DEVELOPMENT OF A PARAMETRIC COMPUTER MODEL FOR AUTOMATING THE PRODUCTION OF POWER STATION DRY ASH DUMP GROWTH PLANS

André Kreuiter

A dissertation submitted to the Faculty of Engineering, University of the Witwatersrand, Johannesburg, in fulfillment of the requirements for the degree of Master of Science in Engineering.

Johannesburg 1998

DECLARATION

I declare that this dissertation is my own, unaided work. It is being submitted for the Degree of Master of Science in Engineering in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other University.

Kreuiter

Andre Kreuiter

28th day of JANUARY 1998

ABSTRACT

Generating growth plans for power station dry ash dumps having main and standby conveyor stacking systems is very time consuming using manual analysis methods. This usually prohibits investigating sufficient options or the routine evaluation of operating variations. Not achieving or changing any of the multitude of geometric, physical or production design assumptions over the 50 year construction life, can result in the dump growth deviating significantly from the original plan. Out of phase or too rapid long term growth situations can ensue, with costly modifications sometimes needed to return to acceptable growth plans or provide additional capacity.

It was postulated that a parametrically driven computer model would facilitate rapid and cost effective dump growth evaluation. This dissertation documents the development of a prototype, spreadsheet-based, parametric modeling program for automating the production of dry ash dump growth plans. The system showed that sensitivity, optimisation and routine evaluation exercises now become practicable.

ACKNOWLEDGMENTS

I gratefully acknowledge the financial assistance and computer facilities made available by Eskom in the development of this work.

I would also like to express my gratitude to my supervisor, Prof. G E Blight, for always being enthusiastic and encouraging about the conducted research.

Finally, to my parents and my wife Elizabeth for their support and particularly to my wife for putting up with me too often spending more time with my computer than with her for the duration of this project.

DISCLAIMER

This project presents a prototype spreadsheet-based computer modeling program that models the growth of power station dry ash dumps.

The University of the Witwatersrand and the author of this program will not be held responsible for any losses incurred as a result of using this program.

Use of the program is subject to the above condition being agreed to by the user.

CONTENTS Page

LIST OF FIGURES

Figure Page

Figure **Page**

Figure Page

Figure Page

NOMENCLATURE

In order to keep the width of the spreadsheet columns of the prototype program as small as possible, to enable the maximum amount of information to be viewed simultaneously on the monitor, substantial use of acronyms had to be made. Minimal use of these acronyms have been made in the body of the dissertation and they are given mostly for use in interpreting the spreadsheet columns and graph printouts in the appendices.

Acronym	Description
1M-BLA	axis 1 main baseline angle
1M-SA	axis 1 main slew angle
1S-BLA	axis 1 standby baseline angle
1S-SA	axis 1 standby slew angle
2M-E-LN	axis 2 main end length (frontstack crest length)
2M-ECL	axis 2 main extendible conveyor length
2S-E-LN	axis 2 standby end length
2S-ECL	axis 2 standby extendible conveyor length
AD	as delivered
ANG	angle
AToDurStShA	ash tonnage during stacker shift ashing
AUt%	ashing utilisation %
Betw	between
BHi	backstack height (i)
BL-IL	base line intersection line
BL-IL2	base line intersection line 2
BL-IL3	base line intersection line 3
BLA	baseline angle
BS	backstack

BSei	backstack side slope end (i)
BSi	backstack slope (i) (forward)
BSRi	backstack roadway width (i) (centerline conveyor to backstack toe)
BSsi	backstack side slope start (i)
C-Ln	conveyor length
C-SH	conveyor shift
CATo@StAE	cumulative ash tonnage at stacker ashing end
CATo@StAS	cumulative ash tonnage at stacker ashing start
CATo@StShE	cumulative ash tonnage at stacker shift end
CD-TV	cumulative dump total volume
CLen	conveyor length
CM-F&BV	cumulative main frontstack & backstack volume
Conv	conveyor
CP	conveyor position
CS-FSV	cumulative standby frontstack volume
CSpArTo@StSh	cumulative spreader ashing rate tonnage at stacker shift
CSpATo@SpSh	cumulative spreader ash tonnage at spreader shift
CStATo	cumulative stacker ash tonnage
CUMASH	cumulative ashmake
CV	calorific value
DBSSC	distance between start points of (main and standby) shiftable conveyors
DD	dry density
Deg	degrees
Dei	distance at end (i) (shiftable conveyor end point to frontstack end crest)
Dsi	distance at start (i) (shiftable conveyor start point to frontstack end crest)

Dys	days
E Sp-S St	end spreader (shift) to start stacker (shift)
E St-S Sp	end stacker (shift) to start spreader (shift)
E-LNG	end length (length of crest at end)
ECL	extendible conveyor length
EQT	equivalent tonnage capacity
EQTON	equivalent tonnage capacity
ESO	energy sent out
EUF	energy utilisation factor
Ext	extendible
FlipSlpTwst	Flip slope that is twisted
Foll	follow
FollowE	follow from previous at end
FollowS	follow from previous at start
FS	frontstack
Fstack	frontstack
G(i)	Gamma(i)
Gam(i)	gamma(i) angle between shiftable conveyor and extendible conveyor position(i) (degrees)
Gwh	gigawatt hours
H(i)	height(i)
LBS1	lost backstack length line 1
LBS2	lost backstack length line 2
LBS3	lost backstack length line 3
LBSL	lost backstack length
LstFs	lost frontstack length (distance to cut back frontstack from conveyor start point)
M-BSV	main backstack volume
M-F&BV	main frontstack & backstack volume
M-FSV	main frontstack volume

MAIN	main system
MBS	main backstack
MSSe	main side slope end
MSSs	main side slope start
MW	megawatt
No	number
PDBSC	perpendicular distance between shiftable conveyors
Perim	perimeter
Pos	position
θi	theta(i) baseline angle of shiftable conveyor position(i) (degrees)
S	start
S-FSV	standby frontstack volume
SEDei	safe edge distance end(i)
SEDir	safe edge distance (i) required
SedShe	safe edge distance short at the end
SEDsi	safe edge distance start(i)
SHTe	safe edge distance short at end
SHTs	safe edge distance short at start
SLA	slew angle
SlAng	slew angle
Sle(i)	shift length end (i)
Sls(i)	shift length start (i)
Sp	spreader (standby system)
SpAct	spreader actual
SpADur	spreader ashing duration
SpAS	spreader ashing start
SpAToDurStA	spreader ash tonnage during stacker ashing
SpAToDurStSh	spreader ash tonnage during stacker shift
SpCA	spreader cumulative angle (baseline angle)
SpCA*5	spreader cumulative angle times 5 (for graph scaling)

SpCEQT	spreader cumulative equivalent tonnage capacity
SpCTon	spreader cumulative tonnage
SpExtCl	spreader extendible conveyor length
SpShCl/2	spreader shiftable conveyor length / 2 (for graph scaling)
SpShEQT	spreader shift equivalent tonnage capacity
SpShS	spreader shift start
SpShTo	spreader shift tonnage capacity
SR(i)	stacking reach (i[illegible]center line shiftable conveyor to new fi[illegible]tstack crest)
SSe(i)	side slope end(i)
SSs(i)	side slope start(i)
SSSe	standby side slope end
SSSs	standby side slope start
St	stacker (main system)
StA[illegible]Ut%	stacker ashing and shift utilization %
StAct	stacker actual
StActAv%	stacker actual availability %
StADur	stacker ashing duration
StAUt%	stacker ashing utilisation %
Stby	standby system
StCA	stacker cumulative angle (baseline angle)
StCA*5	stacker cumulative angle times 5 (for graph scaling)
StCEQT	stacker cumulative equivalent tonnage capacity
StExtCl	stacker extendible conveyor length
StkLn1	stacking length at first backstack cutback line
StkLn2	stacking length at second backstack cutback line
StkLnE	stacking length at end of backstack

StkrGap	stacker gap
StSh	stacker shift
StShCl/2	stacker shiftable conveyor length / 2 (for graph scaling)
StShEQT	stacker shift equivalent tonnage capacity
StShTo	stacker shift tonnage
Ti@SpAE	Time at spreader ashing end
Ti@SpAS	time at spreader ashing start
Ti@SpShE	time at spreader shift end
Ti@StAE	time at stacker ashing end
Ti@StAS	time at stacker ashing start
Ti@StShE	time at stacker shift end
UCF	unit capability factor
Vol	volume
X	x-coordinate for conveyor or ashing geometry
Y	y-coordinate for conveyor or ashing geometry

CHAPTER 1

INTRODUCTION

In 1985 Eskom, the major electricity producer in South Africa, adopted the newer, more environmentally friendly dry ash disposal method for the first time at its new Tutuka power station in preference to the traditional wet ash disposal method which it had used for many decades at its older power stations. Following this milestone move to the new technology, all new Eskom power stations were subsequently provided with dry ash disposal facilities. Another four new dry ashing stations have since been constructed over the last decade, namely Lethabo, Matimba, Kendal and Majuba power stations, showing Eskom's commitment to the new technology.

As it takes almost a decade from concept to commissioning of these large 3 600 to 4 000 megawatt power stations, the design and construction work for these new dry ash dumps had to be done closely following one other. This allowed very little time or opportunity for valuable construction feedback to make subsequent designs more practical and less sensitive to long term growth operational problems.

Due to the size of these large power stations and the commitment to utilize South Africa's low grade coal reserves, rather than higher grade coal such as used overseas, the dry ash dumps planned were of the largest in the world. This posed some unique problems related to siting and operation due to their large size, leaving relatively little margin for error to fit the dumps on the available sites in some instances.

Unless extremely fortunate in getting the design perfectly right the first time, Eskom was embarking on a journey with a steep learning curve at each facility and would have to identify possible operational problems and work out solutions along the way. If any of the multitude of geometric, physical or production design assumptions are not achieved or when necessary changes to the systems are made, the growth rates of the dumps could vary, sometimes significantly from the original design plan, depending on the sensitivity of the design to any particular parameter.

Ideally, the effect of any change or design assumption not achieved should routinely be assessed to determine whether the impact on the growth rate is significant or not. Unfortunately, due to the need to practically duplicate the original amount of work in order to produce new growth plans by manual calculation, these variations were usually not properly evaluated. Instead, engineering judgment was more often relied upon to decide whether the problem seemed serious enough to warrant such an enormous investigation.

After about a decade of dry ash dump operational experience, a number of situations were identified where three of the five dry ash dump's growth rates appeared to have varied significantly from the original growth plans. Situations were identified where either the entire dump was ahead of the original growth plan, or the main and standby ashing systems had gone out of phase with each other, with the standby system going ahead of its growth plan and the main system lagging behind. As these appeared to be significant variations, with concerns that the dumps could either run out of space or become inoperable before the end of the power station's life, due to their dependence on one another for conveyor shifts, studies were initiated to assess the situations.

The evaluation of the three as-built dump growth situations, all needed around the same time, proved to be a difficult task due to the manual analysis methods used and the lack of good growth performance records in the correct format. As-built aerial or tacheometric surveys (See Figures 1.1 and A1-A7) and coal burn records therefore had to be used to back evaluate the average growths to date. This made it difficult to identify the specific problems and causes, as the same overall end result could be achieved by a variation of any of a number of possible parameters, or even a combination of small variations of many parameters.

It soon became clear however, that the difficulty of evaluating the as-built growth situations was only part of the problem. On attempting the next step of trying to find optimum solutions for how best to get the dumps back onto acceptable life-cycle growth plans and how to keep them on track from that point onwards, or provide additional capacity by modifying the dump layout, it was realised that a mammoth task lay ahead due to the number of variations to be analysed with the existing manual methods.

With limited resources due to recent staff downscaling exercises, it was clear that a computerised modeling solution was necessary to aid the designers to more easily

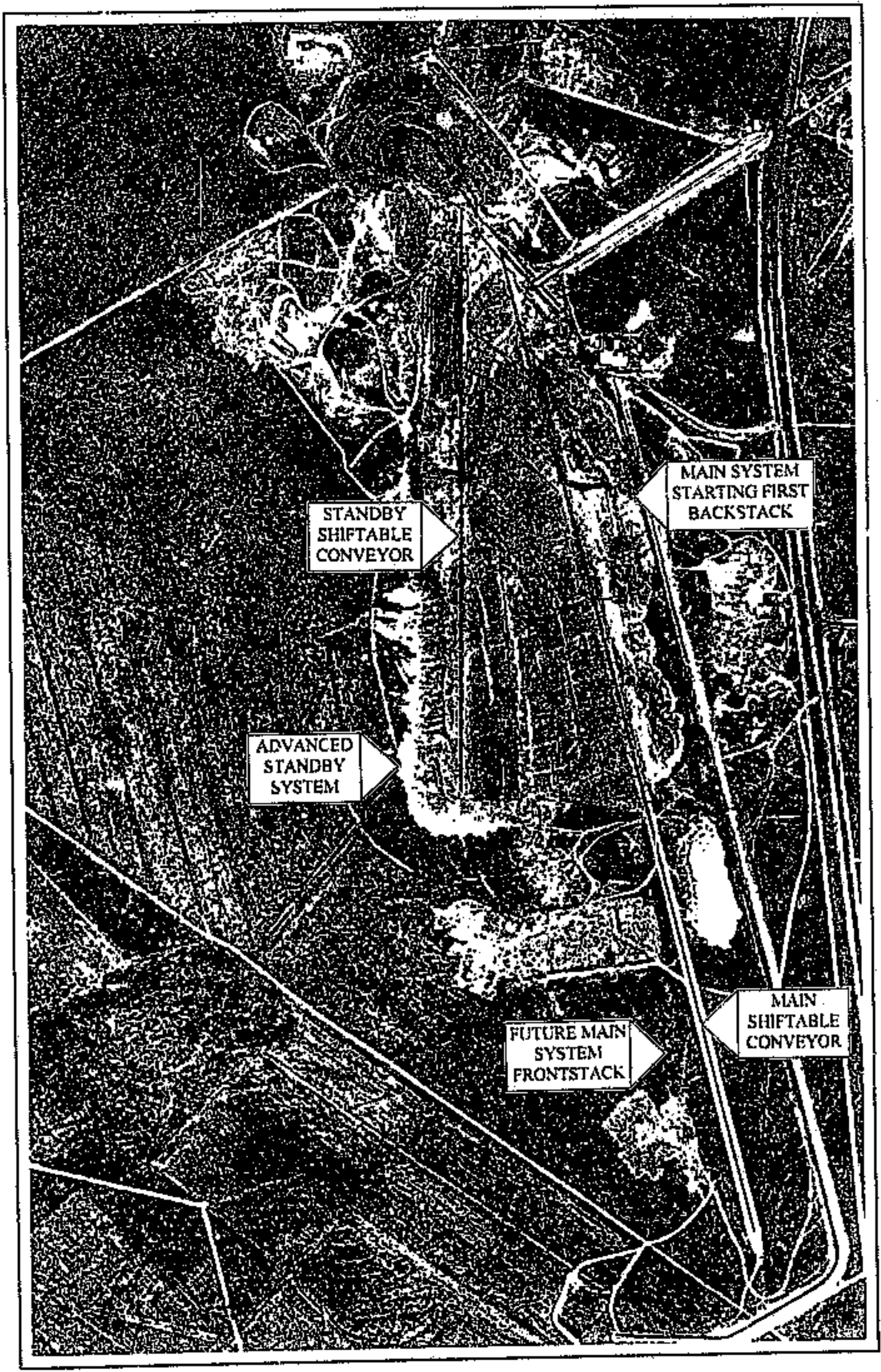


Figure 1.1 - Kendal Ash Dump aerial photo.

duplicate the vast quantity of calculations necessary to reproduce new dump growth plans for all the options, within a reasonable timescale. This would also allow sensitivity analyses and optimization studies to [illegible] one quickly and cost effectively to arrive at optimum solutions.

1.1 Dry Ash Disposal Philosophy

Dry ash disposal basically consists of dumping moistened ash, to limit dustblow, directly onto the ground to form an advancing ash stack, the top of which is then finally shaped using earthmoving plant. The topsoil in front of the advancing ash face is stripped away prior to dumping and placed on top of the ash dump, behind the working area, to enable rehabilitation of the dump. This moving window type operation thus advances from the one side of the site to the other in a horizontal construction mode, rather than vertically as done with a hydraulically placed wet a[illegible] dam.

The ash can be transported and dumped using trucks, but due to the high rate of ash production, being in the order of 400 to 600 tons per hour and suitable dump sites being up to five kilometers from the power station, a conveyor stacking system is usually required.

1.1.1 Conveyor Stacking Philosophy

With a conveyor stacking system, the ash is transported from the power station to the dry ash dump using a series of overland conveyors. From this point the ash is transferred to an extendible conveyor on the dump, which in turn transfers the ash to a shiftable conveyor at the working face of the dump. The shiftable conveyor has a rail mounted tripper car to enable the ash to be transferred to the ash stacking machine at any point along its length. The crawler mounted stacking machine and its tripper car moves up and down the shiftable conveyor, to dump the ash to the side of the conveyor, within the stacking machine's reach.

Two main types of stacking machines are used, a "stacker" or a "spreader". The stacker has a link conveyor pivoted at the tripper car and the stacker's crawler structure. The link conveyor transfers the ash onto a slewable boom conveyor, mounted on the crawler structure, which dumps the ash in position. This long boom conveyor of around 35m in length, can dump the ash over the crest of the advancing ash platform in front of the belt onto the ground to form a "frontstack", which is usually around 20 to 40 meters high.

As the link conveyor is pivoted, once the stacker reaches the head end of the shiftable conveyor, it can move around the head to behind the conveyor. Due to its large size, the stacker can place a second layer of ash around 10 to 12 meters high on top of the frontstack, to form a "backstack", which is an economical way of increasing the dump volume, as the frontstack is usually limited in height by stability and conveyor operating slope limitations during buildup phases. The versatility of this machine makes it well suited to constructing dry ash dumps, although it is a fairly expensive machine.

The cheaper spreader stacking machine, sometimes called a "beltwagon" only has one conveyor mounted on the crawler structure, which pivots in the middle. A fixed, link conveyor is then mounted on the tripper car, pointing towards the front, which transfers the ash onto the spreader's boom conveyor. There is no fixed pivot at this point and the spreader's boom must thus be kept at a constant angle to the link conveyor, to keep the transfer chute in position to prevent ash spillages. The spreader cannot therefore slew its boom during ashing and also cannot form a backstack due to the fixed link conveyor, which makes it less versatile and more expensive with which to place ash, requiring more dozing per cubic meter placed.

The ash stacking machine places the ash in a strip parallel to the shiftable conveyor, to form the frontstack or backstack, within the maximum stacking reach of the machine. At the head and tail ends of the shiftable conveyor, the ash is dozed to form sideslopes, down to the natural ground, where required. Once the available volume for the current shiftable conveyor position has been filled, the shiftable conveyor must be decommissioned and shifted forward closer to the new advancing crest, within the minimum safe edge distance stability requirements, to prevent the ash having to be dozed unnecessarily. The conveyor shift duration is around one to three weeks, depending on the conveyor length and shifting method used, or delays due to breakages being encountered.

Two methods of shifting are used, "parallel" and "radial" shifting. In parallel shifting, the entire length of the shiftable conveyor is shifted forwards a fixed distance, usually called the "shift length", which is limited by the stacking machine's ashing reach and the minimum safe edge distance back from the new crest. The head end of the extendible conveyor is then extended to the new tail position of the shiftable conveyor.

Due to the mass of the stacking machine and its tripper car, the conveyor cannot simply be dragged forwards to its next position. The conveyor must therefore be dragged forward on its built-in skids with a bulldozer, into s-curves and the stacker and tripper car driven through the s-curves to progressively "walk" the shiftable conveyor system to its next position. The electrical power supply and head and tail anchors need to be moved forward to the next position and the conveyor belts cannot run with these moving operations. The entire ashing system must therefore be decommissioned before the shift and recommissioned again afterwards. The total outage time for such a shifting operation is therefore fairly long, taking around two to three weeks, at times being delayed by bad weather or breakages, due to the physically stressing nature of the process on the structures.

In radial shifting, only the head end of the shiftable conveyor is shifted forwards. The tail of the shiftable conveyor and head of the extendible conveyor remain in place, with the shiftable conveyor typically only having slewed about two to three degrees. This is then referred to as the "slew point".

S-curves are also required for radial shifting, however far fewer are required as the slew angle is relatively small, allowing the stacker and tripper to be placed quickly on the new conveyor position at the tail end and the remaining belt simply dragged into place. Furthermore, as only the head end station needs to be shifted forward and no extension of the extendible conveyor is needed, radial shifts take much less time than parallel shifts.

Using a combination of radial and parallel shifting sectors, almost any ash dump layout configuration is conceivable, to suit topographic and existing infrastructure geometric limitations.

1.1.2 Dump Siting Philosophy

The basic ash disposal design requirement is to provide a disposal facility which is available to the power station on a continuous basis over the entire service life of the station. This could be achieved by either providing a number of small new facilities over the station's life, or by providing one big facility for the total station life, this decision being mostly dictated by economics.

A dry ashing facility is more economical to construct as one continuous dump as this lends itself to the continuous advancing concept of shiftable conveyor stacking systems. The initial capital cost for a large or small site would be similar, due to the cost of the conveyor stacking equipment being the major portion and the civil works being similar, due to only needing to provide drainage for the first portion of a big site, which would be extended as needed, as the dump advances. In addition, if a new site was required later during the station's life, the cost of migrating the ash conveyors and stacking plant to the new site would not only be costly due to the need to dismantle and re-erect it, but would require a duplication of some equipment due to the long construction time, in order to maintain acceptable availability to a station now on full load.

In order to meet the power station's ash disposal needs for a 40 to 50 year operating life as a single dump however, would require a typical dry ash dump to be around one to two kilometers wide by three to four kilometers long and around 30 to 50 meters high. The availability of such a large site with acceptable topography for a dry ash dump can be a problem however, with the need to sometimes do expensive stream diversion capital works to allow ashing over valleys.

Normally, the most economical dry ash dump site is used to provide for the life time ashing needs of the power station. If the site becomes filled or becomes inoperable before the end of the station's life, large, unnecessary, additional costs would be incurred in the form of a layout modification or relocation to another site to provide ongoing ashing capability, negatively affecting the long term viability of the power station.

1.1.3 Dump Design Philosophy

Once a suitable site has been identified which will accommodate the total ashing needs, the layout configuration of how the dump will be formed on that particular site, using a conveyor ash stacking system, needs to be determined.

The more versatile and more economic stacker type ash stacking machine is usually chosen to build the main part of the ash dump. Unfortunately, the conveyor stacking system must be taken out of service for a few weeks for each conveyor shift and also for planned maintenance and breakdown periods of a few hours to a number of days, or sometimes even weeks, during the ash deposition period. This usually amounts to an average unavailability of around 15 to 30 percent of the time. As this would amount to a few months a year, a second or standby system must be provided for this relatively long unavailable time.

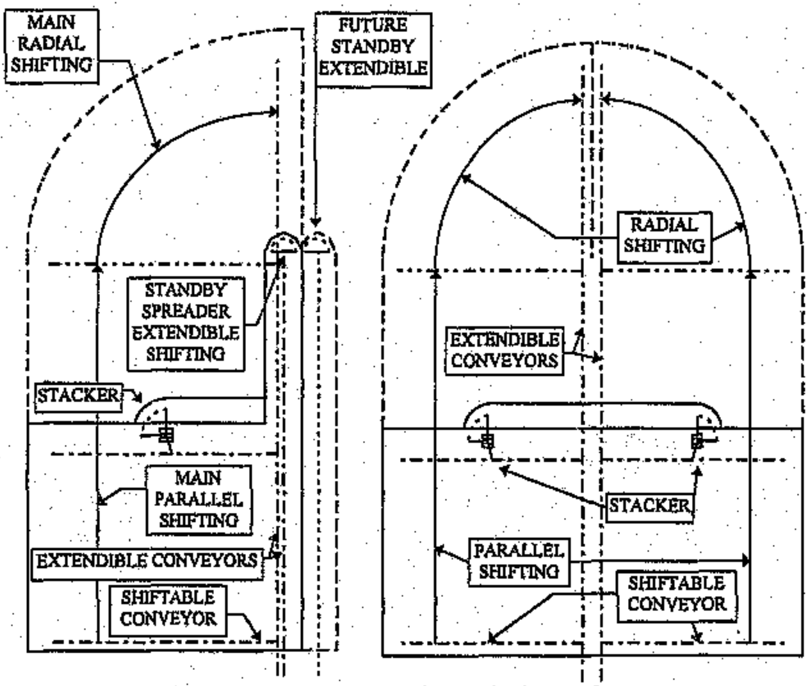
Although the conveyors are usually able to handle about twice the normal ash rate to allow buffer storage recovery from short term outage situations, with the high rates of ash production from such large power stations it would be very expensive to lay down the ash in temporary storage facilities for this length of time and then recover it to return it to the main ashing system once it was back in service.

In fact, the unavailability of the main system could be kept to only a few percent, as is done with the coal delivery system to the power station. This is however only achieved by holding a large quantity of expensive spares in stock as well as maintenance teams on constant call for immediate repair of outages, mostly on overtime. For major breakdowns, longer than acceptable outages are absorbed by the fact that there is a buffer storage capability automatically built into the coal system due to the need for a blending yard, with stacker-reclaimer machines.

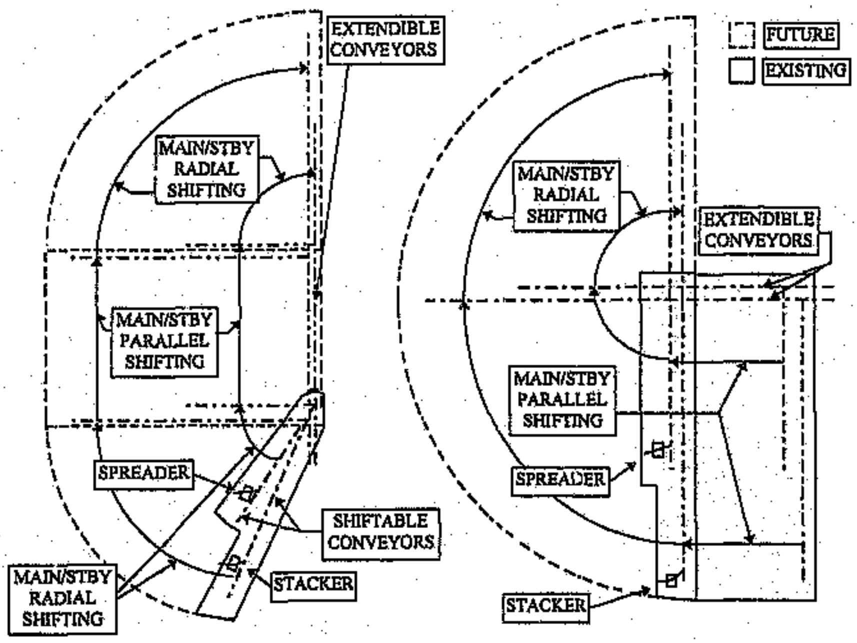
The ashing standby capability could be achieved by using a stacker-reclaimer system, but as there is no need for a blending process with the ash, this more expensive system is not justified, as it would be better to place the ash with a cheaper spreader type machine and not have to pick it up again and replace it on the main system. The dry ashing facility thus needs a similar capacity second conveyor stacking system to provide the standby ashing capability.

The main and standby ashing systems therefore become dependent on each other, each system providing the ashing capability when the other is out of commission for shifting, maintenance and breakdowns. During any conveyor shift, if the remaining system breaks down, a temporary dump and recover emergency facility is usually provided as a backup to ensure availability, allowing for about two weeks ashing. As this occurs very seldom and the ash is always recovered to the ash dump, this does not affect the growth rates.

If the design philosophy is adopted to utilise the expensive main ash stacking system for close to its maximum expected average lifetime availability with only a small factor of safety, as is the case at Tutuka, Matimba and Kendal power stations (See Figure 1.2), a much cheaper standby system can be provided, as it only has to stack ash for about 15 to 30 percent of the time, standing idle for most of its life. The main ashing system is therefore usually provided with the much bigger and more versatile stacker machine, having a higher ashing capacity per conveyor position, less frequent shifting and less dozing per cubic meter placed, resulting in a lower unit ashing operating cost. The smaller capacity standby ashing system is then usually provided with the cheaper, less versatile spreader stacking machine, having a higher unit ashing operating cost due to its shorter reach and not being able to slew its boom, resulting in lower ashing capacity per position and more dozing per cubic meter placed.



a) Tutuka Ash Dump Layout. b) Lethabo Ash Dump Layout



c) Kendal Ash Dump Layout. d) Matimba Ash Dump Layout

Figure 1.2 - Dry Ash Dump Layout Configurations in Eskom.

As the continuous stream of ash from the power station is placed by either one of the systems at a time, the rate of advance of the one system is inversely proportional to the other. Further, as the main system is to be used to its maximum capability with only a very small factor of safety, the main system becomes the critical system, controlling the dump growth, with the standby system's growth dependent on the main system's performance. The two systems are thus dynamically linked, with any variation in the main system's performance not only affecting the main system's growth rate by either slowing it down or speeding it up, but simultaneously having the opposite effect on the standby system's growth.

With this design philosophy, while it may be cheaper, the long term growth rates are very critical, due to the relatively small factor of safety allowed with this concept. This implies an ongoing commitment from the ash dump management to keep the ash dump development on track, in phase with the design program. If this is not done and the systems growth rates kept constantly on track with the design growth plan, using the very small factor of safety allowed to recover from unplanned outages, the systems could easily go too far off the design growth plan and need major remedial action to bring them back into phase.

It is not necessary to adopt this more sensitive operating philosophy, as was done at Lethabo power station (See Figure 1.2), which has two equal stacking machines building separate advancing faces of nearly equal volume, being around a 50 : 50 to 60 : 40 volume split, depending on the layout position. Each stacker system is available for about

70 percent of the time, but is only utilized about 50 to 60 percent, allowing a 10 to 20 percent availability margin able to absorb fairly substantial deviations from the original design philosophy and performance parameters, by simply increasing its utilisation above the designed volume split, until it catches up. The higher margin for error however has a much higher initial capital cost for the second stacker system, although at a cheaper unit ashing cost.

Once the main system design availability has been estimated, say at 75 percent, as in Kendal's case, this is used to determine the required volumes for the main and standby ashing systems, by splitting the total station lifetime ashing volume requirement into this ratio, namely 75 percent main to 25 percent standby volume, in this case. The detailed geometric layout design is then done, to determine the conveyor and dump layout configuration, required to achieve this split. This determines the length of the main and standby shiftable conveyors.

If the volume split is made equal to the utilization split, both systems should theoretically take the same time to fill their associated ash volume, resulting in the same shift frequency. This allows the main and standby conveyor shifts to be conveniently staggered to occur in the middle of each other's ashing period, allowing sufficient planning and preparation time and preventing shift clashes.

The main and standby systems can be totally separate, but it is usually more economical to keep them together to minimise the open ash working areas and allow both systems to utilize the same extendible conveyor platform, which needs to be formed by dozing, as the stacking machines cannot reach back to this position. As a spreader cannot form a backstack, the usual design layout configuration for a stacker-spreader type system is for the standby system to build a portion of the frontstack, with the main system shiftable conveyor following shortly behind it but about twice as long to enable it to build a frontstack next to the standby system while shifting on top of the spreader's and its own frontstack platforms. The main system can then also form a backstack behind its conveyor, on top of both frontstack's, to raise the entire dump width by this height, in order to get the maximum dump volume for the area used.

Once the geometric design philosophy is determined, it must be evaluated in detail to determine the relationships of position to volume for the chosen layout configuration, for the growth plan.

1.1.4 Dump Operating Philosophy

As the main ashing system was usually designed to ash very close to its maximum expected average lifetime availability, the normal operating philosophy was simply to use the main system whenever it was available. With the volume split having been designed in line with this value, the two systems should theoretically stay together or in-phase with one another, with the main system just behind the standby system, over the entire dump construction life.

Because the assumed availability was a life-time average value however, some short term variance in availability per conveyor position would be likely due to the timing of major maintenance or breakdowns, as and when they arise. Some conveyor positions would therefore have relatively little planned maintenance or breakdowns, with only the conveyor shift outage contributing to the unavailability, resulting in a higher than average availability, being in the 90 percent range at times. Other conveyor positions would then have a higher than average amount of planned maintenance and breakdowns, resulting in an availability as low as 40 to 50 percent for that conveyor position.

Teething problems, like control system's sensitivity to lightning strikes or age related failures, would be typical frequent outage situations, causing a general drop in availability sometimes spanning over a number of shifts, until the problem is rectified. With only a small capacity for speeding up the main system, this could take a considerable time to catch up again, if at all and such situations should be quickly picked up and rectified, or the dump could relatively quickly go significantly out of phase.

With the less sensitive Lethabo type configuration, this short term variance poses little operating problem, as either system can go ahead of the other if required, by simply taking over the building of the common extendible conveyor platform. The relatively high availability margin for error easily allowing the lagging system utilization to be increased and the two systems to be brought back in line again, to ensure that they remain in phase over the long term.

With the main system shiftable conveyor kept close behind the standby system shiftable conveyor, as with the stacker-spreader type configuration, a problem can arise if the two systems are not closely managed. While the main system availability is higher than the designed average, the main system cannot be allowed to complete its ashing right up behind the standby system and then simply be stopped to let the standby system fill its platform and shift forwards, even though the two systems would still effectively be shifting forward at the designed average growth rate.

The problem with this situation is that the standby system would effectively become the main system for this period, needing to ash continuously for a considerable period. The main system would however not have any ashing capacity to provide backup to the standby system, as it would be blocked by the standby system, effectively having painted itself into a corner. Any outages on the standby system would now require expensive mobile plant handling of the ash, either by dozing further forwards on the main system or by dump and recover on the emergency ashing facility.

When the main system starts to approach too close to the standby system, it should be stopped from time to time, to allow the standby system to place some ash. This keeps the ratio of ash placed in each system close to the required volume split, keeping the two systems in phase, but requiring close management.

With the standby system always blocking the main system from moving past it, the main system can never go ahead of its growth plan and then fall back to in-phase during low availability periods. A period of low main system availability would therefore always cause the main system to lag behind and the standby system to go ahead of its design plan. The main system therefore always has to catch up after low availability periods, while being limited to the maximum design availability while it is in-phase, just behind the standby system.

In practice, the actual average main system conveyor position over the life of the dump would thus not be just behind the standby system, but rather half way between this and the average distance it falls behind each time. This means that the operating requirement to keep the main system in-phase just behind the standby system would be an impossible task, with it probably only being in that position for a very small percentage of the time.

The solution to the above operating problem is to simply operate the two systems two shifts apart on average and define this as in-phase. The main shiftable conveyor position will then vary from one to three shifts behind, depending on the current main system availability and which system shifted last, the standby system shift opening up the gap and the main system shift closing it. This would allow the main system to be able to go ahead of its average in-phase position to provide for subsequent low availability times by catching up with the standby system at times and then falling back to in-phase during low availability times.

By sometimes being able to go ahead of the average position and fall back and other times first falling back and then catching up, the main system should then be able to maintain this more realistic average in-phase situation. This step of two shifts apart must however be allowed for at the end of the dump, but would be a small percentage loss of capacity in the overall scale of things, while allowing a much more achievable operating requirement.

Another operating problem is a shift clash situation which can occur if the two systems need to be shifted at around the same time, regardless of how close to one another they may be. This situation results when the two systems have different ashing durations, due to the utilization split being different to the designed volume split, causing the shifting times to drift from the ideal of half way during each other's ashing period.

Ideally, this problem should be largely overcome at the design stage by allocating the main and standby systems the correct volume split in line with the main system's average availability. However, not achieving the designed average main system availability, or even short term availability variations will cause this clash to happen from time to time, also requiring close management.

As the main system is already normally operating at its maximum availability during ashing in order to maintain the average designed availability, the usual solution to a shift clash, especially if it is not recognised in sufficient time, is to stop the main system while it still has sufficient ashing space for the next standby system shift and allow the standby system to finish constructing its frontstack platform and move forward.

This unplanned outage of the main system however, results in a further drop in the average availability, causing additional pressure to maintain the average availability with the very small factor of safety allowed and this situation needs to be managed proactively to ensure that it doesn't happen too often. If the shift clash is as the result of short term variations and the average utilization is still equal to the volume split, the dump will now be likely to have a shift clash every time, and a conscious management effort will have to be made to get the two shifts far enough apart from each other again.

Feedback from site showed that the operating shift clash problem was actually a bigger problem than thought, with respect to the out of phase growth. Due to a low risk tolerance, the site operating personnel had adopted the procedure of stopping the main system whenever the standby system came within two to three weeks of its conveyor shift, to allow the standby system ashing to be completed and the conveyor moved forward while the main system was still available.

This was done to prevent the relatively high cost of emergency ashing in the event of a major main system outage during this critical period, where the standby system would then have insufficient capacity to cover the main system outage, needing to shift forwards during this time. This operating philosophy, not allowed for in the original design assumptions, resulted in every standby system shift being equivalent to a shift clash situation, with a significant drop in the average main system availability, now being taken out of service for about two to three weeks per shift more than planned.

The thinking in this case was flawed, as if the main system was about to fail in the last two to three weeks of the standby system's shift, then stopping the main system for this time would not remove this potential failure situation and the main system would then most probably have this breakdown in the middle of the standby system conveyor shift when it was brought back into operation, requiring emergency ashing in any case. The impact of such a change was to simply cause the main system to start lagging behind its growth plan and the standby system to go ahead, requiring additional pressure to catch up again, for no real saving. The cause of this decision was probably attributable to a single such incident, with the well-meaning solution to limit future exposure to such costs having a much more far reaching impact than intended.

The above situation is typical of the need for such operating variations from the design assumptions to be thoroughly evaluated before they are implemented, or as soon as they become known, to determine their impact on the growth plan and allow a decision to be made whether this change is tolerable.

1.1.5 Dump Monitoring Philosophy

It is essential to monitor the actual dump growth as compared to the design growth plan. Failure to perform this essential routine requirement will not only allow undesirable situations to arise, but will allow them to propagate even further.

Previously, the actual time-position information for each system was simply required to be plotted onto the original growth plan, with no easy means of evaluating the long impact of these variations on the remainder of the dump's growth, in terms of out of phase or total growth rates. Only if the actual growth appeared significantly different, or obviously diverging for a long time, was it considered necessary to initiate an investigation and produce a new growth plan.

Usually, when the dump growth is allowed to go out of phase and the two conveyors drift too far apart, this would fairly easily be noticed and could be rectified. If the simple rule of trying to keep the conveyors together, or at least within say two shifts is followed, out of phase monitoring would not strictly be necessary. This should however not result in no monitoring of the actual growth, as there would be no baseline data available for later back analysis.

For an out of phase dump trying to catch up, the conveyors would not be together and a visual check would not be possible, the only way to check the performance being to compare it to the new approved growth plan. The overall dump growth is also impossible to gauge by visual inspection and must be compared against the original growth plan, to ensure the dump will still satisfy its life time capacity requirements.

The main purpose of monitoring is to ensure long term health in terms of sustained availability of the ashing facility to the power station, at minimum cost. Unfortunately, monitoring is not critical to the availability of the ashing facility in the short term, as the dump can continue to operate even though it may be both out of phase and ahead of its overall growth rate. This usually results in the importance of monitoring being forgotten, as operating personnel focus on short term issues to optimise current performance. Even though forgotten, long term issues seldom go away on their own and usually get worse, needing constant management input to keep the dump within manageable limits in the long term.

The growth of a dump is sometimes very sensitive even to seemingly small variations of a parameter in the long term, due to the relatively long period over which a variation may be extrapolated. The cumulative effect of variations should be noted, as the total impact of a number of parameters all being only a few percent out, could result in an unacceptable overall impact. The long term knock-on effect is also important to remember, as a problem of say lost capacity, due to the dump geometry having been built too low or too short for a while, will not normally be able to be made up and while the dump can still operate acceptably now, the overall life would have been shortened. This effect also causes everything in the future to occur at a different time, affecting life-cycle plans.

Thorough monitoring and recording of actual growth performance on the design growth plan is therefore needed to highlight and identify long term growth problem situations. The old method of graphically plotting these performance graph lines will unfortunately only give an indication of whether the actual growth is close to the design curves and not whether it is in fact within acceptable long term limits. (See Figure 1.3) Even a relatively small difference in slope between the two graph lines could end up in a large difference when extrapolated say 40 years into the future. The graphical technique previously used of plotting actual growth on the design growth plan does not therefore allow accurate enough extrapolation of current performance to establish whether it would result in a long term problem.

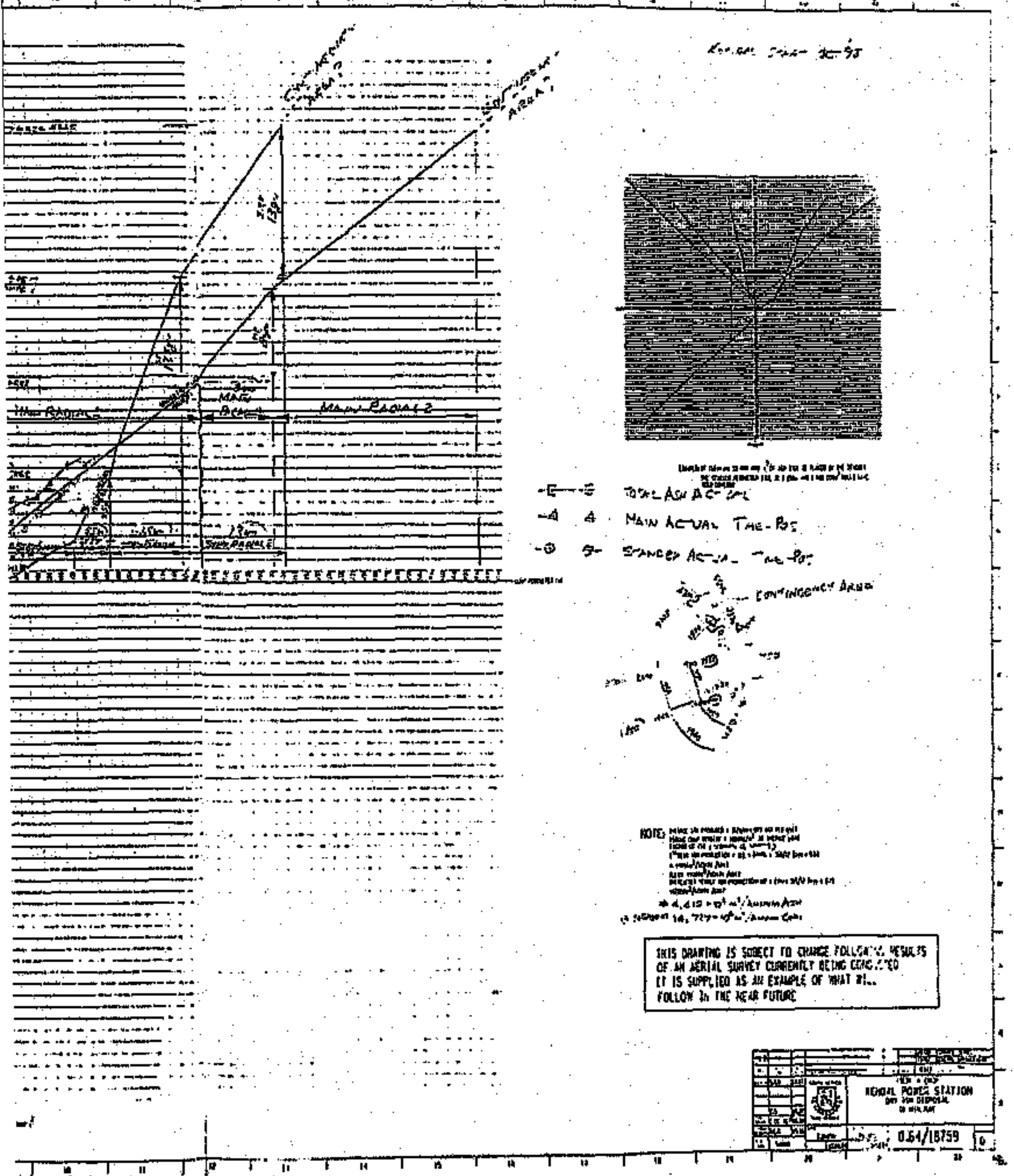
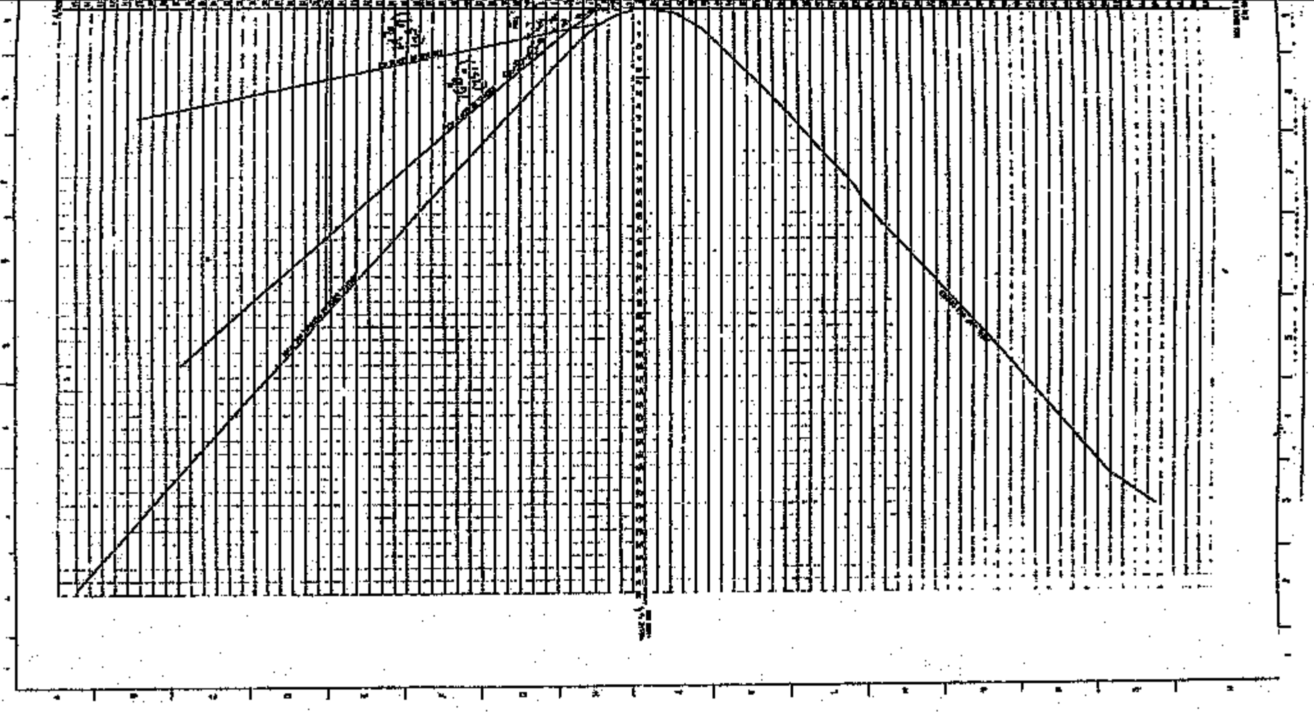


Figure 1.3 - Kendal Ash Dump Growth Plan Showing Actual Growth Monitoring.



In some instances the actual growth performance was not even compared to the original design, being only recorded and not verified or evaluated. This was probably the main reason why some of the dumps' actual growths were allowed to go so far from the original growth plan before it became such an obvious problem that it started to be noticed. Clearly, the savings of not implementing a reasonable monitoring program are insignificant compared to the cost of rectifying the problems which can develop.

A good monitoring program should not only monitor the overall growth performance, but should record and monitor key performance indicators (KPI's) as well. The overall growth monitoring would show up an overall growth problem, but the KPI's would allow the reasons causing the problem to be ascertained.

A change in any of the parameters could already raise alarm, allowing detailed investigation of that parameter before it is allowed to impact the dump too much. KPI's should be compared against the design assumptions to check their variance. This would immediately reflect an operating change, or possibly even an incorrect design assumption. Every time a significant variance is found, its impact on the dump growth should be evaluated, to check the dump's growth sensitivity to this range of variance and to determine whether a modification will be required in the long term or whether the parameter should be more closely controlled.

Not having a means to quickly evaluate these variances, often means that important issues go unaddressed. More importantly, to simply request site operating staff to record information for the sake of recording it and never seeing a use for it, leads to the recording of monitoring data dropping in priority with time, with a degradation or collapse of the monitoring system. It is therefore very important for regular routine evaluation exercises to be carried out and written performance feedback to be given to the monitoring personnel, to enable them to realise the importance of their efforts, if the system is to survive.

The main items requiring monitoring are the as-built dump geometry, overall and system ashing rates, the insitu average ash dump dry density and the shifting and ashing times. An as-built tacheometric survey should be taken at every main system shift and evaluated to check dump geometry, level and slope tolerance, as well as determine shift ash volumes placed for main and standby frontstack and main backstack. Records of conveyor shifting dates as well as frontstack and backstack start and end dates should be kept. The actual tonnages of ash placed within these dates per system and frontstack and backstack should be recorded. This will allow the as-built average ash dry density to be back analysed, from the volume and ash tonnages. The information should be routinely evaluated and plotted on the original growth plan and compiled into a report.

It is important to note that while as-built dump surveys taken once per shift are valuable for growth monitoring purposes, they do not replace the standard Quality Assurance system required of all construction works. These surveys are taken after the fact and are more for long term growth audit checking purposes than for ongoing approval of the construction works. Construction mistakes picked up at this stage often have to be lived with as the shiftable conveyor would either have shifted over the area already or insufficient time would be available to rectify the problem before the conveyor needed to shift onto the area. It is therefore imperative that regular, detailed construction Quality Assurance is also carried out.

1.2 The Dump Growth Plan

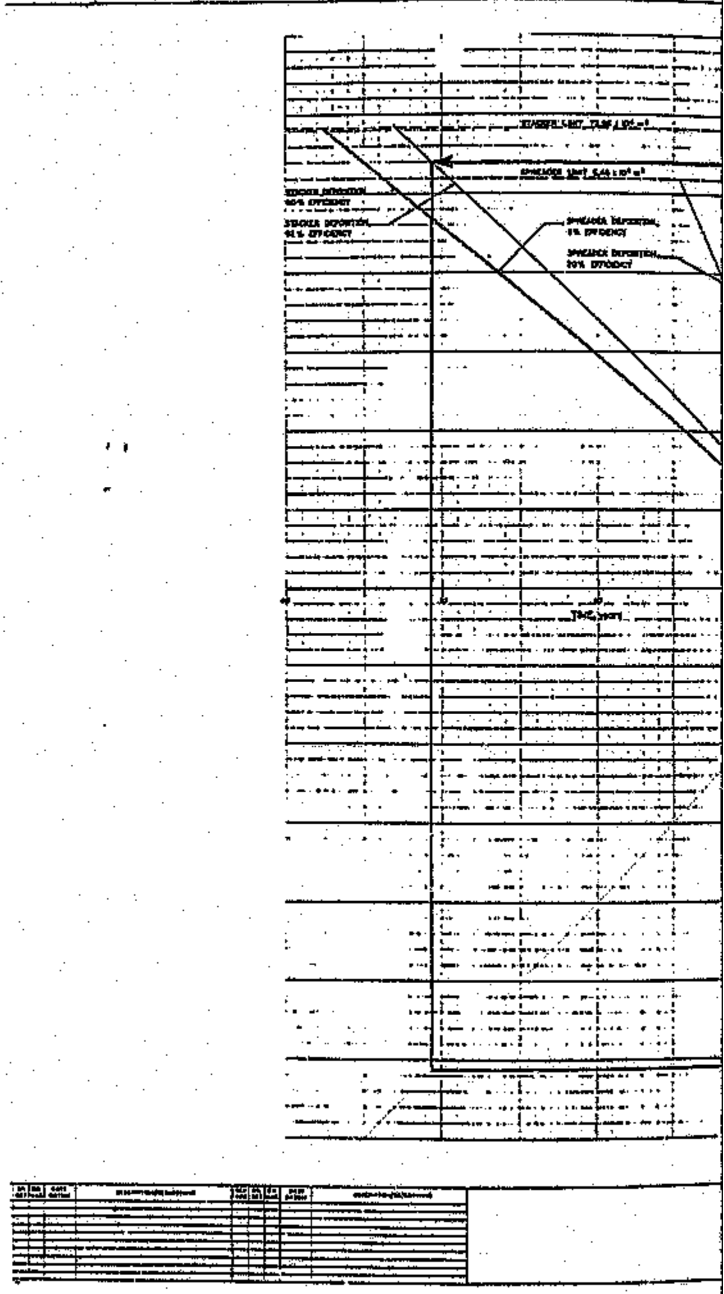
The dump growth plan information is required firstly during the design phase to determine the feasibility of the dump layout configuration and secondly to develop the life cycle plan for the dump. Only when the design is accepted and constructed, is it required for monitoring. The growth plan indicates the overall dump growth, the main and standby relative growth rates and when important points in the life of the dump would be reached. Amongst others, this would show when a change of shifting direction or method was needed, to allow for timeous planning, training or conveyor system modifications. It would show when new capital works like pollution control dams or stream diversions were required, or existing facilities like drains and roads need to be extended, or when the dump would reach areas of higher stability risk, to allow for planning, investigation, monitoring and budgeting exercises.

The method previously used for depicting the dump growth plan was to use a graphical representation, usually plotted as a registered "A0" size drawing, to allow for ease of interpretation and plotting of actual growth performance overlaying the original plan, for monitoring. A four quadrant "coaxial plot" type graph, derived from the traditional wet ash or mining tailings type "rate of rise" growth plan, was used. (See Figure 1.4)

Typically, the dry ash dump growth plan would use three of the quadrants of the coaxial plot. In the first quadrant (See Figure 1.4 top left) was an ash production graph, showing the relationship between cumulative total power station ash volume produced against time, as well as two other curves depicting the ashing rates for the chosen utilization split between the main and standby systems.

The volume axis would be common to the next graph in the second quadrant (See Figure 1.4 top right), which depicted the position versus volume relationship of the dump for the assumed layout configuration and geometry. This was given as two separate curves for the main and standby systems, showing the cumulative ash volume up to any position on the dump. The position axis was usually some physical dimension like extendible conveyor length for parallel shifting systems or dump toe circumference from the start for radial shifts. The conveyor shift position number was sometimes also added.

The above two relationships of the rate of ash deposition and the dump geometry are linked by the common volume parameter, thus giving a relationship between time and position, for each system. This very important time-position relationship is what is needed to evaluate the feasibility of the dump configuration layout by checking that the dump will not be filled before the station's lifetime, or if the two system would go out of phase and the dump becomes inoperable, with the available site not being optimally used. This information would allow the designers


STACKER LIMIT 73.86 x 10^6 m^3
SPREADER LIMIT 5.46 x 10^6 m^3
STACKER DEPOSITION, 40% EFFICIENCY
STACKER DEPOSITION, 41% EFFICIENCY
SPREADER DEPOSITION, 1% EFFICIENCY
SPREADER DEPOSITION, 20% EFFICIENCY
TIME, years

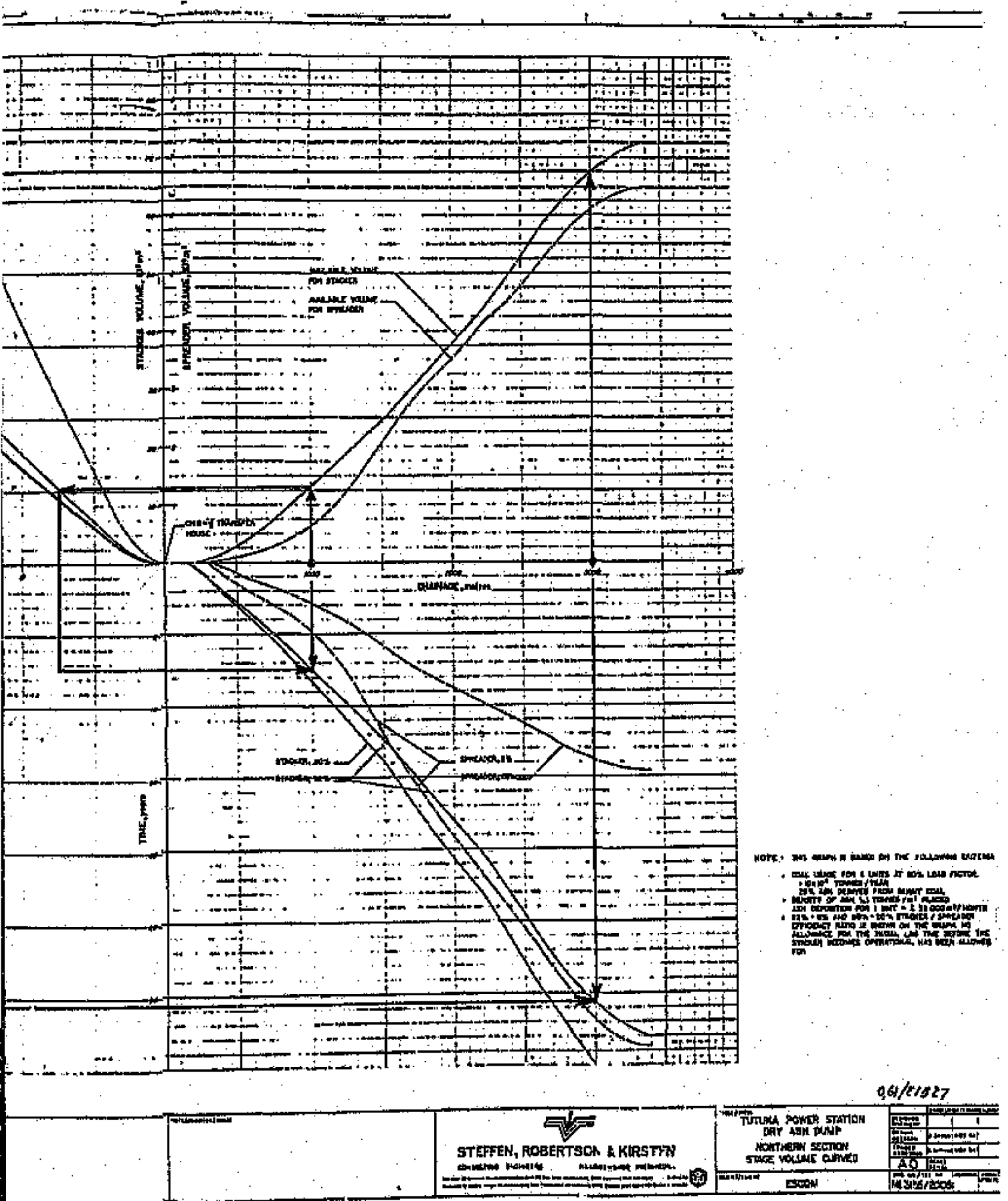


Figure 1.4 - Tutuka Ash Dump Growth Plan Showing Graphical Evaluation.

to modify the dump design to arrive at a feasible design and growth plan. Only once the design and growth are acceptable, the detailed time-position information can be taken off to prepare the life cycle plan.

The position versus time relationships for the two systems were plotted as two graph lines in the third quadrant (See Figure 1.4 bottom right), using the existing common position axis and a second time axis, to enable the time to reach any position of interest to more easily be read off the growth plan. The fourth quadrant was usually not used, but could show information like completed rehabilitation area versus time if the position-area relationship was also determined.

The physical preparation of the growth plan drawing itself was also a time consuming exercise, having to be generated manually on a drawing board or CAD system from the analysis information, for each option or variation. This seems very unnecessary, as plotting of graphs from x-y data is such a simple task nowadays for a powerful computer such as used for a CAD draughting workstation.

1.2.1 Previous Modeling Techniques

The position-volume geometric relationship for the dry ash dump must first be created by fixing the ash conveyor layout configuration and dump construction geometry for the main and standby systems. The dump is split into the main and standby ashing areas according to the assumed volume split, which is assumed equal to the average main to standby lifetime utilization.

This is usually the siting phase of designing a new dry ash dump facility, but could also be required for a problem situation requiring a layout modification solution. This would be dictated by many factors like the required total ashing capacity, stability height limitations, available land, mineral deposits, topography, conveyor stacking systems, dump drainage, rivers or existing infrastructure or other geometric limitations.

Once this overall geometric relationship exists, the position-volume relationship needs to be determined for each system. This was initially done manually by either determining the plan area and multiplying by the height if the dump was a constant height above the ground, or by taking cross sections and using average end areas to determine the volumes. To simplify and save calculation effort, when doing this manually, this information was usually not generated for each conveyor shift position, but rather only at salient points in the dump layout and a smooth curve fitted through the points, to portray the continuous average relationship.

With the advent of powerful digital terrain modeling (DTM) earthworks and road design packages in recent years, it became possible to prepare a static model of a particular ash dump geometry and then determine the volume of any area of interest between the dump model and the original terrain. This considerably reduced the calculation effort, as well as increasing the accuracy of volume calculations. This was still a fairly time consuming exercise, as the extra computing power was usually used to split the dumps up into more detail to give a more accurate position-volume per shift relationship.

Although static, this position-volume modeling exercise was essentially the geometric modeling part of determining the dry ash dump growth. A second modeling exercise, much simpler but just as essential, is the power station life cycle ash production relationship.

The ash production information was usually determined from the projected annual coal burn tonnages for the station, which was then converted to ash tons using the ash percentage in the coal and finally to volume using the average insitu ash dump density. The main and standby ash deposition relationship curves were then determined by splitting the total cumulative ash volume into the assumed average main:standby utilization split.

1.2.2 Previous Evaluation Techniques

Once the ash production and dump geometric position-volume relationship information had been determined, it was plotted in the form of line graphs on their respective quadrants of the coaxial growth plot. From this information, the desired relationship between time and position was determined graphically on the coaxial plot.

The key to this graphical analysis technique was to use the same volume scale for both relationships on the common volume axis. This tied the two relationships together, linking time to position, allowing the use of this very simple graphic technique, without the need for any mathematical interpolation between the known points on the graphs.

The graphical technique used (See arrows on Figure 1.4) was to simply project lines from salient points for the main and standby systems on the position axis, across to intersect the corresponding position-volume curve in the second quadrant. From this intersection point, a second line was projected at 90 degrees through the common volume axis to intersect the corresponding ash deposition curve. The time at which this particular position would be reached was then determined by extending a third line at 90 degrees from this point down to intersect the time axis. The time-position relationship for each point was thus determined and plotted on the third quadrant graph, for each system. Again, by simply drawing a curve through these points, the continuous average time-position relationships were determined, for the main and standby systems.

1.2.3 Limitations

The main limitation of the above method is the number of manhours needed to evaluate all the geometric and ash production relationships and thereafter to manually generate the coaxial plot growth plan, for any set of assumed parameters. Even with the use of powerful earthworks DTM packages to do the dump geometric modeling and calculate the volumes, this still required a repeat of the work for a change in the assumptions, due to the modeling still being static.

This time limitation was the main cause of usually not evaluating sufficient options or variations of each option, to enable not only optimization exercises to be done to determine the most economic design, but also to allow the impact of varying any critical parameter to be evaluated, tc determine the sensitivity of the particular design configuration to the expected variation of this parameter. This feedback is required to evaluate the practicality of the design, or highlight critical parameters needing close monitoring and management.

The static manual analysis method did not allow for any immediate feedback during the design phase, to allow the designer to see the impact of a change of any parameter immediately, on either the dump's geometric layout, or the dump growth. This would allow not only the development of a feel for the sensitivity of the input parameters, but would also allow the designer to identify immediately if an insufficient or inappropriate value had been used. This would also allow clash checking, to ensure that a feasible model was being generated.

As the level of detail on the graphs was usually based on salient points and average values, no detailed problems in the configuration like the potential for frequent shift clashes could be determined from the graphs. This would not normally be a problem with a dump in phase, but in trying to accelerate the main system to catch up an out of phase situation would require the dump to operate with the utilization split different to the volume split for an extended time, exposing the operation to frequent shift clash situations, which would need to be carefully managed so as not to thwart the acceleration efforts.

1.3 Overall Aims of the Study

The intention of this study was to determine whether the process of producing a dry ash dump growth plan could be automated to provide the designer with a computerised design tool to speed up the evaluation and production of dry ash dump growth plans. Having such a tool would then allow the dump siting, geometric layout configuration design, operation, monitoring and modification needs to be more quickly and cost effectively addressed.

As this study was a pioneering effort in this relatively small specialist field of dry ash dump construction, due to the limited number of such facilities worldwide, it was decided that this first attempt should concentrate on firstly identifying the necessary input parameters and user requirements for such a system and secondly, the developing of a prototype computer model to automatically convert this information into the final dump growth plans, in order to verify the concepts.

The model would be tested by using it to evaluate one of the existing practical out of phase dump situations, which would promote further development as practical implementation difficulties were encountered. The Kendal ash dump out of phase situation was chosen due to the urgent need to evaluate a layout configuration modification proposed by the station personnel, to allow economic and budget decision making.

CHAPTER 2

FORMULATION OF THE PROBLEM

The formulation of the problem came about as a result of many years of frustration in having to apply tedious manual analysis methods to evaluate the growth of dry ash dumps, mostly with less time available than needed to do a comprehensive job, while observing the rapid development of powerful computer packages to solve many other routine tasks.

The advent of powerful and affordable personal computers and computer software packages, which not only removed the drudgery of tasks like for example typing, but catapulted this menial routine into the powerful, yet user friendly arena of word processing, stimulated the author to wonder if such a custom designed computer package could not do the same for the menial task of evaluating the growth of dry ash dumps. Unfortunately, no such computer package was available locally to do this specific task and an attempt was made to evaluate other packages which could possibly assist with solving this problem.

A number of powerful computer packages for designing and evaluating earthworks and roads became available around this time, which it was hoped would be able to assist with speeding up this process, but it was soon found that while they could achieve great productivity in the areas for which they had specifically been created, none of them was closely enough related to the unique problem of evaluating the growth of dry ash dumps to be of significant benefit. It soon became clear that a custom modeling program would probably have to be created in-house, as it would most probably never be made available by the software houses which developed the earthworks packages, due to the very small market and the difficulty to recover the development costs.

Such a package would obviously have great benefit to Eskom, but even if one of these software houses were to be appointed directly to develop such a package specifically for Eskom, a user specification would need to be prepared, needing some form of pilot project to define the input and output requirements. Due to his experience with dry ash dumps in Eskom, it was thus decided that the author should undertake this study as a research project, as a pilot project to formulate the problem and user requirements and develop a prototype modeling program. Based on the results of this study, a decision could be made as to whether to continue with in-house development for the final version, or whether to rather draw on the powerful programming resources of a commercial software development house.

2.1 Statement of Problem

The problem to be addressed is that current methods of evaluating the growth of dry ash dumps having main and standby conveyor stacking systems, are based on a static, manual analysis process, requiring a large amount of work to repeat the entire analysis to determine the new growth plan for any new set of design assumptions. This prohibits the necessary sensitivity, optimization and routine monitoring evaluation exercises which are needed to ensure the dry ash dump growth plan is optimum over the entire life of the power station.

2.2 Hypothesis

It was postulated that a parametrically driven computer model of the growth of a dry ash dump could be developed which would allow a new growth plan to be automatically produced from any set of input parameters. This would then facilitate rapid and cost effective sensitivity, optimization and routine evaluation exercises.

2.3 Parametric Modeling Concept

It was surmised that the concept of parametric modeling would best lead to the solution of automating dry ash dump growth plan evaluation. The growth plan is essentially a system of relationships, which link the input data parameters to the output growth plans. The changing of any of the input data parameters should thus lead automatically to a new growth plan.

Parametric modeling, as opposed to static modeling, can be compared to the difference between arithmetic and algebra. Instead of determining the result to an equation based on static input values, the analysis is set up in the form of a mathematical model based on input variables or parameters. All the same relationships which would be used for a static manual evaluation of the input values, are instead used to form a mathematical model of the overall relationship, from input variables to final output.

The mathematical model can be seen as one big algebraic formula which has already been checked and verified, with the menial calculation process being of no interest to the user, only the input and output. When using a computer program to automatically perform the mathematical model's calculations, the output results can be obtained almost instantaneously upon entering the new input parameters, allowing immediate feedback.

2.4 Literature Survey

Computer library searches were done using the following keywords; dry, ash, dump, conveyor, shift, shiftable, stacker, stacking, spreader, growth, development, bulk, materials, solids, handling, simulation and animation. No references relating directly to dry ash dump growth, using stacking conveyor systems, could however be found.

It soon became clear that the dump growth problem is more closely related to the mechanical engineering bulk solids handling discipline as defined by industry, even though in Eskom the dump layout configuration and growth is usually done by the civil engineering section. This is done because during the siting stage, the ash dump geometry and growth are more closely related to civil constraints associated with layout, stability, drainage, pollution control, bulldozing and access requirements. The conveying and stacking systems themselves are handled by the materials handling section, with the necessary interfacing.

Computer Aided Engineering (CAE), using simulation and animation has been widely applied to materials handling problems over the last few decades, although the main focus was on deterministic and stochastic evaluation of throughput, delays and capacity of fixed systems and not positional growth variations.

Zador(6) reviewed a number of computer programs with respect to their animation capability, as a tool for designing materials handling systems. These included batch mode simulation programs with post processing animation developed many years ago, to brand new "on line" systems showing the results during the simulation analysis. Simulation and animation would be very useful tools for assisting the designer to arrive at optimum dry ash dump layout configurations, as well as to enable management to more easily grasp the operational concepts and make decisions.

Another type of layout configuration application using such simulation programs is the design of harbour facilities. Ramos and Goodwin(7) also reviewed a number of similar computer simulation programs in their article on harbour simulation. They point out that these are merely easier programming languages, specifically designed to make simulation modeling simpler. The model, incorporating the input data and linkage relationships, must still be specifically determined for each particular application and the simulation could in fact be programmed using any general purpose programming language. The advantage of using one of the simulation programming languages is that they are easier to use and have powerful built in functions designed for easily creating a simulation model, allowing the designer to build the model, instead of a programmer.

Zador[6] also stresses the benefit of the design engineer being able to build the simulation model. He states that "Often, process or product design improvements or operational changes suggest themselves in the very activity of building an animation model, or the associated simulation model." He points out that the engineer would never discover these points if someone else was doing the modeling.

Zador[6] highlights the value of simulation as a necessary engineering tool for planning and decision making of bulk materials handling systems, especially as they become more complex. The author had come to the same conclusion with respect to dry ash dumps and this supports the need for such a modeling system for the design and management of dry ash dumps.

None of these simulation packages was available to the author within Eskom and could not be reviewed at the time to determine whether they could in fact be used to model the growth of a dry ash dump and produce the required growth plan. A large part of the problem would still be to identify the necessary modeling input variables and the modeling relationships between them to generate the geometric, ash production and growth models, together with the required outputs and their formats. It was therefore decided that it would still be beneficial to develop a dedicated spreadsheet based prototype model, as this would help to identify the required inputs, relationships, outputs and formats.

The above mentioned simulation modeling software packages could be investigated in the next phase, to determine whether they can be used to build a dry ash dump growth model and produce the necessary growth plan, instead of writing a custom program. The spreadsheet prototype model can then be used as a benchmark to evaluate the other options.

Halvorsen(9) looks at the closely related problem of belt conveyor design. Due to the complexity of the design calculations and the need to repeat them a number of times to arrive at optimum solutions, the cost of engineering becomes a burden, resulting in multiple iterations rarely being carried out when using manual analysis methods. In his review of their in-house written Conveyor Design program, he puts forward a modeling program operating concept of using multiple windows for the input data and outputs, quickly accessible by pressing Special Function Keys on the keyboard, which served to greatly improve the time taken during the optimization phase.

This concept would also be extremely valuable for a dry ash dump growth evaluation program, due to it having a number of input areas, with related numerical and graphical outputs, which the designer needs to see to get visual feedback that the input data has achieved the desired effect. The windows based spreadsheet program allows this to easily be achieved, by resizing, moving and overlaying windows simply by using the mouse. Each window can also be zoomed in or out or panned up or down as needed, without the need to program all this powerful functionality.

The availability of the main ash stacking system is a very important parameter in assessing the growth rates. Lubrich[10] discusses the "Assessment of Equipment According to the Degree of Availability and Utilization ...", fo similar conveyor stacking and reclaiming equipment in open pit mining systems. He stresses the importance of using non-arbitrary definitions for availability and utilization of such systems, so that the information is unambiguous and transferable. He advocates the need to use calendar time as the basis, allowing time outages for various unavailability factors.

The validity of this concept for the power station dry ashing situation was questioned by the author. While it is agreed that the availability of a system must always be time based, the utilization of the two systems is related to the rate at which each system fills its allocated ashing space. As the ashing rate can vary as the number of units on load varies, a theoretical worst case situation could arise where every time the standby system is required, the station happens to be running on full load, with the main system having a lower average ashing rate, due to its longer ashing time. This would result in the utilization time split not being equal to the volume time split.

In order to investigate this situation, the author reviewed the ashing system's time based operating logs of Tutuka's ashing system to determine the time based availability split between the main and standby systems, for the period between two as-built surveys, taken three years apart. This was then compared to the volume split, obtained by a Digital Terrain Modeling (DTM) evaluation of the surveys. The results showed that the two approaches returned almost exactly the same main to standby split, suggesting that this would be a highly unlikely event, especially over long periods.

It is recognised that this situation could still occur, particularly over short time periods, but this would then only affect the short term growth within that particular ashing position and not the average growth of that position. As the growth of the dump is only required to be evaluated on a position basis, with the conveyor position ashing durations being fairly long, ranging from three to nine months usually, the use of a time basis for availability and utilization would be acceptable for the modeling purposes.

The dry ash dump density is an important variable in relating the conveyor position ashing volume to the ash tonnage that would fill this volume, as the ash is dumped at a tonnage rate. The dry density was assumed to be $1000kg/m^3$, for the Kendal dump design, as no Kendal ash was yet available at that stage and it was assumed that the ash should be similar to Lethabo's ash. Occasional insitu and laboratory tests showed that the actual density was much lower at around $850kg/m^3$, which was supported by estimating the average insitu dry ash density by dividing the number of ash tons placed between the dates of two as-built surveys, by the volume between them. Bhana(11) carried out extensive laboratory testing which confirmed this, meaning that the design dump volume would now be 15 percent too small.

One of the requirements for such a dry ash dump layout configuration modeling package would be the integration or at least transferability of the final layout configuration geometry into the Eskom standard MICROSTATION CAD package. Cowden[12] et al describes techniques for using Object Linking and Embedding (OLE) and Dynamic Data Exchange (DDE) techniques to enable porting of layout configuration output data directly into the CAD package. This was however found to very slow and impractical for the application. The simple exporting of the ASCII data from the spreadsheet and loading it into the CAD using a custom utility as a post processing activity once the optimum layout configuration had been determined, was found to be a more practical approach for the prototype system. (See Figures F1 to F3)

2.5 Specific Aims

The specific aims of this study were firstly to identify the detailed operating user requirements of such a modeling program and the modeling concepts and mathematical techniques required for the various parts. The input parameters and the final outputs requirements, would be identified.

Firstly, for the geometrical model, the input parameters and the relationships between them, which are needed to generate the configuration geometry of the main and standby systems of a dry ash dump, to enable the position-volume relationships to be determined, would be identified. The program operating concepts and mathematical modeling techniques, with an automatic plot of the layout to enable feedback for input variable verification, would be determined. The format for setting out of the geometric model input parameters, as well as the position-volume outputs, would also be determined.

Secondly, the input parameters, as well as the relationships defining the ash production model would be determined. The format for setting out of the ash production model input parameters, as well as the time-volume outputs, would also be determined.

Thirdly, a mathematical model called the growth plan model, would be developed to emulate the graphical co-axial plot evaluation technique of generating the time-position relationships for the main and standby system . The growth plan model would use the geometric and ash production model's outputs as its inputs. The final output of the growth plan model would be the automatic production of the dump growth plan plot. The input parameters necessary for this model and their input and output formats would also be determined.

CHAPTER 3

DEVELOPMENT PLATFORM

The available computer hardware and software packages within Eskom would of necessity largely dictate the most appropriate development platform, with Eskom being both the promoter and the main user of the final system. The intention was to develop a dry ash dump growth evaluation package, which could eventually be integrated into Eskom's computer aided draughting system, to allow automatic generation of both the layout configuration and the final dump growth plans as registered drawings.

3.1 Hardware and Software Options

The hardware options considered were either a DOS based personal computer or a Unix based graphics workstation, as they would more easily be able to support the necessary graphical elements of the package. For this reason, the mainframe computer was not considered at all.

The software options considered were:

- Stand alone FORTRAN based package.
- Stand alone "C" based package.

- Add-on "C" based Microstation Development Language (MDL) package, within Eskom's standard Microstation CAD draughting package.
- Stand alone Microsoft Visual Basic based package.
- Lotus 123 Version 3.1 spreadsheet based package.
- Microsoft Excel Version 5 spreadsheet based package, using Visual Basic for Applications as a macro language.

3.2 Advantages and Limitations

The initially available PC was a 386 SX computer with a 14 inch monitor, which quickly proved to be not capable of handling the enormous calculation task required within a reasonable time. In addition, the relatively small monitor did not lend itself to displaying sufficient data to allow easy operation of the program. This problem was solved by simply upgrading the PC to a Pentium based machine, with a 17 inch monitor, due to the relatively low cost of computer hardware in the last few years.

The Unix based graphics workstation was very powerful and had the advantage of having dual 20 inch colour monitors, used for CAD draughting, which would be very useful to display all the necessary input and output areas of the package simultaneously, without the need to swap from one window to the next. The system also had a more powerful earthworks DTM package. The main disadvantage was that there were indications that Eskom would be moving away from these hardware platforms in the future, due to their high maintenance cost and the fact that personal computers were soon likely to become just as powerful, but at a fraction of the purchase and operating cost. Another major disadvantage was that this platform could not run all the considered software packages, like Visual Basic and Microsoft Excel.

The main advantage of the FORTRAN software development platform was the author's considerable experience with this language, but this was overshadowed by FORTRAN not being as powerful as some of the newer "object oriented" languages, as well as not being a macro or add-on development language for the CAD or spreadsheet packages.

The stand alone "C" platform would be the most powerful for a final version of the program, although it would have required the author to start learning the language from scratch and not offer much benefit for the prototype development stage.

The MDL platform, being a "C" based language, would be similar to the above, but with the added advantage of easier integration with the CAD package in the end, for automatic drawing generation. Again, this would be more of an advantage for a final version of the dump growth plan package and not be ideal for the prototype development.

The stand alone Visual Basic platform also had the disadvantage of having to be learnt by the author, but would be easier to learn as it was similar to FORTRAN. The language was also very powerful, as it was object oriented and Windows based, although not as fast as "C". A disadvantage was that it could not easily integrate with the current version of the Microstation CAD package, although the next Microstation version was reported to use Visual Basic as its macro language. As this was not available at the time, it would possibly be more advantageous to the development of the final version of the package.

The version of the Lotus 123 spreadsheet package available to the author was an older, DOS based version, and did not have the functionality needed for the development, although it was used initially to verify some of the principles used. The graphing facility could however only display X-Y graph lines all using the same X-range, making it not capable of being used to automatically draw the layout and growth plans. As Eskom had recently adopted the Microsoft Excel spreadsheet package as a company standard, it was not considered to investigate a newer Windows based version of the Lotus 123 package.

The Microsoft Excel spreadsheet based package had the advantage of being very simple to use as a development platform, having powerful built-in functions and the possibility of writing user defined functions and macros in Visual Basic. The main feature that even made this platform feasible in the first place, was the discovery that, unlike any other spreadsheet package available at the time, the X-Y graphing feature had the capability of being able to display up to 255 individual graph lines, having unique X and Y ranges! This feature was recognised by the author as being able to display both the dump growth plan graphs automatically, as well as the ash dump layout configuration drawing, utilizing it as a parametric drawing tool, as the graph is automatically updated whenever a change to the spreadsheet is made. This would save a tremendous amount of unnecessary work to create such a capability as compared to any of the other platforms considered, with the effort rather being spent on development of the modeling concepts and techniques for this study.

3.3 Chosen Development Platform

The final hardware platform chosen for the prototype development was an obvious choice, with the new Pentium based PC now being available and the Unix based workstation having a limited future. The PC was also essential as only it supported the chosen Microsoft Excel spreadsheet package software development platform.

Essential hardware configuration used:

- Pentium P60 processor. Anything slower was found to take excessive processing time for iteration, although it would still work and would still be much faster than manual evaluation. (Fastest processor available is preferable)
- 16 Mb Ram. (Probably better to use 24-32 Mb)
- 17 inch colour monitor. (1024 x 768 resolution) A smaller monitor is workable, but was found difficult to see enough data at reasonable scales, requiring more manipulation of windows. (20 inch monitor would be preferable to see the maximum information on the screen at once)
- Windows graphics accelerator card. This can speed up the processing time more effectively than a faster processor, due to the heavy graphical processing in the windows environment. (Fastest card available)
- Four colour A4 inkjet printer. (An A3 or even an A0 would be preferable, especially for the final version if the co-

axial plotting format is used again for clearer portrayal of the high density of information on the new growth plan)

Essential software configuration used:

- Microsoft Windows Version 3.1
- Microsoft Excel Version 5.0

CHAPTER 4

DESIGN OF THE PROTOTYPE PROGRAM

The prototype dry ash dump growth plan automation program was designed firstly to emulate the manual evaluation and graphical methods previously used and secondly to improve on these methods.

An attempt was made to base the evaluation on practical, meaningful input parameters, allowing easier monitoring during operation. It was also attempted to provide the designer with a user-friendly operating environment, which would allow him to get immediate visual feedback as to the impact of input data changes, to allow not only verification of the input data, but also the development of a feel for the relationships of the dry ash dump configuration. Lastly it was attempted to redefine the format and information presented on the dump growth plan, to enable easier and better evaluation of options.

This chapter describes the basic design concepts used in developing the prototype model. For detailed operating procedures and programming techniques of the prototype modeling program, the reader is referred to the User Manual (See Appendix G) and the Program Manual (See Appendix H)

4.1 Modeling Concepts

The overriding concept behind this new approach to evaluating the growth plans, is the move away from static manual evaluation methods, to a parametric modeling based system. This produces a system where the output results are a direct function of any set of input variables or parameters, without the designer needing to get bogged down in a multitude of complex, burdensome calculations now handled by the computer, which would merely distract him from concentrating on the real problem of what is the growth plan for a particular set of input parameters.

This is achieved by creating a computer modeling environment which allows the input data parameters and the output result values and graphical representations thereof to be viewed simultaneously on the computer monitor. This creates the visual feedback environment, so vital for simplifying and speeding up the process of arriving at optimum solutions.

The Microsoft Excel spreadsheet environment, being Windows-based, allows this to be done very easily, allowing the designer to move, resize, zoom and overlay windows to see the information pertinent to the stage and focus of the analysis.

4.1.1 Parametric Input Data

The input parameters are specifically defined for each modeling section of the program, exactly defining the desired model end result. They are usually entered in specific input areas (using a green cell background on the spreadsheet to denote input values and turquoise for input formulas (See Figure B1)), with the columns defining the parameters and each row containing the data relating to a specific conveyor position. This is basically in a database format, although with direct access to view and manipulate each individual parameter, allowing either a value or a formula to be entered into any cell, in order to generate the input data. This results in a very flexible and powerful modeling environment.

4.1.2 Program Parametric Models

The models used in the prototype program are the Geometric Model, the Ash Production Model and the Dump Growth Model. The Geometric Model defines the dump geometry and layout configuration producing the Position-Volume relationships, the Ash Production Model defines the rate of ash production by the power station and the Dump Growth Model defines the growth rates for the main and standby systems, producing the final growth plan.

The Geometric Model and the Ash Production Model are independent models, with the Dump Growth Model being dependent on both, relating the rate of ash production to the rate of the main and standby system growth rates, using the main system availability parameters per shift to allocate the ash produced into each conveyor position ashing area and thus determine ashing durations and shifting times. The input data for both the Geometric Model and the Ash Production Model must therefore be defined before the Dump Growth Model can produce a growth plan, although once all the models are defined, any parameter value in any of the models may be changed, with the growth plan immediately reflecting the result.

4.1.3 Visual Feedback Outputs

The visual feedback outputs consist of both numerical result areas usually adjacent to the data input areas for easier cross referencing and graphical representations in the form of graphs or layout plots. The numer: result areas are used to inspect the results to determine whether desired numerical values have been achieved from the input data and the graphical result areas are used to give an overall portrayal of the large amount of data, to verify that the desired overall result has been achieved by the input data.

4.2 Dump Geometric Modeling

The dump Geometric Model is complex from both an input variable definition as well as a modeling relationship point of view. This is mainly due to the large number of input variables and relationships required to define the geometry on a shiftable conveyor position basis.

4.2.1 Geometric Model and Parameters

The dump geometry and layout configuration is totally defined by the conveyor starting positions and the geometric and shifting dimensions for each shiftable conveyor position of both the main and standby systems. This allows total flexibility to move the entire dump around or change its layout geometry by changing any parameter for any conveyor position, at any time during the evaluation. This immediately determines the effect not only on that particular shift, but how this might affect the subsequent shift positions.

The shiftable conveyor for each conveyor position is used as a baseline for defining the ashing and shifting geometry, defining the frontstack, backstack and sideslope ashing as well as conveyor shifting and extending geometry relative to the start (tail) and end (head) positions (See Figure 4.1).

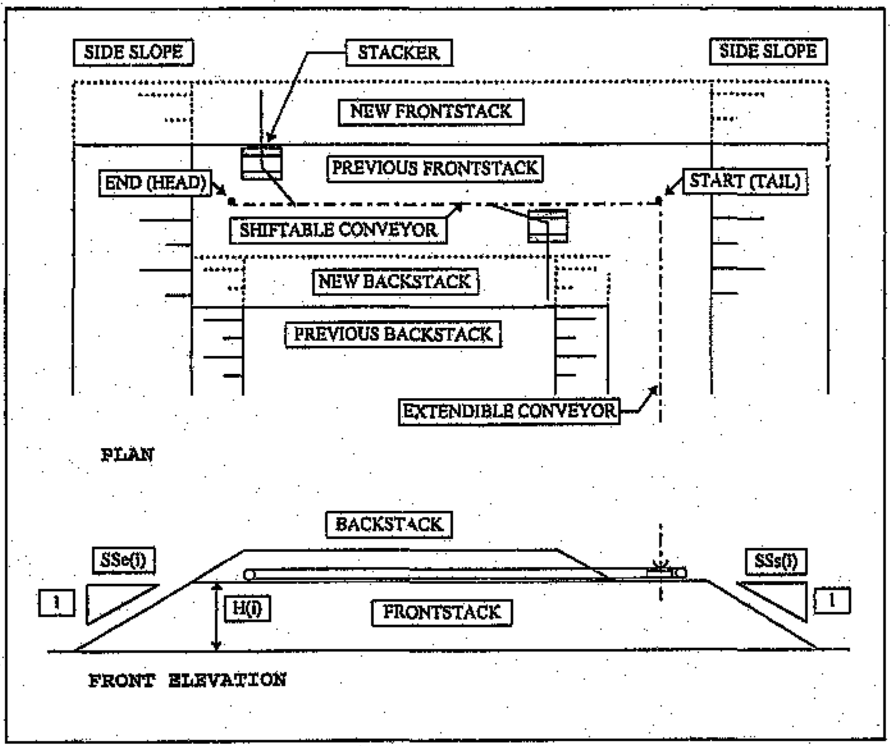


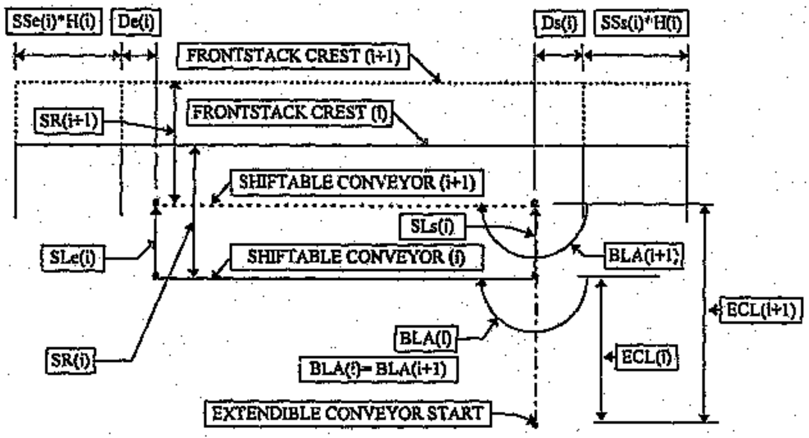
Figure 4.1 - Typical conveyor and Ashing Geometry per Position. (See Nomenclature)

This allows a relative modeling relationship, with the ashing geometry always being related to the conveyor position and tying back to the previous ashing crest. The ashing geometry can thus be determined as a function of how the conveyor is shifted for any particular shift, either parallel or radial.

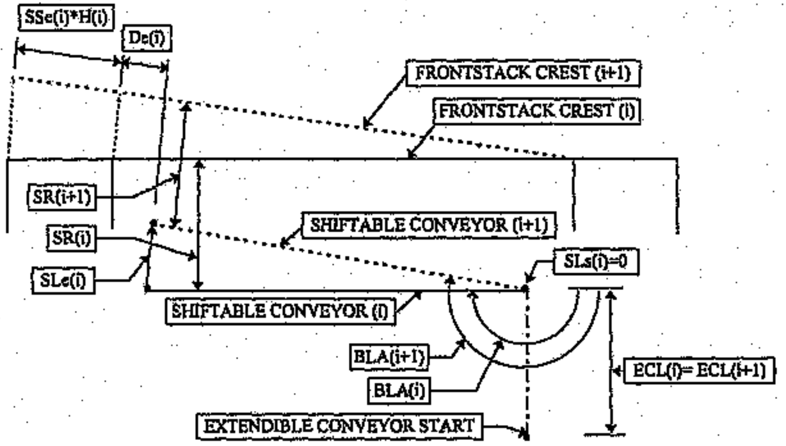
The main and standby systems are modeled totally independent from one another, allowing total flexibility to allow the designer to model almost any conceivable layout configuration with the system. The increased flexibility however implies that the designer must model the dump as he intends to construct it, taking note not to allow the two systems to ash in the same place, or leave gaps between them. This kind of clash checking was not possible to automate in the prototype spreadsheet model without restricting the flexibility and it was decided that the geometric layout plot was quite adequate to check whether there was a clash situation by simple visual inspection, changing the input parameters until the layout looks right.

4.2.2 Radial and Parallel Shifting

Radial and parallel shifting operations of the shiftable conveyor are achieved by simply defining the distance the head and end points of the shiftable conveyor must be shifted forwards, for each conveyor position. Using the same shift distance for both ends results in a parallel shift, while using a shift distance only at the head end and zero at the tail end, automatically results in a radial shift. The extendible conveyor is then extended by the shift distance at the tail end. The frontstack, backstack and side slope ashing geometry then being determined by the stacking reach and edge parameters relative to the new conveyor position head and tail points (See Figures 4.1 & 4.2).



a) PARALLEL SHIFTING



b) RADIAL SHIFTING

Figure 4.2 - Parallel and Radial Conveyor Shifting and Frontstack Ashing Geometry Modeling Concept. (See Nomenclature)

This results in a simple, yet extremely powerful modeling concept, allowing the layout configuration to be determined by simply defining areas of parallel and radial conveyor shifting, with possible lengthening and shortening of the shiftable conveyors, to steer the dump in the desired direction to suit the local topography and other constraints, while the model takes care of generating the ashing geometry, relative to the shiftable conveyor positions.

4.2.3 Position-Volume Relationship

The shiftable conveyor positions information of the Position-Volume relationship, is obtained either from the extendible conveyor extension length for parallel shifting or by determining the slew angle (SLA) for radial shifting, from the shift length input parameters. These are then added to the previous conveyor's position to arrive at the new shiftable conveyor position's base line angle (BLA) and extendible conveyor length (ECL) (See Figures 4.2 and B1).

The frontstack and backstack ashing volume for each conveyor position is determined by calculating the x- and y-coordinates for each vertex of the ashing plan area and using a user function to determine the ashing plan area from the coordinates, independent of the orientation of that particular shift position. The ashing volume for each conveyor position in the prototype was determined by simply multiplying the area by a constant height, as the Kendal ash dump needing the most urgent attention was designed as a constant height dump to achieve maximum volume within the stability constraints.

The geometric calculations are done in a calculation area of the spreadsheet, where the standby frontstack, main frontstack and main backstack conveyor and ashing geometry coordinates, lengths, angles and volumes are determined in a calculation area for each position (See Figure B3). These values are then returned to the numerical feedback and Geometric Model output areas. All the shiftable conveyor positions and ashing capacities are then used to produce the final Position-Volume relationship.

4.2.4 Position-Tonnage Relationship

When first attempting to model a real life practical ash dump example, it was attempted to model the actual dump growth over the previous one or two years, to verify that the model was performing acceptably. Initially the traditional Position-Volume and Time-Volume relationship approach was used, with the average ash dump dry density in this approach used in the Ash Production model to convert the ash tonnages produced to volumes, to arrive at the Time-Volume relationship.

It was found during the modeling however, that it was impossible to get the model to return the same main and standby conveyor shifting times as the actual growth performance. It was then realised that the average density for the 30m high frontstack was much greater than for the 12m backstack. The standby system only has a frontstack, while the main system is around 50 percent frontstack and 50 percent backstack, resulting in the average main system density being much lower than the average standby system density. This results in a certain volume of main system being filled more quickly than the equivalent volume in the standby system.

This lead to a very important deviation from the traditional approach in the new modeling system, namely to move away from using volume per position to rather using an equivalent tonnage capacity. A Position-Tonnage(Capacity) and Time-Tonnage(Produced) relationship approach was then used for the Geometric and Ash Production Models, with the Growth Model then rather determining the dump growth by allocating ash tons into each of the respective main and standby system positions to determine the ashing durations.

It was decided to introduce separate input parameters for the standby frontstack average density, main frontstack average density and main backstack average density in the Geometric Model to determine the Position-Tonnage relationship (See Figure B4). This allows the main and standby systems to have different average frontstack heights, with related average densities. Once this critical change was made, the model was easily able to model the actual growth performance.

4.2.5 Geometric Model Visual Feedback

The Geometric Model visual feedback is given by numerical result feedback, by Position-Volume graphs and by two plan drawings of the layout configuration geometry.

The numerical feedback is achieved by placing critical geometric result information like conveyor position distance or angle next to the data input parameters in the Geometric Model input ranges (See Figure B1). This is assisted by plotting the same information on graphs, to show the relationship more clearly.

The conveyor Position(number)-Volume graph and the conveyor Position(number)-Position(angle or length) graph (See Figure B2) are very useful to pick up changes or discrepancies in volumes and position, by being able to simply inspect the shape of the graphs. Unexpected volume or position changes would then prompt closer inspection of the relevant input parameters for that particular conveyor position.

While the numerical feedback is important to check whether particular angles or distances have been achieved in determining the layout configuration, the layout plots are very valuable to check that the dump is in fact heading in the right direction and the two systems are not clashing or diverging (See Figures B5-B9).

4.3 Ash Production Modeling

The Ash Production Model is the simplest of the three models, from both an input variable definition as well as a modeling relationship point of view. The most difficult aspect of this model is in determining realistic information, so far into the future.

An expected ash production is usually determined using the most likely ash production parameters, which would return the most likely growth plan. An upper bound ashmake using the worst case scenarios is then used to determine how much contingency ashing capacity should be provided for. The use of the expected values is best for design and ongoing monitoring evaluation to return the most likely impacts.

4.3.1 Ash Production Model & Parameters

The ash production is determined from meaningful key performance indicators (KPI's) like number of units in commission, availability and load factors, together with station efficiency and coal quality parameters, to determine the tonnage of coal burnt over a period. The coal burnt is then converted into ash tons using the ash percentage. As mentioned in 4.2.4, the use of the traditional Time-Volume relationship was changed to a Time-Tonnage ash production relationship.

The ash production model is thus based on a simple, direct formula and usually does not take much manipulation to complete. The power of this approach is however that the input parameters are not arbitrary, but rather related directly to meaningful power station planning and performance parameters, allowing both a better appreciation and understanding of the estimates, as well as directly updatable parameters when these values are revised from time to time.

4.3.2 Time-Tonnage Relationship

The Time-Tonnage relationship is produced in the form of a cumulative time versus cumulative tonnage relationship. The values are usually determined on an annual basis for initial estimation purposes, as this is usually the scale of the data available from life-of-mine plans. As mentioned before, the forecasting of life-time ash production makes is extremely difficult to get accurate, as it depends on many unknown factors like the growth of the economy.

A more accurate medium term prediction is usually done on a five year plan moving window basis, allowing the constant updating of at least this information and reviewing the impact on the timing of new capital works or extensions for the five year technical plan and annual budgeting requirements. The timing of long term impacts on the life-cycle plan can also be determined within the accuracy of the estimates to check critical aspects like land availability due to mining, to ensure sound conceptual growth planning.

The current year is usually broken down into monthly information, allowing seasonable variation to be modeled. This is important if the short term growth is to be evaluated to predict when the next conveyor shift is due. In order to allow the inclusion of this kind of valuable information, the growth plan model needed to be designed to handle ash production data having a varying time step between values. This allows say monthly and yearly data in the same table.

4.3.3 Ash Production Visual Feedback

The ashmake visual feedback is in the form of numerical results in the spreadsheet input/output area (See Figure B10), much the same as the geometric model, with cumulative

Time-Tonnage graphs to plot the coalburn and ashmake results (See Figure B11).

The scenario function of Excel was found to be very useful to model the expected and upper bound ashmake predictions in the same spreadsheet. Either of the ashmake scenarios can then be used by the dump growth model, by simply changing the scenario reference. This allows easy switching between the two scenarios for sensitivity analysis.

4.4 Dump Growth Modeling

The dump Growth Model is very complex from a modeling relationship point of view, but relatively simple in terms of input variables and their manipulation

4.4.1 Dump Growth Model and Parameters

The model only uses three basic input variables to define the utilization and thus determine the individual conveyor position ashing and shifting information. The main system availability during ashing and the main system and standby system conveyor shift durations are defined per conveyor position, allowing any one of them to be varied as required for evaluating changes in main system availability or increased shift outages due to say breakages or bad weather, or resolving shift clashes.

4.4.2 Time-Position Relationship

The Position-Tonnage and Time-Tonnage outputs of the Geometric Model and Ash Production Model are imported directly into the Dump Growth Model, for use in determining the Time-Position relationships for the main and standby systems.

The determination of the individual main and standby system ashing durations is a fairly difficult task. This requires the main system availability for that conveyor position and the current ashing rate including any changes in the rate, due to load or coal quality variation during this period, to be taken into account.

Once this ashing duration is determined, it is added to the ashing start time, together with the main system shift time, to arrive at the ashing start time for the next position. These times are then used to determine the required Time-Position relationship for the main system. The main system effectively receives the average power station ash production rate times its availability during the ashing period and no ash during its conveyor shift period.

Although the two systems are dependent on one another for shifting and their growth rates are inversely related, the main system is essentially the independent system in terms of utilization, with the standby system being utilized for the remaining period which the main system is not available.

The standby system thus receives the difference between the average station ashmake for that period and the main system's ashmake, again taking into account any ashmake rate changes during this period . This standby system ashmake is then similarly used to determine the ashing duration for the current standby conveyor position and this and the standby system conveyor shift duration then used to determine the standby Time-Position relationship. The standby system effectively receives the average station ashing rate times 100 percent minus the main system's availability percentage during ashing, during its ashing period and 100 percent of the average station ashmake during the main system's conveyor shift period.

This average ashing rate approach works acceptably, as we are only interested in the shift growth performance on a shift basis, assuming an average growth rate between these points, the short term growth rates of the stacking machine within its ashing period in a direction parallel to the shiftable conveyor having no impact on the average growth of the main or standby system as a whole, perpendicular to the shiftable conveyor. This is why the main system frontstack and backstack tonnage capacities are lumped together in the geometric model, to give only the total ashing time for the combined main frontstack and backstack (See Figure B4).

4.4.3 Dump Growth Visual Feedback

The visual feedback for the dump growth is both by numerical result (See Figure B12) and by graphical representation on the dump growth plan (See Figures B13 & B14). The numerical results are valuable to read off the date for any position to be reached directly, or the overall average main system utilization taking into account the impact of the conveyor shift outage on the main system availability during ashing.

This information can also be seen graphically on the growth plan.

The growth plan is the final outcome of not only the dump growth model, but also both the geometric model and ash production models, with their pertinent information being plotted onto the same graph for evaluation purposes.

4.5 The New Dump Growth Plan

The new dump growth plan for the prototype modeling system is not drawn on a coaxial plot, mainly due to the spreadsheet graphing capability not being able to do this. An attempt was made to place a number of individual graphs adjacent to each other, but this was found to be unsuccessful due to the difficulty in maintaining the same axis scales in each graph, which is a basic assumption of a coaxial plot.

This limitation was overcome by using two y-axis scales, the left axis indicating tonnages and the right axis indicating position in terms of both angle and distance, as well as the main system availability parameters. The x-axis was used for time, with both the Time-Tonnage ashmake graphs for the total ashmake as well as for the main and standby systems, to be plotted (See Figures B13 & B14).

The Position-Tonnage information was not plotted directly onto this graph, as this is not important information for interpreting the growth plan. The Time-Position data for the radial slewing shiftable conveyor position angles and extendible conveyor position lengths for parallel shifting is now plotted. These graphs are usually the most important ones being reviewed to check the relative growth rates of the main and standby systems.

The main and standby system shift times are shown by markers on the ash allocation graph for each system. In addition, vertical lines are produced from the main shift start and end points, extending down over the standby system ash allocation curve. This allows shift clashes to more easily be picked up. The shift position numbers are automatically plotted onto the graph next to the conveyor shifting information, for use in referencing the exact conveyor shift position numbers when attempting to evaluate the system or resolve particular shift clashes.

Extensive use of colour and different line styles was needed in order to allow this high density of information on one graph to be interpreted easily. Once a feel for the information portrayed on such a graph is attained however, a black and white version can quite easily be interpreted.

4.6 Testing and Development

The versatility of the prototype geometrical modeling system was tested with various theoretical and existing dump layout configurations, to verify that it could successfully model typical radial and parallel shifting layout configurations of the stacker-spreader type (See Appendix C). This could easily be checked with the immediate visual feedback from the automatic layout configuration plot during geometric model data input, with the detailed dimension and volume results being checked by manual calculation.

The testing examples not only allowed the development of a feel for the best sequence in populating the Geometric Model input data fields, but also allowed further development of various simple mathematical techniques for generating data. The power of using the spreadsheet for generating the input database was soon realised, as unlike a dumb data file or database of entries, the spreadsheet allows not only data, but also formulas to be entered in any input data field.

This allows the simple, yet powerful linking of each successive parameter equal to the previous one by simply copying this formula to all subsequent cells, allowing only the first field to be altered, with automatic changing of the rest. Changes in say shift length from a point, can simply be entered as one value, overwriting the formula in that cell, with all subsequent values now automatically being equal to this new value. This approach allows the rapid generation of the ash dump layout configuration for the geometric model, as well as subsequent what-if or sensitivity analysis, by showing the immediate overall impact of a general design parameter change, like increasing the conveyor length from a point, with only needing to change the first data value.

Another technique was developed for generating smoothly transitioning data, which varied linearly between two known points, by using a simple linear interpolation formula and copying it to all required cells. The inherent relative address copying feature of the spreadsheet makes this task very easy. This was found to be extremely useful for generating the offset dimensions for the main system frontstack inside crest, to achieve alignment of the inside of the main system frontstack crest, with the outside crest of the existing standby system, due to the slew points being different. The outside crest of the standby system being a circular curve, with a constant radius from its slew point and the inside crest of the main system needing to follow the same circular curve, therefore not being a constant distance from the main system's slew point.

The built-in goal-seeking function of Excel was also found to be extremely useful for determining the shift length needed of a fixed number of shifts, to enable a desired shiftable conveyor base line angle or a particular extendible conveyor length to be reached. This eliminates the need for trial and error iteration, immensely speeding up the model generation process.

4.7 Prototype Program Limitations

The prototype had a number of limitations, mainly due to the inefficiency of programming such a powerful modeling system directly within the spreadsheet cells, with minimal use thus far of more efficient Visual Basic macro processing. This caused the main limitation of memory problems, as a typical spreadsheet file was in the order of two megabytes in size when trying to model a practical dump example like Kendal.

This limited the number of shift positions that could be modeled without the computer "hanging", resulting in a few extrapolations of long term growth having to be made in some instances. This was however done fairly easily, simply extending the general growth trends shown on the growth plan.

The memory limitation forced the deviation from the basic input format requirement of keeping all input parameter data in one input area in a database format, with the calculation areas always referring to this information. The additional link references became onerous to the spreadsheet and a number of input variables had to be placed in the calculation area. A few quick-fix modifications also had to be placed only where needed instead of adding them as a general capability, which is highly undesirable as they aren't always noticed when using the spreadsheet for another application, causing much time wastage to get rid of the anomalies.

Not being able to produce the growth plan in the form of a coaxial plot was a limitation as this would certainly be more readable than using one graph. Unfortunately Excel rescales the graph plot area to suit the data, but possibly a co-axial arrangement of graphs could be controlled using Visual Basic, to improve readability of the growth plan.

The much more inefficient calculation of a spreadsheet, as compared to a custom program, caused even the P60 Pentium personal computer to start taking around 15 to 20 seconds to recalculate a new growth plan. This is still light years faster than the original manual methods, however when trying to vary input parameters on an iterative basis to arrive at optimum solutions, it became a bit frustrating to sit and watch the computer crunching through the calculations, sometimes causing the designer to lose concentration and focus.

It was found that the spreadsheet automatic recalculation feature of Excel should be switched off when changing a number of variables as automatic recalculation after each cell entry before completing all the desired changes was not only a waste of time, but would return meaningless unwanted intermediate answers.

CHAPTER 5

RESULTS AND DISCUSSIONS

The final version of the prototype parametric growth plan modeling system turned out to be a very workable and user friendly modeling environment despite being a prototype, which was also very powerful and certainly succeeded in automating the process of evaluating the growth of dry ash dumps. The system was able to be used in a production environment to evaluate a number of different practical dry ash dump growth problems on the Kendal ash dump.

The evaluations done led to an informed decision being able to be made by the power station management to not implement a proposed conveyor modification which they had believed was needed to get the ash dump back to a healthy growth plan, based on "gut-feel". This resulted in a net present value saving of five million rand, not only proving its worth, but paying for itself and saving the company a substantial amount of money with its first implementation.

5.1 Practical Implementation Examples

The practical application of the prototype modeling system to the out of phase growth problem existing on the Kendal ash dump showed that such a tool could not only easily evaluate the growth plan for any one set of design assumptions, but could also allow the designer to perform feasibility, optimisation and sensitivity studies very quickly and cost effectively, allowing optimum solutions to problems to be determined.

A number of different problems were evaluated by Kreuiter(3,4,5) during the various phases of investigating the Kendal ash dump out of phase growth problem, changing the evaluation focus from feasibility, to what-if, to optimisation, to economic and finally to sensitivity analysis situations, each focusing on different input and output areas of the model. This clearly illustrated the immense value of the system to the owners of such a facility, where the system was easily able to provide answers to important questions, previously considered too costly and time consuming to evaluate, with "gut-feel" decisions invariably being made which usually resulted in further unforeseen problems.

The feasibility analysis situation required evaluating if the current layout configuration and a proposed geometric modification to the standby system would have acceptable long term growths, using the average main system availability performance to date.

Two what-if analysis situations arose. The first required evaluating if a geometric modification could be eliminated, if the station were to increase the main system availability to some higher value, in order that the main system would simply catch up with the standby system before the end of the dump was reached. The second required evaluating if a standby conveyor extension could slow down the standby system sufficiently, to achieve the same result as above.

This was done with two different layout configurations at the current main system availability, extending the standby conveyor at its current position and the shift back and extend option. These evaluations could also be viewed as optimisation exercises, as they not only evaluated the impact, but also returned the optimum parameter values.

The economic analysis situation required evaluating which option would be the most economical, for various feasible layout and availability combinations.

Finally, the sensitivity analysis situation required evaluating how the time for the main system to catch up with the standby system could be reduced, as the main system availability was further increased, for the finally accepted option.

The projected power station ashmake for the remaining life of the station was determined from projected power station performance and coal quality factors. This was done once and used for all evaluations, as the ash dump layout configuration and operating availability would not influence the projected ashmake.

5.1.1 Feasibility Analysis Evaluation

These evaluations simply required the Geometric Model of their proposed layout configurations to be determined, using the geometric modeling facility and then the growth plan for each scenario to be produced by entering the average main system availability to date into the Growth Plan Model. The system automatically produced layout configuration and growth plan plots, which could easily be evaluated for feasible growth by simply comparing the positions of the main and standby systems to see if they reached the end of the dump boundary together.

The current layout configuration was found to be not feasible to continue operating without some form of modification to allow it to provide a continuous ashing facility to the power station for the remaining power station life. (See Figures D1 & D2)

The proposed shift-back and extension of the standby conveyor by 300m modification was found to be feasible in the long term, as the main system would catch up with the standby system about half way through the parallel section. (See Figures D3 & D4) This did not however satisfy the station's requirement to catch up before the end of the first radial shifting section of the dump, to limit the exposure to dust blow from the large out of phase open ashing areas. This prompted the what-if analysis, to determine what length of standby system conveyor extension would be required for the main system to catch up with the standby system before this point.

5.1.2 What-if Analysis Evaluation

The what-if analyses were a little more work to evaluate, as they required some iteration to arrive at the optimum answers. This required changing either the availability parameter in the growth model or the standby shiftable conveyor length parameter in the geometric model iteratively, until a value was found which returned an acceptable growth plan.

Changing the availability was a relatively easy task, requiring only a single parameter to be changed, while using exactly the same geometric model from the above current layout configuration feasibility option. This showed that if the main system availability during ashing could be increased from the average to date value of 70 percent to 81 percent, the main system would catch up with the standby system before the end of the dump, allowing the current layout configuration to be continued with, without the need for a layout modification. (See Figures D5 & D6)

Changing the standby conveyor length however required the changing of a number of other geometric parameters like shortening the main system frontstack length, due to the two systems sharing the old main system's frontstack width. The number of standby system shifts to reach the end of the first radial section also had to be changed, together with the remainder of parallel and radial shifts. This was because the same conveyor shift length over the now longer side crest perimeter, due to the longer radius, would now take more shifts to slew radially through the same total angle. Although this was a lot more work than the availability evaluation, it was still nothing compared to trying to iterate by manual evaluation methods, a practically insurmountable task.

The first of the layout configuration modifications was to determine by what length the standby shiftable conveyor would need to be extended at its current position, in order to have an acceptable growth rate at the projected 70 percent main system availability (See Figures D7 & D8). It was found that the conveyor would need to be extended by 310m, in order to reach the end of the dump together.

The second layout configuration modification was the question raised in 5.1.1 above, to determine the standby shiftable conveyor extension needed for the shift-back option, in order that the two systems could catch up as soon as possible (See Figures D9 & D10). This was found to be 460m instead of the station's proposed 300m, or one and a half times the length, showing how far out a "thumb suck" decision can be. Knowing the now longer and therefore higher cost of the modification needed to achieve their objective of getting the two systems back into phase immediately, allowed the station to compare the cost of fixing the out of phase situation immediately, as compared to the option of no modification and catching up by simply improving the main system availability.

Due to now being able to see the impact of the main system availability on the dump growth, and realising the value of simply improving the main system availability from the rather low 70 percent to date average, the station operating personnel set about improving efficiency and implementing control systems to improve the main system availability. This achieved amazing results, pushing the monthly availability up to high in the 90 percent range almost immediately.

Obviously this was a very short record and would most certainly be lower on average over the long term, due to conveyor shifts, breakdown and maintenance outages, but it was felt that the minimum of 81 percent availability during ashing could easily be sustained, providing an ongoing commitment by management was obtained. It was thus decided to use 81 percent as a reasonable increased main system availability for further evaluation, as this would eliminate the need for a modification on the current system and any higher availability would have a similar effect, only allowing the main system to catch up sooner.

5.1.3 Economic Analysis Evaluation

From the technical report by Kreuiter(3) it was possible to determine which layout configuration and availability options were acceptable options. An economic evaluation was then done by Kreuiter(4) as the next phase of the project, in order to determine the most cost effective option.

The five final options chosen for economic comparison were the current layout configuration and 70 percent availability, with a standby system conveyor modification when it reached the end of the dump (See Figures D11 & D12), the option of extending the standby conveyor at its current position from 990m to 1230m (See Figures D13 & D14) and the standby conveyor shift-back and extend by 450m option (See Figures D15 & D16), all at the average to date 70 percent main system availability. The final two options were the current layout configuration at 81 percent availability (See Figures D17 & D18), requiring no conveyor modification and finally a similar shift-back standby conveyor, but with only a 300m conveyor extension due to using a main system availability of 81 percent (See Figures D19 & D20).

The main focus of these evaluations, was to use the dump growth plan to determine the positions of the main and standby systems at various points in time, in order that the timing for the new drainage, pollution control, topsoil stripping and rehabilitation, stream diversion, land purchase, coal sterilization and conveyor modifications could be determined for use in the net present value economic evaluation. (Two examples of such 5-yearly Time-Position sequences from the economic analysis can be seen in Figures E1-E8.)

As economic costing was not part of the prototype system, this still required a substantial amount of work by a number of disciplines to evaluate the necessary works at the different points in time and then to cost them. It was therefore decided to do the economic evaluation on a five yearly basis, grouping all works within that period at the midpoint of each period. This was done due to the relatively short timescale available before a decision needed to be taken by management, due to budgeting constraints.

Obviously it would be more accurate to cost everything at its actual time needed, but the limitation was again due to the need for extensive manual evaluation methods in the economic evaluation and not the fault of the new growth plan, as all this detailed information was now available. Hopefully in the final version of the growth plan modeling system, this costing and economic evaluation capability could also be automated, again with tremendous time savings.

The economic evaluation showed that the option of no conveyor layout configuration modification by having raised the main system availability during ashing to at least 81 percent, was the most economical option and was in fact five million rand more cost effective than the original "thumb-suck" proposal by the station.

The study was also able to show that this would be the most flexible option, allowing the station operating personnel the opportunity to try and sustain an average main system availability of at least 81 percent during ashing. Failing this, it would simply be a combination between the most economic and the second most economic option, but ultimately requiring a smaller modification, in line with the actual availability they were able to achieve. This option was also the best in terms of cash flow, not requiring an expensive modification at the start and also allowed a version of any of the other options to be implemented at any stage in the future, if the situation changed and warranted this.

5.1.4 Sensitivity Analysis Evaluation

The sensitivity analysis was fairly easy to do using the prototype system, as the geometric model for the chosen option already existed and the variation of the time for the main system to catch up with the standby system could simply be evaluated by altering the main system availability during ashing over a range, and reading off the time to catch up from the growth plots (See Figures D21 to D25).

As can be seen on these graphs, the main system actually crosses over the standby system just after it catches up in these cases. This could never happen practically and the main system would need to be slowed down by reducing its utilization. However, in this case only the information up to the time to catch up was of interest and there was no need to resolve the growth plan beyond this point.

This information was then plotted on a graph and a curve plotted through the points to derive a graph of the continuous relationship between main system availability during ashing to the time to catch up (See Figure D26).

The current to date improved main system availability during ashing was determined from station records, being at 92 percent over the first year and was plotted on the graph, to read off the projected time to catch up, if this could be sustained. As the record becomes longer, a more reliable long term main system availability can be determined, allowing the station to reassess the time to catch up again simply from this graph.

5.2 Other Possible Applications

Besides the above problems the system was used for, it can be used to evaluate the effect of changes to many other input variables not varied here. It can be used to check the effect of loss of volume due to incorrect construction levels. It can also be used to evaluate the impact on overall main system availability, due to a longer shift length being used, requiring less frequent shifting, either by using a longer stacking machine, by doing additional bulldozing or by allowing the stacking machine and shiftable conveyor closer to the frontstack edge, by tolerating higher risks in exchange for a higher level of stability monitoring.

The impact of long term major stacking system outages to replace major stacking system working parts, say once every ten years, can be evaluated to check the impact of one very low main system position availability and the time needed to catch up again. The best time to do this maintenance work can thus be determined, moving it away from critical times.

The impact of out of phase growth on the stripping and replacing of topsoil for rehabilitation of the backstack can be evaluated, to determine whether stockpiling will be necessary. This information is vital to update the topsoil management plan, to ensure that valuable topsoil resources are not lost by covering them with ash, causing a problem at the end of the dump life when the main system backstack eventually catches up.

The system will be an invaluable aid for the siting and design of new dry ashing facilities, to be able to not only evaluate a number of possible sites, but in fact to be able to determine the optimum layout configuration on each site before doing economic comparisons. Feedback to the materials handling section can be given as to what the optimum stacking machine configuration would be for a particular site, allowing a more customized stacking machine design, instead of taking off-the-shelf designs and trying to build the most economical dump with such a machine, as was done in the past.

The system can be used as a teaching aid, to allow a designer to develop a feel for the dynamics of dry ash dump growth relationships. The practicality of new design concepts can be evaluated by being able to "build" the dump in a simulation environment. Too frequent conveyor shifting or sensitivity to go out of phase can be evaluated and layout configuration changes made to make the design more practical.

The ash production model, which was not varied at all for the above practical evaluations, could be varied by altering the KPI's of the power station, based on various load growth and life of mine quality plans, to determine the impact on both out of phase growth and too rapid growth, ultimately affecting the capacity.

One of the interesting observations from varying the ashing rate is that this actually impacts the average main system availability. This is not obvious, and was picked up because the new growth plan plots both the main system availability during ashing as well as the overall main system availability including shifting. The average main system availability is reduced with an increase in ashing rate. This is because the conveyor shifting time is the same, while the ashing duration will reduce, making the impact of the same shifting outage a larger percentage. This is important to evaluate, when the station has been running on less than full load for its early life and will grow towards its full capacity with time. Availabilities recorded in the early life could be difficult to sustain when full load is reached, especially with probable higher incidence of breakdowns due to age-related failures, both placing additional pressure on the usually low factor of safeties adopted for main system growth.

A very important use is for routine evaluation of operational variations to design assumptions. The actual values for these variables can be substituted for design assumptions and extrapolated to the end of the station life, to determine their impact and whether additional controlling of that particular parameter is necessary, or whether it can be tolerated in the dump growth.

The number of individual variables that can be focused on to determine the impact on the dump growth is not only large, but when combinations of them are evaluated together, an almost endless number of combinations is possible. At the Matimba ash dump, the overall dump growth was seen to be ahead of the growth plan, but no obvious reason for it could be found, with all variables investigated seemingly close enough to the design assumptions. An investigation revealed that a number of variables were each only a few percent above or below their design assumptions, however each one caused a slight increase in growth rate, combining to make the overall impact significant. Regular monitoring and evaluation would not only assist in identifying the variations, but could also enable the station to determine whether any set of variations was tolerable, if say the one variation was offsetting the other.

5.3 Improvements Required

Although it was initially intended that this prototype would only be developed to assist in identifying the necessary modeling concepts, input variables, output variables and plots, along with their formats, the spreadsheet prototype turned out to be a very powerful tool. It will probably take a while for a final version to be produced, with the prototype still able to provide a very good service in the meantime. It does however have many limitations and especially the geometric modeling capability would need to be modified, if say it was needed to evaluate a two-stacker system like Lethabo, having two backstacks.

The memory limitations would probably make this difficult, but the existing complex four-cycle radial backstack modeling capability could probably be done away with and an average backstack volume used, as the impact would be small due to this being the small end of the triangle. As there are so many areas of uncertainty in future extrapolation over 4 to 5 decades, this level of detail is not warranted for long term growth evaluations and the average volumes would result in the same overall average growth rates in the long term. Most of the dumps are in any case now moving to a more efficient two-cycle ashing procedure, simplifying the backstack geometry.

This level of detail is probably only warranted for the current shift positions to allow the estimated shifting time to be determined more accurately. This would then however also need a much higher level of both short term ashing rates to be entered as well as main system actual availability. Reducing the level of complexity in the modeling relationships where not warranted, could possibly allow more shifts to be modeled without running into memory problems.

A valuable improvement would be the ability to key in the number of main and standby shift positions and have a Visual Basic macro set up the calculation areas and links to the output layout plots. Possibly this entire area of geometric modeling processing to determine the plotting coordinates and position ashing volumes could be written as a Visual Basic macro, not only allowing the above, but probably speeding up the calculations by using arrays instead of the spreadsheet cell calculations.

A Visual Basic macro utility could be written to automatically write the dump geometric modeling output coordinates to an ASCII file in the correct format for easy importing into the Microstation CAD system. This is still a very useful activity, allowing layout drawings to be compiled.

If a capability to generate the dump top surface levels using a forward slope and the shift distance was added, then a three dimensional surface could be exported to the CAD system, allowing contours, cross sections and slope analysis of the dump model to be evaluated using the powerful tools developed for earthworks modeling. The benefit would not only be speed, but accuracy due to not having to redo the dump model in the CAD environment in order to produce the necessary layout construction drawings.

A digital terrain modeling approach could be developed for the ground surface using a grid of points exported from the earthworks modeling package. This would allow easy interpolation of the ground levels below any point. If say three points were to be used along the frontstack crest, the actual frontstack heights could automatically be determined, allowing a non-constant height frontstack to be modeled. The importing of contour lines and boundaries in ASCII format could allow these to be plotted on the layout configuration plot to facilitate positioning of the dump during siting exercises.

A capability to automatically produce time-position layouts (See Figures E1-E8) would be extremely valuable. Again, this could probably be written as a Visual Basic macro to draw the position of the standby and main systems onto the geometric modeling layout plot, for any time requested. All the necessary information for this already exists in the model, having been extracted manually from the growth plans for the economic evaluations.

An animation facility could possibly be developed using Visual Basic, to allow a time step to be entered, whereupon the system would use the Time-Position information of the main and standby systems for these points in the dump life and display them in a sequential animation, by drawing and then erasing the conveyor and frontstack crest lines at positions corresponding to the time steps. This would allow a better visualisation and understanding of the dump growth to be attained, for the designers, ash dump operators and management.

A net present value costing model could be developed in the system, allowing the cost of conveyor shifting, extending and stacker and spreader utilization to be evaluated for various layout configurations. A capability to allow additional bulldozing of ash beyond the stacking machine's reach to increase the position ashing capacity and reduce shifting frequency, could then also be built into the costing model, as this would always be an economical offset of spending more money on bulldozing to effect savings in conveyor shifting, with the optimum configurations to be determined.

The dumps were all originally designed with the concept of the new frontstack advancing crest to be constructed parallel to the current shiftable conveyor position. This is because the ash stacking machines basically operate in this way by traveling parallel to the shiftable conveyor and placing the final frontstack crest to their maximum reach, parallel to the existing shiftable conveyor.

In radial shifting however, it was found more recently by feedback from site mobile plant operating costs, that it is actually cheaper to build the new frontstack crest parallel to the next conveyor position. This method saves on dozing, while still providing the minimum safe edge distance between the new conveyor position and the new crest, although requiring more survey control to ensure the minimum safe edge distance is maintained. An option to toggle between these types of dump construction should be developed, to allow flexibility to model both and allow economic comparisons.

An actual date scale could be plotted on the new growth plan on the second x-axis to allow not only the time from the start for any event to be read off the first x-axis, but the actual year as well. This would simply require plotting at least one of the graphs with this x-range, on the second x-axis.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

In this dissertation the development of a prototype parametric modeling computer program, for automating the evaluation of growth plans for power station dry ash dumps constructed using main and standby stacking systems, was presented. The prototype was developed using a Microsoft Excel spreadsheet with Visual Basic user functions, on an IBM compatible P60 microprocessor personal computer.

The prototype was developed to facilitate the identification of the necessary modeling concepts, input variables, relationships, outputs and their formats, together with the desired user requirements and operating environments, to enable them to be more easily and thoroughly determined. This was seen as a first and necessary step to prepare the way for a more powerful and user friendly final version of such a system to be developed, based on the lessons learnt from this project.

6.1 Conclusions

The prototype computer modeling system developed on the spreadsheet platform to automate dry ash dump growth plan evaluation, showed that the previous manual and graphical based evaluation techniques could not only successfully be computerised, but improved upon, resulting in a relatively fast, powerful and workable design and evaluation tool. It also showed that the parametric modeling concept, with automatic visual feedback in the form of numerical and graphical outputs next to the input parameters, created a very flexible and intuitive environment in which the designer can operate, allowing a very rapid process of homing-in to the desired solution.

The deviation from using the traditional Position-Volume and Time-Volume modeling relationships to derive the Time-Position growth relationship using the common volume parameter, to the new approach of using the Position-Tonnage(Capacity) and Time-Tonnage(Produced) relationships to derive the Time-Position growth relationship using the common tonnage parameter, proved to be a major improvement on the original method. This allowed the more detailed modeling of the dump growth per shift to be achieved, resulting in good correlation with actual growth main and standby conveyor shifting times.

Practical implementation of the prototype to evaluate real problems on a dry ash dump, showed that such a tool could not only easily evaluate the growth plan for any one set of design assumptions, but could also allow the designer to perform feasibility, what-if, optimisation and sensitivity studies very quickly and cost effectively, allowing optimum solutions to problems to be determined and ongoing evaluation of construction variations to timeously and cost effectively be achieved.

6.2 Recommendations for Future Work

Following this study, the next phase of producing a final version of the dry ash dump growth plan evaluation computer modeling system should be undertaken. The prototype should be used as a basis to not only identify the necessary input data, modeling, output, formats and operating requirements, but the limitations and additional features identified during the process should be addressed and incorporated into the final system.

The development platform for the final system should be carefully chosen, to allow good integration with the growth plan and construction drawing output requirements. The option of an add-on package to the Microstation CAD package would probably give the best integration with existing drawings and plotting, plus allow all the DTM evaluation capabilities of the earthworks package to be harnessed.

In the interim period until such a final version of the system can be produced, the prototype should be improved slightly by eliminating all the short cut development fixes which were made due to time and memory limitations during the practical implementation phase to make it more user friendly. The prototype system can then be used to address other practical problems in the meantime, until a final version can be produced. Depending on the time required to produce the final version, it may be worth while adding some of the new features identified to the prototype, which would not only improve the capability of the prototype, but allow further identification of user requirements, modeling techniques and practical problems to assist with development of the final version.

APPENDIX A AS-BUILT ASH DUMP SURVEYS

(Showing as-built layout and dump growth.)

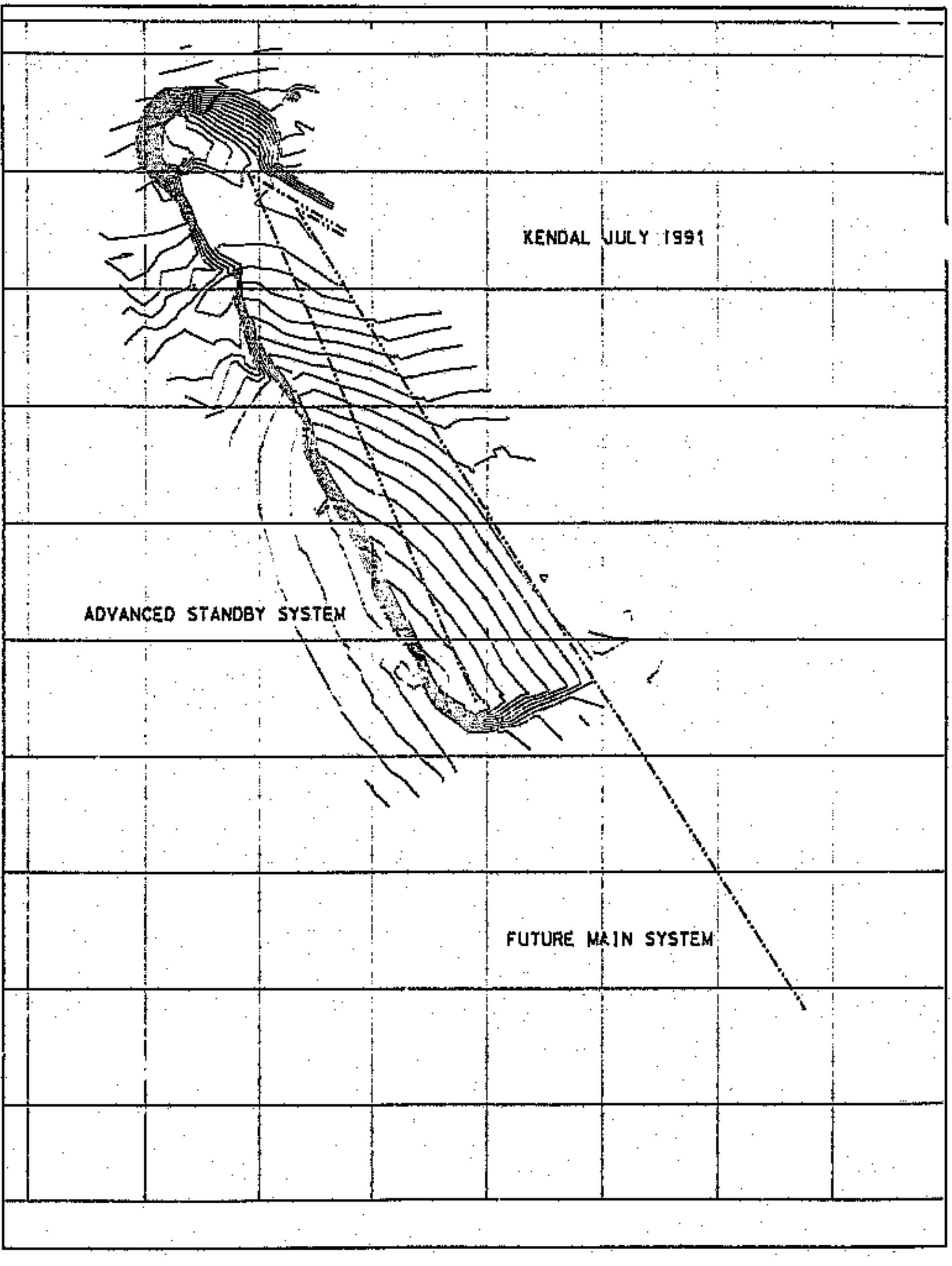


Figure A1 - Kendal Ash Dump - As-Built Survey July 1991.

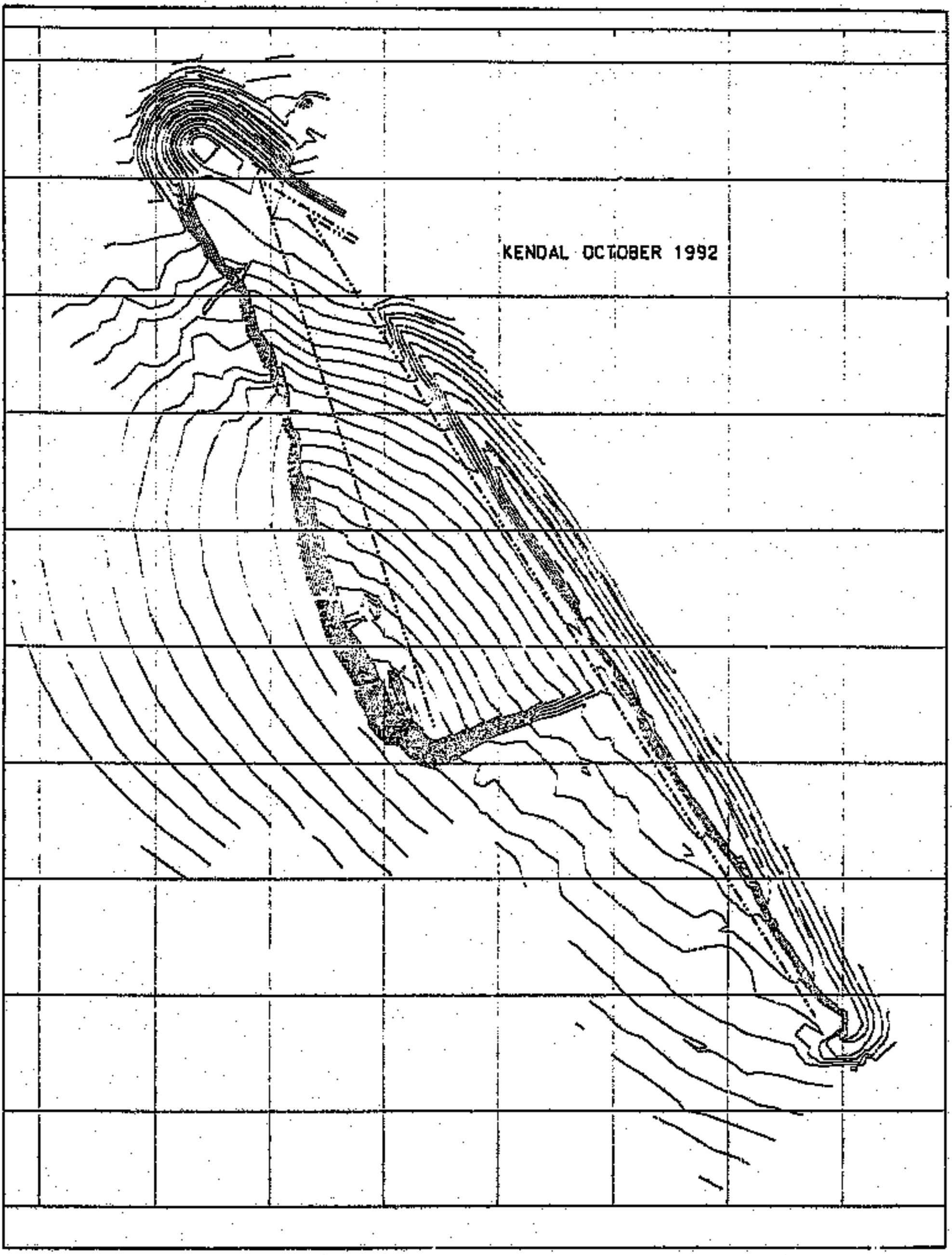


Figure A2 - Kendal Ash Dump - As-Built Survey October 1992.

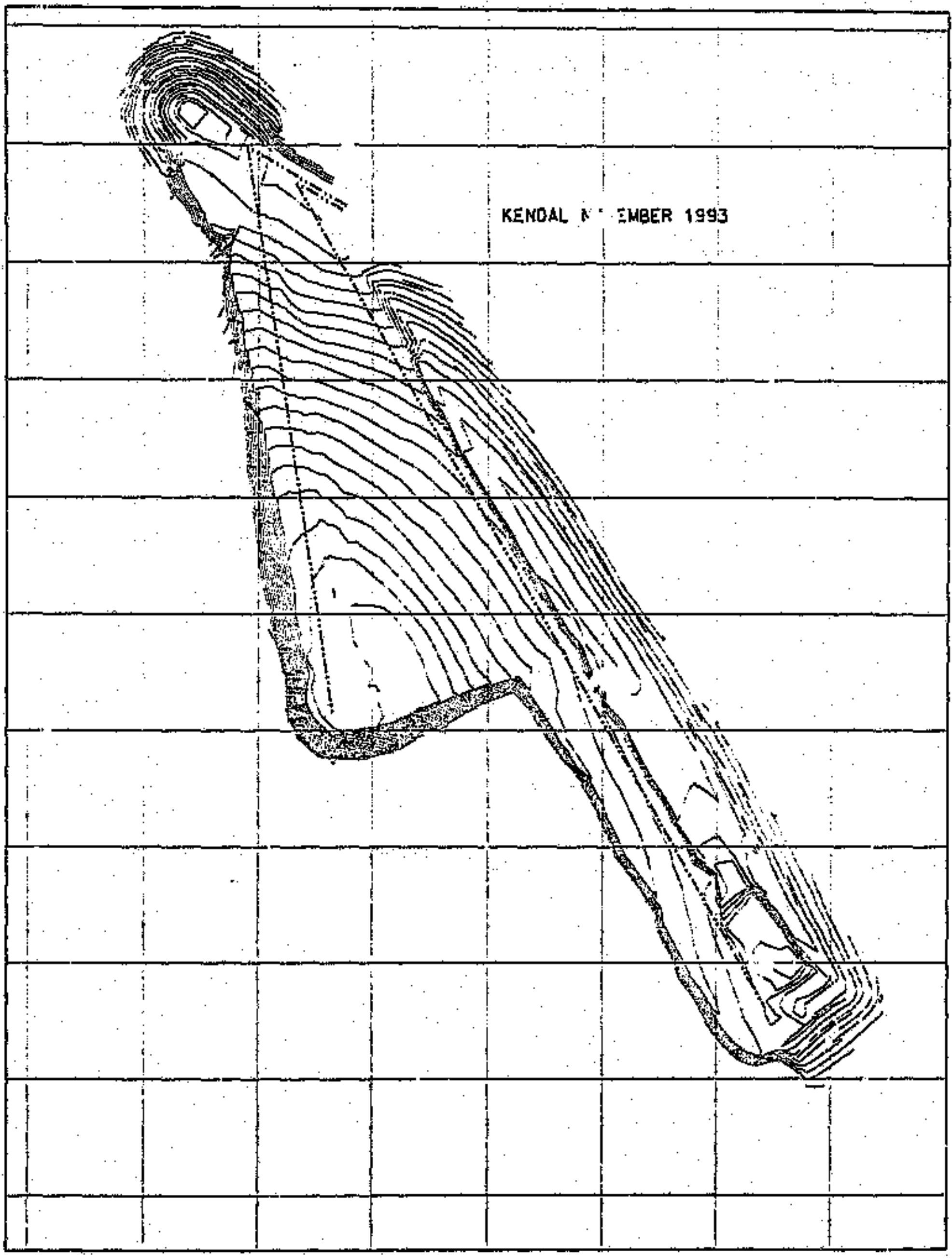


Figure A3 Kendal Ash Dump - As-Built Survey November 1993.

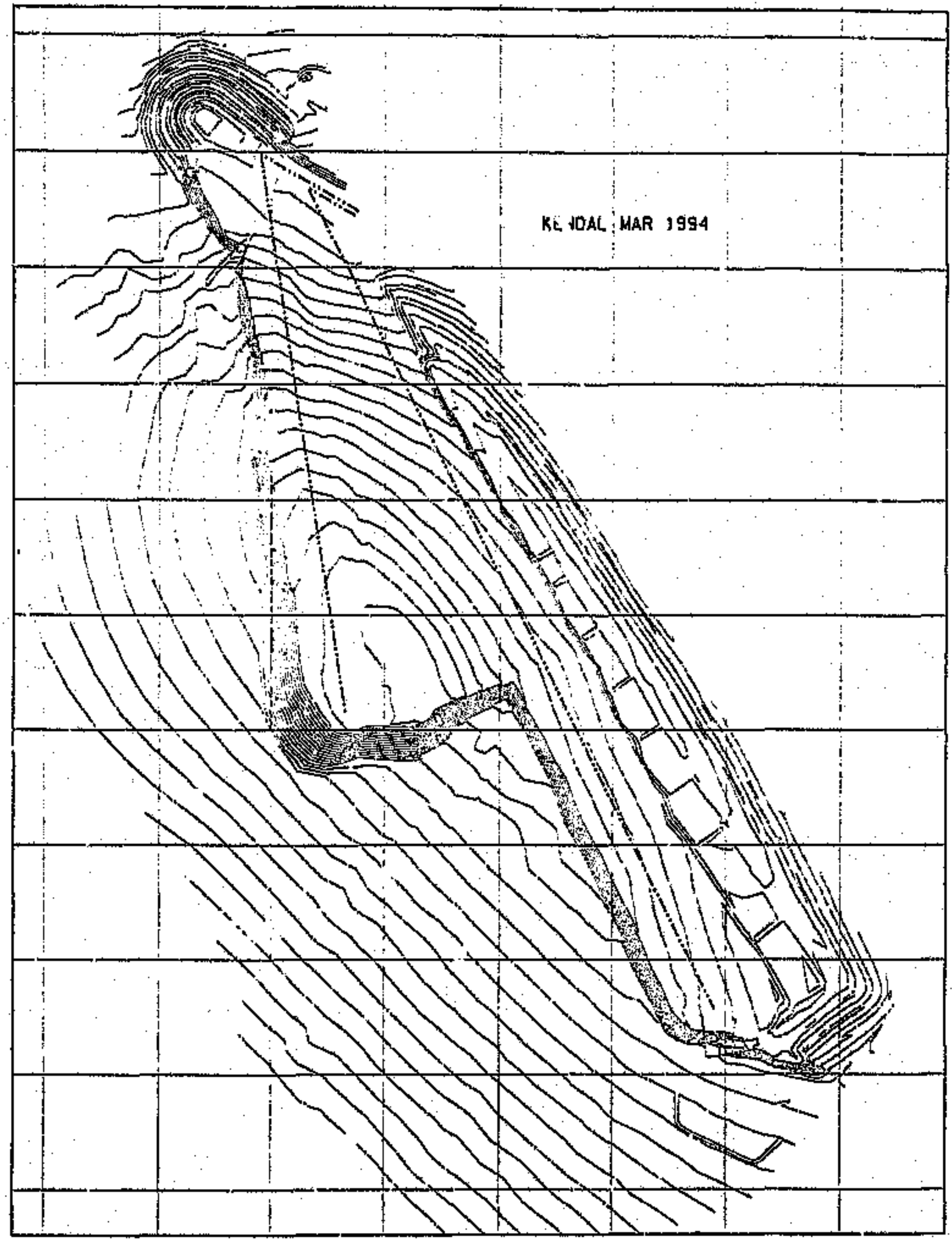


Figure A4 - Kendal Ash Dump - As-Built Survey March 1994.

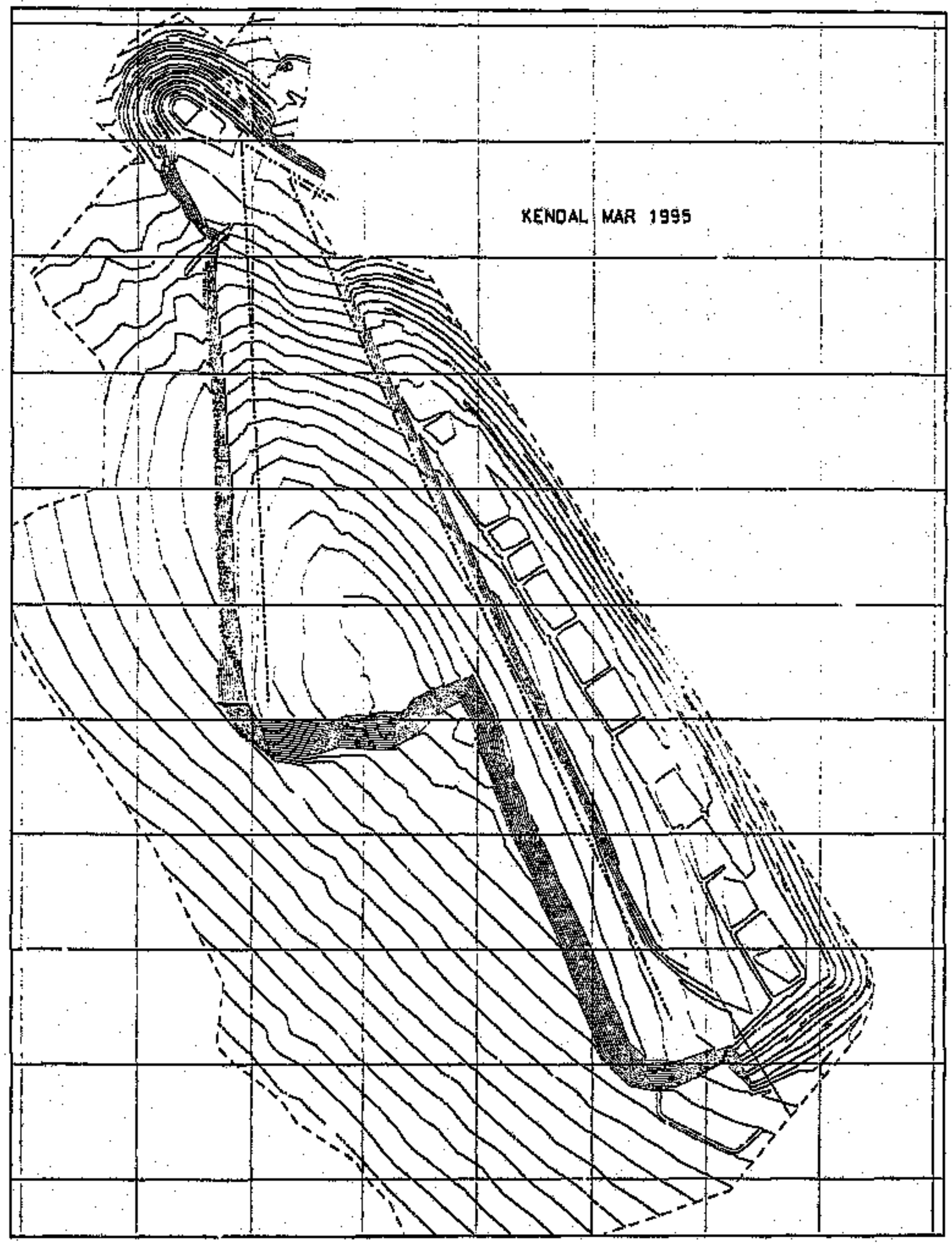


Figure A5 - Kendal Ash Dump - As-Built Survey March 1995.

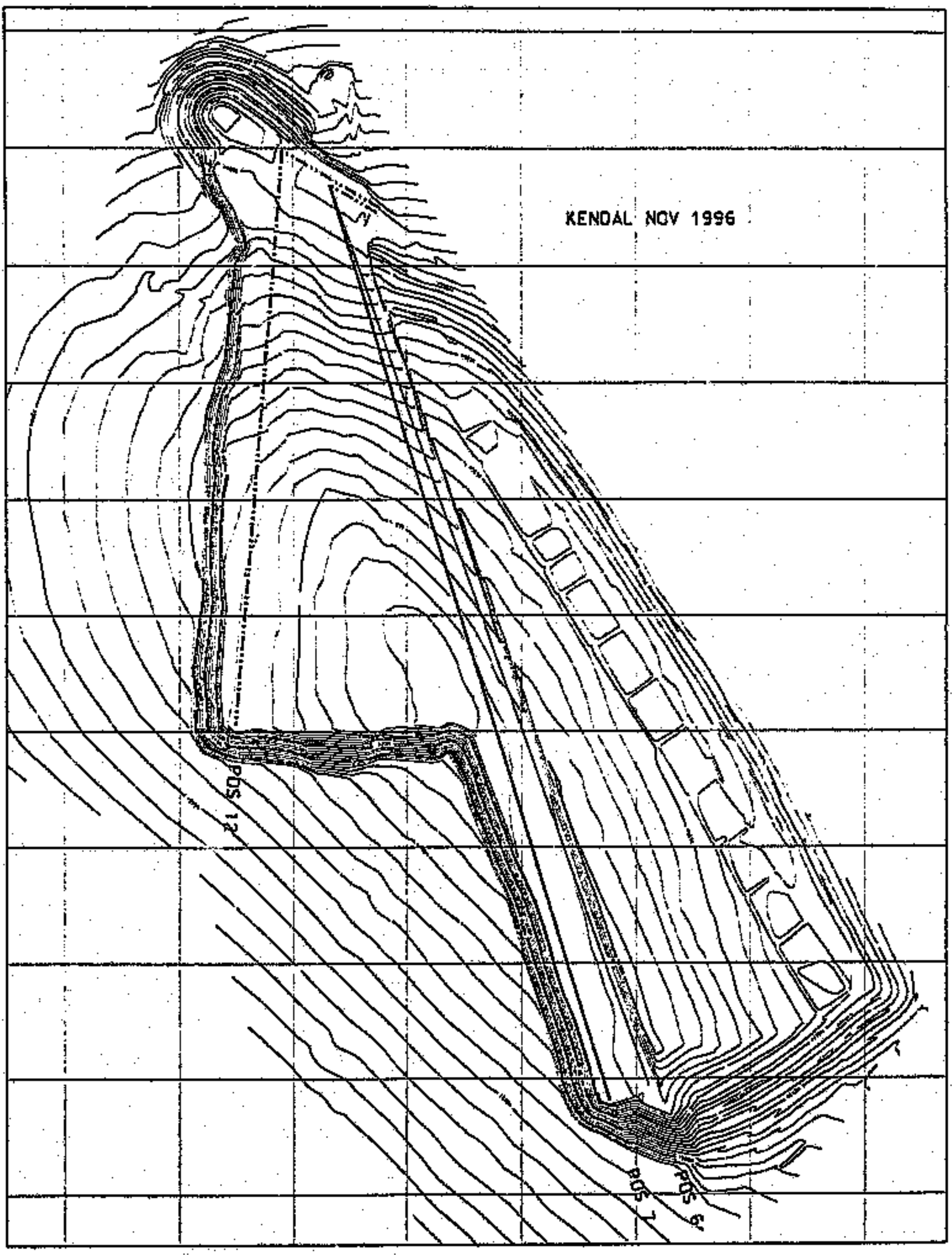


Figure A6 - Kendal Ash Dump - As-Built Survey November 1996.

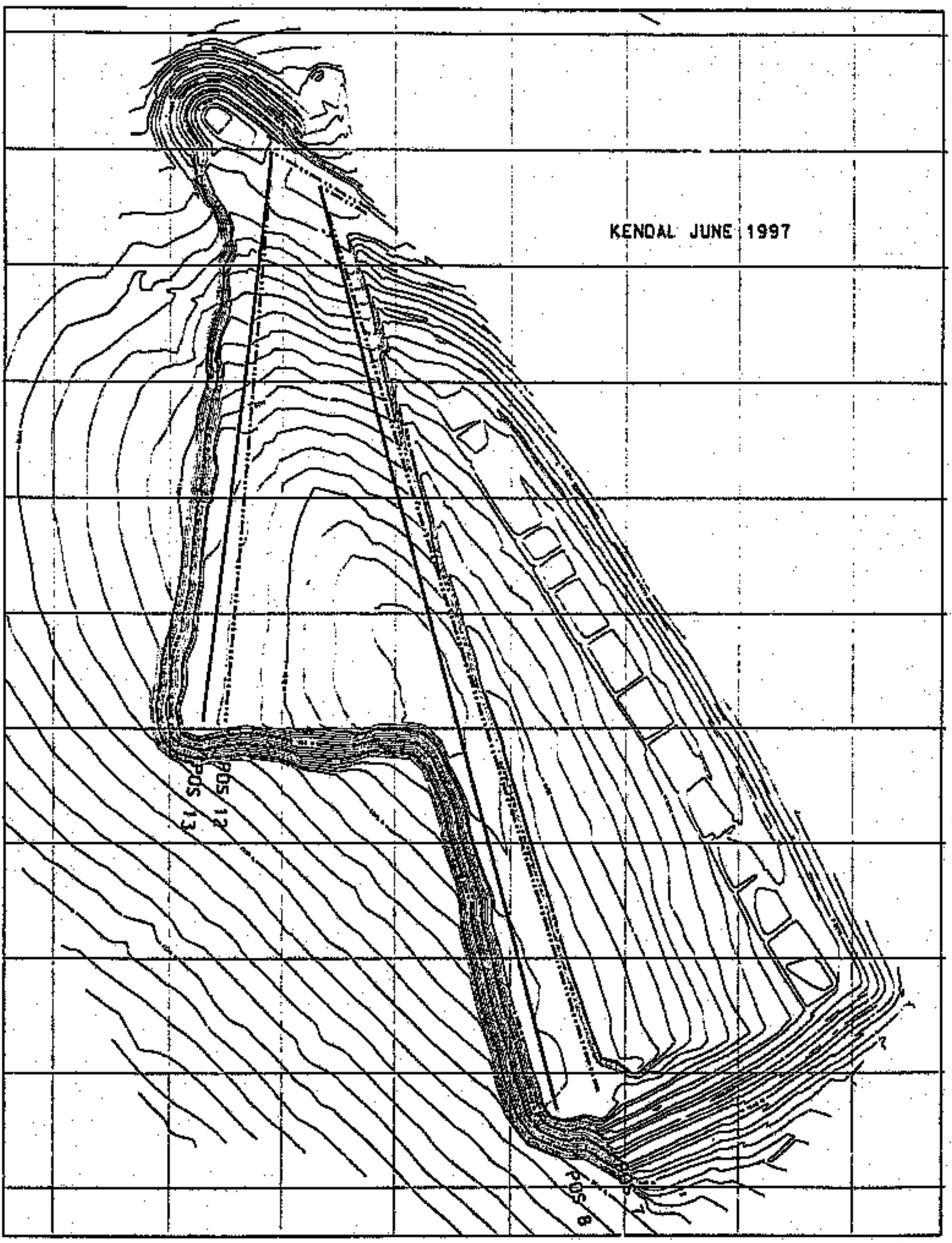


Figure A7 - Kendal Ash Dump - As-Built Survey June 1997.

APPENDIX B SPREADSHEET DESCRIPTION PRINTOUTS

The figures in this appendix are given to show the format and data types of the various input, calculation and output areas of the prototype spreadsheet modeling system. Although some of the figures are actually in the form of tables, they have been classified as figures in this appendix as the exact data portrayed in these examples is not important here.

Due to the high density of information needed to plot a dump geometric configuration layout plot or the new growth plan information for both the main and standby systems, both on a per-shift basis, plotting in colour was necessary in order to be able to interpret the mass of overlaid lines. In order to plot in colour on an A4 sheet within the required margins, some of the areas had to be reduced resulting in quite small print at times. It was felt that this is acceptable here as the figures are intended to give an overview of the various areas, with the actual values not being as important for this purpose.

File: DAD_GP2.XLS Sheet: GeoMod

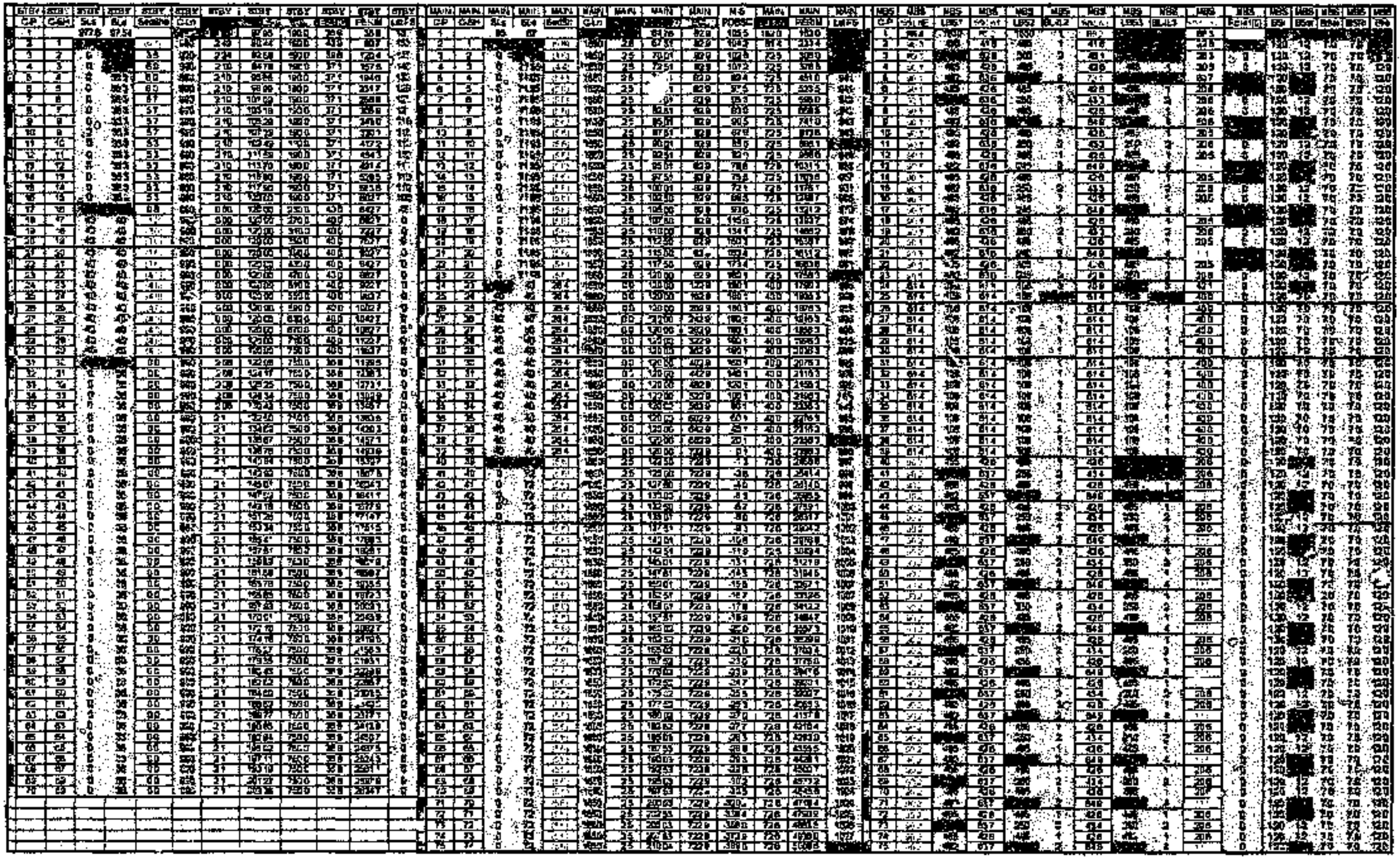


Figure B1 - Geometric Model - Standby & Main Frontstack & Main Backstack - Input & Feedback Areas.

File: DAD_GP2.XLS Sheet: GeoMod

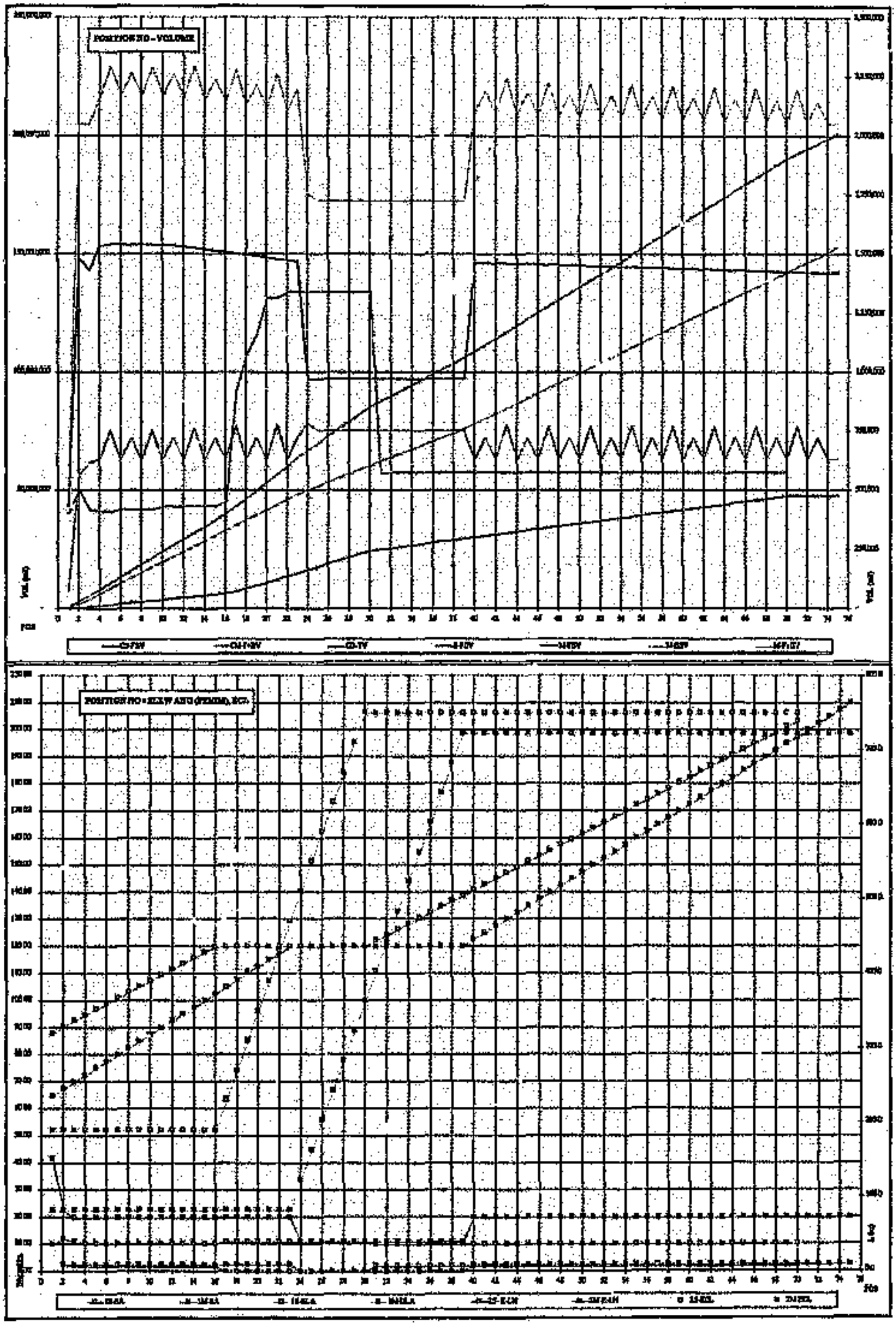


Figure B2 - Geometric Model - Position Number-Volume & -
Angle/Distance Graphs.

File: DAD_GP2.XLS Sheet: GeoMod

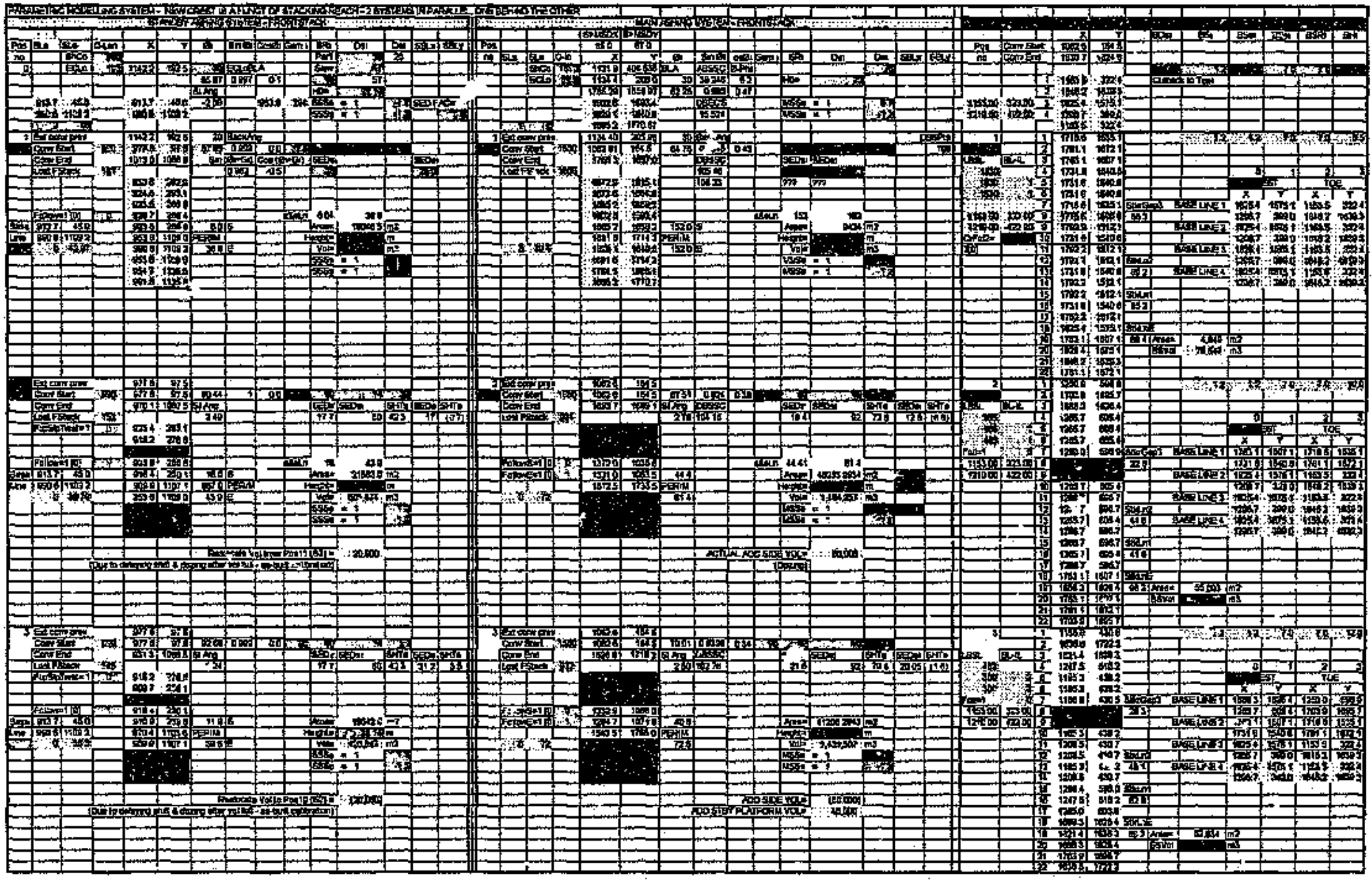


Figure B3 - Geometric Model - Standby & Main Frontstack & Main Backstack - Calculation Areas.

File: DAL_GP2.XLS Sheet: GeoMod

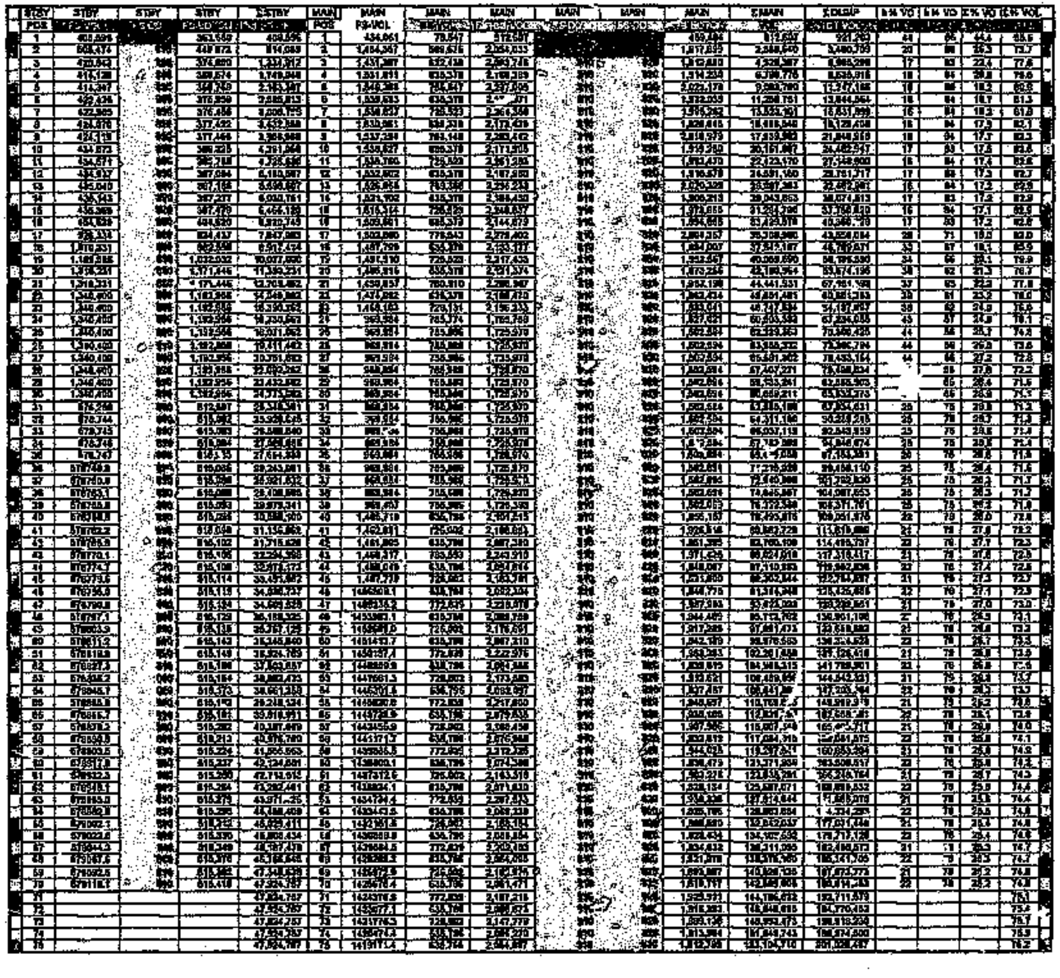


Figure B4 - Geometric Model - Density Input & Position-Volume/Tonnage Output Area.

File: DAD_GP2.XLS Sheet: GeoMod

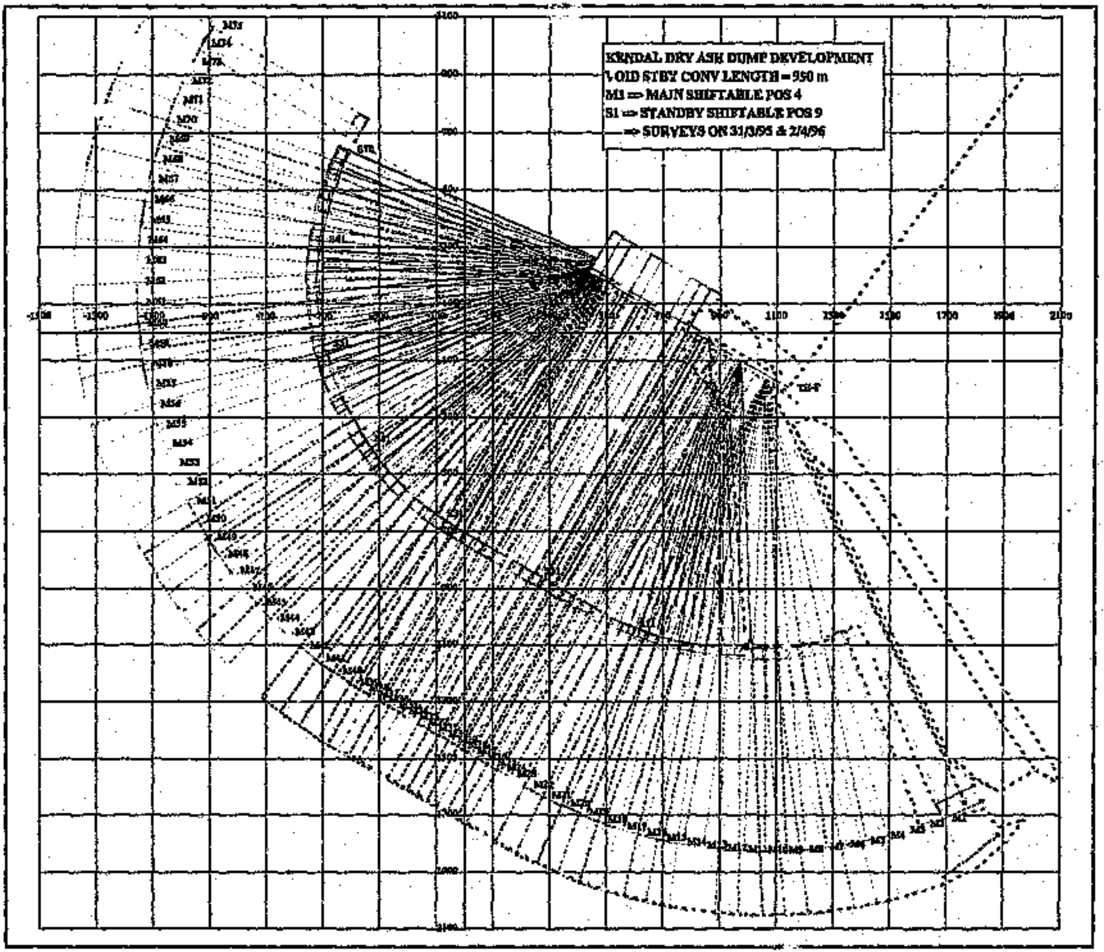


Figure B5 - Geometric Model - Main & Standby Conveyor & Frontstack - Layout Configuration Plot.

File: DAD_GP2E.XLS Sheet: GeoMod

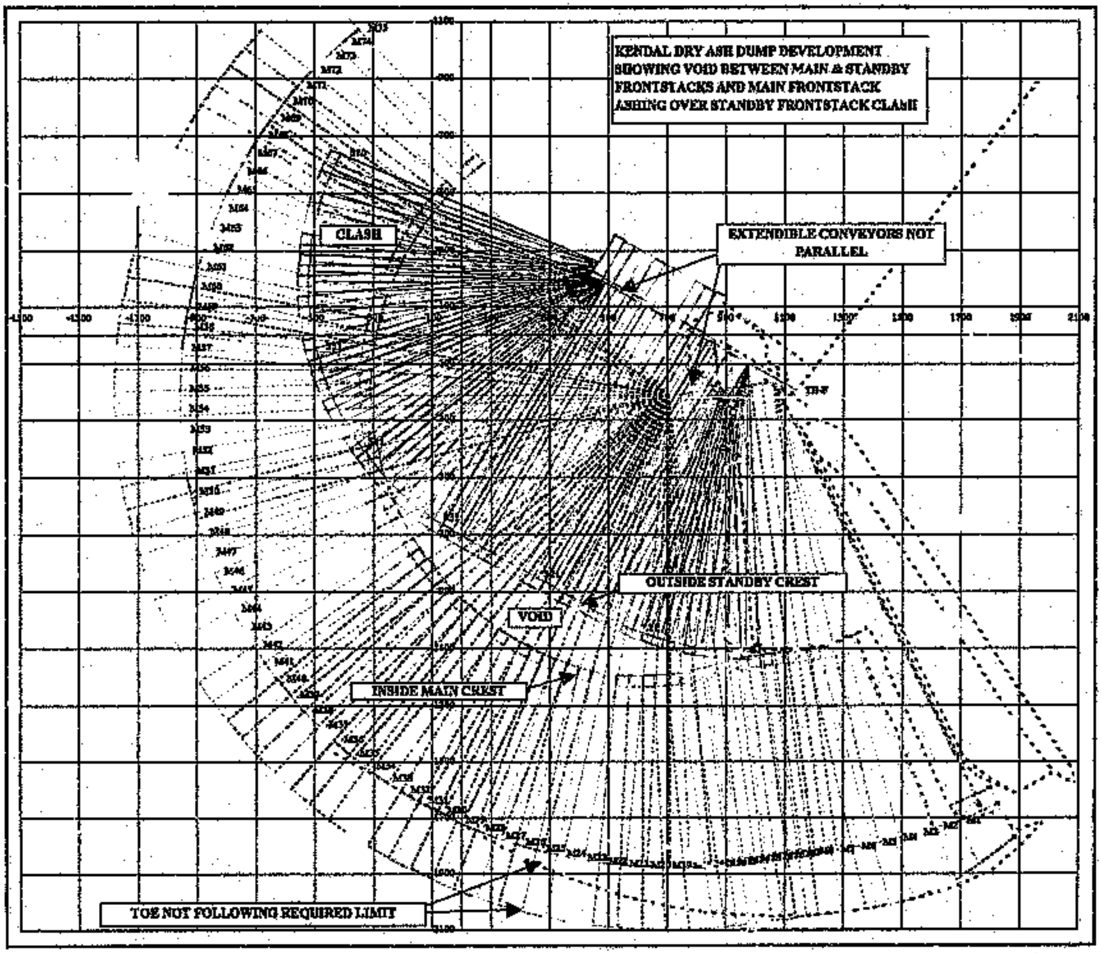


Figure B6 - Geometric Model - Layout Configuration Plot Showing Frontstack Void & Clash Situations.

File: DAD_GP2.XLS Sheet: GeoMod

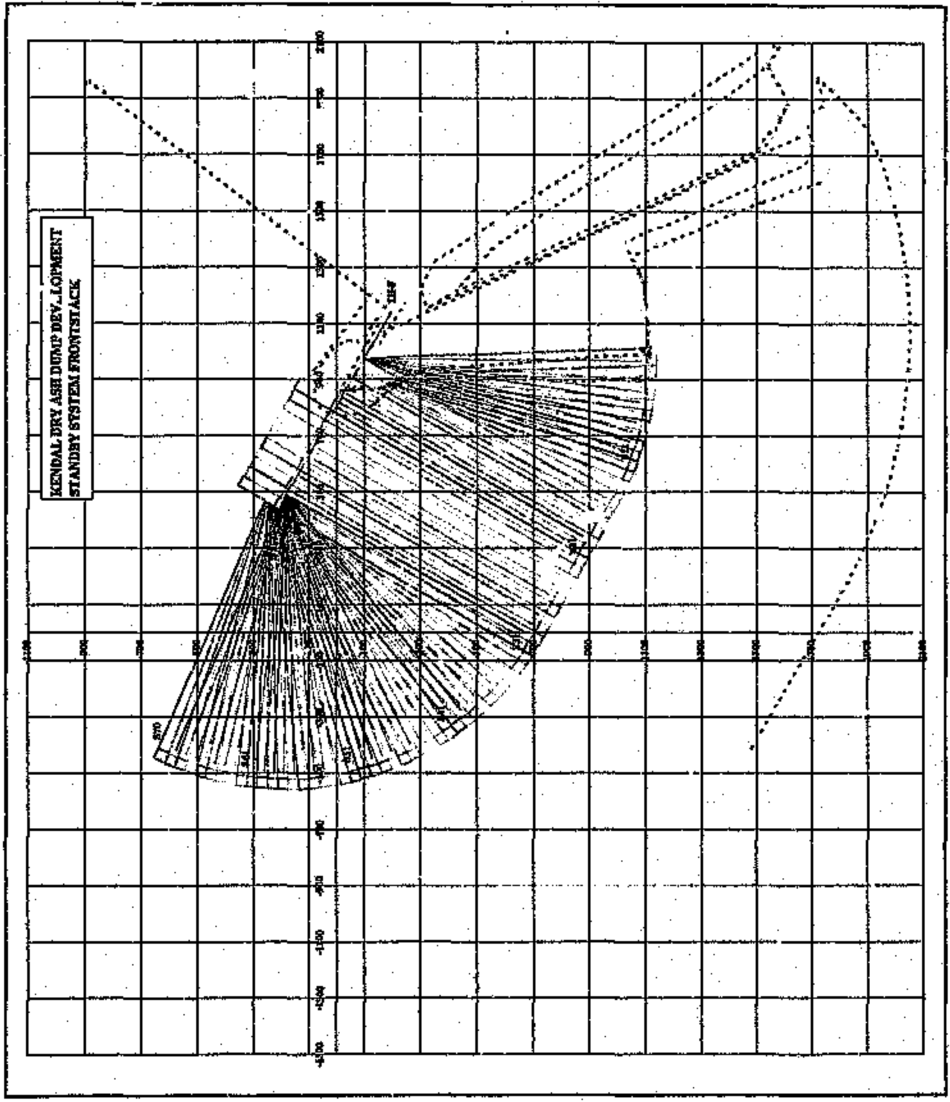


Figure B7 - Geometric Model - Standby Conveyor & Frontstack - Layout Configuration Plot.

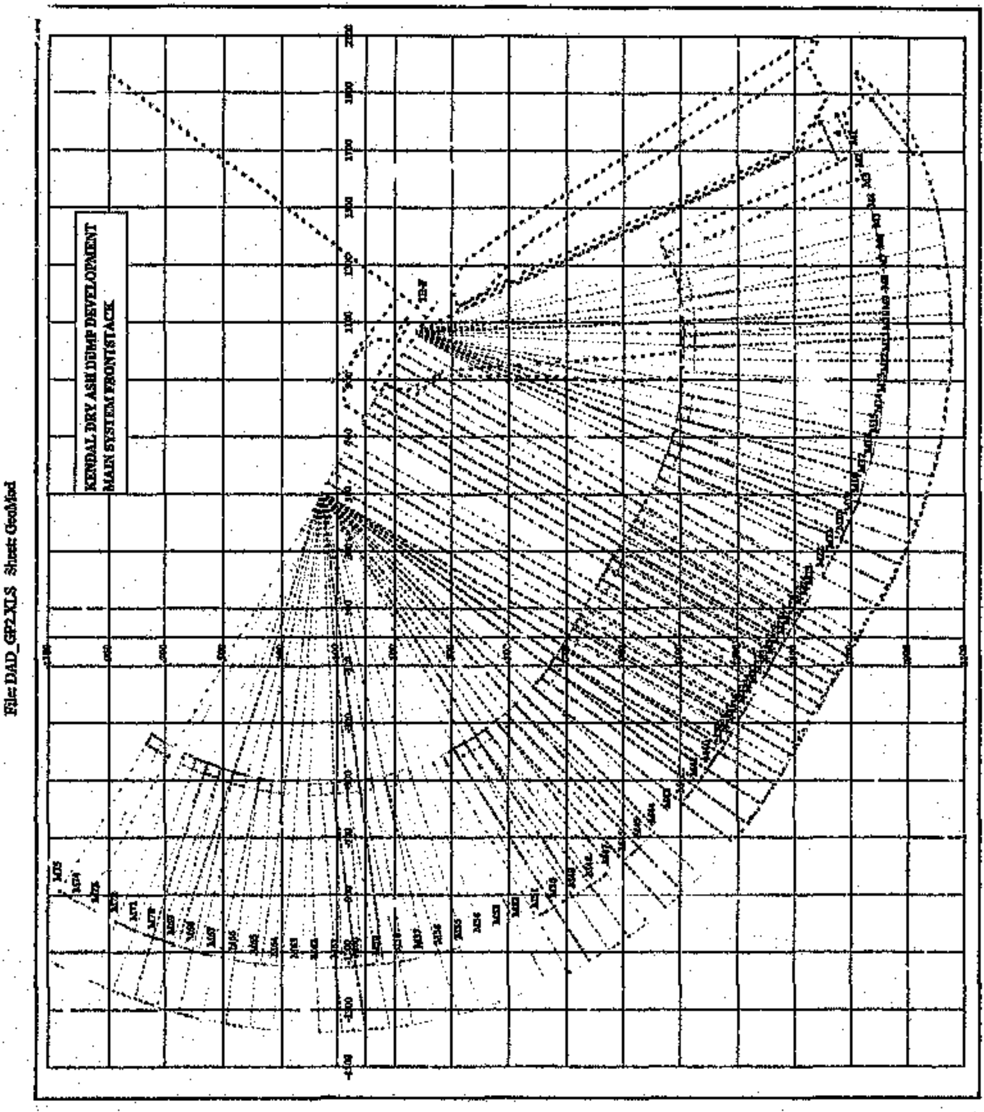


Figure B8 - Geometric Model - Main Conveyor & Frontstack - Layout Configuration Plot.

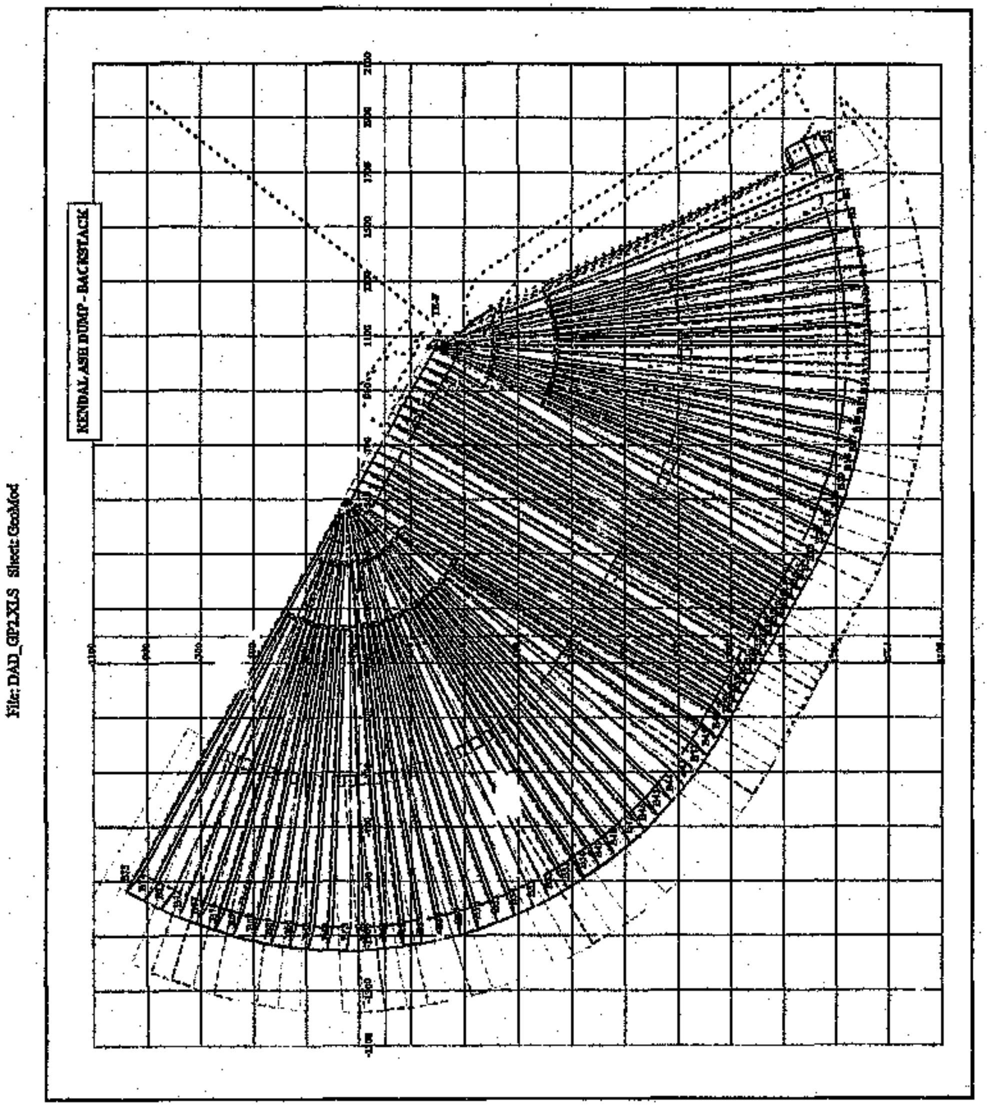


Figure B9 - Geometric Model - Main System Frontstack & Backstack - Layout Configuration Plot.

File: DAD_GP2 XLS Sheet: AshPrzMod

ASH PRODUCTION MODEL SPREADSHEET												EXPECTED
Years From St	Year	NO UNITS	NET UNIT ESO MW	UCF %	EUF %	GWh Required Sent Out GWh/y	C.V. (AD) MJ/kg	Overall efficiency	Coal Tons A.D. tons	Ash (AD) %	Ash dry tons	Ash dry tons (Cum)
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	21132	19.8	[illegible]	11,217,894	29.5	3,309,220	3,309,220
2	1997	6	640	90.0	[illegible]	23009	19.5	[illegible]	12,241,385	30.1	3,684,651	6,993,871
3	1998	6	640	90.0	[illegible]	23614	19.3	[illegible]	12,657,222	30.2	3,822,481	10,816,352
4	1999	6	640	90.0	[illegible]	24825	19.0	34.6	13,526,127	30.6	4,138,995	14,955,346
5	2000	6	640	90.0	[illegible]	24522	18.9	34.8	13,441,531	30.8	4,139,992	19,095,338
6	2001	6	640	90.0	[illegible]	25733	18.3	34.7	14,190,548	30.5	4,328,685	23,424,023
7	2002	6	640	90	85.0	25733	19.0	34.7	14,051,290	30.8	4,325,409	27,749,431
8	2003	6	640	90.0	85.0	25733	19.0	34.7	14,061,420	32.2	4,524,684	32,274,115
9	2004	6	640	90.0	85.0	25733	19.2	34.7	13,924,987	33.4	4,649,135	36,923,251
10	2005	6	640	90.0	85.0	25733	19.3	34.6	13,862,839	34.2	4,744,418	41,667,669
11	2006	6	640	90.0	85.0	25733	18.5	34.8	14,472,763	33.2	4,805,102	46,472,770
12	2007	6	640	90.0	85.0	25733	18.3	34.6	14,841,514	34.8	5,092,611	51,565,382
13	2008	6	640	90.0	85.0	25733	18.0	34.6	14,896,310	34.5	5,181,235	56,746,617
14	2009	6	640	90.0	85.0	25733	18.7	[illegible]	14,359,475	34.4	4,941,095	61,687,712
15	2010	6	640	90.0	85.0	25733	18.5	34.5	14,694,640	33.7	4,947,097	66,634,809
16	2011	6	640	90.0	85.0	25733	18.1	34.4	14,878,606	34.4	5,119,728	71,754,538
17	2012	6	640	90.0	85.0	25733	17.8	34.4	15,411,190	34.3	5,288,637	77,043,175
18	2013	6	640	90.0	85.0	25733	18.0	34.3	15,004,884	33.4	5,009,681	82,052,856
19	2014	6	640	90.0	85.0	25733	18.4	34.3	14,700,120	32.9	4,839,573	86,892,429
20	2015	6	640	90.0	85.0	25733	19.1	34.2	14,182,076	32.9	4,669,023	91,561,452
21	2016	6	640	90.0	85.0	25733	18.0	34.2	15,070,791	33.5	5,045,701	96,607,153
22	2017	6	640	90.0	85.0	25733	18.2	34.1	14,927,035	34.2	5,108,628	101,715,781
23	2018	6	640	90.0	85.0	25733	18.2	34.1	14,948,953	31.1	4,643,444	106,359,224
24	2019	6	640	90.0	85.0	25733	18.6	34.0	14,493,140	31.5	4,569,252	110,928,477
25	2020	6	640	90.0	85.0	25733	18.4	34.0	14,830,018	33.2	4,923,714	115,852,191
26	2021	6	640	90.0	85.0	25733	19.3	33.9	14,159,316	31.2	4,424,503	120,276,694
27	2022	6	640	90.0	85.0	25733	19.2	33.9	14,254,086	32.4	4,613,192	124,889,886
28	2023	6	640	90.0	85.0	25733	19.3	33.8	14,201,207	32.3	4,582,872	129,472,758
29	2024	6	640	90.0	85.0	25733	18.9	33.8	14,523,246	33.4	4,846,876	134,321,634
30	2025	6	640	90.0	85.0	25733	18.5	33.7	14,822,159	32.4	4,732,316	139,053,949
31	2026	6	640	90.0	85.0	25733	18.6	33.7	14,801,947	33.9	5,024,317	144,078,267
32	2027	6	640	90.0	85.0	25733	19.1	33.6	14,495,327	32.9	4,752,898	148,850,885
33	2028	6	640	90.0	85.0	25733	18.2	33.6	15,171,739	32.1	4,867,852	153,698,517
34	2029	6	640	90.0	85.0	25733	18.5	33.5	14,947,986	32.8	4,907,275	158,605,792
35	2030	6	640	90.0	85.0	25733	18.8	33.5	14,731,443	28.9	4,260,775	162,866,568
36	2031	6	640	90.0	85.0	25733	19.0	33.4	14,598,198	30.7	4,480,186	167,346,754
37	2032	6	640	90.0	85.0	25733	18.8	33.4	14,775,615	29.4	4,342,258	171,689,012
38	2033	6	640	90.0	85.0	25733	19.6	33.3	14,642,035	28.1	4,112,362	175,801,374
39	2034	6	640	90.0	85.0	25733	19.7	33.3	14,142,995	28.9	4,090,578	179,891,952
40	2035	6	640	90.0	85.0	25733	19.7	33.2	14,164,265	28.4	4,017,702	183,909,654
41	2036	6	640	90.0	85.0	25733	19.3	33.2	14,479,682	28.9	4,134,088	188,043,743
42	2037	6	640	90.0	85.0	25733	18.6	33.1	15,047,291	30.2	4,548,044	192,591,787
43	2038	6	640	90.0	85.0	25733	18.0	33.1	15,572,391	28.1	4,373,662	196,965,448
44	2039	6	640	90.0	85.0	25733	19.3	33.0	14,545,478	27.9	4,058,189	201,023,637
45	2040	6	640	90.0	85.0	25733	20.4	33.0	13,782,046	27.4	3,781,104	204,804,741
46	2041	6	640	90.0	85.0	25733	18.2	32.9	15,471,484	31.6	4,892,083	209,696,824
47	2042	6	640	90.0	85.0	25733	18.2	32.9	15,495,033	31.6	4,899,529	214,596,354
						1,197,904	18.9		677,230,854	31.7	214,596,354	
	Coal tonnage required= (3600*energy sent-out) / (C.V.*thermal efficiency)*100											

Figure B10 - Ash Production Model - Input & Output Areas.

File: DAD_GP2.XLS Sheet: AshProMod

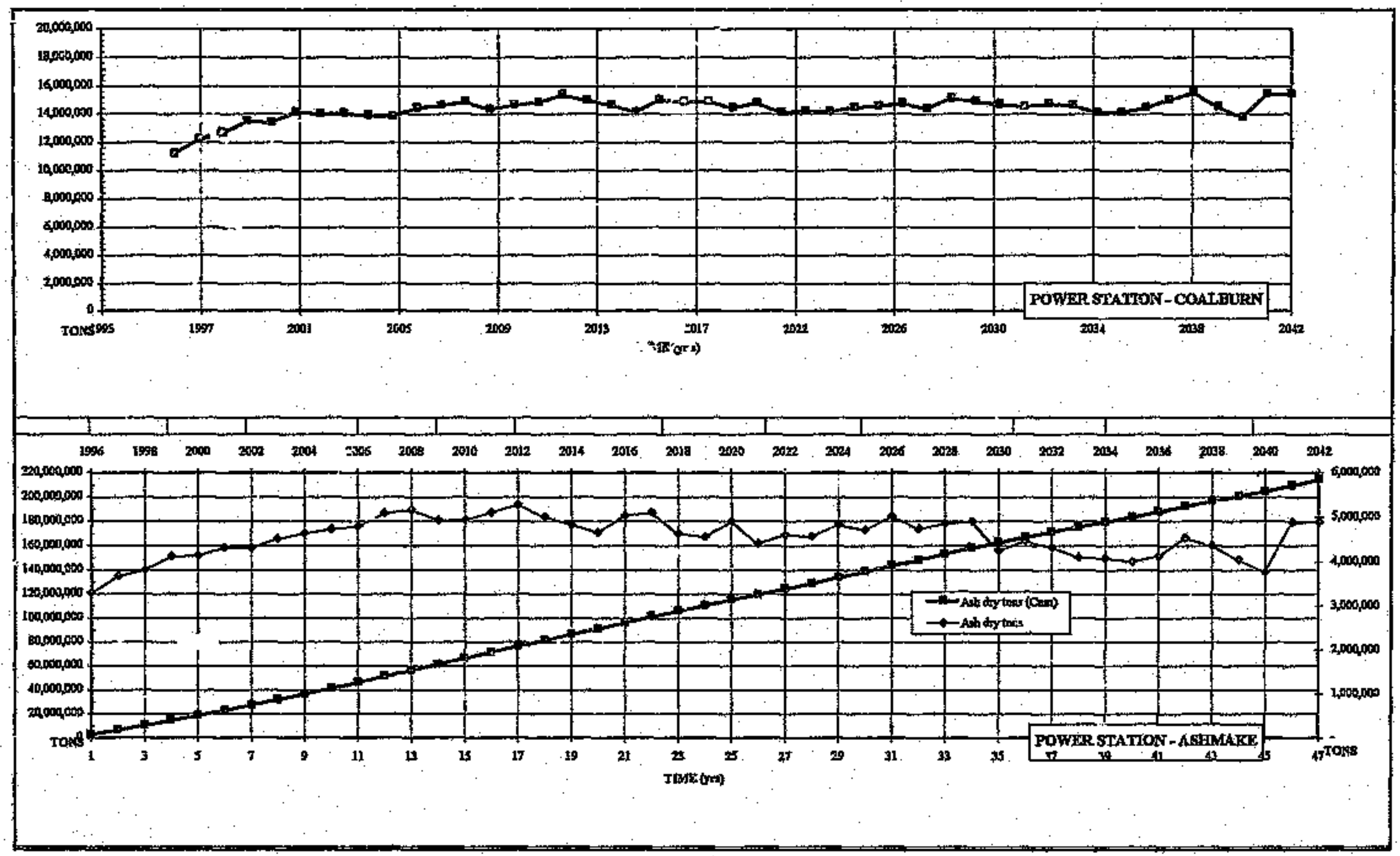
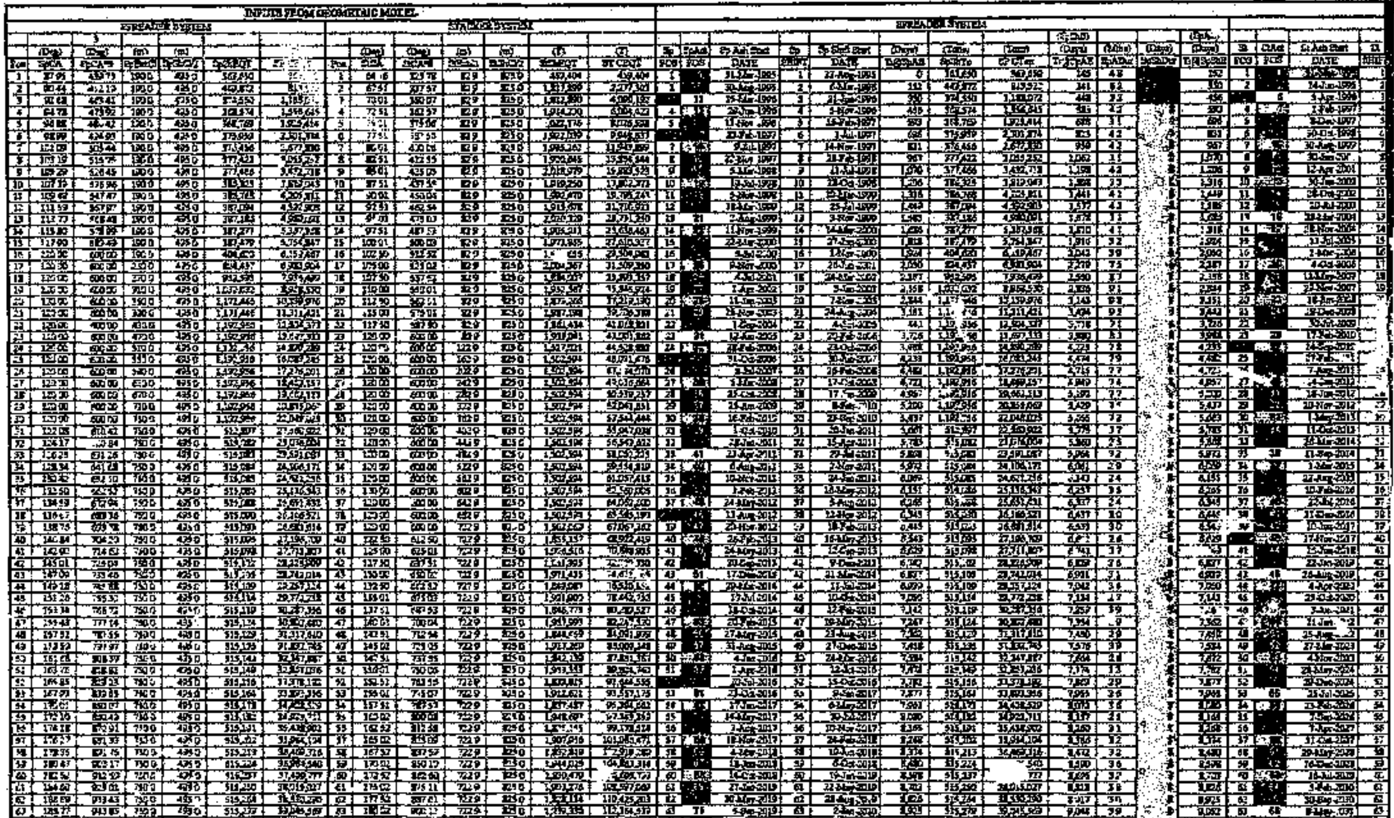


Figure B11 - Ash Production Model - Coalburn & Ashmake Graphs.

Ref DAD_GP2.XLS Sheet: GrwFlnMod



INPUTS FROM GEOMETRIC MODEL

SPREADER SYSTEM

STACKER SYSTEM

Figure B12 - Dump Growth Model - Input and Output Areas.

GROWTH PLAN MODEL INPUTS AND OUTPUTS

STACKER SYSTEM

INPUTS FROM ASH PRODUCTION MODEL

ASHRATE

Stack Start DATE	(TRUCK) Time Betw Trks (Dys)	(DOZER) Time Betw Stacks (Dys)	(Days) T@SSAS	(Tons) CAT@SSAS	(Tons) DENT.	21 AVG	13 AVG*10	(Tons) ATcDnSSA	(Tons) CAT @SSAE	(Days) T@SSAE	(Mths) DADz	(Days) SSbDz	(Days) T@SSRE	(Yrs) D@SSRE	(Tons) CAT@SSRE	AVGA ASSHG	13 AVGA ASSMe*10	(Tons) CATcDnGA	(Tons) SpATcDnSS	TIME y	PERIOD ENDING	(Tons/Yr) COAL BURN	ASH %	(Tons) ASH TONS	(T) CUMULATIVE
31-Mar-1995	6	70	0	0	452,402	[redacted]	249.9	340,514	340,514	61	20	[redacted]	75	2/12	621,984	69.1	671.3	10,510	121,690	0	31-Mar-95			[illegible]	0
19-Mar-1995	4	77	75	621,984	1,877,399	[redacted]	739.7	2,457,704	3,319,068	354	92	[redacted]	371	1	3,256,653	67.7	697.3	639,206	150,985	1/12	30-Apr-95	845,229	27.21	246,891	246,891
23-Jan-1997	68	74	371	3,256,636	1,912,820	[redacted]	700.0	2,385,842	5,360,978	657	95	[redacted]	675	1 10/12	5,975,923	65.8	657.6	770,863	127,427	2/12	31-May-95	1,025,804	28.96	293,622	540,534
24-Nov-1997		72	671	5,975,921	1,924,735	[illegible]	700.0	2,734,814	8,710,537	959	97	[illegible]	980	2 8/12	8,852,984	66.8	668.4	820,368	130,427	3/12	30-Jun-95	910,022	28.5	260,210	800,764
16-Oct-1998			983	8,852,984	2,022,176	[illegible]	700.0	2,881,823	11,724,785	1,296	102	[illegible]	1,309	3 7/12	11,858,406	65.0	659.0	878,647	129,020	4/12	31-Jul-95	875,212	28.82	257,048	1,057,812
16-Aug-1999			1,329	11,858,406	1,902,037	[illegible]	700.0	2,749,771	14,604,177	1,599	95	[illegible]	1,611	4 5/12	14,737,408	66.8	667.8	821,751	133,301	5/12	31-Aug-95	913,364	28.72	259,248	1,313,258
15-Feb-2000			1,613	14,737,408	1,981,162	[illegible]	700.0	2,850,374	17,587,582	1,904	96	[illegible]	1,918	5 3/12	17,727,674	66.3	660.9	818,112	150,722	6/12	30-Sep-95	757,134	28.31	214,343	1,527,400
23-Mar-2001			1,918	17,727,674	1,920,649	[illegible]	700.0	2,741,779	20,477,453	2,190	89	[illegible]	2,204	[illegible]	20,615,930	65.6	649.7	821,134	144,495	7/12	31-Oct-95	877,739	30.79	267,022	1,794,225
10-Jan-2002			2,234	20,619,937	2,018,975	[illegible]	700.0	2,858,316	23,500,195	2,485	92	[illegible]	2,497	6 10/12	23,619,587	66.7	666.5	865,277	147,301	8/12	30-Nov-95	857,512	27.57	272,856	2,064,800
14-Oct-2002			2,497	23,649,587	1,919,230	[illegible]	700.0	2,741,785	26,391,371	2,734	84	[illegible]	2,768	7 7/12	26,540,727	66.4	661.8	827,334	148,380	9/12	31-Dec-95	1,197,574	26.43	315,099	2,376,909
6-Jul-2003			2,768	26,540,725	1,992,470	[illegible]	700.0	2,546,388	29,377,391	3,020	82	[illegible]	3,034	8 4/12	29,548,687	66.2	661.1	811,916	161,310	10/12	31-Jan-96	725,212	25.64	277,074	2,659,981
9-Mar-2004			3,034	29,548,657	1,915,878	[illegible]	700.0	2,736,488	32,285,310	3,285	77	[illegible]	3,285	9	32,486,599	66.0	660.0	821,225	171,349	11/12	29-Feb-96	1,033,370	28.74	296,453	2,946,034
14-Nov-2004			3,290	32,456,690	2,022,329	[illegible]	700.0	2,965,384	35,342,802	3,518	78	[illegible]	3,516	9 8/12	35,514,232	66.1	650.8	828,153	172,349	1	31-Mar-96	886,272	27.12	245,614	3,211,648
23-Jul-2005			3,516	35,314,222	1,905,213	[illegible]	700.0	2,721,772	38,235,384	3,743	70	[illegible]	3,737	10 4/12	38,416,327	63.7	666.1	816,526	180,363	1 9/12	31-Dec-96	8,393,300	29.3	2,464,289	5,676,130
11-Feb-2006			3,737	38,416,327	1,973,825	[illegible]	700.0	2,809,807	41,235,124	3,974	71	[illegible]	3,988	10 11/12	41,422,495	66.1	657.6	845,942	185,112	2 9/12	1997	11,160,271	30.1	3,374,346	9,050,472
22-Sep-2006			3,988	41,422,468	1,884,076	[illegible]	700.0	2,756,431	44,129,107	4,132	67	[illegible]	4,206	11 6/12	44,315,428	65.4	654.9	841,985	186,123	3 9/12	1998	11,182,398	30.2	3,379,381	12,429,858
28-Apr-2007			4,226	44,315,429	2,004,337	[illegible]	700.0	2,883,711	47,378,803	4,412	68	[illegible]	4,425	12 1/12	47,380,226	65.9	655.1	859,914	201,408	4 9/12	1999	11,187,431	30.4	3,478,173	15,905,998
15-Nov-2007			4,425	47,380,228	1,889,027	[illegible]	700.0	2,691,438	50,071,656	4,612	62	[illegible]	4,636	12 8/12	51,273,284	65.1	651.3	807,451	201,418	5 9/12	2000	11,842,441	30.8	3,644,490	19,550,508
4-Jun-2008			4,626	51,273,284	1,952,567	[illegible]	700.0	2,782,182	53,282,458	4,814	82	[illegible]	4,823	13 3/12	53,271,630	66.1	651.5	836,814	229,024	6 9/12	2001	12,349,365	30.5	3,764,919	23,317,527
14-Dec-2008			4,868	53,271,630	1,873,246	[illegible]	700.0	2,676,093	55,987,582	5,007	59	[illegible]	5,021	13 9/12	58,156,341	66.9	660.3	807,826	218,757	7 9/12	2002	12,637,028	30.8	3,894,378	27,217,495
16-Jul-2009			5,021	58,190,591	1,797,198	[illegible]	700.0	2,828,854	58,985,105	5,222	66	[illegible]	5,336	14 4/12	59,191,388	65.6	654.3	801,886	198,102	8 9/12	2003	13,622,782	32.2	4,390,958	31,421,345
3-Feb-2010			5,316	59,129,288	1,852,474	[illegible]	700.0	2,286,630	61,854,328	5,424	62	[illegible]	5,458	14 11/12	62,252,441	65.1	651.5	798,133	178,421	9 9/12	2004	13,182,411	33.4	4,467,318	35,890,661
31-Aug-2010			5,438	62,592,441	1,893,161	[illegible]	700.0	2,701,487	64,811,927	5,635	68	[illegible]	5,747	15 6/12	65,012,316	65.3	651.1	828,224	198,413	10 9/12	2005	13,794,810	34.2	4,702,315	40,592,974
19-Feb-2011			5,647	65,012,390	1,527,771	[illegible]	700.0	2,102,458	67,390,818	5,790	90	[illegible]	5,853	16 1/12	67,299,176	66.1	645.0	834,457	205,398	11 9/12	2006	14,031,351	33.2	4,657,288	45,250,262
25-Jul-2011			5,853	67,299,176	1,502,394	[illegible]	700.0	2,146,582	69,548,718	5,952	48	[illegible]	5,973	16 4/12	69,751,095	63.9	678.9	643,857	225,398	12 9/12	2007	15,997,619	34.8	5,555,292	50,781,914
31-Dec-2011			5,973	69,751,026	1,502,394	[illegible]	700.0	2,146,562	71,857,818	6,159	48	[illegible]	6,173	16 10/12	72,139,791	61.9	618.8	643,969	212,133	13 9/12	2008	15,667,278	34.8	5,449,549	56,151,463
4-Jun-2012			6,133	72,139,791	1,502,594	[illegible]	700.0	2,146,562	74,750,316	6,273	47	[illegible]	6,289	17 3/12	74,868,488	61.7	657.0	643,969	212,131	14 9/12	2009	15,616,445	34.4	5,367,139	61,318,622
6-Nov-2012			6,282	74,868,485	1,502,954	[illegible]	700.0	2,146,562	76,619,049	6,451	47	[illegible]	6,445	17 8/12	76,827,131	61.3	657.0	643,869	212,133	15 9/12	2010	15,325,944	33.7	5,171,436	66,492,058
17-Apr-2013			6,445	76,827,181	1,502,594	[illegible]	700.0	2,146,562	78,877,785	6,592	49	[illegible]	6,606	18 1/12	78,174,468	61.9	633.3	643,959	220,943	16 9/12	2011	15,499,127	34.4	5,363,954	71,846,012
27-Sep-2013			6,606	79,174,289	1,507,394	[illegible]	700.0	2,146,562	81,303,249	6,746	49	[illegible]	6,770	18 7/12	81,572,192	64.5	643.1	643,959	200,943	17 9/12	2012	16,318,234	34.3	5,530,050	77,376,893
12-Mar-2014			6,770	81,572,192	1,502,394	[illegible]	700.0	2,144,552	83,768,754	6,922	50	[illegible]	6,936	19	83,182,273	64.1	641.0	643,969	174,120	18 9/12	2013	15,634,392	33.4	5,228,884	82,615,505
28-Aug-2014			6,936	83,182,273	1,502,394	[illegible]	700.0	2,146,562	85,909,687	7,093	51	[illegible]	7,126	19 6/12	86,201,337	64.2	641.9	643,969	198,122	19 9/12	2014	15,372,614	32.4	5,000,992	87,676,497
15-Feb-2015			7,105	86,201,337	1,502,394	[illegible]	700.0	2,144,557	88,390,159	7,261	51	[illegible]	7,275	19 11/12	88,537,399	64.3	642.8	643,959	187,279	20 9/12	2015	14,860,329	31.9	4,802,618	92,558,131
3-Aug-2015			7,275	88,577,227	1,502,494	[illegible]	700.0	2,146,565	90,530,951	7,426	53	[illegible]	7,450	20 5/12	90,871,241	64.4	643.3	643,889	187,279	21 9/12	2016	15,750,229	33.5	5,276,550	97,835,429
22-Jan-2016			7,450	90,871,241	1,502,394	[illegible]	700.0	2,146,562	93,017,883	7,578	52	[illegible]	7,622	20 11/12	91,225,191	64.3	640.0	643,959	202,392	22 9/12	2017	15,659,360	34.2	5,352,398	103,178,041
8-Jul-2016			7,622	91,223,191	1,502,394	[illegible]	700.0	2,146,552	95,364,757	7,773	49	[illegible]	7,786	21 4/12	95,569,142	64.0	639.7	643,957	202,398	23 9/12	2018	15,631,822	31.1	4,855,739	108,033,930
17-Dec-2016			7,784	95,569,142	1,502,394	[illegible]	700.0	2,146,562	97,715,704	7,933	49	[illegible]	7,947	21 9/12	97,918,120	64.9	639.7	643,960	203,418	24 9/12	2019	15,198,225	31.5	4,778,301	112,812,237
27-May-2017			7,947	97,919,120	1,502,394	[illegible]	700.0	2,146,562	100,093,752	8,091	48	[illegible]	8,107	22 3/12	100,270,595	63.9	639.0	643,989	204,973	25 9/12	2020	15,308,319	33.2	5,340,962	117,461,219
3-Nov-2017			8,107	100,270,595	1,507,069	[illegible]	700.0	2,149,812	102,618,627	8,254	47	[illegible]	8,268	22 8/12	100,621,319	63.9	639.0	643,744	230,913	26 9/12	2021	14,857,127	31.2	4,626,011	122,188,340
4-Apr-2018			8,268	102,621,319	1,599,157	[illegible]	700.0	2,849,275	106,271,544	8,463	54	[illegible]	8,477	23 3/12	103,457,797	65.3	651.2	795,057	186,253	27 9/12	2022	14,903,273	32.4	4,854,333	127,412,392
8-Jun-2019			8,477	105,457,797	1,806,316	[illegible]	700.0	2,752,164	108,571,383	8,624	58	[illegible]	8,658	23 10/12	108,320,243	65.6	655.7	825,096	183,277	28 9/12	2023	14,840,315	32.7	4,792,545	132,204,944
12-Nov-2019			8,652	108,321,245	1,831,395	[illegible]	700.0	2,644,843	111,078,080	8,900	56	[illegible]	8,914	24 5/12	111,221,367	63.5	654.6	790,435	183,277	29 9/12	2024	15,187,573	33.4	5,070,780	137,275,889
23-Apr-2020			8,914	111,221,367	1,971,475	[illegible]	700.0	2,818,339	114,077,703	9,123	69	[illegible]	9,137	25	114,275,108	65.6	655.9	844,801	187,495	30 9/12	2025	15,271,147	37.4	4,940,827	142,224,493
9-Oct-2020			9,137	114,275,178	1,849,067	[illegible]	700.0	2,641,551	116,876,740	9,324	67	[illegible]	9,338	25 7/12	117,274,244	65.1	651.3	792,458	199,495	31 9/12	2026	15,679,553	33.9	5,354,188	147,478,679
25-Mar-2021			9,338	117,274,245	1,921,905	[illegible]	700.0	2,749,572	119,899,818	9,548	59	[illegible]	9,582	26 2/12	119,997,283	65.8	656.2	823,872	177,471	32 9/12	2027	15,303,157	32.0	4,967,878	152,445,522
28-Dec-2021			9,542	119,907,282	1,846,715	[illegible]	700.0	2,618,295	122,836,330	9,775	58	[illegible]	9,784	26 10/12	122,253,579	65.6	655.8	801,475	185,040	33 9/12	2028	15,814,971	36.1	5,090,558	157,477,072
11-Jun-2022			9,784	122,320,579	1,957,993	[illegible]	700.0	2,797,535	124,617,711	9,995	70	[illegible]	10,020	27 5/12	125,307,731	65.7	656.6	839,140	185,040	34 9/12	2029	15,371,280	32.8	5,131,791	162,610,858
13-Jan-2023			10,020	125,807,783	1,844,457	[illegible]	700.0	2,684,961	128,437,253	10,239	68	[illegible]	10,223	28	128,621,516	65.4	654.2	790,482	183,024	35 9/12	2030	15,403,492	28.3	4,445,713	167,126,550
25-Jun-2023			10,223	128,621,510	1,917,267	[illegible]	700.0	2,718,595	131,365,875	10,432	69	[illegible]	10,446	28 7/12	131,944,205	65.6	650.0	821,667	183,024	36 9/12	2031	15,422,228	[illegible]	4,583,582	171,811,739
14-May-2024			10,446	131,544,205	1,842,517	[illegible]	700.0	2,631,657	134,179,922	10,638	63	[illegible]	10,652	29 2/12	134,392,616	65.7	652.4	782,488	124,493	37 9/12	2032	15,485,624	27.4	4,840,929	176,152,662
19-Dec-2024			10,646	134,370,615	1,967,393	[illegible]	700.0	2,790,524	137,180,925	10,859	66	[illegible]	10,857	29 9/12	137,557,428	65.4	654.4	807,131	192,375	38 9/12	2033	[illegible]	29.1	4,500,459	180,653,171
11-Jul-2025			10,857	137,291,426	1,803,855	[illegible]	700.0	2,828,303	139,980,823	11,061	64	[illegible]	11,075	30 4/12	140,371,622	65.9	652.9	[illegible]	129,403	39 9/12	2034	[illegible]	28.9	4,277,729	184,930,900
9-Feb-2026			11,075	140,371,602	1,912,802	[illegible]	700.0	2,787,335	142,963,907	11,273	65	[illegible]	11,287	30 11/12	143,156,467	[illegible]	653.9	812,475	201,530	40 9/12	2035	[illegible]	[illegible]	4,201,519	189,137,419
24-Aug-2026			11,287	143,126,407	1,837,467	[illegible]	700.0	2,674,980	145,735,443	11,473	60	[illegible]	11,484	31 6/12	145,931,979	[illegible]	653.1	787,496	231,330	41 9/12	2036	[illegible]	[illegible]	4,319,230	193,456,648
24-Mar-2027			11,484	145,931,979	1,941,657	[illegible]	700.0	2,789,853	148,715,330	11,682	65	[illegible]	11,698	32 1/12	148,906,415	[illegible]	653.3	815,186	170,824	42 9/12	2037	[illegible]	[illegible]	4,378,124	198,211,772
17-Oct-2027			11,678	148,906,415	1,805,335	[illegible]	700.0	2,621,690	151,358,326	11,888	63	[illegible]	11,902	32 7/12	151,718,779	65.3	652.6	785,691	180,024	43 9/12	2038	16,761,8[illegible]	28.1	4,371,784	202,785,536
15-May-2028			11,902	151,718,729	1,907,956	[illegible]	700.0	2,755,625	154,444,383	12,099	65	[illegible]	12,113	33 2/12	154,637,622	65.3	651.9	817,696	195,250	44 9/12	2039	15,216,348	27.9	4,242,887	207,028,373
2-Dec-2028			12,111	154,637,435	1,827,219	[illegible]	700.0	2,613,509	157,257,969	12,301	62	[illegible]	12,315	33 9/12	157,453,223	65.1	651.6	785,425	179,235	45 9/12	2040	14,412,571	27.4	3,954,095	211,983,482
2-Jul-2029			12,315	157,453,223	1,944,025	[illegible]	700.0	2,777,276	160,250,980	12,512	65	[illegible]	12,526	34 4/12	160,477,216	65.4	653.7	829,153	196,206	46 9/12	2041	16,173,971	31.6	5,135,904	216,099,324
22-Jan-2030			12,526	160,427,216	1,850,479	[illegible]	700.0	2,834,573	163,042,138	12,716	62	[illegible]	12,733	34 11/12	163,213,090	65.7	657.0	784,481	170,904	47 9/12	2042	16,331,758	31.6	5,127,498	221,223,786
16-Sep-2030			12,750	163,213,026	1,907,278	[illegible]	700.0	2,718,966	165,893,286	12,953	73	[illegible]	12,967	35 6/12	166,107,750	65.9	658.6	815,650	175,904	48 9/12	2043	16,872,022	31.0	5,356,547	226,589,471
23-Apr-2031			12,967	165,102,980	1,854,124	[illegible]	700.0	2,811,621	168,714,580	13,176	68	[illegible]	13,189	36 2/12	169,224,285	65.6	655.8	789,488	172,705	49 9/12	2044	16,972,002	31.6	5,386,547	231,916,178
11-Dec-2031			13,189	168,894,285	1,857,926	[illegible]	700.0	2,773,480	171,664,766	13,405	71	[illegible]	13,419	36 9/12	171,843,462	65.7	657.4	811,144	176,497	50 9/12	2045	16,972,002	31.6	5,363,547	237,322,725
22-Jul-2032			13,419	171,543,443	1,855,785	[illegible]	700.0	2,808,264	174,493,730	13,632	69	[illegible]	13,642	37 5/12	174,625,502	65.6	656.2	787,185	174,372	51 9/12	2046	16,972,002	31.6	5,366,547	242,659,271
15-Mar-2033			13,643	174,625,501	1,891,580	[illegible]	700.0	2,112,857	177,398,358	13,859	73	[illegible]	13,879	38	177,530,109	65.9	655.6	813,577	164,961	52 9/12	2047	16,972,002	31.6	5,386,547	248,035,819
3-Nov-2033			13,872	177,478,109	1,859,434	[illegible]	700.0	2,604,963	180,128,014	14,100	73	[illegible]	14,114	38 8/12	180,272,985	62.8	658.3	781,472	164,951	53 9/12	2048	16,972,002	31.6	5,366,547	253,422,366
13-Jun-2034			14,114	180,272,985	1,904,612	[illegible]	700.0	2,749,767	183,238,153	14,340	77	[illegible]	14,309	39 4/12	183,200,852	65.1	650.7	822,334	164,077	54 9/12	2049	16,972,002	31.6	5,368,547	258,788,913
7-Mar-2035			14,302	183,250,852	1,821,078	[illegible]	700.0	2,801,512	185,822,341	14,587	73	[illegible]	14,601	40	185,953,625	63.9	658.7	785,482	161,154	55 9/12	2050	16,972,002	31.6	5,363,547	264,158,460
12-Nov-2035			14,601	185,943,475	1,899,857	[illegible]	700.0	2,556,434	188,489,322	14,806	77	[illegible]	14,830	40 8/12	188,810,174	65.1	661.8	811,457	161,154	56 9/12	2051	16,972,002	31.6	5,366,547	269,522,007
2-Jul-2036			14,850	188,822,174	1,808,717	[illegible]	700.0	2,530,367	191,428,241	15,079	72	[illegible]	15,084	41 4/12	191,574,164	65.8	658.1	779,180	165,100						
27-Feb-2037			15,084	191,574,164	1,929,012	[illegible]	700.0	2,757,025	194,351,379	15,320	74	[illegible]	15,324	42	194,351,258	65.9	659.1	827,105	182,427						
28-Sep-2037			15,304	194,317,225	1,818,393	[illegible]	700.0	2,524,790	197,128,965	15,523	65	[illegible]	15,537	42 7/12	197,330,822	65.4	654.0	778,417	182,477						
15-May-2038			15,537	197,310,022	1,888,138	[illegible]	700.0	2,676,775	200,008,591	15,742	70	[illegible]	15,763	43 2/12	200,185,023	65.7	616.8	809,101	175,402						
23-Dec-2038			15,765	200,185,023	1,813,584	[illegible]	700.0	2,597,856	202,778,429	15,976	68	[illegible]	15,984	43 10/12	202,959,884	65.6	652.6	777,422	157,436						
14-Aug-2039			15,984	203,972,834	1,812,799	[illegible]	700.0	2,559,712	205,528,576	16,237	73	[illegible]	16,221	44 5/12	205,692,334	65.9	648.6	776,954	164,778						

Ref: DAD_GP2.XLS Sheet; GrwPlnMod

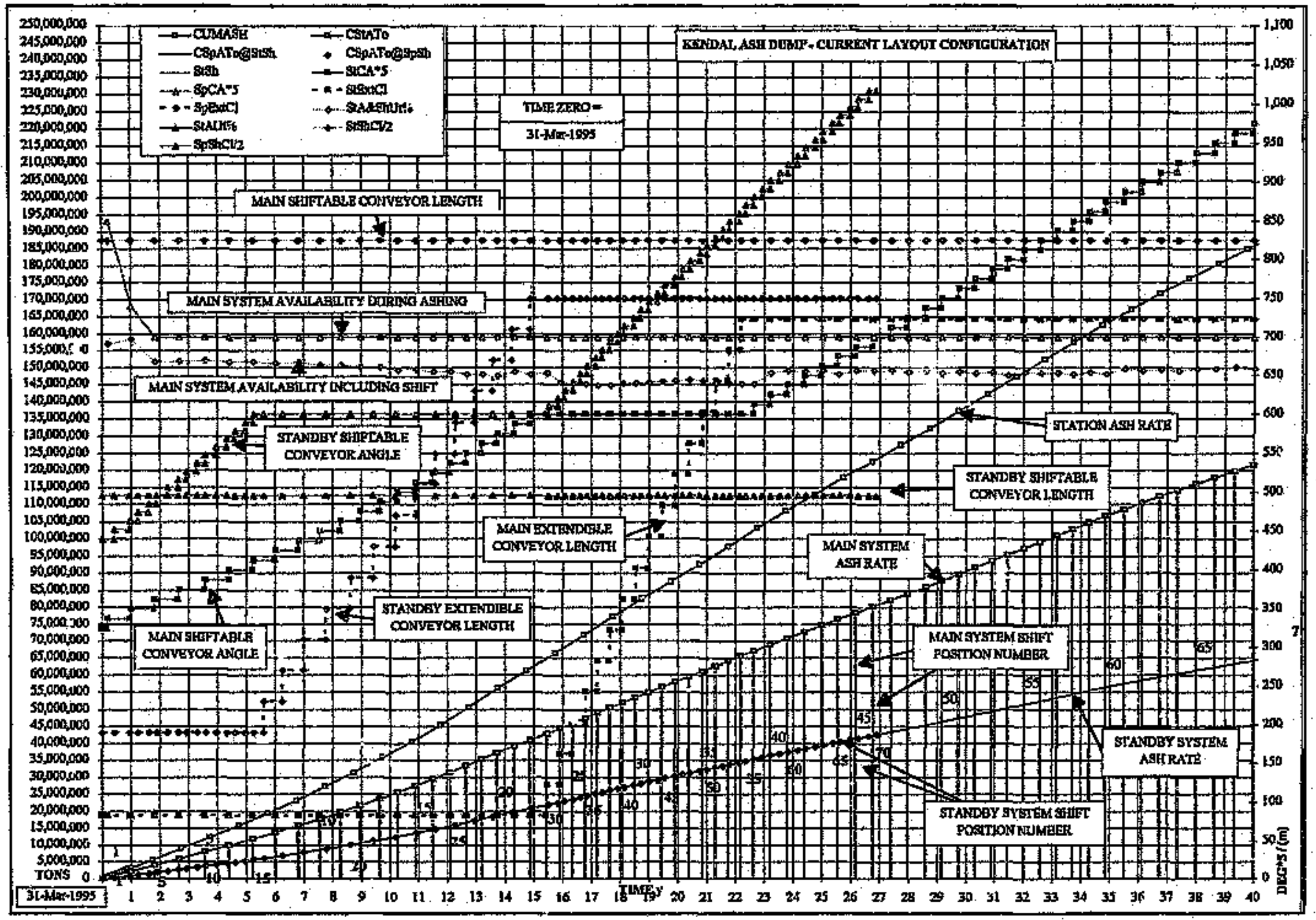


Figure B13 - Dump Growth Model - Growth Plan.

Ref: DAD_GP2.XLS Sheet: GrwPlnMod

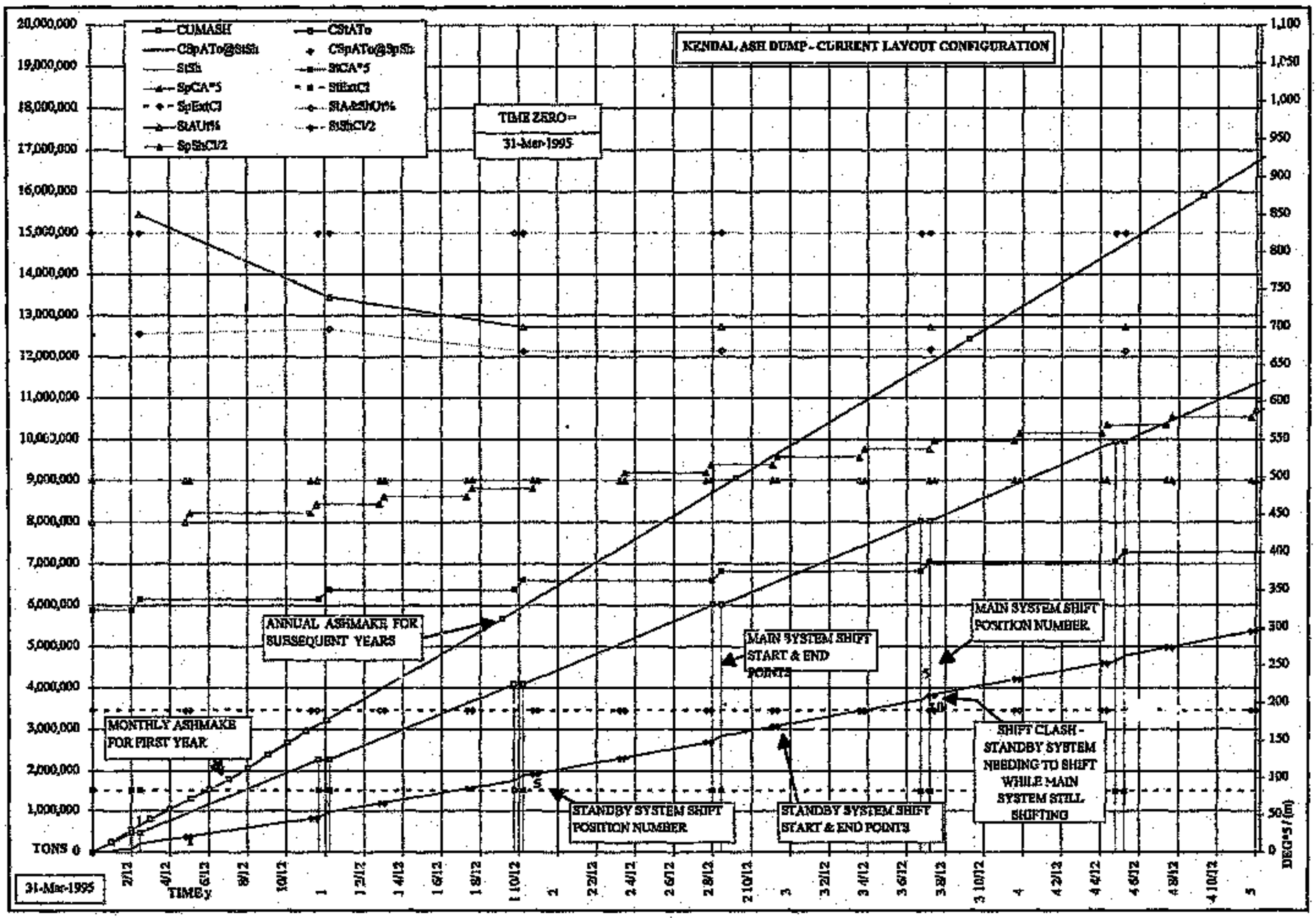


Figure B14 - Dump Growth Model - Five Year Growth Plan Showing Main & Standby Shift Details & Relationships.

APPENDIX C MODEL VERIFICATION PRINTOUTS

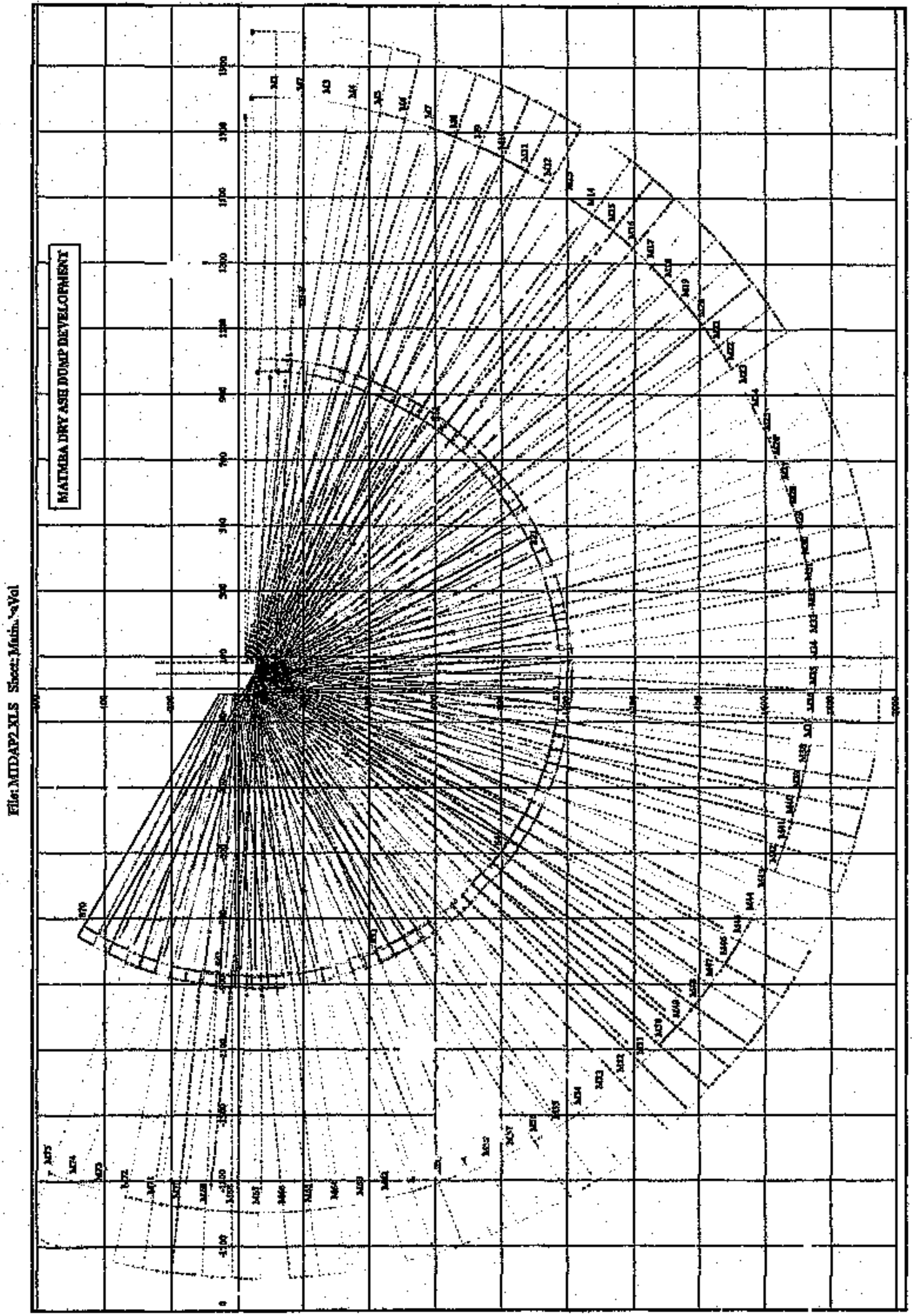


Figure C1 - Geometric Modeling - Radial Only Dump, Matimba Ash Dump Original Layout - Frontstack.

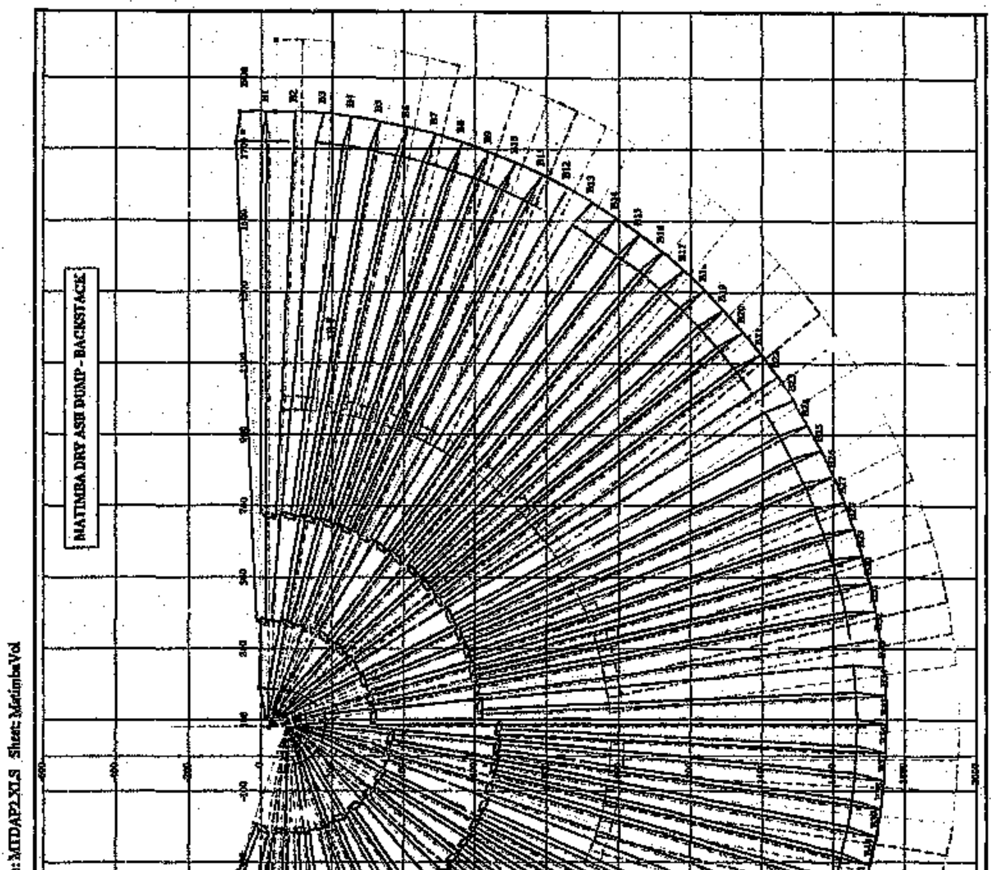
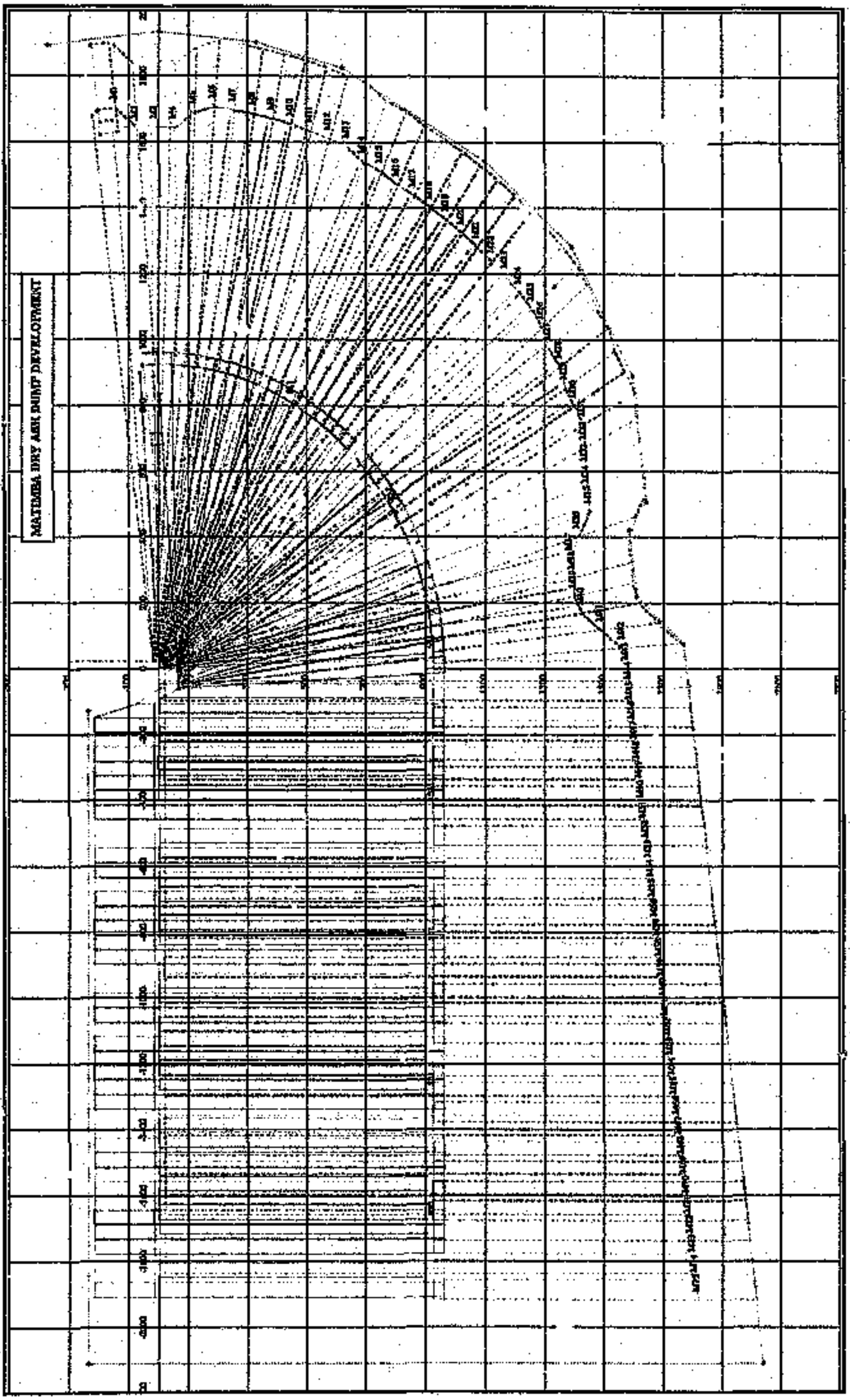


Figure C2 - Geometric Modeling - Radial Only Dump, Matimba Ash Dump Original Layout - Backstack.



File: MTDAPA.XLS Sheet MC Vol

Figure C3 - Matimba Ash Dump - New Layout with Dam Cutbacks & Increasing Main System Width - Frontstack.

File MTDAP3.XLS Sheet MatimbaVol

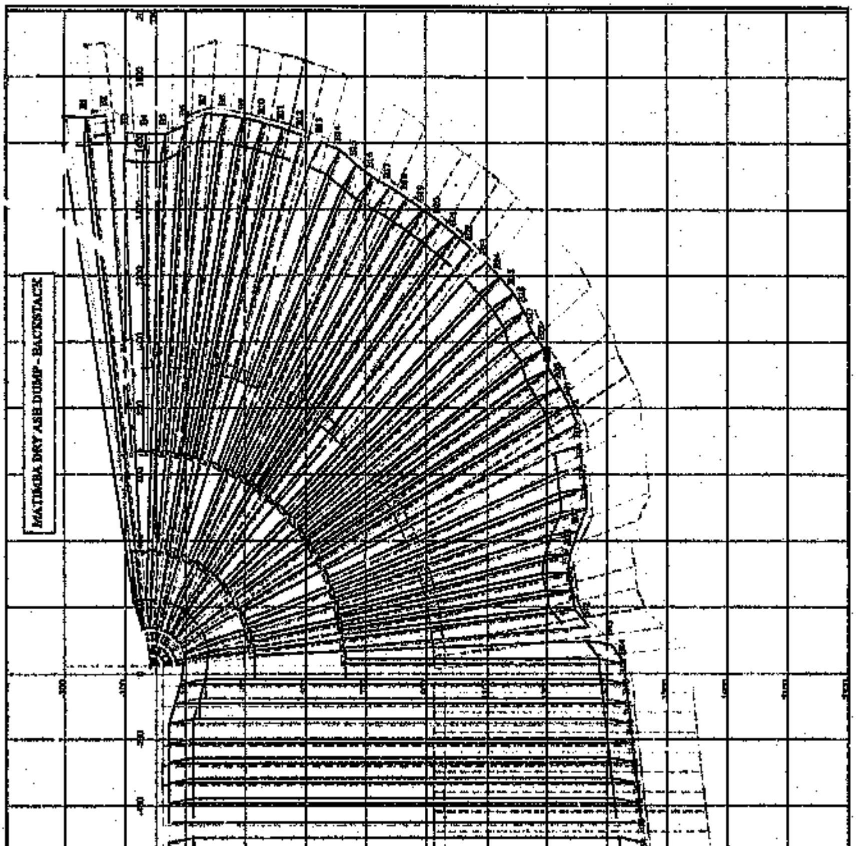


Figure C4 - Matimba Ash Dump - New Layout with Dam Cutbacks & Increasing Main System Width - Backstack.

File: TUADEX1.XLS Sheet: KendalVol

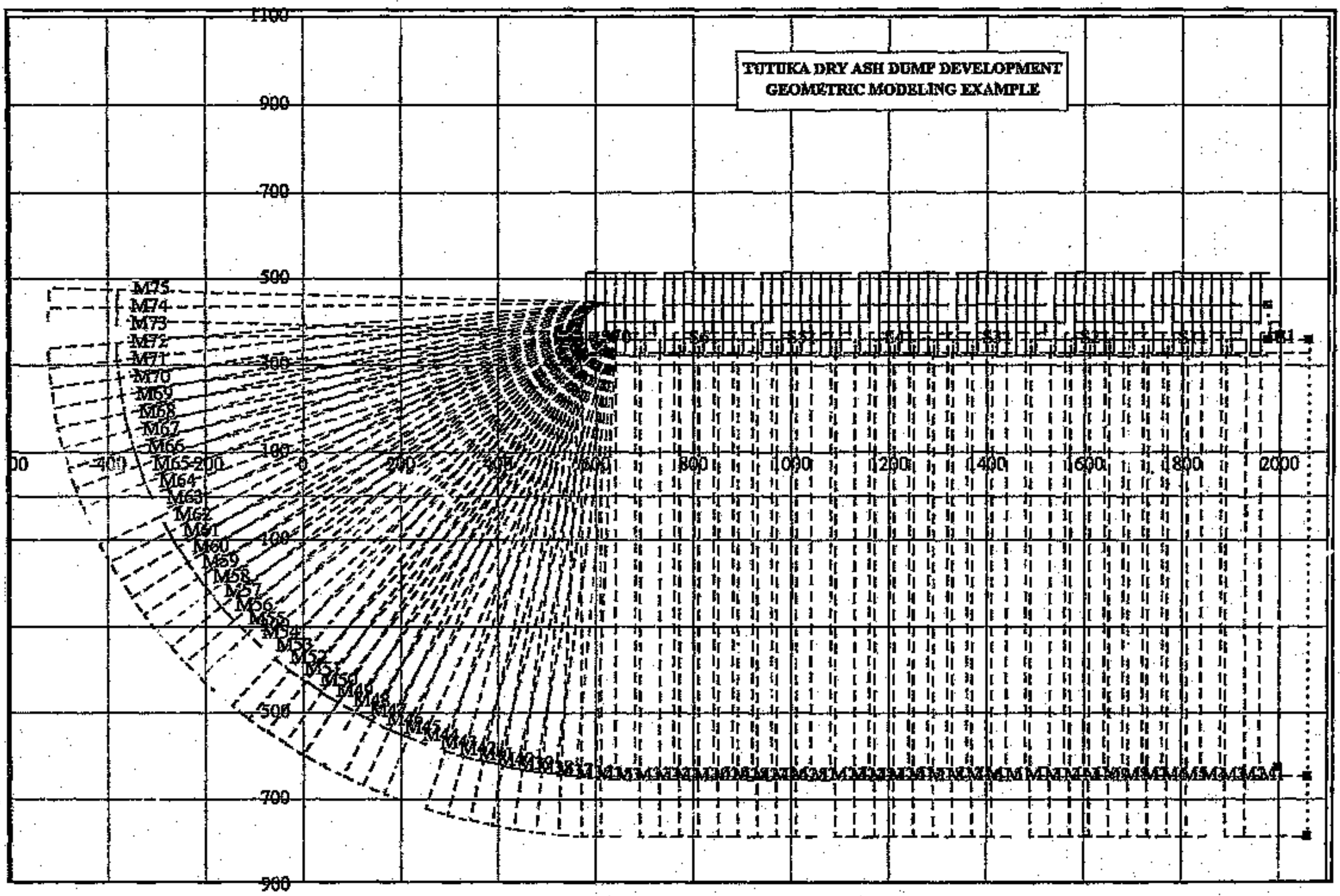


Figure C5 - Geometric Modeling - Tutuka Ash Dump Standby & Main Frontstack.

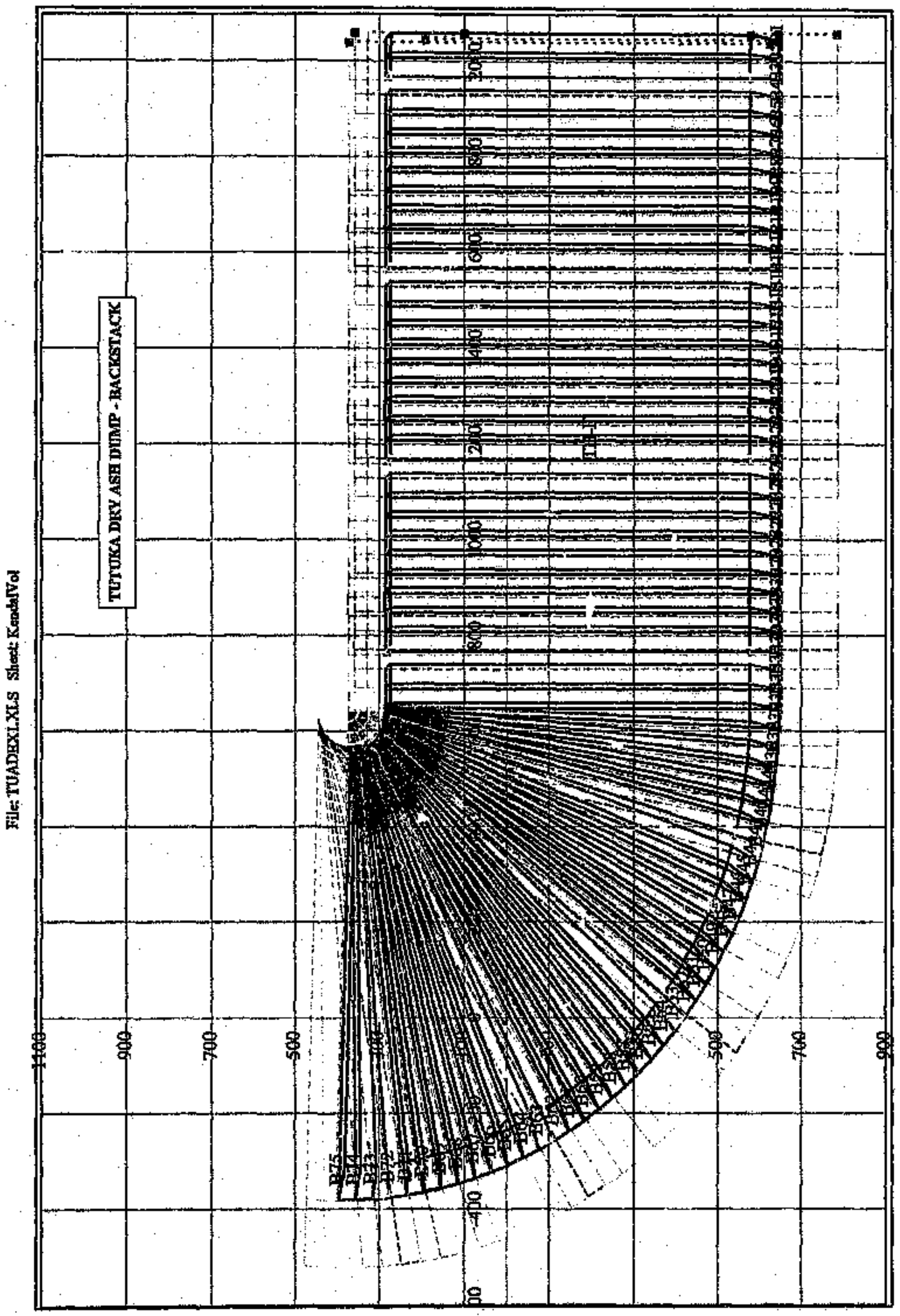


Figure C6 - Geometric Modeling - Tutuka Ash Dump Main Frontstack & Backstack.

APPENDIX D PRACTICAL EXAMPLES PRINTOUTS

a) Feasibility Analysis Evaluation Examples

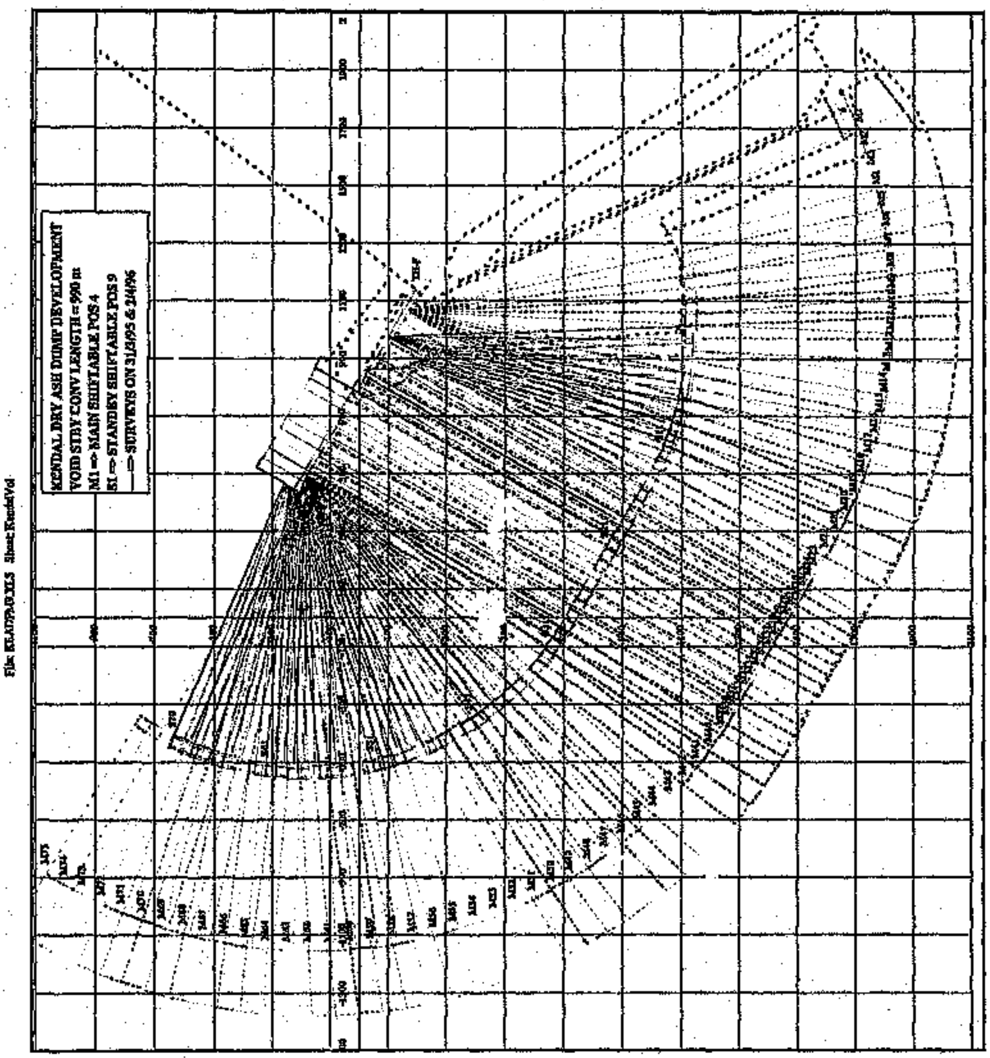


Figure D1 - Feasibility Evaluation - Current Geometry (70% Stacker Availability) - Layout Plot.

File: KEADPM9.XLS Sheet: KendalAshRt

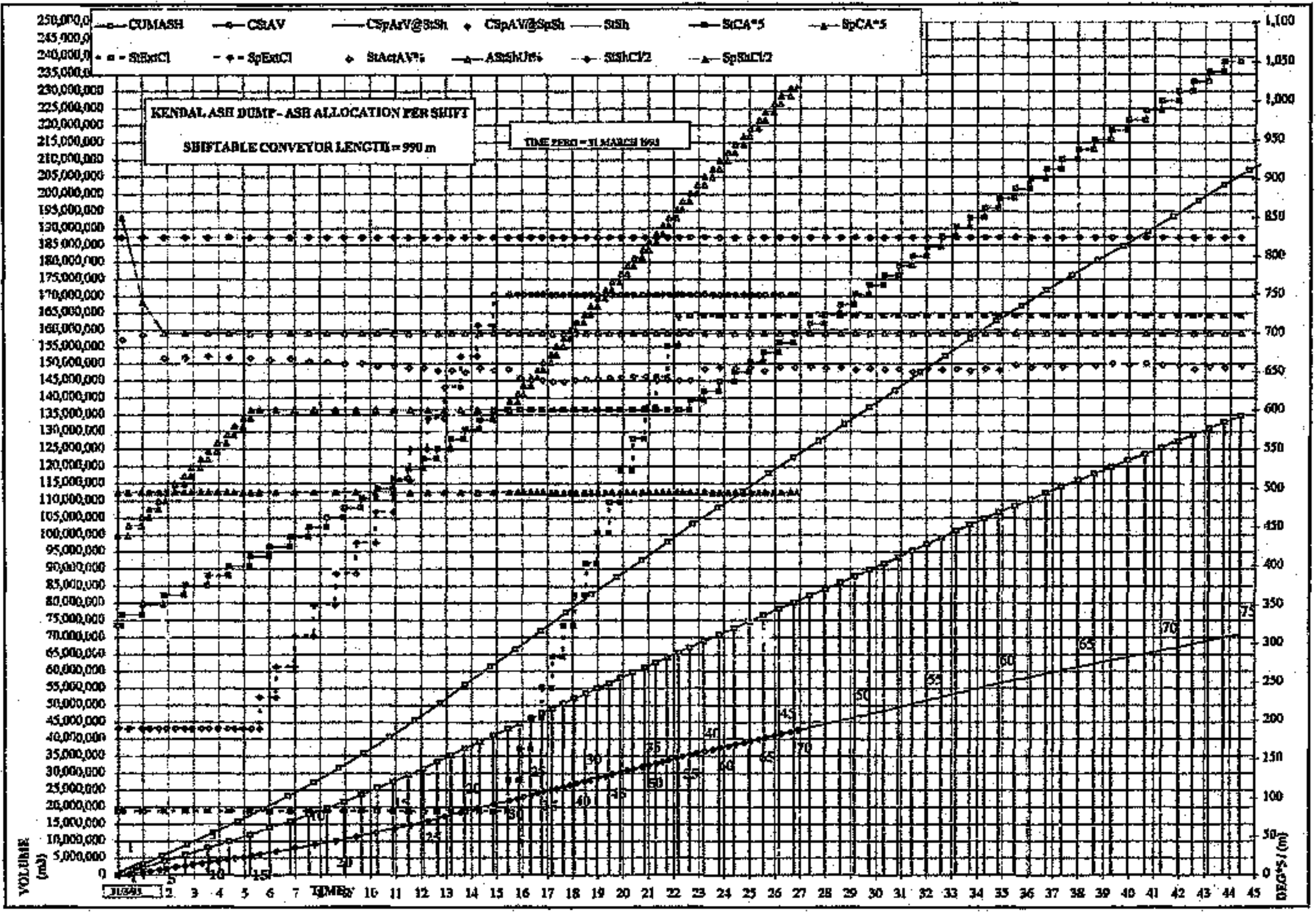


Figure D2 - Feasibility Evaluation - Current Geometry (70% Stacker Availability) - Growth Plan.

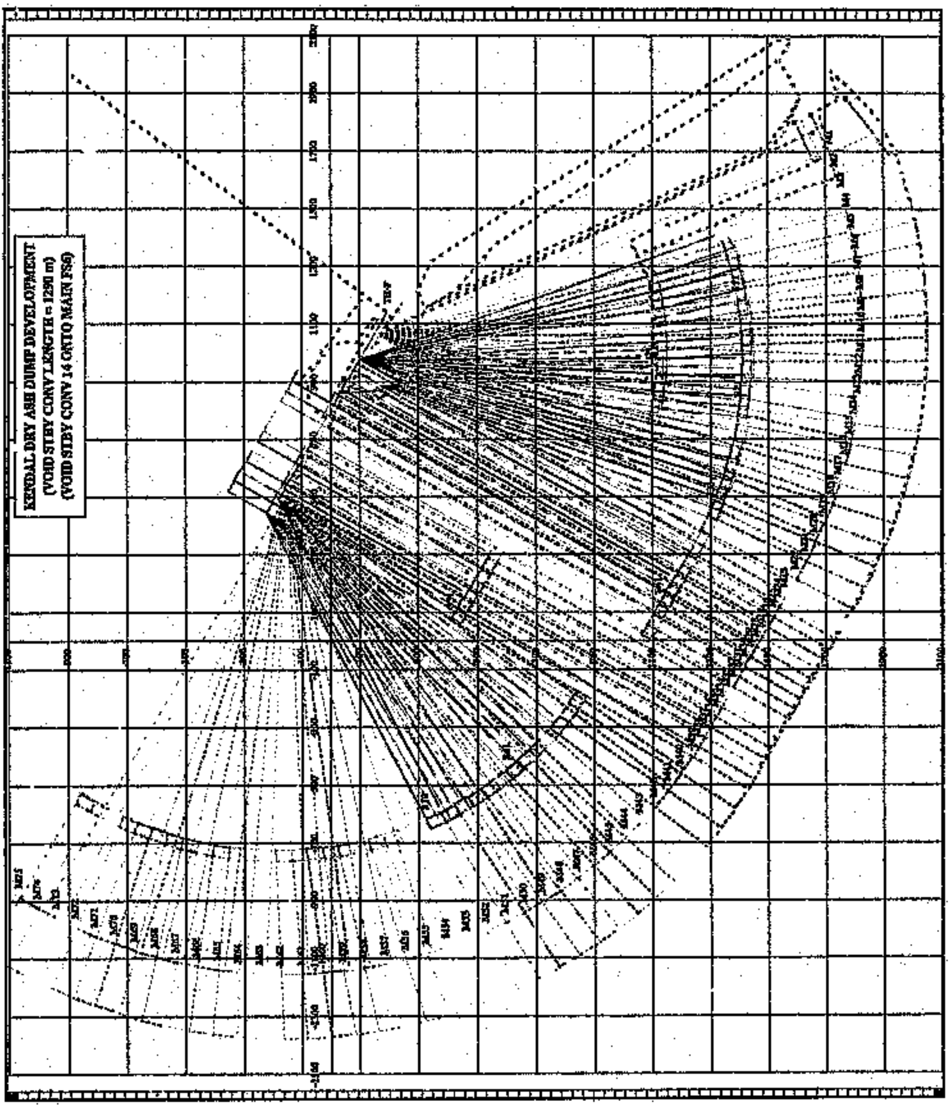


Figure D3 - Feasibility Evaluation - Shift Back Standby & Extend 300m (70% Stkr. Avail'ty) - Layout Plot.

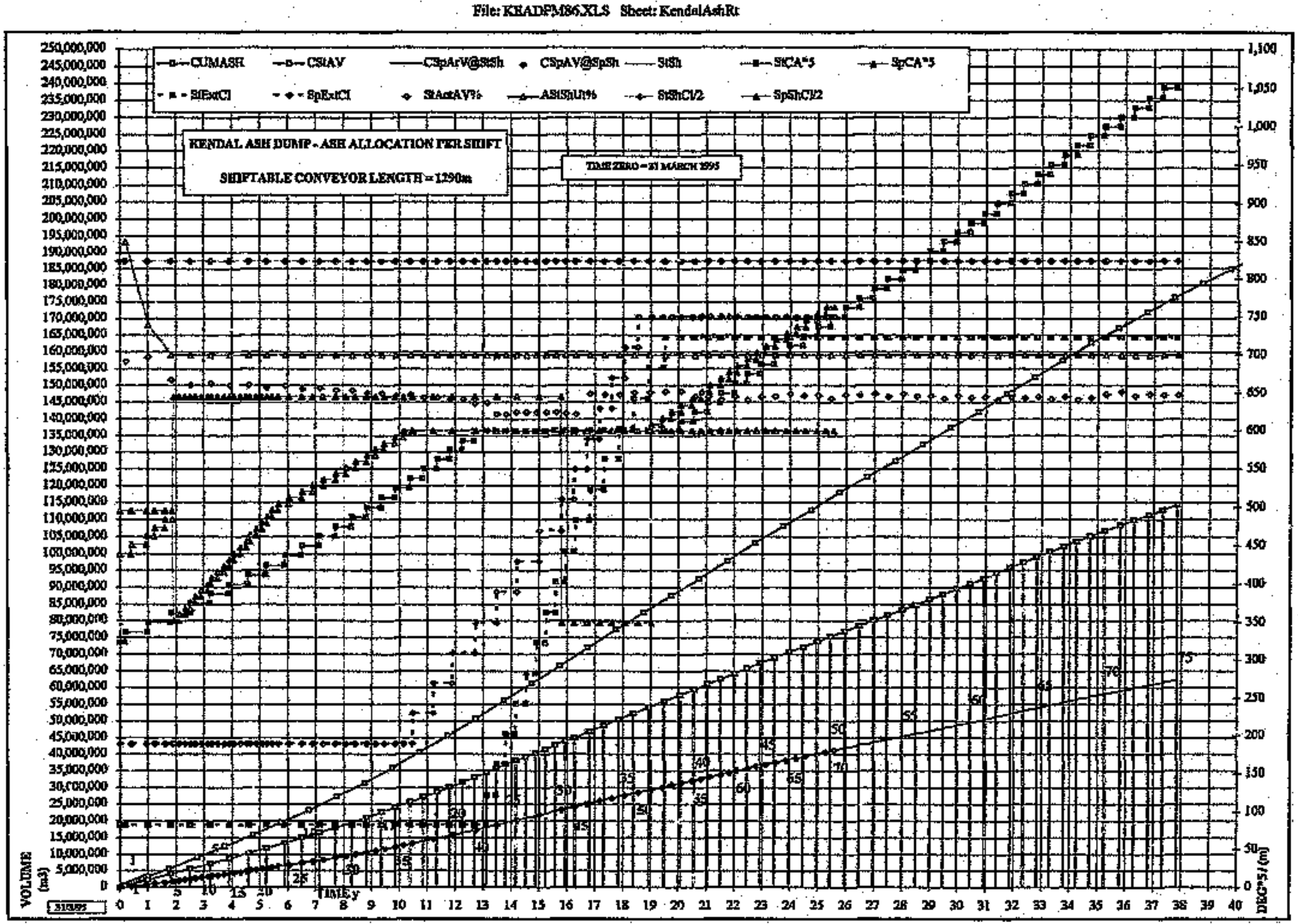


Figure D4 - Feasibility Evaluation - Shift Back Standby & Extend 300m (70% Stkr. Avail'ty) - Growth Plan.

b) What-if Analysis Evaluation Examples

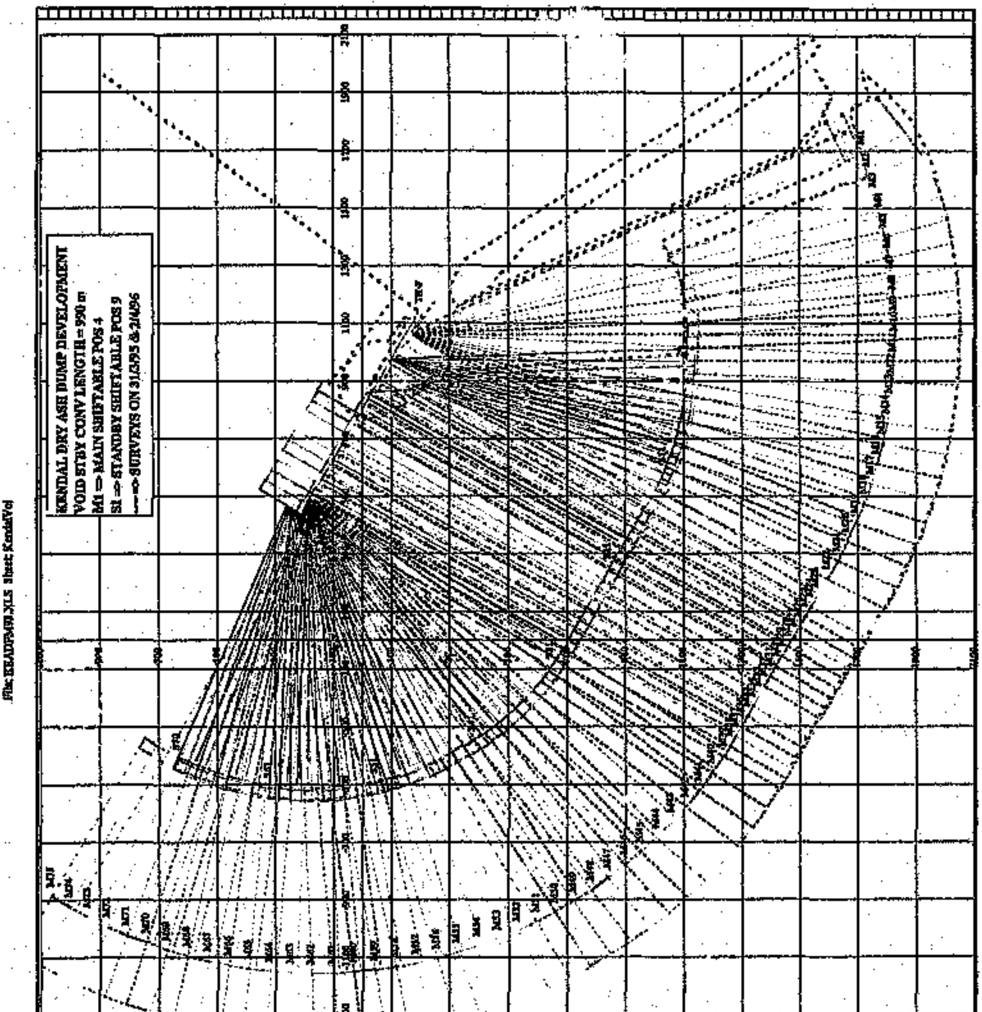


Figure D5 - What-If Evaluation - Current Geometry, (81% Stacker Availability) - Layout Plot.

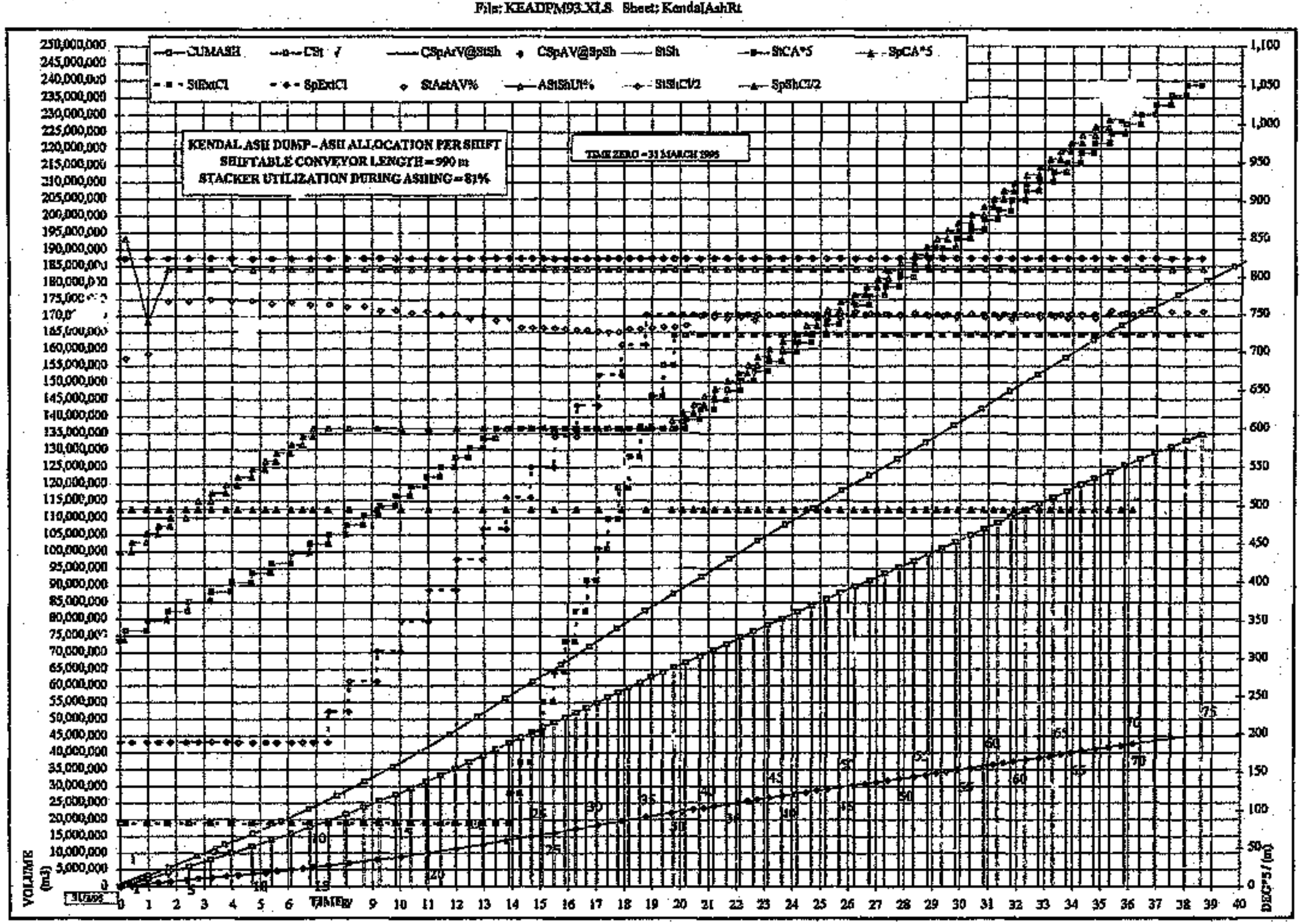


Figure D6 - What-If Evaluation - Current Geometry, (81% Stacker Availability) - Growth Plan.

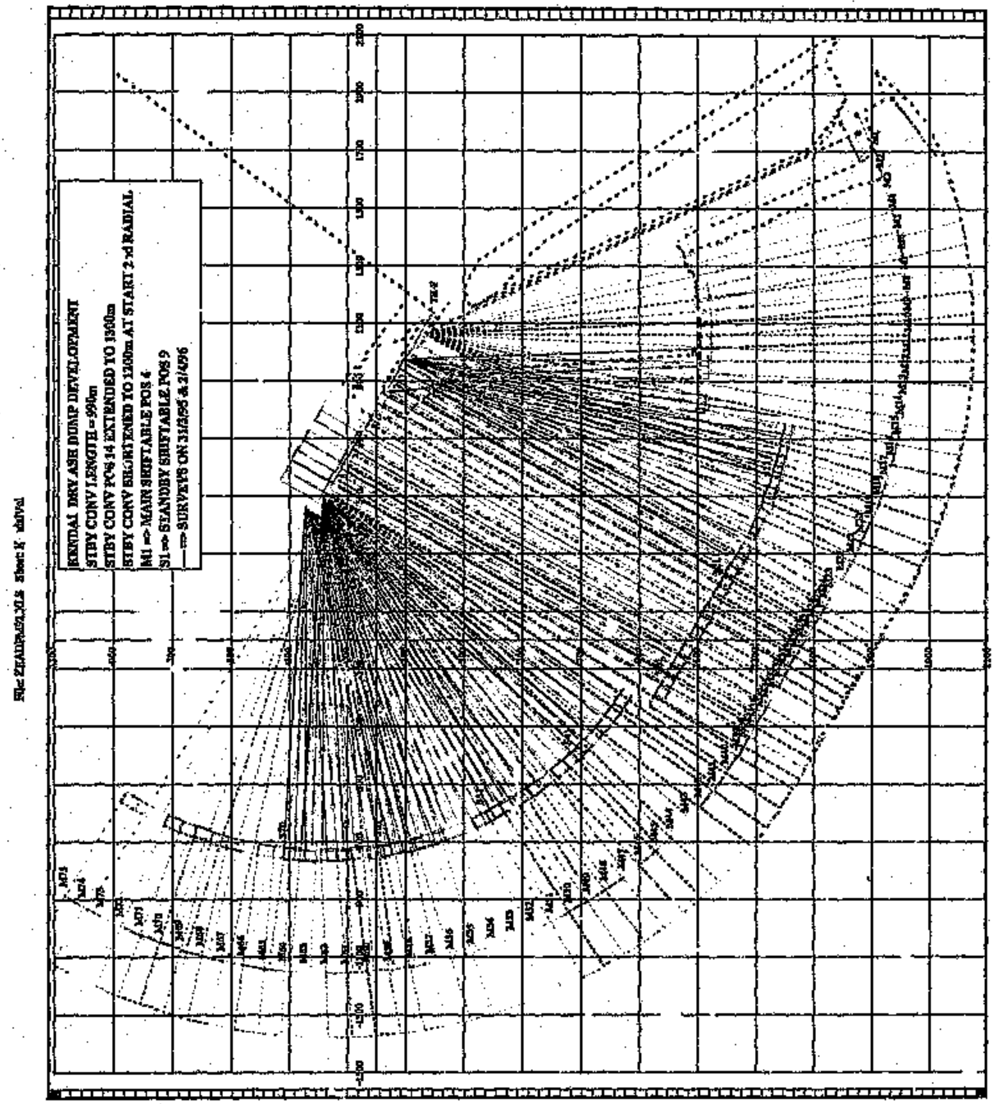


Figure D7 - What-If Evaluation - Extend Standby @ Current Position (70% Stkr. Availability) - Layout Plot.

File: KEADPM92.XLS Sheet: KendalAshRt

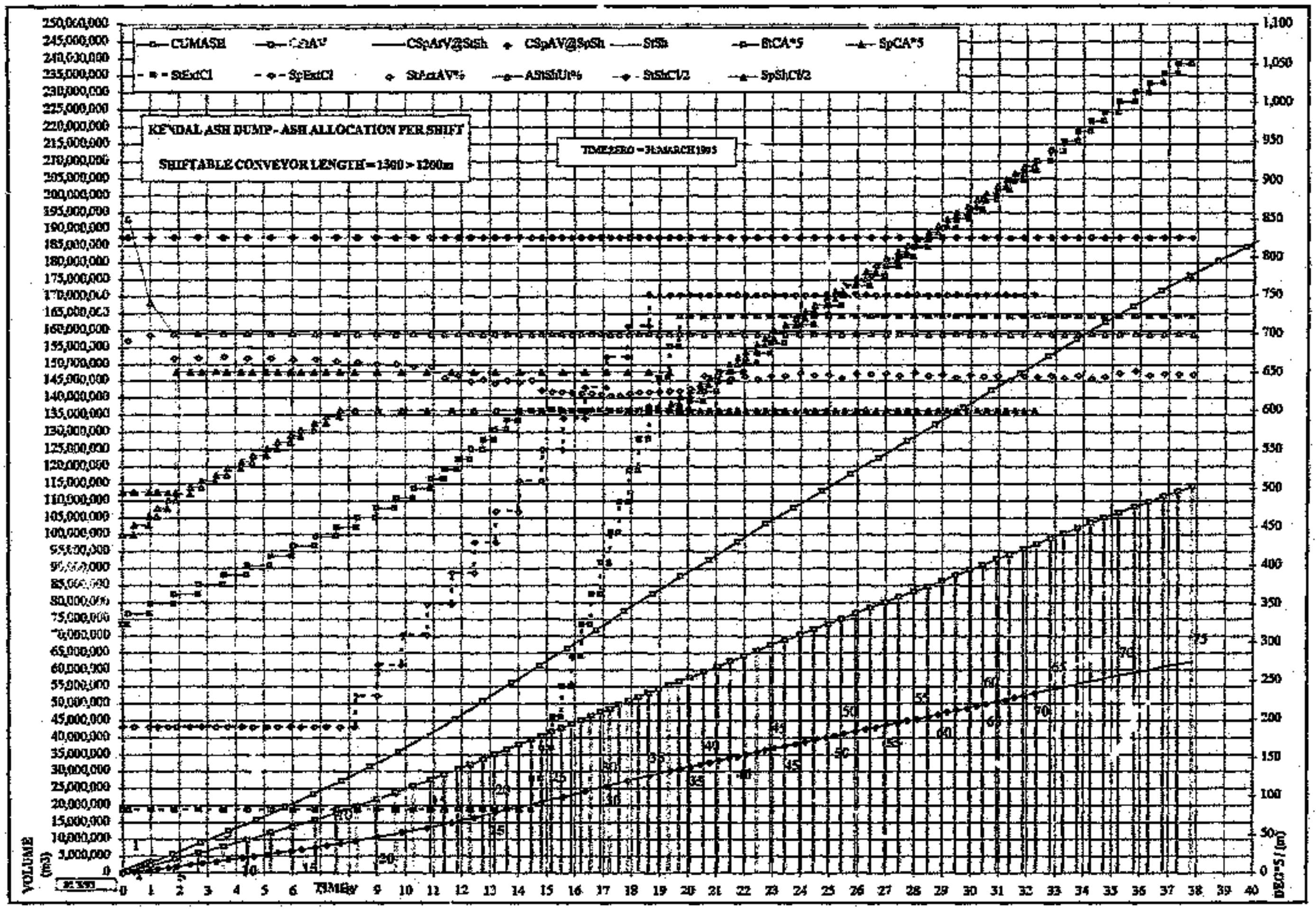


Figure D8 - What-If Evaluation - Extend Standby @ Current Position (70% Stkr. Availability) - Growth Plan.

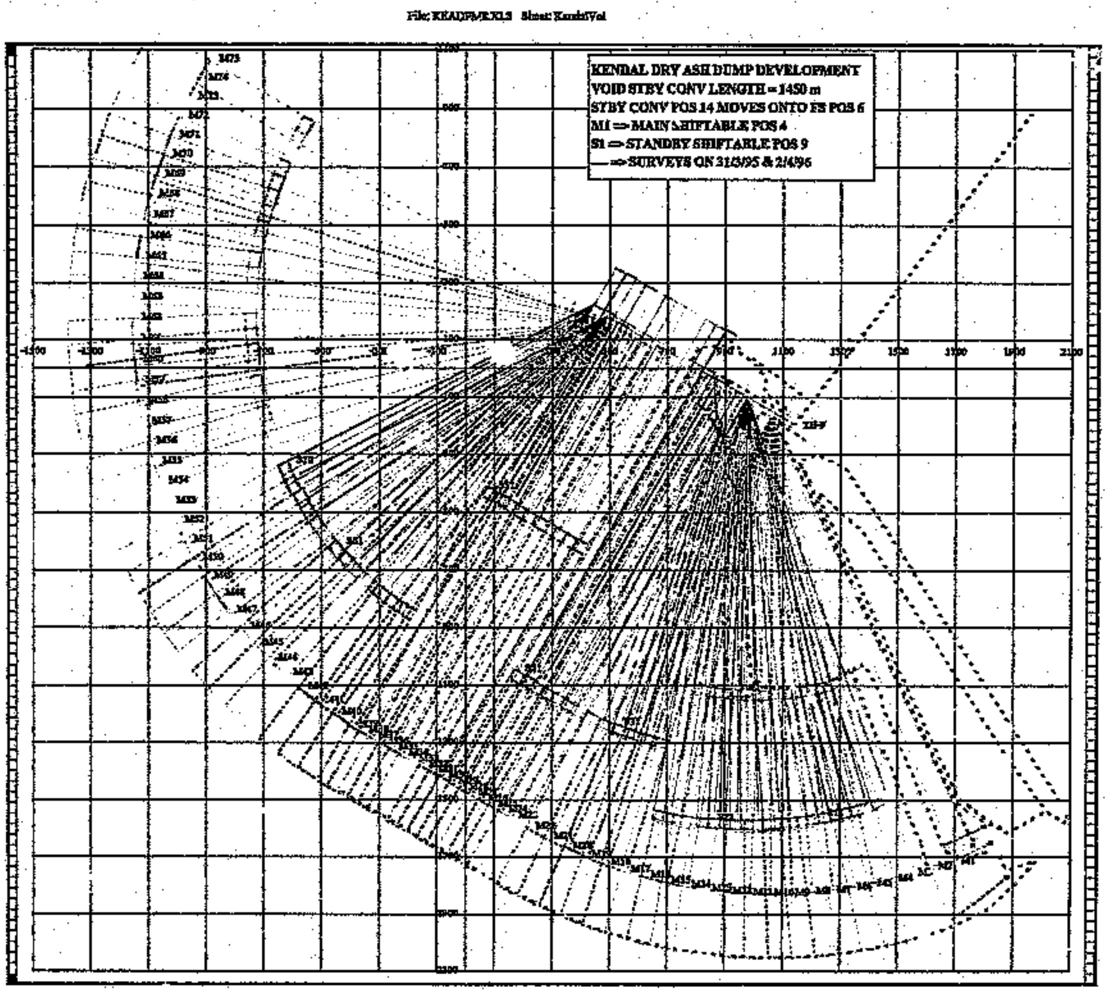


Figure D9 - What-If Evaluation - Shift Back Standby & Extend, Stay in Phase (70% Stkr. Avail'ty) - Layout Plot.

File: KEADPM8.XLS Sheet: KendalAshRt

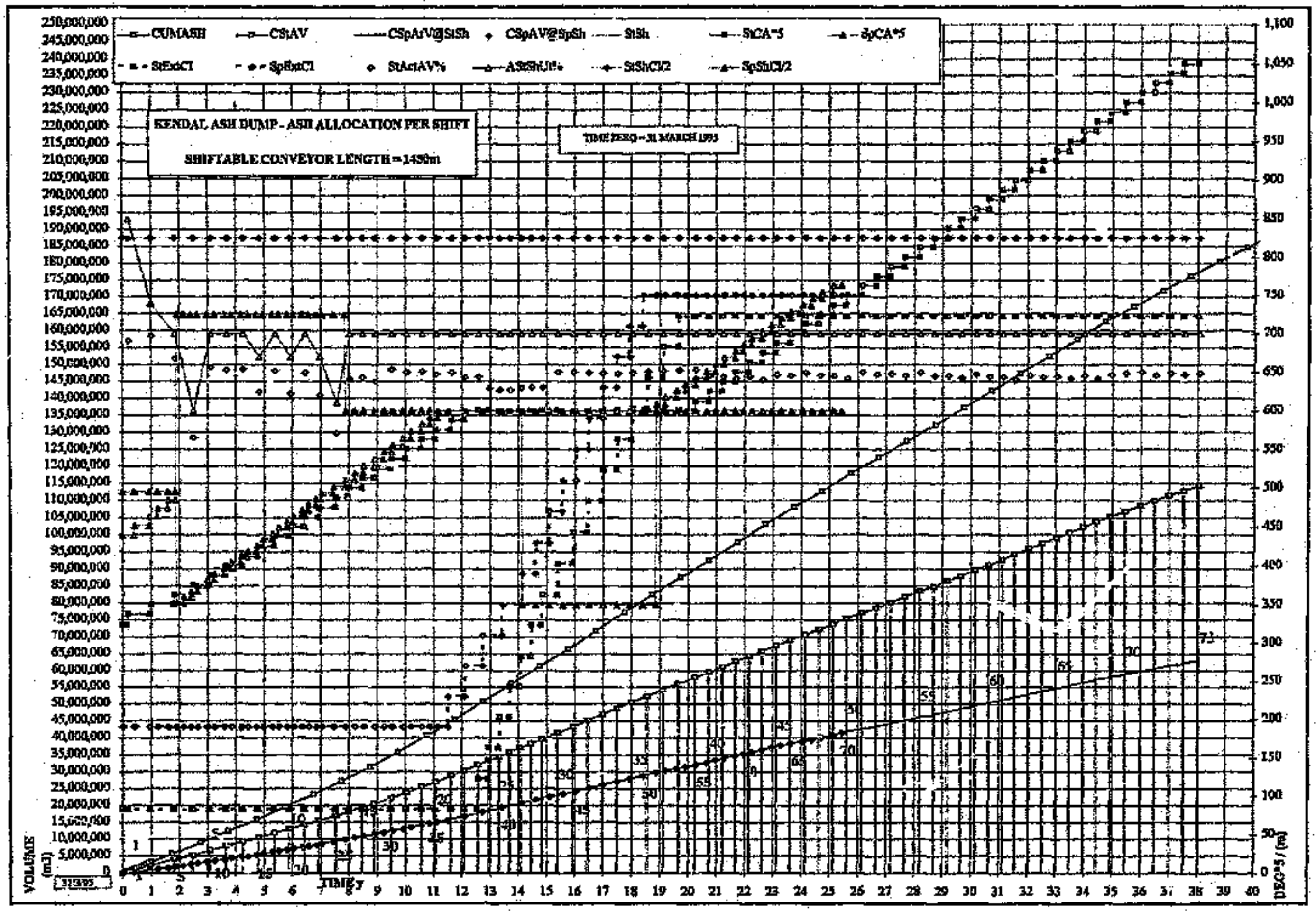


Figure D10 - What-If Evaluation - Shift Back Standby & Extend, Stay in Phase (70% Stkr. Avail'ty) - Growth Plan.

c) Economic Analysis Evaluation Examples

The economic analysis evaluation exercises were done by interpreting the growth plans manually, to check where the main and standby systems were positioned, in the five year intervals. This was done by drawing vertical lines at these points and reading the corresponding baseline angles or extendible conveyor lengths off the right hand axis of the growth plan.

As the intention of this section is to show the information and technique used to extract this information from the growth plan manually, these originally colour plots had to be photostatted to show the manual information. In order to facilitate interpretation of the important information being shown in each case, the use of colour highlighting had to be made.

On the layout plots, a green line shows the standby system shifting sequence and a blue line the main system. A pink line shows the standby shiftable conveyor length at the various stages.

On the growth plan, a solid green line shows the standby system baseline angle, while a dotted green line shows the standby system extendible conveyor length. Similarly a solid blue line shows the main system baseline angle, while a dotted blue line shows the main system extendible conveyor length. A solid pink line shows the standby shiftable conveyor length variation. Orange was used to show the time position manual interpretation.

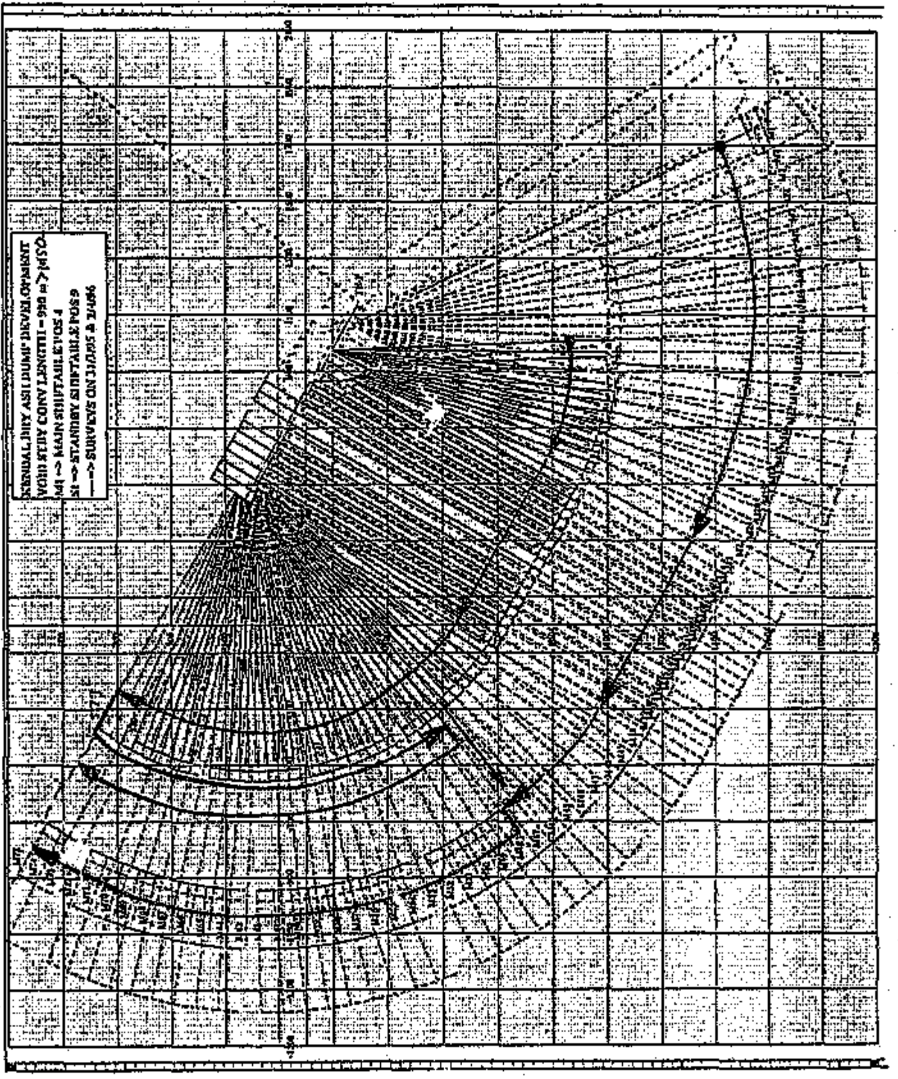


Figure D11 - Economic Evaluation - Current Situation (70% Stacker Availabilit'') - Layout Plot.

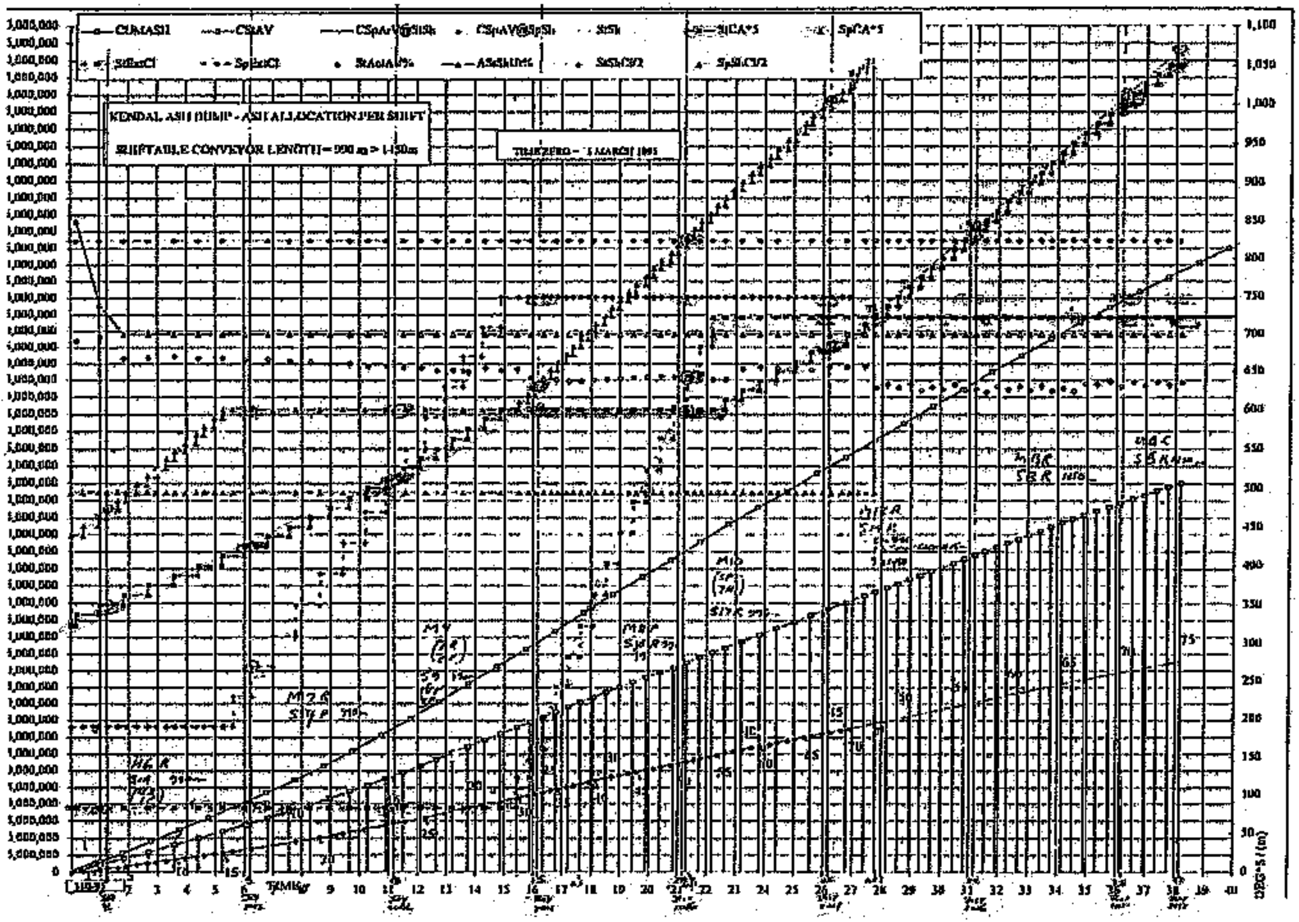


Figure D12 - Economic Evaluation - Current Situation (70% Stacker Availability) - Growth Plan.

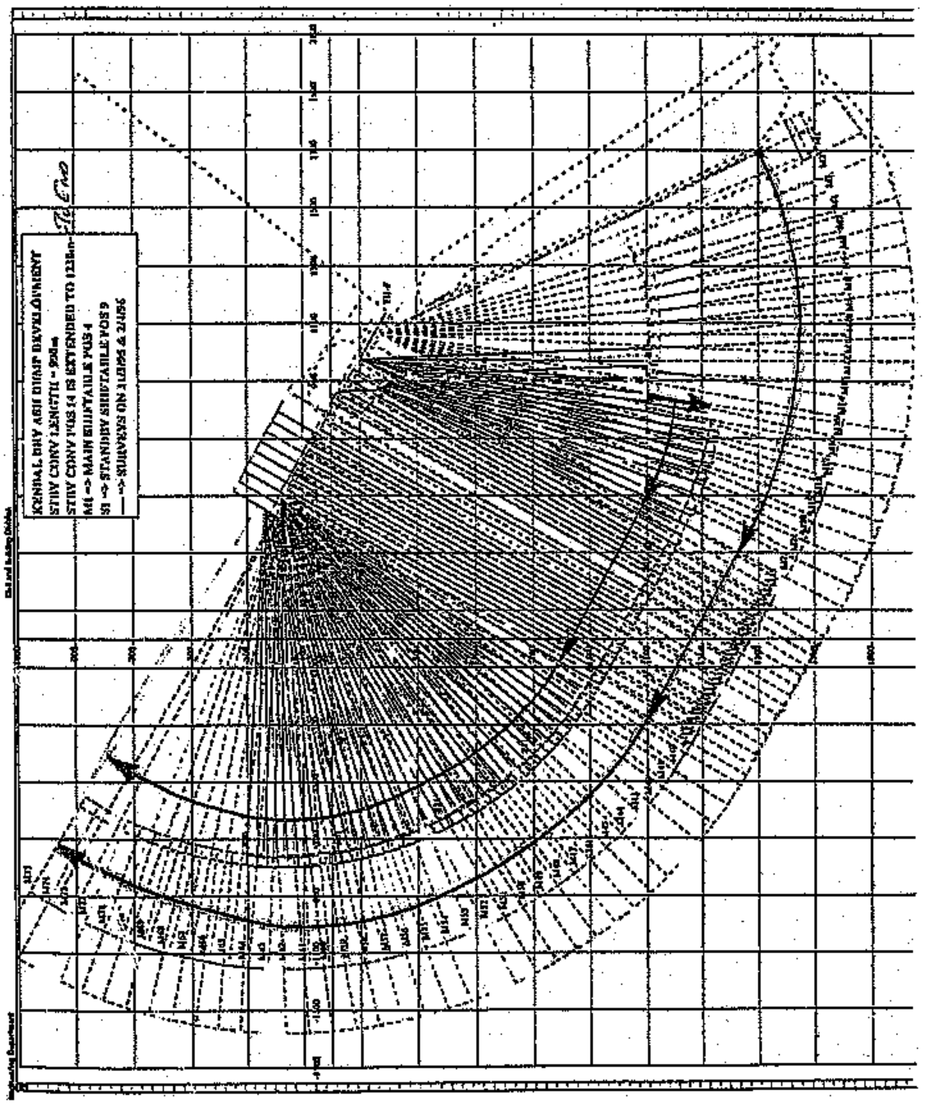


Figure D13 - Economic Evaluation - Extend Standby @ Current Position (70% Stkr. Availability) - Layout Plot.

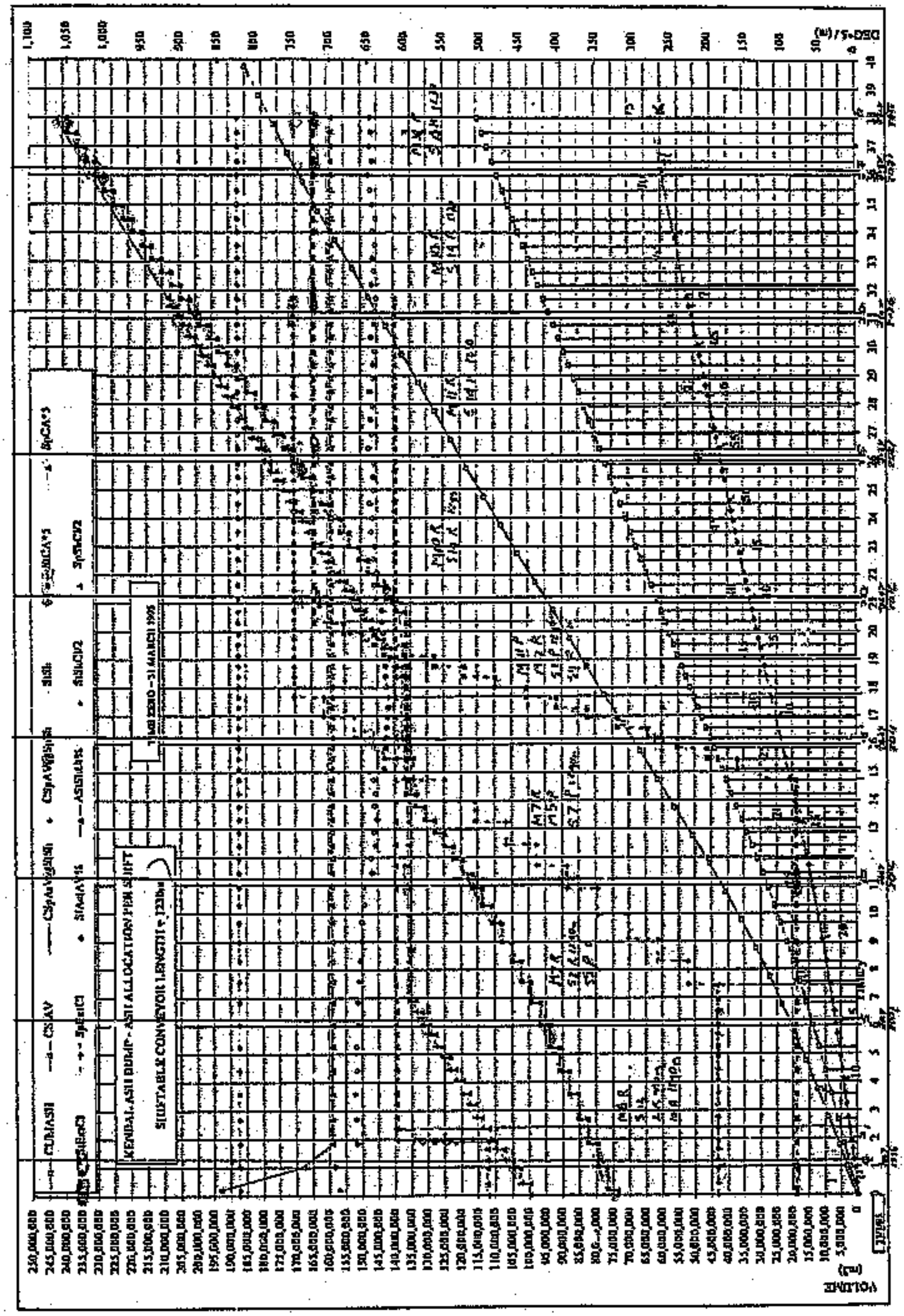


Figure D14 - Economic Evaluation - Extend Standby @ Current Position (70% Stkr. Availability) - Growth Plan.

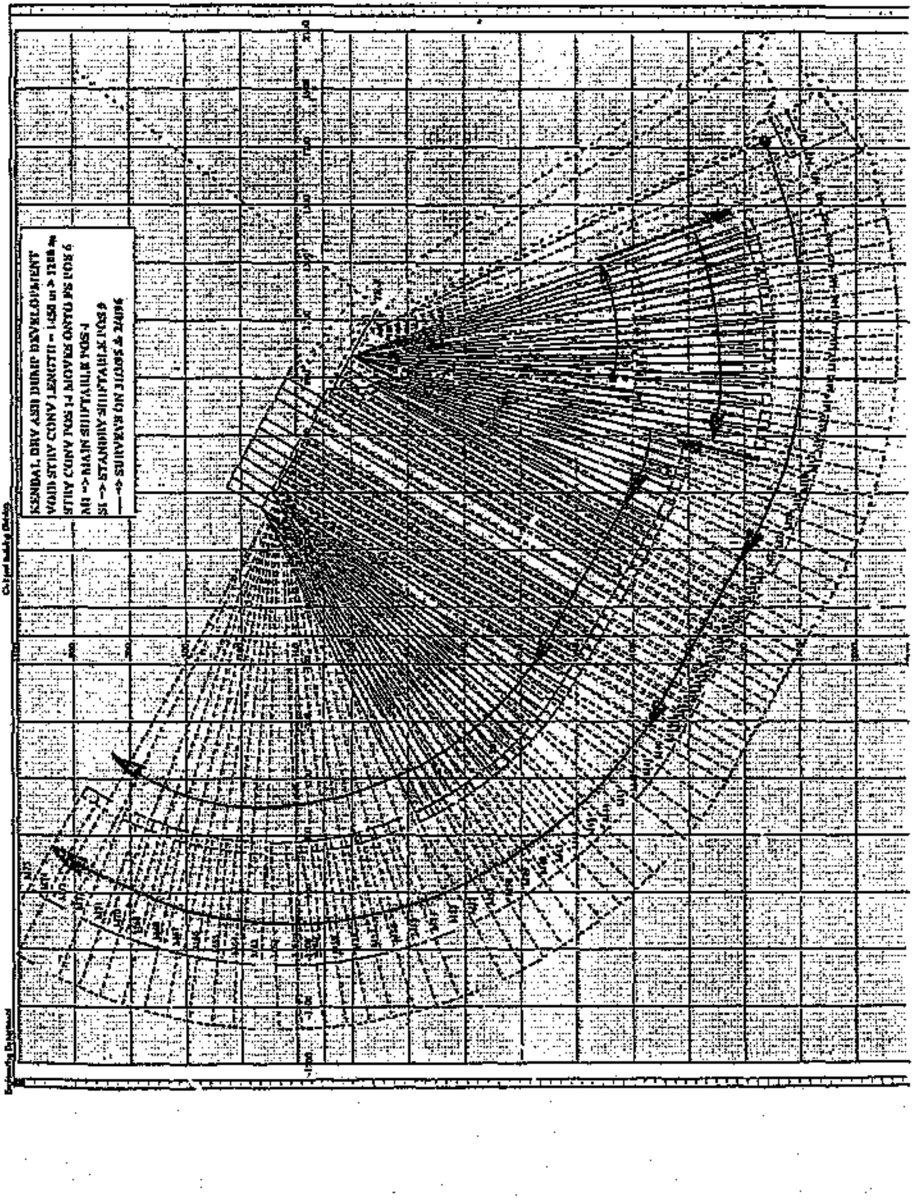


Figure D15 - Economic Evaluation - Shift Back Standby & Extend, (70% Stkr. Avail'ty) - Layout Plot.

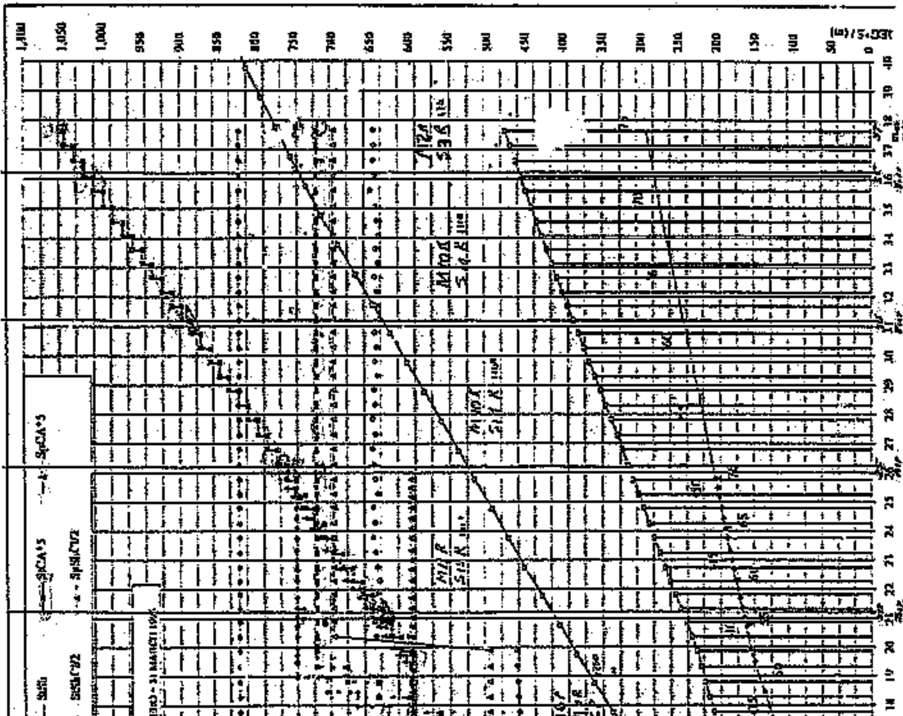


Figure D16 - Economic Evaluation - Shift Back Standby & Extend, (70% Stkr. Avail'ty) - Growth Plan.

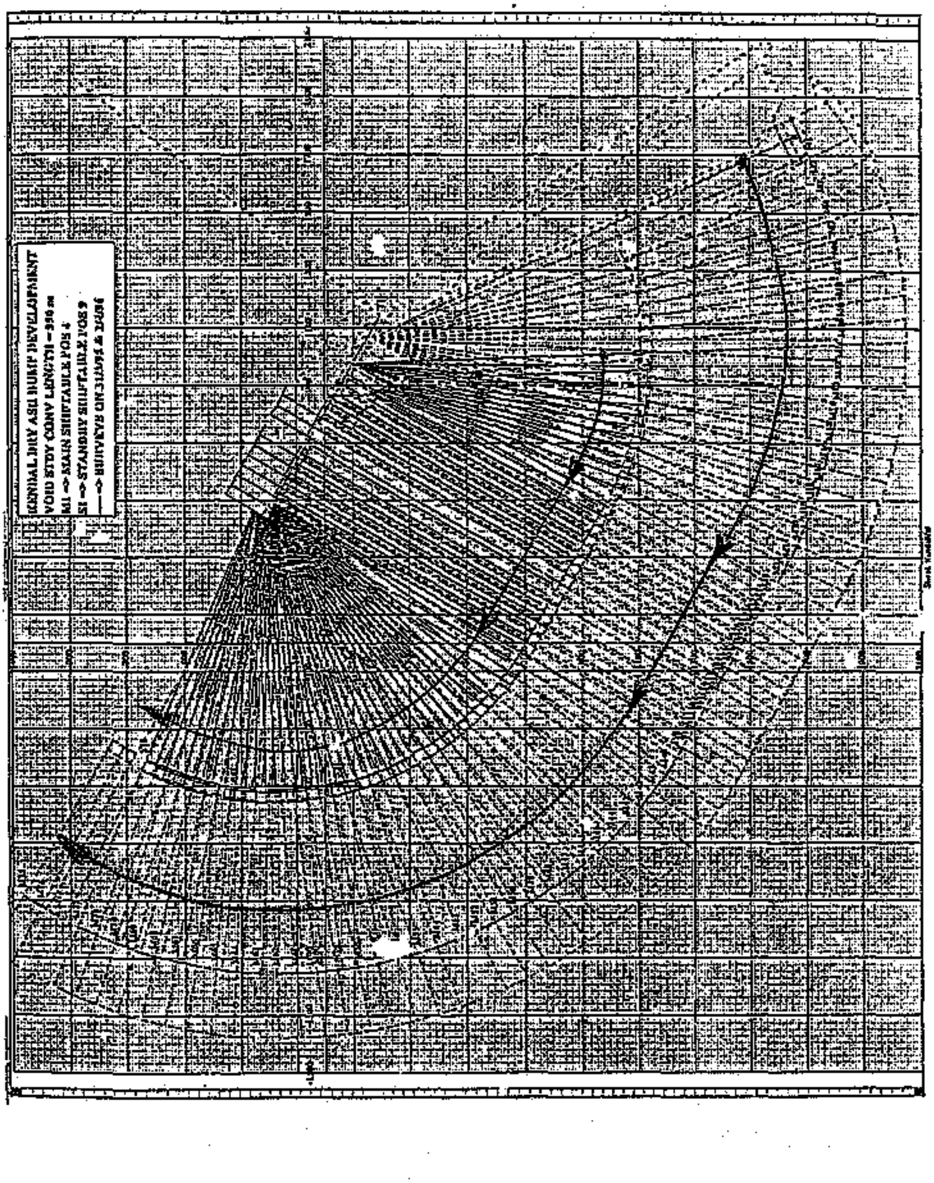


Figure D17 - Economic Evaluation - Current Geometry, (81% Stacker Availability) - Layout Plot.

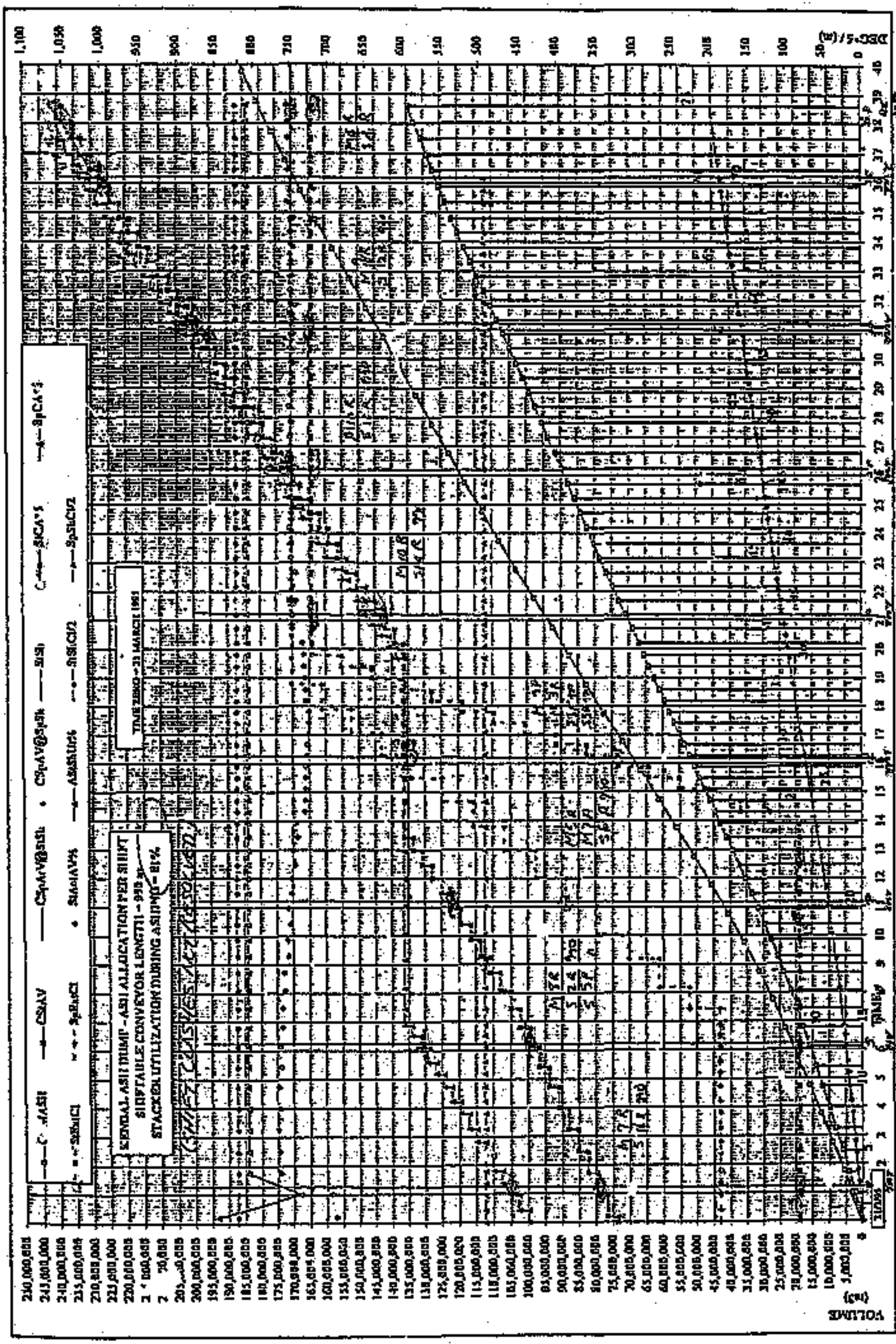


Figure D18 - Economic Evaluation - Current Geometry, (81% Stacker Availability) - Growth Plan.

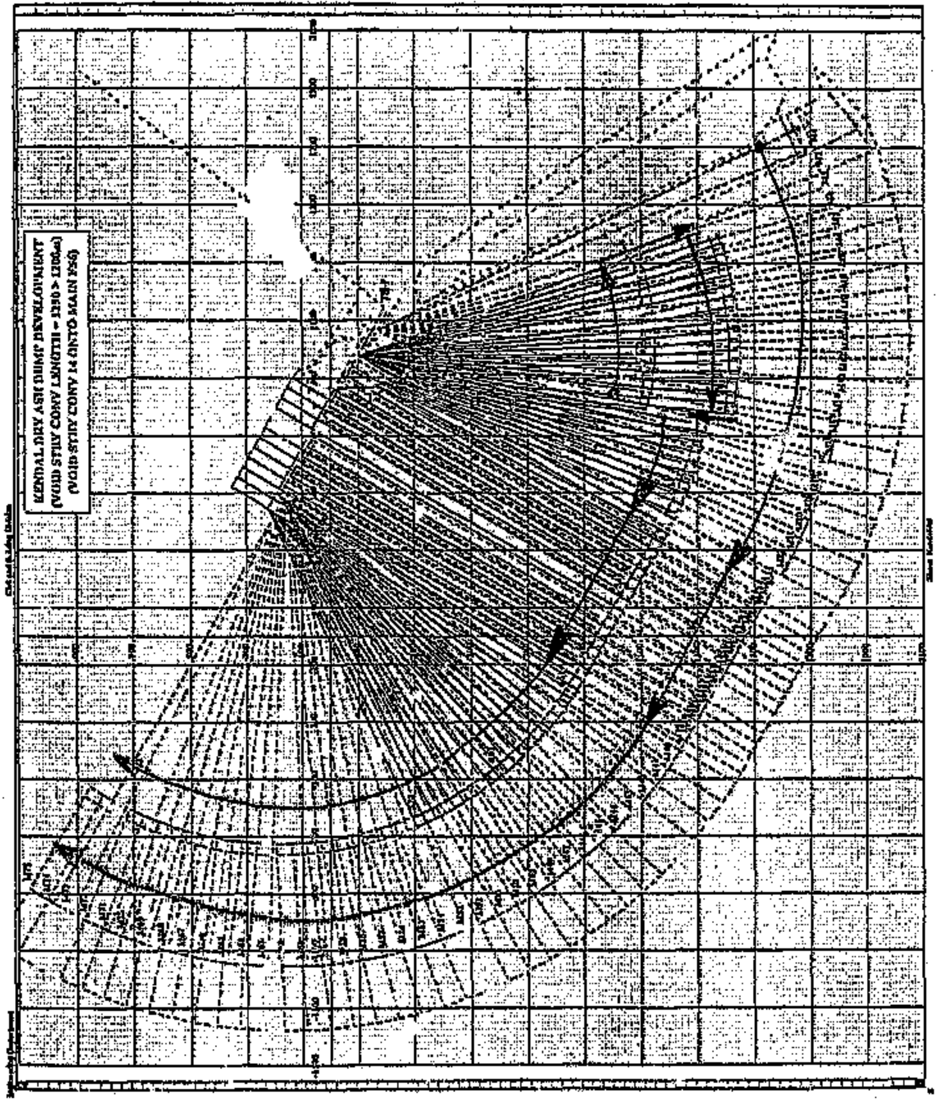


Figure D19 - Economic Evaluation - Shift Back Standby &
Extend, (81% Stkr. Availability) - Layout Plot.

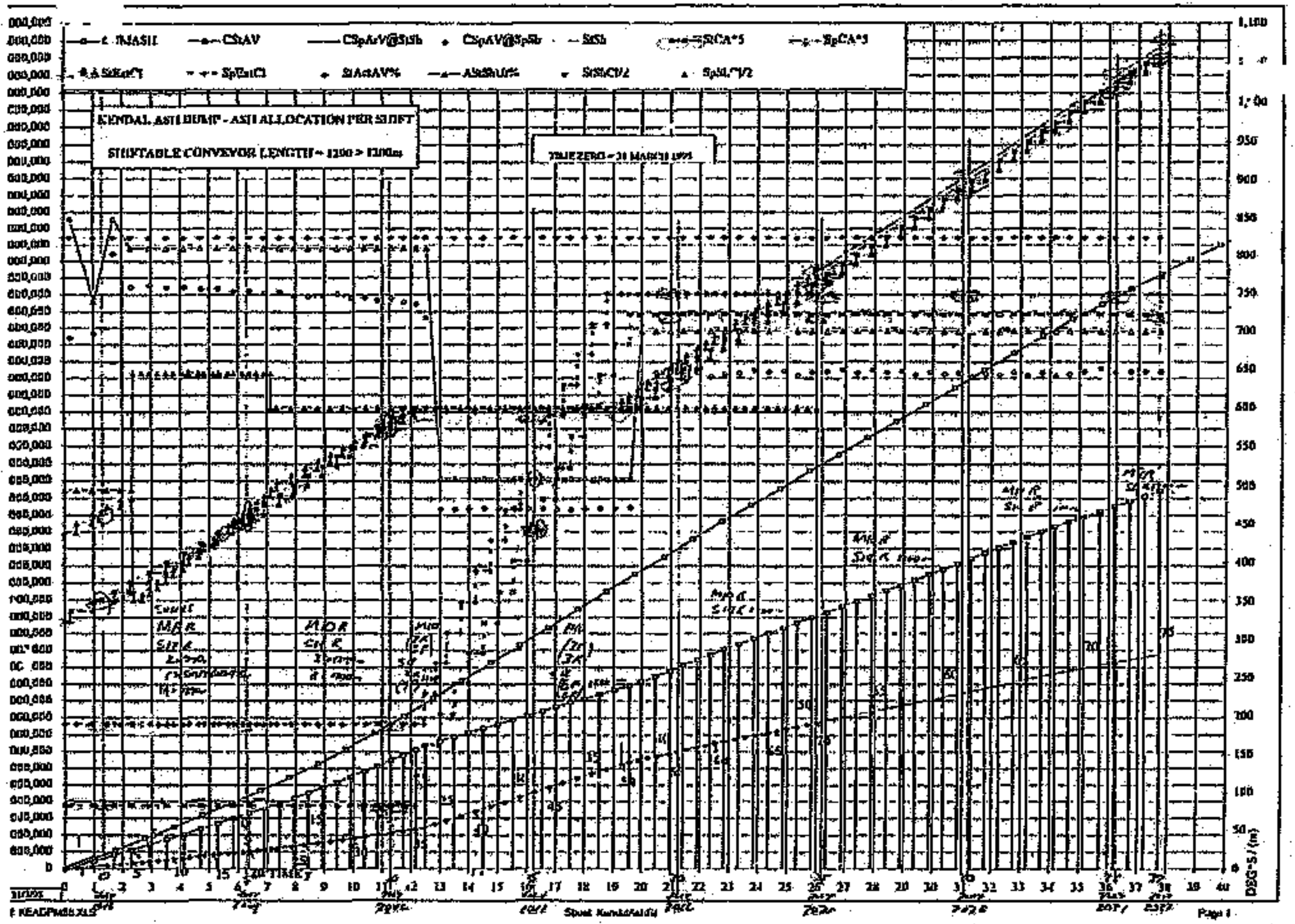


Figure D20 - Economic Evaluation - Shift Back Standby & Extend, (81% Stkr. Availability) - Growth Plan.

d) Sensitivity Analysis Evaluation Examples

The sensitivity analysis evaluation exercises were done by interpreting the growth plans manually, to check where the main and standby systems were positioned at the time the main system caught up with the standby system. The main system graphs were allowed to cross over the standby system, even though this is physically impossible, as only the point of catching up was of interest in this case, not the remaining dump performance.

As the intention of this section is to show the information and technique used to extract this information from the growth plan manually, these originally colour plots had to be photostatted to show the manual information. In order to facilitate interpretation of the important information being shown in each case, the use of colour highlighting had to be made.

On the layout plot, a green line shows the standby system shifting sequence and a blue line the main system.

On the growth plans, a solid green line shows the standby system baseline angle, while a dotted green line shows the standby system extendible conveyor length. Similarly a solid blue line shows the main system baseline angle, while a dotted blue line shows the main system extendible conveyor length. Yellow was used to show the manual interpretation of the time taken for the main system to catch up with the standby system.

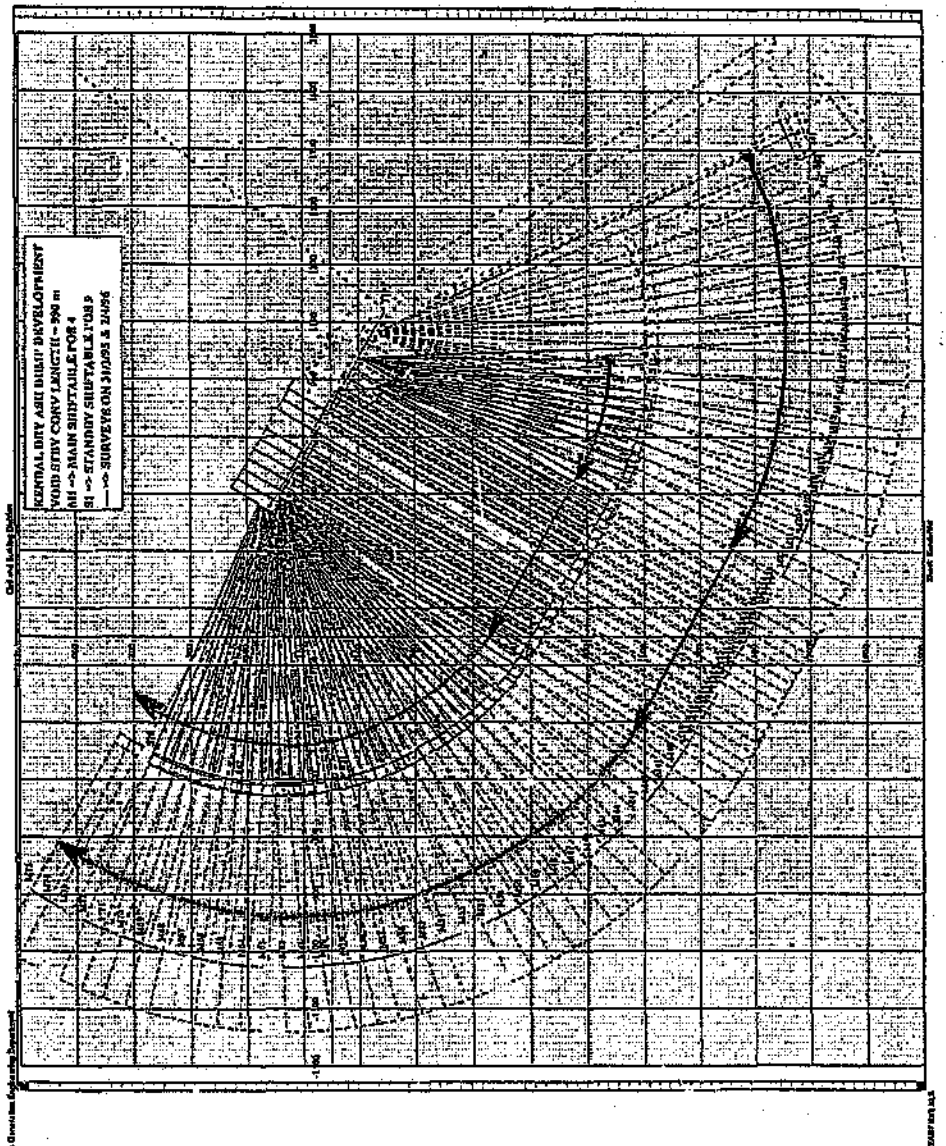


Figure D21 - Sensitivity Evaluation - Layout Plot.

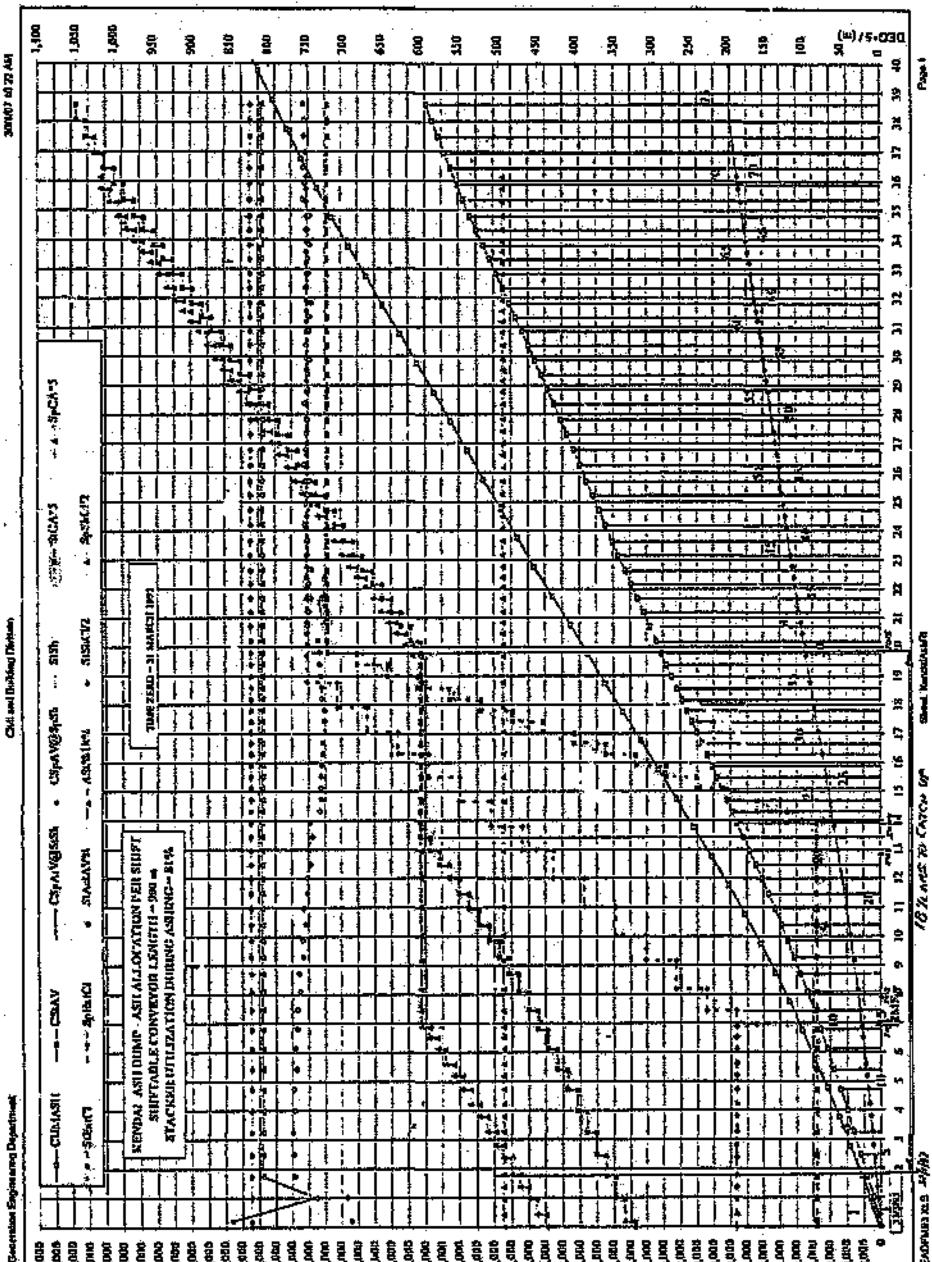


Figure D22 - Sensitivity Evaluation - (81% Stacker Availability) - Growth Plan.

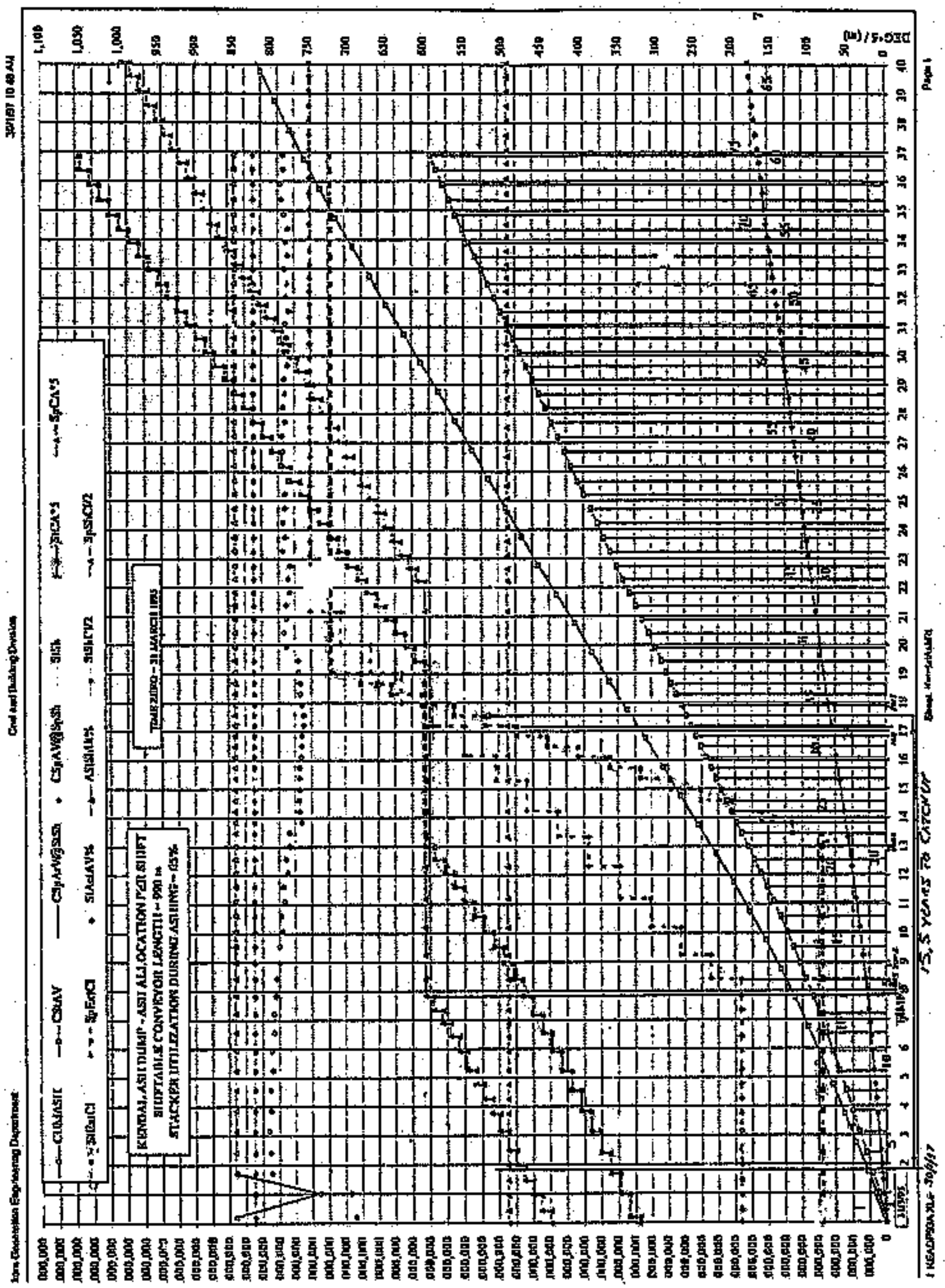


Figure D23 - Sensitivity Evaluation - (85% Stacker Availability) - Growth Plan.

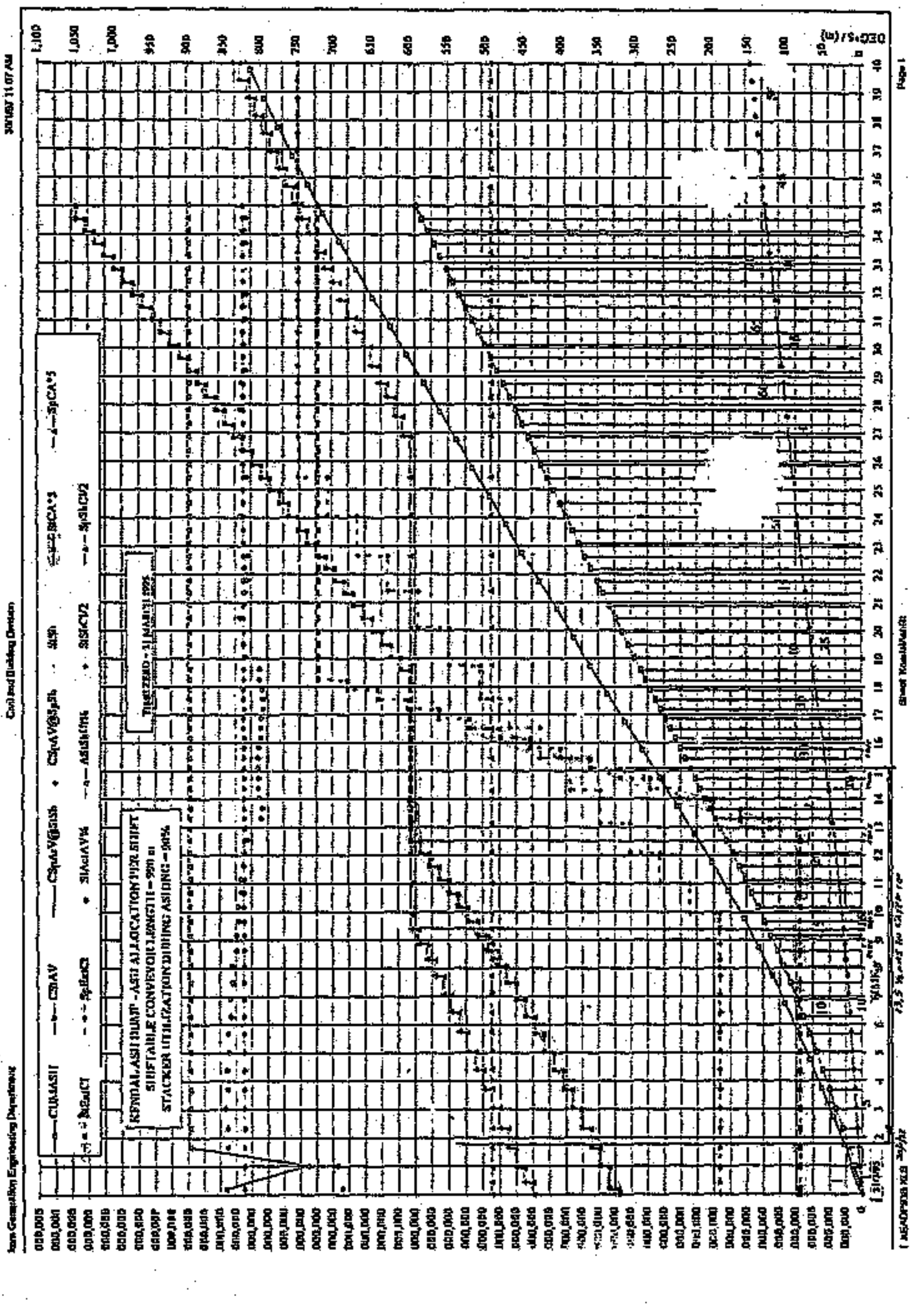


Figure D24 - Sensitivity Evaluation - (90% ker Availability) - Growth Plan.

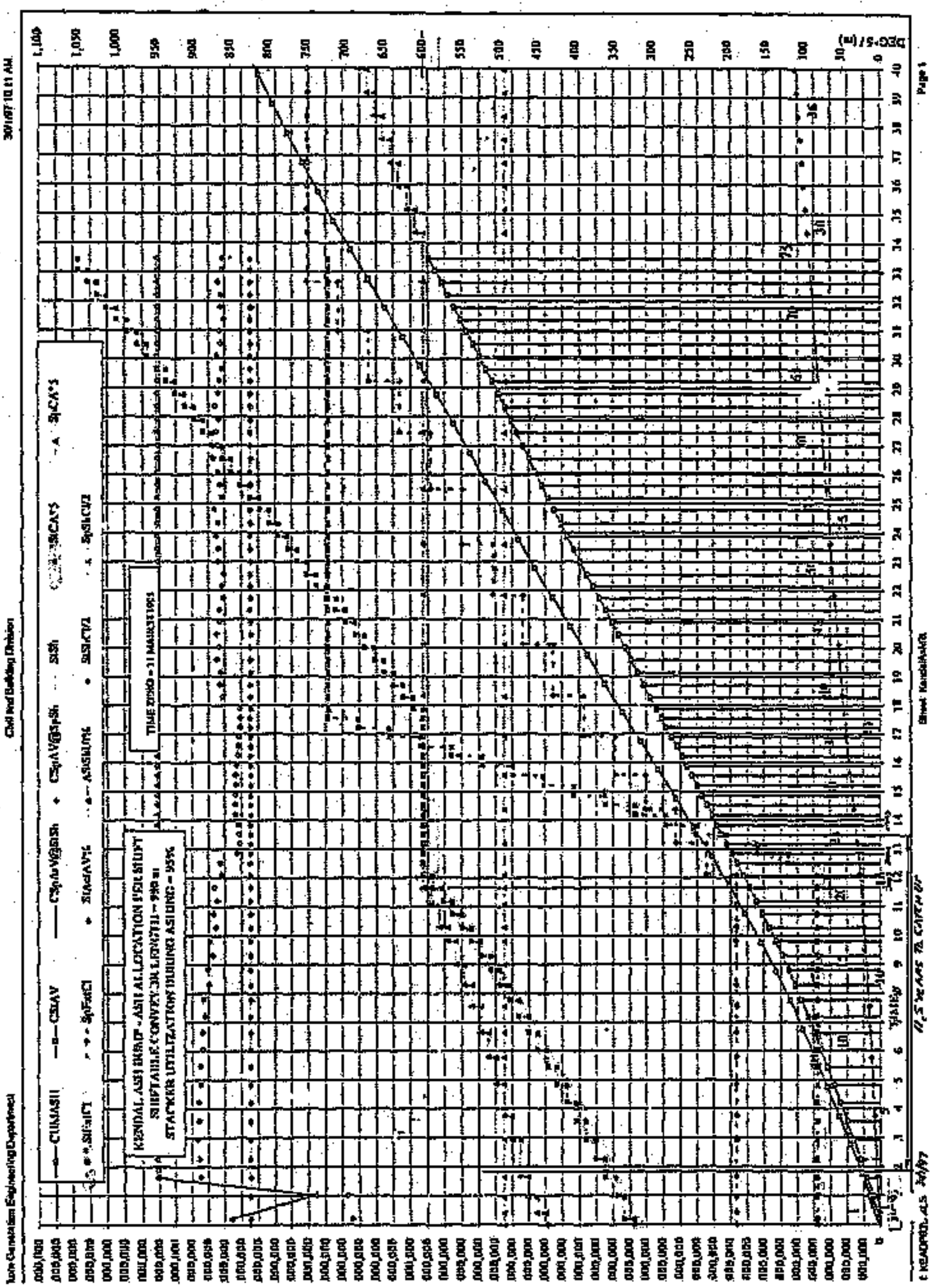


Figure D25 - Sensitivity Evaluation - (95% Stacker Availability) - Growth Plan.

TABLE 1 - KENDAL ASH DUMP - STACKER CATCH UP PERIOD

STACKER AVAILABILITY DURING ASHING (%)	TIME TO CATCH UP (Yrs)	SPREADER END RADIAL TO BEGIN PARALLEL (Yrs)	STACKER END RADIAL TO BEGIN PARALLEL (Yrs)	NOTE: The stacker catch up period is the time for the stacker system to catch up within
81	18	5.5	12	one shift behind the spreader system as a function of the stacker availability during ashing.
85	15.5	6.5	11.5	The stacker system shift time was 14 days and the spreader system 8 days for this evaluation.
90	13.5	8	11	Catch up periods rounded to the nearest half year.
95	11.5	10	10.5	Time zero is 30 January 1997.
81	17			Stacker system shift time = 10 days
85	14.5			
90	12.5			
95	10.5			Stacker system shift time = 10 days

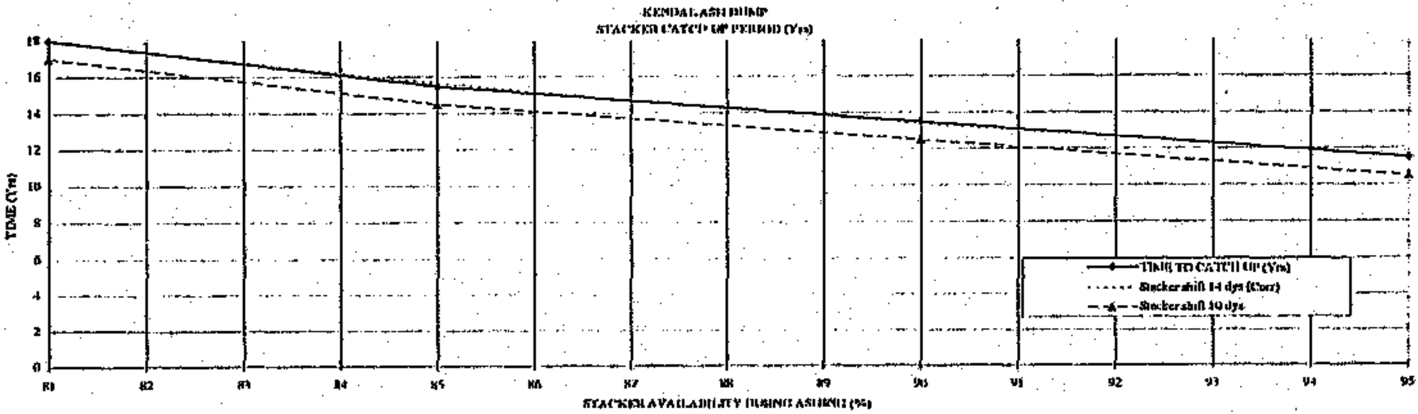


Figure D26 - Sensitivity Evaluation - Stacker Availability versus Time to Catch Up Graph.

APPENDIX E TIME-POSITION LAYOUT EXAMPLES

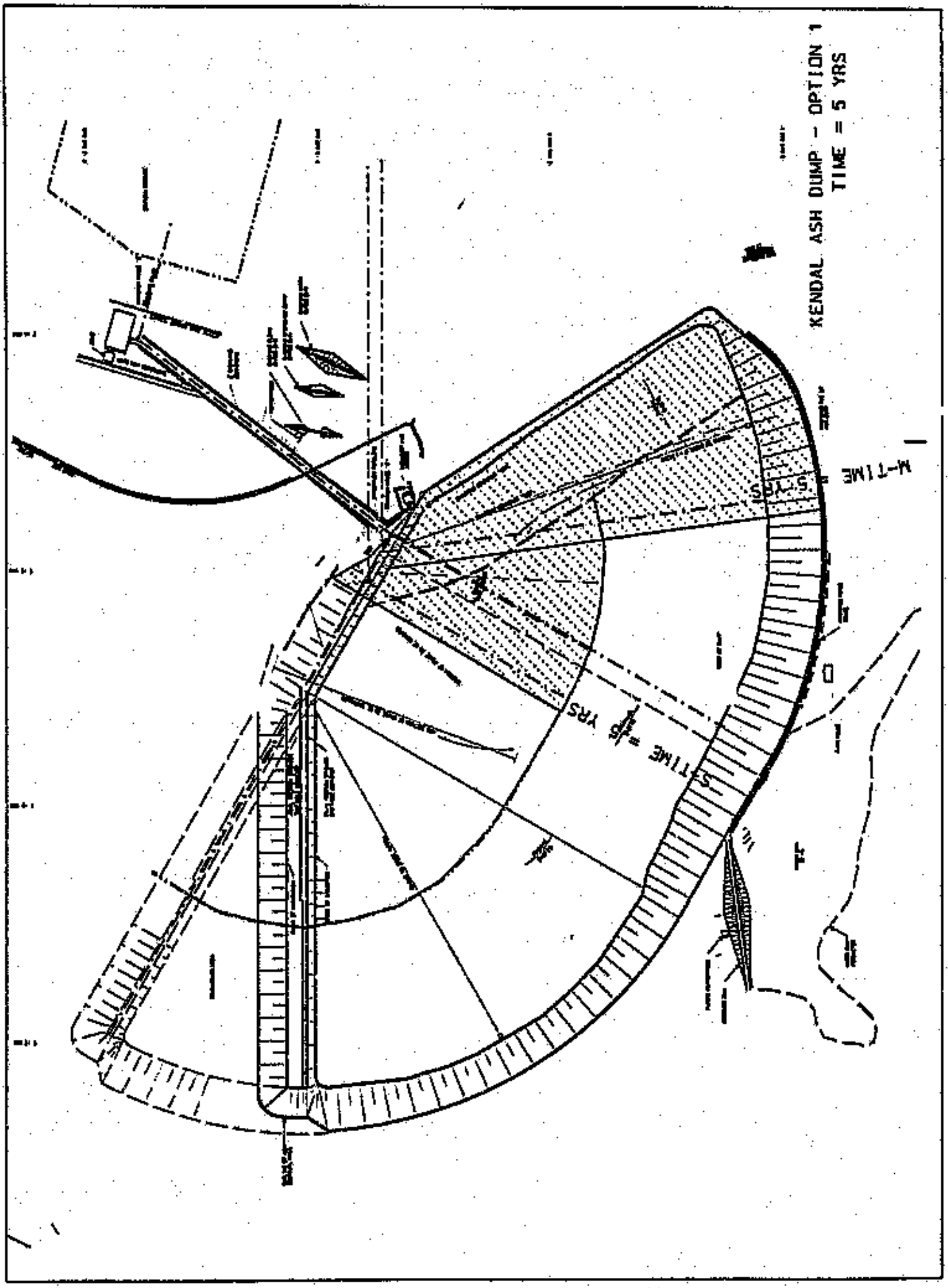


Figure E1 - Time-Position Plot - Economic Evaluation, Current Geometry (70% Stkr. Avail'ty) Time = 5 Yrs.

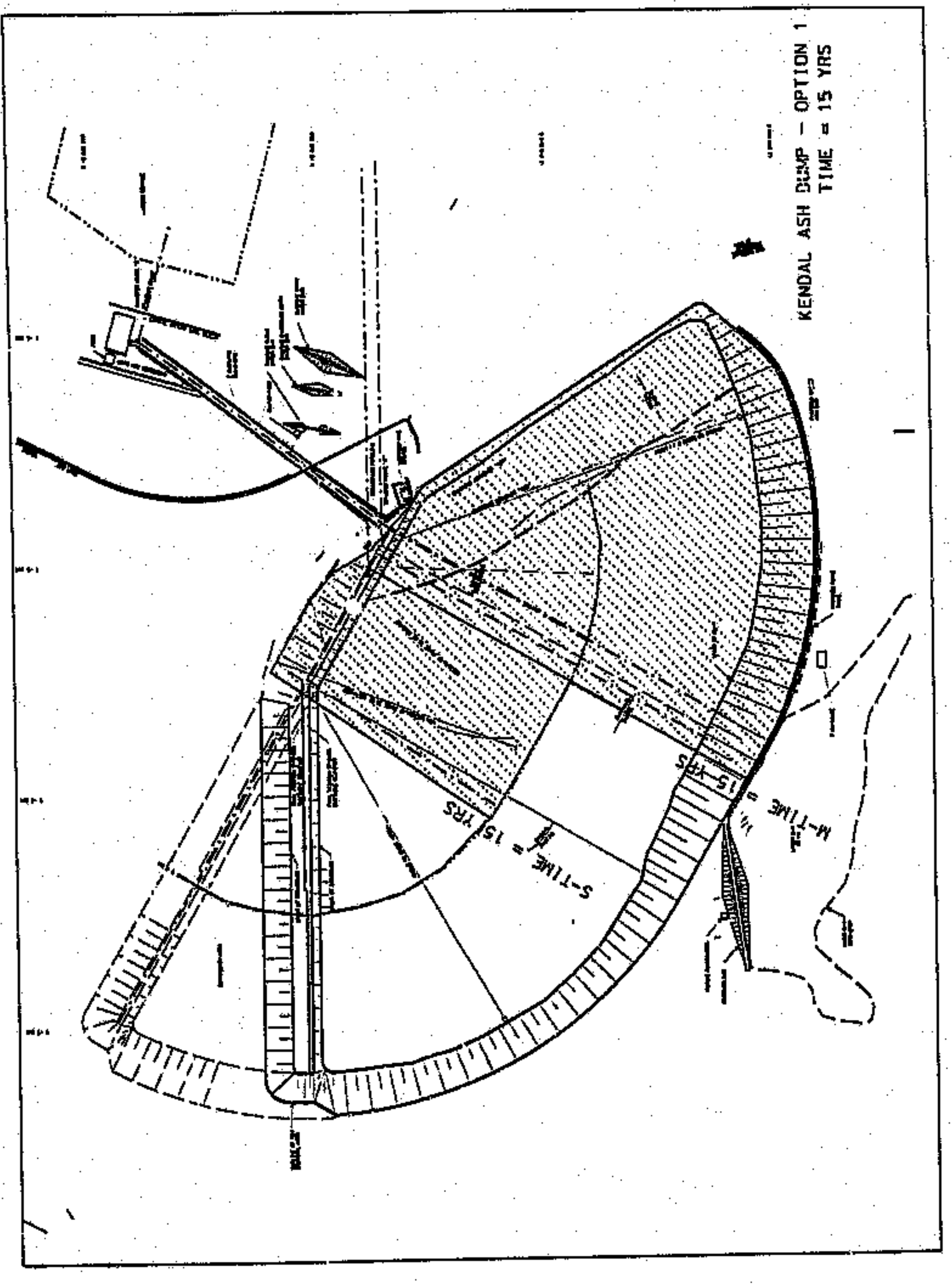


Figure E2 - Time-Position Plot - Economic Evaluation, Current Geometry (70% Stkr. Avail'ty) Time = 15 Yrs.

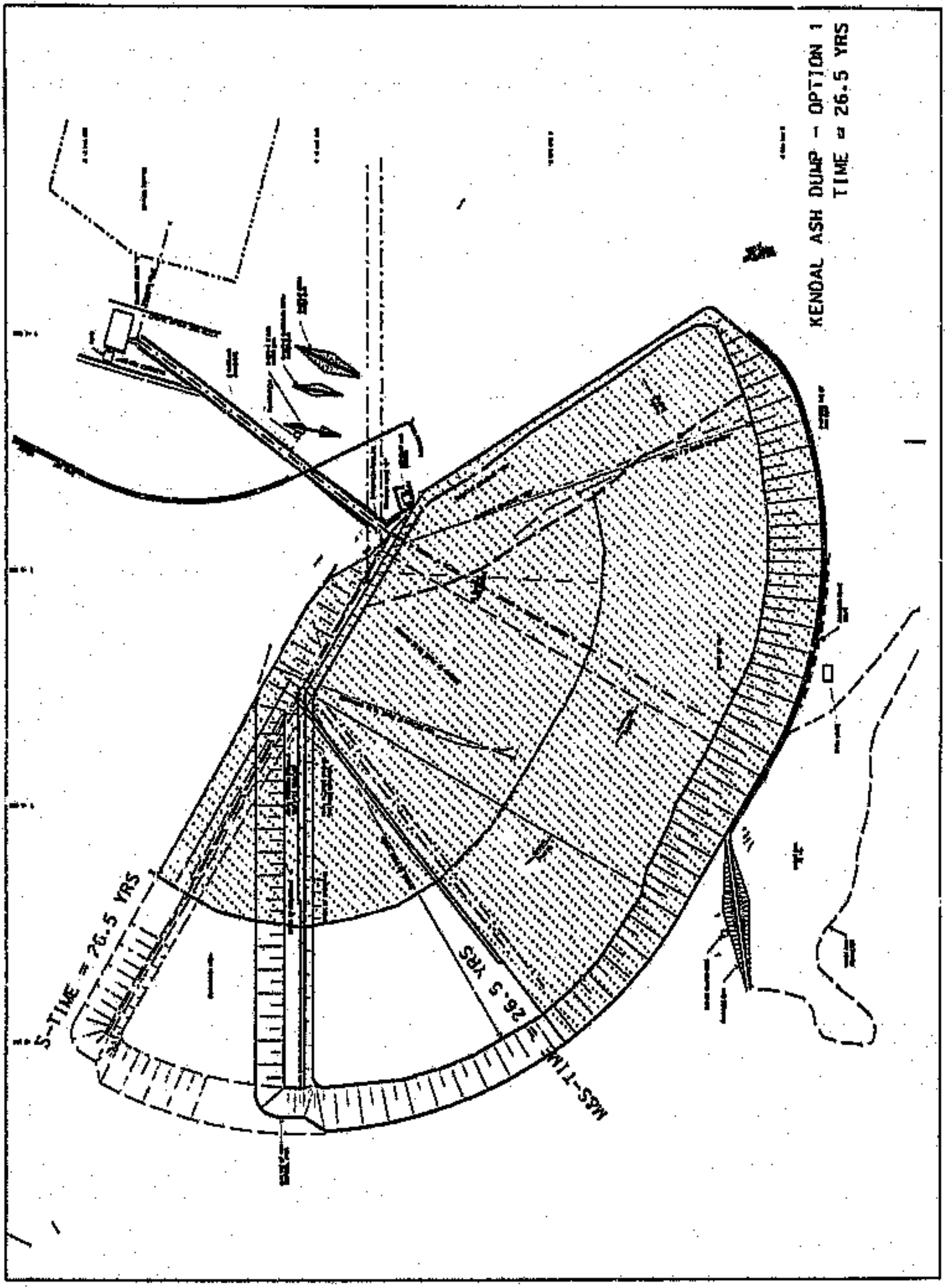


Figure E3 - Time-Position Plot - Economic Evaluation, Current Geometry (70% Stkr. Avail'ty) Time = 26.5 Yrs.

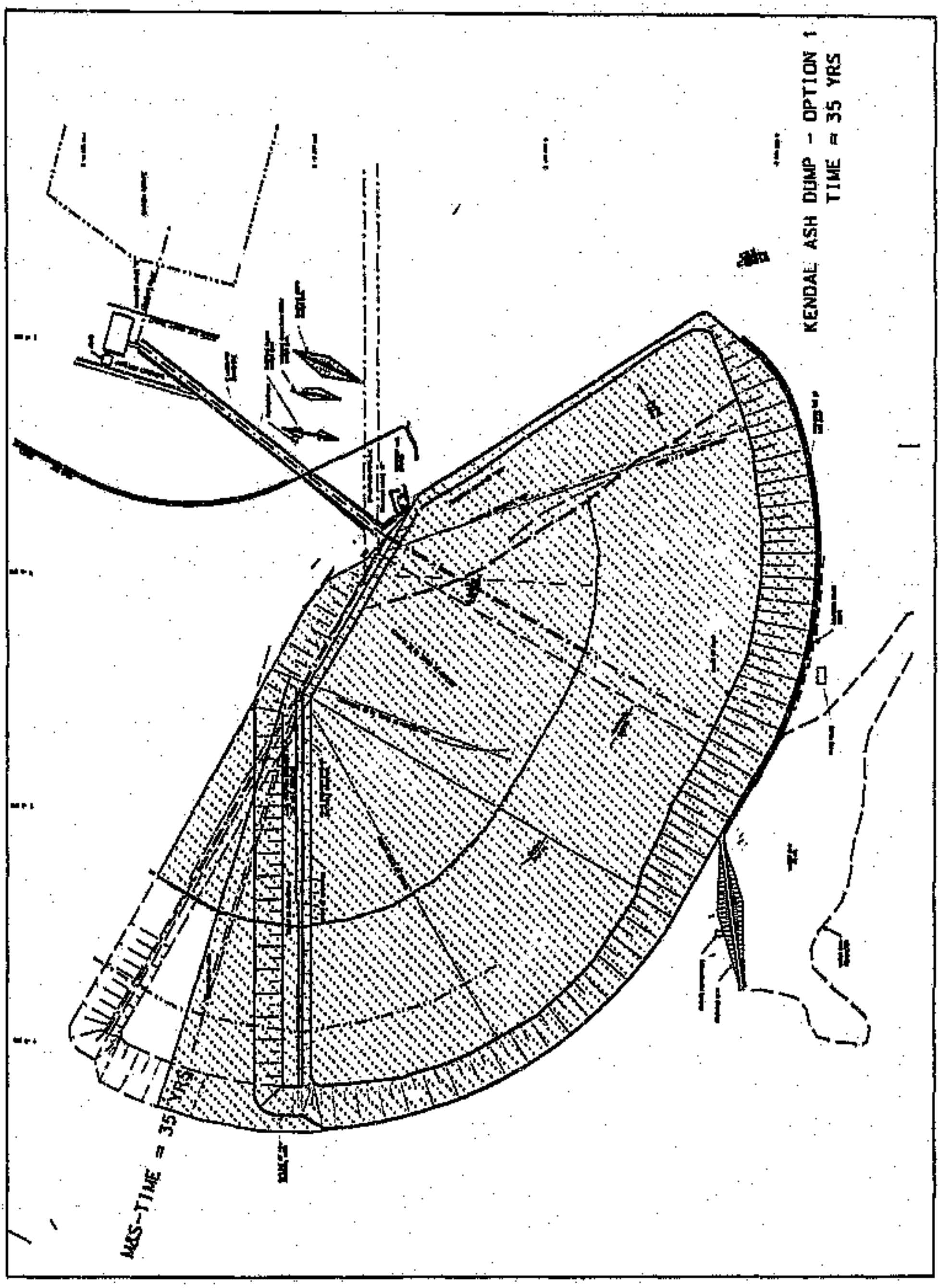


Figure E4 - Time-Position Plot - Economic Evaluation, Current Geometry (70% Stkr. Avail'ty) Time = 35 Yrs.

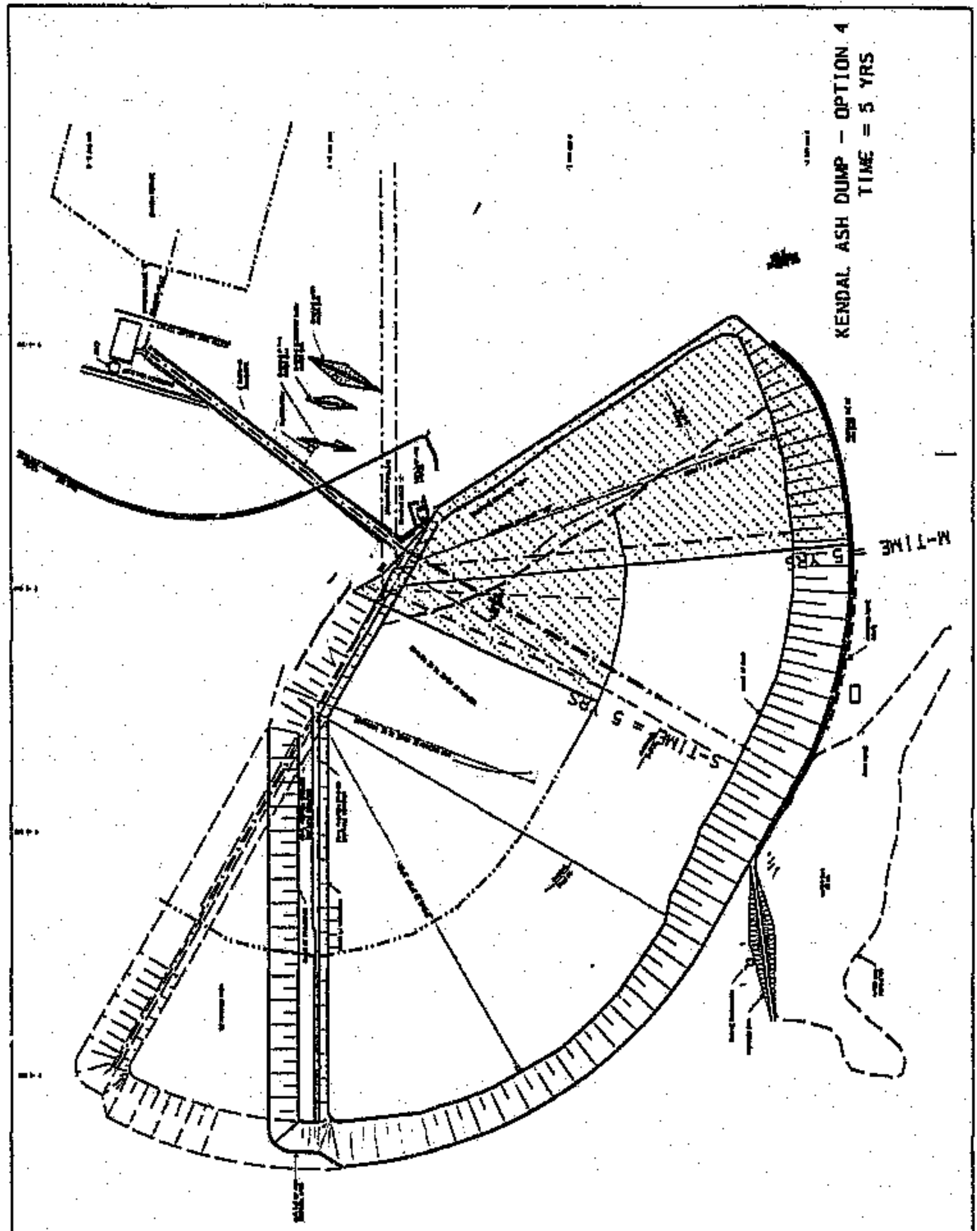


Figure E5 - Time-Position Plot - Economic Evaluation, Current Geometry (81% Stkr. Avail'ty) Time = 5 Yrs.

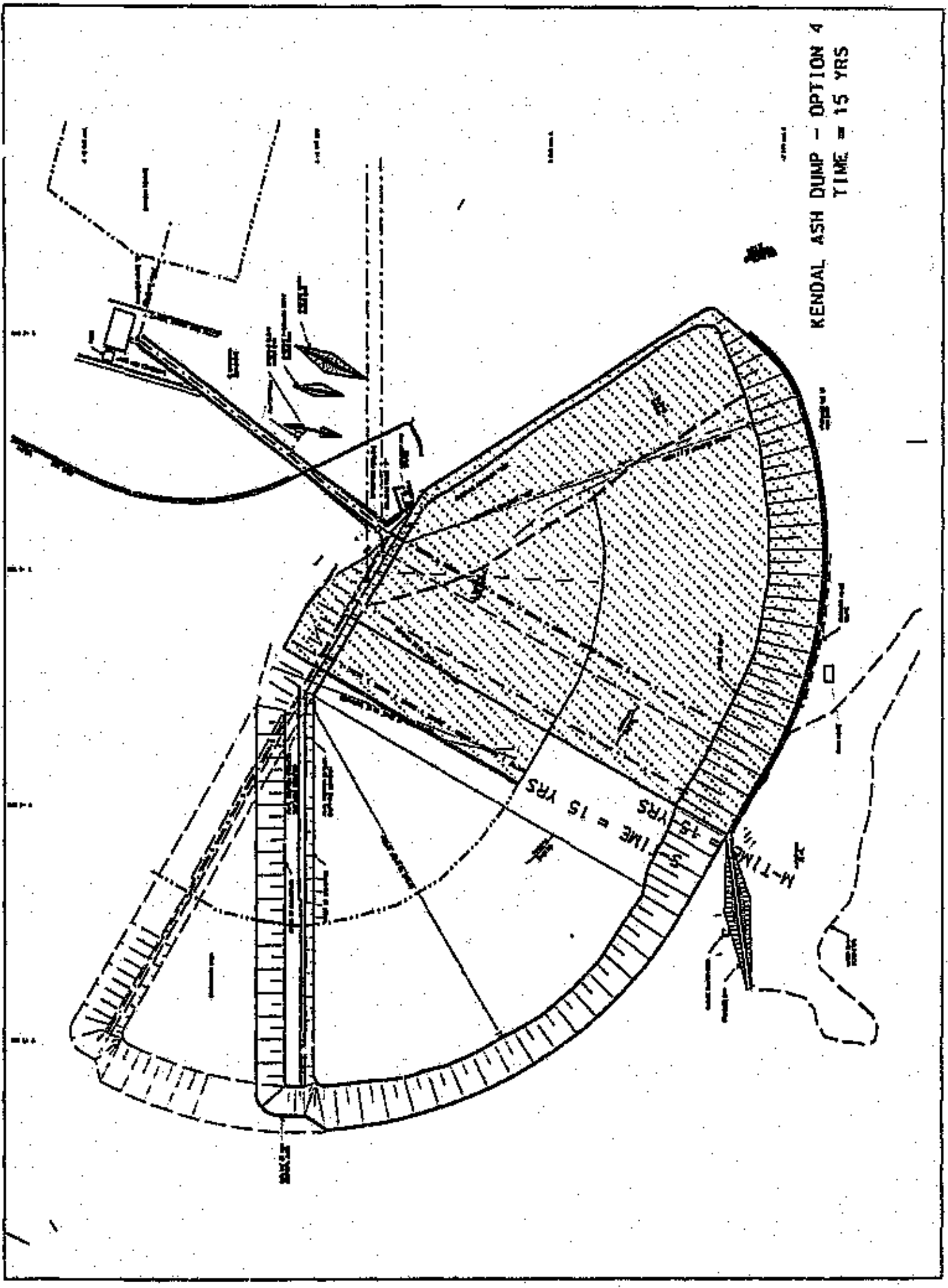


Figure E6 - Time-Position Plot - Economic Evaluation, Current Geometry (81% Stkr. Avail'ty) Time = 15 Yrs.

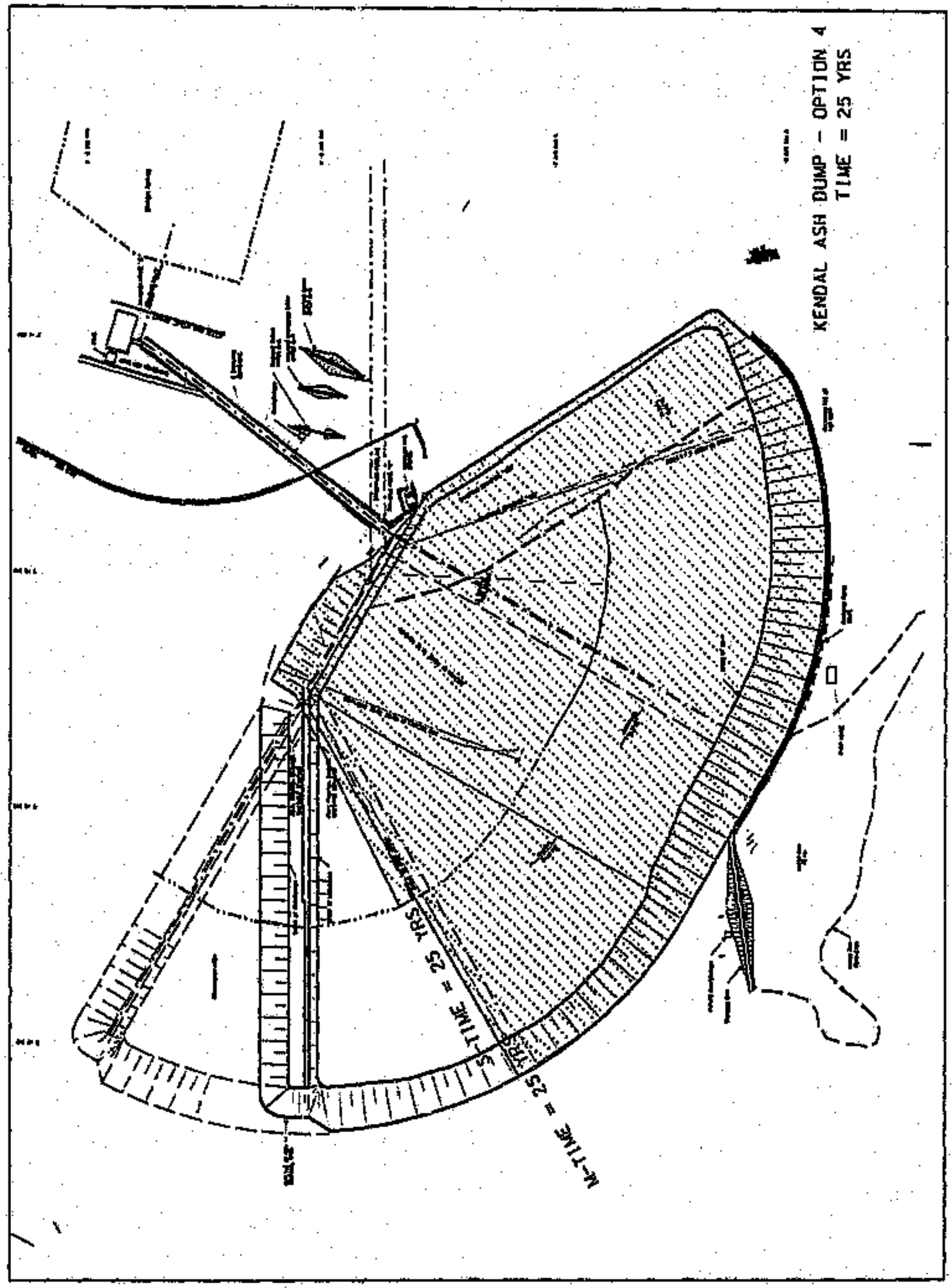


Figure E7 - Time-Position Plot - Economic Evaluation, Current Geometry (81% Stkr. Avail'ty) Time = 25 Yrs.

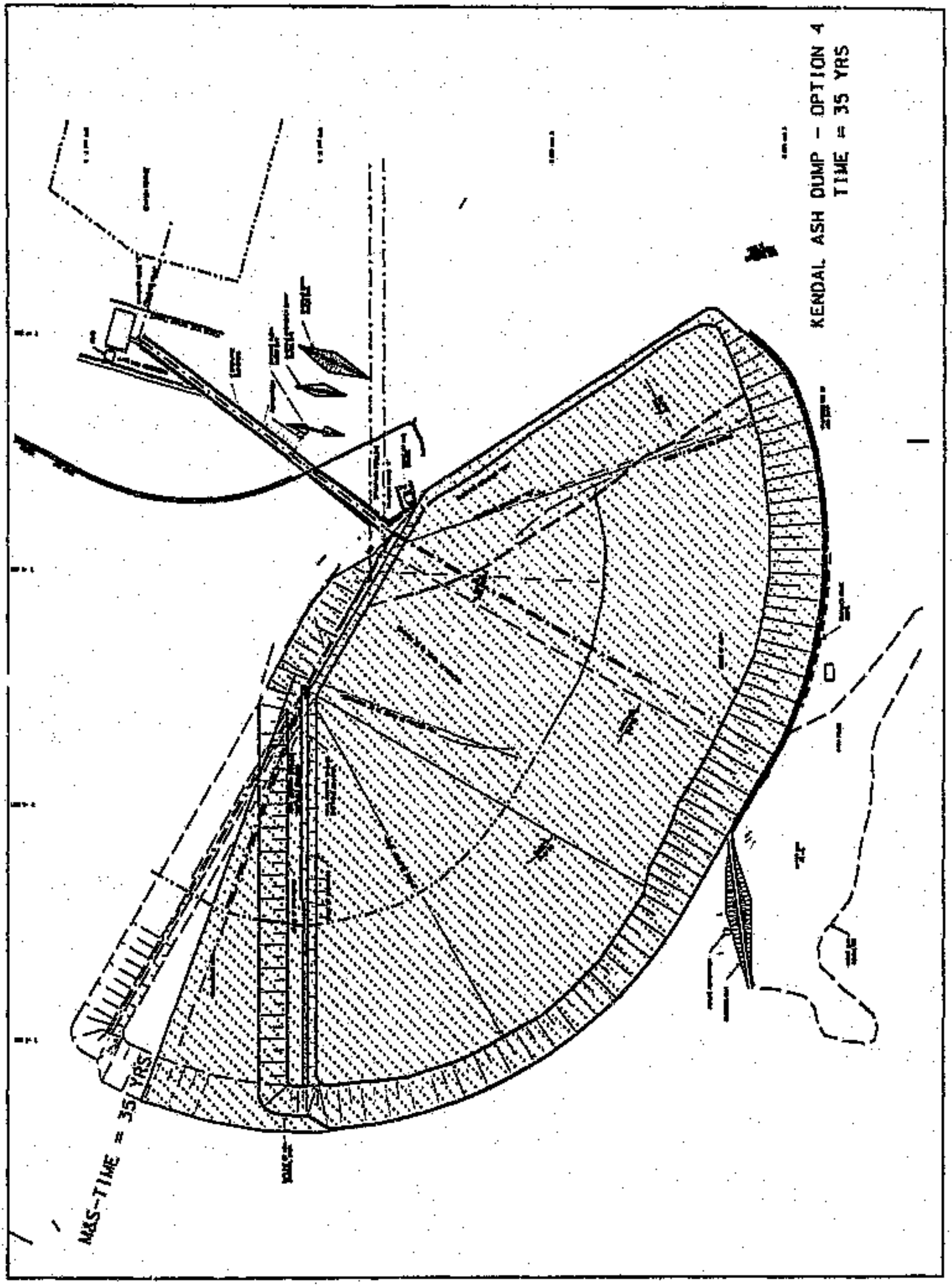


Figure E8 - Time-Position Plot - Economic Evaluation, Current Geometry (81% Stkr. Avail'ty) Time = 35 Yrs.

APPENDIX F GEOMETRY TO CAD EXAMPLES

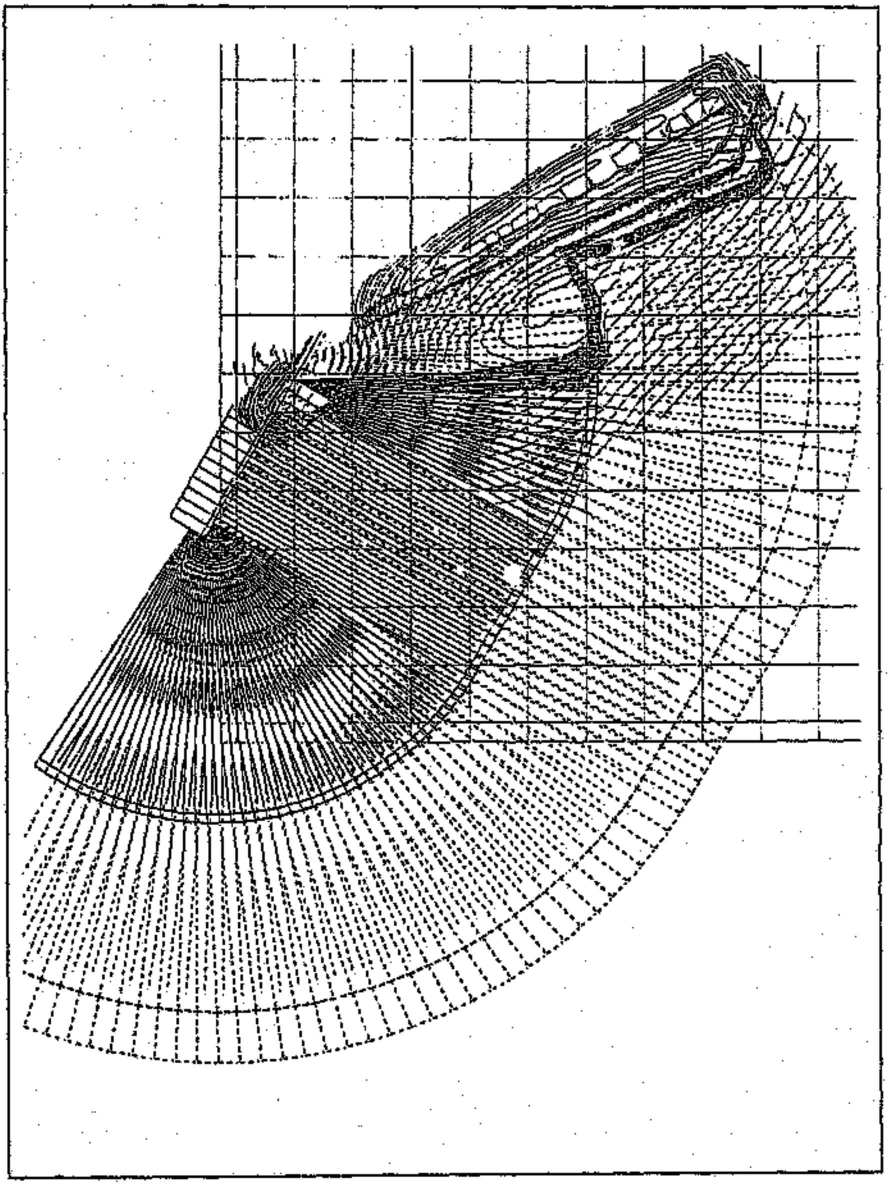


Figure F1 - Kendal Main and Standby System Geometry Imported into CAD.

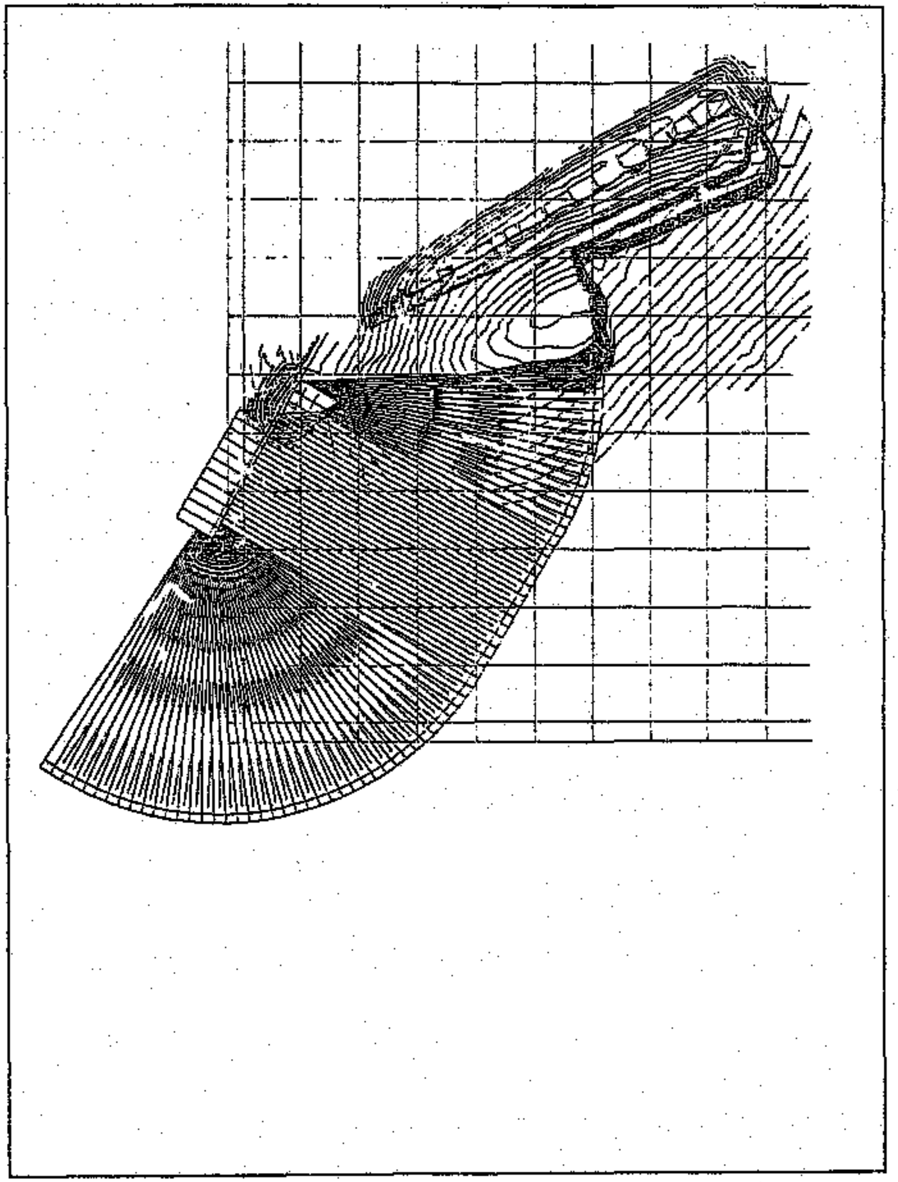


Figure F2 - Kendal Standby System Geometry Imported into CAD.

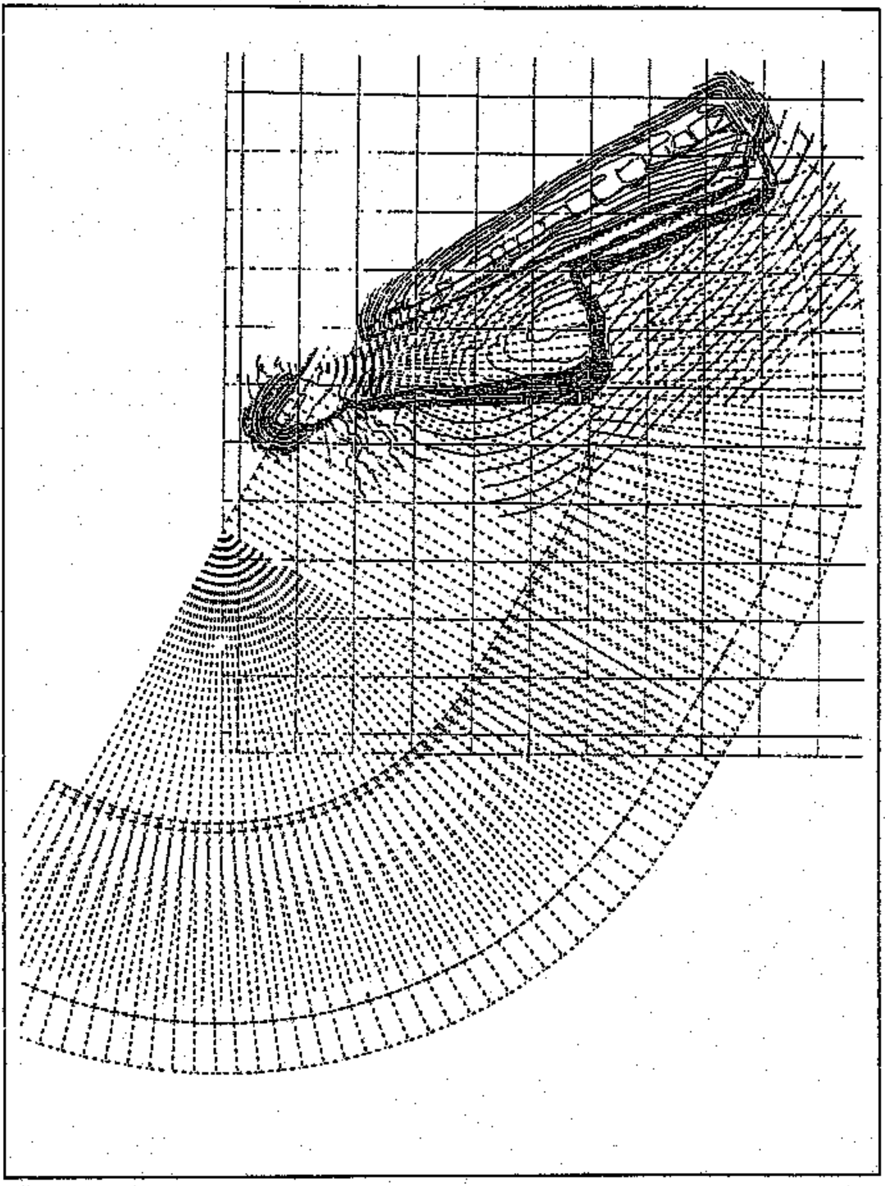


Figure F3 - Kendal Main System Geometry Imported into CAD.

APPENDIX G SPREADSHEET USER MANUAL

G.1 LOADING AND SETTING UP THE SPREADSHEET

It is assumed that the user is familiar with the Microsoft Excel 5.0 operating environment. If not, the user is referred to the Excel 5.0 Users Guide(15). Following are the basic steps to starting and setting up the spreadsheet for easiest use:

1. Start Microsoft Excel 5.0 from Windows.
2. Set the recalculation to "manual" and "recalculate before save" to off, to prevent unnecessary recalculation of the spreadsheet until the user has entered in sufficient data to wish to view the result.
3. Open the spreadsheet workbook. (DAD_GP2.XLS)
4. Use the window control to set the windows in normal window mode, to enable rapid selecting, moving and resizing of individual windows with the mouse.
5. Five separate windows are set up. Additional windows can be opened if desired, depending mostly on the size of the monitor and speed of the processor and graphics card for updating. Any of the spreadsheet worksheets can be accessed in any window by using the worksheet tabs, however as different zoom ratios can be set in different windows, it is better to use dedicated windows for certain spreadsheet areas to prevent having to re-zoom too often. The desired window can then easily be viewed by simply clicking on it with the mouse or selecting it from the window menu, to bring it to the top.
6. The various input and output areas needing to be manipulated and viewed, have been defined as named ranges, to facilitate quick moving to any area for input, viewing or printing. Use the Excel "Name Box"

to easily select any desired named range. The named ranges used for input, visual feedback and printing in the spreadsheet are:

a) GeoMod worksheet:
  - i) SMBInpA - standby, main & backstack input & numerical feedback areas. (See Figure B1)
  - ii) SMBCalcA - standby, main & backstack calculation & input areas. (See Figure B3)
  - iii) PosTonOutP - position tonnage output area. (See Figure B4)
  - iv) MSFSLytPlt - main & standby frontstack layout plot. (See Figure B5)
  - v) StLytPlt - standby frontstack layout plot. (See Figure B7)
  - vi) MLytPlt - main frontstack layout plot. (See Figure B8)
  - vii) MBSLytPlt - main backstack layout plot. (See Figure B9)

b) AshProMod worksheet:
  - i) AshProTbl - ash production table input & numerical feedback area. (See Figure B10)
  - ii) AshProGrphs - ash production feedback graphs. (See Figure B11)

c) GrwPlnMod worksheet:
  - i) DmpGrthCalcA - dump growth calculation, input & numerical feedback areas. (See Figure B12)
  - ii) GPlnPltA4 - growth plan plot A4 size. (See Figure B13)

7. The five standard windows are normally used for:

a) Window 1 - Geometric model numerical input and output. (GeoMod tab, named ranges "SMBInpA", "SMBCalcA" & "PosTonOutP")

b) Window 2 - Geometric modeling layout plot zoomed in view. (GeoMod tab, named ranges "MSFSLytPlt" & "MBSLytPlt")

c) Window 3 - Geometric modeling layout plot overall view. (GeoMod tab, named ranges "MSFSLytPlt" & "MBSLytPlt")

d) Window 4 - Growth plan graph. (GrwPlnMod tab, named range "GPlnPltA4")

e) Window 5 - Growth plan numerical input and output. (GrwPlnMod tab, named range "DmpGrthCalcA")

8. The Ash Production Model can be viewed in any window (AshProMod tab, named ranges "AshProTbl" & "AshProGrphs") and doesn't need a dedicated window as it is usually not varied as much as the Geometric Model or Dump Growth Model.

G.2 WORK FLOW

Either the Geometric Model or the Ash Production Model can be created firs , being independent of one another. Usually though, it is best to start with the Ash Production Model, as it is the easiest and requires the minimum of manipulation. More importantly, the ash production is usually the independent variable in this exercise, with the dump geometry and ash stacking plant needing to be designed or modified, to accommodate the ash production. Once the Ash Production Model is defined, the Geometric Model should be defined, followed by the Dump Growth Model, for a first pass.

Only when all three models are properly defined will a meaningful growth plan be returned, although due to the way the Excel spreadsheet works, it will calculate a growth plan based on whatever input data is present when the "F9" recalculate button is pressed and the user should use caution to not accept a growth plan without checking that all the necessary input data is satisfactory.

If the growth plan is not acceptable in terms of growth phasing or overall dump growth rate, either the main system availability, or the dump geometry parameters which will affect the relative ashing rates, volume split between the main and standby systems or total dump volume, can be changed to try and arrive at an acceptable growth plan. This would be a second or subsequent pass through the process and may require some iteration to arrive at an acceptable design situation.

The amount of iteration will also be influenced greatly depending on whether one is trying to evaluate an existing dump geometry to check on its growth, or whether one is trying to iterate towards an acceptable dump layout configuration geometry for a new dump siting exercise. For siting a new dump, the individual shift heights will have to be checked separately if the dump is not a constant height dump like Kendal, until some sort of DTM approach is added to automate this process.

The work flow logic is easiest described by the use of a flowsheet diagram (See Figure G1), to enable the user to get a feel for the modeling sequence. Any of the input parameters can however be entered at any time and in any sequence, once the user is familiar with what he is doing.

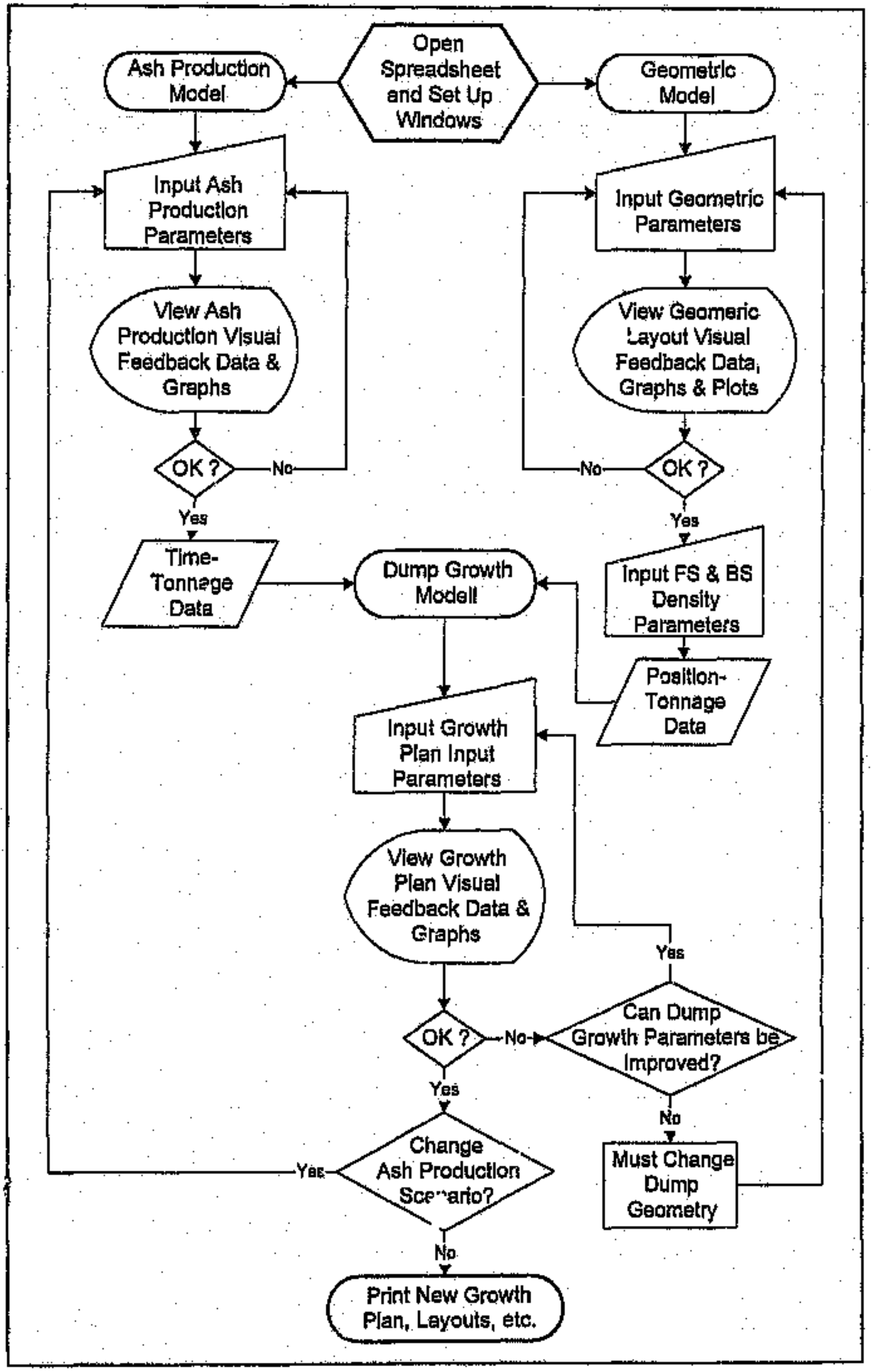


Figure G1 - Flowchart for using the Prototype Dump Growth Modeling spreadsheet.

The user must however, remember to recalculate the spreadsheets manually by pressing the "F9" key before viewing any of the numerical, layout configuration plots or graphs for visual feedback, before making any decisions about the acceptability of any input parameters.

G.3 INPUT PARAMETERS

There are a multitude of parameters to be input in order to define the three models in the spreadsheet. The Geometric Model requires by far the most parameters to define the conveyors and dump geometry for the standby and main frontstacks and the main backstacks, as well as the average dry ash density, on a per-shift position basis, to define the Position-Tonnage relationship.

The standby system frontstack requires 12 initial position setting up parameters, with nine parameters from position 1 onwards in the calculation area and another four in the input area per shift position, giving 13 parameters required per standby frontstack shift position. The main system frontstack requires eight initial position setting up parameters, with nine parameters from position 1 onwards in the calculation area and another four in the input area per shift position, giving 13 parameters required per main frontstack shift position. The main system backstack requires six initial position setting up parameters, with 11 per shift position, from position 1 onwards. A further one parameter per standby system shift position is required for the average frontstack dry ash density and two for the main system frontstack and backstack average dry ash density.

The main system has been set up with 75 shift positions and the standby system with 70 positions, as this was the number needed for the current Kendal ash dump layout configuration. (More shift positions can be added if required, but would require manual setting up and linking of formulas and graphical outputs.) This gives a total of (12 + (13 * 70) + 1) = 923 standby system parameters and (8 + (13 * 75) + 1) + (6 + (11 * 75) + 1) = 1 816 main system frontstack and backstack parameters. This results in a total of 2 739 parameters to define the Geometric Model Position-Tonnage relationship, for this number of main and standby shifts.

This would seem to be a monumental task to define so many parameters, but fortunately most of the parameters remain constant throughout, with usually only the shift length and conveyor lengths changing to generate the various radial and parallel shifting sectors of the dump. If the following shift position parameters are simply linked to the previous position parameter, only the first one needs to be changed to reflect a general change from that point onwards. The Geometric Model is however designed with this many individual parameters per shift position in order to allow total flexibility for any of the parameters to be varied at any point in the model.

G.3.1 Geometric Model Input

A brief tour of the various input areas of the Geometric Model is given to assist the user in becoming familiar with the spreadsheet. The spreadsheet is initially set up with the Kendal current geometry parameters, which are given here as default parameters for reference. Before using the spreadsheet for another dump, the user must ensure that all input variables are linked by a formula to the previous shift's parameter value, to ensure that no special parameter changes remain which would only apply to the previous case.

This is why it is good practice to always colour the background of data values entered in green and formulas in turquoise as a standard, as these changes are then easily picked up later. The use of the Position Number-Volume and Position Number-Angle/Distance graphs (See Figure B2) are very useful for picking up unexpected changes by inspection of the shape of the graph line. One can then easily go to the position number input or calculation area to check for any anomalies.

Although one can enter in any of the parameters in any order, it is better to follow some basic sequence to allow gradual building of the model from the visual feedback information. The suggested procedure follows: (See Figures B1, B3, B4 & G2-G7)

1. Input the model start point as an (Xo,Yo) coordinate. The standby system shiftable conveyor start point is used as the model start point. The values are entered in the first row of the standby system shift length columns ("Sls" and "Sle", yellow background) in the "SMBInpA" range.

2. Input the distance from the standby system shiftable conveyor start point to the main system shiftable conveyor start point as (ΔX,ΔY) values. The values are entered in the first row of the main system shift length columns. ("Sls" and "Sle", yellow background)

3. Input the shiftable conveyor lengths in the first row of the standby and main "C-Ln" columns.

4. Input the shiftable conveyor starting baseline angle in the first row of the standby and main "SLA" columns.

5. Input the initial position setup parameters in the "SMBCalcA" range position 0 standby, main and backstack areas. The parameters required are: [Typical Kendal current configuration values in square brackets]

   Standby Frontstack:

   - ECL o [190] (initial extendible conveyor length)
   - ECLoBLA [30] (initial extendible conveyor baseline angle)
   - SLs o [0] (to set up initial frontstack crest baseline radial to first conveyor pos)
   - SLe o [36] (shift length end)
   - SR o [60] (stacking reach)
   - DS o(parallel) [30] (to set up initial frontstack crest baseline to tie back to)
   - DS o(radial) [57] (to set up initial frontstack crest baseline to tie back to)
   - H o [22.14] (frontstack height)
   - SSSe o [1.2] (side slope end)
   - SSSs o [-1.2] (side slope start, to tie onto existing standby system)
   - SED FAC [0.8] (SEDi = Hi * SED FAC)

Main Frontstack:

- SLs o [0] (to set up initial frontstack crest baseline radial to first conveyor pos)
- SLe o [72] (shift length end)
- H o [20] (frontstack height)
- MSSe o [6.7] (side slope end)
- MSSs o [-1.2] (side slope start to tie onto existing standby system outside slope)
- De o [20] (distance from shiftable conveyor end point to crest)

Main Backstack:

- BDs o [182] (cutback to toe of baseline)
- BS o [1,2] (backstack forward slope)
- BSs o [9.8] (backstack start side slope)
- BSe o [7] (backstack end side slope)
- BSR o [7] (backstack roadway width between conveyor and toe)
- BH o [9.5] (backstack height)

6. Input the first (and subsequent if required) position input values in the calculation area ("SMBCalcA").

Standby Frontstack:

- Follow [1] (side slope crest and toe to follow from previous)
- FlipSlpTwst [0] (Flip slope that is twisted, when going from negative to positive slope and following)
- Gam i [90] (angle between extendible conveyor and shiftable conveyor)
- SR i [60] (stacking reach)

- Ds i [14] (distance from shiftable conveyor start point to start crest)
- De i [20] (distance from shiftable conveyor end point to end crest)
- H i [22.14] (frontstack height)
- SSSe i [1.2] (side slope at end)
- SSSs i [-1.2] (side slope at start, to tie onto existing standby system)

Main Frontstack:

- FollowS [1] (start side slope crest and toe to follow from previous)
- FollowE [1] (end side slope crest and toe to follow from previous)
- Gam i [90] (angle between extendible conveyor and shiftable conveyor)
- SR i [92] (stacking reach)
- Ds i [10] (distance from shiftable conveyor start point to start crest)
- De i [40] (distance from shiftable conveyor start point to end crest)
- H i [27] (frontstack height)
- MSSe i [7.5] (side slope at end)
- MSSs i [-1.2] (side slope at start to tie onto existing standby system outside slope)

Main Backstack:

No backstack parameters exist in the calculation area, as all were correctly put into the input area of the "SMBInpA" range. The main and standby system parameters will eventually also all only be in the input area, making it unnecessary to need to change parameters in the calculation area. This is not only a more difficult process, due to each position using 22 lines, requiring paging up and down, bu if the worksheet is not protected, the calculation formulas could be changed or deleted by mistake.

7. Input the remainder of the standby and main frontstack and main backstack parameters in the "SMBInpA" range.
Standby Frontstack:
   - SLs i [0] (radial) [36] (parallel)
   - SLe i [40] (radial or parallel)
   - LstFs [0] (normal) [167] (tie into existing standby frontstack)

   Main Frontstack:
   - SLs i [0] (radial) [72] (parallel)
   - SLe i [40] (radial or parallel)
   - LstFs [0] (normal) [924] (tie into existing standby frontstack)

   Main Backstack:
   - BS i [1.2] (backstack forward slope)
   - BSs i [1.2] (backstack start side slope)
   - BSe i [7] (backstack end side slope)
   - BSR i [7] (backstack roadway width between conveyor and toe)
   - BH i [9.5] (backstack height)

   The remainder of the backstack input parameters are required to define the complex backstack forming sequence, either a four-cycle, two-cycle or a one-cycle stacking procedure. This is required as the stacker cannot travel the complete distance down to the start end during radial shifts, due to the size of the stacker and the relatively small slew angle.

In the past, a four-cycle sequence has been used to place a short backstack, from the furthest position the stacker can travel down behind the conveyor. This is then followed by a medium length backstack, as the conveyor is now slewed at twice the angle. A short backstack must first be built again and finally a full length backstack can be built, as the stacker is then able to get right into the start end corner. With this procedure the stacker must always walk in from the end to the start behind the shiftable conveyor and then build the backstack from start to end.

More recently, a two-cycle backstack sequence has been adopted, where the stacker builds a medium length backstack from the end towards the start, ashi itself into a corner. The shiftable conveyor is then shifted away, which gives the stacker sufficient space to get out between the previous backstack toe and the new shiftable conveyor position, building the second cycle full length backstack from start to end.

The backstack modeling was therefore designed to accommodate both the above procedures, as well as a single-cycle which would be used during parallel shifting. Typical parameter values for the four-, two- and single-cycle procedures are given below:

Four-cycle: (Radial)

	(i)	(i+1)	(i+2)	(i+3)
LBS1	[485]	[485]	[485]	[485]
LBS2	[485]	[250]	[485]	[250]
BL-IL2	[1]	[2]	[1]	[2]
LBS3	[485]	[250]	[485]	[160]
BL-IL3	[1]	[2]	[1]	[4]
Foll	[0]	[0]	[0]	[1]

Two-cycle: (Radial)

	(i)	(i+1)
LBS1	[485]	[485]
LBS2	[485]	[250]
BL-IL2	[1]	[2]
LBS3	[485]	[160]
BL-IL3	[1]	[2]
Foll	[0]	[1]

One-cycle: (Parallel)

	(i)
LBS1	[108]
LBS2	[108]
BL-IL2	[1]
LBS3	[108]
BL-IL3	[1]
Foll	[1]

G.3.2 Ash Production Model Input

The input for the Ash Production Model is self explanatory (See Figures B10 & B12), using the same rules for entering either values or formulas. The values are usually available from life-of-mine plans and power station load forecasting information. Eight different parameters are required here (Years from Start and Year are really the same information) and if done on an annual basis for say a 50 year station life, this would result in 400 parameters to define the Time-Tonnage relationship.

This model was developed after the Kendal evaluation exercises and as Kendal did not require a variation of the ashmake scenario, these Time-Tonnage outputs were not used in the Dump Growth Model for the ashmake inputs. This is why there is a difference between the values and the time steps in the Dump Growth Model input area. This table can easily be modified to return the same type of output and then the input ranges in the Dump Growth Model linked back to the Ash Production Model by simple spreadsheet formula references. Once this linkage is made, the "expected" and "upper bound" scenarios can be used to quickly check the sensitivity of this variation on the dump growth.

G.3.2 Dump Growth Model Input

Only four parameters are required here (See Figure B12), the start date (which should be the same as the ash production start from the Ash Production Model) and the standby system conveyor shift duration, main system conveyor shift duration and the stacker availability during ashing, on a per-shift basis.

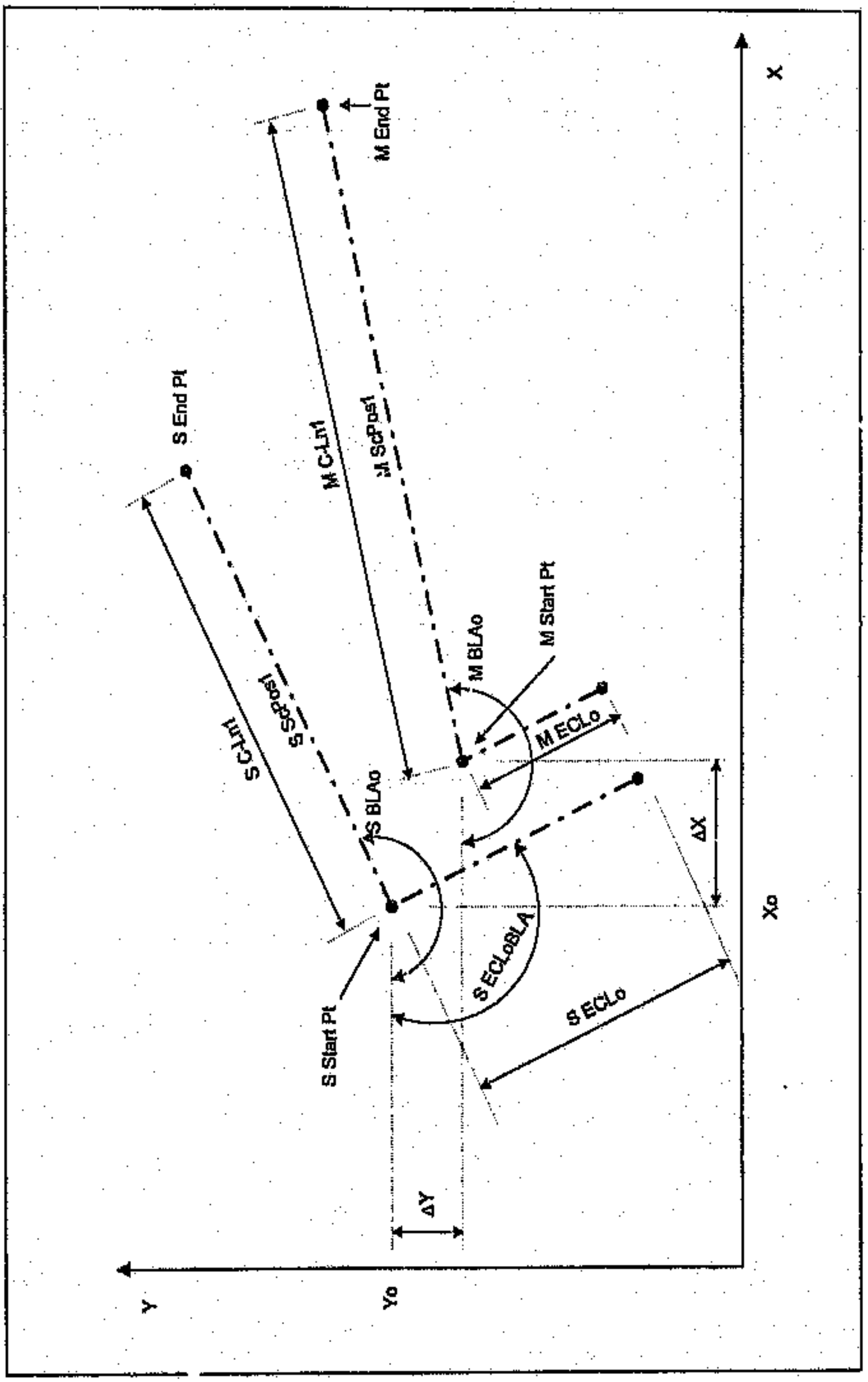


Figure G2 - Geometric Model Position(0) Conveyor Setup Input Parameters.

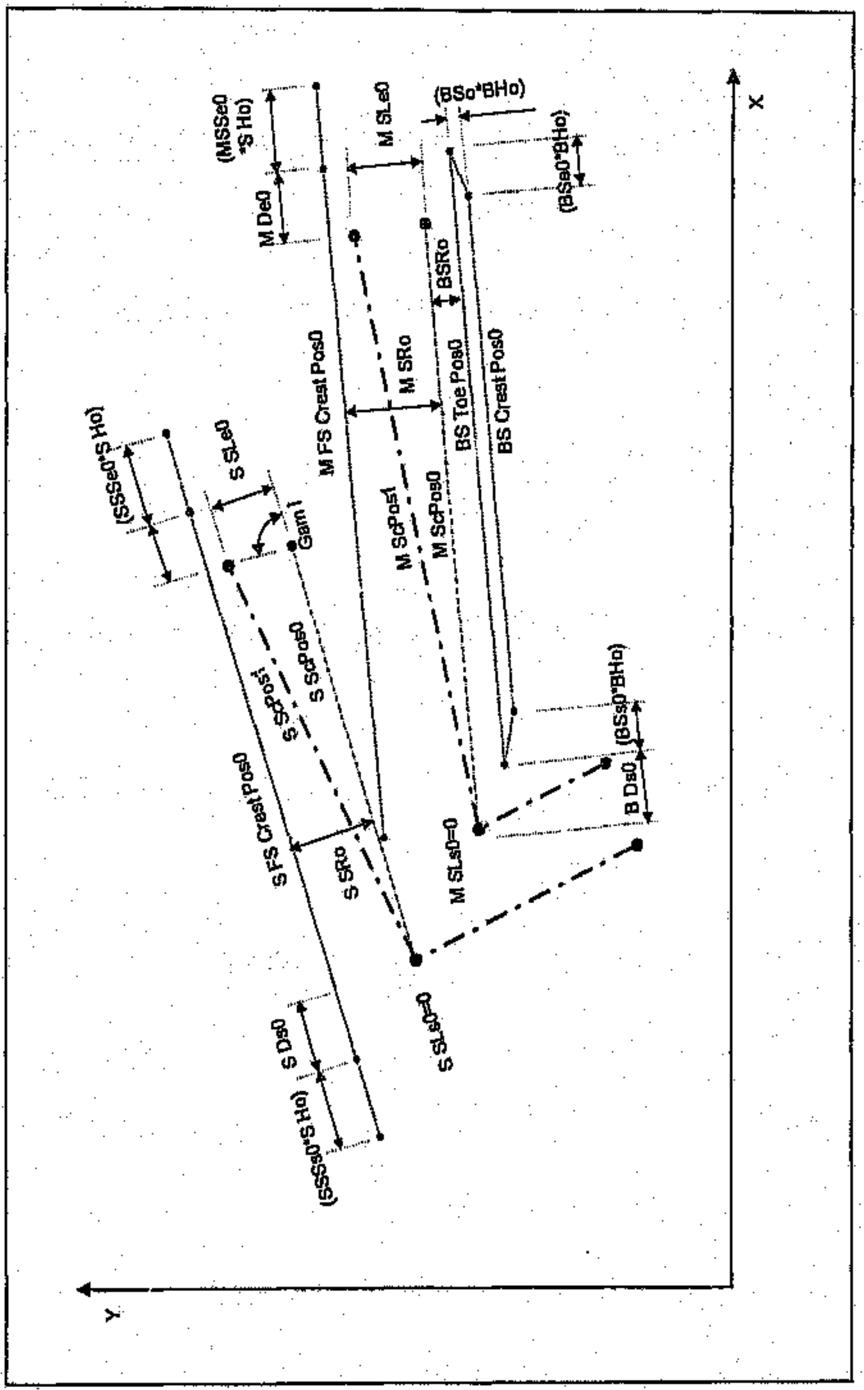


Figure G3 - Geometric Model Position(0) Frontstack & Backstack Input Parameters - Radial.

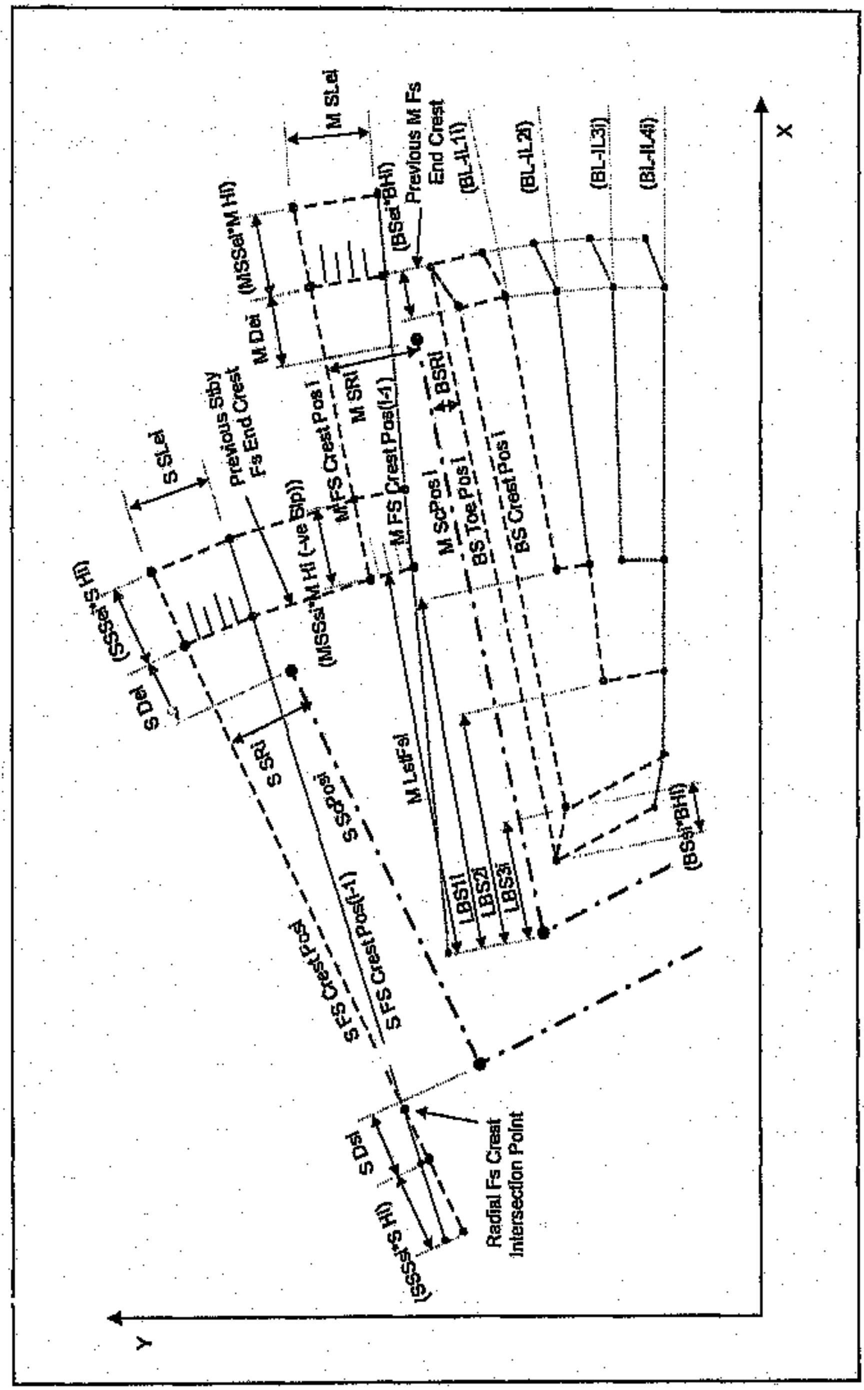


Figure G4 · Geometric Model Position(i) Frontstack & Backstack Input Parameters - Radial.

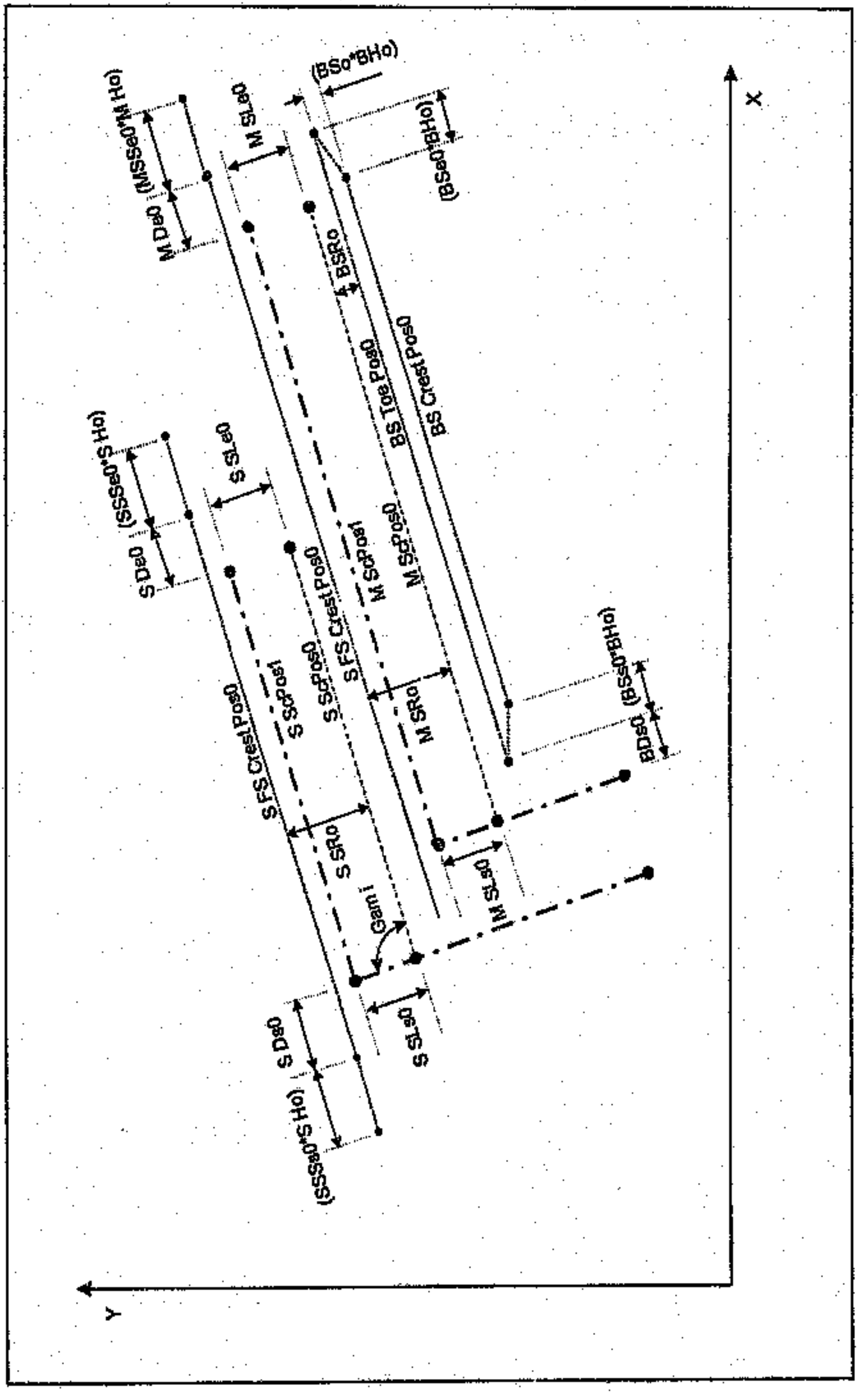


Figure G5 - Geometric Model Position(0) Frontstack & Backstack Input Parameters - Parallel.

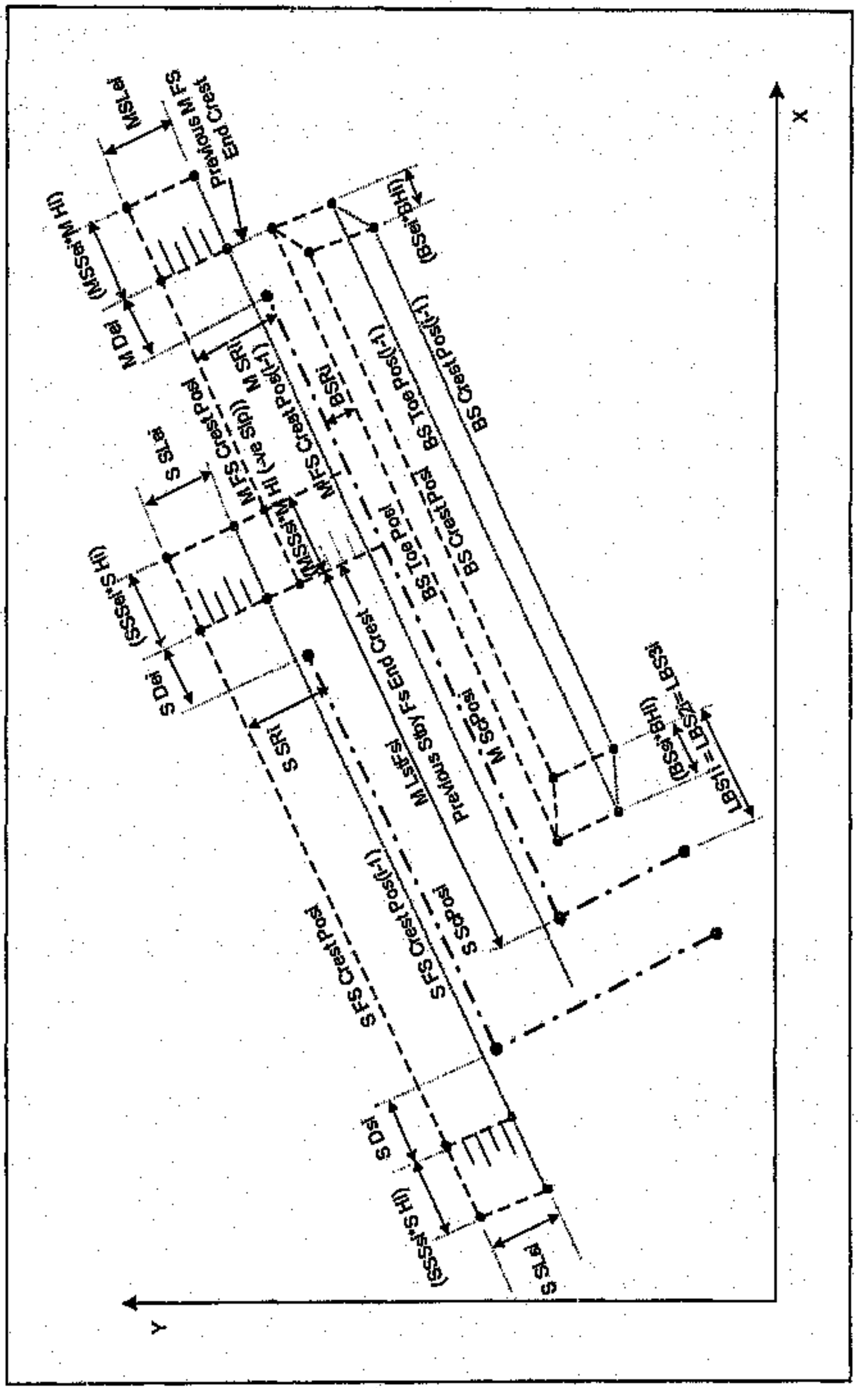
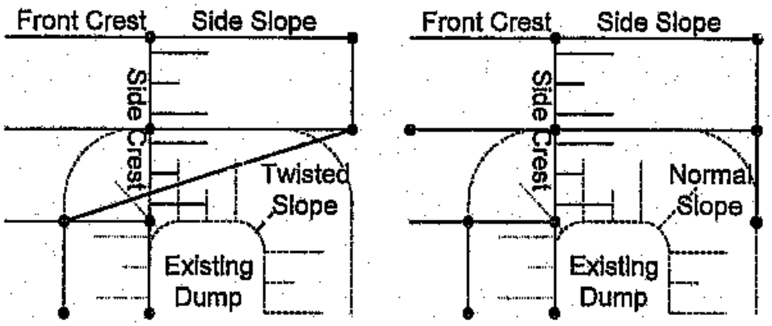
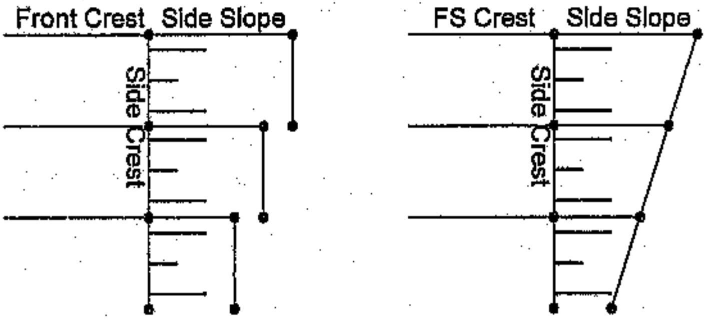


Figure G6 - Geometric Model Position(i) Frontstack & Backstack Input Parameters - Parallel.



a) Side Slope FlipSlpTwst = 0 b) Side Slope FlipSlpTwst = 1

B. Side Slope FlipSlpTwst Parameter (Changing from a negative to a positive slope)



a) Side Slope Follow = 0 b) Side Slope Follow = 1

A. Side Slope Follow Parameter

Figure G7 - Geometric Model Input Variable Explanations.

APPENDIX H SPREADSHEET PROGRAM MANUAL

H.1 SPREADSHEET PROGRAM CODE

Although the Dump Growth Modeling system, developed on the Excel 5.0 spreadsheet as a prototype, is merely a very high level form of programming, the spreadsheet does not lend itself to printing out the programming code like traditional programming languages. Although the formulas in the individual cells can be printed out, it would be impossible to follow their logic without being able to see the row and column references on the spreadsheet pages as well, as cell references to rows and columns are used in the formulas and not the column variable names.

Viewing the actual prototype spreadsheet models would be much more beneficial to anyone wishing to modify the prototype, but the final version of the modeling system would be much more efficiently done using a traditional programming language, or possibly one of the simulation languages mentioned by Zador[6] and Ramos and Goodwin[7]. The auditing function of Excel was found to be extremely useful for checking the programming logic and cell references during development, debugging and verification, as the audit function will draw arrows back to all cells referred to in the current cell formula, or to all the cells which refer back to the current cell. (See Figures H3 & H4)

In addition, due to the way the spreadsheet works, many ingenious work-around techniques had to be developed for the prototype, which would be of little value to a traditional program language without these limitations. As the intention of this project was to develop a prototype modeling system to assist in identifying the necessary input parameters, outputs, formats and modeling techniques for a final more user-friendly and integrated program, it was deemed sufficient to rather describe the prototype program's logic in the form of modeling concepts and flowsheet logic diagrams.

H.2 MODELING CONCEPTS

The input parameters used by the spreadsheet are described in more detail in the USER MANUAL and NOMENCLATURE. As mentioned there, due to the need to keep the column widths as small as possible to enable the maximum amount of information to be viewed simultaneously, fairly cryptic acronyms had to be used to name the various input and output parameters. These parameter names are placed at the top of the columns in the various input, output and calculation areas. Either the conveyor shift or position number is placed to the left of the input areas (See Figure B1) or as a shift position number in the top left of the individual system shift position calculation area ranges (See Figure B3). The column parameter names could therefore be considered as array variable names, with conveyor position indices (eg MECL(i)) to describe the parameters per conveyor position. A description of the modeling concepts follows:

H.2.1 Geometric Model

This model is fairly complex, both from an input parameter and calculation point of view and requires a large amount of calculation to arrive at the Time-Tonnage geometric relationship for the main and standby systems. The basic concept of the Geometric Model is fairly simple though and models each individual conveyor shift position, for the main and standby system, with a number of geometric parameters which fully describes each shiftable conveyor position and its ashing areas. These parameters firstly define the shiftable conveyor and extendible conveyor positions for a particular shift relative to the previous conveyor position and then define the frontstack and backstack ashing geometry relative to the conveyor position from which it will be formed.

Using this governing concept, the dump ashing geometry parameters relative to the shiftable conveyors can be entered, which are usually fairly constant for different radial or parallel sectors of the dump and then all that is needed to generate the complete ash dump layout configuration geometry and related shift position volumes, would be to define the conveyor shifting parameters per position, to steer the dump in almost any conceivable direction, within the site's layout and geometric limitations, as well as the physical and practical limitations of this type of conveyor stacking equipment.

The concept used to define the conveyor shifting length and type, either parallel or radial shifting, is to simply specify a distance which the start and end points must be moved forwards from the current shiftable conveyor start and end points. The ashing geometry modeling for the frontstack and backstack also uses this shifting information to decide whether a radial or parallel frontstack or backstack ashing geometry will be constructed. Basically, if a zero distance shift length is specified for the shiftable conveyor start point, then a radial shift results, with only the end point being shifted forwards, while equal shift lengths result in a parallel shift.

If the shiftable conveyor length is increased or shortened for any shift, the new end point is positioned this shift length in front of an equivalent conveyor length for the current shift, acting as a baseline, to ensure that the end point distance in radial shifts is still only one stacking reach away from the previous backstack. If it were to be projected from the current shiftable conveyor end point and then the conveyor extended, the new end point distance back to the previous backstack could be much greater than the stacking reach, implying not only dozing backwards, but probably a huge amount of dozing forwards to be able to shift the shiftable conveyor end point this far forwards.

The ashing geometry for the frontstack and backstack areas is then determined relative to the new shiftable conveyor start and end points. The frontstack and backstack volumes are determined in the prototype by determining the plan area of the new frontstack or backstack and multiplying it by a constant height parameter for each shift and system. A varying dump height was not allowed for in the prototype, as it would simply be a large amount of additional work, not essential for developing the dump growth modeling concepts for this project. It was also unnecessary for modeling the Kendal ash dump practical problem situations due to the Kendal dump being a constant height above the ground.

Although the natural ground does of course vary over hills and valleys and the ash is dumped at an angle of repose against the previous face and not with vertical front slopes, the basis for the volume estimate was that as a frontstack cross-section taken at right angles to the shiftable conveyor is a parallelogram shape, the area is the same as the area of a rectangle with the same top length, being base times perpendicular height. Integrating these cross-section areas would give the same volume as the plan area multiplied by the perpendicular height. The backstack is almost always a constant height to get the maximum ash volume within the stacking height limitation. In the event that either the frontstack or backstack heights are not constant for any reason, this can simply be handled in the prototype by entering in an average height value, determined at the center of gravity of the area.

Obviously some form of automatic height sensing procedure will be essential for the final version, as this will allow non-constant height dumps to more easily and accurately be modeled, especially for siting exercises, where the designer would like to move the dump around to get the optimum location and layout configuration, possibly for a number of sites and even trying different layout configurations or different starting points on one site.

The volume of the frontstack and backstack sections between the start and end crests is thus determined in this way, with the side slopes at the start and ends being determined from average end areas of the triangles at the previous and new crest lines and the distance between them. Using a positive slope results in a positive slope volume which must be added to the inside volume. Using a negative slope implies that the slope is under the inside section and must be deducted from the inside section volume, as this volume has already been placed by a previous ashing exercise or the standby system, which is always ahead of the main system.

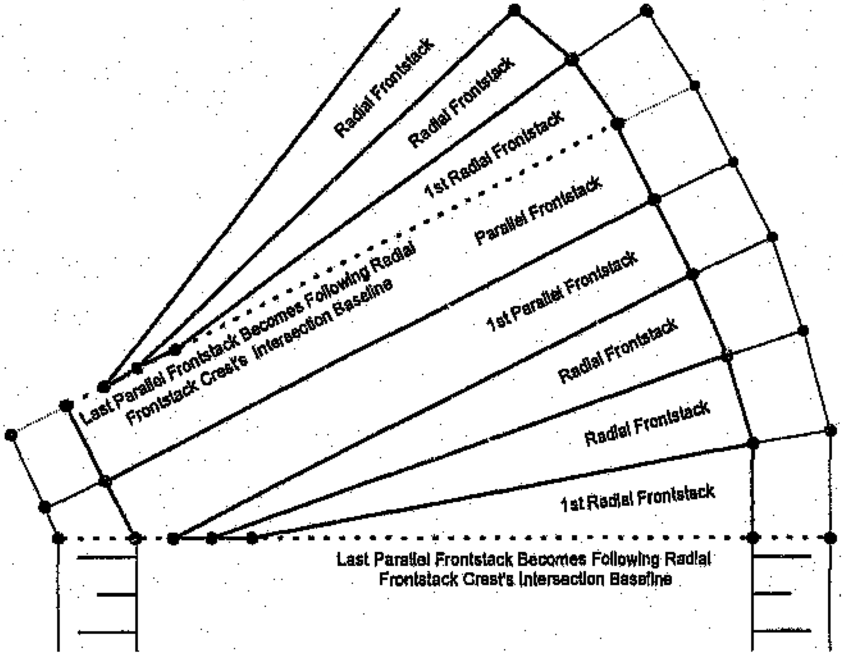
As the three volumes are always added together, a negative slope will automatically have the desired effect.

The (x,y) coordinates for the extendible and shiftable conveyors, as well as the frontstack and backstack ashing geometry are determined for each shift position. The area of the shape of the inside sections of the ash, which is used to determine the volumes, is then determined from the shape's corner coordinates, independent of what shape the area is, the shape being determined by the conveyor shifting parameters. These coordinates are then also used to draw the layout configuration plot, giving a direct link between the inputs, volumes and graphical visual feedback. This ties in well with the concept of "...if the graphics looks right, the volumes will also be correct."

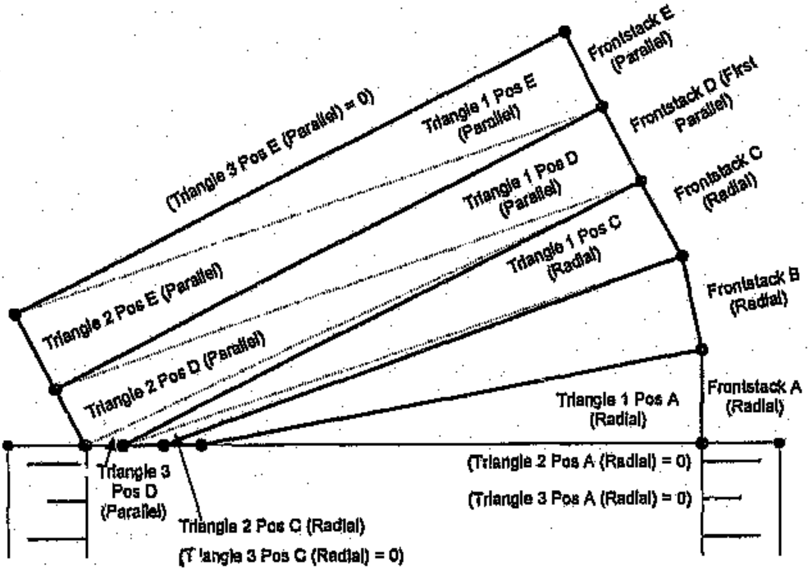
This modeling approach is fairly complex for the standby system, as a parallel shift would usually result in a four-cornered shape, while a radial shift would be triangular for the first shift and practically triangular for the rest, however actually consist of four corners, due to the way they intersect the previous frontstack crest baseline. This radial intersection baseline is always the last parallel frontstack crest line (See Figure H1). If the frontstack is cut back using the "LstFs" parameter, both a radial and parallel frontstack would have four corners.

An anomaly occurs when going from a radial section to a parallel section, with the first parallel shift inside area actually consisting of a five-cornered shape. This was handled in the spreadsheet modeling by always using a five-cornered shape to define the standby frontstack inside areas, which was then divided into three triangles. The area of each triangle was then determined from the triangle's (x,y) coordinates by using the user function "Area" (See Appendix I) and the three areas added together to give the total frontstack inside area.

The five-cornered shapes would always have three positive value triangle areas, while the four-cornered shapes would have two positive value triangle areas and one zero value triangle area, due to two of the five points being coincident. The triangular shaped first radial shift frontstack would only have one positive value triangle area and two zero value triangle areas, due to three of the five points being coincident. (See Figure H1)



b) Standby Frontstack Parallel to Radial Shift Intersection Baseline



a) Standby Frontstack Position Area Triangles

Figure H1 - Geometric Model Standby Frontstack Area Geometry.

The main system frontstack is much simpler, due to it always being cut back and the frontstack crest never intersecting the previous frontstack crest baseline. This always results in a four-cornered inside area shape, for both radial and parallel shifts. Another user function was developed which would determine the area of a four-cornered shape from the corner's (x,y) coordinates, as this would require much fewer input values, not having to repeat values common to each triangle. The "Area4" user command (See Appendix I) is more efficient than dividing the four-cornered shape into two triangles and calculating the area of each and totaling the result in the cell formula. The side slopes are determined in the same way as for the standby system.

Actually a similar formula could be developed for a five-cornered shape, which would be much more efficient and easier to reference, but would need to be checked that it does not return incorrect answers if some corners are coincident. This can be done as a temporary modification to the prototype to try and improve its efficiency in the meantime.

The backstack volumes are much more complex to model, due to the complex four-cycle radial ashing procedure traditionally used. (See Figures G4 & G6) This was required due to the large size of the stacker and the relative small slew angles, making it impossible for the stacker to travel the entire distance down towards the start point, after a full backstack has been placed. The four cycle procedure allows the first backstack in the cycle to be built from the furthest point the stacker can reach, with the next shift allowing the stacker to go a little further, due to the larger open angle between the first backstack and the second shiftable conveyor position. The third cycle must again be a short backstack similar to the first, with the last backstack being able to be built all the way to the start point side.

In order to model this, three four-cornered shapes were used, with the user being able to define the distance to cut back each shape from the shiftable conveyor start point and which of the last four backstack crest lines to ash back to in each shape. (See Figure G4) The user function XIn and YIn (See Appendix I) were used to determine the intersection points of the cutback lines, with the relevant baselines to ash back to. The area of each of these three four-cornered shapes is determined similar to the main system frontstack inside area, and the side slope volumes determined similar to the frontstack side slopes.

Although this procedure is complex, it has great flexibility in that it allows the designer to model either a four-cycle, a two-cycle or a single-cycle backstacking operation. Parallel shifting of the main system allows the stacker to walk the full distance down to the start to form a full backstack every time, resulting in a single-cycle backstacking operation. Recently an innovative two-cycle radial backstacking approach has been tried which requires the stacker to build a short first-cycle backstack from the end point to the start point, ashing itself into a corner. Once the shiftable conveyor is moved away, it can build a full backstack from the start side to the end side. This results in an "out and back" procedure, with the frontstack also being built in two directions, resulting in a saving of 50% of the traveling distance for the stacker to place the same volume of ash, a considerable saving over a 50 year station life, considering the main system belt is usually around 1700m long.

The slew angles, baseline angles, extendible conveyor lengths and vertices' coordinates for the conveyors and ashing geometry are determined using basic trigonometry, to determine the geometry (x,y) coordinates. The parametric modeling technique used in the spreadsheet prototype to produce the automatic layout configuration plot of the standby and main system's conveyor and frontstack and backstack shapes, was to define a sequence for the vertices' (x,y) coordinates in adjacent X- and Y-columns, which were then simply added to an X-Y graph as separate line series for each of the positions. (See Figures B3, B5 & B7)

The standby system plots the extendible conveyor extension and shiftable conveyor using three points and the frontstack ashing front crest and sideslopes using eight points. In order to draw one position's conveyors and frontstack geometry using one line series, to limit the number of line series (Excel limit = 255) and allow the same colour to be used for one position, a gap was left between the conveyor and the frontstack geometry points, to prevent Excel drawing a meaningless connecting line from the end of the shiftable conveyor to the start of the frontstack geometry. The frontstack geometry used some dummy points to limit the amount of space required for each position, by drawing the line over itself in some cases. This is better than leaving a gap and then having to specify the same starting point again and can't be seen on the plot. (See Figure H2)

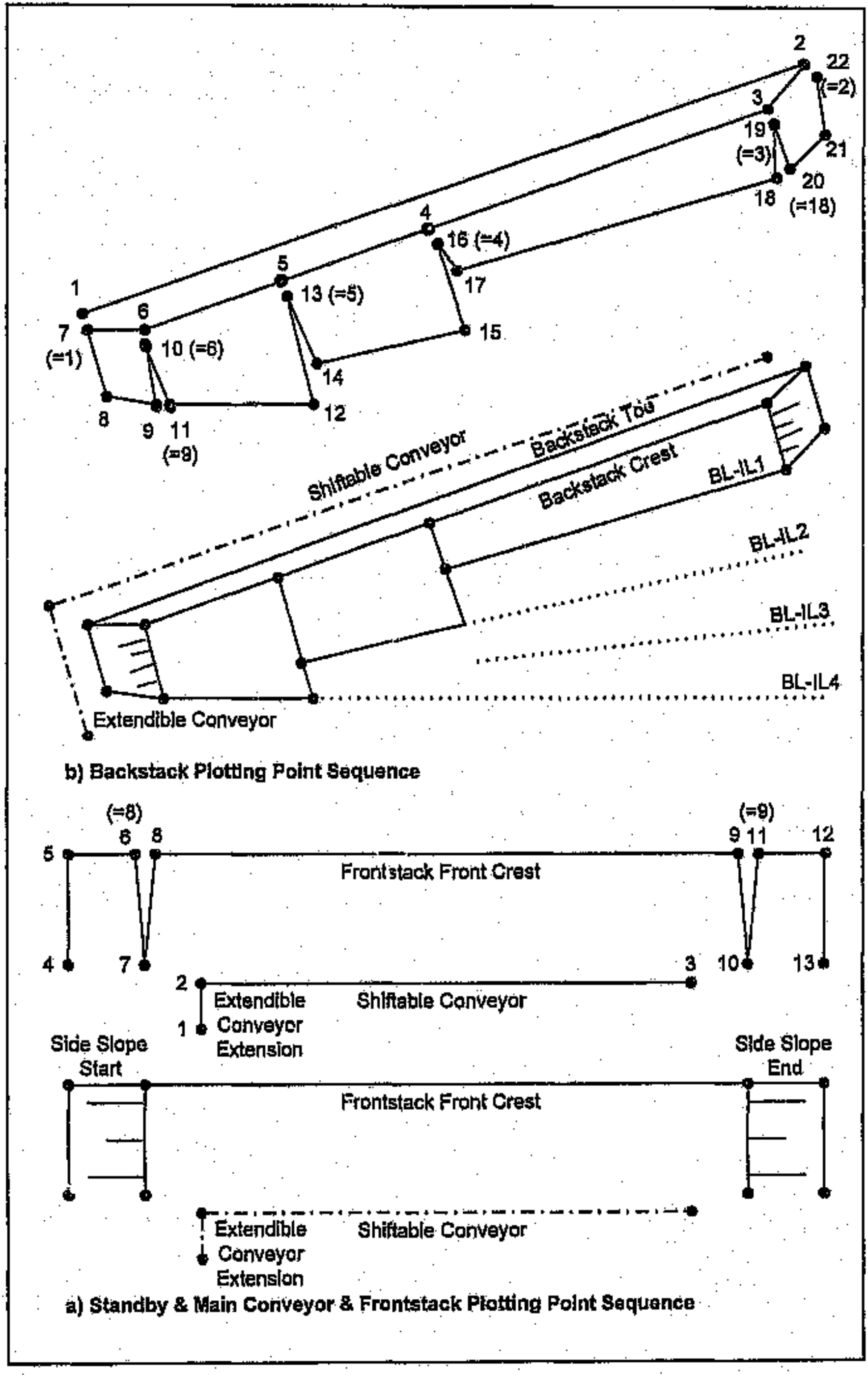


Figure H2 - Geometric Model Frontstack & Backstack Plotting Geometry Coordinate Sequence.

The main system conveyor and frontstack geometry is done in the same way as the standby system. (See Figures B3, B5 & B8) The frontstack side crests and front crest, as well as the two side slopes front edges and toe are thus drawn, with the new position's shiftable conveyor being seen standing on the previous position's frontstack. This geometry is simply laid against the previous position, giving the impression of the frontstack area added. The front slope toe line of the frontstack is not drawn, as this has little benefit, while making the already complicated per-shift layout configuration plot even more difficult to interpret. For clarity, the standby system geometry is drawn in a solid line and the main system in a dotted line, with each shift in a different colour, relating back to the vertical colour bars on the edges of the input and output areas and the number's colour in the calculation area ranges. (See Figures [illegible], B3 & B5)

The backstack geometry is determined in a similar way to the frontstack's, relative to the main system shiftable conveyor start and end points. (See Figures B3 & B9) In this case it was deemed necessary to also include the backstack front slope toe line, as not only is the backstack front slope crest line important to check that the stacker can reach to this point, but the access roadway between the shiftable conveyor and the backstack front toe line must be specified to allow either single or two lane operating and maintenance access behind the shiftable conveyor, after the new backstack has been formed. (See Figures G4 & G6)

This more complicated backstack geometry also including the three cutback areas, needed 22 points to describe the line series. (See Figure H2) This was drawn on another plot, together with the main system frontstack and conveyors. This allows the backstack geometry to be seen together with its shiftable conveyor and main frontstack end side slopes.

The final part of the Geometric Model is the converting of the position frontstack and backstack volumes into an equivalent tonnage capacity, by simply multiplying the volume by the average dry density. (See Figure B4) The main system frontstack and backstack use different density parameters due to their very different heights, but are added together to return only a total main system equivalent tonnage capacity, as growth performance within the shift was not required.

H.2.2 Ash Production Model

This model is very simple, both from an input parameter and calculation point of view. The estimated energy sent out (ESO Gwh/y) is determined from the number of units in commission, the net unit power rating in MW, the availability (UCF) and energy utilization factor (EUF) percentages and converted to Gwh/y. The required coal burn tonnages are determined by dividing this value by the calorific value (CV) of the coal and overall station efficiency factor, taking care of the units, to produce the coal tonnages per year. This is then multiplied by the ash percentage to determine the dry ash tons produced per year. These are then added to give the cumulative Time-Tonnage ash production information. (See Figure B10)

H.2.3 Dump Growth Model

This model is very simple from an input parameter point of view, but fairly complex from a calculation point of view. The per-shift Geometric Model Position-Tonnage information (main and standby shiftable conveyor baseline angle, extendible conveyor lengths, shiftable conveyor lengths and equivalent tonnage capacity) and cumulative Ash Production Model Time-Tonnage information is used, together with an ashing start date parameter, the main system stacker availability during ashing and the main and standby shiftable conveyor shifting time parameters.

The dump growth is a fairly tricky relationship to determine on a per-shift basis, as the ash production rate can vary at any point in time, depending on the time step used for the modeling. It was felt necessary to allow any time step interval to be used at any time, to allow annual estimates for long term planning and seasonal or monthly time steps for the first one to five years, to allow more accurate short and medium term evaluation and planning.

The ash production time steps bear no relation to the main or standby shifting times and a change in ashing rate could happen during a shift or during an ashing period, or it could be constant for a few shifts, depending on the ash production time step at that particular time. The solution to this problem was found to be that the cumulative time - cumulative tonnage ash production relationship always had to be used, to interpolate the cumulative time from the start for a particular cumulative ash tonnage to be reached and then adding say the shifting time to this time to arrive at the cumulative time to the end of the shift. The cumulative ash tonnage produced by the end of the shift was then determined by using the reverse ash production relationship, to interpolate the cumulative ash tonnage produced at this time. By deducting these critical ashing or shifting start and end point cumulative times from one another, the total times or tonnages between these points could be determined, no matter how the relationship had varied in between the two points, due to the difference in cumulative values always being used.

The main system is the independent variable in this exercise, and the analysis must start with the main system. The time to fill a main system shift equivalent tonnage capacity is determined by dividing the shift equivalent tonnage capacity by the ashing availability for that position. This tonnage is added to the cumulative ash produced at the start of the position, which is zero at the start and would be equal to the cumulative ash tonnage at the end of the previous main system shift for all other shifts. The total time that this tonnage would have been placed into either the main or standby systems is then interpolated from the ash production information. As mentioned above, the shift time is then added to the above time to determine the time to reach the end of the main system shift. The cumulative tonnage produced at this time is then similarly interpolated. Deducting the actual ash placed by the main system in these periods from the difference in the cumulative ash tonnages at the start and end times, gives the remaining tonnage of ash which was placed by the standby system, during the main system ashing time and during the main system conveyor shifting time.

The main system thus effectively receives an average ash rate equal to the total cumulative ash rate over its ashing period, multiplied by the main system availability during ashing parameter and zero ash tonnage during its shifting period. This information then gives the stepped graph for the main system ashing rate on the new growth plan. (See Figures B13 & B14 ("CStATo" line series))

The standby system ash tonnage received during the main system's ashing period and the ash tonnage received during the main system's conveyor shift period are then accumulated to produce the cumulative stepped standby system ash rate, given on the new growth plan (See Figures B13 & B14 ("CSpATo@StSh" line series)) Clearly, this graph shows that the standby system is receiving the difference between the total cumulative ash production over the main system's ashing period and the main system' ashing rate and all of the ash produced during the main system's conveyor shifting period. All ashing for the main and standby systems within any main system period is considered to be done at an average ashing rate over that main system ashing or shifting period, independent of whether there may have been any ash production time step rate changes during that period. This effectively converts the original cumulative ash production time step relationship into a new cumulative ash production time step relationship at the start and end points of the main system ashing and shifting periods, the total cumulative ash tonnages at these times being the same as the original.

The time for the standby system to have completed ashing its equivalent tonnage capacity per shift is determined in a similar way to the main system, however a new interpolation lookup table is generated from the above spreader cumulative ashing rate information. The times to reach the end of the standby system's ashing capacity are then simply interpolated from this table using the cumulative standby system shift ashing times.

All this information and the shiftable conveyor position baseline and extendible conveyor lengths plus the main and standby shiftable conveyor lengths per position is then simply arranged in an area of the spreadsheet in the correct order to give the necessary position, length or availability value at each of the critical time points, to give the stepped shiftable conveyor baseline angle or extendible conveyor length graphs.

The standby system's shifting times are dependent on the main : standby volume split, stacker ashing utilization and conveyor shifting times, but there is no back verification that the standby system can in fact shift when its equivalent tonnage capacity it filled, as the main system may also need to shift at this point. As the main system is the independent variable here, it will either have to shift when it reaches the end of its ashing space, or it should have been stopped sooner to allow the standby system to fill up the last portion of its area and shift before the main system needs to shift. This is simulated by simply allocating the main system a lower ashing availability for that position, to reflect the additional outage time.

This shift clash outage time as well as the maintenance and breakdown outage times during ashing could be added into the Dump Growth Model as a time outage parameter in days, rather calculating the average main system availability during ashing. This would be done by adding these outage times to the time to fill the main system's equivalent tonnage capacity for a shift and dividing the time to place the equivalent tonnage capacity at 100 percent ashing rate, by this total time taken from the start to the actual end of main system ashing.

To facilitate the identification of these shift clash situations, two vertical lines were drawn down from the main system conveyor shift start and end times which can easily show the relationship between the main system and standby system's conveyor shift's start and end times. The standby system shift time was plotted on the standby system ash production graph as a separate line, having only markers at the shift start and end times, with the standby system ashing rate having no markers. The shift position numbers for the main and standby systems were added into the new growth plan by using the data point labels of the shifting line series, every five positions. This allows the exact shift positions clashing to easily be identified and individually modified in the Dump Growth Model or possibly even the Geometric Model.

A summary of the Dump Growth Model calculation sequence follows: (See Figures H3-H4 & B13-B14, the User Manual in Appendix G and the Nomenclature, for more detailed explanation of the variable names)

Main System Growth: (See the circled numbers next to the column header variable names and audit linkage arrows on Figure H3. These variable numbers are given here in braces {}, the variable name in brackets () and the units of the variable in square brackets [])

{1} = Input (Stacker Ash Start Date) [Date]
{2} = Input from Main Pos-Tonnage Geometric Model output (StShTo) [Tons/shift]
{3} = Input (StAUt%) [%]
{4} = {2}/{3} * 100 (AToDurStShA) [Tons]
{5} = 0 at Start, $\{5\}_i = \{10\}_{i-1}$ (CATo@StAS) [Cumulative tons]
{6} = {5} + {4} (CATo@StAE) [Cumulative tons]
{7} = LKUPCAT{6} * 365 (Ti@StAE) [days from start]
{8} = Input (StShDur) [days]
{9} = {7} + {8} (Ti@StShE) [days from start]
{10} = LKUPCAV{9} (CATo@StShE) [cumulative tons]
{11} = {1} + {7} (Stacker shift start) [date]
{12} = 0 at Start, $\{12\}_i = \{9\}_{i-1}$ (Ti@StAS) [days from start]
{13} = {1} + {12} (Stacker Ash Start) [date]
{14} = {3} * ({7} - {12}) / ({9} - {12}) (AvStA&ShUt%) [%]
{15} = {6} - {5} - {2} (SpAToDurStA) [Tons/shift]
{16} = {10} - {6} (SpAToDurStSh) [Tons/shift]

LKUPCAT - Linear interpolation procedure to determine cumulative time from start in years as a function of cumulative ash tonnage produced.

LKUPCAV - Linear interpolation procedure to determine cumulative ash tonnage produced as a function of cumulative time from start in days.

Standby System Growth: (See the circled numbers next to the column header variable names and audit linkage arrows on Figure H4. These variable numbers are given here in braces {}, the variable name in brackets () and the units of the variable in square brackets [])

{1} = Input (Stacker Ash Start Date) [Date]
{2} = {1} (Spreader Ash Start Date) [Date]
{3} = Input from Standby Pos-Tonnage Geometric Model output (SpShTo) [Tons/shift]
$\{4\}_i = \{3\}_i + \{4\}_{i-1}$ (S[illegible]Ton) [Cumulative tons]
{5} = LKUPSPT{4} * 365 (Ti@SpAE) [days from start]
{6} = Input (SpShDur) [days]
{7} = {5} + {6} (Ti@SpShE) [days from start]
{8} = 0 at Start, $\{8\}_i = \{7\}_{i-1}$ (Ti@SpAS) [days from start]
{9} = {2} + {5} (Spreader Shift Start) [date]
{10} = {2} + {8} (Spreader Ash Start) [date]

LKUPSPT - Linear interpolation procedure to determine cumulative time from start in years as a function of standby system cumulative ash tonnage rate.

H.2.4 Program Logic Flowchart

A program logic flowchart was produced to give an overall impression of the calculation processing logic to go from the Ash Production Model and Geometric Model inputs, to the new growth plan. (See Figure H5)

											STACKER SYSTEM	
		① ,⑬		⑪	(E Sp-S St)	(E St-S Sp)	⑫	⑤	②	③		④	⑥
St	St Act	St Ash Start	St	St Shift Start	Time Betw	Time Betw	(Days)	(Tons)	(Tons)	St	St	(Tons)	(Tons)
POS	POS	DATE	SHIFT	DATE	Shifts (Dys)	Shifts (Dys)	Ti@StAS	CATo@StAS	StShTo	AUt%	AUt%*10	AToDurStShA	CATo@StAE
1	4	① 31-Mar-1995	1	31-May-1995	61	70	0	0	② 459,404	[illegible]	849.9	540,514	540,514
2	[illegible]	14-Jun-1995	2	19-Mar-1996	4	77	75	661,964	1,817,899	[illegible]	739.7	④ 2,457,704	3,119,668
[illegible]	6	5-Apr-1996	3	18-Jan-1997	66	14	371	⑤ 3,256,653	1,812,890	[illegible]	700.0	2,589,842	⑥ 5,846,496
4	7	1-Feb-1997	4	24-Nov-1997	2	79	673	5,975,923	1,914,230	70.0	700.0	2,734,614	8,710,537
5	8	8-Dec-1997	5	16-Oct-1998			983	8,839,964	2,022,176	70.0	700.0	2,888,823	11,728,786
6	[illegible]	30-Oct-1998	6	⑪ 16-Aug-1999			1,309	11,858,406	1,922,039	70.0	700.0	2,745,771	14,604,177
7	[illegible]	30-Aug-1999	7	16-Jun-2000			1,613	14,737,508	1,995,262	70.0	700.0	2,850,374	17,587,882
8	11	30-Jun-2000	8	29-Mar-2001			⑫ 1,918	17,727,674	1,920,645	70.0	700.0	2,743,779	20,471,453
9	12	⑬ 12-Apr-2001	9	16-Jan-2002			2,204	20,615,939	2,018,979	70.0	700.0	2,884,256	23,500,195
10	[illegible]	30-Jan-2002	10	14-Oct-2002			2,497	23,649,587	1,919,250	70.0	700.0	2,741,785	26,391,373
11	14	28-Oct-2002	11	6-Jul-2003			2,768	26,540,765	1,992,470	70.0	700.0	2,846,386	29,387,151
12	[illegible]	20-Jul-2003	12	9-Mar-2004			3,034	29,548,667	1,915,678	70.0	700.0	2,736,683	32,285,350
13	16	23-Mar-2004	13	14-Nov-2004			3,280	32,456,699	2,020,329	70.0	700.0	2,886,184	35,342,883
14	17	28-Nov-2004	14	29-Jun-2005			3,530	35,514,232	1,905,213	70.0	700.0	2,721,732	38,235,964
15	[illegible]	13-Jul-2005	15	15-Feb-2006			3,757	38,416,327	1,973,865	70.0	700.0	2,819,807	41,236,134
16	[illegible]	1-Mar-2006	16	20-Sep-2006			3,988	41,422,456	1,894,656	70.0	700.0	2,706,651	44,129,107
17	[illegible]	4-Oct-2006	17	28-Apr-2007			4,206	44,315,429	2,004,367	70.0	700.0	2,863,381	47,178,810
18	21	12-May-2007	18	15-Nov-2007			4,425	47,380,228	1,884,007	70.0	700.0	2,691,438	50,071,666
19	22	29-Nov-2007	19	4-Jun-2008			4,626	50,273,084	1,952,567	70.0	700.0	2,789,382	53,062,466
20	[illegible]	18-Jun-2008	20	14-Dec-2008			4,828	53,271,490	1,873,266	70.0	700.0	2,676,095	55,947,584
21	24	28-Dec-2008	21	16-Jul-2009			5,021	56,156,341	1,987,198	70.0	700.0	2,838,854	58,995,195
22	[illegible]	30-Jul-2009	22	[illegible]-Feb-2010			5,236	59,193,388	1,862,434	70.0	700.0	2,660,[illegible]20	61,854,008
23	26	17-Feb-2010	23	[illegible]-Aug-2010			5,438	62,052,441	1,933,041	70.0	700.0	2,761,487	64,813,927
[illegible]	27	14-Sep-2010	24	13-Feb-2011			5,647	65,012,360	1,527,021	70.0	700.0	2,181,458	67,193,818
25	[illegible]	27-Feb-2011	25	24-Jul-2011			5,813	67,399,176	1,502,594	70.0	700.0	2,146,562	69,545,738
26	[illegible]	7-Aug-2011	26	31-Dec-2011			5,973	69,751,096	1,502,594	70.0	700.0	2,146,562	71,897,658
27	[illegible]	14-Jan-2012	27	4-Jun-2012			6,133	72,109,791	1,502,594	70.0	700.0	2,146,562	74,256,353
28	31	18-Jun-2012	28	6-Nov-2012			6,289	74,468,486	1,502,594	70.0	700.0	2,146,562	76,615,048
29	32	20-Nov-2012	29	17-Apr-2013			6,445	76,827,181	1,502,594	70.0	700.0	2,146,562	78,973,743
30	33	1-May-2013	30	27-Sep-2013			6,606	79,174,686	1,502,594	70.0	700.0	2,146,562	81,321,249
31	34	11-Oct-2013	31	12-Mar-2014			6,770	81,522,192	1,502,594	70.0	700.0	2,146,562	83,668,754
32	[illegible]	26-Mar-2014	32	28-Aug-2014			6,936	83,862,875	1,502,594	70.0	700.0	2,146,562	86,009,437
33	36	11-Sep-2014	33	15-Feb-2015			7,105	86,203,557	1,502,594	70.0	700.0	2,146,562	88,350,120
34	37	1-Mar-2015	34	8-Aug-2015			7,275	88,537,399	1,502,594	70.0	700.0	2,146,562	90,683,961
35	38	22-Aug-2015	35	27-Jan-2016			7,450	90,871,241	1,502,594	70.0	700.0	2,146,562	93,017,803

Figure H3 - Dump Growth Model Main System Dump Growth Calculation Area.

⑦ (Days) Ti@StAE	(Mths) StADur	⑧ (Days) StShDur	⑨ (Days) Ti@StShE	(Yrs) Ti@StShE	⑩ (Tons) CATo@StSh3	⑭ AvStA &ShUt%	18 AvStA &ShUt%*10	⑮ (Tons) SpAToDurStA	⑯ (Tons) SpAToDurStSh
61	2.0	14	75	2/12	661,964	69.1	691.3	81,110	121,450
354	9.2	[illegible]	371	1	3,256,653	69.7	697.2	639,805	136,905
659	9.5	14	673	1 10/12	5,972,923	66.8	667.6	776,953	129,427
⑦ 969	9.7	14	983	2 8/12	8,839,964	66.8	668.4	820,384	129,427
1,295	10.3	⑧ 14	⑨ 1,309	3 7/12	11,858,406	67.0	669.9	866,647	129,620
1,599	9.5	14	1,613	4 5/12	⑩ 14,737,508	66.8	667.8	823,731	133,331
1,904	9.6	14	1,918	5 3/12	17,727,674	66.8	667.9	855,112	139,792
2,190	8.9	14	2,204	6	20,615,939	66.6	665.7	823,134	144,486
2,483	9.2	14	2,497	6 10/12	23,649,587	66.7	666.5	865,277	149,393
2,754	8.4	14	2,768	7 7/12	26,540,765	66.4	663.8	822,536	149,393
3,020	8.3	14	3,034	8 4/12	29,548,667	66.3	663.1	853,916	161,515
3,266	7.7	14	3,280	9	32,456,699	66.0	660.3	821,005	171,349
3,516	7.8	14	3,530	9 8/12	35,514,232	66.1	660.8	865,855	171,349
3,743	7.0	14	3,757	10 4/12	38,416,327	⑭ 65.7	656.8	816,520	180,363
3,974	7.1	14	3,988	10 11/12	41,422,456	65.8	657.6	⑮ 845,942	186,322
4,192	6.7	14	4,206	11 6/12	44,315,429	65.5	654.9	811,995	⑯ 186,322
4,411	6.8	14	4,425	12 1/12	47,380,228	65.5	655.3	859,014	201,418
4,612	6.2	14	4,626	12 8/12	50,273,084	65.1	651.3	807,431	201,418
4,814	6.2	14	4,828	13 3/12	53,271,490	65.1	651.5	836,814	209,024
5,007	5.9	14	5,021	13 9/12	56,156,341	64.9	649.3	802,828	208,757
5,222	6.6	14	5,236	14 4/12	59,193,388	65.4	654.3	851,656	198,192
5,424	6.2	14	5,438	14 11/12	62,052,441	65.1	651.5	798,186	198,433
5,633	6.4	14	5,647	15 6/12	65,012,360	65.3	653.1	828,446	198,433
5,799	5.0	14	5,813	15 11/12	67,399,176	64.1	641.0	654,437	205,358
5,959	4.8	14	5,973	16 4/12	69,751,096	63.9	638.9	643,969	205,358
6,119	4.8	14	6,133	16 10/12	72,109,791	63.9	638.8	643,969	212,133
6,275	4.7	14	6,289	17 3/12	74,468,486	63.7	637.0	643,969	212,133
6,431	4.7	14	6,445	17 8/12	76,827,181	63.7	637.0	643,969	212,133
6,592	4.9	14	6,606	18 1/12	79,174,686	63.9	639.3	643,969	200,943
6,756	4.9	14	6,770	18 7/12	81,522,192	64.0	640.1	643,969	200,943
6,922	5.0	14	6,936	19	83,862,875	64.1	641.0	643,969	194,120
7,091	5.1	14	7,105	19 6/12	86,203,557	64.2	641.9	643,969	194,120
7,261	5.1	14	7,275	19 11/12	88,537,399	64.3	642.6	643,969	187,279
7,436	5.3	14	7,450	20 5/12	90,871,241	64.4	643.8	643,969	187,279
7,608	5.2	14	7,622	20 11/12	93,220,191	64.3	643.0	643,969	202,388

LKUPCATi

LKUPCAV
(T)

SPREADER SYSTEM														
		②, ⑩		⑨	⑧	③	④	⑤(SpShS)		⑥	⑦(SpAS)			①
Sp	SpAct	Sp Ash Start	Sp	Sp Shift Start	(Days)	(Tons)	(Tons)	(Days)	(Mths)	(Days)	(Days)	St	StAct	St Ash Start
POS	POS	DATE	SHIFT	DATE	Ti@SpAS	SpShTo	SP CTon	Ti@SpAE	SpADur	SpShDur	Ti@SpShE	POS	POS	① DATE
1	9	② 31-Mar-1995	1	23-Aug-1995	0	363,650	363,650	145	4.8	[illegible]	132	1	4	[illegible]
2	[illegible]	30-Aug-1995	2	6-Mar-1996	152	③ 449,872	813,522	341	6.2	[illegible]	350	2	[illegible]	14-Jun-1995
[illegible]	11	15-Mar-1996	3	21-Jun-1996	350	374,550	④ 1,188,072	448	3.2	[illegible]	456	[illegible]	6	5-Apr-1996
4	12	29-Jun-1996	4	5-Nov-1996	456	368,574	1,556,645	⑤ 585	4.2	[illegible]	593	4	7	1-Feb-1997
5	[illegible]	13-Nov-1996	5	15-Feb-1997	593	368,769	1,925,414	688	3.1	[illegible]	⑦ 696	5	[illegible]	8-Dec-1997
[illegible]	[illegible]	23-Feb-1997	6	1-Jul-1997	696	375,959	2,301,374	823	4.2	[illegible]	831	6	[illegible]	30-Oct-1998
7	[illegible]	9-Jul-1997	7	14-Nov-1997	⑧ 831	376,456	2,677,830	959	4.2	[illegible]	967	7	[illegible]	30-Aug-1999
8	16	22-Nov-1997	8	⑨ 25-Feb-1998	967	377,422	3,055,252	1,062	3.1	[illegible]	1,070	8	11	30-Jun-2000
9	17	⑩ 5-Mar-1998	9	11-Jul-1998	1,070	377,466	3,432,718	1,198	4.2	[illegible]	1,206	9	12	12-Apr-2001
10	18	19-Jul-1998	10	28-Oct-1998	1,206	386,325	3,819,043	1,308	3.3	[illegible]	1,316	10	13	30-Jan-2002
11	19	5-Nov-1998	11	10-Mar-1999	1,316	386,768	4,205,811	1,441	4.1	[illegible]	1,449	11	14	28-Oct-2002
12	[illegible]	18-Mar-1999	12	25-Jul-1999	1,449	387,094	4,592,905	1,577	4.2	[illegible]	1,585	12	[illegible]	20-Jul-2003
13	21	2-Aug-1999	13	3-Nov-1999	1,585	387,186	4,980,091	1,678	3.1	[illegible]	1,686	13	16	23-Mar-2004
14	22	11-Nov-1999	14	14-Mar-2000	1,686	387,277	5,367,368	1,810	4.1	[illegible]	1,818	14	17	28-Nov-2004
15	23	22-Mar-2000	15	27-Jun-2000	1,818	387,479	5,754,847	1,916	3.2	[illegible]	1,924	15	18	13-Jul-2005
16	[illegible]	5-Jul-2000	16	1-Nov-2000	1,924	404,620	6,159,467	2,042	3.9	[illegible]	2,050	16	[illegible]	1-Mar-2006
17	[illegible]	9-Nov-2000	17	26-Jun-2001	2,050	824,437	6,983,904	2,279	7.5	[illegible]	2,287	17	[illegible]	4-Oct-2006
18	26	4-Jul-2001	18	24-Mar-2002	2,287	952,595	7,936,499	2,550	8.7	[illegible]	2,558	18	21	12-May-2007
19	27	1-Apr-2002	19	3-Jan-2003	2,558	1,032,032	8,968,530	2,836	9.1	[illegible]	2,844	19	22	29-Nov-2007
20	28	11-Jan-2003	20	7-Nov-2003	2,844	1,171,446	10,139,976	3,143	9.8	[illegible]	3,151	20	23	18-Jun-2008
21	29	15-Nov-2003	21	24-Aug-2004	3,151	1,171,446	11,311,421	3,434	9.3	[illegible]	3,442	21	24	28-Dec-2008
22	[illegible]	1-Sep-2004	22	4-Jun-2005	3,442	1,192,956	12,504,377	3,718	9.1	[illegible]	3,726	22	[illegible]	30-Jul-2009
23	31	12-Jun-2005	23	20-Feb-2006	3,726	1,192,956	13,697,333	3,980	8.3	[illegible]	3,988	23	26	17-Feb-2010
24	32	28-Feb-2006	24	23-Oct-2006	3,988	1,192,956	14,890,289	4,225	7.8	[illegible]	4,233	[illegible]	27	14-Sep-2010
[illegible]	33	31-Oct-2006	25	30-Jun-2007	4,233	1,192,956	16,083,245	4,474	7.9	[illegible]	4,482	25	28	27-Feb-2011

LKUPSPT

Figure H4 - Dump Growth Model Main System Dump Growt
Calculation Area.

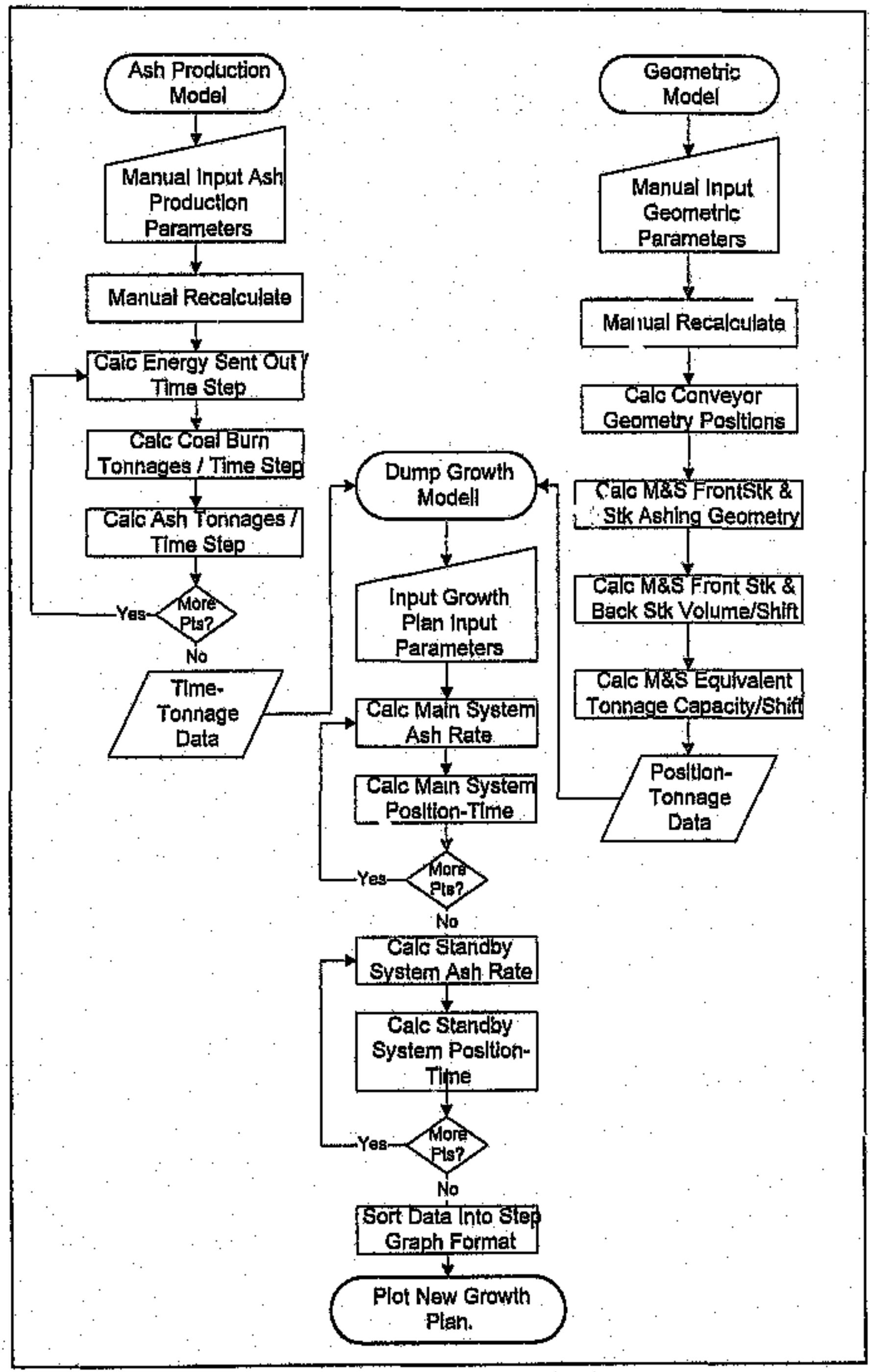


Figure H5 - Program Logic Flowchart for Automating the Growth Plan.

APPENDIX I VISUAL BASIC USER FUNCTIONS

```
Function XIn(x1, y1, x2, y2, x3, y3, x4, y4)
'Function XIn calculates the X-coordinate of the
'intersection point of two lines

    If x1 = x2 And x3 <> x4 Then
        Xi = x1
        Mb = (y4 - y3) / (x4 - x3)
        Cb = y3 - Mb * x3
        Yi = Cb + Mb * Xi
        XIn = Xi
        ElseIf x3 = x4 And x1 <> x2 Then
            Xi = x3
            Ma = (y2 - y1) / (x2 - x1)
            Ca = y1 - Ma * x1
            Yi = Ca + Ma * Xi
            XIn = Xi
            Else
                Ma = (y2 - y1) / (x2 - x1)
                Ca = y1 - Ma * x1
                Mb = (y4 - y3) / (x4 - x3)
                Cb = y3 - Mb * x3
                Xi = (Cb - Ca) / (Ma - Mb)
                Yi = Ca + Ma * Xi
                XIn = Xi
    End If
End Function

'******************************************************* ***
```

```
Function YIn(x1, y1, x2, y2, x3, y3, x4, y4)
'Function YIn calculates the X-coordinate of the
'intersection point of two lines

    If x1 = x2 And x3 <> x4 Then
        Xi = x1
        Mb = (y4 - y3) / (x4 - x3)
        Cb = y3 - Mb * x3
        Yi = Cb + Mb * Xi
        YIn = Yi
        ElseIf x3 = x4 And x1 <> x2 Then
            Xi = x3
            Ma = (y2 - y1) / (x2 - x1)
            Ca = y1 - Ma * x1
            Yi = Ca + Ma * Xi
            YIn = Yi
            Else
                Ma = (y2 - y1) / (x2 - x1)
                Ca = y1 - Ma * x1
                Mb = (y4 - y3) / (x4 - x3)
                Cb = y3 - Mb * x3
                Xi = (Cb - Ca) / (Ma - Mb)
                Yi = Ca + Ma * Xi
                YIn = Yi
    End If
End Function

'*************************************************************
```

```
Function Lng(x1, y1, x2, y2)
'Function Lng calculates the length of the line
'between two points

    Lng = ((y2 - y1) ^ 2 + (x2 - x1) ^ 2) ^ 0.5

End Function

'*************************************************************

Function Area(x1, y1, x2, y2, x3, y3)
'Function Area calculates the area of a triangle
'given three points

    Area = Abs(((x1 * y2) + (x2 * y3) + (x3 * y1) - (x2 *
            y1) - (x3 * y2) - (x1 * y3)) / 2)

End Function

'*************************************************************

Function Area4(x1, y1, x2, y2, x3, y3, x4, y4)
'Function Area4 calculates the area of a four sided figure
'given the four vertice points

    Area4 = Abs(((x1 * y2) + (x2 * y3) + (x3 * y4) + (x4 *
            y1) - (x2 * y1) - (x3 * y2) - (x4 * y3) - (x1 *
            y4)) / 2)

End Function

'*************************************************************
```

```
Function Pdl(x1, y1, x2, y2, x3, y3)
'Function Pdl calculates the perpendicular distance between
a point and a line
'using the point slope form of the straight line equation
and that the slope of a perpendicular line is
'equal to the negative reciprocal of the other line. ( m2 =
-1 / m1 )  The first two points define the line.
'The length is found by finding another point on the
perpendicular line and finding the intersection between
'the lines using XIn and YIn and using Lng to find the
length.

    m1 = (y2 - y1) / (x2 - x1)
    m2 = -1 / m1
    y4 = 0
    x4 = x3 - y3 / m2
    x5 = XIn(x1, y1, x2, y2, x3, y3, x4, y4)
    y5 = YIn(x1, y1, x2, y2, x3, y3, x4, y4)
    Pdl = Lng(x3, y3, x5, y5)

End Function

'************************************************
```

REFERENCES

1. Oliver, A. Kendal Power Station. Dry Ash Disposal Facility. Operating Manual. Internal Report, Eskom: Generation Engineering Department (GED), May 1993.

2. Van Wyk, W. Lethabo Power Station. Ash Dump Operating Manual. Internal Report, Eskom, (Roshcon), Jun 1992.

3. Kreuiter, A. Technical Evaluation of the Out Of Phase Dump Situation and the Dump Development Options to Bring it Back Into Phase. Report No:23CBKE004A, Internal Report Kendal Power Station, Eskom: GED, May 1996.

4. Kreuiter, A. Economic Evaluation of the Out Of Phase Dump Situation and the Dump Development Options to Bring it Back Into Phase. Report No:23CBKE004B, Internal Report Kendal Power Station, Eskom: GED, Oct 1996.

5. Kreuiter, A. Sensitivity Evaluation of The Out Of Phase Dump Situation and the Dump Development Options to Bring it Back Into Phase. Report No:23CBKE004C, Internal Report Kendal Power Station, Eskom: GED, Dec 1997.

6. Zador, A.T. Animation - A Tool for Designing Material Handling Systems, Bulk Solids Handling Journal. Vol 12, No 3, Sep 1992, pp. 381-392.

7. Ramos, C.M. and Goodwin, P.J. Simulation of Harbour Facilities, Bulk Solids Handling Journal. Vol 9, No 2, May 1989, pp. 135-143.

8. Zador, A.T. Computer Simulation for Port Design, Bulk Solids Handling Journal. Vol 4, No 1, Mar 1984, pp. 23-27.

9. Halvorsen, N.M. Computer Aided Design of Belt Conveyors, Bulk Solids Handling Journal. Vol 3, No 4, Nov 1983, pp. 757-762.

10. Lubrich, W.S.W. Assessment of Equipment According to the Degree of Availability and Utilization in Open Pit Systems, Bulk Solids Handling Journal. Vol 8, No 6, Dec 1992, pp. 701-706.

11. Bhana, Y. Geotechnical Properties of Ash from Dry Ash Dumps. MSc(Eng) Dissertation. University of the Witwatersrand, (In Preparation).

12. Cowden, R, et al. Microstation Bible. Onword Press, 1993.

13. Spiegel, M.R. Theory and Problems of Vector Analysis. SI (Metric) Ed, Schaum's Outline Series, McGraw-Hill Book Company, 1974.

14. Kindle, J.H. Theory and Problems of Plane and Solid Analytic Geometry. Schaum's Outline Series, McGraw-Hill Book Company, 1950.

15. Microsoft Excel Version 5.0 User's Guide. Document No:XL57926-0394, Microsoft Corporation, 1993-1994.

16. Microsoft Excel Version 5.0 Visual Basic User's Guide. Document No:XL57927-0394, Microsoft Corporation, 1993-1994.

17. Mansfield, R. The Visual Guide to Visual Basic for Applications. Ventana Press, 1994.

18. Walkenbach, J. Excel 5 for Windows Power Programming Techniques. IDG Books Worldwide, Inc, 1994.

Author: Kreuiter, Andre.

Name of thesis: Development of a parametric computer model for automating the production of power station dry ash dump growth plans.

PUBLISHER:
University of the Witwatersrand, Johannesburg