg/l)	Ca (mg/l)	Mg (mg/l)	Cl (mg/l)	SO4 (mg/l)	COD (mg/l)	K (mg/l)	TSS (mg/l)	TDS (mg/l)	Fe (mg/l)	Mn (mg/l)	COMMENT
243	Evaporator effluent	14-Feb-00	376	TOPLEVEL					450	445	178	31	113							
244	Evaporator effluent	15-Feb-00	376	TOPLEVEL					163	14.2	21.4	42.3	379							
245	Evaporator effluent	16-Feb-00	376	TOPLEVEL					87.5	21	7	2.9	31.6							
246	Evaporator effluent	17-Feb-00	376	TOPLEVEL					225	42	21	10.6	63.4							
247	Evaporator effluent	18-Feb-00	376	TOPLEVEL					175	14	13	7.2	52.5							
248	Evaporator effluent	21-Feb-00	376	TOPLEVEL					162.5	12.2	32.3	3.8	57.2							
249	Evaporator effluent	22-Feb-00	376	TOPLEVEL					237.5	17.8	0	5.8	58							
250	Evaporator effluent	23-Feb-00	376	TOPLEVEL					187.5	14.24	57	5.7	30							
251	Evaporator effluent	24-Feb-00	376	TOPLEVEL					4000	8.8	1.3	113.8	871.8							Sample very dark (BL contamin
252	Evaporator effluent	25-Feb-00	376	TOPLEVEL					687.5	5.9	3	30	107.1							
									637.55	59.514	33.4	25.31								
						####	#####	#NUM!	206.3	14.2	17.0	8.9	60.7	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	
253	PF and CRF2 effluent	14-Feb-00	443	TOPLEVEL					1670	356	0	98	3392							
254	PF and CRF2 effluent	15-Feb-00	443	TOPLEVEL					over range			1035	9050							Dregs contamination
255	PF and CRF2 effluent	16-Feb-00	443	TOPLEVEL					1675	235	50	117	5425							
256	PF and CRF2 effluent	17-Feb-00	443	TOPLEVEL					112.5	370	306	121.6	218.8							
257	PF and CRF2 effluent	18-Feb-00	443	TOPLEVEL					3175	57	7	137.1	3776.7							
258	PF and CRF2 effluent	21-Feb-00	443	TOPLEVEL					125	213.6	71.2	53.3	63.7							
259	PF and CRF2 effluent	22-Feb-00	443	TOPLEVEL					225	231.4	0	67.9	128.3							
260	PF and CRF2 effluent	23-Feb-00	443	TOPLEVEL					5000	89	0	237	9729.7							Dregs contamination
261	PF and CRF2 effluent	24-Feb-00	443	TOPLEVEL					13500	3.8	0.8	434.9	12509.3							Dregs contamination
262	PF and CRF2 effluent	25-Feb-00	443	TOPLEVEL					7625	14.8	0	499.1	14063.7							
						####	#####	#NUM!	1675.0	213.6	0.8	129.4	4600.9	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	
263	E-stage effluent	21-Jun-99	110	BLEACHPLNT		56	8.1	32.3	70	15.6	7.4	53.5	29	3040		18	284			gum, conventional bleaching
264	E-stage effluent	24-Jun-99	110	BLEACHPLNT		64	9.1	1110	350	19.2	3.6	201	87	1280		125	1265			pine & gum, conventional bleach
265	E-stage effluent	25-Jun-99	110	BLEACHPLNT		58	8	111	6.5	15.6	7.92	4.52	9.73	80		5	12			pine & gum, conventional bleach
266	E-stage effluent	30-Jun-99	110	BLEACHPLNT		50	7.7	113	6.5	14.8	7.68	1	9.1	6.5		5	36			pine, conventional bleaching
267	E-stage effluent	01-Jul-99	110	BLEACHPLNT		13	8.9	686	180	18	10.3	64.1	83.7	480		8	695			pine, conventional bleaching; ter
268	E-stage effluent	02-Jul-99	110	BLEACHPLNT		70	11.4	1873	600	672	237	57.8	103.3	6000		2785	275			pine, conventional bleaching
269	E-stage effluent	28-Sep-99	110	BLEACHPLNT		54	7.36	265	36	-	-	33.4	8.9	44		103.3		0.34	0.52	
270	E-stage effluent	11-Oct-99	110	BLEACHPLNT		64	7.98	3960	965	28	9.27	904	100	1080		3810		0.15	0.49	
271	E-stage effluent	14-Feb-00	110	BLEACHPLNT					1960	570	285		12728							
272	E-stage effluent	15-Feb-00	110	BLEACHPLNT					2125	178	267	1769	226.3							
273	E-stage effluent	16-Feb-00	110	BLEACHPLNT					1176	157	448	1474	123.2							
274	E-stage effluent	17-Feb-00	110	BLEACHPLNT					430	427	178	2035.8	277.2							
275	E-stage effluent	18-Feb-00	110	BLEACHPLNT					2600	57	45	5898.5	306.5							
276	E-stage effluent	21-Feb-00	551	TOPLEVEL					1650	204.7	409.4	1580.6	141.8							
277	E-stage effluent	22-Feb-00	551	TOPLEVEL					1700	133.5	44.5	876.8	1117.1							
278	E-stage effluent	23-Feb-00	551	TOPLEVEL					1830	142.4	409.4	1448.9	901.6							
279	E-stage effluent	24-Feb-00	551	TOPLEVEL					1570	534	391.6	62.5	3871.2							
280	E-stage effluent	25-Feb-00	551	TOPLEVEL					1540	178	427.2	1678	1481.9							
AVERAGE						53.29	8.63	1159.71	1101.47	209.33	198.80	1130.62	1269.21	1281.50		977.33	456.60	0.25	0.51	
						57.00	8.05	476.50	1070.50	142.40	178.00	876.80	132.50	780.00	#NUM!	60.65	279.50	0.25	0.51	
281	D/C stage effluent	22-Jun-99	94	BLEACHPLNT		36	7.1	2070	720	22.8	6.72	683.4	99	1440		28	2278			gum, ozone bleaching
282	D/C stage effluent	23-Jun-99	94	BLEACHPLNT		39	3	1773	510	39.4	6.18	645	104	2400		235	65			gum, conventional bleaching
283	D/C stage effluent	24-Jun-99	94	BLEACHPLNT		38	1.4	5720	490	26.4	6.24	363	2295	1120		90	2825			pine & gum, conventional bleach
284	D/C stage effluent	25-Jun-99	94	BLEACHPLNT		35	7	120	120	14.8	6.96	141	10.6	124		55	348			pine & gum, conventional bleach
285	D/C stage effluent	30-Jun-99	94	BLEACHPLNT		61	1.9	3800	870	90.8	35	443	1881	870		125	3956			pine, conventional bleaching, ter
286	D/C stage effluent	01-Jul-99	94	BLEACHPLNT		36	7.8	288	60	14.8	8.16		19.1	640		12	285			pine, conventional bleaching
287	D/C stage effluent	02-Jul-99	94	BLEACHPLNT		54	5.3	1424	435	21.6	11.3	618.6	22.8	720		1305	185			pine, conventional bleaching
288	D/C stage effluent	28-Sep-99	94	BLEACHPLNT		55	1.55	6710	640	36.1	29.3	1649.3	159.8	2400		2840		3.5	2.7	
289	D/C stage effluent	11-Oct-99	94	BLEACHPLNT		54	1.65	697	950	60.32	48.39	1807	279	1840		4637		0.71	5.39	
290	D/C stage effluent	14-Feb-00	94	BLEACHPLNT					1240	997	427	2093	403.2							
291	D/C stage effluent	15-Feb-00	94	BLEACHPLNT					1260	107	283	2023	298.8							
292	D/C stage effluent	16-Feb-00	94	BLEACHPLNT					1200	157	519	1965.2	334.2							
293	D/C stage effluent	17-Feb-00	94	BLEACHPLNT					400	934	356	1961	355.6							
294	D/C stage effluent	18-Feb-00	94	BLEACHPLNT					1170	285	356	2689.8	390.4							
295	D/C stage effluent	21-Feb-00	94	BLEACHPLNT					950	53.4	498.4	1568.9	206.4							
296	D/C stage effluent	22-Feb-00	94	BLEACHPLNT					1250	258.1	151.3	1507.5	243.3							
297	D/C stage effluent	23-Feb-00	94	BLEACHPLNT					890	151	409.7	1195.5	224							
298	D/C stage effluent	24-Feb-00	94	BLEACHPLNT					380	106.8	178	564.7	121.3							
299	D/C stage effluent	25-Feb-00	94	BLEACHPLNT					280	284.8	569.6	2918.2	308.1							
AVERAGE						45.33	4.08	2511.33	727.11	192.69	205.59	1379.84	408.19	1283.78		1036.33	1420.29	2.11	4.05	
						39.00	3.00	1773.00	720.00	90.80	151.30	1538.20	243.30	1120.00		125.00	348.00	2.11	4.05	
300	ClO2 plant effluent	21-Jun-99	645	TOPLEVEL		30	10.6	986	7500	10	3.6	8881	4430	600		[illegible]	[illegible]			

ERP REF #	SAMPLE DESCRIPTION	DATE	MS STREA	DIAGRAM HEADING	FLOW RATE (kg/min)	P (°C)	pH	EC (uS/cm)	Na (mg/l)	Ca (mg/l)	Mg (mg/l)	Cl (mg/l)	SO4 (mg/l)	COD (mg/l)	K (mg/l)	TSS (mg/l)	TDS (mg/l)	Fe (mg/l)	Mn (mg/l)	OMMEN
301	ClO2 plant effluent	22-Jun-99	645	TOPLEVEL		20	6.9	7570	15000	17.6	3.84	19258	9520	3160		292	7830			gum, ozone bleaching
302	ClO2 plant effluent	23-Jun-99	645	TOPLEVEL		15	6.6	124	9	20.2	4.18	11.7	10.6	4		5	5620			gum, conventional bleaching
303	ClO2 plant effluent	24-Jun-99	645	TOPLEVEL		23	0	7120	50	0	0		399	1120		5	155			pine & gum, conventional bleact
304	ClO2 plant effluent	25-Jun-99	645	TOPLEVEL		8	6.6	5.5	5.5	14.4	6.72	23.9	8.3	56		5	4			pine & gum, conventional bleact
305	ClO2 plant effluent	30-Jun-99	645	TOPLEVEL		30	1.7	7140	2900	0	0	2142	504	2900		170	9496			pine, conventional bleaching
306	ClO2 plant effluent	01-Jul-99	645	TOPLEVEL		13	7.6	124	10	16.4	8.4	15.7	10.8	160		2	165			pine, conventional bleaching: loc
307	ClO2 plant effluent	02-Jul-99	645	TOPLEVEL		35	4.3	1823	575	24.8	13.4	838.7	28.5	760		1620	105			pine, conventional bleaching. loc
308	ClO2 plant effluent	02-Dec-99	645	TOPLEVEL	361			3810				703								
309	ClO2 plant effluent	03-Dec-99	645	TOPLEVEL	361			3530				887								
310	ClO2 plant effluent	06-Dec-99	645	TOPLEVEL	382			18200				1000								
311	ClO2 plant effluent	07-Dec-99	645	TOPLEVEL	424			3370				474								
312	ClO2 plant effluent	08-Dec-99	645	TOPLEVEL	694			3810				749								
313	ClO2 plant effluent	09-Dec-99	645	TOPLEVEL	597			10580				2426								
314	ClO2 plant effluent	10-Dec-99	645	TOPLEVEL	368			1350				186								
315	ClO2 plant effluent	14-Dec-99	645	TOPLEVEL	354			12240				3318								
316	ClO2 plant effluent	15-Dec-99	645	TOPLEVEL	354			3200				1367								
317	ClO2 plant effluent	17-Dec-99	645	TOPLEVEL	368			4910				906								
318	ClO2 plant effluent	20-Dec-99	645	TOPLEVEL	417			3340				492								
319	ClO2 plant effluent	21-Dec-99	645	TOPLEVEL	382			1301				271								
320	ClO2 plant effluent	04-Jan-00	645	TOPLEVEL	431			945				186								
321	ClO2 plant effluent	14-Feb-00	645	TOPLEVEL					16875	0	0	9222	8607							
322	ClO2 plant effluent	16-Feb-00	645	TOPLEVEL					100	36	35	649	51.2							
323	ClO2 plant effluent	17-Feb-00	645	TOPLEVEL					320	64	25	221	51.3							
324	ClO2 plant effluent	18-Feb-00	645	TOPLEVEL					2800	32	46	2910.9	1498.8							
325	ClO2 plant effluent	21-Feb-00	645	TOPLEVEL					14200	17.8	11.9	8994.2	7123.9							
326	ClO2 plant effluent	22-Feb-00	645	TOPLEVEL					60	39.2	32	266.7	56.7							
327	ClO2 plant effluent	23-Feb-00	645	TOPLEVEL					70	35.6	7.1	357.7	50.6							
328	ClO2 plant effluent	24-Feb-00	645	TOPLEVEL					1600	42.7	10.7	1789	828.7							
329	ClO2 plant effluent	25-Feb-00	645	TOPLEVEL					3780	17.8	17.8	3639.9	1941.7							green in colour, no ClO2 smell
AVERAGE					422.5	21.5	5.1	4687.0	3330.4	26.2	16.5	1693.7	1597.0	969.0		449.3	2442.5			
percentile					382.0	21.5	6.6	3370.0	575.0	17.8	8.4	838.7	399.0	680.0	#NUM!	75.5	366.5			
330	#3 uptake effluent	21-Jun-99	226	TOPLEVEL		39	6.1	756	255	22	5	383.9	118.7	200		384	556			gum, conventional bleaching
331	#3 uptake effluent	22-Jun-99	226	TOPLEVEL		33	6.8	418	77	14.8	4.32	116.7	29	440		92	484			gum, ozone bleaching
332	#3 uptake effluent	23-Jun-99	226	TOPLEVEL		36	5.4	762	195	18.8	5.94	253	51	704		135	47390			gum, conventional bleaching
333	#3 uptake effluent	24-Jun-99	226	TOPLEVEL		34	4.2	561	135	19.6	6.24	865	26	4		240	455			pine & gum, conventional bleact
334	#3 uptake effluent	25-Jun-99	226	TOPLEVEL		34	6.9	86	86	20.8	5.52	193	17.9	104		4005	312			pine & gum, conventional bleact
335	#3 uptake effluent	30-Jun-99	226	TOPLEVEL		41	5.8	778	185	16	7.68	208	23.7	185		3385	28			pine, conventional bleaching
336	#3 uptake effluent	01-Jul-99	226	TOPLEVEL		42	7.4	410	110	14	4.56	90.1	10.2	40		4	245			pine, conventional bleaching
337	#3 uptake effluent	02-Jul-99	226	TOPLEVEL		34	8.7	311	80	23.6	12.7	31.3	32.4	160		245	60			pine, conventional bleaching
338	#3 uptake effluent	14-Feb-00	226	TOPLEVEL					244	56.9	0	359	50.4							
339	#3 uptake effluent	15-Feb-00	226	TOPLEVEL					237.5	14.2	128.2	254	35							
340	#3 uptake effluent	16-Feb-00	226	TOPLEVEL					217.5	17.8	0	302.5	30							
341	#3 uptake effluent	17-Feb-00	226	TOPLEVEL					305	0	0	407	44.3							
342	#3 uptake effluent	18-Feb-00	226	TOPLEVEL					435	7	7	813	66.1							
343	#3 uptake effluent	21-Feb-00	226	TOPLEVEL					357.5	89	145.9	553.7	60.6							
344	#3 uptake effluent	22-Feb-00	226	TOPLEVEL					1680	53.4	35.6	257.8	26.6							
345	#3 uptake effluent	23-Feb-00	226	TOPLEVEL					287.5	53.4	142.4	349.2	33.7							
346	#3 uptake effluent	24-Feb-00	226	TOPLEVEL					275	42.7	23.1	325.8	34.4							
347	#3 uptake effluent	25-Feb-00	226	TOPLEVEL					105	35.6	46.3	239.1	24.8							
VERAGE							6.41	510.25	140.38	18.70	6.50	267.63	38.61	229.63		1061.25	6191.25			
						35.00	6.45	489.50	227.50	20.20	6.62	280.15	33.05	172.50	#NUM!	242.50	383.50	#NUM!	#NUM!	
348	#2 Digester floor drain	21-Jun-99	534	TOPLEVEL		34	9.1	206	725	32.8	13.2	82.7	933.5	2200		162	2920			gum, conventional bleaching
349	#2 Digester floor drain	22-Jun-99	534	TOPLEVEL		44	9.4	616	180	20.8	3.6	60	75.7	4000		598	724			gum, ozone bleaching
350	#2 Digester floor drain	23-Jun-99	534	TOPLEVEL		42	11.6	4490	1725	24.6	4	116	484	3400		620	2925			gum, conventional bleaching
351	#2 Digester floor drain	24-Jun-99	534	TOPLEVEL		42	11.8	7540	1600	656	18	209	742	5000		445	12760			pine & gum, conventional bleact
352	#2 Digester floor drain	25-Jun-99	534	TOPLEVEL		32	11.4	1100	1100	358	71.5	295	331	3120		685	5208			pine & gum, conventional bleact
353	#2 Digester floor drain	14-Feb-00	534	TOPLEVEL					6875	0	0									
354	#2 Digester floor drain	15-Feb-00	534	TOPLEVEL					6000	712	356	155	2023							
355	#2 Digester floor drain	16-Feb-00	534	TOPLEVEL					6000	35.6	0	256.7	1567							
356	#2 Digester floor drain	17-Feb-00	534	TOPLEVEL					3100	sample too dark		154.3	1738							
357	#2 Digester floor drain	18-Feb-00	534	TOPLEVEL					4750	28.4	30	253.4	2474.5							
358	#2 Digester floor drain	21-Feb-00	534	TOPLEVEL					300	142.4	0	103.4	140.7							
359	#2 Digester floor drain	22-Feb-00	534	TOPLEVEL					950	89	89	211.9	295.1							
360	#2 Digester floor drain	23-Feb-00	534	TOPLEVEL					1850	33.7	12.8	92.5	477.5							
361	#2 Digester floor drain	24-Feb-00	534	TOPLEVEL					6000	29.1	17	329.2	1870.1							
AVERAGE						38.8	10.68	2790.4	2939.643	166.3385	47.31538	178.3923	1011.7	3544		502	4007.4			

ERP REF #	SAMPLE DESCRIPTION	DATE	MS STREA	DIAGRAM HEADING	FLOW RATE (kg/min)	TEMP (°C)	pH	EC (uS/cm)	Na (mg/l)	Ca (mg/l)	Mg (mg/l)	Cl (mg/l)	SO4 (mg/l)	COD (mg/l)	K (mg/l)	TSS (mg/l)	TDS (mg/l)	Fe (mg/l)	Mn (mg/l)	COMMENT 662
50%						42	11.4	1100	1787.5	33.7	13.2	155	742	3400		598	2925			
362	Hot water effluent	14-Feb-00	544	TOPLEVEL					5	?1282?	?0?	2.6	4.9							
363	Hot water effluent	15-Feb-00	544	TOPLEVEL					10	10.7	7	2.8	5.3							
364	Hot water effluent	16-Feb-00	544	TOPLEVEL					6	3.56	14.2	2.7	5.4							
365	Hot water effluent	17-Feb-00	544	TOPLEVEL					5	14	7	2.3	3.9							
366	Hot water effluent	18-Feb-00	544	TOPLEVEL					3	29	21	1.6	2.8							
367	Hot water effluent	21-Feb-00	544	TOPLEVEL					10.5	10.7	10.7	7.3	10.3							
368	Hot water effluent	22-Feb-00	544	TOPLEVEL					2.5	7.12	3.58	2	3.1							
369	Hot water effluent	23-Feb-00	544	TOPLEVEL					2.5	7.12	3.56	2.1	1.7							
370	Hot water effluent	24-Feb-00	544	TOPLEVEL					6	17.8	17.8	2.2	6							
371	Hot water effluent	25-Feb-00	544	TOPLEVEL					2.5	5.9	17.8	3.1	2.5							
50%						####	#####	#NUM!	5	10.7	10.7	2.45	4.4	#NUM!	#NUM!	#NUM!	#NUM!			
372	Bleach plant floor drain	01-Jul-99	200	BLEACHPLNT		38	3.6	950	240	23.6	9.84	211	102	1120		800	106			pine, conventional bleaching
373	Bleach plant floor drain	02-Jul-99	200	BLEACHPLNT		32	11.1	1732	550	116	36.2	13.3	86.4	6400		2705	500			pine, conventional bleaching
374	Bleach plant floor drain	06-Jul-99	200	BLEACHPLNT		30	7.8	1041	300	46	8.4	359.3	10.7	200		875	150			pine, conventional bleaching
375	Bleach plant floor drain	23-Aug-99	200	BLEACHPLNT		30	1.72	5360	200	29	5.9	863	1488	2400		14	7793			pine, conventional bleaching
376	Bleach plant floor drain	24-Aug-99	200	BLEACHPLNT			12.62	over range	130000	12.5	20.2							8.1	3.16	
377	Bleach plant floor drain	25-Aug-99	200	BLEACHPLNT			11.48	6450	4600	30.1	46.2							2.12	2.4	
378	Bleach plant floor drain	26-Aug-99	200	BLEACHPLNT			5.04	1760	337.5	17.5	4.5	494.1	33.8	292		1110	2217	0.12	1.12	
379	Bleach plant floor drain	27-Aug-99	200	BLEACHPLNT			4.61	728	140	33.7	20.2	33.6	420.6	14.6		5220	2783	0.68	3.8	
380	Bleach plant floor drain	30-Aug-99	200	BLEACHPLNT			5.92	2360	570	111.1	23.2	64.2	1528.5	21.8		352	3037	0.32	2.93	
381	Bleach plant floor drain	14-Feb-00	200	BLEACHPLNT					1600	1068	712	1633	294							
382	Bleach plant floor drain	15-Feb-00	200	BLEACHPLNT					740	115.7	222.5	804	91							
383	Bleach plant floor drain	16-Feb-00	200	BLEACHPLNT					1600	128.2	284.7	1513	147.4							
384	Bleach plant floor drain	17-Feb-00	200	BLEACHPLNT					1200	748	199	1800	277							
385	Bleach plant floor drain	18-Feb-00	200	BLEACHPLNT					1300	185	385	2404.8	319.8							
386	Bleach plant floor drain	21-Feb-00	200	BLEACHPLNT					430	71.2	213.6	432.5	67.7							
387	Bleach plant floor drain	22-Feb-00	200	BLEACHPLNT					490	97.9	169.1	500.5	39.7							
388	Bleach plant floor drain	23-Feb-00	200	BLEACHPLNT					1430	356	498.4	1768.3	290							
389	Bleach plant floor drain	24-Feb-00	200	BLEACHPLNT					220	49.8	36.6	227.3	43.4							
390	Bleach plant floor drain	25-Feb-00	200	BLEACHPLNT					285	71.2	0	393.6	40.4							
VERAGE							7.1	2548	15215	46.6	19.4	291	524	1493		1582	2369	2.268	2.682	
50%						31	5.92	1746	550	71.2	36.6	494.1	102	292	#NUM!	875	2217	0.68	2.93	
391	Bleach effluents clarifier overflow	21-Jun-99	11	OLDEFFL		52	3.3	211	620	45.2	15.8	399.3	758.6	1120		28	2464			gum, conventional bleaching
392	Bleach effluents clarifier overflow	12-Jul-99	11	OLDEFFL		53	3.9	2590	1125	42.4	20.4	1169	315	1200		105	4480			pine, conventional bleaching
393	Bleach effluents clarifier overflow	23-Aug-99	11	OLDEFFL		52	2.38	4170	1100	468	46.8	1365	1281	8800		176	4187			pine, conventional bleaching
394	Bleach effluents clarifier overflow	24-Aug-99	11	OLDEFFL		47	6.23	3420	1550	936	93.6	1032	295.3	4400		100	3390			pine, conventional bleaching
395	Bleach effluents clarifier overflow	25-Aug-99	11	OLDEFFL			12.43	over range	6850	0	8.2	1031.6	295.3	2800		666	40827	1.62	0.83	
396	Bleach effluents clarifier overflow	26-Aug-99	11	OLDEFFL			6.65	55	20	43.7	1.9	48.8	9.92	880		1110	2217	0.24	0.18	
397	Bleach effluents clarifier overflow	27-Aug-99	11	OLDEFFL			5.97	409	80	32.4	15	18.5	538.4	18.3		oil contan	2900	0.88	1.38	
398	Bleach effluents clarifier overflow	30-Aug-99	11	OLDEFFL			13.24	over range	56500			3286.6	1902.1	19		1642	263047	0.12	3.59	
AVERAGE							6.76	1809	8480.6	224.0	28.8	1043.9	674.5	2405		547	40439	0.715	1.495	
50%						52	6.1	1499.5	1112.5	43.7	15.8	1031.8	426.7	1160	#NUM!	176	3788.5	0.56	1.105	#NUM!
399	Weak black liquor #1 Digester	10-Jan-97	120	TOPLEVEL											2100					Lab data base (K Nisbet, 17/2/0
400	Weak black liquor #1 Digester	01-Nov-99	120	TOPLEVEL		93	13.4	19280	41750	94.1	55.76	1171.6	1795.1	152000		2625	160047	12.5	55.76	special samples by Gibson, pine
401	Weak black liquor #1 Digester	03-Nov-99	120	TOPLEVEL		93	13.16	18020	42500	82.24	48.18	1387.4	447.7	176000		5375	134753	10.4	78.18	special samples by Gibson; pine
402	Weak black liquor #1 Digester	04-Nov-99	120	TOPLEVEL		92	13.01	17570	29250	134.5	62.18	1199.9	2127	150000		3860	93377	16.89	62.18	special samples by Gibson; pine
403	Weak black liquor #1 Digester	14-Feb-00	120	TOPLEVEL																
404	Weak black liquor #1 Digester	15-Feb-00	120	TOPLEVEL								2151	1509							
405	Weak black liquor #1 Digester	16-Feb-00	120	TOPLEVEL					28750			808.1	4670							
406	Weak black liquor #1 Digester	17-Feb-00	120	TOPLEVEL					27500			729	1856							
407	Weak black liquor #1 Digester	18-Feb-00	120	TOPLEVEL					31750	39	16	1521.1	2189.2							
408	Weak black liquor #1 Digester	21-Feb-00	120	TOPLEVEL					30000	16.8	26.2	1041.9	2815.8							
409	Weak black liquor #1 Digester	22-Feb-00	120	TOPLEVEL					33750	57.6	7.7	706.1	2565.5							
410	Weak black liquor #1 Digester	23-Feb-00	120	TOPLEVEL					33000	25.2	17.4	715	1979.5							
411	Weak black liquor #1 Digester	24-Feb-00	120	TOPLEVEL					36250	9.8	115	728.1	2678.7							
662	Weak black liquor #1 Digester	25-Jan-01										936			1185					
412	Weak black liquor #1 Digester	25-Feb-00	120	TOPLEVEL					33750	8.1	12.5	1379.8	2634							
AVERAGE						92.7	13.2	18290.0	33477.3	51.9	40.1	1113.5	2272.3	######	1642.5	3953.3	129392.3	13.3	65.4	
Percentile						93	13.16	18020	33000	39	26.2	1041.9	2158.1	152000	1642.5	3860	134753	12.5	62.18	
413	Weak black liquor #2 Digester	10-Jan-97	251	FIBRELINE#2											2150					Lab data base (K Nisbet, 17/2/0
414	Weak black liquor #2 Digester	01-Nov-99	251	FIBRELINE#2		80	13.09	18670	35000	80.76	94.44	958.1	1844.6	144000		3550	124117	9.32	94.44	special samples by Gibson; pine
415	Weak black liquor #2 Digester	03-Nov-99	251	FIBRELINE#2		79	12.95	17910	36250	81.52	51.56	1118.8	1248.4	144000		7095	144880	11.29	51.56	special samples by Gibson; pine
416	Weak black liquor #2 Digester	04-Nov-99	251	FIBRELINE#2		80	12.61	16900	18000	85.1	89.26	819.54	3191.2	122000		3920	144620	8.07	89.26	special samples by Gibson, pine
417	Weak black liquor #2 Digester	28-Sep-99	251	FIBRELINE#2		90	13.12	-	21750	27.4	31.2	8460	166560	14000		[illegible]				

ERP REF #	SAMPLE DESCRIPTION	DATE	MS STREA	DIAGRAM HEADING	FLOW RATE (kg/min)	P (°C)	pH	EC (uS/cm)	Na (mg/l)	Ca (mg/l)	Mg (mg/l)	Cl (mg/l)	SO4 (mg/l)	COD (mg/l)	K (mg/l)	TSS (mg/l)	TDS (mg/l)	Fe (mg/l)	Mn (mg/l)		COMMENT
418	Weak black liquor #2 Digester	11-Oct-99	251	FIBRELINE#2		79	12.96	19980	28250	52.65	83.03	4461	1758	154000		443		4.62	15.76		bleach plant mass balance sam
419	Weak black liquor #2 Digester	15-Feb-00	251	FIBRELINE#2								625	2181								
420	Weak black liquor #2 Digester	16-Feb-00	251	FIBRELINE#2					31750			799.8	2307								
421	Weak black liquor #2 Digester	17-Feb-00	251	FIBRELINE#2					32500			840	2512								
422	Weak black liquor #2 Digester	18-Feb-00	251	FIBRELINE#2					31250	59	14	998.1	3173.3								
423	Weak black liquor #2 Digester	21-Feb-00	251	FIBRELINE#2					29250	50.9	22.3	819.7	2828.3								
424	Weak black liquor #2 Digester	22-Feb-00	251	FIBRELINE#2					37750	24.8	15.8	791.1	3185.2								
425	Weak black liquor #2 Digester	23-Feb-00	251	FIBRELINE#2					35750	22.1	14.8	750.4	2745.5								
426	Weak black liquor #2 Digester	24-Feb-00	251	FIBRELINE#2					32500	8.2	9.2	610.1	2857.3								
661	Weak black liquor #2 Digester	01-Jan-25										961			1419						
427	Weak black liquor #2 Digester	25-Feb-00	251	FIBRELINE#2					34250	8.4	11.1	1586.4	4167.8								
AVERAGE						81.6	12.9	17827	31096	46	40	1640	14326	141000		4855	137872	9.56	78.42		
50 percentile						80	12.96	18290	32500	50.9	22.3	840	2786.9	144000	1784.5	3920	144620	9.32	51.56		#NUM!
428	Fresh salt cake (in ppm unless stated otherwis	01-Nov-99	422&424	TOPLEVEL								NaCl=2.0%	Na2SO4=86.9%								analysis requested by M Carter
429	Salt cake ex day silo (in ppm unless stated oth	13-Jan-97													5280						Lab data base (K Nisbet, 17/2/0
430	Salt cake ex conveyor (in ppm unless stated o	13-Jan-97													29400						Lab data base (K Nisbet, 17/2/0
431	Salt cake Tugela (in ppm unless stated otherw	23-Jan-98	422&424	TOPLEVEL					36.7%	634	580		44.40%		3604			301	103		Lab data base (K Nisbet, 17/2/0
432	Salt cake Rustenburg (in ppm)	23-Jan-98	422&424	TOPLEVEL					32.9%	193	11		69.20%		122			12	<1		Lab data base (K Nisbet, 17/2/0
433	Salt cake Tugela (in ppm unless stated otherw	09-Feb-98	422&424	TOPLEVEL					32.3%	714	603		41.50%					700		<2	Lab data base (K Nisbet, 17/2/0
434	Salt cake Rustenburg (in ppm)	09-Feb-98	422&424	TOPLEVEL					33.1%	<357	<301		53.90%					<350		<2	Lab data base (K Nisbet, 17/2/0
435	Salt cake Tugela (in ppm unless stated otherw	08-Apr-98	422&424	TOPLEVEL					36.0%	533	447				2531			201	85		Lab data base (K Nisbet, 17/2/0
436	Salt cake Tugela reactor prod (in ppm)	28-Apr-98	422&424	TOPLEVEL					46.1%	2600	1500				7180			150	100		Lab data base (K Nisbet, 17/2/0
437	Salt cake Tugela copeland prod (in ppm)	24-Aug-98	422&424	TOPLEVEL					38.3%	1879	1117		12% S		4746			129	77		Lab data base (K Nisbet, 17/2/0
438	Salt cake Piet Retief (in ppm)	11-Sep-98	422&424	TOPLEVEL					32.5%	610	558				2839			212	87		Lab data base (K Nisbet, 17/2/0
439	Salt cake Tugela copeland prod (in ppm)	11-Jan-99	422&424	TOPLEVEL					34.1%	2470	2025		10.7% S		5579			301	202.5		Lab data base (K Nisbet, 17/2/0
440	Salt cake Piet Retief (in ppm)	Sep-99	422&424	TOPLEVEL					33.7%	900	600		14.5% S		2435			428	67		Lab data base (K Nisbet, 17/2/0
441	Salt cake Tugela (in ppm unless stated otherw	Sep-99	422&424	TOPLEVEL					36.0%	3100	1500		10% S		5684			324	172	0	Lab data base (K Nisbet, 17/2/0
	Saltcake (Protea)														700						
	Saltcake (Protea)														200						
	Saltcake (Protea)														200						
	Saltcake (Protea)														300						
	Saltcake (Protea)														300						
	Saltcake (Protea)														200						
	Salt cake trucks at Ngodwana														13000						
	Salt cake trucks at Ngodwana														3000						
	Salt cake trucks at Ngodwana														3000						
	Salt cake trucks at Ngodwana														7000						
	Salt cake trucks at Ngodwana														1000						
442	Salt cake Piet Retief (in ppm)	02-Nov-99	422&424	TOPLEVEL			11.5		Sulphate as Na2SO4=81.7%;Carbonate as Na2CO3=17%;Hydroxide as NaOH=0.6%;Chloride as NaCl=0.3%;Potas												Mondi Piet Retief lab certificate
						####	11.5	#NUM!	0.341	807	601.5	#NUM!	0.4915	#NUM!	2919.5	#NUM!	#NUM!	256.5	93.5		
443	Unslaked lime Ngodwana (ppm unless stated	Feb-87							17064	397 g/l	9750							2798	3791		Lab data base (K Nisbet, 17/2/0
444	Unslaked lime Ngodwana (ppm unless stated	Mar-87							8550	519 g/l	9272		1870 as S		315			2736	4945		Lab data base (K Nisbet, 17/2/0
445	Unslaked lime Ngodwana (ppm unless stated	Apr-87											4165 as S								Lab data base (K Nisbet, 17/2/0
446	Unslaked lime Ngodwana (ppm unless stated	Feb-88							1484	638 g/l	301		8000 as S					4197	5421		Lab data base (K Nisbet, 17/2/0
447	Unslaked lime Ulco (in ppm)	Feb-88								663 g/l	6633		200 as S					699	8519		Lab data base (K Nisbet, 17/2/0
448	Ngodwana lime (in ppm)	May-97							15400	597 g/l	11300		2900 as S		578			2359	1781	1	Results based on dried sample
449	Unslaked lump lime (in ppm)	May-98								677 g/l	12422		40 as S					2168	7099		Lab data base (K Nisbet, 17/2/0
450	Ngodwana lime (in ppm)	Jan-99							22400		14600		50 as S		1073			36000	1209		Lab data base (K Nisbet, 17/2/0
451	Idwala lime (in ppm)	Feb-99									13630		360 as S					2168	6319		Lab data base (K Nisbet, 17/2/0
452	Ngodwana lime (in ppm)	Apr-99							19900		13600				1045			3468	2425		Lab data base (K Nisbet, 17/2/0
453	Idwala lime (in ppm)	May-99									13569		120 as S					2098	6510		Lab data base (K Nisbet, 17/2/0
454	Ngodwana lime (in ppm)	Aug-99							15000		16300		2000 as S		1571			3110	4964		Lab data base (K Nisbet, 17/2/0
455	Richards Bay lime (in ppm)	Sep-99							7800	645 g/l	11000		<2000 as S		312			1185	5187		Lab data base (K Nisbet, 17/2/0
456	Tugela lime (in ppm)	Sep-99							12100	663 g/l	14800		<2000 as S		547			2954	2774	0	Lab data base (K Nisbet, 17/2/0
457	Idwala lime (in ppm)	Oct-99							7600	630 g/l	16000				1700			1900	10000		Lab data base (K Nisbet, 17/2/0
458	Wood analysis Pinus Patula (ppm on dried sar	09-Jan-92							111	388	164	50	39.36 as S		352.7			6.66	77.21		SW chloride value from V Bohm
459	Wood analysis wattle (ppm on dried sample)	27-Mar-92							39	730	180	800	24 as S		520			8.6	< 0.06		HW chloride value from V Bohm
460	Wood analysis CTE (ppm on dried sample)	27-Mar-92							125	390	140		42 as S		540			28	90		moisture=37.77%
461	Wood analysis Glandis (ppm on dried sample)	27-Mar-92							165	988	184		29.1 as S		830			14	27		moisture=31.89%
									Na %			Cl %			K %				Moist %		
462	Ash from #2 CRF	10-Jan-97													2.1						Lab data base (K Nisbet, 17/2/0
	#2 CRF boiler bank ash	18-Dec-00							36.7			4.1			3.3						
	#2 CRF boiler bank ash	21-Dec-00							42.1			2.8			3.2						

REF #	SAMPLE DESCRIPTION	DATE	MS STREA	DIAGRAM HEADING	FLOW RATE (kg/min)	P (°C)	pH	EC (uS/cm)	Na (mg/l)	Ca (mg/l)	Mg (mg/l)	Cl (mg/l)	SO4 (mg/l)	COD (mg/l)	K (mg/l)	TSS (mg/l)	TDS (mg/l)	Fe (mg/l)	Mn (mg/l)	COMMENT
	#2 CRF boiler bank ash	28-Dec-00							42.7			4.0			3.2					
	#2 CRF boiler bank ash	04-Jan-01							43.5			3.9			3.2					
	#2 CRF boiler bank ash	09-Jan-00							39.0			2.0			3 1					
	#2 CRF boiler bank ash	05-Feb-01							34.2			1.1			2.3					
	#2 CRF boiler bank ash	31-Jan-01							30.5			1.3			2.3					
	#2 CRF boiler bank ash	02-Feb-01							34.2			1.2			2.3					
	#2 CRF boiler bank ash	30-Jan-01							35 5			2.0			2.3					
Average									37.6			2.5			2.7					
50%									36.7			2.0			3.1					
463	Smelt	10-Jan-97													29 g/kg					Lab data base (K Nisbet, 17/2/0
464	Dregs S1								10.6%	19.7%	1.61%		0.88% as S		0.21%			1.36%	1.10%	Results based on sample dry we
465	Dregs S1	04-Jul-96							11.0%	14.7%	2.0%				0.21%			2.00%	1.40%	Results based on sample dry we
466	Soap sold	13-Sep-99	373	TOPLEVEL					14.4% as Na2SO4											gum run (K Nisbet, 16/11/99)
467	#3 Uptake bleached pulp bales sold	06-Aug-99	221	TOPLEVEL					648.8mg/kg total	71.3 mg/kg	47.4 mg/kg	564 mg/kg soluble	144 mg/kg							analysis
468	lime mud washer underflow		34	CHEM REC												38% solids				A
469	Gum BOC into mill	Jan 99 - Jun 99	53	TOPLEVEL	111															
470	Gum logs into mill	Jan 99 - Jun 99	52	TOPLEVEL	304.2															
471	Pine BOC into mill	Jan 99 - Jun 99	51	TOPLEVEL	411.2															
472	Pine logs into mill (excluding GWD)	Jan 99 - Jun 99	54	TOPLEVEL	1837.3															
473	Pine logs to groundwood	Jan 99 - Jun 99	55	TOPLEVEL	499.5															
474	Sawdust	Feb 99 - Jun 99			7.97															
475	Oversize chips	Feb 99 - Jun 99			23															
476	Bark burnt	Feb 98 - Jan 99			67.6															
477	Bark burnt	Feb 99 - Jun 99			105															
478	Bark recovered (Culterra, Braaks)	Feb 98 - Jan 99			87.3															
479	Bark recovered (Culterra, Braaks)	Feb 99 - Jun 99			91.1															
480	Bark to macro dump	Feb 98 - Jan 99			78.9															
481	Bark to macro dump				66															
482	Bark sold				42.5															
483	Demin raw water intake	Oct 97 - Mar 98	4	BOILERS	4809															average value from spreadshee
484	Demin raw water intake	Apr 98 - Sept 98	4	BOILERS	4246															average value from spreadshee
485	Demin raw water intake	Oct 98 - Mar 99	4	BOILERS	4115															average value from spreadshee
486	Demin raw water intake	Apr 99 - Aug 99	4	BOILERS	5146															average value from spreadshee
VERAGE					4579															
487	Demin water produced	Oct 97 - Mar 98	11&12&	BOILERS	4702															average value from spreadshee
488	Demin water produced	Apr 98 - Sept 98	11&12&	BOILERS	4190															average value from spreadshee
489	Demin water produced	Oct 98 - Mar 99	11&12&	BOILERS	4056															average value from spreadshee
490	Demin water produced	Apr 99 - Aug 99	11&12&	BOILERS	5055															average value from spreadshee
VERAGE					4501															
491	Demin H2SO4 usage	Sept 97 - Feb	6	BOILERS	1.163															average value from spreadshee
492	Demin H2SO4 usage	Mar 98 - Aug 9	6	BOILERS	1.414															average value from spreadshee
493	Demin H2SO4 usage	Sept 98 - Feb	6	BOILERS	0.943															average value from spreadshee
494	Demin H2SO4 usage	Mar 99 - Aug 9	6	BOILERS	0.921															average value from spreadshee
VERAGE					1.110															
495	Demin NaOH (as 48%) usage	Oct 97 - Mar 98	10	BOILERS	1.997															average value from spreadshee
496	Demin NaOH (as 48%) usage	Apr 98 - Sept 98	10	BOILERS	1.350															average value from spreadshee
497	Demin NaOH (as 48%) usage	Oct 98 - Mar 99	10	BOILERS	1.089															average value from spreadshee
498	Demin NaOH (as 48%) usage	Apr 99 - Aug 99	10	BOILERS	1.410															average value from spreadshee
VERAGE					1.461															
499	Gas coal usage	Jan 97 - Dec 97			125.3															
500	Gas coal usage	Jan 98 - Dec 98			106.4															
501	Gas coal usage	Jan 99 - Oct 99			119.1															
502	Lime production	Jan 97 - Dec 97			173															
503	Lime production	Jan 98 - Dec 98			166															
504	Lime production	Jan 99 - Oct 99			194.5															
505	Active alkali production	Jan 97 - Dec 97			252															
506	Active alkali production	Jan 98 - Dec 98			225.9															
507	Active alkali production	Jan 99 - Oct 99			213.2															
508	Lime sales	Mar 99 - Oct 99			18.14															
509	Caustic addition - mill wide	Sep 95 - Aug 96	6+322+6	TOPLEVEL	7.74															
510	Sulphur addition - chemical section	Sep 95 - Aug 96	632+490	TOPLEVEL	1.16															Fax from P Louw to A Knobel, 2
511	#2 CRF sulphur addition		490	TOPLEVEL	1.56 (0 - 3.13)															Fax from P Louw to A Knobel, 2

REF #	SAMPLE DESCRIPTION	DATE	MS STREAM	DIAGRAM HEADING	FLOW RATE (kg/min)	P (°C)	pH	EC (uS/cm)	Na (mg/l)	Ca (mg/l)	Mg (mg/l)	Cl (mg/l)	SO4 (mg/l)	COD (mg/l)	K (mg/l)	TSS (mg/l)	TDS (mg/l)	Fe (mg/l)	Mn (mg/l)	COMMENT
512	#2 CRF sulphur addition		490	TOPLEVEL	1.04 - 5.21															Faan
512	Saltcake addtion - chemical section	Sep 95 - Aug 9	422+424	TOPLEVEL	18.5															Fax from P Louw to A Knobel, 2
513	Saltcake usage	Oct 98 - Sep 9	422+424	TOPLEVEL	26.9															
514	#2 CRF saltcake usage		424	TOPLEVEL	20.83 - 27.78															Michael Carter, 4/11/99
515	#1 CRF saltcake usage		422	TOPLEVEL	6.94															Michael Carter, 4/11/99
516	course ash	Jan 98 - Sept 9	454	TOPLEVEL	17.0															average values for Jan 98 to Se
517	course ash	Oct 98 - Jan 99	454	TOPLEVEL	17.5															
518	fly ash	Jan 98 - Sept 9	430	TOPLEVEL	158.9															average values for Jan 98 to Se
519	fly ash	Oct 98 - Jan 99	430	TOPLEVEL	170.4															
520	wet ash	Jan 98 - Sept 9	426	TOPLEVEL	37.9															average values for Jan 98 to Se
521	wet ash	Oct 98 - Jan 99	426	TOPLEVEL	34.5															
522	Evaps1 misc streams effluent - fresh water		123	EVAPORAT	16.84															Michael Carter, 27/10/99
523	Evaps1 misc streams effluent - steam/condensate		NYD	EVAPORAT	3.456															Michael Carter, 27/10/99
524	Evaps2 misc streams		125	EVAPORAT	41.1															Michael Carter, 27/10/99
525	Gas producer effluent - steam/condensate		36	EVAPORAT	6.155															Michael Carter, 27/10/99
526	HVLC drain tank effluent		NYD		8.12															Michael Carter, 27/10/99
527	Condensate generated in evaps #1		126	EVAPORAT	2160															Michael Carter, 27/10/99
528	Condensate generated in evaps #2		31	EVAPORAT	6000															Michael Carter, 27/10/99
529	Effluent to flume (calculated)		50	EVAPORAT	4357.5															does not account for evaporatio
530	Condensate from 3rd effect evporator set #2																			
531	PF boiler blow down	Apr 98 - Apr 99	31	PF_BOILER	111.7															average value for Apr 98 to Apr
532	PF boiler feed (demin water & return condensa	Apr 98 - Apr 99	44	PF_BOILER	6820															average value for Apr 98 to Apr
533	PF boiler soot blowing steam (evaporation loss	Apr 98 - Apr 99	43	PF_BOILER	2.011															average value for Apr 98 to Apr
534	Condensate to PF boiler	Apr 98 - Apr 99	26	PF_BOILER	2237															average value for Apr 98 to Apr
535	PF boiler submerged scraper conveyor flow	Sept/Oct 99	56	PF_BOILER	125															measured using bucket&stopwa
536	CRF2 blow down	Apr 98 - Apr 99	3	CRF2	72.17															average value for Apr 98 to Apr
537	CRF2 feed (demin water & return condensate)	Apr 98 - Apr 99	45	CRF2	3460															average value for Apr 98 to Apr
538	CRF2 soot blowing steam (evaporation losses	Apr 98 - Apr 99	NYD	CRF2	227.7															average value for Apr 98 to Apr
539	Condensate to CRF2	Apr 98 - Apr 99	6	CRF2	2512															average value for Apr 98 to Apr
540	CRF2 saltcake loss through stack	Aug 98 - Jul 99	31	CRF2	(total particulates)															MC, 18/8/99
541	CRF2 floor drain (flow from spill tank)		50	CRF2	652.8 - 979.2															Michael Carter, 5/11/99
542	CRF1 steam generation (14 bar gauge, saturated)		2	CRF_1	80 TPH @ 400 LPM black liquor															e-mail from MC
543	CRF2 steam generation (90 bar, 447°C)		5	CRF2	230 TPH @ 1400 LPM black liquor															e-mail from MC
544	PF boiler steam generation		42&50	PF_BOILER	8 tons steam/ton coal															coal CV=23MJ/kg; bark CV=10M
545	1100 kPa steam supply	Apr 98 - Apr 99	82	BOILERS	1520															average value for Apr 98 to Apr
546	415 kPa steam supply	Apr 98 - Apr 99			2681															average value for Apr 98 to Apr
547	1520 kPa steam supply	Apr 98 - Apr 99			583															average value for Apr 98 to Apr
548	415 blow off	Apr 98 - Apr 99		BOILERS	121.6															average value for Apr 98 to Apr
549	TG2 vent	Apr 98 - Apr 99		BOILERS	4095															average value for Apr 98 to Apr
550	steam feed pump 2	Apr 98 - Apr 99		BOILERS	77															average value for Apr 98 to Apr
551	steam feed pump 4	Apr 98 - Apr 99		BOILERS	450.4															average value for Apr 98 to Apr
552	ID fan steam	Apr 98 - Apr 99		BOILERS	133															average value for Apr 98 to Apr
553	8 965 / 1 100 kPa RED Sta	Apr 98 - Apr 99		BOILERS	550.3															average value for Apr 98 to Apr
554	desup water to 1 100 kPa	Apr 98 - Apr 99		BOILERS	1.73															average value for Apr 98 to Apr
555	1 100 / 415 kPa RED Sta	Apr 98 - Apr 99		BOILERS	74.94															average value for Apr 98 to Apr
556	desup water to 415 kPa	Apr 98 - Apr 99		BOILERS	39.37															average value for Apr 98 to Apr
557	desup water to 1 520 kPa	Apr 98 - Apr 99		BOILERS	88.42															average value for Apr 98 to Apr
558	condensate from evaps	Apr 98 - Apr 99	361&363	TOPLEVEL	1006															average value for Apr 98 to Apr
559	exst mill cond sys	Apr 98 - Apr 99		TOPLEVEL	571															average value for Apr 98 to Apr
560	condensate from NP	Apr 98 - Apr 99	302	TOPLEVEL	395.1															average value for Apr 98 to Apr
561	condensate from KLB	Apr 98 - Apr 99	505	TOPLEVEL	662.5															average value for Apr 98 to Apr
562	condensate from U/B uptake	Apr 98 - Apr 99		TOPLEVEL	356.5															average value for Apr 98 to Apr
563	condensate from dig pulp	Apr 98 - Apr 99		TOPLEVEL	349.8															average value for Apr 98 to Apr
564	condensate to power BLR D/A	Apr 98 - Apr 99		TOPLEVEL	4077															average value for Apr 98 to Apr
565	Stormwater into ponds	Jan 99 - Jul 99	420	TOPLEVEL	1221.7															
566	Stormwater discharge	01-Jun-99	323	TOPLEVEL	861															T Leske, 7/7/99

ERP REF #	SAMPLE DESCRIPTION	DATE	MS STREAM	DIAGRAM HEADING	FLOW RATE (kg/min)	P (°C)	pH	(uS/cm)	Na (mg/l)	Ca (mg/l)	Mg (mg/l)	Cl (mg/l)	(mg/l)	(mg/l)	K (mg/l)	(mg/l)	(mg/l)	(mg/l)	Mn (mg/l)	COMMENT
567	foul condensate flow rate from foul tank (?CFC	21-Sep-99	?5?	CHEM_REC	2500 - 3200															flow measured by Gibson; repor
568	Turpentine sold	Jan 99 - Jul 99	531	TOPLEVEL	0.785															turpentine monthly sales figures
569	Soap sold	Jan 97 - Jun 99	373	TOPLEVEL	23.17															Soap sales figures (Gibson, 20/
570	sodium hydrosulfite useage on groundwood	Jan 99 - Dec 99	84	TOPLEVEL	0.728															hydrosulfite useage from E Stre
571	Effluent sludge	Feb 98 - Jan 99	602	TOPLEVEL	157.7															
572	Dregs/grits	Feb 98 - Jan 99	341	TOPLEVEL	11.1															
573	TG2 cooling tower blowdown to unaccounteds		25	CT_TG2	292.9															blowdown (m3/h) = 158/(COC-1
574	TG2 cooling tower blowdown to unaccounteds		25	CT_TG2	667															system volume 1500m3, water
575	TG2 cooling tower side stream filter			CT_TG2	13333															system volume 1500m3, water
576	TG2 cooling tower backwash rate on side stream filter		15	CT_TG2	0.83															system volume 1500m3, water
577	TG2 cooling tower circulation rate		?14?	CT_TG2	145000															system volume 1500m3, water
578	TG2 cooling tower evaporation		12	CT_TG2	2633															system volume 1500m3, water
579	TG2 cooling tower drift loss			CT_TG2	83.33															system volume 1500m3, water
580	TG2 cooling tower make up		10	CT_TG2	3384															system volume 1500m3, water
581	Lube oil cooling tower circulation rate		?16?	CT_LUBE OIL	7600															system volume 150m3, water d
582	Lube oil cooling tower evaporation and drift losses		12	CT_LUBE OIL	92.7															system volume 150m3, water d
583	Lube oil cooling tower make up		6	CT_LUBE OIL	278.3															system volume 150m3, water d
584	Lube oil cooling tower blow down		NYD	CT_LUBE OIL	186.7															system volume 150m3, water d
585	Evaps 1 cooling tower circulation rate		11	CT_1_EVAP	22500															system volume 400m3, water d
586	Evaps 1 cooling tower evaporation and drift losses		12	CT_1_EVAP	366.7															system volume 400m3, water d
587	Evaps 1 cooling tower make up		10	CT_1_EVAP	483.3															system volume 400m3, water d
588	Evaps 1 cooling tower blow down		16	CT_1_EVAP	116.7															system volume 400m3, water d
589	Evaps 2 cooling tower circulation rate		25	CT_2_EVAP	110000															system volume 938m3, water d
590	Evaps 2 cooling tower evaporation and drift losses		30	CT_2_EVAP	1450															system volume 938m3, water d
591	Evaps 2 cooling tower make up		13	CT_2_EVAP	1917															system volume 938m3, water d
592	Evaps 2 cooling tower blow down		16	CT_2_EVAP	466.7															system volume 938m3, water d
593	Kiln cooling tower evaporation				8.33															system volume 35m3, water dT
594	Kiln cooling tower drift loss				80															system volume 35m3, water dT
595	Kiln cooling tower make up				101.7															system volume 35m3, water dT
596	Kiln cooling tower blow down				93.3															system volume 35m3, water dT
597	lime kiln stack		95	CHEM_REC	663.1 (moisture)															total flow =
598	#2 SDT vent		43	CRF2	0.02 (moisture)															2.34m3/h, negligible particulate
599	#2 Fiber line HVLC emission		160	FIBRELINE#2	665 m^3/min								TRS as S = 1.50 kg/BD ton pulp							Values for HW run; SW generat
600	#1 Fiber line HVLC emissions		43	FIBRELINE#1	585 m^3/min								TRS as S = 1.50 kg/BD ton pulp							Values for HW run; SW generat
601	#2 Evaporator HVLC emissions		45	EVAPORAT	731 m^3/min	58.3	Gas moisture = 19.6%						TRS as S = 0.987 kg/min							Values for HW run; SW generat
602	Total HVLC system		375	TOPLEVEL	2094 m^3/min	57	Gas moisture = 18%						TRS as S = 2.3 kg/min							Values for HW run; SW generat
603	Total LVHC system		530	TOPLEVEL	27.5 m^3/min	52	Gas moisture = 13%						TRS as S = 2.05 kg/min							Values for HW run; SW generat
604	#3 uptake backwater to 3 stage diffusion wash	22-Sep-99	202	BLEACHPLNT	2400															TDC data (DWB, 22/9/99)
605	#3 uptake backwater to D2 stage	22-Sep-99	45	BLEACHPLNT	5000															TDC data (DWB, 22/9/99)
606	contaminated condensate to 3 stage diffusion	22-Sep-99	145	BLEACHPLNT	3000															TDC data (DWB, 22/9/99)
607	hot water to D29	22-Sep-99	106	BLEACHPLNT	2000															TDC data (DWB, 22/9/99)
608	hot water to D29	04-Mar-99	106	BLEACHPLNT	2067															Conventional bleach plant mass
609	hot water to D29	18-Mar-99	106	BLEACHPLNT	2050															Conventional bleach plant mass
610	SWL to OWL reactor	04-Mar-99	12	BLEACHPLNT	209.9															Conventional bleach plant mass
611	SWL to OWL reactor	18-Mar-99	12	BLEACHPLNT	72															Conventional bleach plant mass
612	NaOH (5.2%) to bleach plant	04-Mar-99	160	BLEACHPLNT	104.7															Conventional bleach plant mass
613	NaOH (5.2%) to bleach plant	18-Mar-99	160	BLEACHPLNT	73															Conventional bleach plant mass
614	ClO2 to bleach plant	04-Mar-99	85	BLEACHPLNT	1158.7															Conventional bleach plant mass
615	ClO2 to bleach plant	18-Mar-99	85	BLEACHPLNT	921															Conventional bleach plant mass
616	MgSO4 to bleach plant	04-Mar-99	141	BLEACHPLNT	12.4															Conventional bleach plant mass
617	MgSO4 to bleach plant	18-Mar-99	141	BLEACHPLNT	12															Conventional bleach plant mass
618	MgSO4 to bleach plant	Jan 99 - Dec 99	141	BLEACHPLNT	4.735						48% MgSO4		48% MgSO4							Buyers' figures for 1999 (K Pauw
619	Process water to bleach plant	04-Mar-99	163	BLEACHPLNT	91.5															Conventional bleach plant mass
620	Process water to bleach plant	18-Mar-99	163	BLEACHPLNT	105															Conventional bleach plant mass
621	HP steam to O2 delignification	04-Mar-99	112	BLEACHPLNT	47.69															Conventional bleach plant mass
622	HP steam to O2 delignification	18-Mar-99	112	BLEACHPLNT	44.8															Conventional bleach plant mass
623	Process water to ClO2 plant	18-May-99	510	TOPLEVEL	950															

REF #	SAMPLE DESCRIPTION	DATE	MS STREA	DIAGRAM HEADING	(kg/min)	P (°C)	pH	(uS/cm)	Na (mg/l)	Ca (mg/l)	Mg (mg/l)	Cl (mg/l)	(mg/l)	(mg/l)	K (mg/l)	(mg/l)	(mg/l)	(mg/l)	Mn (mg/l)	COMMENT [redacted]
624	Process water to ClO2 plant	24-May-99	510	TOPLEVEL	1083															Mass balance over ClO2 plant (
625	Steam to ClO2 plant	18-May-99	641	TOPLEVEL	143.3															Mass balance over ClO2 plant (
626	Steam to ClO2 plant	24-May-99	641	TOPLEVEL	154.7															Mass balance over ClO2 plant (
627	SWL to ClO2 plant	18-May-99	516	TOPLEVEL	7.64															Mass balance over ClO2 plant (
628	SWL to ClO2 plant	24-May-99	516	TOPLEVEL	7.64															Mass balance over ClO2 plant (
629	Cl2 to ClO2 plant	18-May-99	642	TOPLEVEL	844.2															Mass balance over ClO2 plant (
630	Cl2 to ClO2 plant	24-May-99	642	TOPLEVEL	882															Mass balance over ClO2 plant (
631	ClO2 production rate	18-May-99	651	TOPLEVEL	1055															Mass balance over ClO2 plant (
632	ClO2 production rate	24-May-99	651	TOPLEVEL	1102.5															Mass balance over ClO2 plant (
633	ClO2 plant effluent	18-May-99	645	TOPLEVEL	91.3															Mass balance over ClO2 plant (
634	ClO2 plant effluent	24-May-99	645	TOPLEVEL	204.2															Mass balance over ClO2 plant (
635	waste plant fresh water usage		100	TOPLEVEL	650															design data (C Mbense, 17/8/99
636	waste plant steam usage		92	TOPLEVEL	27															design data (C Mbense, 17/8/99
637	wood chip feed rate to #2 F/L	09-Apr-99	1	FIBRELINE#2	1062.7															Conventional bleach plant mass
638	wood chip feed rate to #2 F/L	19-Apr-99	1	FIBRELINE#2	1062.7															Conventional bleach plant mass
639	SWL to #2 F/L	09-Apr-99	23	FIBRELINE#2	2062.83															Conventional bleach plant mass
640	SWL to #2 F/L	19-Apr-99	23	FIBRELINE#2	1670.9															Conventional bleach plant mass
641	Backwater from #1 F/L	09-Apr-99	171	FIBRELINE#2	1713.8															Conventional bleach plant mass
642	Backwater from #1 F/L	19-Apr-99	171	FIBRELINE#2	1585.1															Conventional bleach plant mass
643	Backwater from #2 uptake	09-Apr-99	163	FIBRELINE#2	2442															Conventional bleach plant mass
644	Backwater from #2 uptake	19-Apr-99	163	FIBRELINE#2	1327.7															Conventional bleach plant mass
645	Water from bleach plant	09-Apr-99	144	FIBRELINE#2	5856.4															Conventional bleach plant mass
646	Water from bleach plant	19-Apr-99	144	FIBRELINE#2	5011.6															Conventional bleach plant mass
647	HP Steam	09-Apr-99		FIBRELINE#2	179															Conventional bleach plant mass
648	HP Steam	19-Apr-99		FIBRELINE#2	165															Conventional bleach plant mass
649	LP Steam	09-Apr-99		FIBRELINE#2	3520															Conventional bleach plant mass
650	LP Steam	19-Apr-99		FIBRELINE#2	3460															Conventional bleach plant mass
651	Condensate return	09-Apr-99		FIBRELINE#2	3833.42															Conventional bleach plant mass
652	Condensate return	19-Apr-99		FIBRELINE#2	4148.06															Conventional bleach plant mass
653	Turpentine sold	09-Apr-99	80	FIBRELINE#2	0.891															Conventional bleach plant mass
654	Turpentine sold	19-Apr-99	80	FIBRELINE#2	0.891															Conventional bleach plant mass
655	Condensate from turpentine system	09-Apr-99	81	FIBRELINE#2	144.38															Conventional bleach plant mass
656	Condensate from turpentine system	19-Apr-99	81	FIBRELINE#2	133.375															Conventional bleach plant mass
657	WBL to evaps	09-Apr-99	91	FIBRELINE#2	4834.5															Conventional bleach plant mass
658	WBL to evaps	19-Apr-99	91	FIBRELINE#2	3734.5															Conventional bleach plant mass
659	Rejects to #1 F/L	09-Apr-99	162	FIBRELINE#2	69.75															Conventional bleach plant mass
660	Rejects to #1 F/L	19-Apr-99	162	FIBRELINE#2	69.75															Conventional bleach plant mass