GASP IV SIMULATION OF FLUSH WATER RECYCLING SYSTEMS

R. L. Fehr, J. R. Nuckols, O. J. Loewer,
and J. P. Bowden
Agricultural Engineering, University of Kentucky

ABSTRACT

The evaluation of the performance and the determination of the optimum design of a limited size recycling system for livestock waste handling are highly complex. To aid in evaluating this system, a computer program has been developed that is capable of modeling the effects of alternate flushing system designs and management operations. The model inputs include animal category, water storage container dimensions (multiple storage areas are allowed), flushing frequency and flush volume. The model defines the internal processes occurring over time in various components of the system, and determines the effects of management decisions on the system's performance. This paper describes the computer model including available management options. In addition, the results of a simulation are presented and discussed.

INTRODUCTION

Many changes have been experienced in livestock production in recent years. Producers have switched from small diversified operations to large specialized production units. This practice has been encouraged as land prices have increased, federal water quality standards have been enacted, and labor has become more difficult to obtain. In addition, with increasing prices, livestock waste once viewed as a worthless nuisance, is becoming a valuable source of fertilizer. To meet these new criteria of design, producers require livestock facilities with efficient waste handling systems.

One system used to meet some of these new criteria is the flushing of livestock wastes from facilities to outside storage. Such a system presently requires relatively large quantities of fresh water with sufficient storage or a lagoon in order to provide waste water treatment prior to recycling of the flush water. Fresh water volume requirements limit the practicality of this system. Likewise, the disadvantages of lagoon type systems, including state regulations, excessive nutrient loss, large land areas and initial construction, also limit their application (4,5).

The above-mentioned factors are causing limited size storage volumes with recycling systems to be considered as a viable alternative. These systems should reduce the nutrient loss to a level closer to that of pit storage, reduce land area requirements, and thereby minimize initial construction costs. The system's size must provide adequate volume for the waste solids to settle out and be stored as well as for keeping solid concentrations in the supernatent low enough to allow recycling.

Little information is available to assist producers and engineers in understanding how limited size recycling systems will perform. One model has been developed to monitor various parameters and determine their interaction, but it is limited to one species of livestock and does not allow for modeling the effects of management (1). Analytical solutions cannot accurately account for changes in settling rate, solids concentration or sludge buildup, because of long periods of calculation with changes occurring frequently (2,6).

The model described here was developed to aid in determining the optimum design and operation of limited size recycling systems. By monitoring various waste water parameters as they change with both time and management decisions, the model provides producers and engineers a tool to aid in the evaluation of these systems. The model, called FLUSH (Flowing Liquid Utilization as a System of Handling), was developed so that a number of waste handling alternatives could be readily evaluated. By manipulation of various input parameters, the user retains control over such sub-systems as recycling of flush water, sludge wasting options, mixed liquor wasting alternatives, as well as the physical design of the system structures.

FLUSH was designed not only as a tool for the engineer, but also as an aid to the farmer so that he may be able to evaluate readily his existing needs with respect to livestock waste handling systems for enclosed animal units. The simulated system was given this two-fold capability by means of dividing the input data into two sections: a scientific section for the researcher/engineer and a "hands-on" section for the extension programmer/farmer.

THE FLUSH SIMULATION PACKAGE

The limited size recycling system depicted in Figure 1 can be factored into a quadra-component flowchart for simulation purposes. The four

Flush simulation (continued)

components in the flowchart would represent the "materials" of the system and their continuity, the materials being 1) rapidly settleable solids, 2) normally settleable solids, 3) suspended solids, and 4) waste-water comprised from urine, feces, and dilution water (3). A simplified systems dynamics flowchart is presented in Figure 2, which would typify the "continuity" of any one of the components in the system. This idealized flowchart would, for the most part, be duplicated for simulation of materials flow in Stage 2 to Stage N, depending on the desired number of storage tanks to be incorporated into the system. An upper limit of 2 tanks exists for the current FLUSH package.

As can be seen from the flowchart, total levels of solids and water in the system can be ascertained by summing across the quadra-component chart, then solids concentrations, solids production, supernatant and sludge depths can be derived from these summations.

The computer simulation of the flush manure handling system is based on the continuity relationship:

$$Mass_{T_1} = [Q_I C_{I_1} - Q_O C_{O_1}] * dt \qquad (1)$$

where

$Mass_{T_1}$ = Change in concentration

Q_I = Influent flowrate

C_{I_1} = Influent concentration

Q_O = Effluent flowrate

C_{O_1} = Effluent concentration

The mass (or volume if specific weight conditions are accounted for) of component 1 at any point and time in the system can be determined from the influent concentration of component 1 and the flowrate to the point, the corresponding effluent characteristics, and the time period of study. For convenience, the "materials" flow of this simulation will be volumetric.

The FLUSH system was programmed in the GASP IV fortran language, utilizing the combined continuous and discrete technique suggested by Pritsker (7). The reasoning behind selection of GASP IV was fourfold:

1. The FORTRAN format of GASP IV allowed for the mathematics in the simulation to be readily handled,
2. Applicability of the system to the GASP IV input-output format,
3. The system could be described as a "flow of materials" problem, readily addressable to GASP IV continuous simulation techniques, and

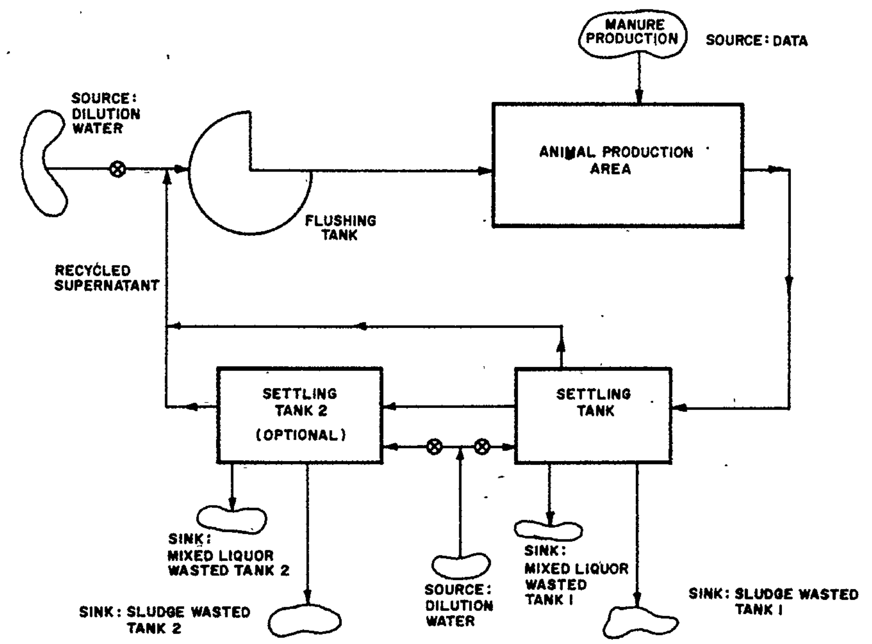

FIGURE I. SCHEMATIC DIAGRAM OF THE MANURE FLUSH SYSTEM SIMULATED

4. The added range of the GASP IV simulation language to incorporate such discrete time events as addition of dilution water, manipulation of flow rates, monitoring of solids concentrations, sludge wasting options, and time-dependent cycling events into the FLUSH simulation system.

PROGRAM INPUT

The input format to the FLUSH program is subdivided into two entries; (1) the scientific data input package providing basic tools for the manipulation of the simulated system by a researcher/engineer. This package is pre-programmed prior to "hands-on" utilization in an extension application. (2) The "hands-on" farm input package that allows a farmer to evaluate his system with the very basic inputs that would be readily accessable to most any farm operation. Once the simulated system has been pre-programmed by the design engineer encorporating data such as solids settling regime, solids concentrations, etc., the FLUSH package becomes readily accessable to the farmers' input consisting of basic livestock management data. Because the scientific input package preprograms the simulated system for a variety of animal waste types, the scope of utility for the "hands-on" system is greatly enhanced.

SCIENTIFIC DATA INPUT PACKAGE (SDI)

A sample input data sheet for the SDI package is presented in Table 1. Inputs involving waste composition, waste production rates, characteristics of the waste with respect to a dynamic settling system, and physical design parameters of the system such as desired solids concentrations and storage tank structural characteristics are developed in this package for up to 10 different animal waste categories (i.e. swine feeder hogs, sows with piglets-farrow house, etc.). The SDI consists of 81 data cards, each explicitly detailed in the program documentation.

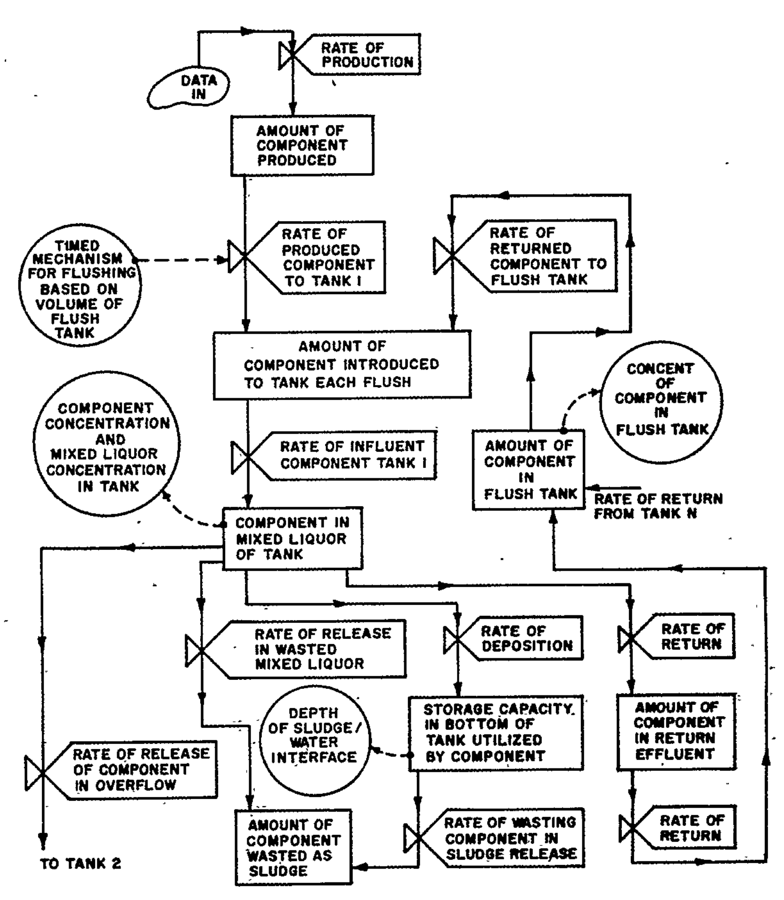

FIGURE 2. FLOW CHART OF A COMPONENT IN THE SIMULATED FLUSH SYSTEM

FARM EXTENSION INPUT PACKAGE (FEI)

A sample input data sheet for the FEI package is presented in Table 2. In this package the farm operation being simulated is described according to animal category, number and average weight of animals, food and temperature adjustment factors, selected sludge handling, recycle procedure and capacity, and basic physical design parameters. The FEI consists of 11 data input cards, each explicitly described in the program documentation. Within the FEI are a number of inputs which allow for various methods of system management.

One of the management input decisions controls the method of settled sludge removal from the storage area. The sludge can be removed on a periodic basis or when the sludge reaches a specified level. For periodic removal the user must provide the interval between removal operations. If the interval is too long the sludge level will increase until it fills the entire storage capacity of the first tanks. At that time all of the additional solids produced will enter a second storage area. These two options allow the user to evaluate two different design requirements - one in which the system must be designed for a fixed management procedure and another in which the management must vary to allow for fixed design specifications.

The method for dilution water addition can also be selected in the FEI. Because the maximum allowable solids concentration in the mixed liquor has been set in the SDI package, when this concentration is achieved the model will automatically add dilution water in the component where required. Water will continue to be added in that component until the concentration is less than the control limit set in the SDI. Dilution water will also be added if the mixed liquor depth goes below the limit specified in the FEI. The four alternatives for dilution water addition are: 1) no dilution based on

TABLE I

Scientific Data Input Package (SDI)

By Animal Category:			
Daily production of water per Kg of animal	______	Kg/Kg-DAY	(0.10)[a]
Daily production of solids per Kg of animal	______	Kg/Kg-DAY	(0.10)
Percent solids in the waste as produced	______	%	(15.)
Percent of total solids produced that are rapidly settleable solids	______	%	(70.)
Percent of total solids produced that are normally settleable solids	______	%	(20.)
Percent of total solids produced that are suspended solids	______	%	(10.)
Solids density in the waste as produced	______	Kg/M^3	(1,200.)
Density of the total waste produced	______	Kg/M^3	(1,000.)
Percent of total water produced in the urine	______	%	(80.)
Percent of total water produced in the feces	______	%	(20.)
Cumulative percent of total daily waste output every 2 hours during a day — __,__,__,__,__,__,__,__,__,__,__,__ (0. ,10.,20.,30.,40.,50.,60.,70.,80.,85.,90.,95.,100.)		%	
Percent water in the total settled sludge	______	%	(90.)
Tank 1 shape factor (settling rate adjustment)	______		(1.0)
Tank 2 shape factor (settling rate adjustment)	______		(1.0)
For All Animal Categories:			
Maximum concentration of solids in the mixed liquor	______	Kg/M^3	(50,000.)
Concentration of solids in the mixed liquor which is low enough to stop the dilution pump	______	Kg/M^3	(10,000.)

a/ Values used for simulation presented.

time, only on the concentration of solids in all tanks, 2) dilution based on time in storage tank 1 and the flush tank, and on concentration in all tanks, 3) dilution based on time in storage tank 2 and on concentration in all tanks, and 4) dilution based on time and concentration in all tanks. For methods utilizing time sequenced dilution, the interval must be specified as well as the length of operation. This allows the user to develop management procedures which will prevent excessive solids concentrations in the mixed liquor without requiring the operator to monitor their level.

The method of wasting mixed liquor must also be specified because the model does not remove any mixed liquor when the sludge is removed. No maximum volume is specified for tank 2 because it must be able to hold all the overflow from tank 1 if the option of no mixed liquor wasting is utilized. Other options for the mixed liquor include condinuous wasting (wasting rate must be specified), wasting based on solids concentration in the mixed liquor, and wasting based on mixed liquor depth.

TABLE II

Farm Extension Input Package (FEI)

Animal category --	________		(1)[a]
Number of animals --------------------------------------	________		(200.)
Average weight of the animals ---------------------------	________	Kg	(68.)
Tank sizing procedure			
-Size restrictions included -----------------------------	________	M^3	(90.)
-No size limit, program determines tank size required -	________		
Maximum tank depth --------------------------------------	________	M	
Tank surface area			
-Tank 1 ---------________ M^2 (30.); -Tank 2 -----------	________	M^2	
Initial volumes of water in the tanks			
-Tank 1 ---------________ M^3 (30.); -Tank 2 -----------	________	M^3	(0.)
Minimum depth of supernatant water for recycling ----------	________	M	(.3)
Recycle pump capacity -----------------------------------	________	M^3/Min	(.1)
Volume of the flush device ------------------------------	________	M^3	(3.0)
Sludge removal procedure			
-All settled sludge removed at a specified time -------	________	(X)	
-Settled sludge removed according to settling rate ----	________		
Sludge removal interval ---------------------------------	________	min	(20,160.)
Dilution water addition procedure			
-Dilution based on solids concentration only ----------	________	(X)	
-Dilution based on solids concentration and time for any combination of tanks ----------------------	________		
Dilution interval length of operation per interval ---------	________	min	
-Length of operation per interval ----------------------	________	min	
Dilution flow rates --------------------------------------	________	M^3/Min	(.1)
Mixed liquor removal procedure			
-Continuous removal -----------------------------------	________		
-Removal based on concentration of solids -------------	________		
-No removal allowed -----------------------------------	________	(X)	
Allowance for evaporation			
-Considered ---	________		
-Not considered ---------------------------------------	________		
Feed ration factor (waste production adjustment) ----------	________		(1)
Temperature factor (waste production adjustment) ----------	________		(1)

a/Values used for simulation presented.

Flush simulation (continued)

The FEI allows the modeler the choice of either simulating a specified system (tank 1's maximum volume specified) or letting the simulation determine the size of tank 1 required.

PROGRAM OUTPUT

The FLUSH program has been designed so that a number of output formats can be achieved, giving the user greater versatility in obtaining his exact needs. Output is available for all of the components described in Figure 2 and for each of the four components of the simulation system: rapidly settleable solids, normally settleable solids, suspended solids, and wastewaters (urine + feces + dilution water).

A FLUSH simulation was performed on a 200-head swine finishing building, and some of the results are presented in Figure 3. The data input for the SDI and FEI packages is included in Tables 1 and 2. The graphs presented in Figure 3 show the changes in the a) settled sludge depth, b) mixed liquor depth, and c) mixed liquor solids concentrations in the simulated storage tank. As can be seen in Figure 3a, the settled sludge depth increases uniformly until the time when the management decision to remove all the settled sludge occurs (Table 2 - Sludge Wasting Procedure). At that time all the settled sludge is removed, after which the solids again began to build up uniformly.

The mixed liquor solids concentration (Figure 3c) increases throughout the simulation. Removal of settled sludge does not remove mixed liquor solids as indicated by the continual increase in mixed liquor solids concentration. The gradual change in mixed liquor solids was one of the primary reasons for the development of this model, because the waste management system may work well for a time period but eventually these solids must be diluted. FLUSH can be used to determine when the mixed liquor solids concentration is above exceptable limits and the amount of dilution water required. This would be difficult to do with reasonable accuracy using hand calculations.

Changes in the mixed liquor depth (Figure 3b) were small for the example simulation run, owing to the time interval plotted. Figure 4 indicates the changes that are occurring in the mixed liquor depth using a smaller time interval for plotting. As previously noted, the FEI package requires a minimum depth of mixed liquor to be specified and when the mixed liquor depth becomes less than that minimum the dilution pump is operated. Determining when or the amount of dilution is required to maintain a minimum mixed liquor depth would be difficult for a long time period.

VALIDATION

A limited size recycling system is being constructed at the University of Kentucky which will allow for model validation with controlled operating conditions. However, the concept of program validation is complicated because there are two basic sources

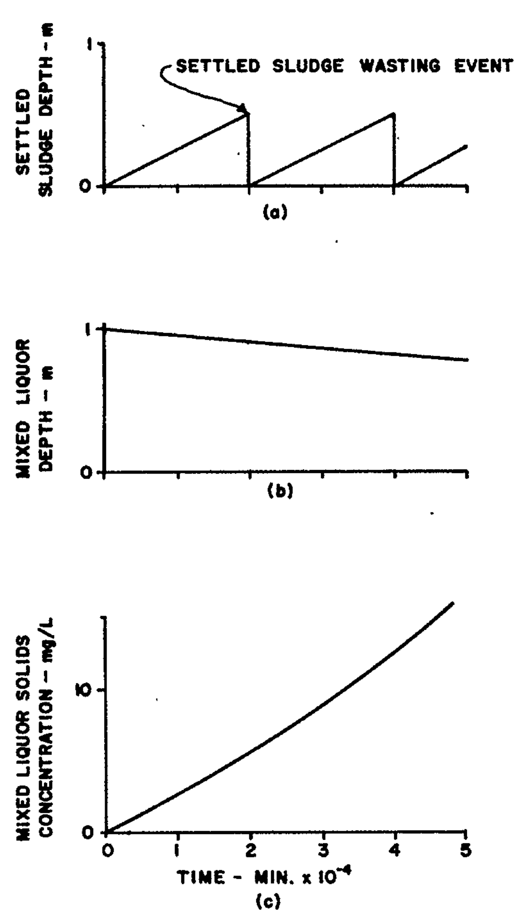

Figure 3. RESULTS OF A FLUSH SIMULATION

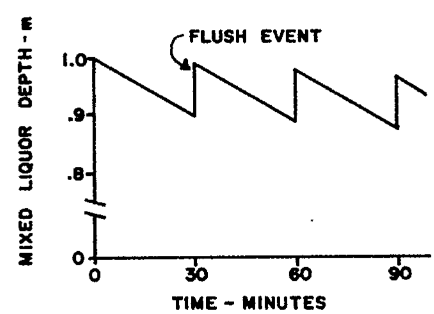

Figure 4. MIXED LIQUOR DEPTH VARIATION RESULTING FROM RECYCLING

of error, the model and the SDI package. Error in the model should be limited because it utilizes a calculation system which maintains a mass balance throughout the simulation, i.e., solids produced must be in the flush device, storage tanks, or must be removed. The SDI package data may contain errors, resulting from the research techniques used to obtain the data compared with actual operating conditions. Even if one considers the present lack of program and data validation, the model provides a tool capable of more accurate results than hand-calculated estimates.

SUMMARY

The model described provides a tool for both the researcher and the producer to use in evaluating flush system designs. It is capable of determining design problems prior to construction and evaluating proper management procedures for systems currently in use but not functioning correctly. Use of the GASP IV simulation language permits the model to display the results of the simulation in a variety of ways depending on the final use. The program maintains applicability at almost any stage in the design evaluation process and is limited almost only by the ingenuity of the user.

REFERENCES

1. Audsley, E. A mathematical model, analytical solution and computer programme for the intergrated pig slurry treatment system. National Institute of Agricultural Engineering, Silsoe, England.

2. Jett, S. C., H. E. Hamilton and I. J. Ross. 1975. Settling characteristics of swine manure. Transactions of the ASAE. 18(6):1128.

3. Jett, S. C., I. J. Ross, H. E. Hamilton and V. W. Hays. 1974. Size distribution and nutritional value of swine manure separates. Transactions of the ASAE. 17(5):965.

4. Jones, D. D., J. C. Nye, B. C. Horsfield and R. O. George. 1976. Gutter flushing systems for swine buildings. Cooperative Extension Service, Purdue University, West Lafayette, Indiana. AE-87.

5. Livestock Waste Facilities Handbook. 1975. Midwest Plan Service, Iowa State University, Ames, Iowa.

6. Moore, J. A., R. O. Hegg, D. C. Scholy and Egon Strauman. 1975. Settling solids and animal waste slurries. Transactions of the SAE. 18(4):694.

7. Pritskeer, A. A. 1974. The GASP IV simulation language. John Wiley and Sons, Inc. New York.