A Computer Simulation of the Rotary Drum Brownstock Washer System Using the Monte Carlo Method of Distribution Sampling

Jacqueline K. Pease
Western Michigan University

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A COMPUTER SIMULATION OF THE ROTARY DRUM BROWNSTOCK WASHER SYSTEM USING THE MONTE CARLO METHOD OF DISTRIBUTION SAMPLING

by

Jacqueline K. Pease

A Thesis
Submitted to the
Faculty of The Graduate College
in partial fulfillment of the requirements for the degree of Master of Science
Department of Paper and Printing Science and Engineering

Western Michigan University
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A steady-state probabilistic model is chosen to simulate the brownstock washing system's uncertainty which arises from unpredictable process fluctuations and measurement noise. Distribution sampling is used to construct multiple mass balances of a washing system. Included in this model is a linear relationship describing the correlation between dilution and displacement which allows displacement ratio to be generated based on dilution factor. This is an improvement over a similar, earlier model which considers all variables to be independent. There is no statistical difference between the mean output of the simulation and the means of data sets collected at two different mills. Additional work is required to determine whether the observed variability in variance estimates is within expected bounds.
ACKNOWLEDGEMENTS

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Jacqueline K. Pease
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A computer simulation of the rotary drum brownstock washer system using the Monte Carlo method of distribution sampling

Pease, Jacqueline K., M.S.
Western Michigan University, 1987
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CHAPTER I

INTRODUCTION

Brownstock Washing - Purpose

The purpose of brownstock washing is to remove the maximum amount of dissolved solids (DS), left from the pulping process, with the least amount of dilution water. The DS that remain with the pulp after washing, termed carryover, can interfere with subsequent operations such as bleaching and papermaking. When the solids leave these processes they become a source of color, biological oxygen demand, and chemical oxygen demand at the effluent treatment system (1). Much of the water required to accomplish the solids removal will eventually have to be evaporated to recover the cooking chemicals. This results in the need to optimize dilution water usage, which is limited by evaporator capacity, with the degree of washing desired. There are a variety of methods to accomplish this task, all of which consist of the processes of dilution and thickening and/or displacement. The most common means of brownstock washing used in the pulp and paper industry utilizes rotary vacuum drum washers set up in a counter-current fashion.
Brownstock Washing - Basic Operation

The basic operation of a typical rotary vacuum drum washer begins when the "dirty" pulp enters the washer and is diluted in the vat. The drum turns in the vat and pulp sticks to its outside surface due to a vacuum created inside the drum (see figure 1). The vacuum is caused by a drop leg which siphons the liquor from the pulp slurry in the vat through the face of the vacuum drum. The filtrate flows down the length of the drop leg (which determines the amount of vacuum) to the seal chamber. These steps comprise the dilution/thickening portion of the washing.
process. The displacement portion of washing begins as shower water is applied to the mat of pulp. The "cleaner" shower water is meant to displace the "dirtier" liquor contained in the mat. The pulp is then discharged from the drum. Pulp consistencies in the vat and mat are approximately 1 and 16 percent, respectively.

Vacuum drum washers are usually set up in a counter-current series of 2 to 5 washers (see figure 2). The residence time in each washing stage is generally two to five minutes (2). The operation works in such a way that the "cleanest" water washes the "cleanest" pulp and the "dirtiest" water washes the "dirtiest" pulp. Dilution
water enters the system as shower water for the final stage of washing. Filtrate from this stage is split; the majority is recycled and used to dilute the pulp entering the vat of the same washing stage. The remainder of the filtrate from this stage is used as shower water in the preceding washing stage. The same flow pattern is continued for each stage. At the first stage (the dirtiest pulp) the filtrate is used to dilute the pulp coming from the blow tank. Of the excess filtrate, a portion may be used to quench the cook in the pulping process, the rest is sent to recovery where the cooking chemicals are re-claimed.
CHAPTER II

REVIEW OF SELECTED LITERATURE

Washing Theory

**Washing Losses**

The DS contained in the black liquor exiting the pulping operation consist of a combination of lignin fragments and other alkaline soluble constituents from the wood, as well as the inorganic material originating in the white liquor used in pulping (1). Therefore the black liquor makeup depends on the wood species, the amount of cooking liquor used and its chemical content, and the degree of delignification that occurred during the cook.

Historically, the kraft industry has expressed washing loss in terms of sodium sulfate (saltcake) per ton of pulp. There is very little salt cake, however, in the washed pulp (1,3). BOD, color, and sodium are all actually removed at different rates when washed (4), and the magnitude to which each constituent is removed is not clear (5,6). Also the ratio of sodium to organic matter in the dissolved solids may vary widely. For these reasons it is important that losses be determined and reported as total dissolved solids per unit of pulp. According to Perkins and Jackson (1) the use of salt cake loss as a measure of washing efficiency should be obsolete.
Washing Efficiency

The overall efficiency of the washer system is expressed as the weight of DS washed out of the pulp per unit of pulp production divided by the weight of DS exiting the digester (before dilution) per unit of pulp production multiplied by 100. The weight of DS washed out of the pulp is simply the difference in the weight of DS exiting with the pulp from the digester, and that which is exiting the washing system in the liquor contained in the pulp mat.

As previously stated, there are two basic mechanisms of washing that are occurring: dilution/extraction and displacement. The efficiency of the dilution/extraction phase is generally dependent on the respective consistencies to which the pulp is diluted and then thickened. The displacement phase is more complex. Were displacement washing ideal, no mixing would take place between the wash liquor and the dirty liquid being displaced, and complete displacement of the dirty liquor would be accomplished with a volume of wash liquid equal to the amount contained in the pulp mat. In real life, however, mixing at the interface between wash liquid and the liquid to be displaced does take place.
Displacement Ratio Concept

In the early days of brownstock washing, in order to construct a material balance around a washing operation it was necessary to make an assumption of the amount of soluble solids removal accomplished by each stage. Perkins, Welsh, and Mappus (7) alleviated this problem with the introduction of the displacement ratio. If the washing done by each stage is expressed in terms of the reduction in soluble solids, a measure of efficiency for the showers can be defined as the ratio of the actual reduction in dissolved solids to the maximum possible reduction. This ratio is called the displacement ratio (DR), which can be calculated as follows:

\[ DR = \frac{(vat\ DS - mat\ DS) - (vat\ DS - shower\ DS)}{vat\ DS - shower\ DS} \]  (1)

In this equation the variables vat, mat, and shower DS represent the dissolved solids content in the liquid fraction at each of these locations. From another approach, \( DR = \frac{W_s}{W_p} \), where \( W_s \) equals the weight of the shower liquor remaining in the washed mat and \( W_p \) equals the total weight of liquor leaving with the pulp.

The ratio \( W_s/W_p \) was derived theoretically by Perkins, Welsh, and Mappus by making the following assumptions: (a) the washing action of the showers is a series of perfect dilutions and thickenings, with the shower liquor being applied in \( n \) equal portions, and (b) the mat consistency
returns to its original consistency after each application of shower liquor.

\[ \frac{W_s}{W_p} = 1 - \left[ \frac{(nW_p)}{W_p(n+1) + DF} \right]^n \]  \hspace{1cm} (2)

Here \( n \) represents the number of shower applications on a single stage, and \( DF \) is the dilution factor for the system. The dilution factor (see equation 3) is defined as the net amount of water added to the system per unit of O.D. pulp. The net amount of water added means the weight of shower water applied less the weight of liquid leaving the system in the final pulp mat.

\[ DF = \frac{\text{shower - mat liq}}{\text{O.D. pulp}} \]  \hspace{1cm} (3)

Equation 2 becomes a theoretical correlation between displacement and dilution. Empirical data do not coincide with the theoretical curve because the washing action of the showers is not a series of perfect dilutions and extractions.

Simple Pore Model

Klein (8) developed a simple pore model of a pulp mat to determine the relationship between the removal of dissolved solids from a pulp mat and the usage of wash water. The simple pore model is used to define the internal structure of a pulp mat as a series of circular cylinders each of the same length and with equivalent radii. As liquid passes through a cylindrical pore, viscous drag at the pore walls forces the flow in the middle of the pore
to be greater than the flow at the wall. Klein theorizes that this phenomenon will limit the efficiency attainable in the displacement zone of a washer from ever reaching its maximum; i.e., the DR can never reach 1.

Klein defines the wash liquor ratio (WLR) as the quantity of wash liquid applied, divided by the quantity of liquid leaving with the mat of pulp (equation 4). It is not clear whether or not Klein used the term "quantity" to represent mass or volume. Throughout this paper WLR will represent the above ratio in terms of mass.

\[
\text{WLR} = \text{lbs. shower/lbs. mat liq.} \tag{4}
\]

When wash water is applied to an equal amount of "dirty" liquid present in the mat, the WLR=1 and theoretically DR=1. Of course, the DR only approaches 1. Klein developed the following relationships from lab data and the cylindrical pore model.

\[
\begin{align*}
\text{DR} &= \text{WLR} \quad \text{for WLR} < 0.5 \tag{5} \\
\text{DR} &= (1 - 1/4\text{WLR}) \quad \text{for WLR} > 0.5 \tag{6}
\end{align*}
\]

The first relationship (eq. 5) suggests that below a WLR of 0.5 the DR and WLR behave theoretically, above 0.5 (eq. 6) there is a deviation from theory.

**Local Efficiency Model**

Cullinan (9) defines a term he refers to as the local efficiency, located anywhere within the wash zone (see figure 3) in the following way:
Here \( X_n \) equals the solute concentration in the wash liquor leaving any point in the wash zone of the \( n \)th stage (filtrate DS), \( X_{n+1} \) is the solute concentration in the wash liquor feed to the \( n \)th stage (shower DS), \( C \) is the solute concentration in the cake within the wash zone (mat DS), and \( E \) is the local efficiency. Cullinan then incorporated equation 7 (for local efficiency) in a differential material balance which he integrated over the wash zone to arrive at the following equation:

\[
C_n - \bar{X}_{n+1} = E(\frac{C}{n+1} - \bar{X}_{n+1})
\]

In equation 8, \( C_n \) is the solute concentration in the cake exiting the \( n \)th filter (exiting mat DS), \( b_n \) equals the solute concentration in the reslurried feed to the \( n \)th filter (vat DS), and \( N \) equals the wash ratio. \( N \) is the same as WLR except \( N \) is a ratio expressed in terms of volume whereas WLR in this work is a ratio expressed in terms of mass. Cullinan algebraically incorporated equation 8.
with the definition of DR to arrive at the following equation:

$$DR = 1 - e^{-EN}$$  \hspace{1cm} (9)

For perfect plug flow, all the mat water is displaced by an equal amount of shower water, in other words $X_n = b_n$, until complete displacement then $X_n = X_{n+1}$. If complete mixing exists within the displacement zone (complete mixing of shower water with mat water) then $X_n = C$. In real life, some mixing and diffusion occurs between the shower water and the mat liquid but not complete mixing. Cullinan's $E$ factor (local efficiency) is a measure of the degree of mixing and diffusion.

Modeling the Brownstock Washer

**Constructing The Mass Balance**

Using the displacement ratio concept discussed earlier it is possible to make a complete material balance around a brownstock washing system. This is accomplished on a single washing stage by computing the black liquor dissolved solids balances around (a) the mat, using the displacement ratio, (b) the entire washing stage, and (c) the vat.

For a washing system consisting of more than one washer, the material balance is complicated by the counter current flow pattern of pulp and dilution water. There-
fore to complete the balance, an estimate is made for the
dissolved solids, either entering or exiting the system.
If the decision is made to guess the dissolved solids ex­
itig the system in the final stage (carryover), then the
above balances are carried out on each stage (starting
with the last) using the estimated value. After this has
been completed the calculated value of the dissolved sol­
ids content of the liquor entering the washers is compared
with the known value. If the two values are different the
estimated value of carryover is altered appropriately and
the process repeated until the calculated and measured
values are equal to the desired tolerance level. To alle­
viate this slow and tedious procedure, Miner (10) wrote a
computer program to complete material balances of brown­
stock washers using the above concepts.

The Use of Generalized Computer Systems

The brownstock washer has been modeled using general­
ized computer systems which are based on the principle
that all flow diagrams are made up of certain basic blocks
or unit operations. Calculations for a wide variety of
pulp mill flow diagrams are possible when subroutines for
pulp mill unit operations are used. A process flow dia­
gram is converted into block diagrams showing all the unit
operations involved. Generally, for recycle streams the
flows and concentrations are estimated and the material
balances completed using an iterative process until a specified level of accuracy is reached for the balance. Examples of such generalized computer systems are GEMS developed by T. A. Kotnour, DYSCO developed by the University of Michigan and modified by the Institute of Paper Chemistry for use in pulp and paper mill simulations, and MAPPS developed by the Institute of Paper Chemistry for pulp and paper mill simulations (11).

Edwards, et al. (11) discussed the use of GEMS for material balance calculations. They evaluated the GEMS system using very extensive mass balance data that was collected in the oxygen bleaching pilot plant at MoDo's Husum mill as part of the Stiftelsen Skogsindustrins Vatten- och Luftvardsforskning (SSVL) environmental care project. They reported that the agreement between the measured and calculated concentrations was "relatively good" especially when it was taken into consideration that the data were mill data and that "steady-state is only relative under mill conditions" (11).

The Use of Stochastic Variables

Freedman (2) talks about a model-based, computer-coordinated scheme to control brownstock washers. The model uses steady state modeling for estimation purposes and dynamic modeling for tracking purposes. The control scheme also uses stochastic modeling to account for unpre-
dictable process upsets and measurement noise. Chip quality variables such as moisture, size, and packing density and pulp characteristics such as Kappa number are listed as causes for process disturbances. Unpredictable changes in pulp properties, such as these, present difficulties when modeling a washing process. Measurement noise, occurring from sampling and lab analysis, is also a cause of uncertainty.

Mitcham (12) also used stochastic variables to model the brownstock washing process. He incorporated a form of the Monte Carlo method, called distribution sampling, with Miner's (10) computer program for mass balance calculations of a washing system. In general, the means and standard deviations of the input variables were used to set up a distribution for each variable. Based on probability a value was sampled at random from each distribution, the mass balance calculations of the washer were conducted and the carryover was calculated. The process was repeated 1000 times, thereby giving a complete distribution of carryover. Mitcham was sampling independently for washer outputs and inputs; since the output of a washer becomes the input of a subsequent washer, this was incorrect.
CHAPTER III

PRESENTATION OF THE PROBLEM

Perkins (13) makes the point that it theoretically takes at least 24 hours for a continuous washing system to return to equilibrium (steady-state) once any change is made to the entering elements of the system. The system is actually in a continuous state of flux since changes in white liquor concentration, chip moisture, chip feed, any internal flow, wash water flow, and chip temperature can effect the equilibrium of the washing system. Essentially a true steady-state condition never exists in a mill operation. Therefore it is important to consider the effects that the process variability have on the output.

The major purpose of a simulation is to check the effect of a process variable change (such as dilution, or an addition of equipment) on the efficiency of the washer system. Actually going out in the mill and altering the system to see these effects can be costly and time consuming. For this reason it is beneficial to have an idea of the effects that a process change will create, prior to the introduction of the change in the mill.

Variability should also be included in a simulation model since a definite change in a steady-state condition may not even be seen if there is a large degree of variability in the outcome. Mitcham's (12) idea of using dis-
distribution sampling to simulate a washer is an excellent way to model the variability that exists in the brownstock washer. One important aspect of washing theory that needs to be incorporated in Mitcham's model is the dependence that exists between variables (he assumed all variables to be independent). A known, major dependence that exists is the relationship between dilution and displacement in the wash zone. This investigation incorporates the dependence of displacement on dilution into a simulation of the brownstock washer using the Monte Carlo method of distribution sampling.
CHAPTER IV

METHODOLOGY USED

Modeling And The Monte Carlo Method

Concepts Of Mathematical Modeling

According to Mihram (14) there are essentially five steps to follow in the development of a model: (a) system analysis, in which the system's components and the interrelationships that exist between these components are studied; (b) system synthesis, in which the program is written; (c) model verification, which consists of debugging the program (will it produce the anticipated behavior?); (d) model validation, used to establish the degree of comparability between the model and the system it is mimicking; and (e) model analysis, used to make inferences about the system using the simulation.

Deterministic and probabilistic are terms used in modeling. A deterministic problem is known with certainty and it can be static or dynamic. A probabilistic problem refers to a situation that is not known with certainty but can be described by a probability density function. As with deterministic problems, probabilistic problems can also be static or dynamic. Modeling the brownstock washer then becomes modeling a steady-state probabilistic problem.
The Monte Carlo Method

The name and systematic development of Monte Carlo methods date back to the 1940's, however, use of this type of method began much earlier. An early example was in 1908 when Student (W. S. Gusset) used experimental sampling to help add confidence in his t-distribution. Monte Carlo methods were first implemented as a research tool during World War II with work on the atomic bomb (15).

A broad definition of Monte Carlo could be any technique for solving a model using random numbers. According to Kleijnen (16), applications of Monte Carlo using the above definition would include: (a) solving deterministic problems, (b) distribution sampling (model sampling), and (c) stochastic simulation. A deterministic problem has no direct association with a random process, but if theory exposes an underlying expression that describes some unrelated random process, the deterministic problem can be solved by solving the related problem using Monte Carlo. Deterministic problems could include solving integrals, the calculation of a constant such as \( \pi \) and solving differential equations.

Distribution sampling is used when one variable, the output, is a known function of other variables, the inputs, which have known distributions to sample from. In order to estimate the distribution of the output variable,
values from each of the input variables are drawn at random from their respective distributions and the resulting output variable is calculated. This process is repeated several times to yield an estimate of the output variable's distribution. As previously discussed, Mitcham used distribution sampling to model the brownstock washer. Stochastic simulation is similar to distribution sampling, but refers to the experimentation of a model over time.

Kleijnen (16) gives the following distinguishing characteristics between simulation and distribution sampling: (a) the output variable in distribution sampling is a relatively simple function of the inputs, whereas the output variable in simulation is a very complicated function which cannot be formulated explicitly except by the use of a computer program; (b) the function in distribution sampling is static, in contrast to simulation in which the relationships are dependent on time and therefore dynamic.

Mihram (14) would prefer to make the distinction that the Monte Carlo method should only include the solving of problems in which statistical estimates are used to give solutions to formalized models that could theoretically be solved by means of operations defined by mathematics or numerical analysis, in other words, deterministic problems. He would like to separate sampling experiments (distribution sampling) from the Monte Carlo method. He
would also like to separate stochastic simulation modeling from the Monte Carlo method. Therefore, according to Mihran, the term Monte Carlo method should only be used with respect to solving a deterministic problem.

Since the terminology of Monte Carlo varies from author to author, it is necessary to clarify in what way it will be used in the present study. Any reference to the Monte Carlo method throughout the remainder of this paper will be made with reference to distribution sampling.

System Analysis

Correlation Between Displacement and Dilution

Displacement is dependent on the amount of dilution that is applied to the washing operation. As previously discussed, suggested models describing this correlation have appeared in the literature. Perkins, Welsh, and Mappus (7) suggested a theoretical relationship (eq 2) based on the assumptions that each shower application is a perfect dilution and extraction and that the mat consistency returns to its original consistency after each shower application. Klein (8) arrived at a relationship between WLR and DR that suggests DR behaves theoretically until the WLR reaches 0.5 (eq 5 and eq 6), where it deviates from theoretical behavior. Cullinan (9) derived an equation (eq 9) relating DR to a value similar to WLR.
based on his definition of local efficiency.

It becomes difficult to relate the DR to the DF since the two do not seem to share any common points. For instance, when no shower water is applied to the mat the DR will be zero. Complicating matters, when no shower water is applied the DF will be a negative value since it depends on the consistency of the mat. The WLR, on the other hand, is zero when no shower water is applied to the mat. The DF and WLR can be related by the following equation:

\[ \text{WLR} = 1 + \frac{(\text{DF})(\text{MAT})}{(100 - \text{MAT})} \]  

(10)

In this equation MAT represents the fiber consistency (%) contained in the final stage mat.

The DR is bounded by 0 and 1, however it will never actually reach the value of 1; it can only approach it. The WLR is bounded by 0 on the lower end and is unbounded on the upper end. If plotted, the DR would increase with respect to WLR and asymptotically approach its upper limit of 1. If the dependence of DR on WLR were a first order rate equation, the relationship would look like this:

\[ \text{DR} = 1 - e^{k \text{WLR}} \]  

(11)

where \( k \) represents an experimental constant. Equation 11 resembles equation 9, with the exception that WLR represents a weight ratio of shower water to final mat liquor, and Cullinan (9) chooses to use \( E \), his term for local efficiency to represent the deviation of DR from its theo-
retical value.

Equation 11 can be manipulated to produce a linear form, as follows:

\[ \ln(1-\text{DR}) = k\text{WLR} \]  

(12)

which suggests that a plot of \( \ln(1-\text{DR}) \) versus WLR would give a straight line with a slope of \( k \), and a \( y \) intercept of zero.

Support For Proposed Correlation

For the above relationship (eq 12) to be a true representation of the dependence of \( \text{DR} \) on the WLR a plot of actual data should be a straight line which goes through the origin. To test the relationship it is necessary to obtain data of \( \text{DR} \) with respect to WLR over a wide enough range of WLR so that a correlation may be seen.

Statistical Treatment of Data

A straight line is usually represented by the formula, \( y = \alpha + \beta x \), where \( \beta \) is the slope of the line and \( \alpha \) is the \( y \) intercept. If data shows a particular linear correlation then it should have a slope. To test the hypothesis that a group of data has a slope of zero (\( H_0: \beta = 0 \)) versus the hypothesis that there is a significant slope, an F test may be used. This is accomplished by performing a least squares linear regression of the data. From the output of the linear regression, an F statistic may be
calculated by dividing the mean square regression by the mean square error (F=MSR/MSE). If the value of F is greater than the critical F statistic (F_C) at 1 and N-1 degrees of freedom (d.f.), found from F tables, then there is significant evidence to reject H_0, i.e. there is evidence of a relationship between x and y.

According to Snedecor and Cochran (18) a test can be performed to see if data, that is represented by a straight line, goes through the origin or not. To test the hypothesis that the line goes through zero (H_0: \alpha=0) versus the hypothesis that it does not, a least squares linear regression is performed (fitting the usual 2 parameters of "a" to estimate a and "b" to estimate \beta to the data). Using the output of the linear regression the following t statistic may be calculated:

\[
t = \frac{(\bar{Y} - b\bar{X})}{\sqrt{\text{MSE} \left\{ \frac{1}{n} + \frac{\bar{X}^2}{\sum(X-\bar{X})^2} \right\}^{1/2}}} \quad (13)
\]

This t statistic can be compared to the critical value t_C at N-1 d.f., found from a t table. If the absolute value of t is greater then t_C there is significant evidence to reject H_0, i.e. there is evidence to prove the line does not go through the origin. If, on the other hand, the opposite is true (t_C>t) there would be no significant reason to assume that the line did not go through the origin.

**Back-Up Data**

Perkins, Welsh, and Mappus (7) published a plot of
empirical data of DR versus DF for each of 3 washing stages. If a constant mat consistency of 16% is assumed, plots can be made of \( \ln(1-DR) \) versus WLR for each washing stage (see figures 4, 5, and 6). For all three stages the

![Graph](image)

**Figure 4. Washer 1**  
(Data Source: Perkins, Welsh, & Mappus)

F-test showed significant evidence (at significance level \( \alpha=0.05 \)) of a relationship between \( \ln(1-DR) \) and WLR. For stages 1 and 2 results of the t test described earlier were non-significant at a 95% confidence (\( \alpha=0.05 \)), i.e. with 95% confidence, there is no reason to assume that the line does not go through the origin. The data for stage 3 gave a non-significant t statistic at 99.5% confidence
Though a non-significant result does not prove that the line goes through zero, it does mean that it can not be disproved at the particular significance level.

Service and Seymour (19) published a plot of experimental data for displacement ratio as a function of dilution ratio. They define dilution ratio as the volume of shower water applied to the pulp mat, divided by the volume of liquid retained in the pulp mat. Therefore it is similar to WLR except it is based on volume instead of mass. If it is assumed that the specific gravity of the
shower liquid is the same as that of the liquid retained in the pulp mat their term dilution ratio becomes equal to WLR. If the Service and Seymour data is applied to equation 12 (see figure 7) and the hypotheses described earlier are tested, the data shows a definite correlation (significant F test at $\alpha=.05$). The t test is non-significant at 95% confidence; there is no evidence (at $\alpha=.05$) to suggest that the line does not go through the origin.

Muller (20) created a laboratory simulation of the brownstock washing process. In preliminary washing trials
he used NaCl as a dissolved solids tracer over a wide range of dilutions. In later trials he simulated each stage, in a three stage system, using brownstock and liquor samples collected from S.D. Warren Paper Company at Muskegon, Michigan. Plots of equation 12 using these data are shown in figures 8 through 11. Figure 8 (NaCl trial) shows a straight line correlation between \( \ln(1-DR) \) as it is related to WLR. With 95% confidence there is no significant evidence to suggest that the line does not go through zero.

Figure 7. Entire Washing System
(Data Source: Service & Seymour)
The three data sets from the brownstock washer simulation (figures 9-11) all have significant F-tests (at \( \alpha=0.05 \)), suggesting a significant relationship between WLR and \( \ln(1-\text{DR}) \). The t-test for these data sets is also significant (at \( \alpha=0.05 \)) which gives evidence that the line does not pass through the origin. Since the line must pass through the origin (when \( \text{WLR}=0, \text{DR}=0 \)), these data tend to suggest the following, more complicated, model relating the two parameters of WLR and DR to each other:

\[
\frac{\text{DR}}{\text{DR}^*} = 1 - e^{k \text{WLR}}
\]

Figure 8. NaCl Tracer Study  
(Data Source: Muller)
Where $DR^*$ is the maximum attainable DR for the particular washer, which can be thought of as the ultimate DR achieved when there is perfect displacement. Equation 14 suggests that the perfect displacement may not be 1; there may be an inaccessible portion of dissolved solids which does not allow the DR to approach 1, but rather a value which is less than 1. $DR/DR^*$ is the fraction of the maximum DR attainable, for the particular washer in question. Note that equation 14 reduces to equation 11 when $DR^*$ is equal to 1, the theoretical maximum DR. The model de-
scribed by equation 14, an outcome of the recent work by Muller (20), is a more complex model to simulate then that described by equation 11. This work, underway at the time of the conception of the model described by equation 14, continues the use of equation 11 to describe the relationship between DR and WLR, as it is a more convenient model to simulate and there is evidence which suggests it could be a model.
Distribution Sampling

Mitcham's computer simulation (12) essentially computed 1000 mass balances of a washing system to characterize that system's variability. As mentioned earlier, he used distribution sampling to choose values for each input variable needed to complete the mass balances. The input variables needed for a mass balance of a washing system are the fiber consistencies of the vats and mats.
for each stage and for the pulp entering the system from
the blow tank (prior to dilution), the dissolved solids
content of the liquor fraction of the blow tank pulp and
of the shower water entering at the final stage washer,
the displacement ratio for each stage, and the system di-
lution factor.

**Sampling From A Normal Distribution**

Assume that observations are independently selected
from a population having a mean of \( \mu \) and a standard devi-
ation of \( \sigma \). The Central Limit Theorem states (21) that
when the sample size becomes large, the sampling distribu-
tion of \( \bar{X} \) will tend toward a normal distribution with a
mean of \( \mu \) and a standard deviation of \( \sigma_{\bar{X}} \). The Central
Limit Theorem applies regardless of the shape of the popu-
lation frequency distribution. With this in mind, a nor-
mal distribution should be adequate to describe the vari-
ability that exists around the population mean of a vari-
able that possesses no boundary conditions that need to be
met.

To generate numbers based on a normal distribution
the following transformation may be used (22):

\[
x = \left( \frac{-2 \ln(R_1)}{\sigma_{\bar{X}}} \right)^{1/2} \cos(2\pi R_2) \sigma_{\bar{X}} + \bar{X} \quad (15)
\]

where \( R_1 \) and \( R_2 \) are random numbers generated from a uni-
form distribution from 0 to 1. Mitcham (12) used this ap-
proach to generate values for the dilution factor of a
Sampling From A Log-Normal Distribution

The variables which represent fiber consistency or dissolved solids content are percents or fractions (ppm). These variables possess a boundary condition in that they can not fall below zero. These percents are also small in comparison to the total; as an example, the vat consistency is usually only about 1%. When boundary conditions such as these exist, and values are generated based on a normal distribution around a mean value that is small, impossible outliers can easily be generated. To handle this problem Mitcham used log-normal distributions to characterize all the variables which were percents.

A log-normal distribution is a skewed distribution which has no values less than zero. When all of the values which make up the log-normal frequency distribution are transformed by taking their natural log, the transformed values possess a normal distribution. Also as the mean of the log-normal distribution becomes greater (moves away from zero), the distribution takes on the look of a normal distribution. These characteristics make the log-normal distribution favorable for sampling bounded variables without generating impossible values.

According to Aitchison and Brown (23) the mean \( \alpha \), and the variance \( \beta^2 \), of a log-normal distribution (the un-
transformed data) are given by the following two equations:

\[ a = e^{\mu + \sigma^2/2} \]  \hspace{1cm} (16)

\[ \beta^2 = e^{2\mu + \sigma^2}(e^{\sigma^2} - 1) \]  \hspace{1cm} (17)

where \( \mu \) and \( \sigma^2 \) are the mean and variance of the transformed data (having a normal distribution), respectively. Equations 16 and 17 can be manipulated to produce the following equations:

\[ \mu = \ln a - \sigma^2/2 \]  \hspace{1cm} (18)

\[ \sigma^2 = \ln(1 + \beta^2/a^2) \]  \hspace{1cm} (19)

Equations 18 and 19 make it possible to calculate the mean \( \mu \), and the variance \( \sigma^2 \), of log transformed data (possessing a normal distribution) from the mean \( a \) and the variance \( \beta^2 \), of untransformed data (possessing a log-normal distribution).

To generate a value from a log-normal distribution which has a sample mean \( \bar{x} \), and variance \( s^2 \), equation 19 is used to calculate the variance of the transformed data set by replacing \( a \) with \( \bar{x} \), and \( \beta^2 \) with \( s^2 \). The mean of the transformed data set is calculated using equation 18. A value \( x \) can now be generated using equation 15 by replacing \( \bar{x} \) with \( \mu \) and \( s \) with \( \sigma \). The value \( x \) represents a generated value from the normal distribution associated with the transformed data. To convert this value into one associated with the original data distributed log-normally, the exponent of \( x \) is taken (value=\( e^x \)).
Sampling Displacement Ratio Based On Wash Liquor Ratio

To sample a value of the DR of a washing system, which is based on a sample made for dilution, requires manipulation. The linear form of the proposed relationship between displacement and dilution, equation 12, suggests that if the parameter k is known, the DR can easily be determined for a given value of WLR. Since the line must pass through the origin, only one other point needs to be found in order to calculate k. If samples are taken, when operating at consistent conditions, a group of data result (since variability exists) for WLR and LN(1-DR). This group of data, essentially a cluster of points around a small area of the plot of WLR versus LN(1-DR), is used to estimate the regression line and in turn calculate k. The group of data is also used to get an idea of the variability that exists about the regression line.

Linear Regression Through Zero

To calculate k for a washing stage requires the use of a variation of the commonly used method of least squares linear regression. In regular least squares linear regression \( y = \alpha + \beta x \) two parameters are estimated, the slope \( \beta \) and the y-intercept \( \alpha \). For the relationship described by equation 12, \( y = \ln(1-DR) \), \( x = WLR \), and \( \beta = k \). The \( \alpha \) must be zero, since when the WLR is zero, the DR is zero,
and therefore the \( \ln(1-\text{DR}) \) must also equal zero. To force a linear regression through the origin, i.e. estimating only one parameter instead of two, requires different equations than are commonly used for two parameter estimation.

According to Snedecor and Cochran (18) the least squares estimate (b) of \( \beta \) when \( \alpha=0 \) is given by:

\[
b = \frac{\sum x_i y_i}{\sum x_i^2}
\]

Equation 20 can be used to get an estimate of \( k \) that will allow values of \( \text{DR} \) to be generated based on the values that are generated for WLR. The data, sampled from an actual system that will be used to arrive at values for the means and standard deviations of the input variables, can just as easily be used to calculate \( k \).

**Variability About The Regression Line**

Variability needs to be taken into consideration when generating an appropriate value of \( \text{DR} \) based on a pick of WLR. Generally speaking, at certain levels of dilution there should be values of \( \text{DR} \) that are impossible. At the same time there is not a specific value of \( \text{DR} \) that is associated with a specific value of WLR, as equation 12 might lead one to believe. Equation 12 may more accurately be written as:

\[
\ln(1-\text{DR}) = k\text{WLR} + E
\]

where \( E \) represents the degree of uncertainty that exists
in the system. Uncertainty can occur in operational areas such as changes in chip moisture, temperature fluctuation anywhere in the system, poor mixing, poor drainage on the drum, etc.. Uncertainty can also result in sampling techniques and lab analysis of the washing results. To incorporate this uncertainty into the model, the variation in the regression must be estimated.

Snedecor and Cochran (18) state that the mean square error about the regression line when it has been forced through the origin is as follows:

\[
S_{y,x}^2 = \frac{\sum y_i^2 - \left( \frac{\sum x_i y_i}{\sum x_i} \right)^2}{n-1}
\]  \hspace{1cm} (22)

where \( n \) is the number of samples and \( S_{y,x}^2 \) is the mean square error about the regression line (the square root of \( S_{y,x}^2 \) is equal to the standard error of estimate of \( y \) given \( x \), written as \( S_{y,x} \)). Neter and Wasserman (24) state that for a given value of \( x \), called \( x_0 \), the standard deviation associated with \( y \) at that value, given by \( S_{y,x_0} \), is as follows:

\[
S_{y,x_0} = S_{y,x} \left[1 + \left( \frac{x_0^2}{\sum x_i^2} \right) \right]^{1/2}
\]  \hspace{1cm} (23)

Equation 23 describes the degree of variability in \( y \) given a certain pick of \( x \).

**Incorporating Dependence In The Model**

The dilution factor of a washing system is a well known parameter in the paper industry and is commonly measured for a washing system. The wash liquor ratio, by
contrast, is not so well known and usually is not measured. For this reason the computer model uses measured samples of DF that are later converted to WLR using the mat consistency by the computer. The user does not need to deal with WLR at all.

To characterize a washing system, the operator collects samples from the washing system to be analyzed such that, for each sampling run made a value can be calculated for the dilution factor and the displacement ratio for each stage. Samples are collected to determine the fiber consistency (%) for the mats, vats, and the blow tank, and the dissolved solids content for the liquor coming from the blow tank (%) and the final stage shower (ppm). Individual values are needed for the dependent variables of displacement ratio, dilution factor, and mat consistency. The means and standard deviations only are needed for the rest of the variables.

The individual values of the system DF and the mat consistency for each washing stage are used to calculate individual values for the WLR for each washing stage. These values together with their corresponding values of DR are used to perform a least squares linear regression forced through the origin, for each washing stage, of y (ln(1-DR)) versus x (WLR). The slope, standard error of y given x, and the sum of squares of x are calculated and stored in a file along with the means and standard devia-
tions of all the variables. The data, in the file, are used later to generate individual values for each of the variables during a simulation.

During a simulation, data is generated using the Monte Carlo method of distribution sampling. Values are generated for the DF using its measured values of mean and standard deviation and by sampling from a normal distribution using equation 15. Values for fiber consistency in the blow tank, mats, and vats, and the dissolved solids content in the blow tank and final shower are generated based on log-normal distributions using equations 18 and 19, to calculate a mean and standard deviation for each variable based on transformed data sets, possessing a normal distribution. These values are used in equation 15 to generate random values, based on normal distributions, of which the exponents are taken to arrive at random values corresponding to log-normal distributions. The generated values of mat consistency and dilution factor are used to calculate a value of the WLR for each washing stage.

The calculated value of WLR for each washing stage is multiplied by the factor k (slope found in linear regression) for each stage, to arrive at the expected value of \( Y_E, x_0 (\ln(1-DR)) \) at the particular value of WLR \( (x_0) \). The standard deviation associated with this expected value can be given by equation 23. To generate a value of y based on \( x_0 \), a normal distribution is assumed for y. The mean
\( y_{E,xo} \) and standard deviation \( S_{y,xo} \) are used in equation 15 to generate a value from a normal distribution. From the \( y \) thus generated, DR is calculated \( (DR=1-e^Y) \).

**General Program Structure**

**Program Main Body**

The main body of the program consists of the menu, a mass balance portion, and a convergence routine. The menu gives the user the option to run a simulation, make the original data file required to run a simulation, or end the program execution.

A simulation begins by going to the data generation subroutine and getting a value for each variable: the blow tank fiber consistency and dissolved solids content, the final shower dissolved solids content, the fiber consistency of the vat and mat and the displacement ratio for each stage of washing, and the system dilution factor. The mass balance begins as it makes a guess for the final stage carryover. Beginning with the final stage, a solids balance is carried out around the mat, the vat, and the entire stage, and is continued until a value for the blow tank dissolved solids is calculated. The calculated value is compared with the value received from data generation, and based on the difference, a new guess is made for the carryover. The balancing process is repeated until the
calculated and generated values of blow tank dissolved solids match. After the system has been balanced, program operation continues by going back to data generation to receive a second set of values for all of the input variables. The entire process continues until 5000 iterations have been made, after which the program moves to the output subroutines where the user has certain output options to choose from.

The convergence routine which makes successive guesses of carryover until the washing system balances, is based on the Half-Interval method described by Carnahan and Wilkes (25). This method can be used if the actual value being sought falls within a known range of values. In general, the idea is to cut the interval in half, test to see in which half the value falls, cut the new (smaller) interval in half, and repeat the sequence until the value is found to some acceptable level of accuracy.

In more specific terms, guesses are made for the carryover (fraction of DS in the final mat which must fall between 0 and 1), and new guess decisions are made based on the difference between the calculated and actual values of blow tank dissolved solids. When choosing subsequent guesses the important parameters become the guess, the difference, the previous guess and difference, and the placement of the two outside limits which define the interval within which the actual value of carryover must
fall.

The convergence routine used to balance the washing system requires the initial setup of 2 guesses (with their respective differences) to be made. These guesses are greater than the actual value of carryover, but within the range set up to begin the convergence routine. Specifically speaking the first and second guesses are 2 and 1, respectively, and the initial limits are 0 and 4 (set up arbitrarily such that the first two guesses fall within the range while still remaining greater than the actual value). Each guess has a difference (absolute value) associated with it. The two differences are compared, and in the case of the first 2 guesses, the current difference (corresponding to the 2nd guess) will be less than the last difference (corresponding to the 1st guess), since the 2nd guess is closer to the actual value than the 1st. The upper limit can be moved to the midpoint between the 1st and 2nd guess, since it would be impossible for the actual value to fall above the midway point. The 2nd guess and its difference are now saved as the last guess and difference, and a new guess is made at the midpoint between the upper and lower limits. The process continues comparing the differences and guesses, to decide which limit to move, until the interval becomes small enough (within the accepted level of tolerance) and the actual value of carryover is converged upon.
Subroutine 1: Data Generation

This subroutine is used once for each mass balance conducted (5000) during a simulation run. The means and standard deviations of the variables are used to generate a value for each variable based on the type of distribution set up for it. A normal distribution is used for the system dilution factor. Log-normal distributions are used for the mat and vat consistencies, the blow tank consistency and dissolved solids, and the shower dissolved solids, since these variables are bounded and fall closer to their lower then upper limit. The DF and the mat consistencies are used to calculate the WLR for each stage, and these values are used to generate values for the DR for each stage.

Subroutine 2: Automatic Output

After the 5000 independent iterations through the mass balance portion (which also operates a number of iterations through the convergence routine, for each of the 5000 main iterations), the program operation shifts to the output subroutines. The mean, standard deviation, and overall range of values are output for the washing efficiency, the pounds carryover per ton of production, the pounds excess filtrate per ton of production, and the percent dissolved solids contained in the filtrate. The user
is then given the option to view the distribution for any
of the above output and/or the distribution, mean, stand-
ard deviation, and overall range of data for the displace-
ment ratios and/or the wash liquor ratios.

Subroutine 3: Distribution Output

The frequency distributions for washing efficiency,
carryover, excess filtrate production, and filtrate dis-
solved solids are printed with this subroutine. Based on
the overall range of the 5000 values, 20 increments are
set up, and the frequency of occurrence within these divi-
sions is printed.

Subroutine 4: Displacement Ratio Output

This subroutine calculates and prints the mean,
standard deviation, overall range, and frequency distribu-
tion for the generated values of displacement ratio for
each washing stage.

Subroutine 5: Wash Liquor Ratio Output

This subroutine is the same as subroutine 4 except it
is used to output information about the calculated values
of wash liquor ratio, based on the generated values of mat
consistency and dilution factor.
Subroutine 6: Create Original Data File

An original data file is set up so that the user need only enter all the data pertaining to a mill once. This involves entering the means and standard deviations of the blow tank fiber consistency and dissolved solids content, the final shower dissolved solids content, and the vat consistency for each stage. Individual data must be entered for the displacement ratio for each stage, the mat consistency for each stage, and the system dilution factor. It is required that the same number of sampling times is used for all the variables that must have individual data entered.

After all the data have been entered, the program goes to the linear regression subroutine to calculate the slope of the line of \( \ln(1-DR) \) versus WLR and the standard error of estimate about this regression line. Upon completing the regression the program returns to this subroutine to create the data file containing all the information needed to run a simulation for the particular mill.

Subroutine 7: Linear Regression Through the Origin

Individual data of the mat consistency and dilution factor are used to calculate individual values of WLR. These values are used in conjunction with the DR values to perform a linear regression of \( \ln(1-DR) \) with respect to
WLR. This regression is different than typical least squares regression in that the line is being forced through the origin.

**Subroutine 8: Variable Changes**

When a user wants to see what will happen to her/his washing system if she/he makes a change in a variable's mean and/or standard deviation from what was entered in the original data file, computer operation moves to this subroutine to handle the change prior to running the simulation. The changes made will not alter the actual data file permanently, but only for the current simulation run.

The data file that has been previously entered for the desired washing system is read into the computer's memory and printed out for the user. The operator then decides what, if any, variables she/he wishes to change. If the user wishes to make a change in the number of stages, in the independent variables, or in the dependent variables, program control switches to the appropriate subroutine to handle the desired change.

**Subroutine 9: Dependent Variable Changes**

If changes are desired in any of the dependent variables (mat consistency, dilution factor, and/or displacement ratio) they are carried out in this subroutine. It must be noted that any change in these dependent variables
will move the system off the regression line set up by the measured values. Since individual data are required to do a regression, when changes are desired in the mean and/or standard deviation of a dependent variable, the cluster of data will be altered. The change occurs in such a way as to keep the same general outlay of data but move it for a mean and squeeze it in or spread it out for a change in the standard deviation. This data shifting is accomplished using the following equations:

To Change $\bar{X}$:  
$$x_n = \bar{x}_n + x_c - \bar{x}_c$$  \hspace{1cm} (24)

To Change $S$:  
$$x_n = (S_n/S_c)(x_c - \bar{x}_c) + \bar{x}_c$$  \hspace{1cm} (25)

where $x$ represents a data point and the subscripts $n$ and $c$ represent the new condition and the current condition, respectively. After changes have been made to all the desired dependent variables the linear regression subroutine is carried out again.

**Subroutine 10: Stages Changes**

If the user wishes to remove a stage from the current washing system or add a new washing stage subroutine 10 is used. If adding a washing stage, the means and standard deviations for the vat and mat consistencies, and the displacement ratio are asked for. Individual values of the dependent variables are obtained by changing the previous last stage of washing data to conform to the input mean and standard deviation. If it is desired to delete a
washing stage from the system, the last stage will be taken away.

**Subroutine 11: Independent Variable Changes**

If the user wishes to alter any of the independent variables (vat consistency, blow tank consistency, blow tank dissolved solids, and the final shower dissolved solids) the changes are made in this subroutine. For the independent variables, alterations in means and/or standard deviations are handled by simply changing the desired variable(s) for the particular simulation run.
CHAPTER V

RESULTS

The brownstock washer simulation program PULPWASH.BAS can be seen in Appendix A. It is written in the programming language VAX-11 BASIC, and implemented with the operating system VAX/VMS. The variable dictionary, the program documentation, and an example of how to run the program PULPWASH.BAS can be found in Appendices B, C, and D, respectively.

Mill Data

Data Collection

To use the simulation PULPWASH.BAS samples are taken from a brownstock washing system during a period of time when the washers are operating consistently. As many sampling times as possible are utilized over the time period so that reliable results can be acquired; the more samples taken, the more reliable the results achieved.

For each sampling time, a grab sample of undiluted pulp from the blow tank is acquired, along with samples from the vat and mat of each stage. Composite samples across the width of the system are suggested since concentration gradients exist (13,19,26). A filtrate sample for each stage, and a sample of the final stage shower water
are also collected for each sampling time.

In the laboratory, the filtrate and shower samples are filtered through a Millipore, glass fiber filter to remove any suspended material. The filtered liquid is dried to find the weight fraction of dissolved solids. Decanted liquid from the blow tank and vat samples, and liquid fractions squeezed from each mat, are treated in the same manner as the filtrate and shower specimens, to arrive at the weight fraction of dissolved solids in the liquid portion of these samples. The pulp fraction is washed repeatedly, removing the dissolved solids which remain, to obtain the fiber consistency. For each sampling time and stage, the displacement ratio is calculated from the dissolved solids data, and the dilution factor is calculated from the final shower water flow rate, the production rate, and the final mat fiber consistency.

**Mill Data - Fit With Proposed Correlation**

Data collected by the author from S.D. Warren Paper Company at Muskegon, Michigan and data collected by Miner (10) from two unnamed mills, referred to as Mill A, an unbleached kraft paper mill in the southern United States, and Mill B, a linerboard mill using southern pine, are used to test the simulation. A summary of these data sets appears in Appendix E. Figures 12 through 20 contain plots of the proposed dependence of dilution on displace-
Figure 12. S.D. Warren - Drum 1

Figure 13. S.D. Warren - Drum 2

Figure 14. S.D. Warren - Drum 3
Figure 15. Mill A - Drum 1

Figure 16. Mill A - Drum 2

Figure 17. Mill A - Drum 3

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Figure 18. Mill B - Drum 1

Figure 19. Mill B - Drum 2

Figure 20. Mill B - Drum 3
ment, equation 12, for the data from these three mills. The lines drawn through the plots (figures 12-20), representing the proposed correlation between displacement and dilution, do not visually correspond to the data. In fact the F test, described earlier to assess the question of a linear relationship, is non-significant in all cases. The reason the data has such a high degree of scatter is due to the narrow range of dilution factor under which these data were collected and the high degree of variability that exists in brownstock washing systems. Since it is known that a relationship exists between dilution and displacement and there seems to be evidence which supports the proposed correlation, the simulation is continued with the proposed model.

Model Verification

Model verification, as stated earlier, consists of debugging the program. In the general sense "debugging" refers to correcting mistakes so that the program will run, and afterwards making sure that all calculations within the program are performed without error. In the more specific case of model verification, "debugging" also refers to the ability of the simulation to meet the behavior that is expected of it. In the case of the program PULPWASH.BAS there are two important requirements which must be met: (a) the means and standard deviations of the
individual values generated, for each variable, during the simulation must equal the means and standard deviations which were entered for these variables by the user; and (b) the program must produce consistent results each time it is used.

**Generated Data Compared To Entered Data**

**Standard Deviations**

To compare the standard deviations of the generated data for a particular variable with that of the measured data (input to the computer) a variance ratio, F test is used to test the hypothesis $H_0: \sigma^2_1 = \sigma^2_2$ versus the two tailed alternative hypothesis (variances are not equal). The F statistic is calculated as follows:

$$F = \frac{s^2(\text{larger})}{s^2(\text{smaller})} \quad (26)$$

The statistic is compared with the critical F, found in an F table, at n-1 d.f. for the larger and for the smaller variance. The variance ratio test has a lack of robustness when the condition of non-normality exists; a tendency which causes an increase in the probability of obtaining greater ratios when this condition exists. The lack of robustness forces the statistic to declare the variances to be unequal more often when non-normality exists than it would if the data were from a normal distribution. Therefore, if the variance ratio test does not find sig-
nificant evidence of an inequality of variances, when the data is distributed non-normally, it is not likely that another test, less restricted by normality, will give a different conclusion (17).

Applying the variance ratio test to the standard deviations of the generated values (when the number of iterations equals 1000) versus those measured for the S.D. Warren data (see Table 1) produce non-significant results when a two-tailed test is conducted at $\alpha=0.20$. This means there is no reason to assume the variances for the generated values are different from those which are measured, at this degree of significance. Similar results occur for Mill A and Mill B (Appendix F) with the exception of the displacement ratio for Mill B's drum 2. This value gives

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Variance Ratio Test For S.D. Warren Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>variable</td>
<td>standard deviation</td>
</tr>
<tr>
<td>blow tank DS</td>
<td>1.970000</td>
</tr>
<tr>
<td>blow tank cons.</td>
<td>0.430000</td>
</tr>
<tr>
<td>shower DS</td>
<td>29.00000</td>
</tr>
<tr>
<td>vat 1 cons.</td>
<td>0.180000</td>
</tr>
<tr>
<td>vat 2 cons.</td>
<td>0.110000</td>
</tr>
<tr>
<td>vat 3 cons.</td>
<td>0.050000</td>
</tr>
<tr>
<td>mat 1 cons.</td>
<td>0.858520</td>
</tr>
<tr>
<td>mat 2 cons.</td>
<td>0.781710</td>
</tr>
<tr>
<td>mat 3 cons.</td>
<td>0.657804</td>
</tr>
<tr>
<td>DF</td>
<td>0.653404</td>
</tr>
<tr>
<td>DR 1</td>
<td>0.039449</td>
</tr>
<tr>
<td>DR 2</td>
<td>0.050527</td>
</tr>
<tr>
<td>DR 3</td>
<td>0.022748</td>
</tr>
</tbody>
</table>
a significant result at $\alpha=0.20$ (evidence of an inequality of variances) which at $\alpha=0.10$, becomes non-significant.

The displacement ratio standard deviations are the most difficult to mimic. The lack of ability to reject the null hypothesis that the variances are equal is, in part, a result of the large difference in the degrees of freedom of the two samples. The standard deviations of the displacement ratios can be more closely matched by changing the input standard deviations arbitrarily, until the desired output is achieved. There is a limit however, in the degree of change which can be accomplished, seeming to depend on the shape of the data scatter with respect to the regression line comparing $\ln(1-DR)$ to WLR. This is a problem if it is desired by the user to analyze the sensitivity that the output parameters have to changes made in the standard deviation of displacement ratio values.

**Means**

Since the preliminary $F$ procedure to test for variance inequalities is non-significant, an exact two-sample $t$ procedure can be used to test for mean differences (27). The pooled variance calculated as follows:

$$s^2_p = \frac{[(n_1-1)s^2_1 + (n_2-1)s^2_2]/(n_1+n_2-2)}{n_1+n_2-2}$$  \hspace{1cm} (27)

is used to calculate the following test statistic:

$$t = \frac{(\bar{X}_1 - \bar{X}_2)}{[s^2_p(1/n_1+1/n_2)]^{\frac{1}{2}}}$$  \hspace{1cm} (28)

This test statistic when compared to the critical value of
t, found from a t table, at α/2 with (n_1+n_2-2) d.f., is used to test the hypothesis H_0:μ_1=μ_2 versus its two-tailed alternative.

When the two-sample t test is applied to the means of the generated values (where the number of iterations is equal to 1000) in comparison to those of the measured values, the results are non-significant at α=0.05 for all three data sets. In other words, there is no reason, at this level of significance, to assume that the means are not equal. The results of the S.D. Warren data are shown in table 2. Similar results for Mill A and Mill B may be viewed in Appendix F.

Table 2
Two-Sample t Test For S.D. Warren Data
(at α=0.05, t_0=1.960)

<table>
<thead>
<tr>
<th>variable</th>
<th>mean value measured</th>
<th>mean value generated</th>
<th>two-sample t statistic</th>
</tr>
</thead>
<tbody>
<tr>
<td>blow tank DS</td>
<td>12.18500</td>
<td>12.15090</td>
<td>0.041090</td>
</tr>
<tr>
<td>blow tank cons.</td>
<td>7.4900000</td>
<td>7.490810</td>
<td>-0.004560</td>
</tr>
<tr>
<td>shower DS</td>
<td>268.00000</td>
<td>267.0770</td>
<td>0.077870</td>
</tr>
<tr>
<td>vat 1 cons.</td>
<td>1.0600000</td>
<td>1.064930</td>
<td>-0.066450</td>
</tr>
<tr>
<td>vat 2 cons.</td>
<td>1.0700000</td>
<td>1.073560</td>
<td>-0.076010</td>
</tr>
<tr>
<td>vat 3 cons.</td>
<td>1.1100000</td>
<td>1.108590</td>
<td>0.068868</td>
</tr>
<tr>
<td>mat 1 cons.</td>
<td>14.41830</td>
<td>14.41520</td>
<td>0.009279</td>
</tr>
<tr>
<td>mat 2 cons.</td>
<td>13.13500</td>
<td>13.12730</td>
<td>0.023695</td>
</tr>
<tr>
<td>mat 3 cons.</td>
<td>13.64330</td>
<td>13.67250</td>
<td>-0.106560</td>
</tr>
<tr>
<td>DF</td>
<td>4.278330</td>
<td>4.289490</td>
<td>-0.041900</td>
</tr>
<tr>
<td>DR 1</td>
<td>0.895667</td>
<td>0.894021</td>
<td>0.084367</td>
</tr>
<tr>
<td>DR 2</td>
<td>0.787333</td>
<td>0.786799</td>
<td>0.022468</td>
</tr>
<tr>
<td>DR 3</td>
<td>0.7545000</td>
<td>0.751932</td>
<td>0.175266</td>
</tr>
</tbody>
</table>
An increase in the number of iterations performed for the simulation, unexpectedly, does not increase the degree of repeatability of the simulation output. This seems to be especially pronounced in the standard deviations (rather than the means) of the output variables. To test the consistency of the output, several runs (usually 10) are performed on the simulation using the data for Mill B, at increasingly greater numbers of iterations. The resultant means and standard deviations are used to perform two tests, a Bartlett's test and an F test. The statistical probabilities for the Bartlett's test and the F test are used to judge the equality of the variances and means of the successive runs at a particular number of iterations. Bartlett's probability is used for a variance check; if the probability is less than the desired significance level ($\alpha$), the test shows significant evidence of an inequality between variances. The F test is used to test the equality of a group of means; similarly if the F probability is less than the desired significance level ($\alpha$) the test shows significant evidence of an inequality between means. A computer program called Advanced Analysis of Variance, written by Western Michigan University is used to perform the Bartlett's and F tests.

It seems logical to assume that when the proper num-
ber of iterations are performed in a simulation, the output mean and standard deviation, of the values calculated at each iteration, will be equal each time the simulation is performed. The simulation, carried out several times at various iteration levels ranging from 5000 to 60000, for Mill B data, produces erratic changes in the Bartlett’s probability and the F probability for all four of the output variables (for the variables of carryover and efficiency transformed values are used in the test since their output is skewed, unlike the lbs. filtrate and % DS in the filtrate variables which appear normal). The results are shown in Table 3 for the % DS in the excess filtrate; these results are representative of the results for the other three variables.

Since an increase in the number of iterations does

<table>
<thead>
<tr>
<th>runs</th>
<th>iterations</th>
<th>Bartlett's probability</th>
<th>F probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>5000</td>
<td>0.186</td>
<td>0.316</td>
</tr>
<tr>
<td>10</td>
<td>7000</td>
<td>0.184</td>
<td>0.382</td>
</tr>
<tr>
<td>10</td>
<td>9000</td>
<td>0.746</td>
<td>0.503</td>
</tr>
<tr>
<td>10</td>
<td>10000</td>
<td>0.027</td>
<td>0.176</td>
</tr>
<tr>
<td>10</td>
<td>10000</td>
<td>0.829</td>
<td>0.348</td>
</tr>
<tr>
<td>5</td>
<td>30000</td>
<td>0.550</td>
<td>0.450</td>
</tr>
<tr>
<td>5</td>
<td>30000</td>
<td>0.230</td>
<td>0.429</td>
</tr>
<tr>
<td>5</td>
<td>60000</td>
<td>0.997</td>
<td>0.335</td>
</tr>
<tr>
<td>5</td>
<td>60000</td>
<td>0.065</td>
<td>0.343</td>
</tr>
</tbody>
</table>
not improve the ability of the simulation to become more consistent, and there is such wide variation in duplicate results at the same number of iterations, a probable cause for the inconsistency of the output is the random numbers. After all, the only thing that changes each time the simulation is used is the random numbers, which are more accurately termed pseudo random numbers, since the computer generates them.

A program, written by the author to test the above assumption, is used to generate numbers from a normal distribution, which has arbitrarily been given a mean of 30 and standard deviation of 10. Table 4 shows the results.

<table>
<thead>
<tr>
<th>runs</th>
<th>iterations</th>
<th>Bartlett's probability</th>
<th>F probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>10000</td>
<td>0.907</td>
<td>0.261</td>
</tr>
<tr>
<td>10</td>
<td>10000</td>
<td>0.116</td>
<td>0.289</td>
</tr>
<tr>
<td>10</td>
<td>10000</td>
<td>0.169</td>
<td>0.236</td>
</tr>
<tr>
<td>10</td>
<td>10000</td>
<td>0.649</td>
<td>0.256</td>
</tr>
</tbody>
</table>

Simpson (28) mentions that sometimes the nonrandom behavior of so called random numbers can be corrected by simply changing the multiplier used in the function to generate the pseudo random number sequences. Hultquist...
(29) gives some schemes to allow "more-random" sequences to be generated from "less-random" ones for the IBM PC. Sievers (30) mentions the use of subroutines which have been thoroughly tested to generate random numbers rather than using the random number generator RND of Basic. Sievers also mentions that round off error can be a problem when calculating variances on the computer and that there are methods which can be used to minimize this error. Further examination of the expected variability from run to run of the simulation PULPWASH.BAS is in order, to see if it falls within the assumptions of the Bartlett's test. While it is noteworthy to mention that methods discussed by these authors could aid in the problem described above, it is beyond the scope of this thesis to correct problems associated with the VAX system's random number generator.

Model Validation

As previously stated, model validation refers to the degree to which the simulation output resembles the system it is attempting to model. Specific to this work, it also is important to compare the current simulation model, which includes a proposed correlation between dilution and displacement, with the previous model (12) which assumes all variables to be independent.
Comparison Of The Two Models

Mitcham's (12) model which assumes each variable to be independent, was first written in Basic on the DEC-10 main frame computer system and, as stated previously, contained a flaw. He treated the outputs and inputs to each stage independently. A program similar to the original program has since been implemented on the VAX computer in Basic. This program, written by the author entitled WASHER.BAS, differs from the first in that the error has been corrected, and the convergence routine and other portions of the program are more efficient. Tables 5, 6, and 7 contain the resultant means and standard deviations of carryover for 10 (or more) runs using the program WASHER.BAS (model without correlation) and the more recent

<table>
<thead>
<tr>
<th>Model With Correlation</th>
<th>Model Without Correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \bar{X} )</td>
<td>s</td>
</tr>
<tr>
<td>11.6245</td>
<td>5.90372</td>
</tr>
<tr>
<td>11.6502</td>
<td>5.80391</td>
</tr>
<tr>
<td>11.7047</td>
<td>5.96746</td>
</tr>
<tr>
<td>11.7820</td>
<td>6.16060</td>
</tr>
<tr>
<td>11.7258</td>
<td>6.16761</td>
</tr>
<tr>
<td>11.6342</td>
<td>5.98502</td>
</tr>
<tr>
<td>11.6267</td>
<td>5.99897</td>
</tr>
<tr>
<td>11.6010</td>
<td>5.73333</td>
</tr>
<tr>
<td>11.6657</td>
<td>5.88957</td>
</tr>
<tr>
<td>11.6051</td>
<td>5.77658</td>
</tr>
</tbody>
</table>

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program PULPWASH.BAS (model with correlation); each run consists of 5000 iterations.

The two models do not produce results which can legitimately be compared, due to the different methods used to generate values of DR. Mitcham's (12) model assumes that all the variables are independent, and thus produces unconditional DR variances (they do not depend on the variability for any other variable). In contrast, the model which is implemented in the program PULPWASH.BAS generates values for DR that are based on WLR; this produces conditional DR variances. The respective output for each of these models, since based on the unconditional and conditional variabilities of DR, essentially has different units and therefore, cannot be legitimately compared.

<table>
<thead>
<tr>
<th>Model With Correlation</th>
<th>Model Without Correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \bar{X} )</td>
<td>( s )</td>
</tr>
<tr>
<td>31.1308</td>
<td>28.1163</td>
</tr>
<tr>
<td>30.7422</td>
<td>27.7363</td>
</tr>
<tr>
<td>30.2407</td>
<td>27.2415</td>
</tr>
<tr>
<td>31.5637</td>
<td>29.4434</td>
</tr>
<tr>
<td>30.2640</td>
<td>26.7946</td>
</tr>
<tr>
<td>30.9675</td>
<td>28.6751</td>
</tr>
<tr>
<td>30.3068</td>
<td>27.7053</td>
</tr>
<tr>
<td>31.0673</td>
<td>28.4973</td>
</tr>
<tr>
<td>30.5479</td>
<td>27.6234</td>
</tr>
<tr>
<td>31.4783</td>
<td>28.6199</td>
</tr>
</tbody>
</table>

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Table 7
Comparison Of the Two Models
Output Of Carryover
Using Mill B Data

<table>
<thead>
<tr>
<th>Model With Correlation</th>
<th>Model Without Correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \bar{X} )</td>
<td>( s )</td>
</tr>
<tr>
<td>67.2591</td>
<td>45.6095</td>
</tr>
<tr>
<td>67.1240</td>
<td>44.5353</td>
</tr>
<tr>
<td>66.7384</td>
<td>45.7546</td>
</tr>
<tr>
<td>67.2031</td>
<td>43.9140</td>
</tr>
<tr>
<td>67.2633</td>
<td>45.0685</td>
</tr>
<tr>
<td>67.0551</td>
<td>45.3825</td>
</tr>
<tr>
<td>67.3906</td>
<td>47.0879</td>
</tr>
<tr>
<td>66.9776</td>
<td>45.7241</td>
</tr>
<tr>
<td>68.3639</td>
<td>46.1781</td>
</tr>
<tr>
<td>68.4349</td>
<td>46.6833</td>
</tr>
<tr>
<td>66.5934</td>
<td>45.1835</td>
</tr>
</tbody>
</table>

Even though a comparison of the two models is not necessarily justified, it is clear to see the wide difference in the performance of the two programs in terms of the standard deviation of carryover. More variation from run to run is caused by the program WASHER.BAS, which assumes all variables to be independent, than is caused by the program PULPWASH.BAS, which attempts to include the dependence of displacement on dilution in washing. Even though there is significant evidence that the output from PULPWASH.BAS is not consistent (discussed previously), it is clearly more consistent than the older model.

The improvement in the consistency from run to run of the new model over the old is due entirely to the addition of the correlation between dilution and displacement to...
the model. The wild variations caused by the old model occur when extreme values of dilution are paired with values of displacement which are also extreme and in a region impossible to achieve for the specific value of dilution factor. This is precisely the reason for adding the dependence to the model in the first place, i.e. to avoid pairing values of displacement ratio with values of dilution factor which cannot correspond to each other.

Since the distributions of the samples of the means of carryover are of an unknown distribution, the nonparametric comparison technique termed the Mann-Whitney test is used to compare the values from the two simulation models. As previously noted, the outputs from the two models are not based on the same type of variances (conditional and unconditional), therefore caution must be used when comparing the two sets of means. Assuming the means are values drawn from the overall population, a comparison can be made using MINITAB to generate the Mann-Whitney probabilities comparing the two models for each mill. Both the S.D. Warren and Mill A means of carryover for the new model are significantly different from the means of carryover from Mitcham's model at $\alpha=0.0002$, while the Mill B means of carryover are significantly different at a level of 0.0001.
Comparison Of Simulation Output With Measured Results

Table 8 lists the expected (measured) output for the three mills. Table 9 lists the average means and standard deviations for the simulation runs, using PULPWASH.BAS at 5000 iterations; the individual output for each run may be seen in Appendix F.

<table>
<thead>
<tr>
<th>Source</th>
<th>Carryover lbs/ton</th>
<th>Filtrate % DS</th>
<th>Efficiency %</th>
</tr>
</thead>
<tbody>
<tr>
<td>S.D. Warren</td>
<td>6</td>
<td>34.00</td>
<td>14.09</td>
</tr>
<tr>
<td>Mill A</td>
<td>7</td>
<td>43.70</td>
<td>13.80</td>
</tr>
<tr>
<td>Mill B</td>
<td>5</td>
<td>89.84</td>
<td>15.59</td>
</tr>
</tbody>
</table>

Table 9
Average Simulated Results With 5000 Iterations

<table>
<thead>
<tr>
<th>Source</th>
<th>Carryover lbs/ton</th>
<th>Filtrate % DS</th>
<th>Efficiency %</th>
</tr>
</thead>
<tbody>
<tr>
<td>S.D. Warren</td>
<td>10</td>
<td>11.66</td>
<td>9.04</td>
</tr>
<tr>
<td>Mill A</td>
<td>10</td>
<td>30.83</td>
<td>14.41</td>
</tr>
<tr>
<td>Mill B</td>
<td>11</td>
<td>67.31</td>
<td>15.07</td>
</tr>
</tbody>
</table>

To test the equivalence of the simulated results with those which are measured, it is assumed that the carryover values possess a log normal distribution and the dissolved solids in the filtrate is distributed normally. Efficiency output was not compared since standard deviation data...
is not available for Mill's A and B. Using the program Advanced Analysis of Variance (WMU), a Bonferroni Welch procedure is conducted to test the hypothesis $H_0: \mu_i = \mu_j$ versus its two tailed alternative for the carryover results, which are transformed to achieve a normal distribution. The Bonferroni Welch procedure is chosen since Bartlett's test for equality of variance is significant at $\alpha=0.25$ and there is a large difference in sample sizes (27).

Each pairwise test for equality of carryover means, comparing the several simulation runs and the measured results, are non-significant at $\alpha=0.05$, for both Mills A and B. In other words there is no significant evidence which would suggest a difference between the measured mean and simulated means for Mill A and B results. All the simulated means were significantly ($\alpha=0.05$) different from the measured mean for the S.D. Warren carryover data. The same results are encountered for the % dissolved solids in the filtrate; Mills A and B show no significant differences, whereas S.D. Warren's measured results are significantly ($\alpha=0.05$) different from the simulated values.

One possible explanation for the model's inability to mimic the S.D. Warren data, is the reliability of the data itself. The measurements for mat and vat samples are not composites taken across the width of the washer, since it was not possible, at the time of sampling, to obtain such
samples. Instead the samples were taken from one side of the washers. The blow tank data is also questionable, since samples were drawn from a line which contained a valve for dilution when routine samples were taken by the mill. At the time of sampling, the mill was also intermittently sampling on a routine basis diluted samples from the blow tank. Even though the line was flushed prior to sampling to get rid of excess dilution water, it is possible that the blow tank samples were still diluted.

Model Analysis

The computer simulation PULPWASH.BAS can be used to estimate the effect of a change in a variable on the washing system without actually implementing the change. It can also be used for a sensitivity analysis, to give the user some idea of which variable's variation causes the largest effect on the output, and therefore which parameters are most important to measure accurately. Examples of the utility of the program PULPWASH.BAS appear below.

Change In The Mean

To examine the outcome of a change in the mean of an input variable, such as dilution factor, the program may be used by loading the appropriate data file and entering the desired change for the variable of the user's choice. Since the model produces results which are variable, it is
advisable to run more than one simulation at the original and altered conditions so that a more accurate assessment may be made of the outcome.

As an example, Table 10 lists the average of several runs performed on Mill B data, which can be used to examine the outcome of increasing the dilution factor of a washing system. The first line of data in Table 10 is the average results of 11 runs which were conducted using the measured values for the input variables. The second line is the average results of 10 runs which were conducted by changing the mean DF to 4.0. The individual output for each run may be viewed in Appendices G and H.

Table 10
Comparison Of Average Simulated Results With A Change In The Mean Dilution Factor

<table>
<thead>
<tr>
<th>Entered DF</th>
<th>Carryover (lbs/ton)</th>
<th>Excess Filtrate (lbs/ton)</th>
<th>DS In Filtrate (%)</th>
<th>Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\bar{X}$ s</td>
<td>$\bar{X}$ s</td>
<td>$\bar{X}$ s</td>
<td>$\bar{X}$ s</td>
</tr>
<tr>
<td>1.23</td>
<td>0.52</td>
<td>67.31</td>
<td>45.56</td>
<td>14687</td>
</tr>
<tr>
<td>4.00</td>
<td>0.52</td>
<td>18.83</td>
<td>12.73</td>
<td>20216</td>
</tr>
</tbody>
</table>

The results of the example are as expected; an increase in the dilution factor causes an increase in the amount of and the dilution of the excess filtrate, and the carryover is decreased which increases the overall washing efficiency. At first glance, the variation of carryover seems to be markedly decreased from an increase in the dilution factor.
mean dilution factor, however, the coefficient of variation in carryover remains unchanged (68%).

**Decrease In Variability**

As another example of the utility of the simulation program, the following comparison is made to illustrate the sensitivity the output variables have to a 50% decrease in the standard deviation of two variables: the dilution factor and the blow tank dissolved solids. As in the previous example, several runs are performed with no changes made and then with the desired change, to ensure reliability in any conclusions which are made. The data for Mill B is used to illustrate this example. Table 11 contains the average mean and standard deviation of the output variables for 11 runs each, with the following conditions: (a) with no changes made to the input variables, (b) with a 50% decrease in the standard deviation of the input variables.

<table>
<thead>
<tr>
<th>Change</th>
<th>Carryover (lbs/ton)</th>
<th>Excess Filtrate (lbs/ton)</th>
<th>DS In Filtrate (%)</th>
<th>Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Change</td>
<td>67.31 45.56</td>
<td>14687 1746</td>
<td>15.07</td>
<td>1.81 97.01</td>
</tr>
<tr>
<td>Blow DS</td>
<td>67.33 45.21</td>
<td>14690 1744</td>
<td>15.06</td>
<td>1.23 97.01</td>
</tr>
<tr>
<td>DF</td>
<td>61.01 31.18</td>
<td>14686 1497</td>
<td>15.06</td>
<td>1.64 97.29</td>
</tr>
</tbody>
</table>

Table 11
Comparison Of Average Simulated Results With A 50 Percent Decrease In Standard Deviation
blow tank %DS, and (c) with a 50% decrease in the standard deviation of the DF. The data for the individual runs which make up table 11 can be seen in appendices G and H.

The individual means for each run are treated as individual samples drawn from the main population, and the two treatments are compared to the population with no treatment, using the Mann-Whitney nonparametric test. This test is chosen since the populations do not need to be from a normal distribution, and the only conclusion desired is whether or not the change has an effect on the outcome. The individual standard deviations for each simulation run are treated the same way as the means; the assumption being, since the Mann-Whitney test does not take the population distribution into account, that the standard deviations are not distributed in the same manner as means will not matter. The resultant probabilities of the Mann-Whitney test are listed in table 12.

The probabilities listed in table 12 are the proba-

<table>
<thead>
<tr>
<th>50% Dec.</th>
<th>Excess Carryover (lbs/ton)</th>
<th>Excess Filtrate (lbs/ton)</th>
<th>DS In Filtrate (%)</th>
<th>Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blow DS</td>
<td>.8955 .3579 .2122 .8438 .5767 .0001 .7427 .7180</td>
<td>.0001 .0001 .8696 .0001 .7928 .0001 .0001 .0001</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
bilities at which the test becomes significant. In other words, a low probability would suggest a greater likelihood that the two groups were different, i.e. the decrease in variation caused a significant difference in the output variable. The results of the Mann-Whitney test suggest that there is a significant difference in the mean and standard deviation of carryover when the dilution factor variation is decreased by 50%. By contrast the carryover mean and standard deviation do not change significantly when the blow tank DS standard deviation is decreased. The variation in the amount of excess filtrate is altered significantly by a decrease in variation of dilution factor but not by a decrease in variation of blow tank dissolved solids. The variability in the concentration of dissolved solids in the filtrate is significantly affected by both the dilution factor and blow tank dissolved solids variability. The variability in the washing efficiency is only significantly affected by a decrease in the variability of the dilution factor.

As is the case with the mean carryover, the mean efficiency is also altered by a decrease in the dilution factor standard deviation. The distributions of carryover and efficiency are both highly skewed, whereas the distributions of amount and concentration of excess filtrate are more symmetrical (see the output in Appendix D). A decrease in the variability of a highly skewed variable af-
ffects the tail end of the distribution more than the opposite side, which forces the mean to change. By contrast a symmetrical distribution is affected equally on both sides when its variability is changed.
CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

The program PULPWASH.BAS, written to continue the work of Mitcham (12), adds the dependence of dilution and displacement to a Monte Carlo simulation of the brown-stock washer. PULPWASH.BAS is an improvement over the previous model, which treated all variables as if they were independent. Without the correlation between variables, impossible extreme values can be simultaneously generated for displacement ratio and dilution factor, which do not correspond to each other. This causes erratic results in the consistency of the simulation from run to run in terms of carryover variability for the program treating variables independently, compared to that which forces displacement to depend on the values generated for dilution.

A comparison of the measured results with the output from PULPWASH.BAS does not reveal a significant (α=0.05) difference in the means, when using Mills A and B data. There is a significant difference in the means for S.D. Warren data, which is attributable to measurement error.

Examples are provided to show how the program may be utilized. These illustrations show the method by which the user may examine (a) the effect process changes have on the outcome of a washing system, and (b) the sources of
washing system variability.

The consistency of the output of the program PULPWASH.BAS, though an improvement over the old model, is not uniform from run to run. Since this inconsistency exists it is necessary to complete several runs of the simulation in order to have confidence in the results. Even though the simulation works in double precision, round off error in the method of calculating standard deviations for the output variables could be a problem. The generation of "good" random numbers is essential to the program, therefore methods must be analyzed to find better ways to generate such numbers. There is also a need to examine the amount of variability more closely to determine if it is actually beyond expected levels.

A better method for generating values for two correlated variables is needed, such that the user will have more control over the generated values of these variables. In the program PULPWASH.BAS the user has little control of the standard deviation of DR. This limits the interpretive powers of the simulation with respect to the effect the variability of DR has on the outcome.

The collection of as many data sets as possible are needed in order to give the model a thorough validation. Duplicate data sets obtained from the same mill, may also be beneficial. Other models describing the dependence of dilution on displacement, such as the model described by
equation 14, should be implemented into a similar program to test their ability to mimic a washing system using the Monte Carlo method of distribution sampling.
REFERENCES


APPENDIX A

PROGRAM LISTING FOR PULPWASH.BAS
100 !++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
110 |
120 | PROGRAM MAIN BODY
130 |
140 !++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
150 RANDOMIZE
160 DIM NUMBER=5000
170 DIM AMOUNT(20),AMOUNT DR(20,10),CARRYOVER (NUMBER),DR.BAT (10,100),DISPLACEMENT (NUMBER),10
180 DIM W/LAT10 (NUMBER),10;AMOUNT, W/LR. (20,10),FREG.L/RR. (20,10)
190 DIM EFFICIENCY(NUMBER),EVAPODR (NUMBER),EVAPODRATOR (NUMBER),FREQ.DR. (20,10),
200 DIM MAT.FIB.DAT (10,100),DF.DAT (100),RZ(20),RZ(20,RZ(20),R.Z(20,100),R.Z(20),10)
210 !++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
220 PRINT / PRINT / PRINT / PRINT "PROGRAM MENU"
230 PRINT
240 PRINT TAB(3) "1" CREATE ORIGINAL DATA FILE" 
250 PRINT TAB(3) "2" RUN SIMULATION WITH OPTION TO ALTER DATA FOR CURRENT RUN"
260 PRINT TAB(3) "3" EXIT"
270 PRINT \ PRINT "|" Note: To run this program you must set the computer to double precision."
280 PRINT TAB(3) "1" If you have not done so, please exit the program and type the following!
290 PRINT TAB(9) "SET "DOUBLE" 
300 PRINT TAB(9) "RUN"
310 PRINT
320 INPUT "WHAT IS YOUR CHOICE:"CHOICE
330 IMPOSSIBLE=0 \ IMPOSSIBLE,HAT=0
340 IF CHOICE=1 THEN IF CHOICE=2 THEN IF CHOICE=3 THEN PRINT "TRY AGAIN" \ OOTO 220
350 IF CHOICE=1 THEN GOSUB 5720
360 IF CHOICE=1 THEN GOTO 220
370 IF CHOICE=2 THEN GOSUB 7200
380 IF CHOICE=3 THEN GOTO 10580
390 !++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
400 FOR JX=1 TO STAGEX
410 TDO.LOW(JX)=0 \ TDO.HIGH(JX)=0
420 NEXT JX
430 IMPOSSIBLE=0
440 FOR COUNT1=1 TO NUMBER
450 GOSUB 1070
460 GH.DS(STAGEX)=SH.DS/1000000
470 FOR IX=1 TO STAGEX
480 IN-LI.G.FIB(IX)=(100-FLIB.N/I(IX))/FLIB.N/I(IX)
490 MAT.LIG.FIB(IX)=(100-MAT.LIG.FIB(IX))/MAT.LIG.FIB(IX)
500 VAT.LIG.FIB(IX)=(100-VAT.LIG.FIB(IX))/VAT.LIG.FIB(IX)
510 NEXT IX
520 SHOWER(STAGEX)=DF+MAT.LIG.FIB(STAGEX)
530 RANGE1=0
540 RANGE2=4
550 GUESS.DS(STAGEX)="(RANGE1+RANGE2)/2"
560 FOR IX=STAGEX TO 1 STEP -1
570 VAT.DS(IX)=(DF(IX)*SH.DS(IX)-GUESS.DS(IX))/(DF(IX)-1)
580 FIL.DS(IX)=MAT.LIG.FIB(IX)+SHOWER(IX)*SH.DS(IX)
590 FIL.DS(IX)=FIL.DS(IX)+SHOWER(IX)*SH.DS(IX)
600 FIL.DS(IX)=FIL.DS(IX)-MAT.LIG.FIB(IX)*GUESS.DS(IX)
610 FIL.DS(IX)=FIL.DS(IX)/(VAT.LIG.FIB(IX)+SHOWER(IX)-MAT.LIG.FIB(IX))
620 FILTRATE(IX)=IN-LIG.FIB(IK)+SHOWER(IX)-MAT.LIG.FIB(IX)
630 CALC.DS(IX)=FIL.DS(IX)*VAT.LIG.FIB(IX)-IN-LIG.FIB(IK)
640 CALC.DS(IX)=VAT.LIG.FIB(IX)*VAT.DS(IX)-CALC.DS(IX)+IN.LIG.FIB(IX)
650 GUESS.$(I+1)=CALC.$(I+1)
660 SH.DS.$(I+1)=FIL.$DS.$(I+1)
670 SHOWER.$(I+1)=FILRATE.$(I+1)
680 NEXT IX
690 ++++++++++++++++++++++++++++++++++++++++++ Convergence Routine ++++++++++++++++++++++++++++++++++++++++++
700 DIFF=CALC.DS.$(I+1)-BLOW.DS/100
710 DIFF=ABS(DIFF)
720 IF DIFF<0.00001 THEN GOTO 870
730 Q2=Q2+1
740 IF Q2=1000 THEN PRINT "NOT CONVERGING AT COUNTZ="COUNTZ" ARE YOU WORKING IN DOUBLE PRECISION?" \ STOP
750 IF Q2=1 THEN LAST.GUESS=GUESS.DS(STAGEZ) \ LAST.DIFF=DIFF \ GUESS.DS(STAGEZ)=1 \ GOTO 560
760 IF (GUESS.DS(STAGEZ)>LAST.GUESS) AND (DIFF-LAST.DIFF) THEN RANGEZ=(GUESS.DS(STAGEZ)-LAST.GUESS)/2
770 IF (GUESS.DS(STAGEZ)<LAST.GUESS) AND (DIFF-LAST.DIFF) THEN RANGEZ=(GUESS.DS(STAGEZ)-LAST.GUESS)/2
780 IF (GUESS.DS(STAGEZ)>LAST.GUESS) AND (DIFF-LAST.DIFF) THEN RANGEZ=(GUESS.DS(STAGEZ)+LAST.GUESS)/2
790 IF (GUESS.DS(STAGEZ)<LAST.GUESS) AND (DIFF-LAST.DIFF) THEN RANGEZ=(GUESS.DS(STAGEZ)+LAST.GUESS)/2
800 IF DIFF-LAST.DIFF THEN GUESS.DS(STAGEZ)=(GUESS.DS(STAGEZ)+LAST.GUESS)/2
810 IF Q2=LAST.DIFF THEN GOTO 560
820 IF (RANGE1-LAST.GUESS) AND (LAST.GUESS>RANGE2) THEN GOTO 550
830 LAST.GUESS=GUESS.DS(STAGEZ)
840 LAST.DIFF=DIFF
850 GOTO 550
860 ++++++++++++++++++++++++++++++++++++++++++++ Balance Complete - Final Calculations ++++++++++++++++++++++++++++++++++++++++++++ 870 CARRYOVER(COUNTZ)=GUESS.DS(STAGEZ) \ MAT.LIQ.FIB(STAGEZ)=2000
880 EVAP.DS(COUNTZ)=FIL.DS.$(I+1)=100
890 EVAPORATION(COUNTZ)=FILRATE.$(I+1)=2000
900 BLOW.DS.FIB=IN.LIQ.FIB.$(I+1)=BLOW.DS/100
910 MAT.DS.FIB=MAT.LIQ.FIB(STAGEZ)=GUESS.DS(STAGEZ)
920 EFFICIENCY(COUNTZ)=(BLOW.DS.FIB-MAT.DS.FIB)$100/BLOW.DS.FIB
930 FOR JX=1 TO STAGEZ
940 DISPLACEMENT(COUNTZ,JX)=DR(JX)
950 WLRATIO(COUNTZ,JX)=WLR.JX(JX)
960 NEXT JX
970 Q2=0
980 NEXT COUNTZ
990 GOTO 1600
1000 PRINT \ PRINT \ GOTO 220
1010 SUBROUTINE 11: DATA GENERATION
1020
1030 !
1040 !
1050 !
1060 !
1070 DEF FN.DEV(A,B)
1080 FN.DEV=SGELOG(1+4*2^B/2)
1090 FN.END
1100 DEF FN.MEAN(C,D)
1110 FN.MEAN=LOG(C)-D^2/2
1120 FN.END
1130 DEF FN.VALUE(E,F)
1140 FN.VALUE=((SGELOG(2LOG(RND)))*COS(2#PI*RND))#E#F
1150 FN.END
1160 ! Independent Variables !
1170 DEVF.I=FN.DEV(FIBER.IN-STD,FIBER.IN-MEAN)
1180 MEAN.FI=FN.MEAN(FIBER.IN-MEAN,DEVF.I)
1190 VALUE.FI=FN.VALUE(DEVF.I,MEAN.FI)

83
1200 FIBER.IN(J)=EXP(VALUE.FI)
1210 FOR JX=1 TO STAGEX
1220 DEV.VAT(JX)=FN.DEV(VAT,STANDARD(JX),VFIB.HOUNT(JX))
1230 MEAN.VAT(JX)=FN.MEAN(VAT,STANDARD(JX),VFIB.HOUNT(JX))
1240 VALUE.VAT(JX)=FN.VALUE(VAT,STANDARD(JX),VFIB.HOUNT(JX))
1250 EXP.VAT(JX)=EXP(VALUE.VAT(JX))
1260 DEV.MAT(JX)=FN.DEV(MAT,STANDARD(JX),VFIB.HOUNT(JX))
1270 MEAN.MAT(JX)=FN.MEAN(MAT,STANDARD(JX),VFIB.HOUNT(JX))
1280 VALUE.MAT(JX)=FN.VALUE(MAT,STANDARD(JX),VFIB.HOUNT(JX))
1290 MAT.FIB(JX)=EXP(VALUE.MAT(JX))
1300 NEXT JX
1310 FOR JX=1 TO (STAGEX-1)
1320 FIBER.IN(JX+1)=MAT.FIB(JX)
1330 NEXT JX
1340 DEV.BLS=FN.DEV(BLON.DS.STANDARD(BLOON.DS.HOUNT))
1350 MEAN.BLS=FN.MEAN(BLON.DS.STANDARD,BLON.DS.HOUNT)
1360 VALUE.BLS=FN.VALUE(BLON.DS.HOUNT)
1370 BLON.DS=EXP(VALUE.BLS)
1380 DEV.SH=FN.DEV(SH.DS.STANDARD(SH.DS.HOUNT))
1390 MEAN.SH=FN.MEAN(SH.DS.HOUNT)
1400 VALUE.SH=FN.VALUE(SH.DS.HOUNT)
1410 SH.DS=EXP(VALUE.SH)
1420 DF=FN.VALUE(DEV.STANDARD,DEV.MEAN)
1430 ++++++++++++++++++++ Dependent Variables ++++++++++++++++++++ 
1440 FOR JX=1 TO STAGEX
1450 WLR.I(JX)=DF(MAT.FIB(JX))/(100-MAT.FIB(JX))
1460 MEAN.Y.X(JX)=WLR.I(JX)*MEAN.FIB(JX)
1470 DEV.Y.X(JX)=WLR.I(JX)*DEV.FIB(JX)
1480 Y.X(JX)=DF(MAT.FIB(JX))/MEAN.Y.X(JX)
1490 DR(JX)=1-EXP(Y.X(JX))
1500 IF (DR(JX)>0) AND (DR(JX)<1) GOTO 1550
1510 IF BR(JX)<0 THEN TOO.LOW(JX)=TOO.LOW(JX)+1
1520 IF BR(JX)>1 THEN TOO.HIGH(JX)=TOO.HIGH(JX)+1
1530 IMPOSSIBLE=1
1540 IF IMPOSSIBLE<500 THEN GOTO 1480 ELSE GOTO 1570
1550 NEXT JX
1560 RETURN
1570 PRINT '500 IMPOSSIBLE VALUES OF DISPLACEMENT RATIO HAVE BEEN GENERATED, OCCURRING AS FOLLOWS:
1580 PRINT TAB(20), STAGE,TAB(40), DR,DR, DR=1'
1590 IX=1 TO STAGEX
1600 PRINT TAB(21),IX, TAB(41), TOO.LOW(IX), TAB(61), TOO.HIGH(IX)
1610 NEXT IX
1620 PRINT 'DO TO THIS PROBLEM THE CURRENT SIMULATION HAS BEEN TERMINATED' \ GOTO 220
1630 +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
1640 +
1650 | SUBROUTINE 21: AUTOMATIC OUTPUT
1660 +
1670 ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++ Calculate Averages, Standard Deviations, and Overall Ranges +++++++++++++++++++++++++++++++++++++++
1680 AVG.CARRYOVER=0 \ AVG.EVAP.DS=0 \ AVG.EVAPORATOR=0 \ AVG.EFFICIENCY=0
1690 C.SUM.SQ=0 \ EV. DS.SUM.SQ=0 \ EV.SUM.SQ=0 \ EFF.SUM.SQ=0
1700 SMALL.C=CARRYOVER(IX) \ LARGE.C=CARRYOVER(IX)
1710 SMALL.EV=EVAPORATOR(IX) \ LARGE.EV=EVAPORATOR(IX)
1720 SMALL.EFF=EFFICIENCY(IX) \ LARGE.EFF=EFFICIENCY(IX)
1740 ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
1750 FOR IX=1 TO NUMBERX
1760 AVG.CARRYOVER=AVG.CARRYOVER+CARRYOVER(IX)
1770 AVG.EVAP.DS=AVG.EVAP.DS+EVAP.DS(IX)
1780 AVG.EVAPORATOR=AVG.EVAPORATOR+EVAPORATOR(IX)
1790 AVG.EFFICIENCY=AVG. EFFICIENCY+EFFICIENCY(IX)
1800 IF CARRYOVER(IX)<SMALL.C THEN CARRYOVER=SMALL.C
1810 IF EVAP.DS(IX)<SMALL.EV.DS THEN SMALL.EV.DS=EVAP.DS(IX)
1820 IF EVAPORATOR(IX)<SMALL.EV THEN SMALL.EV=EVAPORATOR(IX)
1830 IF EFFICIENCY(IX)<SMALL.EFF THEN SMALL.EFF=EFFICIENCY(IX)
1840 IF CARRYOVER(IX)>LARGE.C THEN LARGE.C=CARRYOVER(IX)
1850 IF EVAP.DS(IX)>LARGE.EV THEN LARGE.EV=EVAP.DS(IX)
1860 IF EVAPORATOR(IX)>LARGE.EV THEN LARGE.EV=EVAPORATOR(IX)
1870 IF EFFICIENCY(IX)>LARGE.EFF THEN LARGE.EFF=EFFICIENCY(IX)
1880 C.SUN.SD=C.SUN.SD+(CARRYOVER(IX)^2)
1890 EV.DS.SUN.SD=EV.DS.SUN.SD+(EVAP.DS(IX)^2)
1900 EV.SUN.SD=EV.SUN.SD+(EVAPORATOR(IX)^2)
1910 EFF.SUN.SD=EFF.SUN.SD+(EFFICIENCY(IX)^2)
1920 NEXT IX
1930 AVG.CARRYOVER=AVG.CARRYOVER/NUMBERX
1940 AVG.EVAP.DS=AVG.EVAP.DS/NUMBERX
1950 AVG.EVAPORATOR=AVG.EVAPORATOR/NUMBERX
1960 AVG. EFFICIENCY=AVG. EFFICIENCY/NUMBERX
1970 C.RANGE=LARGE.C-SMALL.C
1980 EV.DS.RANGE=LARGE.EV.DS-SMALL.EV.DS
1990 EV.RANGE=LARGE.EV-SMALL.EV
2000 EFF.RANGE=LARGE.EFF-SMALL.EFF
2010 DEV.CARRYOVER=SQR((C.SUN.SD-(NUMBERX*(AVG.CARRYOVER^2)))/(NUMBERX-1))
2020 DEV.EVAP.DS=SQR((EV.DS.SUN.SD-(NUMBERX*(AVG.EVAP.DS^2)))/(NUMBERX-1))
2030 DEV.EVAPORATOR=SQR((EV.SUN.SD-(NUMBERX*(AVG.EVAPORATOR^2)))/(NUMBERX-1))
2040 DEV.EFFICIENCY=SQR((EFF.SUN.SD-(NUMBERX*(AVG.EFFICIENCY^2)))/(NUMBERX-1))
2050 PRINT"+++++++++++++++++++++++++++Print Output+++++++++++++++++++++++
2060 PRINT \ PRINT \ PRINT
2070 PRINT "**************************************************************************
2080 PRINT
2090 PRINT TAB(36);"SIMULATION OUTPUT"
2100 PRINT
2110 PRINT "**************************************************************************
2120 PRINT PRINT TAB(31);"NUMBER OF ITERATIONS ="NUMBERX \ PRINT
2130 PRINT TAB(18);"FACTOR RELATING DISPLACEMENT RATIO TO WASH LIQUOR RATIO"
2140 PRINT TAB(36);"L/N(1-DR)=(K)(WLR)"
2150 PRINT \ PRINT TAB(36);"STAGE"TAB(50);"K"
2160 FOR IX=1 TO STAGES
2170 PRINT TAB(36);"INIT(47)\SLOPE(IX)"
2180 NEXT IX
2190 NEXT IX
2200 IF IMPOSSIBLE=0 GOTO 2270
2210 PRINT TAB(51);"NOTE! TO COMPLETE THIS SIMULATION IT WAS NECESSARY TO THROUGH OUT IMPOSSIBLE IMPOSSIBLE IMPOSSIBLE"
2220 PRINT TAB(11);"VALUES OF DISPLACEMENT RATIO THAT WERE GENERATED. THEY OCCURRED AS FOLLOWS!"
2230 PRINT
2240 PRINT TAB(32);"STAGE"TAB(42);"DR0=0\TAB(52);"DR=1"
2250 FOR JX=1 TO STAGES
2260 PRINT TAB(33);"J2\TAB(43)\TOO.LOW(JX)\TAB(53)\TOO.HIGH(JX)"
2270 NEXT JX \ PRINT \ PRINT
2280 PRINT TAB(11);"POUNDS DISSOLVED SOLIDS CARRIED OVER IN FINAL MAT PER TON O.D. PULP"
2290 PRINT \ PRINT
2300 PRINT \ PRINT
2310 PRINT \ PRINT
2300 PRINT TAB(8)*"AVERAGE"*AVG.CARRYOVER*TAB(29)*"PERCENT EXCESS FILTRATE PER TON O.D. PULP* 
2310 PRINT \ PRINT 
2320 PRINT TAB(25)*"STANDARD DEVIATION"*DEV.CARRYOVER**TAB(59)*"OVERALL RANGE"*IC.RANGE 
2330 PRINT TAB(25)*"POUNDS EXCESS FILTRATE PER TON O.D. PULP* 
2340 PRINT \ PRINT 
2350 PRINT TAB(8)*"AVERAGE"*AVG.EVAPORATOR**TAB(29)*"STANDARD DEVIATION"*DEV.EVAPORATOR**TAB(59)*"OVERALL RANGE"*IEV.RANGE 
2360 PRINT \ PRINT 
2370 PRINT TAB(23)*"PERCENT DISSOLVED SOLIDS IN EXCESS FILTRATE* 
2380 PRINT \ PRINT 
2390 PRINT TAB(23)*"PERCENT OVERALL EFFICIENCY FOR THE WASHING SYSTEM* 
2400 PRINT TAB(23)*"STANDARD DEVIATION**DEV.EFFICIENCY**TAB(59)*"OVERALL RANGE"*IEEFF.RANGE 
2410 PRINT \ PRINT 
2420 PRINT TAB(20)*"PERCENT OVERALL EFFICIENCY FOR THE WASHING SYSTEM* 
2430 PRINT TAB(20)*"STANDARD DEVIATION**DEV.EFFICIENCY**TAB(59)*"OVERALL RANGE"*IEEFF.RANGE 
2440 PRINT \ PRINT 
2450 PRINT TAB(8)*"AVERAGE"*AVG.EFFICIENCY**TAB(29)*"STANDARD DEVIATION**DEV.EFFICIENCY**TAB(59)*"OVERALL RANGE"*EFF.RANGE 
2460 PRINT \ PRINT 
2470 PRINT "++++++++++++++++++++++++++++++++++++++++++++++++++++++ Other Output Options ++++++++++++++++++++++++++++++++++++++++++++++++" 
2480 "++++++++++++++++++++++++++++++++++++++++++++++++++++++ Other Output Options ++++++++++++++++++++++++++++++++++++++++++++++++" 
2490 PRINT \ PRINT 
2500 PRINT *YOU HAVE THE OPTION TO VIEW ANY OF THE FOLLOWING DISTRIBUTIONS* 
2510 PRINT 
2520 PRINT TAB(10)*"A CARRYOVER* 
2530 PRINT TAB(10)*"B FILTRATE TO EVAPORATORS* 
2540 PRINT TAB(10)*"C DISSOLVED SOLIDS IN FILTRATE TO EVAPORATORS* 
2550 PRINT TAB(10)*"D EFFICIENCY* 
2560 PRINT TAB(10)*"E EACH STAGE DISPLACEMENT RATIO (AVERAGE AND STD. DEV. INCLUDED)* 
2570 PRINT TAB(10)*"F EACH STAGE WASH LIQUOR RATIO (AVERAGE AND STD. DEV. INCLUDED)* 
2580 PRINT \ INPUT "HOW MANY OF THE ABOVE WOULD YOU LIKE TO SEE? ZZZZ" 
2590 IF ZZZZ<>6 THEN PRINT "ONLY 6 OPTIONS WERE GIVEN. TRY AGAIN.* \ GOTO 2580 
2600 IF ZZZZ=0 THEN RETURN 
2610 PRINT 
2620 DDDS 2690 
2630 RETURN 
2640 "++++++++++++++++++++++++++++++++++++++++++++++++++++++ Other Output Options ++++++++++++++++++++++++++++++++++++++++++++++++" 
2650 "++++++++++++++++++++++++++++++++++++++++++++++++++++++ Other Output Options ++++++++++++++++++++++++++++++++++++++++++++++++" 
2660 | SUBROUTINE 31 DISTRIBUTION OUTPUT | 
2670 | 
2680 | "++++++++++++++++++++++++++++++++++++++++++++++++++++++ Other Output Options ++++++++++++++++++++++++++++++++++++++++++++++++" 
2690 IF ZZZZ<1 THEN INPUT "ENTER THE LETTER CORRESPONDING TO THE DISTRIBUTION YOU WANT TO SEE*DIST*(1) 
2700 IF (ZZZZ=1) AND (DIST*(1)="A") THEN PRINT \ PRINT \ GOTO 2810 
2710 IF (ZZZZ=1) AND (DIST*(1)="B") THEN PRINT \ PRINT \ GOTO 2810 
2720 IF ZZZZ<>1 THEN GOTO 2820 
2730 IF ZZZZ<>6 THEN DIST*(1)="A" \ DIST*(2)="B" \ DIST*(3)="C" \ DIST*(4)="D" \ DIST*(5)="E" \ DIST*(6)="F" \ GOTO 2870 
2740 PRINT "ENTER THE LETTERS CORRESPONDING TO THE DISTRIBUTIONS YOU WANT TO SEE (EA. FOLLOWED BY RETURN)* 
2750 FOR IX=1 TO ZZZZ 
2760 INPUT DIST*(IX) 
2770 NEXT IX 
2780 PRINT \ PRINT 
2790 PRINT "++++++++++++++++++++++++++++++++++++++++++++++++++++++ Carryover Frequency of Occurrence ++++++++++++++++++++++++++++++++++++++++++++++++" 
2800 PRINT \ PRINT TAB(25)*"DISTRIBUTION OUTPUT" \ PRINT 
2810 PRINT "++++++++++++++++++++++++++++++++++++++++++++++++++++++ Carryover Frequency of Occurrence ++++++++++++++++++++++++++++++++++++++++++++++++" 
2820 FOR IX=1 TO ZZZZ 
2830 "++++++++++++++++++++++++++++++++++++++++++++++++++++++ Carryover Frequency of Occurrence ++++++++++++++++++++++++++++++++++++++++++++++++" 
2840 IF DIST*(IX)<"A" THEN GOTO 3020 
2850 "++++++++++++++++++++++++++++++++++++++++++++++++++++++ Carryover Frequency of Occurrence ++++++++++++++++++++++++++++++++++++++++++++++++" 
2860 IF DIST*(IX)<"A" THEN GOTO 3020
DIVISION=C.RANGE/20
R1(I)=SMALL.C \ R2(I)=SMALL.C
FOR IX=2 TO 19
R1(IX)=R2(IX-1)
R2(IX)=R1(IX)+DIVISION
NEXT IX
R1(20)=R2(19) \ R2(20)=LARGE.C
FOR IX=1 TO 20
FREQ(IX)=0
NEXT IX
FOR IX=1 TO NUMBERZ
FOR JX=1 TO 19
IF (R1(JX)<CARRYOVER(IX)) AND (CARRYOVER(IX)<R2(JX)) THEN FREQ(JX)=FREQ(JX)+1
NEXT JX
IF (R1(20)<CARRYOVER(IX)) AND (CARRYOVER(IX)<R2(20)) THEN FREQ(20)=FREQ(20)+1
NEXT IX

DIVISION=EV.RANGE/20
R1(I)=SMALL.EV \ R2(I)=SMALL.EV+DIVISION
FOR IX=2 TO 19
R1(IX)=R2(IX-1)
R2(IX)=R1(IX)+DIVISION
NEXT IX
R1(20)=R2(19) \ R2(20)=LARGE.EV
FOR IX=1 TO 20
FREQ(IX)=0
NEXT IX
FOR IX=1 TO NUMBERZ
FOR JX=1 TO 19
IF (R1(JX)<EVAPORATOR(IX)) AND (EVAPORATOR(IX)<R2(JX)) THEN FREQ(JX)=FREQ(JX)+1
NEXT JX
IF (R1(20)<EVAPORATOR(IX)) AND (EVAPORATOR(IX)<R2(20)) THEN FREQ(20)=FREQ(20)+1
NEXT IX

DIVISION=EV.DS.RANGE/20
R1(I)=SMALL.EV.DS \ R2(I)=SMALL.EV.DS+DIVISION
FOR IX=2 TO 19
R1(IX)=R2(IX-1)
R2(IX)=R1(IX)+DIVISION
NEXT IX
R1(20)=R2(19) \ R2(20)=LARGE.EV.DS
FOR IX=1 TO 20
FREQ(IX)=0
NEXT IX
FOR IX=1 TO NUMBERZ
FOR JX=1 TO 19
IF (R1(JX)<EVAP.DS(IX)) AND (EVAP.DS(IX)<R2(JX)) THEN FREQ(JX)=FREQ(JX)+1
NEXT JX
IF (R1(20)<EVAP.DS(IX)) AND (EVAP.DS(IX)<R2(20)) THEN FREQ(20)=FREQ(20)+1
NEXT IX

DIVISION=EFF.RANGE/20

DIVISION=EV.DS.RANGE/20
R1(I)=SMALL.EV.DS \ R2(I)=SMALL.EV.DS+DIVISION
FOR IX=2 TO 19
R1(IX)=R2(IX-1)
R2(IX)=R1(IX)+DIVISION
NEXT IX
R1(20)=R2(19) \ R2(20)=LARGE.EV.DS
FOR IX=1 TO 20
FREQ(IX)=0
NEXT IX
FOR IX=1 TO NUMBERZ
FOR JX=1 TO 19
IF (R1(JX)<EVAP.DS(IX)) AND (EVAP.DS(IX)<R2(JX)) THEN FREQ(JX)=FREQ(JX)+1
NEXT JX
IF (R1(20)<EVAP.DS(IX)) AND (EVAP.DS(IX)<R2(20)) THEN FREQ(20)=FREQ(20)+1
NEXT IX

DIVISION=EFF.RANGE/20

DIVISION=EV.DS.RANGE/20
R1(I)=SMALL.EV.DS \ R2(I)=SMALL.EV.DS+DIVISION
FOR IX=2 TO 19
R1(IX)=R2(IX-1)
R2(IX)=R1(IX)+DIVISION
NEXT IX
R1(20)=R2(19) \ R2(20)=LARGE.EV.DS
FOR IX=1 TO 20
FREQ(IX)=0
NEXT IX
FOR IX=1 TO NUMBERZ
FOR JX=1 TO 19
IF (R1(JX)<EVAP.DS(IX)) AND (EVAP.DS(IX)<R2(JX)) THEN FREQ(JX)=FREQ(JX)+1
NEXT JX
IF (R1(20)<EVAP.DS(IX)) AND (EVAP.DS(IX)<R2(20)) THEN FREQ(20)=FREQ(20)+1
NEXT IX

DIVISION=EFF.RANGE/20
3400 R1(I)=SMALL.EFF \ R2(I)=SMALL.EFF+DIVISION
3410 FOR IX=2 TO 19
3420 R1(IX)=R2(IX-1)
3430 R2(IX)=R1(IX)+DIVISION
3440 NEXT IX
3450 R1(20)=R2(19) \ R2(20)=LARGE.EFF
3460 FOR IX=1 TO 20
3470 FREQ(IX)=0
3480 NEXT IX
3490 FOR IX=1 TO NUMER
3500 FOR JX=1 TO 19
3510 IF (R1(JX)<EFFICIENCY(IX)) AND (EFFICIENCY(IX)<R2(JX)) THEN FREQ(JX)=FREQ(JX)+1
3520 NEXT JX
3530 IF (R1(20)<EFFICIENCY(IX)) AND (EFFICIENCY(IX)<R2(20)) THEN FREQ(20)=FREQ(20)+1
3540 NEXT IX
3550 IF DIST4(KX)="E" THEN GOSUB 4030
3560 IF DIST4(KX)="E" GOTO 3960
3570 IF DIST4(KX)="F" THEN GOSUB 4890
3580 IF DIST4(KX)="F" GOTO 3960
3590 ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++ Print Distributions ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++!
3600 THEMOST=FREQ(1)
3610 FOR IX=2 TO 20
3620 IF FREQ(IX)>THEMOST THEN THEMOST=FREQ(IX)
3630 NEXT IX
3640 IF THEMOST>6000 THEN EACHX=200
3650 IF (THEMOST>5000) AND (THEMOST<6000) THEN EACHX=100
3660 IF (THEMOST>3000) AND (THEMOST<5000) THEN EACHX=75
3670 IF (THEMOST>2000) AND (THEMOST<3000) THEN EACHX=50
3680 IF (THEMOST>1000) AND (THEMOST<2000) THEN EACHX=35
3690 IF (THEMOST>900) AND (THEMOST<1000) THEN EACHX=25
3700 IF (THEMOST>900) AND (THEMOST<1200) THEN EACHX=20
3710 IF (THEMOST>900) AND (THEMOST<1200) THEN EACHX=15
3720 IF (THEMOST>3000) AND (THEMOST<4000) THEN EACHX=10
3730 FOR IX=1 TO 20
3740 IF IX=1 THEN EACHX=5
3750 FOR IX=1 TO 20
3760 AMOUNT(IX)=FIX(FREQ(IX)/EACHX)
3770 NEXT IX
3780 PRINT \ PRINT
3790 IF DIST4(KX)="A" THEN PRINT TAB(34);"CARRYOVER DISTRIBUTION"
3800 IF DIST4(KX)="A" THEN PRINT TAB(34);"----------------------------------- \ PRINT
3810 IF DIST4(KX)="B" THEN PRINT TAB(31);"EXCESS FILTRATE DISTRIBUTION"
3820 IF DIST4(KX)="B" THEN PRINT TAB(31);"----------------------------------- \ PRINT
3830 IF DIST4(KX)="C" THEN PRINT TAB(24);"DISSOLVED SOLIDS IN FILTRATE DISTRIBUTION"
3840 IF DIST4(KX)="C" THEN PRINT TAB(24);"----------------------------------- \ PRINT
3850 IF DIST4(KX)="D" THEN PRINT TAB(33);"EFFICIENCY DISTRIBUTION"
3860 IF DIST4(KX)="D" THEN PRINT TAB(33);"----------------------------------- \ PRINT
3870 PRINT \ PRINT TAB(8);"RANGE";TAB(22);"FREQ";TAB(35);"( EACH X =";EACHX;")"
3880 FOR IX=1 TO 20
3890 PRINT \ PRINT R1(IX);TAB(10);"*";R2(IX);TAB(22);"FREQ(IX))
3900 FOR IX=1 TO AMOUNT(IX)
3910 PRINT TAB(28);"*";
3920 NEXT JX
3930 NEXT IX
3940 PRINT \ PRINT
3950 PRINT **                                                                                     **
3960 NEXT KZ
3970 RETURN
3980 **                                                                                         **
3990 SUBROUTINE 4: DISPLACEMENT RATIO OUTPUT
4000 **                                                                                         **
4010 **                                                                                         **
4020 FOR JX=1 TO STAGEX
4030 AVG.DISPLACEMENT(JX)=0
4040 DR, SUM.SQ(JX)=0 **                      **
4050 SMALL, DR(JX)=DISPLACEMENT(IZ, JX)
4060 LARGE, DR(JX)=DISPLACEMENT(IZ, JX)
4070 NEXT JZ
4080 **                                                                                         **
4090 **                                                                                         **
4100 **                                                                                         **
4110 FOR IX=1 TO NUMBERX
4120 AVG.DISPLACEMENT(JX)=AVG.DISPLACEMENT(JX)+DISPLACEMENT(IX, JX)
4130 DR, SUM.SQ(JX)=DR, SUM.SQ(JX)+(DISPLACEMENT(IX, JX)^2)
4140 IF DISPLACEMENT(IX, JX)<SMALL, DR(JX) THEN SMALL, DR(JX)=DISPLACEMENT(IX, JX)
4150 IF DISPLACEMENT(IX, JX)>LARGE, DR(JX) THEN LARGE, DR(JX)=DISPLACEMENT(IX, JX)
4160 NEXT IX
4170 AVG.DISPLACEMENT(JX)=AVG.DISPLACEMENT(JX)/NUMBERX
4180 DR, RANGE(JX)=LARGE, DR(JX)-SMALL, DR(JX)
4190 DIVISION(JX)=DR, RANGE(JX)/20
4200 DEV, DISPLACEMENT(JX)=SQRT((DR, SUM.SQ(JX)-NUMBERX*(AVG.DISPLACEMENT(JX)^2))/(NUMBERX-1))
4210 R.1(IX, JX)=SMALL, DR(JX)
4220 R.2(IX, JX)=LARGE, DR(JX)+DIVISION(JX)
4230 NEXT JZ
4240 **                                                                                         **
4250 FOR JX=1 TO STAGEX
4260 FOR IX=2 TO 19
4270 R.2(IX, JX)=R.2(IX-1, JX)
4280 R.2(IX, JX)=R.1(IX, JX)+DIVISION(JX)
4290 NEXT IX
4300 R.1(20X, JX)=R.2(19X, JX)
4310 R.2(20X, JX)=LARGE, DR(JX)
4320 FOR IX=1 TO 20
4330 FREQ, DR(IX, JX)=0
4340 NEXT IX
4350 NEXT JZ
4360 FOR JX=2 TO STAGEX
4370 FOR IX=1 TO NUMBERX
4380 FOR IX=1 TO 19
4390 IF (R.1(IX, JX)<DISPLACEMENT(IX, JX)) AND (DISPLACEMENT(IX, JX)<R.2(IX, JX)) THEN FREQ, DR(IX, JX)=FREQ, DR(IX, JX)+1
4400 NEXT IX
4410 IF (R.1(20X, JX)<DISPLACEMENT(IX, JX)) AND (DISPLACEMENT(IX, JX)<R.2(20X, JX)) THEN FREQ, DR(20X, JX)=FREQ, DR(20X, JX)+1
4420 NEXT IX
4430 **                                                                                         **
4440 THEHOST(JX)=FREQ, DR(IX, JX)
4450 FOR IX=2 TO 20
4460 IF FREQ, DR(IX, JX)>THEHOST(JX) THEN THEHOST(JX)=FREQ, DR(IX, JX)
4470 NEXT IX
4480 IF THEHOST(JX)>6000 THEN EACHX(JX)=200
4490 IF (THEHOST(JX)>4500) AND (THEHOST(JX)<6000) THEN EACHX(JX)=100
4500 IF (THEHOST(JX)>3000) AND (THEHOST(JX)<=4500) THEN EACHX(JX)=75
4510 IF (THEHOST(JX)>2100) AND (THEHOST(JX)<=2100) THEN EACHX(JX)=50
4520 IF (THEHOST(JX)>1500) AND (THEHOST(JX)<=1200) THEN EACHX(JX)=25
4530 IF (THEHOST(JX)>1200) AND (THEHOST(JX)<=900) THEN EACHX(JX)=10
4540 IF (THEHOST(JX)>900) AND (THEHOST(JX)<=300) THEN EACHX(JX)=5
4550 IF (THEHOST(JX)>300) AND (THEHOST(JX)<=125) THEN EACHX(JX)=2
4560 FOR HX=1 TO 20
4570 NEXT HX
4580 NEXT JX
4590 PRINT 'PRINT TAB(30)'"DISPLACEMENT RATIO OUTPUT"\ PRINT
4600 PRINT "*********************************************************************
4610 PRINT 'PRINT TAB(30)'"DISPLACEMENT RATIO FOR STAGE'JXZ
4620 PRINT TAB(30)"*"PRINT USING "R.4(R.IX,JX)\PRINT TAB(10)"*"PRINT USING "R.2(R.IX,JX)\ PRINT TAB(22)"FREQ.RATI(JX,JX)\ PRINT TAB(35)"( EACH X ="EACHX(JX)"
4630 FOR IX=1 TO 20
4640 PRINT \PRINT TAB(1)\ PRINT USING "R.4(R.IX,JX)\PRINT TAB(10)"*"PRINT USING "R.2(R.IX,JX)\ PRINT TAB(22)"FREQ.RATI(JX,JX)\ PRINT TAB(35)"( EACH X ="EACHX(JX)"
4650 NEXT IX
4660 NEXT JX
4670 PRINT \PRINT
4680 NEXT JX
4690 PRINT "*********************************************************************
4700 SUBROUTINE 51 WASH LIQUID RATIO OUTPUT
4710 FOR JX=1 TO STAGEZ
4720 AVG.WLR(JX)=0
4730 W.SUM.SD(JX)=0
4740 SMALL.W(JX)=WLRATIO(IJX,JX)
4750 LARGE.W(JX)=WLRATIO(IJX,JX)
4760 NEXT JX
4770 FOR IX=1 TO NUMBERZ
4780 AVG.WLR(JX)=AVG.WLR(JX)+WLRATIO(IJX,JX)
4790 W.SUM.SD(JX)=W.SUM.SD(JX)+WLRATIO(IJX,JX)^2
4800 IF WLRATIO(IJX,JX)>SMALL.W(JX) THEN SMALL.W(JX)=WLRATIO(IJX,JX)
4810 IF WLRATIO(IJX,JX)>LARGE.W(JX) THEN LARGE.W(JX)=WLRATIO(IJX,JX)
4820 NEXT IX
4830 AVG.WLR(JX)=AVG.WLR(JX)/NUMBERZ
4840 W.RANGE(JX)=LARGE.W(JX)-SMALL.W(JX)
DIVISION(JX)=W.RANGE(JX)/20

DEVI.WRL(JZ)=SQRT(W.SUM(SU(JJ,JX))-(NUMBER2*(AVG.WRL(JX)**2))/(NUMBER2-1))

R.1(JX,JZ)=SMALL.W.JX)

R.2(JZ,JX)=DIVISION(JX)

NEXT JZ

XXXXXXXXXXXXXXXXXXXXXXXXX Frequency of Occurrence XXXXXXXXXXXXXXXXXXXXXXXXXXXX

FOR JX=1 TO STAGEZ

FOR II=2 TO 19

R.1(JX,JZ)=R.2(JX-1,JZ)

R.2(JZ,JX)=R.1(JX,JZ)+DIVISION(JX)

NEXT IX

NEXT JX

NEXT JZ

NEXT JX

FOR JZ=1 TO STAGEZ

FOR II=1 TO NUMBERZ

FOR Hz=1 TO 19

IF R.1(Hz,JX)<WLRATIO(JX,JZ) AND (WLRATIO(JX,JZ)<R.2(HZ,JX)) THEN FREQ.WRL(HZ,JX)=FREQ.WRL(HZ,JX)+1

NEXT Hz

NEXT JX

NEXT JZ

XXXXXXXXXXXXXXXXXXXXXXXXX Print Output XXXXXXXXXXXXXXXXXXXXXXXXXXXX

THEMOST(JX)=FREQ.WRL(JX,JZ)

FOR Hz=2 TO 20

IF FREQ.WRL(HZ,JX)>THEMOST(JX) THEN THEMOST(JX)=FREQ.WRL(HZ,JX)

NEXT Hz

IF THEMOST(JX)>6000 THEN EACHX(JX)=200

IF (THEMOST(JX)>4500) AND (THEMOST(JX)<6000) THEN EACHX(JX)=100

IF (THEMOST(JX)>3000) AND (THEMOST(JX)<4500) THEN EACHX(JX)=75

IF (THEMOST(JX)>2100) AND (THEMOST(JX)<3000) THEN EACHX(JX)=50

IF (THEMOST(JX)>1500) AND (THEMOST(JX)<2100) THEN EACHX(JX)=35

IF (THEMOST(JX)>1200) AND (THEMOST(JX)<1500) THEN EACHX(JX)=25

IF (THEMOST(JX)>900) AND (THEMOST(JX)<1200) THEN EACHX(JX)=20

IF (THEMOST(JX)>600) AND (THEMOST(JX)<900) THEN EACHX(JX)=15

IF (THEMOST(JX)>300) AND (THEMOST(JX)<600) THEN EACHX(JX)=10

IF (THEMOST(JX)>125) AND (THEMOST(JX)<300) THEN EACHX(JX)=5

IF THEMOST(JX)<125 THEN EACHX(JX)=2

FOR Hz=1 TO 20

AMOUNT.WRL(HZ,JX)=FIX(FREQ.WRL(HZ,JX)/EACHX(JX))

NEXT Hz

NEXT JX

PRINT \ PRINTTAB(32)"*WASH LIQUOR RATIO OUTPUT" \ PRINT

PRINT "XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX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

PRINT \ PRINTTAB(32)"*WASH LIQUOR RATIO FOR STAGE*" JX

PRINT TAB(30)"*WASH LIQUOR RATIO FOR STAGE*" JX

PRINT TAB(30)"*AVERAGE=1AVG.WRL(JX)TAB(28)*" \ PRINT

PRINT TAB(B)"*STANDARD DEVIATION*1DEV.WRL(JX)TAB(59)1*OVERALL RANGE*1W.RANGE(JX)

PRINT \ PRINTTAB(B)"*RANGE*1TAB(22)*1FREQ*1TAB(35)*1(EACH X =1EACHX(JX))1*

FOR Hz=1 TO 20

PRINT \ PRINT R.1(JX,JZ)TAB(10)1"*IR.2(JX,JZ)TAB(22)1FREQ.WRL(JX,JZ)

FOR Hz=1 TO AMOUNT.WRL(JX,JZ)
5400 PRINT TAB(28)"*X*"
5410 NEXT IX
5420 NEXT IX
5430 PRINT \ PRINT
5440 NEXT JZ
5450 PRINT "***************************************************************************"
5460 RETURN
5470 |***************************************************************************|
5480 | | SUBROUTINE 61 CREATE ORIGINAL DATA FILE |
5490 | |***************************************************************************|
5700 |***************************************************************************|
5710 |*************************************************************************** Input Independent Variables (Means and Standard Deviations)***************************************************************************|
5740 INPUT *ENTER A NAME FOR YOUR DATA FILE (UP TO 9 CHARACTERS PLUS AN OPTIONAL 3 LETTER EXTENSION)*'NAME$ |
5750 PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ PRINT \ 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PRINT
FOR JX=1 TO STAGEX
FOR IX=1 TO TIMEX
PRINT TAB(5);STAGE="XJZTAB(20)";TIME="XJZTAB(35)"; \ INPUT *DR="IDR.DAT(JX,IX)
NEXT IX
PRINT
NEXT JX
PRINT \ INPUT *DO YOU NEED TO MAKE CORRECTIONS TO THE ABOVE VALUES OF DISPLACEMENT RATIO (Y OR N) *IA
IF A<"Y" THEN IF A<"Y" THEN IF A<"N" THEN IF A<"N" THEN PRINT *TRY AGAIN* \ GOTO 6220
IF A="Y" OR (A="Y") THEN GOTO 6130
PRINT \ PRINT
PRINT *ENTER THE VALUES FOR MAT CONSISTENCY, FOR EACH STAGE, AT EACH SAMPLING TIME*
PRINT
FOR JX=1 TO STAGEX
FOR IX=1 TO TIMEX
PRINT TAB(5);STAGE="XJZTAB(20)";TIME="XJZTAB(35)"; \ INPUT *MAT="IMAT.FIB.DAT(JX,IX)
NEXT IX
PRINT
NEXT JX
PRINT \ INPUT *DO YOU NEED TO MAKE CORRECTIONS TO THE ABOVE VALUES OF MAT CONSISTENCY (Y OR N) *IA
IF A<"Y" THEN IF A<"Y" THEN IF A<"N" THEN IF A<"N" THEN PRINT *TRY AGAIN* \ GOTO 6340
IF A="Y" OR (A="Y") THEN GOTO 6250
++++++Calculate Mean and Standard Deviation of Dependent Variables +++++++++++++++++++++++++++++++++++++++++++++++
DF.MEAN=0
DF.SUM.SQ=0
FOR JX=1 TO STAGEX
MAT.FIB.MEAN(JX)=0 \ DR.MEAN(JX)=0
DF.SUM.SQ(JX)=0 \ DF.SUM.SQ(JX)=0
NEXT JX
FOR IX=1 TO TIMEX
DF.MEAN=DF.MEAN+DF.DAT(IX)
DF.SUM.SQ=DF.SUM.SQ+(DF.DAT(IX)*2)
NEXT IX
DF.MEAN=DF.MEAN/TIMEX
DF.STD=SQRT((DF.SUM.SQ-(DF.MEAN*2))/(TIMEX-1))
FOR JX=1 TO STAGEX
FOR IX=1 TO TIMEX
MAT.FIB.MEAN(JX)=MAT.FIB.MEAN(JX)+MAT.FIB.DAT(JX,IX)
MAT.SUM.SQ(JX)=MAT.SUM.SQ(JX)+(MAT.FIB.DAT(JX,IX)*2)
DR.MEAN(JX)=DR.MEAN(JX)+DR.DAT(JX,IX)
DR.SUM.SQ(JX)=DR.SUM.SQ(JX)+(DR.DAT(JX,IX)*2)
NEXT IX
MAT.FIB.MEAN(JX)=MAT.FIB.MEAN(JX)/TIMEX
MAT.FIB.STD(JX)=SQRT((MAT.SUM.SQ(JX)-(MAT.MAT.FIB.MEAN(JX)))/(TIMEX-1))
DR.MEAN(JX)=DR.MEAN(JX)/TIMEX
DR.STD(JX)=SQRT((DR.SUM.SQ(JX)-(DR.MEAN(JX)*2))/(TIMEX-1))
NEXT JX
GOSUB 6970
++++++Output to Data File +++++++++++++++++++++++++++++++++++++++++++++
OPEN NAME FOR OUTPUT AS FILE #IX, ACCESS WRITE
PRINT #IX,TIMEX","STAGEX
PRINT #IX,BLOW.DS.MEAN","BLOW.DS.STD
PRINT #IX,FIBER.IN.MEAN","FIIBER.IN.STD
PRINT #IX,SH.DS.MEAN","SH.DS.STD
93
6700 PRINT $1Z, VAT.FIB.MEAN(I2);"'IVAT.FIB.STD(I2)
6710 NEXT I2
6720 FOR I2 = 1 TO STAGEZ
6730 PRINT $1Z, VAT.FIB.MEAN(I2);"'IVAT.FIB.STD(I2)
6740 NEXT I2
6750 FOR I2 = 1 TO STAGEZ
6760 PRINT $1Z, DR.MEAN(I2);"'IDR.STD(I2)
6770 NEXT I2
6780 PRINT $1Z, DF.MEAN(I2);"'IDR.STD
6790 FOR JZ = 1 TO TIMEX
6800 PRINT $1Z, VAT.FIB.DAT(I2, JZ);"'IDR.DAT(I2, JZ)
6810 NEXT JZ
6820 NEXT I2
6830 NEXT I2
6840 FOR JZ = 1 TO TIMEX
6850 PRINT $1Z, DF.DAT(JZ)
6860 NEXT JZ
6870 FOR I2 = 1 TO STAGEZ
6880 PRINT $1Z, SLOPE(I2);"'ISYX(I2);"'WLR.SUM.SQ(I2)
6890 NEXT I2
6900 CLOSE $1Z
6910 RETURN
6920 ###############################################################################
6930 1 SUBROUTINE 7: LINEAR REGRESSION THROUGH THE ORIGIN
6940 1
6950 1###############################################################################
6960 1 FOR JZ = 1 TO TIMEX
6970 1 WLR(JZ, I2) = (DF.DAT(I2) * (VAT.FIB.DAT(JZ, I2) / (100 - VAT.FIB.DAT(JZ, I2))) + 1
6980 1 NEXT I2
6990 1 WLR.SUM.SQ(JZ) = 0
7000 1 Y.SUM.B0(JZ) = 0
7010 1 WLR.Y.SUM(JZ) = 0
7020 1 NEXT JZ
7030 1 FOR JZ = 1 TO TIMEX
7040 1 WLR.SUM.SQ(JZ) = WLR.SUM.SQ(JZ) + (WLR(JZ, I2)^2)
7050 1 WLR.Y.SUM(JZ) = WLR.Y.SUM(JZ) + (WLR(JZ, I2) * (LOG(1 - DR.DAT(JZ, I2)))^2)
7060 1 WLR.Y.SUM(JZ) = WLR.Y.SUM(JZ) + (WLR(JZ, I2) * LOG(1 - DR.DAT(JZ, I2)))
7070 1 NEXT I2
7080 1 SLOPE(JZ) = WLR.Y.SUM(JZ) / WLR.SUM.SQ(JZ)
7090 1 SYX(JZ) = SQRT((Y.SUM.SQ(JZ) - (WLR.Y.SUM(JZ)^2 / WLR.SUM.SQ(JZ))) / (TIMEX - 1))
7100 1 NEXT JZ
7110 1 RETURN
7120 ###############################################################################
7130 1 SUBROUTINE 8: VARIABLE CHANGES
7140 1
7150 1###############################################################################
7160 1 PRINT \ PRINT
7170 1 INPUT 'ENTER THE NAME OF THE FILE THAT CONTAINS THE WASHING DATA YOU WISH TO SIMULATE' NAMES
7180 1 "+++++++++++++++++++++++++++++++++++++++++++++++++++++++ Input Data File ++++++++++++++++"
7190 1 OPEN NAMES FOR INPUT AS FILE $1Z, ACCESS READ
7200 1 INPUT $1Z, TIMEX, STAGEZ
7210 1
7220 INPUT #1*X,BLOW.DS,MEAN,BLOW.DS,STD
7220 INPUT #1*X, FIBER.IN,MEAN,FIBER.IN,STD
7270 INPUT #1*X, SH.DS,MEAN,SH.DS,STD
7290 FOR IX=1 TO STAGEX
7290 INPUT #1*X,VAT,FIB.MEAN(IX)+VAT,FIB.STD(IX)
7300 NEXT IX
7310 FOR IX=1 TO STAGEX
7320 INPUT #1*X,HAT,FIB.MEAN(IX)+HAT,FIB.STD(IX)
7330 NEXT IX
7340 FOR IX=1 TO STAGEX
7350 INPUT #1*X,BF.BF.MEAN(IX)+B.F.BF.STD(IX)
7360 NEXT IX
7370 FOR IX=1 TO STAGEX
7380 FOR IX=1 TO STAGEX
7390 FOR IX=1 TO TIMEX
7400 INPUT #1*X,HAT,BF.DAT(IX,IX),BF.DAT(IX,IX)
7410 NEXT IX
7420 NEXT IX
7430 FOR IX=1 TO TIMEX
7440 INPUT #1*X,DF,DAT(IX)
7450 NEXT IX
7460 FOR IX=1 TO STAGEX
7470 INPUT #1*X,GLOOD(IX),SYX(IX),WL.R.SUN.SQ(IX)
7480 NEXT IX
7490 CLOSE #1X
7500 ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++ Print Data File ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++!
7510 PRINT 
7520 PRINT "WOULD YOU LIKE TO VIEW THE DATA IN THIS FILE (Y OR N)"$A$+
7530 IF A$="Y" THEN IF A$="Y" THEN IF A$="Y" THEN PRINT "TRY AGAIN" \ GOTO 7520
7540 IF A$="Y") OR (A$="N") THEN GOTO 7720
7550 PRINT 
7560 PRINT TAB(11)"VARIABLE"TAB(34)"STAGE"TAB(44)"MEAN"TAB(53)"STANDARD DEVIATION"
7570 PRINT TAB(11)"MEAN"TAB(35)"MEAN"TAB(35)"STANDARD DEVIATION"
7580 PRINT \ PRINT "BLOW TANK DISSOLVED SOLIDS (X)"TAB(35)"MEAN"TAB(53)"BLOW.DS,STD"
7590 PRINT "BLOW TANK FIBER CONSISTENCY (X)"TAB(35)"MEAN"TAB(53)"FIBER.IN,STD"
7600 PRINT "SHOWER DISSOLVED SOLIDS (X)"TAB(35)"MEAN"TAB(53)"SH.DS,STD"
7610 FOR IX=1 TO STAGEX
7620 PRINT "VAT FIBER CONSISTENCY (X)"TAB(35)"VAT,FIB.MEAN(IX)TAB(53)"VAT,FIB.STD(IX)
7630 NEXT IX
7640 FOR IX=1 TO STAGEX
7650 PRINT "HAT FIBER CONSISTENCY (X)"TAB(35)"HAT,FIB.MEAN(IX)TAB(53)"HAT,FIB.STD(IX)
7660 NEXT IX
7670 PRINT "DILUTION FACTOR"TAB(35)"DILUTION"TAB(42)"MEAN"TAB(53)"DILUTION"TAB(53)"MEAN"
7680 FOR IX=1 TO STAGEX
7690 PRINT "DISPLACEMENT RATIO"TAB(35)"JZ,TAB(42)"JZ,TAB(53)"JZ,TAB(53)"JZ
7700 NEXT IX
7710 ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++ Options to Change Data ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++!
7720 PRINT 
7730 PRINT "YOU HAVE THE OPTION TO MAKE CHANGES TO ANY OF THE FOLLOWING VARIABLES"
7740 PRINT 
7750 PRINT TAB(5)"A NUMBER OF WASHING STAGES"
7760 PRINT TAB(5)"B BLOW TANK BLACK LIQUID DISSOLVED SOLIDS"
7770 PRINT TAB(5)"C BLOW TANK FIBER CONSISTENCY"
7780 PRINT TAB(5)"D FINAL STAGE SHOWER DISSOLVED SOLIDS"
7790 PRINT TAB(5)"E VAT FIBER CONSISTENCY(ICS)"
795
7800 PRINT TAB(5):"F MAT FIBER CONSISTENCY(IES)"
7810 PRINT TAB(5):"O DILUTION FACTOR" 
7820 PRINT TAB(5):"H DISPLACEMENT RATIO(S)"
7830 PRINT 
7840 INPUT "HOW MANY OF THE ABOVE 8 VARIABLES WOULD YOU LIKE TO ALTER FOR THIS RUN?\n7850 PRINT 
7860 IF VUZ=0 THEN PRINT "THERE ARE ONLY 8 OPTIONS, TRY AGAIN" \ GOTO 7840 
7870 IF VUZ=0 THEN RETURN 
7880 IF VUZ=0 THEN CHANGE(1)="A" \ CHANGE(2)="B" \ CHANGE(3)="C" \ CHANGE(4)="D" \ CHANGE(5)="E" 
7890 IF VUZ=0 THEN CHANGE(6)="F" \ CHANGE(7)="G" \ CHANGE(8)="H" \ GOTO 7950 
7900 IF VUZ=1 THEN PRINT "ENTER THE LETTER ASSOCIATED WITH THE VARIABLE YOU WANT TO CHANGE!CHANGE(1) \ GOTO 7950 
7910 PRINT "ENTER THE LETTERS ASSOCIATED WITH THE VARIABLES YOU WANT TO CHANGE (EA FOLLOWED BY RETURN)"
7920 FOR IX=1 TO VUZ 
7930 INPUT CHANGE(IX) 
7940 NEXT IX 
7950 STAGE.CH=0 \ INDEP.CH=0 \ DEP.CH=0 \ DR.CH=0 \ DF.CH=0 
7960 FOR IX=1 TO VUZ 
7970 IF CHANGE(IX)="A" THEN STAGE.CH=1 
7980 IF CHANGE(IX)="B" THEN INDEP.CH=INDEP.CH+1 
7990 IF CHANGE(IX)="C" THEN INDEP.CH=INDEP.CH+1 
8000 IF CHANGE(IX)="D" THEN INDEP.CH=INDEP.CH+1 
8010 IF CHANGE(IX)="E" THEN INDEP.CH=INDEP.CH+1 
8020 IF CHANGE(IX)="F" THEN DEP.CH=DEP.CH+1 
8030 IF CHANGE(IX)="G" THEN DEP.CH=DEP.CH+1 \ DF.CH=1 
8040 IF CHANGE(IX)="H" THEN DEP.CH=DEP.CH+1 \ DR.CH=1 
8050 NEXT IX 
8060 IF STAGE.CH=1 THEN GOSUB 9530 
8070 IF DEP.CH=0 THEN GOSUB 9480 
8080 IF INDEP.CH=0 THEN GOSUB 9620 
8090 "+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++ Check For Impossible Changes ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++"
8100 IMPOSSIBLE.DR=0 \ IMPOSSIBLE.MAT=0 
8110 FOR JZ=1 TO STAGE 
8120 TOO.HIGH.DR(JZ)=0 \ TOO.LOW.DR(JZ)=0 \ TOO.HIGH.MAT(JZ)=0 \ TOO.LOW.MAT(JZ)=0 
8130 NEXT JZ 
8140 FOR JZ=1 TO STAGE 
8150 FOR IX=1 TO TIMEX 
8160 IF DR.DAT(JZ,IX)=1 THEN TOO.HIGH.DR(JZ)=TOO.HIGH.DR(JZ)+1 
8170 IF DR.DAT(JZ,IX)=0 THEN TOO.LOW.DR(JZ)=TOO.LOW.DR(JZ)+1 
8180 IF MAT.FIB.DAT(JZ,IX)=1 THEN TOO.LOW.MAT(JZ)=1 
8190 IF MAT.FIB.DAT(JZ,IX)=0 THEN TOO.HIGH.MAT(JZ)=1 
8200 NEXT IX 
8210 PRINT 
8220 IMPOSSIBLE.DR=IMPOSSIBLE.DR+TOO.LOW.DR(JZ)+TOO.HIGH.DR(JZ) 
8230 IMPOSSIBLE.MAT=IMPOSSIBLE.MAT+TOO.LOW.MAT(JZ)+TOO.HIGH.MAT(JZ) 
8240 NEXT JZ 
8250 IMPOSSIBLE.DR=IMPOSSIBLE.DR+100/(TIMEX*STAGE) \ IMPOSSIBLE.MAT=IMPOSSIBLE.MAT+100/(TIMEX*STAGE) 
8260 IF (IMPOSSIBLE.DR=0) AND (IMPOSSIBLE.MAT=0) GOTO 8410 
8270 IF IMPOSSIBLE.DR=0 GOTO 8330 
8280 PRINT "THE CHANGE MADE IN DISPLACEMENT RATIO WILL CAUSE APPROX.*IMPOSSIBLE.DR=*
8290 PRINT TAB(10):"STAGE=ITAB(20)";"X <=0";"ITAB(30)";"Z >1"
8300 FOR JZ=1 TO STAGE 
8310 PRINT TAB(12);JZ;"ITAB(20)+(TOO.LOW.DR(JZ)*100/TIMEX)*ITAB(30);(TOO.HIGH.DR(JZ)*100/TIMEX) 
8320 NEXT JZ 
8330 IF IMPOSSIBLE.MAT=0 GOTO 8390 
8340 PRINT "THE CHANGE MADE IN MAT CONS. WILL CAUSE APPROXIMATELY*IMPOSSIBLE.MAT=*
8350 PRINT "IMPOSSIBLE VALUES TO OCCUR*"
0350 PRINT TAB(10),'STAGE'=TAB(20),'X <=0*TAB(30),'X >=100'
0360 FOR JZ=1 TO STAGE
0370 PRINT TAB(12),JZ,TAB(20),(TOO.LOW.MAT(JZ)#100/TIMEX),TAB(30),(TOO.HIGH.MAT(JZ)#100/TIMEX)
0380 NEXT JZ
0390 PRINT 'TRY AGAIN' \ GSUB 8480
0400 GOTO 8100
0410 IF (DEF.CH=0) OR (STAGE.CH=1) THEN GSUB 6970
0420 RETURN
0430 1**************************************************************************
0440 | 1**************************************************************************
0450 SUBROUTINE 91: DEPENDENT VARIABLE CHANGES
0460 | 1**************************************************************************
0470 1**************************************************************************
0480 IF IMPOSSIBLE.MAT>0 THEN XX=STAGE \
GOTO 8550
0490 IF IMPOSSIBLE.RO>0 THEN XX=STAGE \ GOTO 9190
0500 IF (DEF.CH=2) AND (DF.CH=1) AND (DR.CH=1) GOTO 8990
0510 IF (DEF.CH=1) AND (DF.CH=1) GOTO 8990
0520 IF (DEF.CH=1) AND (DR.CH=1) GOTO 9170
0530 IF STAGE.CH=1 THEN XX=STAGE-1 ELSE XX=STAGE
0550 FOR JZ=1 TO XX
0560 PRINT 'PRINT'
0570 PRINT 'WHAT CHANGES DO YOU WANT TO MAKE IN THE MAT CONSISTENCY FOR STAGE*JZ'
0580 PRINT
0590 PRINT TAB(S)+1 MEAN'
0600 PRINT TAB(S)+2 STANDARD DEVIATION'
0610 PRINT TAB(S)+3 MEAN AND STANDARD DEVIATION'
0620 PRINT TAB(S)+4 NO CHANGES'
0630 PRINT
0640 PRINT 'WHAT IS YOUR CHOICE*JZ'
0650 IF (AX<1) OR (AX>4) THEN PRINT 'TRY AGAIN' \ GOTO 8640
0660 IF AX=4 GOTO 8930
0670 IF AX=2 GOTO 8760
0680 PRINT \
PRINT
0690 INPUT 'NEW MEAN='INew.Mean
0700 OLD.MEAN=HAT.FIB.MEAN(JZ)
0710 HAT.FIB.MEAN(JZ)=NEW.MEAN
0720 FOR IX=1 TO TIMEX
0730 HAT.FIB.DAT(JZ,IX)=HAT.FIB.MEAN(JZ)+(HAT.FIB.DAT(JZ,IX)-OLD.MEAN)
0740 NEXT IX
0750 IF AX=1 GOTO 8930
0760 PRINT \
PRINT
0770 INPUT 'NEW STANDARD DEVIATION='INew.STD
0780 OLD.STD=HAT.FIB.STD(JZ)
0790 HAT.FIB.STD(JZ)=NEW.STD
0800 FOR IX=1 TO TIMEX
0810 HAT.FIB.DAT(JZ,IX)=HAT.FIB.DAT(JZ,IX)-HAT.FIB.MEAN(JZ)*HAT.FIB.STD(JZ)/OLD.STD-HAT.FIB.MEAN(JZ)
0820 NEXT IX
0830 NEXT JZ
0840 IF IMPOSSIBLE.DR>0 THEN GOTO 9180
0850 IF IMPOSSIBLE.MAT>0 AND (IMPOSSIBLE.DR=0) THEN RETURN
0860 IF (DEF.CH=2) AND (DF.CH=0) AND (DR.CH=1) GOTO 9170
0870 IF (DEF.CH=1) AND (DF.CH=0) AND (DR.CH=0) GOTO 9470
0880 1**************************************************************************
0890 PRINT \
PRINT
Dilution Factor 1**************************************************************************
B900 PRINT "WHAT CHANGE DO YOU WANT TO MAKE IN THE DILUTION FACTOR?"
B910 PRINT
B920 PRINT TAB(1)'1 MEAN"
B930 PRINT TAB(S)'2 STANDARD DEVIATION"
B940 PRINT TAB(S)'3 MEAN AND STANDARD DEVIATION"
B950 PRINT
B960 INPUT "WHAT IS YOUR CHOICE?";IAX
B970 IF (A2=1) OR (A2=3) THEN PRINT "TRY AGAIN" \ GOTO B960
B980 IF A2=2 GOTO 9700
B990 PRINT \ PRINT
9000 INPUT \NEW MEAN="\NEW MEAN
9010 \OLD MEAN=\DF MEAN
9020 \DF MEAN=\NEW MEAN
9030 FOR IX=1 TO TIMEZ
9040 \DF DAT(IX)=\DF MEAN+(\DF DAT(IX)-\OLD MEAN)
9050 NEXT IX
9060 IF A2=1 GOTO 9140
9070 PRINT \ PRINT
9080 INPUT \NEW STANDARD DEVIATION="\NEW STD
9090 \OLD STD=\DF STD
9100 \DF STD=\NEW STD
9110 FOR IX=1 TO TIMEZ
9120 \DF DAT(IX)=\(\DF DAT(IX)-\DF MEAN)\DF STD/\OLD STD)+\DF MEAN
9130 NEXT IX
9140 IF (\DEP CH=2) AND (\DF CH=1) AND (\DR CH=0) GOTO 9470
9150 IF (\DEP CH=1) AND (\DF CH=1) GOTO 9470
9160 ".......................................................... Displacement Ratio .........................................................."
9170 IF STAGE CH=1 THEN XX=STAGEX-1 ELSE XX=STAGEX
9180 FOR JZ=1 TO A2
9190 PRINT \ PRINT
9200 PRINT "WHAT CHANGE DO YOU WANT TO MAKE IN THE DISPLACEMENT RATIO FOR STAGE";JZ
9210 PRINT
9220 PRINT TAB(S)'1 MEAN"
9230 PRINT TAB(S)'2 STANDARD DEVIATION*
9240 PRINT TAB(S)'3 MEAN AND STANDARD DEVIATION"
9250 PRINT TAB(S)'4 NO CHANGE"
9260 PRINT
9270 INPUT "WHAT IS YOUR CHOICE?";AZX
9280 IF (A2=1) OR (A2=4) THEN PRINT "TRY AGAIN" \ GOTO 9270
9290 IF A2=4 GOTO 9460
9300 IF A2=2 GOTO 9390
9310 PRINT \ PRINT
9320 INPUT \NEW MEAN="\NEW MEAN
9330 \OLD MEAN=\DR MEAN(JZ)
9340 \DR MEAN(JZ)=\NEW MEAN
9350 FOR IX=1 TO TIMEZ
9360 \DR DAT(IX,IX)=\DR MEAN(JZ)+(\DR DAT(IX,IX)-\OLD MEAN)
9370 NEXT IX
9380 IF A2=1 GOTO 9460
9390 PRINT \ PRINT
9400 INPUT \NEW STANDARD DEVIATION="\NEW STD
9410 \OLD STD=\DR STD(JZ)
9420 \DR STD(JZ)=\NEW STD
9430 FOR JZ=1 TO TIMEZ
9440 \DR DAT(JZ, IX)=\(\DR DAT(JZ, IX)-\DR MEAN(JZ))\DR STD(JZ)/\OLD STD+\DR MEAN(JZ)
9450 NEXT IX
9460 NEXT JZ
9470 RETURN
9490 ***********************************************************************************************
9500 SUBROUTINE 101 STAGE CHANGES
9520 ***********************************************************************************************
9530 PRINT \ PRINT
9540 PRINT 'WOULD YOU LIKE TO?'
9550 PRINT
9560 PRINT TAB(S)+1 'ADD A NEW WASHING STAGE'\ GOTO 9570
9570 PRINT TAB(S)+2 'REMOVE YOUR LAST WASHING STAGE'\ GOTO 9580
9590 INPUT 'WHAT IS YOUR CHOICE'\AX
9600 IF AX=2 THEN STAGE=STAGE-1 \ STAGE.CH=0 \ GOTO 9760
9610 STAGE=STAGE+1
9620 PRINT \ PRINT 'INPUT THE FOLLOWING DATA FOR STAGE NUMBER'\STAGE
9630 PRINT \ INPUT 'VAT FIBER CONSISTENCY (X): MEAN = '\VAT.FIB.MEAN(STAGE)
9640 PRINT \ INPUT 'VAT FIBER CONSISTENCY (X): STD. DEV. = '\VAT.FIB.STD(STAGE)
9650 PRINT \ INPUT 'MAT FIBER CONSISTENCY (X): MEAN = '\MAT.FIB.MEAN(STAGE)
9660 PRINT \ INPUT 'MAT FIBER CONSISTENCY (X): STD. DEV. = '\MAT.FIB.STD(STAGE)
9670 PRINT \ INPUT 'DISPLACEMENT RATIO: MEAN = '\DR.MEAN(STAGE)
9680 PRINT \ INPUT 'DISPLACEMENT RATIO: STD. DEV. = '\DR.STD(STAGE)
9690 N2=STAGE \ N2=STAGE-1
9700 FOR IX=1 TO TIME
9710 MAT.FIB.DAT(N2,IX)=MAT.FIB.MEAN(IX)+(MAT.FIB.DAT(N2,IX)-MAT.FIB.MEAN(IX))\MAT.FIB.DAT(N2,IX)+MAT.FIB.STD(N2,IX)\MAT.FIB.STD(IX)
9720 MAT.FIB.DAT(N2,IX)=MAT.FIB.DAT(N2,IX)-\MAT.FIB.DAT(N2,IX)+MAT.FIB.MEAN(IX)\MAT.FIB.STD(N2,IX)\MAT.FIB.STD(IX)
9730 DR.DAT(N2,IX)=DR.MEAN(IX)+(DR.DAT(N2,IX)-DR.MEAN(IX))\DR.DAT(N2,IX)+DR.DAT(IX)-DR.MEAN(IX)\DR.DAT(IX)
9740 NEXT IX
9760 RETURN
9770 ***********************************************************************************************
9780 SUBROUTINE 111 INDEPENDENT VARIABLE CHANGES
9790 ***********************************************************************************************
9810 FOR IX=1 TO N2
9820 IF CHANGE(IX)="B" GOTO 10000
9830 IF CHANGE(IX)="C" GOTO 10000
9840 IF CHANGE(IX)="D" GOTO 10000
9850 PRINT \ PRINT
9860 PRINT 'WHAT CHANGE DO YOU WANT TO MAKE IN THE BLOW TANK DISSOLVED SOLIDS'
9870 PRINT
9880 PRINT TAB(S)+1 'MEAN'\ GOTO 9890
9890 PRINT TAB(S)+2 'STANDARD DEVIATION'\ GOTO 9900
9900 PRINT TAB(S)+3 'MEAN AND STANDARD DEVIATION'\ GOTO 9910
9910 PRINT
9920 INPUT 'WHAT IS YOUR CHOICE'\AX
9930 IF (AX<1) OR (AX>3) THEN PRINT 'TRY AGAIN' \ GOTO 9920
9940 IF AX=2 GOTO 9980
9950 PRINT \ PRINT
9960 INPUT 'NEW MEAN='\BLOW.DS.MEAN
9970 IF AX=1 GOTO 10000
9980 PRINT \ PRINT
9990 INPUT 'NEW STANDARD DEVIATION='\BLOW.DS.STD
1000 PRINT \ PRINT
1001 IF AX=1 GOTO 10000
10000 IF CHANGES(1Z)<>"C" GOTO 10170
10010 "------------------------------------- Blow Tank Consistency -------------------------------------"
10020 PRINT / PRINT
10030 PRINT "WHAT CHANGE DO YOU WANT TO MAKE IN THE BLOW TANK FIBER CONSISTENCY?" / PRINT
10040 PRINT
10050 PRINT TAB(5):'1 MEAN'
10060 PRINT TAB(5):'2 STANDARD DEVIATION'
10070 PRINT TAB(5):'3 MEAN AND STANDARD DEVIATION'
10080 PRINT
10090 INPUT "WHAT IS YOUR CHOICE?" /AX
10100 IF (AX<1) OR (AX>3) THEN PRINT "TRY AGAIN" / GOTO 10090
10110 IF AX=2 GOTO 10150
10120 PRINT / PRINT
10130 INPUT "NEW MEAN=" /FIBER.IN.MEAN
10140 IF AX=1 GOTO 10170
10150 PRINT / PRINT
10160 PRINT "NEW STANDARD DEVIATION=" /FIBER.IN.STD
10170 IF CHANGES(1Z)<>"D" GOTO 10340
10180 "------------------------------------- Shower Dissolved Solids -------------------------------------"
10190 PRINT / PRINT
10200 PRINT "WHAT CHANGE DO YOU WANT TO MAKE IN THE FINAL STAGE SHOWER CONCENTRATION (PPM)?" / PRINT
10210 PRINT
10220 PRINT TAB(5):'1 MEAN'
10230 PRINT TAB(5):'2 STANDARD DEVIATION'
10240 PRINT TAB(5):'3 MEAN AND STANDARD DEVIATION'
10250 PRINT
10260 INPUT "WHAT IS YOUR CHOICE?" /AX
10270 IF (AX<1) OR (AX>3) THEN PRINT "TRY AGAIN" / GOTO 10260
10280 IF AX=2 GOTO 10320
10290 PRINT / PRINT
10300 INPUT "NEW MEAN=" /ISH.DS.MEAN
10310 IF AX=1 GOTO 10340
10320 PRINT / PRINT
10330 PRINT "NEW STANDARD DEVIATION=" /ISH.DS.STD
10340 IF CHANGES(1Z)<>"C" GOTO 10540
10350 "------------------------------------- Vat Consistency -------------------------------------"
10360 IF STAGE.CH<1 THEN XZ=STAGEX-1 ELSE XZ=STAGEX
10370 FOR JX=1 TO XZ
10380 PRINT / PRINT
10390 PRINT "WHAT CHANGE DO YOU WANT TO MAKE IN THE VAT CONSISTENCY FOR STAGE" / JX
10400 PRINT
10410 PRINT TAB(5):'1 MEAN'
10420 PRINT TAB(5):'2 STANDARD DEVIATION'
10430 PRINT TAB(5):'3 MEAN AND STANDARD DEVIATION'
10440 PRINT TAB(5):'4 NO CHANGE'
10450 PRINT
10460 INPUT "WHAT IS YOUR CHOICE?" /AX
10470 IF (AX<1) OR (AX>4) THEN PRINT "TRY AGAIN" / GOTO 10460
10480 IF AX=4 GOTO 10550
10490 IF AX=2 GOTO 10530
10500 PRINT / PRINT
10510 INPUT "NEW MEAN=" /IVAT.FIB.MEAN(JX)
10520 IF AX=1 GOTO 10550
10530 PRINT / PRINT
10540 INPUT "NEW STANDARD DEVIATION=" /IVAT.FIB.STD(JX)
APPENDIX B

VARIABLE DICTIONARY FOR PULFWASH.BAS
A%  Stores the desired change to be made in a variable.

A$  Stores the answer to a "yes or no" question.

AMOUNT(a)  Stores the number of symbols (x's) that will be printed to represent the frequency of occurrence in 20 defined ranges; where "a" represents each of these ranges in an array. Used when printing a variable's distribution.

AMOUNT.DR(a,b)  Stores the number of symbols (x's) that will be printed to represent the frequency of occurrence in 20 defined ranges; where "a" represents each of these ranges and "b" represents each washing stage. Used when printing displacement ratio distributions.

AMOUNT.WLR(a,b)  Stores the number of symbols (x's) that will be printed to represent the frequency of occurrence in 20 defined ranges; where "a" represents each of these ranges and "b" represents each washing stage. Used when printing wash liquor ratio distributions.

AVG.CARRYOVER  Average value of CARRYOVER(a).

AVG.DISPLACEMENT(a,b)  Average value of DISPLACEMENT(a,b); where "a" represents each washing stage.

AVG.EFFICIENCY  Average value of EFFICIENCY(a).

AVG.EVAP.DS  Average value of EVAP.DS(a).

AVG.EVAPORATOR  Average value of EVAPORATOR(a).

AVG.WLR(a)  Average value of WLRATIO(a,b); where "a" represents each washing stage.

BLOW.DS  Dissolved solids (%) in the blow tank black liquor before dilution (generated value).

BLOW.DS.FIB  Weight of dissolved solids per unit weight oven dry fiber in the blow tank.
<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BLOW.DS.MEAN</td>
<td>Average value of dissolved solids (%) in the blow tank liquor (input to the program).</td>
</tr>
<tr>
<td>BLOW.DS.STD</td>
<td>The standard deviation associated with BLOW.DS.MEAN (input to the program).</td>
</tr>
<tr>
<td>CALC.DS(a)</td>
<td>The calculated value of dissolved solids (fraction) coming into a stage from the blow tank or a subsequent mat; where &quot;a&quot; represents each washing stage.</td>
</tr>
<tr>
<td>CARRYOVER(a)</td>
<td>The weight of dissolved solids per ton oven dry fiber in the final mat; where &quot;a&quot; represents each iteration (5000).</td>
</tr>
<tr>
<td>CHANGE$(a)</td>
<td>Stores which variables the operator wants to alter before a simulation run; where &quot;a&quot; represents the number of variables the operator wants to change.</td>
</tr>
<tr>
<td>CHOICE</td>
<td>The option chosen by the user from the program menu.</td>
</tr>
<tr>
<td>COUNT%</td>
<td>Counts the number of iterations made when running the simulation (usually 5000).</td>
</tr>
<tr>
<td>C.RANGE</td>
<td>The overall range (largest-smallest) of CARRYOVER(a).</td>
</tr>
<tr>
<td>C.SUM.SQ</td>
<td>The sum of the squares of each carryover value (CARRYOVER(a)).</td>
</tr>
<tr>
<td>DEP.CH</td>
<td>Stores the number of changes desired by the user for the dependent variables: mat consistency, dilution factor, and displacement ratio.</td>
</tr>
<tr>
<td>DEV.BLS</td>
<td>Transformed standard deviation of the blow tank black liquor solids (used in data generation).</td>
</tr>
<tr>
<td>DEV.CARRYOVER</td>
<td>The standard deviation associated with AVG.CARRYOVER.</td>
</tr>
<tr>
<td>DEV.DISPLACEMENT(a)</td>
<td>The standard deviation associated with AVG.DISPLACEMENT(a); where &quot;a&quot;</td>
</tr>
</tbody>
</table>
represents each washing stage.

**DEV.EFFICIENCY**
The standard deviation associated with AVG.EFFICIENCY.

**DEV.EVAP.DS**
The standard deviation associated with AVG.EVAP.DS.

**DEV.EVAPORATOR**
The standard deviation associated with AVG.EVAPORATOR.

**DEV.FI**
Transformed standard deviation of the fiber consistency of the blow tank (used in data generation).

**DEV.MAT(a)**
Transformed standard deviation of the mat fiber consistency (used in data generation); where "a" represents each washing stage.

**DEV.SH**
Transformed standard deviation of the final stage shower water dissolved solids concentration (used in data generation).

**DEV.VAT(a)**
Transformed standard deviation of the vat fiber consistency (used in data generation); where "a" represents each washing stage.

**DEV.WLR(a)**
The standard deviation associated with AVG.WLR(a); where "a" represents each washing stage.

**DEV.Y.X(a)**
The standard deviation of Y based on the pick of X (used in the generation of DR); where Y=ln(1-DR), X=WLR.I(a), and "a" represents each washing stage.

**DF**
Dilution factor (generated value).

**DF.CH**
Identifies whether the user wants to alter the value of dilution factor prior to the simulation run or not.

**DF.DAT(a)**
Dilution factor (individual data input to the program); where "a" represents each sampling time.

**DF.MEAN**
Average value of DF.DAT(a).
DF.STD  
Standard deviation associated with DF.MEAN.

DF.SUM.SQ  
The sum of the squares of each dilution factor value (DF.DAT(a)).

DIFF  
Difference between the calculated value of blow tank black liquor solids and the input value.

DISPLACEMENT(a,b)  
Stores the generated values of displacement ratio (DR(a)); where "a" represents each iteration (5000) and "b" represents each washing stage.

DIST$(a)  
Stores what distribution(s) the user wants printed; where "a" represents the number of distributions the user wants to see.

DIVISION  
Stores the length of the increment needed to divide the overall range of a variable into 20 equal divisions. Used when printing a distribution.

DIVISION(a)  
Stores the length of the increment needed to divide the overall range of a variable into 20 equal divisions; where "a" represents each washing stage. Used when printing distributions for wash liquor ratio or displacement ratio.

DR(a)  
Displacement ratio (generated value); where "a" represents each washing stage.

DR.CH  
Identifies whether the user wants to alter the displacement ratio(s) prior to running a simulation or not.

DR.DAT(a,b)  
Displacement ratio (individual data input to the program); where "a" represents each washing stage and "b" represents each sampling time.

DR.MEAN(a)  
Average value of DR.DAT(a,b); where "a" represents each washing stage.

DR.RANGE(a)  
Overall range (largest-smallest) of DISPLACEMENT(a,b); where "a"
represents each washing stage.

**DR.STD(a)**

Standard deviation associated with DR.MEAN(a); where "a" represents each washing stage.

**DR.SUM.SQ(a)**

The sum of the squares of the displacement ratio values (either DISPLACEMENT(a,b) or DR.DAT(a,b)); where "a" represents each washing stage.

**EACHX**

Stores the number of data points that each symbol (x) will represent. Used when printing a distribution.

**EACHX(a)**

Stores the number of data points that each symbol (x) will represent; where "a" represents each washing stage. Used when printing a distribution for displacement ratio or wash liquor ratio.

**EFFICIENCY(a)**

Overall washing efficiency (%); where "a" represents each iteration (5000).

**EFF.RANGE**

The overall range (largest-smallest) of the values of EFFICIENCY(a).

**EFF.SUM.SQ**

The sum of the squares of washing efficiency values (EFFICIENCY(a)).

**EVAP.DS(a)**

Dissolved solids (%) in the excess filtrate; where "a" represents each iteration (5000).

**EVAPORATOR(a)**

Pounds excess filtrate per ton of oven dry pulp; where "a" represents each iteration (5000).

**EV.DS.RANGE**

The overall range (largest-smallest) of the values of EVAP.DS(a).

**EV.DS.SUM.SQ**

The sum of the squares of the dissolved solids in the excess filtrate (EVAP.DS(a)).

**EV.RANGE**

The overall range (largest-smallest) of the values of EVAPORATOR(a).

**EV.SUM.SQ**

The sum of the squares of the pounds
excess filtrate (EVAPORATOR(a)).

FIBER.IN(a)  Fiber consistency (%) entering a particular washing stage (generated value); where "a" represents each washing stage.

FIBER.IN.MEAN  Average fiber consistency (%) coming from the blow tank (input value).

FIBER.IN.STD  The standard deviation associated with FIBER.IN.MEAN.

FIL.DS(a)  Dissolved solids (fraction) in the filtrate; where "a" represents each washing stage.

FILTRATE(a)  Pounds filtrate per oven dry fiber; where "a" represents each washing stage.

FN.DEV(A,B)  Function used to calculate the standard deviation of the log transformed data.
A=The standard deviation of the untransformed data.
B=The mean of the untransformed data.

FN.MEAN(C,D)  Function used to calculate the mean of the log transformed data.
C=The mean of the untransformed data.
D=The log transformed standard deviation.

FN.VALUE(E,F)  Function used to generate a value based on a normal distribution.
E=The standard deviation.
F=The mean.

FREQ(a)  Stores the frequency of occurrence of a variable within a defined increment; where "a" represents each of the 20 increments. Used when printing a distribution.

FREQ.DR(a,b)  Stores the frequency of occurrence of a variable within a defined increment; where "a" represents each of the 20 increments and "b" represents each
washing stage. Used when printing
displacement ratio distributions.

**FREQ.WLR(a,b)**
Stores the frequency of occurrence of
a variable within a defined increment;
where "a" represents each of the 20
increments and "b" represents each
washing stage. Used when printing the
wash liquor ratio distributions.

**GUESS.DS(a)**
Dissolved solids (fraction) contained
in the mat, the guess refers to the
guess that must be made for the final
washing stage to begin the convergence
routine to make the washing system
balance; where "a" refers to each
washing stage.

**H%**
Counter variable.

**I%**
Counter variable.

**IMPOSSIBLE**
Stores the number of impossible values
of displacement ratio that are
generated during the simulation run.

**IMPOSSIBLE.DR**
Stores the number of impossible values
of displacement ratio that are created
when the user wishes to alter the mean
and/or standard deviation prior to the
simulation run.

**IMPOSSIBLE.MAT**
Stores the number of impossible values
of mat consistency that are created
when the user wishes to alter the mean
and/or standard deviation prior to the
simulation run.

**INDEP.CH**
Stores the number of changes the user
wants to make to the independent
variables: blow tank dissolved
solids, blow tank fiber consistency,
vat fiber consistency, and final
shower dissolved solids.

**IN.LIQ.FIB(a)**
The weight ratio of liquor to fiber
entering; where "a" represents each
washing stage.

**J%**
Counter variable.
K%  Counter variable.
LARGE.C  Largest value of CARRYOVER(a).
LARGE.DR(a)  Largest value of DISPLACEMENT(a,b); where "a" represents each washing stage.
LARGE.EFF  Largest value of EFFICIENCY(a).
LARGE.EV  Largest value of EVAPORATOR(a).
LARGE.EV.DS  Largest value of EVAP.DS(a).
LARGE.W(a)  Largest value of WLRATIO(a,b); where "a" represents each washing stage.
LAST.DIFF  Stores the last difference between the calculated blow tank dissolved solids and the actual value. Used in the convergence routine to balance the washer.
LAST.GUESS  Stores the last guess of dissolved solids in the mat. Used in the convergence routine to balance the washer.
M%  Stores the value of (STAGE%-1).
MAT.DS.FIB  The weight of dissolved solids per unit weight of fiber in the final stage mat, after the system has been balanced.
MAT.FIB(a)  Generated value of fiber consistency (%) in the mat; where "a" represents each washing stage.
MAT.FIB.DAT(a,b)  Individual data for the fiber consistency (%) in the mat (input to the program); where "a" represents each washing stage and "b" represents each sampling time.
MAT.FIB.MEAN(a)  The average value of MAT.FIB.DAT(a,b); where "a" represents each washing stage.
MAT.FIB.STD(a)  The standard deviation associated with MAT.FIB.MEAN(a); where "a" represents
each washing stage.

**MAT.LIQ.FIB(a)**
The weight ratio of liquor to fiber in the mat; where "a" represents each washing stage.

**MAT.SUM.Sq(a)**
The sum of the squares of the mat fiber consistency data (MAT.FIB.DAT(a,b)); where "a" represents each washing stage.

**MEAN.BLS**
The transformed mean of blow tank black liquor solids (used in data generation).

**MEAN.FI**
The transformed mean of the fiber consistency entering the system from the blow tank (used in data generation).

**MEAN.MAT(a)**
The transformed mean of the fiber consistency in the mat (used in data generation); where "a" represents each washing stage.

**MEAN.SH**
The transformed mean of the dissolved solids concentration in the final stage shower (used in data generation).

**MEAN.VAT(a)**
The transformed mean of the fiber consistency in the vat (used in data generation); where "a" represents each washing stage.

**MEAN.Y.X(a)**
The mean value of Y based on the picked value of X; where Y=ln(1-DR), X=WLR.I(a), and "a" represents each washing stage.

**N%**
Stores the value of STAGE% (the number of stages).

**NAME$**
The name given to the data file to store the collected data from a mill.

**NEW.MEAN**
Stores the value of the new mean of a variable that the operator wishes to alter prior to a simulation run.

**NEW.STD**
Stores the value of the new standard
deviation of a variable that the operator wishes to alter prior to a simulation run.

**NUMBER%**

The number of iterations in the simulation run (currently 5000).

**OLD.MEAN**

Stores the value of the old mean of a variable that the operator wishes to alter prior to a simulation run.

**OLD. STD**

Stores the value of the old standard deviation of a variable that the operator wishes to alter prior to a simulation run.

**Q%**

Counts the number of iterations through the convergence routine to balance the washing system (maximum is currently 1000).

**RANGE1**

Smallest possible value of the dissolved solids (fraction) in the final mat. Used in the convergence routine to balance the washing system. Note: the actual value of GUESS.DS(a) must fall between RANGE1 and RANGE2 in order for the system to converge.

**RANGE2**

Largest possible value of the dissolved solids (fraction) in the final mat. See RANGE1 definition.

**R1(a)**

Defines the smallest value for each of 20 increments that make up the entire range of a variable; where "a" represents each of these increments. Used when printing a variable's distribution.

**R2(a)**

Defines the largest value for each of 20 increments that make up the entire range of a variable; where "a" represents each of these increments. Used when printing a variable's distribution.

**R.1(a, b)**

Defines the smallest value for each of 20 increments that make up the entire range of a variable; where "a" represents each of the 20 increments.
and "b" represents each washing stage. Used when printing distributions for displacement ratio or wash liquor ratio.

R.2(a,b) Defines the largest value of each of 20 increments that make up the entire range of a variable; where "a" represents each of the 20 increments and "b" represents each washing stage. Used when printing distributions for displacement ratio or wash liquor ratio.

SH.DS Generated value of the dissolved solids concentration (ppm) in the final stage shower.

SH.DS(a) Dissolved solids concentration (fraction) in the shower; where "a" represents each washing stage.

SH.DS.MEAN Average value of dissolved solids concentration (ppm) in the final stage shower (input to the program).

SH.DS.STD Standard deviation associated with SH.DS.MEAN (input to the program).

SHOWER(a) Weight of shower water per unit weight of fiber; where "a" represents each washing stage.

SLOPE(a) The slope of the regression line relating WLR with ln(1-DR); where "a" represents each washing stage.

SMALL.C Smallest value of CARRYOVER(a).

SMALL.DR(a) Smallest value of DISPLACEMENT(a,b); where "a" represents each washing stage.

SMALL.EFF Smallest value of EFFICIENCY(a).

SMALL.EV Smallest value of EVAPORATOR(a).

SMALL.EV.DS Smallest value of EVAP.DS(a).

SMALL.W(a) Smallest value of WLRATIO(a,b); where "a" represents each washing stage.
<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>STAGE%</td>
<td>The number of washing stages.</td>
</tr>
<tr>
<td>STAGE.CH</td>
<td>Stores whether or not the user wants to make a change in the number of stages.</td>
</tr>
<tr>
<td>SYX(a)</td>
<td>Stores the value of the standard error of Y given X about the regression line; where Y=ln(1-DR), X=WLR, and &quot;a&quot; represents each washing stage.</td>
</tr>
<tr>
<td>THEMOST</td>
<td>Stores the one increment out of 20, that holds the largest frequency of values. Used when printing a distribution of a variable.</td>
</tr>
<tr>
<td>THEMOST(a)</td>
<td>Stores the one increment out of 20, that holds the largest frequency of values; where &quot;a&quot; represents each washing stage. Used when printing distributions of displacement ratio or wash liquor ratio.</td>
</tr>
<tr>
<td>TIME%</td>
<td>The number of sampling times used when collecting data from a washing system. Individual data points are entered for mat consistency, displacement ratio, and dilution factor and it is necessary that the number of sampling times is equal for each variable.</td>
</tr>
<tr>
<td>TOO.HIGH(a)</td>
<td>Stores the number of values of displacement ratio that are greater than or equal to 1 during data generation of a simulation run; where &quot;a&quot; represents each washing stage.</td>
</tr>
<tr>
<td>TOO.HIGH.DR(a)</td>
<td>Stores the number of values of displacement ratio that are greater than or equal to 1 when the operator is making a change to the mean and/or the standard deviation of DR prior to a simulation run; where &quot;a&quot; represents each washing stage.</td>
</tr>
<tr>
<td>TOO.HIGH.MAT(a)</td>
<td>Stores the number of values of mat consistency that are greater than or equal to 100 when the operator is making a change to the mean and/or the standard deviation of mat cons. prior</td>
</tr>
</tbody>
</table>
TOO.LOW(a) Stores the number of values of displacement ratio that are less than or equal to 0 during data generation of a simulation run; where "a" represents each washing stage.

TOO.LOW.DR(a) Stores the number of values of displacement ratio that are less than or equal to 0 when the operator is making a change to the mean and/or the standard deviation of DR prior to a simulation run; where "a" represents each washing stage.

TOO.LOW.MAT(a) Stores the number of values of mat consistency that are less than or equal to 0 when the operator is making a change to the mean and/or standard deviation of mat cons. prior to a simulation run; where "a" represents each washing stage.

VALUE.BLS The generated value of the transformed data of blow tank black liquor dissolved solids.

VALUE.FI The generated value of the transformed data of the blow tank fiber consistency; where "a" represents each washing stage.

VALUE.MAT(a) The generated value of the transformed data of the mat consistency; where "a" represents each washing stage.

VALUE.SH The generated value of the transformed data for dissolved solids in the final stage shower.

VALUE.VAT(a) The generated value of the transformed data of the vat consistency; where "a" represents each washing stage.

VAT.DS(a) Dissolved solids (fraction) in the vat; where "a" represents each washing stage.

VAT.FIB(a) Fiber consistency (%) in the vat.
(generated); where "a" represents each washing stage.

**VAT.FIB.MEAN(a)**  
Average fiber consistency (%) in the vat (input to the program); where "a" represents each washing stage.

**VAT.FIB.STD(a)**  
Standard deviation associated with VAT.FIB.MEAN(a); where "a" represents each washing stage.

**VAT.LIQ.FIB(a)**  
The weight ratio of liquor to fiber in the vat; where "a" represents each washing stage.

**VV%**  
The number of variables the user would like to alter prior a simulation.

**WLR(a,b)**  
The wash liquor ratio calculated from original mat consistency and dilution factor data; where "a" represents each washing stage and "b" represents each sampling time.

**WLRATIO(a,b)**  
Stores the generated values of wash liquor ratio (WLR.I(a)); where "a" represents each iteration (5000) and "b" represents each washing stage.

**WLR.I(a)**  
The individual pick of wash liquor ratio calculated from a generated mat consistency and a generated dilution factor; where "a" represents each washing stage.

**WLR.SUM.SQ(a)**  
The sum of the squares of the individual data of wash liquor ratio (WLR(a,b)); where "a" represents each washing stage.

**WLR.Y.SUM(a)**  
The sum of the products of the individual data WLR(a,b) and ln[1-DR.DAT(a,b)]; where "a" represents each washing stage.

**W.RANGE(a)**  
Overall range (largest-smallest) of WLRATIO(a,b); where "a" represents each washing stage.

**W.SUM.SQ(a)**  
The sum of the squares of the generated data of wash liquor ratio
\( WLRATIO(a,b) \); where "a" represents each washing stage.

\( X_1 \quad \text{Equal to AVG.DISPACEMENT(a) (used to shorten a print statement).} \)

\( X_2 \quad \text{Equal to DEV.DISPACEMENT(a) (used to shorten a print statement).} \)

\( X_3 \quad \text{Equal to DR.RANGE(a) (used to shorten a print statement).} \)

\( X\% \quad \text{Counter value which changes depending on whether or not the user wants to increase the number of washing stages (if an increase } X\%=STAGE%-1 \text{ if no increase than } X\%=STAGE\%).} \)

\( Y.I(a) \quad \text{Generated value of } ln(1-DR); \text{ where "a" represents each washing stage.} \)

\( Y.SUM.SQ(a) \quad \text{The sum of the squares of the individual values of } ln[1-DR.DAT(a,b)]; \text{ where "a" represents each washing stage.} \)

\( ZZ\% \quad \text{Stores the number of distributions the operator wants to see.} \)
APPENDIX C

PROGRAM DOCUMENTATION FOR PULPWASH.BAS
PROGRAM MAIN BODY

<table>
<thead>
<tr>
<th>Line(s)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>150</td>
<td>The RANDOMIZE statement forces the computer's random number generator to give a different sequence of random numbers each time the program is used. Without this command, the random numbers generated when the random number function RND is used, would be the same each time the program was run.</td>
</tr>
<tr>
<td>160</td>
<td>Sets the number of simulation iterations to 5000.</td>
</tr>
<tr>
<td>170-200</td>
<td>Dimension statements for the variables which are arrays.</td>
</tr>
</tbody>
</table>

Program Menu

<table>
<thead>
<tr>
<th>Line(s)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>220-320</td>
<td>Gives the user options for the running of the program and reminds them of the need to be in double precision when running the simulation. Double precision must be set while in BASIC and prior to running the program.</td>
</tr>
<tr>
<td>330</td>
<td>Initializes the variables which are used to count the number of impossible values created when the user makes changes to the input variables of DR and mat consistency.</td>
</tr>
<tr>
<td>340</td>
<td>If the user has not entered an appropriate answer in response to the program menu, this line catches the mistake and reprints the menu options.</td>
</tr>
<tr>
<td>350-60</td>
<td>Switches program control to subroutine 6. After returning from subroutine 6, the computer goes back to the program menu.</td>
</tr>
<tr>
<td>370</td>
<td>Switches program control to subroutine 8. After returning from this subroutine, the computer continues on to the mass balance portion of the main program.</td>
</tr>
<tr>
<td>380</td>
<td>If the user chooses to end program execution, program control switches to the end of the program (line 10630).</td>
</tr>
</tbody>
</table>
Mass Balance

400-30 Initializing the variables, which are used to keep track of values generated for DR which are either too low or too high, and the total number of impossible values generated.

440 Begins the loop which completes 5000 iterations through the simulation (loop ends line 980).

450 Program control switches to subroutine 1 for data generation.

460 Converts the final stage shower water concentration of dissolved solids from ppm to a weight fraction.

470-510 Loop used to calculate the weight fractions of liquor to fiber contained in the input, the mat, and the vat of each washing stage.

520 Calculates the weight of shower water applied per unit weight OD pulp production.

530-40 Sets up the initial outside limits (range) for the convergence routine.

550 The guess (weight fraction of carryover) needed for the convergence routine falls half way between the two outside limits.

560 Begins the loop to perform the mass balance calculations for the washing system (loop ends line 680). Note: the calculations progress from the last washing stage to the first.

570 Calculates the dissolved solids in the vat.

580-610 Calculates the dissolved solids in the filtrate.

620 Calculates the lbs. of filtrate per lb. of pulp.

630-40 Calculates the dissolved solids entering the washing stage.

650-70 Sets up the values for the carryover dissolved solids, the shower dissolved solids, and the weight of shower water applied for the next stage's calculations. Note: if stage three had just been balanced these lines would set up the
calculations for stage 2.

End of the mass balance loop (loop begins line 560).

**Convergence Routine**

700-10 Calculates the absolute value of the difference between the calculated and the actual (generated) values of blow tank dissolved solids content.

720 Checks to see if the difference is within the tolerance allowed. If it is, program control switches to the final calculations for the particular mass balance.

730-40 Counts the number of iterations required to converge on the correct carryover dissolved solids to make the system balance. If this number gets too large (>1000) the simulation is terminated.

750 After the first iteration, the values for the guess and difference are set to equal the last guess and the last difference. The second guess is made and program control switches to line 560 where the loop for the mass balance calculations begins. Note: it is necessary to have the first two guesses and their corresponding differences set up above the actual value of carryover which is being searched for. In this case the actual value is a fraction and therefore between 0 and 1. The initial range is set between 0 and 4, the first guess=2, and the second guess=1 so that as the convergence process begins the first two guesses needed to begin the convergence routine are well above the actual value.

760 If the value of a guess is less than the last guess and the difference associated with the guess is less then the last difference, then the guess is closer to the actual value then the last guess and farther away from the upper limit. The upper limit can be placed half way between the guess and last guess without worry of skipping over the actual value.

770 If the value of a guess is less than the last
If the value of a guess is greater than the last guess and the difference associated with the guess is greater than the last difference, then the guess is farther away from the actual value then the last guess was. Since the guess is too low, the lower limit can be safely placed half way between the guess and the last guess without worry of skipping over the actual value.

If the value of a guess is greater than the last guess and the difference associated with the guess is less than the last difference, then the guess is closer to the actual value then the last guess and farther away from the lower limit. The lower limit can be placed half way between the guess and last guess without worry of skipping over the actual value.

If the value of a guess is greater than the last guess and the difference associated with the guess is greater than the last difference, then the guess is farther away from the actual value then the last guess was. Since the guess is too high, the upper limit can be safely placed half way between the guess and the last guess without worry of skipping over the actual value.

If the difference associated with the current guess is exactly equal to the last difference, the actual value must fall directly in the middle of the guess and the last guess. If this is the case, the new guess is set up and program control is switched to line 560 where the loop for the mass balance calculations begins.

If the last guess falls between the newly set up interval the current guess must have gone too far in one direction, causing the last guess to be closer (lines 770 or 790 were true). If this is the case then the last guess and last difference should remain as such since the current guess and difference fall outside the range. Program control is moved to line 550 where a new guess is calculated.

If line 820 is not true, then the current guess falls between the lower and upper limits and the last guess does not. The current guess and difference are assigned the names last guess and last difference and program control moves to line 550 where a new guess is calculated.
Balance Complete - Final Calculations

870-960 Values that will eventually be needed in the output subroutines are stored in arrays (5000 values for each array). These values include the carryover in terms of lbs. dissolved solids per ton O.D. pulp, the percent dissolved solids in the excess filtrate, the lbs. excess filtrate per ton O.D. pulp, the overall washing efficiency, and the generated displacement ratios and wash liquor ratios.

970 Resets Q% to zero for the next iteration in the simulation. Q% keeps track of the number of times through the convergence routine required to balance a washing system.

980 Ends the loop which completes 5000 iterations through the simulation (loop begins line 440).

990-1000 Sends program control to the output subroutines controlled by subroutine 2. After returning from the output subroutines, program control switches back to the program menu.

SUBROUTINE 1: DATA GENERATION

Define Functions

1070-90 Defines the function FN.DEV(A,B) which is used to calculate the standard deviation of log transformed data from the mean (B) and standard deviation (A) of untransformed data.

1100-20 Defines the function FN.MEAN(C,D) which is used to calculate the mean of log transformed data from the mean of the untransformed data (C) and the standard deviation of the log transformed data (D).

1130-50 Defines the function FN.VALUE(E,F) which is used to generate a random value based on the probability described by a normal distribution, with mean F and standard deviation E. The equation uses two random numbers between 0 and 1, each generated by the computer when it encounters the function RND (see note about the
Randomize command with line 150 discussion).

Independent Variables

1170-200 Based on a log-normal distribution, these lines generate a value for the fiber consistency (%) entering the washing system from the blow tank prior to dilution.

1210-1300 Based on log-normal distributions, this loop generates a value for the vat fiber consistency (%) and the mat fiber consistency (%), for each washing stage.

1310-30 Since the mat of the first stage becomes the input to the second stage and so on, this loop assigns the inputs of all the stages except the first with the appropriate mat values.

1340-70 Based on a log-normal distribution, these lines generate a value for the dissolved solids (%) contained in the liquor fraction, of the pulp entering the system, from the blow tank, prior to dilution.

1380-1410 Based on a log-normal distribution, these lines generate a value for the dissolved solids (ppm) contained in the shower water applied to the final washing stage.

1420 This line generates a value for the dilution factor of a washing system, based on a normal distribution.

Dependent Variables

1440 Begins a loop that increments the number of stages (loop ends line 1550).

1450 Calculates a value for wash liquor ratio from the values generated for mat consistency and dilution factor.

1460 Calculates the estimated value of \( y (\ln(1-DR)) \) at the wash liquor ratio calculated in line 1450.
1470 Calculates the standard deviation of $y$ given a particular value of $x$ (WLR).

1480 Assuming a normal distribution, generates a value for $y$ using the estimate of $y$ (line 1460) as the mean and the standard deviation of $y$ given a particular value of $x$ (line 1470) as the standard deviation.

1490 Calculates the DR from the generated value of $y$ (line 1480).

1500-40 Keeps track of the number of impossible values of DR that are generated. When an impossible value is encountered another value of $y$ is generated (line 1480). If as many as 500 impossible values are generated, program operation stops.

1550 Ends the loop (loop begins line 1440).

1560 Returns program control to the mass balance portion of the main program.

1570-1620 These lines give statements to the user as to where the impossible values of DR are occurring, prior to terminating the simulation (due to 500 impossible values being generated).

**SUBROUTINE 2: AUTOMATIC OUTPUT**

1680-90 Initializes the sum of squares and average variables to zero.

1700-30 Sets the variables that will store the smallest and largest values of the output variables to the first value contained in each output array.

**Calculate Averages, Standard Deviations, and Overall Ranges**

1750 Begins a loop to increment the 5000 values of each output variable: carryover, DS to the evaporator, lbs. filtrate to the evaporator, and washing efficiency (loop ends line 1920).

1760-90 Sums all the values for the output variables so that the average can be calculated.
1800-30 Finds the smallest value (of the 5000) for each output variable listed above.

1840-70 Finds the largest value (of the 5000) for each output variable listed above.

1880-910 Calculates the sum of squares of the output variables, listed above, so that the standard deviation can be calculated.

1920 Ends the loop (loop begins line 1750).

1930-60 Calculates the average value for each of the output variables.

1960-2000 Calculates the range (largest-smallest) of the data for each output variable.

2010-40 Calculates the standard deviation for each of the output variables.

Print Output

2060-470 Prints the automatic output information. This information includes: the factor \( k \) used to relate WLR to \( \ln(1-DR) \) for each washing stage; the number of impossible values of DR that were generated and where they occurred; and the mean, standard deviation, and range of data for the output variables.

Other Output Options

2490-580 Options are listed for the user to print distributions for any of the output variables and for the generated values of displacement ratio and wash liquor ratio. The user is asked how many distributions he/she would like to view.

2590 If the user fails to enter the proper number of distributions to be viewed, the input statement is repeated.

2600 If no further output is desired by the user, the program switches to line 1000 where it is
Program control is switched to subroutine 3 for further output, after control switches back from this subroutine, it is returned to line 1000, where it is returned to the program menu.

SUBROUTINE 3: DISTRIBUTION OUTPUT

The user inputs which distribution(s) are desired by the letter associated with each.

Prints out a heading.

Begins a loop which increments the number of distributions chosen (loop ends line 3960).

Carryover Frequency of Occurrence

If the array storing the distributions chosen by the user does not equal "A" for this iteration through the loop, program control switches to line 3020 where it will check distribution "B".

The range of carryover values is divided by 20 to determine the length of each of 20 increments that will be used when printing out the frequency distribution.

The lower and upper limits are set up for each of the 20 increments used to print out the carryover distribution.

Initializes the array which will contain the number of values of carryover which occur in the 20 increments.

Counts the number of values of carryover (out of 5000) which fall within the 20 increments set up over the entire range of the values that occurred.

Quantity Excess Filtrate Frequency of Occurrence

If the array storing the distributions chosen by
the user does not equal "B" for this iteration through the loop, program control switches to line 3200 where it will check distribution "C".

3030-180 Same as lines 2850-3000, only for lbs. excess filtrate values.

### Excess Filtrate DS Frequency of Occurrence

3200 If the array storing the distributions chosen by the user does not equal "C" for this iteration through the loop, program control switches to line 3380 where it will check distribution "D".

3210-360 Same as lines 2850-3000, only for % DS contained in the excess filtrate values.

### Washing Efficiency Frequency of Occurrence

3380 If the array storing the distributions chosen by the user does not equal "D" for this iteration through the loop, program control switches to line 3550 where it will check distribution "E".

3390-540 Same as lines 2850-3000, only for washing efficiency values.

3550-60 If the array storing the distributions chosen by the user equals "E" for this iteration through the loop, program control switches to subroutine 4, for displacement ratio output. After finishing subroutine 4, the program goes to line 3960 to continue the loop; in this way the print section is skipped since it was carried out in the subroutine.

3570-80 If the array storing the distributions chosen by the user equals "F" for this iteration through the loop, program control switches to subroutine 5, for wash liquor ratio output. After finishing subroutine 5, the program goes to line 3960 to continue the loop; in this way the print section is skipped since it was carried out in the subroutine.
Print Distributions

3600-30 Finds the increment (out of 20) which contains the most values for the particular variable whose distribution is printed at this time.

3640-740 Determines how many values will be represented by each symbol "X", depending on the number of values contained in the increment having the most values. These lines would have to be altered if different printout dimensions are desired.

3750-70 Decides the number (an integer) of symbols to print in each of the 20 increments to represent the frequency distribution of the 5000 values for a particular variable.

3780-870 Prints the heading for the distribution.

3880-930 Prints the X's to represent values for each of the 20 increments that make up the frequency distribution. Note: the semicolons appearing at the end of lines 3890 and 3910 cause the printer to stay on the same line. The first print statement encountered in line 3890 causes the printer to move to the next line before the next increment's values are printed.

3960 Ends the loop (loop begins line 2820).

3970 Returns program control to subroutine 2 (automatic output).

SUBROUTINE 4: DISPLACEMENT RATIO OUTPUT

4030-80 Loop initializes the variables which are used to sum all the values and sum the squares of the values of DR. The first of the 5000 values of DR is set equal to the variables storing the smallest and the largest values. This is carried out for each washing stage.

Calculate Average, Standard Deviation, and Overall Range

4100 Begins a loop which increments each washing
Begins a loop which, at a particular stage, increments the 5000 values of DR (loop ends line 4160).

Sums the values of DR, used to calculate the average value.

Sums the squares of the values of DR, used to calculate the standard deviation.

Finds the smallest of the 5000 values of DR.

Finds the largest of the 5000 values of DR.

Ends the loop which deals with the 5000 values of DR at a particular washing stage (loop begins line 4110).

Calculates the average value of DR at each stage.

Calculates the range of the values of DR at each stage.

Cuts the overall range of data for DR into 20 increments which will be used to print a frequency distribution, for each washing stage.

Calculates the standard deviation for DR at each stage.

Sets up the lower and upper limits for the first of the 20 increments used to print a frequency distribution for the DR of each stage.

Ends the loop which works with each washing stage (loop begins line 4100).

**Frequency of Occurrence**

Begins a loop which increments each washing stage (loop ends line 4350).

Loop sets up the lower and upper limits for the 2nd through 19th increments used to print a frequency distribution of DR for a particular washing stage.
Sets up the 20th increment used to print a frequency distribution for each DR.

Initializes the variable which will store the frequency of occurrence of values in each of 20 increments.

Ends the loop which works with each washing stage (loop begins line 4250).

Begins a loop which increments each washing stage (loop ends line 4620).

Begins a loop which increments each of the 5000 values of DR at a particular washing stage (loop ends line 4420).

Begins a loop which increments the first 19 intervals, at a particular value (out of 5000), at a particular stage of washing (loop ends line 4400).

Checks if 1 of 19 increments contains a particular value of DR, for a particular stage of washing. When a value falls within the upper and lower limits of an increment, it is counted to find the total number of values which are contained within each interval.

Ends the loop which works with the first 19 increments (loop begins line 4380).

Same as line 4390, except for the 20th increment.

Ends the loop which works with each value at a particular stage of washing (loop begins line 4370).

Print Output

Finds the increment (out of 20) which contains the most DR values, for a particular washing stage.

Determines how many values will be represented by each symbol "X" depending on the number of values contained in the increment having the
most values. These lines would have to be altered if different printout dimensions are desired.

4590-610 Decides the number (an integer) of symbols to print in each of the 20 increments to represent the frequency distribution for the generated values of DR.

4620 Ends the loop which deals with each washing stage (loop begins line 4360).

4630-50 Prints heading.

4660 Begins a loop which increments each stage (loop ends line 4810).

4670-710 Prints headings and average, standard deviation, and range of data.

4720 Begins a loop to print each increment, at a particular stage (loop ends line 4790).

4730-80 These lines are used to print a single line (1 increment) of the DR distribution. Note lines 4730, 4740, 4750, and 4770 end in semicolons; this punctuation causes the printer to remain on the same line when printing. The first print statement used on line 4730 causes the printer to move to the next line of printing. Note also that these lines essentially do the same thing that is carried out in lines 3890-3920. The difference is that outliers can occur for DR that are as low as 0.0NNNNNN, where N is any single digit; this causes the computer to print the above number in scientific notation which takes more space and causes the output to shift over. The PRINT USING statement is used to force the output to be in the form written above.

4790 Ends the loop which deals with each interval (loop begins line 4720).

4810 Ends the loop which deals with each washing stage (loop begins line 4660).

4830 Returns program control to line 3560 in subroutine 3, where it will continue in the loop to print the desired distributions.
SUBROUTINE 5: WASH LIQUOR RATIO OUTPUT

4890-940 Same as lines 4030-4080 in subroutine 4, except used for the WLR.

Calculate Average, Standard Deviation, and Overall Range

4960-5090 Same as lines 4100-4230 in subroutine 4, except used for the WLR.

Frequency of Occurrence

5110-280 Same as lines 4250-4420 in subroutine 4, except used for the WLR.

Print Output

5300-510 Same as lines 4440-4650 in subroutine 4, except used for the WLR.

5520-60 Prints the heading for the distribution.

5570-620 Same as lines 3880-3930 in subroutine 3.

5660 Returns program control to line 3580 in subroutine 3, where it will continue in the loop to print the desired distributions.

SUBROUTINE 6: CREATE ORIGINAL DATA FILE

Input Independent Variables

5740 The user inputs the name of the data file which will store measured data for a specific washing system. The file name can be 9 characters long (or less) and can have an optional extension that is 3 characters long (or less). The name is separated from the extension with a period and no spaces.

5750 The user inputs the number of washing stages in
their washing system.

5760-860 The user is asked to enter the mean and standard deviation of the measured values for each of the independent variables. These variables include: the dissolved solids (%) contained in the final stage shower (ppm) and contained in the liquor fraction of the pulp entering the washing system from the blow tank, prior to any dilution; and the fiber consistency (%) of the vat for each stage and the pulp entering the washing system from the blow tank, prior to any dilution.

5870-90 The user is asked if any mistakes were made in entering the means and standard deviations of the dependent variables. If the user responds with a "Y" or a "y", the program simply repeats lines 5760-5860.

5930 The user is asked the number of sampling times that were made to measure the data for the washing system. This value is used in conjunction with the dependent variables in which individual data must be entered. Note it is a requirement of this program that the number of sampling times used is the same for each dependent variable.

Input Dependent Variables

5950-6030 Initialization of the variables that will store the individual data for each of the dependent variables.

6050-90 The user is asked to input the values of DF; each value is entered after its corresponding sampling time is printed as a prompt to the user.

6100-20 The user is asked if any mistakes were made in entering the DF data. If the user responds with a "Y" or a "y", the program simply repeats lines 6050-6090.

6140-210 The user is asked to input each washing stage's values of DR; each value is entered after its corresponding stage number and sampling time is printed as a prompt to the user.
The user is asked if any mistakes were made in entering the DR data. If the user responds with a "y" or a "Y", the program simply repeats lines 6140-6210.

The user is asked to input each washing stage's values for mat consistency (%) ; each value is entered after its corresponding stage number and sampling time is printed as a prompt to the user.

The user is asked if any mistakes were made in entering the mat consistency data. If the user responds with a "y" or a "Y", the program simply repeats lines 6260-6330.

Calculate Mean & Standard Deviation of Dependent Variables

Initializes the variables used to sum the measured values and the squares of the measured values for the dependent variables to zero.

Loop used to sum the individual measured values of DF so that the average can be calculated, and to sum the squares of the individual values so that the standard deviation can be calculated.

Calculates the average and standard deviation of the measured values of DF.

Begins a loop which increments each stage (loop ends line 6610).

Loop used to sum the individual measured values of mat consistency and DR so that their averages can be calculated, and to sum the squares of the individual values so that their standard deviations can be calculated, for a particular stage.

Calculates the average and standard deviation of the measured values of mat consistency, for a particular stage.

Calculates the average and standard deviation of the measured values of DR, for a particular stage.

Ends the loop which deals with each stage (loop
begins line 6500).

Switches program control to subroutine 7 (regression).

**Output to Data File**

Opens a terminal format file for output (meaning the computer creates the file space) using channel #1%, with an access to write information to the newly created file, using this channel.

Prints to the file the number of sampling times used, and the number of washing stages in the system. Note: the comma between variables must be placed in quotation marks so that the computer will write the comma to the file. In this way the computer will see the entry as two separate variables when the file is inputed. In contrast, if the comma was separating the variables without quotation marks, it would not be printed in the file and the computer would see the two entries as one when read from the file. When printing to a file, the same channel number (in this case #1%) that was used to open the file, must be used to print to it.

Prints to the file the blow tank dissolved solids, average and standard deviation.

Prints to the file the blow tank fiber consistency, average and standard deviation.

Prints to the file the final shower dissolved solids, average and standard deviation.

Prints to the file the vat fiber consistency, average and standard deviation, for each washing stage.

Prints to the file the mat fiber consistency, average and standard deviation, for each washing stage.

Prints to the file the DR, average and standard deviation, for each washing stage.

Prints to the file the DF, average and standard
deviation.

6790-830 Prints to the file the individual data for mat consistency and DR, for each sampling time and each stage of washing. The format in the file, will be all of the individual data for the first stage (in a line with mat, DR) followed by all the individual data for the second stage, etc.

6840-60 Prints to the file the individual data for the DF, for each sampling time.

6870-90 Prints to the file the slope of the regression line, the standard error of y given x about the regression line, and the sum of squares of x, for each washing stage (where y=ln(1-DR) and x=WLR).

6900 Closes the file opened through channel #1%.

6910 Returns program control to line 360 of the program.

SUBROUTINE 7: LINEAR REGRESSION THROUGH THE ORIGIN

6970 Begins a loop that increments the number of stages (loop ends line 7040).

6980-7000 Loop used to calculate the WLR from the individual values of mat fiber consistency and DF, at each sampling time, for each washing stage. Note: the individual values can include the actual measured values or the altered data produced in the variable changes subroutines; they are not, however, the values which are randomly generated from probability distributions.

7010-30 Initializes variables that will be used to find a sum.

7040 Ends the loop that increments the number of stages (loop begins line 6970).

7050 Begins a loop that increments the number of stages (loop ends line 7130).

7060 Begins a loop that increments the sampling times (loop ends line 7100).
Calculates the sum of the squares of the values of WLR (1 at each sampling time) for each stage.

Calculates the sum of the squares of the values of y (1 at each sampling time) for each stage. Note y=ln(1-DR).

Calculates the sum of the products of the individual values (1 at each sampling time) of WLR and y, for each stage. Note y=ln(1-DR).

Ends the loop that increments the sampling times (loop begins line 7060).

Calculates the slope of the least squares linear regression which has been forced through the origin, of the values of ln(1-DR) with respect to WLR, for each washing stage.

Calculates the standard error of ln(1-DR) given WLR for the regression line which has been forced through the origin, for each washing stage.

Ends the loop that increments the number of stages (loop begins line 7050).

Returns program control back to the line following the statement which sent control here.

SUBROUTINE 8: VARIABLE CHANGES

Input Data File

Opens the terminal format file, storing washing data previously entered using subroutine 6, for input to the computer through channel #1%, with an access to read the file contents through this channel.

Reads in the values stored in the data file through channel #1%. Note the input statements have the same format as the print statements in lines 6650-6890, with the exception of the commas (see the note listed after line 6650 about commas).
Closes the file opened through channel #1%.

Print Data File

The user is asked if they want to view the data contained in the file or not. If the answer is "N" or "n" the computer skips over the section which prints the data, to line 7720, where options are given to change variables.

A table is printed containing the means and standard deviations of the input variables: fiber consistency of the vat(s), mat(s), and blow tank; dissolved solids content of the blow tank and shower; and the DF and DR(s).

Options To Change Data

A table is printed giving a letter associated with each of the above variables.

The user is first asked how many of the variables are to be altered.

If the user enters something other than an integer, or an integer greater than the number of variables (8) the computer goes back to line 7840. If the user enters 0, the computer moves to the mass balance section in the main body of the program. If the user enters all 8, then the array storing the letters associated with the variables desired is filled with each variable, so the user won't need to enter each letter.

The user enters the letter associated with the variable(s) that are desired.

Variables (used to sum the number of changes desired in each category of variables), are initialized to zero.

This loop counts the number of changes that will be made for dependent variables and independent variables. It also sets up flags (variables which are either 0 or 1), to show if a change in the number of stages, in the DF, or in the DR, will be made or not.
If a change in the number of stages is to be made, program control switches to subroutine 10, line 9530.

If change(s) are desired in any of the dependent variables, program control switches to subroutine 9, line 8480.

If change(s) are desired in any of the independent variables, program control switches to subroutine 11, line 9820.

Check For Impossible Changes

Variables which will store the number of impossible values created for mat consistency and DR, are initialized to zero. Note: the variables IMPOSSIBLE.MAT and IMPOSSIBLE.DR were also initialized to zero in line 330. It is necessary that these variables are initialized in both locations of the program. If either is greater than zero when entering subroutine 9 for dependent variable changes, the program will assume it is in the subroutine to make changes again, since the first time impossible values were made.

This loop sums the number of impossible values of mat consistency and DR that were created when the means and/or standard deviations were changed in subroutine 9. It also sums the number of incorrect values occurring in each stage and whether these values were too high or too low.

Calculates the percent impossible values which were created for both mat consistency and DR.

If the % impossible values of mat consistency equals 0, and the % impossible values of DR equals 0, program control switches to line 8410.

If the % impossible values of DR equals 0, program control switches to line 8330. Note: if the computer gets to this line it means that one or both the mat or DR has impossible values.

If there are impossible values created for DR,
the percent created, in which stage these values are occurring, and whether they are too low or too high is printed for the users information.

8330 If the % impossible values of mat consistency equals 0, program control switches to line 8390. Note: if the computer gets to this line it means that one or both the mat or DR has impossible values.

8340-80 If there are impossible values created for mat consistency, the percent created, in which stage these values are occurring, and whether they are too low or too high is printed for the users information.

8390-400 Since impossible values for mat consistency and/or DR have occurred when trying to change their means and/or standard deviations, the user is given another opportunity to change these values and computer control is switched back to subroutine 9.

8410 Program control is sent to subroutine 7 for a recalculation of the linear regression output if there has been changes made in the dependent variables or the number of stages has been increased.

8420 Returns program control to the mass balance portion of the main program body, after all changes have been completed.

SUBROUTINE 9: DEPENDENT VARIABLE CHANGES

8480 If the variable IMPOSSIBLE.MAT is greater than zero, then there were impossible values created the first time changes were made, and corrections are being attempted on this time through the subroutine. The number of stages is equal to the counting variable X% and program control switches to line 8550 where mat changes begin.

8490 If the variable IMPOSSIBLE.DR is greater than zero, then there were impossible values created the first time changes were made and corrections are being attempted on this time through the subroutine. The number of stages is equal to
the counting variable X% and program control switches to line 9180 where DR changes begin.

8500 If the number of dependent changes is equal to 2, and both DF and DR are to be changed, program control passes over the mat changes and moves to DF changes at line 8890.

8510 If the number of dependent changes is equal to 1, and the DF is to be changed, program control passes over the mat changes and moves to DF changes at line 8890.

8520 If the number of dependent changes is equal to 1, and the DR is to be changed, program control passes over the mat and DF changes and moves to DR changes at line 9170.

Mat Consistency

8540 If any stage changes were desired by the user, these changes were made (in subroutine 10) prior to the dependent changes. At the end of subroutine 10, STAGE.CH was made to equal 0 if a decrease in stages had occurred, and equal to 1 if an increase in stages was made. If no changes in stage number were desired STAGE.CH=0. The counter variable X%=STAGE%-1 when an increase in stages has been made, and X%=STAGE% when no increase has been made, since any change in a dependent variable would not include a new stage.

8550 Begins the loop which increments the number of stages that need to have changes made to mat consistency (loop ends line 8830).

8570-640 Asks the user to enter the type of change (mean and/or standard deviation or no change) desired in mat consistency for a particular stage of washing.

8650-70 If the user enters an incorrect answer (anything other than an integer or an integer above 4 or below 1), program control switches back to 8640 to reenter a choice. If no change is desired, program control switches to line 8830 where the loop is continued for the next stage. If the user wishes to change the standard deviation...
only, program control switches to line 8760 to make this change.

8690-740 The new mean is entered and the old and new mean are used to move the measured data points so that they reflect the new mean but still possess the same standard deviation.

8750 If the user does not wish to change the standard deviation for the mat consistency of the current stage, program control switches to line 8830 where the loop is continued for the next stage.

8770-820 The new standard deviation is entered and the old and new standard deviation and the current mean are used to move the measured data points so that they reflect the new standard deviation but still possess the current mean.

8830 Ends the loop which increments the number of stages which need to have mat consistency changes made (loop begins line 8550).

8840 If the variable IMPOSSIBLE.DR is greater than zero, then there were impossible values created the first time changes were made, and corrections are being attempted on this time through the subroutine. If both IMPOSSIBLE.DR and IMPOSSIBLE.MAT are greater than zero, the number of stages was already assigned to the counting variable X% in line 8480. If only IMPOSSIBLE.DR is greater than zero, then X% was assigned in line 8490 and the operation was switched to line 9180 to begin DR changes. Therefore if this line (8840) is true, then both variables are greater than zero, so X% has already been assigned, and program operation needs only to be switched to line 9180 for DR changes.

8850 If IMPOSSIBLE.MAT is greater than zero, but IMPOSSIBLE.DR is not, then computer operation is returned to line 8400 where it then goes to line 8100 to check for more impossible values.

8860 If the number of dependent changes equals 2, and the DF is not to be changed, program control passes over the DF changes and moves to DR changes at line 9170.

8870 If the number of dependent changes equals 1, and
the DF and DR are not to be changed (only mat changes are made), then program control switches to line 9470 where it is returned to line 8080 in subroutine 8.

**Dilution Factor**

8890-960 Asks the user to enter the type of change (mean and/or standard deviation) desired in the dilution factor.

8970-80 If the user enters an incorrect answer (anything other than an integer or an integer above 3 or under 1), program control switches back to line 8960 to reenter a choice. If the user wishes to change the standard deviation only, program control switches to line 9070 to make this change.

8990-9050 Same as lines 8690-8740.

9060 If the user does not wish to change the standard deviation for the DF, program control switches to line 9140.

9070-130 Same as lines 8770-8820.

9140 If the number of dependent changes is equal to 2, and no change is to be made to DR (the mat and DF were changed), program control passes over the DR changes to line 9470 where it is returned to subroutine 8.

9150 If the number of dependent changes is equal to 1 and a DF change was made, program control passes over the DR changes to line 9470 where it is returned to subroutine 8.

**Displacement Ratio**

9170 Same as line 8540.

9180 Begins a loop which increments the number of stages that need to have changes made to DR (loop ends line 9460).

9190-270 Asks the user to enter the type of change (mean
and/or standard deviation or no change) desired in DR for a particular stage of washing.

9280-300 If the user enters an incorrect answer (anything other than an integer or an integer above 4 or under 1), program control switches back to 9270 to reenter a choice. If no change is desired, program control switches to line 9460 where the loop is continued for the next stage. If the user wishes to change the standard deviation only, program control switches to line 9390 to make this change.

9310-370 Same as lines 8690-8740.

9380 If the user does not wish to change the standard deviation for the DR of the current stage, program control switches to 9460 line where the loop is continued for the next stage.

9390-450 Same as lines 8770-8820.

9460 Ends the loop which increments the number of stages which need to have DR changes made (loop begins line 9180).

9470 Returns program control to line 8080 in subroutine 8.

SUBROUTINE 10: STAGE CHANGES

9530-90 Asks the user to enter the type of change (add or delete a washing stage at the end of a system) desired.

9600 If the user chose to remove a washing stage, the variable STAGE% is reduced by one, the variable STAGE.CH is changed from 1 to 0 (so that 1 will indicate a stage increase has been made), and program control switches to line 9760 where it is returned to subroutine 8.

9610 The variable STAGE% is increased by one.

9620-80 The user is asked to input a mean and standard deviation for the DR, and the vat and mat fiber consistencies, for the new final washing stage.

9690-750 The data points for the mat consistency and DR
of the previous final washing stage, are used in conjunction with the means and standard deviations entered for the stage addition, to move the measured data points in such a way that they reflect the entered means and standard deviations. It is necessary to have individual values for mat and DR, so that a linear regression may be performed to find the factor k relating WLR with DR for the new stage.

9760 Returns program control to line 8070 in subroutine 8.

SUBROUTINE 11: INDEPENDENT VARIABLES CHANGES

9820 Begins a loop which increments the number of variable changes desired by the user (loop ends line 10560).

9830 If the array containing the variable changes desired does not equal "B" for this iteration through the loop, program control switches to line 10000.

Blow Tank Dissolved Solids

9850-920 Asks the user to enter the type of change (mean and/or standard deviation) desired in the blow tank dissolved solids (%).

9930-40 If the user enters an incorrect answer (anything other than an integer or an integer above 3 or below 1), program control goes back to line 9920 to reenter a choice. If the user wishes to change the standard deviation only, program control switches to line 9980 to make this change.

9960 Asks the user for the new mean.

9970 If the user does not wish to change the standard deviation, program control moves to line 10000.

9990 Asks the user for the new standard deviation.

10000 If the array containing the variable changes desired does not equal "C" for this iteration

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through the loop, program control switches to line 10170.

**Blow Tank Consistency**

10020-90 Asks the user to enter the type of change (mean and/or standard deviation) desired in the blow tank fiber consistency (%).

10100-10 If the user enters an incorrect answer, program control switches back to 10090 to reenter a choice. If the user wishes to change the standard deviation only, program control switches to line 10150 to make this change.

10130 Asks the user for the new mean.

10140 If the user does not wish to change the standard deviation, program control moves to line 10170.

10160 Asks the user for the new standard deviation.

10170 If the array containing the variable changes desired does not equal "D" for this iteration through the loop, program control moves to line 10340.

**Shower Dissolved Solids**

10190-260 Asks the user to enter the type of change (mean and/or standard deviation) desired in the final shower dissolved solids concentration (ppm).

10270-80 If the user enters an incorrect answer, program control switches back to line 10260 to reenter a choice. If the user wishes to change the standard deviation only, program control switches to line 10320 to make this change.

10300 Asks the user for the new mean.

10310 If the user does not wish to change the standard deviation, program control moves to line 10340.

10330 Asks the user for the new standard deviation.

10340 If the array containing the desired variable
changes does not equal "E" for this iteration through the loop, program control is moved to line 10560.

Vat Consistency

10360 Same as line 8540 in subroutine 9.

10370 Begins the loop which increments the number of stages that need to have vat consistency changes (loop ends line 10550).

10380-460 Asks the user to enter the type of change (mean and/or standard deviation or no change) desired in vat fiber consistency (%), for a particular stage of washing.

10470-90 If the user enters an incorrect answer, program control switches back to 10460 to reenter a choice. If no change is desired, program control switches to line 10550 where the loop is continued for the next stage. If the user wishes to change the standard deviation only, program control switches to line 10530.

10510 Asks the user for the new mean.

10520 If the user does not wish to change the standard deviation program control is moved to line 10550 to continue the loop for the next stage.

10540 Asks the user for the new standard deviation.

10550 Ends the loop which increments each washing stage (loop begins line 10370).

10560 Ends the loop which increments the number of variable changes desired by the user (loop begins line 9820).

10570 Returns program control to line 8100 in subroutine 8.

END OF PROGRAM

10630 Stops program execution.
APPENDIX D

EXAMPLE OUTPUT OF PULPWASH.BAS
* BASIC
VAX BASIC V3.1
Ready
OLD
Old file name--PULPWASH
Ready
SET /DOUBLE
Ready
RUN
PULPWASH 13-JUL-1987 15:34

PROGRAM MENU
1 CREATE ORIGINAL DATA FILE
2 RUN SIMULATION WITH OPTION TO ALTER DATA FOR CURRENT RUN
3 EXIT

Note: To run this program you must set the computer to double precision.
If you have not done so, please exit the program and type the following:
SET /DOUBLE
RUN

WHAT IS YOUR CHOICE? 1

ENTER A NAME FOR YOUR DATA FILE (UP TO 9 CHARACTERS PLUS AN OPTIONAL 3 LETTER EXTENSION)? SDWARREN.DAT
HOW MANY WASHING STAGES ARE THERE (MAXIMUM 5)? 3

ENTER THE FOLLOWING MEANS AND STANDARD DEVIATIONS:
THE DISSOLVED SOLIDS (%) FROM THE BLOW TANK, MEAN = 12.183
THE DISSOLVED SOLIDS FROM THE BLOW TANK, STD. DEV. = 1.97
THE FIBER CONSISTENCY (%) FROM THE BLOW TANK, MEAN = 7.49
THE FIBER CONSISTENCY FROM THE BLOW TANK, STD. DEV. = 0.43
THE FINAL STAGE SHOWER CONCENTRATION (PPM), MEAN = 268
THE FINAL STAGE SHOWER CONCENTRATION, STD. DEV. = 29
THE VAT FIBER CONSISTENCY (%) FOR STAGE 1, MEAN = 1.06
THE VAT FIBER CONSISTENCY FOR STAGE 1, STD. DEV. = 0.19
THE VAT FIBER CONSISTENCY (%) FOR STAGE 2, MEAN = 1.07
THE VAT FIBER CONSISTENCY FOR STAGE 2, STD. DEV. = 0.11
THE VAT FIBER CONSISTENCY (%) FOR STAGE 3, MEAN = 1.11
THE VAT FIBER CONSISTENCY FOR STAGE 3, STD. DEV. = 0.05
DO YOU NEED TO MAKE CORRECTIONS TO THE ABOVE MEANS AND STANDARD DEVIATIONS (Y OR N)? N

TO ESTABLISH A CORRELATION BETWEEN DILUTION FACTOR AND DISPLACEMENT RATIO
INDIVIDUAL DATA MUST BE ENTERED FOR THE FOLLOWING:

HOW MANY SAMPLING TIMES DID YOU MAKE? 6

ENTER THE VALUES FOR DILUTION FACTOR AT EACH SAMPLING TIME
TIME= 1 DF? 4.35
TIME= 2 DF? 3.44
TIME= 3 DF? 3.74
TIME= 4 DF? 4.11
TIME= 5 DF? 4.97
TIME= 6 DF? 5.07
DO YOU NEED TO MAKE CORRECTIONS TO THE ABOVE VALUES OF DILUTION FACTOR (Y OR N)? N

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ENTER THE VALUES FOR DISPLACEMENT RATIO, FOR EACH STAGE, AT EACH SAMPLING TIME

<table>
<thead>
<tr>
<th>STAGE</th>
<th>TIME</th>
<th>DR</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td></td>
<td>DR? 0.84</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td></td>
<td>DR? 0.892</td>
</tr>
<tr>
<td>1</td>
<td>3</td>
<td></td>
<td>DR? 0.891</td>
</tr>
<tr>
<td>1</td>
<td>4</td>
<td></td>
<td>DR? 0.876</td>
</tr>
<tr>
<td>1</td>
<td>5</td>
<td></td>
<td>DR? 0.957</td>
</tr>
<tr>
<td>1</td>
<td>6</td>
<td></td>
<td>DR? 0.918</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td></td>
<td>DR? 0.768</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td></td>
<td>DR? 0.747</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td></td>
<td>DR? 0.743</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td></td>
<td>DR? 0.665</td>
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<td>5</td>
<td></td>
<td>DR? 0.833</td>
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<tr>
<td>2</td>
<td>6</td>
<td></td>
<td>DR? 0.746</td>
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<tr>
<td>3</td>
<td>1</td>
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<td>DR? 0.754</td>
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<td>2</td>
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<td>DR? 0.715</td>
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<td>3</td>
<td>3</td>
<td></td>
<td>DR? 0.776</td>
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<td>4</td>
<td></td>
<td>DR? 0.752</td>
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<td>3</td>
<td>5</td>
<td></td>
<td>DR? 0.770</td>
</tr>
<tr>
<td>3</td>
<td>6</td>
<td></td>
<td>DR? 0.770</td>
</tr>
</tbody>
</table>

DO YOU NEED TO MAKE CORRECTIONS TO THE ABOVE VALUES OF DISPLACEMENT RATIO (Y OR N)? N

ENTER THE VALUES FOR MAT CONSISTENCY, FOR EACH STAGE, AT EACH SAMPLING TIME

<table>
<thead>
<tr>
<th>STAGE</th>
<th>TIME</th>
<th>MAT</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td></td>
<td>MAT? 13.43</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td></td>
<td>MAT? 13.75</td>
</tr>
<tr>
<td>1</td>
<td>3</td>
<td></td>
<td>MAT? 14.75</td>
</tr>
<tr>
<td>1</td>
<td>4</td>
<td></td>
<td>MAT? 13.98</td>
</tr>
<tr>
<td>1</td>
<td>5</td>
<td></td>
<td>MAT? 14.85</td>
</tr>
<tr>
<td>1</td>
<td>6</td>
<td></td>
<td>MAT? 15.75</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td></td>
<td>MAT? 12.71</td>
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<tr>
<td>2</td>
<td>2</td>
<td></td>
<td>MAT? 13.38</td>
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<td>2</td>
<td>3</td>
<td></td>
<td>MAT? 12.29</td>
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<td>4</td>
<td></td>
<td>MAT? 14.54</td>
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<td>5</td>
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<td>MAT? 12.70</td>
</tr>
<tr>
<td>2</td>
<td>6</td>
<td></td>
<td>MAT? 13.11</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td></td>
<td>MAT? 14.22</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td></td>
<td>MAT? 12.59</td>
</tr>
<tr>
<td>3</td>
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<td>MAT? 13.09</td>
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<td>4</td>
<td></td>
<td>MAT? 13.82</td>
</tr>
<tr>
<td>3</td>
<td>5</td>
<td></td>
<td>MAT? 13.97</td>
</tr>
<tr>
<td>3</td>
<td>6</td>
<td></td>
<td>MAT? 14.17</td>
</tr>
</tbody>
</table>

DO YOU NEED TO MAKE CORRECTIONS TO THE ABOVE VALUES OF MAT CONSISTENCY (Y OR N)? N
PROGRAM MENU
1  CREATE ORIGINAL DATA FILE
2  RUN SIMULATION WITH OPTION TO ALTER DATA FOR CURRENT RUN
3  EXIT

Note: To run this program you must set the computer to double precision. If you have not done so, please exit the program and type the following:
SET /DOUBLE
RUN

WHAT IS YOUR CHOICE? 2

ENTER THE NAME OF THE FILE THAT CONTAINS THE WASHING DATA YOU WISH TO SIMULATE? SWARREN.DAT

WOULD YOU LIKE TO VIEW THE DATA IN THIS FILE (Y OR N)? Y

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>STAGE</th>
<th>MEAN</th>
<th>STANDARD DEVIATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>BLOW TANK DISSOLVED SOLIDS (%)</td>
<td>***</td>
<td>12.185</td>
<td>1.97</td>
</tr>
<tr>
<td>BLOW TANK FIBER CONSISTENCY (%)</td>
<td>***</td>
<td>7.49</td>
<td>.43</td>
</tr>
<tr>
<td>SHOWER DISSOLVED SOLIDS (PPM)</td>
<td>3</td>
<td>268</td>
<td>29</td>
</tr>
<tr>
<td>VAT FIBER CONSISTENCY (%)</td>
<td>1</td>
<td>1.06</td>
<td>.10</td>
</tr>
<tr>
<td>VAT FIBER CONSISTENCY (%)</td>
<td>2</td>
<td>1.07</td>
<td>.11</td>
</tr>
<tr>
<td>VAT FIBER CONSISTENCY (%)</td>
<td>3</td>
<td>1.11</td>
<td>.08</td>
</tr>
<tr>
<td>MAT FIBER CONSISTENCY (%)</td>
<td>1</td>
<td>14.4183</td>
<td>.85852</td>
</tr>
<tr>
<td>MAT FIBER CONSISTENCY (%)</td>
<td>2</td>
<td>13.135</td>
<td>.78171</td>
</tr>
<tr>
<td>MAT FIBER CONSISTENCY (%)</td>
<td>3</td>
<td>13.4433</td>
<td>.657904</td>
</tr>
<tr>
<td>DILUTION FACTOR</td>
<td>***</td>
<td>4.27033</td>
<td>.853404</td>
</tr>
<tr>
<td>DISPLACEMENT RATIO</td>
<td>1</td>
<td>.895667</td>
<td>.394495E-01</td>
</tr>
<tr>
<td>DISPLACEMENT RATIO</td>
<td>2</td>
<td>.787333</td>
<td>.505277E-01</td>
</tr>
<tr>
<td>DISPLACEMENT RATIO</td>
<td>3</td>
<td>.7245</td>
<td>.227486E-01</td>
</tr>
</tbody>
</table>

YOU HAVE THE OPTION TO MAKE CHANGES TO ANY OF THE FOLLOWING VARIABLES
A  NUMBER OF WASHING STAGES
B  BLOW TANK BLACK LIQUOR DISSOLVED SOLIDS
C  BLOW TANK FIBER CONSISTENCY
D  FINAL STAGE SHOWER DISSOLVED SOLIDS
E  VAT FIBER CONSISTENCY(IES)
F  MAT FIBER CONSISTENCY(IES)
G  DILUTION FACTOR
H  DISPLACEMENT RATIO(S)

HOW MANY OF THE ABOVE 8 VARIABLES WOULD YOU LIKE TO ALTER FOR THIS RUN? 1

ENTER THE LETTER ASSOCIATED WITH THE VARIABLE YOU WANT TO CHANGE? D

WHAT CHANGE DO YOU WANT TO MAKE IN THE FINAL STAGE SHOWER CONCENTRATION (PPM)
1  MEAN
2  STANDARD DEVIATION
3  MEAN AND STANDARD DEVIATION

WHAT IS YOUR CHOICE? 1

NEW MEAN = ? 100
### Simulation Output

**Number of Iterations**: 5000

Factor relating displacement ratio to wash liquor ratio:

\[ \ln(1-DR) = (K)(ULR) \]

<table>
<thead>
<tr>
<th>Stage</th>
<th>( K )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-1.35718</td>
</tr>
<tr>
<td>2</td>
<td>-0.957137</td>
</tr>
<tr>
<td>3</td>
<td>-0.835316</td>
</tr>
</tbody>
</table>

**Pounds dissolved solids carried over in final mat per ton O.D. Pulp**

- **Average**: 9.73201
- **Standard Deviation**: 6.09074
- **Overall Range**: 59.6453

**Pounds excess filtrate per ton O.D. Pulp**

- **Average**: 33324.7
- **Standard Deviation**: 2044.17
- **Overall Range**: 15065.2

**Percent dissolved solids in excess filtrate**

- **Average**: 9.04156
- **Standard Deviation**: 1.52659
- **Overall Range**: 11.1599

**Percent overall efficiency for the washing system**

- **Average**: 99.6752
- **Standard Deviation**: 0.196239
- **Overall Range**: 1.92602

You have the option to view any of the following distributions:

- A. Carryover
- B. Filtrate to evaporators
- C. Dissolved solids in filtrate to evaporators
- D. Efficiency
- E. Each stage displacement ratio (average and std. dev. included)
- F. Each stage wash liquor ratio (average and std. dev. included)

How many of the above would you like to see? 4
### DISTRIBUTION OUTPUT

#### CARRYOVER DISTRIBUTION

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#### EXCESS FILTRATE DISTRIBUTION

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# DISSOLVED SOLIDS IN FILTRATE DISTRIBUTION

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# EFFICIENCY DISTRIBUTION

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**DISPLACEMENT RATIO OUTPUT**

**DISPLACEMENT RATIO FOR STAGE 1**

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**DISPLACEMENT RATIO FOR STAGE 2**

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_Average = .892988, Standard Deviation = .468076E-01, Overall Range = .418839_

_Average = .785497, Standard Deviation = .604717E-01, Overall Range = .450677_
### DISPLACEMENT RATIO FOR STAGE 3

AVERAGE: 0.750319  
STANDARD DEVIATION: 0.354619E-01  
OVERALL RANGE: 0.267586

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### WASH LIQUOR RATIO OUTPUT

### WASH LIQUOR RATIO FOR STAGE 1

AVERAGE: 1.71922  
STANDARD DEVIATION: 0.121226  
OVERALL RANGE: 0.861977

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WASH LIQUOR RATIO FOR STAGE 2

AVERAGE = 1.64497
STANDARD DEVIATION = .100415
OVERALL RANGE = .77867

RANGE FREQ ( EACH X = 15 )

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WASH LIQUOR RATIO FOR STAGE 3

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STANDARD DEVIATION = .100618
OVERALL RANGE = .70633

RANGE FREQ ( EACH X = 15 )

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<td>1.66967 - 1.70873</td>
<td>651</td>
</tr>
<tr>
<td>1.70873 - 1.74778</td>
<td>660</td>
</tr>
<tr>
<td>1.74778 - 1.78684</td>
<td>563</td>
</tr>
<tr>
<td>1.78684 - 1.82589</td>
<td>399</td>
</tr>
<tr>
<td>1.82589 - 1.86495</td>
<td>330</td>
</tr>
<tr>
<td>1.86495 - 1.90399</td>
<td>219</td>
</tr>
<tr>
<td>1.90399 - 1.94305</td>
<td>149</td>
</tr>
<tr>
<td>1.94305 - 1.98209</td>
<td>313</td>
</tr>
<tr>
<td>1.98209 - 2.02113</td>
<td>72</td>
</tr>
<tr>
<td>2.02113 - 2.06017</td>
<td>22</td>
</tr>
</tbody>
</table>

PROGRAM MENU

1 CREATE ORIGINAL DATA FILE
2 RUN SIMULATION WITH OPTION TO ALTER DATA FOR CURRENT RUN
3 EXIT

Note: To run this program you must set the computer to double precision. If you have not done so, please exit the program and type the following:
SET /DOUBLE

WHAT IS YOUR CHOICE? 3

END OF EXECUTION

Read
APPENDIX E

DATA SUMMARY FOR
S.D. WARREN, MILL A, AND MILL B
### S.D. Warren Data Summary

<table>
<thead>
<tr>
<th>variable</th>
<th>mean</th>
<th>standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>blow tank DS (%)</td>
<td>12.185</td>
<td>1.97</td>
</tr>
<tr>
<td>blow tank cons (%)</td>
<td>7.49</td>
<td>0.43</td>
</tr>
<tr>
<td>shower DS (ppm)</td>
<td>268</td>
<td>29</td>
</tr>
<tr>
<td>vat 1 cons (%)</td>
<td>1.06</td>
<td>0.18</td>
</tr>
<tr>
<td>vat 2 cons (%)</td>
<td>1.07</td>
<td>0.11</td>
</tr>
<tr>
<td>vat 3 cons (%)</td>
<td>1.11</td>
<td>0.05</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>time</th>
<th>DR 1</th>
<th>DR 2</th>
<th>DR 3</th>
<th>mat 1</th>
<th>mat 2</th>
<th>mat 3</th>
<th>DF</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.840</td>
<td>0.768</td>
<td>0.754</td>
<td>13.43</td>
<td>12.71</td>
<td>14.22</td>
<td>4.35</td>
</tr>
<tr>
<td>2</td>
<td>0.892</td>
<td>0.767</td>
<td>0.715</td>
<td>13.75</td>
<td>13.38</td>
<td>12.59</td>
<td>3.44</td>
</tr>
<tr>
<td>3</td>
<td>0.891</td>
<td>0.743</td>
<td>0.776</td>
<td>14.75</td>
<td>12.29</td>
<td>13.09</td>
<td>3.74</td>
</tr>
<tr>
<td>4</td>
<td>0.876</td>
<td>0.865</td>
<td>0.752</td>
<td>13.98</td>
<td>14.54</td>
<td>13.82</td>
<td>4.10</td>
</tr>
<tr>
<td>5</td>
<td>0.957</td>
<td>0.835</td>
<td>0.752</td>
<td>14.85</td>
<td>12.78</td>
<td>13.97</td>
<td>4.97</td>
</tr>
<tr>
<td>6</td>
<td>0.918</td>
<td>0.746</td>
<td>0.778</td>
<td>15.75</td>
<td>13.11</td>
<td>14.17</td>
<td>5.07</td>
</tr>
</tbody>
</table>

### Mill A Data Summary

<table>
<thead>
<tr>
<th>variable</th>
<th>mean</th>
<th>standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>blow tank DS (%)</td>
<td>16.2</td>
<td>1.6</td>
</tr>
<tr>
<td>blow tank cons (%)</td>
<td>11.1</td>
<td>1.1</td>
</tr>
<tr>
<td>shower DS (ppm)</td>
<td>343</td>
<td>68</td>
</tr>
<tr>
<td>vat 1 cons (%)</td>
<td>2.1</td>
<td>0.7</td>
</tr>
<tr>
<td>vat 2 cons (%)</td>
<td>1.8</td>
<td>0.6</td>
</tr>
<tr>
<td>vat 3 cons (%)</td>
<td>1.6</td>
<td>0.3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>time</th>
<th>DR 1</th>
<th>DR 2</th>
<th>DR 3</th>
<th>mat 1</th>
<th>mat 2</th>
<th>mat 3</th>
<th>DF</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.83</td>
<td>0.79</td>
<td>0.71</td>
<td>12.5</td>
<td>15.5</td>
<td>15.8</td>
<td>0.29</td>
</tr>
<tr>
<td>2</td>
<td>0.88</td>
<td>0.94</td>
<td>0.87</td>
<td>13.2</td>
<td>15.2</td>
<td>14.2</td>
<td>0.92</td>
</tr>
<tr>
<td>3</td>
<td>0.97</td>
<td>0.64</td>
<td>0.86</td>
<td>13.3</td>
<td>12.8</td>
<td>14.7</td>
<td>1.06</td>
</tr>
<tr>
<td>4</td>
<td>0.93</td>
<td>0.92</td>
<td>0.86</td>
<td>14.4</td>
<td>16.3</td>
<td>16.4</td>
<td>1.29</td>
</tr>
<tr>
<td>5</td>
<td>0.78</td>
<td>0.95</td>
<td>0.93</td>
<td>13.5</td>
<td>16.4</td>
<td>16.7</td>
<td>1.68</td>
</tr>
<tr>
<td>6</td>
<td>0.96</td>
<td>0.91</td>
<td>0.85</td>
<td>12.3</td>
<td>15.6</td>
<td>14.7</td>
<td>0.49</td>
</tr>
<tr>
<td>7</td>
<td>0.94</td>
<td>0.91</td>
<td>0.89</td>
<td>13.2</td>
<td>16.2</td>
<td>14.5</td>
<td>0.77</td>
</tr>
</tbody>
</table>
**Mill B Data Summary**

<table>
<thead>
<tr>
<th>variable</th>
<th>mean</th>
<th>standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>blow tank DS (%)</td>
<td>18.6</td>
<td>1.9</td>
</tr>
<tr>
<td>blow tank cons (%)</td>
<td>14.2</td>
<td>1.4</td>
</tr>
<tr>
<td>shower DS (ppm)</td>
<td>156</td>
<td>26</td>
</tr>
<tr>
<td>vat 1 cons (%)</td>
<td>1.36</td>
<td>0.31</td>
</tr>
<tr>
<td>vat 2 cons (%)</td>
<td>2.07</td>
<td>0.65</td>
</tr>
<tr>
<td>vat 3 cons (%)</td>
<td>1.67</td>
<td>0.44</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>time</th>
<th>DR 1</th>
<th>DR 2</th>
<th>DR 3</th>
<th>mat 1</th>
<th>mat 2</th>
<th>mat 3</th>
<th>DF</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.82</td>
<td>0.68</td>
<td>0.86</td>
<td>16.64</td>
<td>16.24</td>
<td>18.37</td>
<td>1.81</td>
</tr>
<tr>
<td>2</td>
<td>0.82</td>
<td>0.67</td>
<td>0.62</td>
<td>15.99</td>
<td>16.62</td>
<td>17.75</td>
<td>1.61</td>
</tr>
<tr>
<td>3</td>
<td>0.90</td>
<td>0.74</td>
<td>0.72</td>
<td>17.00</td>
<td>19.96</td>
<td>18.39</td>
<td>0.47</td>
</tr>
<tr>
<td>4</td>
<td>0.63</td>
<td>0.63</td>
<td>0.63</td>
<td>14.79</td>
<td>17.23</td>
<td>16.58</td>
<td>1.05</td>
</tr>
<tr>
<td>5</td>
<td>0.88</td>
<td>0.68</td>
<td>0.57</td>
<td>16.06</td>
<td>15.57</td>
<td>17.02</td>
<td>1.22</td>
</tr>
</tbody>
</table>

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APPENDIX F

COMPARISON OF GENERATED AND MEASURED MEANS AND STANDARD DEVIATIONS FOR MILL A AND MILL B DATA
### VARIANCE RATIO TEST FOR MILL A DATA

<table>
<thead>
<tr>
<th>variable</th>
<th>standard deviation</th>
<th>F statistic</th>
<th>critical F</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>measured</td>
<td>generated</td>
<td></td>
</tr>
<tr>
<td>blow tank DS</td>
<td>1.600000</td>
<td>1.595450</td>
<td>1.01</td>
</tr>
<tr>
<td>blow tank cons.</td>
<td>1.100000</td>
<td>1.090240</td>
<td>1.02</td>
</tr>
<tr>
<td>shower cons.</td>
<td>68.000000</td>
<td>68.20330</td>
<td>1.01</td>
</tr>
<tr>
<td>vat 1 cons.</td>
<td>0.700000</td>
<td>0.725330</td>
<td>1.07</td>
</tr>
<tr>
<td>vat 2 cons.</td>
<td>0.600000</td>
<td>0.599909</td>
<td>1.00</td>
</tr>
<tr>
<td>vat 3 cons.</td>
<td>0.300000</td>
<td>0.300822</td>
<td>1.01</td>
</tr>
<tr>
<td>mat 1 cons.</td>
<td>0.687992</td>
<td>0.697596</td>
<td>1.03</td>
</tr>
<tr>
<td>mat 2 cons.</td>
<td>1.244610</td>
<td>1.217030</td>
<td>1.05</td>
</tr>
<tr>
<td>mat 3 cons.</td>
<td>0.999047</td>
<td>0.974257</td>
<td>1.05</td>
</tr>
<tr>
<td>DF</td>
<td>0.472209</td>
<td>0.480158</td>
<td>1.03</td>
</tr>
<tr>
<td>DR 1</td>
<td>0.071514</td>
<td>0.105244</td>
<td>2.17</td>
</tr>
<tr>
<td>DR 2</td>
<td>0.112673</td>
<td>0.091083</td>
<td>1.53</td>
</tr>
<tr>
<td>DR 3</td>
<td>0.068487</td>
<td>0.052129</td>
<td>1.73</td>
</tr>
</tbody>
</table>

### VARIANCE RATIO TEST FOR MILL B DATA

<table>
<thead>
<tr>
<th>variable</th>
<th>standard deviation</th>
<th>F statistic</th>
<th>critical F</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>measured</td>
<td>generated</td>
<td></td>
</tr>
<tr>
<td>blow tank DS</td>
<td>1.900000</td>
<td>1.942390</td>
<td>1.04</td>
</tr>
<tr>
<td>blow tank cons.</td>
<td>1.400000</td>
<td>1.401640</td>
<td>1.00</td>
</tr>
<tr>
<td>shower cons.</td>
<td>26.000000</td>
<td>26.29890</td>
<td>1.02</td>
</tr>
<tr>
<td>vat 1 cons.</td>
<td>0.310000</td>
<td>0.308052</td>
<td>1.01</td>
</tr>
<tr>
<td>vat 2 cons.</td>
<td>0.650000</td>
<td>0.657546</td>
<td>1.02</td>
</tr>
<tr>
<td>vat 3 cons.</td>
<td>0.440000</td>
<td>0.427046</td>
<td>1.06</td>
</tr>
<tr>
<td>mat 1 cons.</td>
<td>0.841326</td>
<td>0.839360</td>
<td>1.01</td>
</tr>
<tr>
<td>mat 2 cons.</td>
<td>1.695920</td>
<td>1.722240</td>
<td>1.03</td>
</tr>
<tr>
<td>mat 3 cons.</td>
<td>0.808375</td>
<td>0.812426</td>
<td>1.01</td>
</tr>
<tr>
<td>DF</td>
<td>0.522226</td>
<td>0.510039</td>
<td>1.05</td>
</tr>
<tr>
<td>DR 1</td>
<td>0.106771</td>
<td>0.136447</td>
<td>1.63</td>
</tr>
<tr>
<td>DR 2</td>
<td>0.039370</td>
<td>0.078608</td>
<td>3.99</td>
</tr>
<tr>
<td>DR 3</td>
<td>0.114237</td>
<td>0.159299</td>
<td>1.94</td>
</tr>
</tbody>
</table>
### TWO-SAMPLE T TEST FOR MILL A DATA
(at $\alpha=0.05$, $t_c=1.960$)

<table>
<thead>
<tr>
<th>variable</th>
<th>mean value measured</th>
<th>mean value generated</th>
<th>two-sample t statistic</th>
</tr>
</thead>
<tbody>
<tr>
<td>blow tank DS</td>
<td>16.62000</td>
<td>16.16640</td>
<td>0.945112</td>
</tr>
<tr>
<td>blow tank cons.</td>
<td>11.10000</td>
<td>11.07280</td>
<td>0.068659</td>
</tr>
<tr>
<td>shower cons.</td>
<td>343.0000</td>
<td>345.4640</td>
<td>-0.665110</td>
</tr>
<tr>
<td>vat 1 cons.</td>
<td>2.100000</td>
<td>2.107910</td>
<td>-0.024510</td>
</tr>
<tr>
<td>vat 2 cons.</td>
<td>1.800000</td>
<td>1.816480</td>
<td>-0.056160</td>
</tr>
<tr>
<td>vat 3 cons.</td>
<td>1.600000</td>
<td>1.587410</td>
<td>0.060647</td>
</tr>
<tr>
<td>mat 1 cons.</td>
<td>13.20000</td>
<td>13.18130</td>
<td>0.059086</td>
</tr>
<tr>
<td>mat 2 cons.</td>
<td>15.42860</td>
<td>15.43250</td>
<td>-0.009310</td>
</tr>
<tr>
<td>mat 3 cons.</td>
<td>15.28570</td>
<td>15.24840</td>
<td>0.099626</td>
</tr>
<tr>
<td>DF</td>
<td>0.928571</td>
<td>0.932472</td>
<td>-0.014860</td>
</tr>
<tr>
<td>DR 1</td>
<td>0.898571</td>
<td>0.886993</td>
<td>0.094363</td>
</tr>
<tr>
<td>DR 2</td>
<td>0.865714</td>
<td>0.870718</td>
<td>-0.043820</td>
</tr>
<tr>
<td>DR 3</td>
<td>0.852857</td>
<td>0.856649</td>
<td>-0.043900</td>
</tr>
</tbody>
</table>

### TWO-SAMPLE T TEST FOR MILL B DATA
(at $\alpha=0.05$, $t_c=1.960$)

<table>
<thead>
<tr>
<th>variable</th>
<th>mean value measured</th>
<th>mean value generated</th>
<th>two-sample t statistic</th>
</tr>
</thead>
<tbody>
<tr>
<td>blow tank DS</td>
<td>18.60000</td>
<td>18.67050</td>
<td>-0.080960</td>
</tr>
<tr>
<td>blow tank cons.</td>
<td>14.20000</td>
<td>14.16110</td>
<td>0.061903</td>
</tr>
<tr>
<td>shower cons.</td>
<td>156.0000</td>
<td>155.9170</td>
<td>0.007039</td>
</tr>
<tr>
<td>vat 1 cons.</td>
<td>1.360000</td>
<td>1.354320</td>
<td>0.041125</td>
</tr>
<tr>
<td>vat 2 cons.</td>
<td>2.070000</td>
<td>2.040480</td>
<td>0.100141</td>
</tr>
<tr>
<td>vat 3 cons.</td>
<td>1.670000</td>
<td>1.669700</td>
<td>0.001566</td>
</tr>
<tr>
<td>mat 1 cons.</td>
<td>16.09600</td>
<td>16.11050</td>
<td>-0.038530</td>
</tr>
<tr>
<td>mat 2 cons.</td>
<td>17.12400</td>
<td>17.07340</td>
<td>0.065536</td>
</tr>
<tr>
<td>mat 3 cons.</td>
<td>17.62200</td>
<td>17.63400</td>
<td>-0.032940</td>
</tr>
<tr>
<td>DF</td>
<td>1.232000</td>
<td>1.223240</td>
<td>0.038305</td>
</tr>
<tr>
<td>DR 1</td>
<td>0.810000</td>
<td>0.791154</td>
<td>0.308313</td>
</tr>
<tr>
<td>DR 2</td>
<td>0.680000</td>
<td>0.670458</td>
<td>0.271157</td>
</tr>
<tr>
<td>DR 3</td>
<td>0.680000</td>
<td>0.675703</td>
<td>0.060224</td>
</tr>
</tbody>
</table>

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APPENDIX G

SIMULATION OUTPUT FOR
S.D. WARREN, MILL A, AND MILL B DATA
(number of iterations equals 5000)
### S.D. WARREN OUTPUT

<table>
<thead>
<tr>
<th>run</th>
<th>Carryover (lbs/ton)</th>
<th>Excess Filtrate (lbs/ton)</th>
<th>DS In Filtrate (%)</th>
<th>Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>11.625</td>
<td>5.904</td>
<td>33361</td>
<td>9.014</td>
</tr>
<tr>
<td>2</td>
<td>11.650</td>
<td>5.804</td>
<td>33336</td>
<td>9.018</td>
</tr>
<tr>
<td>3</td>
<td>11.705</td>
<td>5.967</td>
<td>33373</td>
<td>9.051</td>
</tr>
<tr>
<td>4</td>
<td>11.726</td>
<td>6.161</td>
<td>33341</td>
<td>9.050</td>
</tr>
<tr>
<td>5</td>
<td>11.634</td>
<td>5.985</td>
<td>33367</td>
<td>9.044</td>
</tr>
<tr>
<td>6</td>
<td>11.634</td>
<td>5.999</td>
<td>33315</td>
<td>9.031</td>
</tr>
<tr>
<td>7</td>
<td>11.601</td>
<td>5.733</td>
<td>33419</td>
<td>9.071</td>
</tr>
<tr>
<td>8</td>
<td>11.666</td>
<td>5.890</td>
<td>33370</td>
<td>9.069</td>
</tr>
<tr>
<td>9</td>
<td>11.605</td>
<td>5.777</td>
<td>33287</td>
<td>9.030</td>
</tr>
</tbody>
</table>

### MILL A OUTPUT

<table>
<thead>
<tr>
<th>run</th>
<th>Carryover (lbs/ton)</th>
<th>Excess Filtrate (lbs/ton)</th>
<th>DS In Filtrate (%)</th>
<th>Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>31.131</td>
<td>28.116</td>
<td>18058</td>
<td>14.416</td>
</tr>
<tr>
<td>2</td>
<td>30.742</td>
<td>27.736</td>
<td>18069</td>
<td>14.449</td>
</tr>
<tr>
<td>3</td>
<td>30.241</td>
<td>27.242</td>
<td>18018</td>
<td>14.426</td>
</tr>
<tr>
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<td>Efficiency (%)</td>
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APPENDIX H

SIMULATION OUTPUT USING MILL B DATA
WITH CHANGES IN INPUT VARIABLES
(number of iterations equals 5000)
### 50% Decrease in Input Dilution Factor

**Standard Deviation**

(new $s = 0.26$)

<table>
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<th>Carryover (lbs/ton)</th>
<th>Excess DS In Filtrate (lbs/ton)</th>
<th>DS In Filtrate (%)</th>
<th>Efficiency (%)</th>
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### 50% Decrease in Blow Tank Dissolved Solids

**Standard Deviation**

(new $s = 0.95$)

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**CHANGE IN INPUT MEAN DILUTION FACTOR**
(new mean = 4.0)

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