Development of a Software for Feedlot Hydrology/Nutrient Management

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Abstract. *A software program was developed to estimate runoff quality/quantity, make manure nutrient management plans, and design waste storage and treatment facilities. Visual Basic programming language was used to develop the software. The Soil Conservation Service's curve number method and EPIC and AGNPS models were used in the hydrological calculations. A mass balance approach was employed to estimate nutrient fate of manure and runoff throughout a year. Nutrient budget calculations were provided to the user with default values that are either obtained from field studies or from literature. Based on the results obtained from hydrology and manure management calculations, a module was provided to design manure and runoff storage and treatment structures. In the paper, models and their use in the program were explained. Integration of the models with each other was explained with flowcharts. Basic information was provided about the use of the program.*

Introduction

There are many waste management software and spreadsheet programs publicly available via the Internet. One of these programs is Animal Waste Management Software (NRCS, 1995). The program automates the design of animal waste management system components for waste storage facility, waste treatment lagoon, and waste utilization. Fraisse et al. (1996) has developed a Generic Interactive Dairy Model (GIDM) as a tool for creating alternative dairy waste management plans and evaluating the effects of these plans on water quality. Manure Application Planner^{TM} (MAP) is a computer software tool used to develop environmentally sound and economically viable manure application plans. MAP runs an optimization to determine the most cost effective plan that does not over-apply nutrients (CFFM, 2000).

Manure management software is generally available for nutrient management calculations. These softwares cannot be used to estimate the pollution potential of feedlot operations. Other software such as Animal Waste Management Software (AWM) is a useful tool to design storage and treatment structures. However, it can be used for neither manure management nor water quality estimation.

Even though computer programs are available for water quality management, manure nutrient budgeting, and control and treatment structures design, there is no software available containing all these calculations. Water quality models and software are generally considering watershed-based applications and paying less attention to feedlot hydrology.

Therefore, objectives of this paper are (1) to define the models that will be used in the program and (2) to develop a user-friendly software that can be used in feedlot hydrology/nutrient management and runoff/manure storage and treatment structures design.

Methods

Visual basic programming language has been used to develop the software program. Feedlot Hydrology and Manure Management Software consists of three modules, including hydrology, manure management, and storage/treatment structure(s) design. Some default data such as animal manure characteristics, daily manure production rates, monthly evaporation, and rainfall data for all the counties in North Dakota were provided to the user. However, actual data, if known, can be substituted for the default data.

Each module requires data from the previous module. In Figure 1, models and/or literature and their roles in the program are explained.

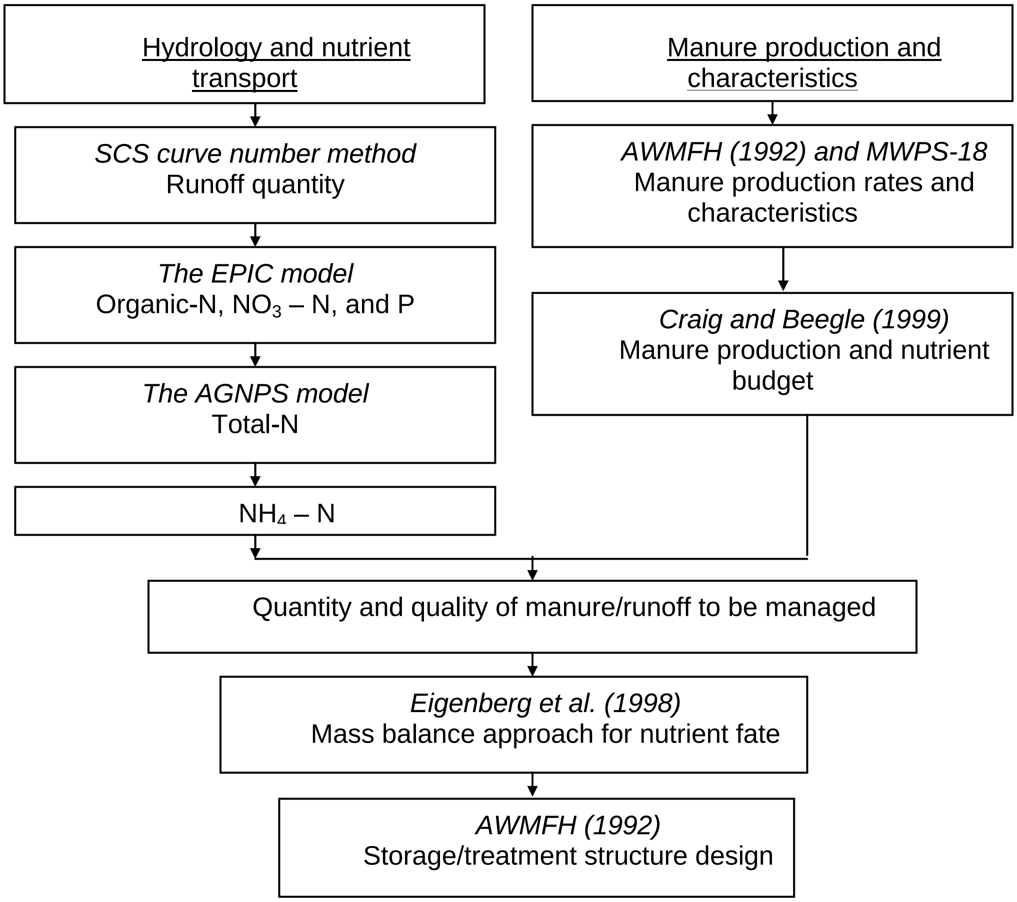


Figure 1. Organizations of the models in the program.

The following modules describe the models and their relation with each other.

Modules

Runoff and Nutrient Transport Module

The runoff and nutrient transport model employs the Soil Conservation Service (SCS) curve number method for runoff prediction (Eq 1, 2, and 3).

$$Q = \frac{(R - 0.2s)^2}{(R + 0.8s)}, \qquad (1)$$

$$s = 25.4 \cdot (\frac{1000}{CN_{avr}} - 10), \qquad (2)$$

$$V = Q.\frac{\left(A_{feedlot} + A_{cont}\right)}{1000}, \qquad (3)$$

Since this software was developed to estimate runoff quantity and quality to make nutrient management plans, monthly rainfall values and evaporation rates were considered. In the program, runoff depth is the runoff generated from the net rainfall for the production year. Default monthly rainfall and evaporation values were provided for each weather station in North Dakota. The weather data were collected by the National Weather Service (NWS). The weather database was obtained from the Animal Waste Management (AWM) software web site.

After calculating the runoff quantity, the nutrient transported with the runoff was calculated. The EPIC model approach was adapted to calculate the runoff carried by organic-N, nitrate-N, sediment phase of P, and soluble phosphorus concentrations. The EPIC model uses the soil nutrient concentrations as an input to runoff and predicts runoff concentrations. However, a feedlot surface is generally covered by manure and is compacted by the animals. Feedlot surface is the source of nutrients. Therefore, in the developed model, when the runoff concentrations are calculated, feedlot surface nutrient contents were considered. In order to provide default data, samples were collected and sent to a commercial laboratory.

Runoff organic-N concentration was calculated using the following equation adapted from EPIC model (Eq. 4). Based on the literature, runoff sediment concentration was assumed to be 1.5 % of runoff volume. Similar to organic-N, runoff nitrate-N concentration was calculated using Eq. 5:

$$OrgN = 0.001 \cdot S_y \cdot ON_{sur} \cdot ER, \qquad (4)$$

$$NO3 - N = Q.NO3_{sur} / 1000, \qquad (5)$$

The EPIC model does not provide a method to predict total runoff N concentration. Therefore, an AGNPS model approach was used. The AGNPS model, unlike the EPIC model, considers a default runoff N concentration value, and then based on the animal density on the feedlot, it predicts runoff N concentration. The percentage of manure pack was calculated based on animal unit density on the feedlot; runoff N concentration was calculated proportional to the percentage of manure pack. If the percentage of manure is 100, it is assumed that runoff N concentration is equal to that of the default runoff concentration. However, if the percentage of manure pack is 75, the runoff N concentration is considered to be 75 % of default value (Eq. 6). After total N concentration, ammonium-N was predicted. Total N is the sum of organic-N, nitrate-N and ammonium-N. Therefore, once the other components are calculated, ammonium-N concentration can be predicted using Eq. (7):

$$N = \frac{\left(PMP.N_{default}\right)}{100}, \qquad (6)$$

$$NH_4 - N = N - \left(OrgN - NO_3 - N\right), \qquad (7)$$

The EPIC model equations were used to predict phosphorus concentrations. Sediment and soluble phases of phosphorus were predicted using Eqs. 8 and 9:

$$P_{sed} = 0.01 \cdot S_y \cdot P_{sur} \cdot ER, \qquad (8)$$

$$P_{sol} = \frac{0.01 \cdot P_{sur} \cdot Q}{k_d}, \text{ and} \qquad (9)$$

$$P_{total} = P_{sed} + P_{sol}, \qquad (10)$$

Manure Management Module

The mass balance approach is used to predict nutrient fate of manure. This approach combines nutrient loss information related to feedlot operations into a descriptive model. The model tracks N and P through each of the system components including collection, storage, treatment, and application and assumes that the operation is a steady-state system (Eigenberg et al., 1998). The model utilizes the NRCS Agriculture Waste Management Field Handbook procedures (Krider et al., 1992).

A schematic representation of the manure management module of the program is given in Figure 2. The dashed line represents the management options.

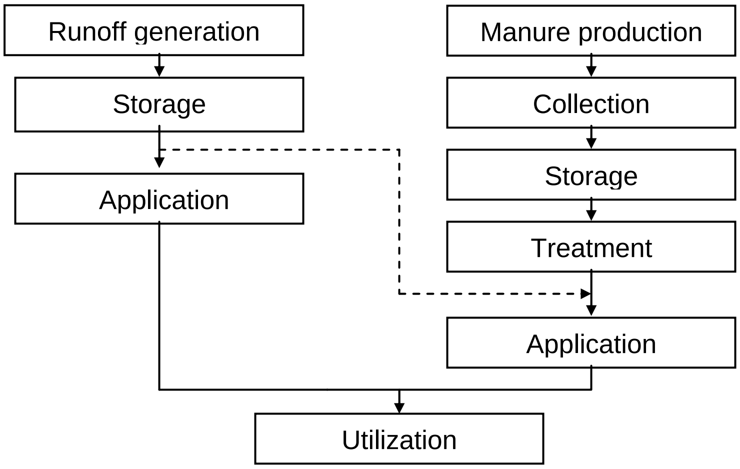


Figure 2. Schematic representation of manure management module

Runoff quality and quantity calculations are based on the hydrology module of the program. Management options allow users to store runoff with manure, or in a separate structure, and apply runoff to the same field with manure or to another field.

The nutrient budgeting procedure given by Craig and Beegle (1999) was employed with the mass balance approach and feedlot hydrology model. The mass balance approach helps the model predict nutrient fate, and the runoff module estimates the nutrient transport from the feedlot. Finally, the budgeting procedure combines these two approaches to calculate application rate, additional fertilizer requirements, and commercial value of manure/runoff generated from the feedlot.

In the nutrient budgeting calculations, animal unit (AU) was used. One AU was considered to be 500-kg live weight. Total manure production for the production season was calculated using the daily manure production per AU, total AUs, and number of days manure is produced (Eq.11):

$$TMP_i = \frac{\left(AU_i . DMP_i . TDMP_i\right)}{1000}, \qquad (11)$$

Nutrient losses during collection, storage, treatment, and application were calculated. Application losses were calculated for four different application methods including broadcasting, incorporation, sprinkling, and injection. The mass balance approach and nutrient loss factors for feedlot manure were adapted from Eigenberg et al. (1998).

Before calculating N and P balanced manure application rates, available N and P for each disposal land were calculated. A field may receive only runoff, only manure, or both. Therefore, the user is asked to enter the percentage of runoff and manure that each disposal field receives. Available N and P were then calculated using Equation 12:

$$AvNut = \left\{ \begin{array}{ll} only\ runoff & \dfrac{(RappNut)}{(0.01 \cdot V \cdot PRR)} \\ only\ manure & \dfrac{(MappNut)}{(0.01 \cdot TMTM \cdot PMR)} \\ runoff\ \&\ manure & \dfrac{(RappNut)}{(0.01 \cdot V \cdot PRR)} + \dfrac{(MappNut)}{(0.01 \cdot TMTM \cdot PMR)} \end{array} \right\}, \qquad (12)$$

Application rates were calculated based on N and P requirements (Eqs. 13 and 14). Then the actual application rate was determined. If the manure is to supply all the nutrient requirements for the crop, the higher of the two application rates was chosen. If the purpose is to maximize the use of manure nutrients, the smaller rate was chosen (Eq. 15):

$$NRate = \frac{NetN\,\mathrm{Re}\,q}{AvailableN}, \qquad (13)$$

$$PRate = \frac{NetP\,\mathrm{Re}\,q}{AvailableP}, \text{ and} \qquad (14)$$

$$ActualAppRate = \left\{ \begin{array}{ll} Manure\ is\ to\ supply\ all\ N\ \&\ P & Max(NRate, PRate) \\ Maximize\ use\ of\ nutrients & Min(NRate, PRate) \end{array} \right\}, \qquad (15)$$

Possible management options for runoff and manure are shown in the following flowchart (Figure 3). If there is no runoff containment structure, the hydrology/nutrient model provides the information about the pollution risk of that particular feedlot operation.

The final step was to estimate the commercial value of nutrients applied. The user was asked to estimate unit prices of commercial fertilizer. The application rate and the N, P, and K values were used to predict the economic benefit of the manure nutrients.

Containment and Treatment Structure Design Module

Manure and runoff storage and treatment pond design criteria are taken from AWMFH (1992) (Eq. 16). It is initially assumed that side slope ratio and liquid depth are known. The manure management module provides data for the runoff and/or manure storage volume requirement. After assigning a length-width ratio, Eq. 16 can be solved. The root of the quadratic equation gives the bottom width of the pond.

$$Vol = \frac{\left(4 \cdot SS^2 \cdot LD^3\right)}{3} + \left(SS \cdot BL \cdot LD^2\right) + \left(SS \cdot BW \cdot LD^2\right) + \left(BL \cdot BW \cdot LD\right), \qquad (16)$$

Other manure storage structures design equations, such as manure stacking structure and rectangular and circular storage tanks, were also taken from AWMFH (1992). MWPS-18 (1993) provides the design criteria for a runoff settling tank and basin.

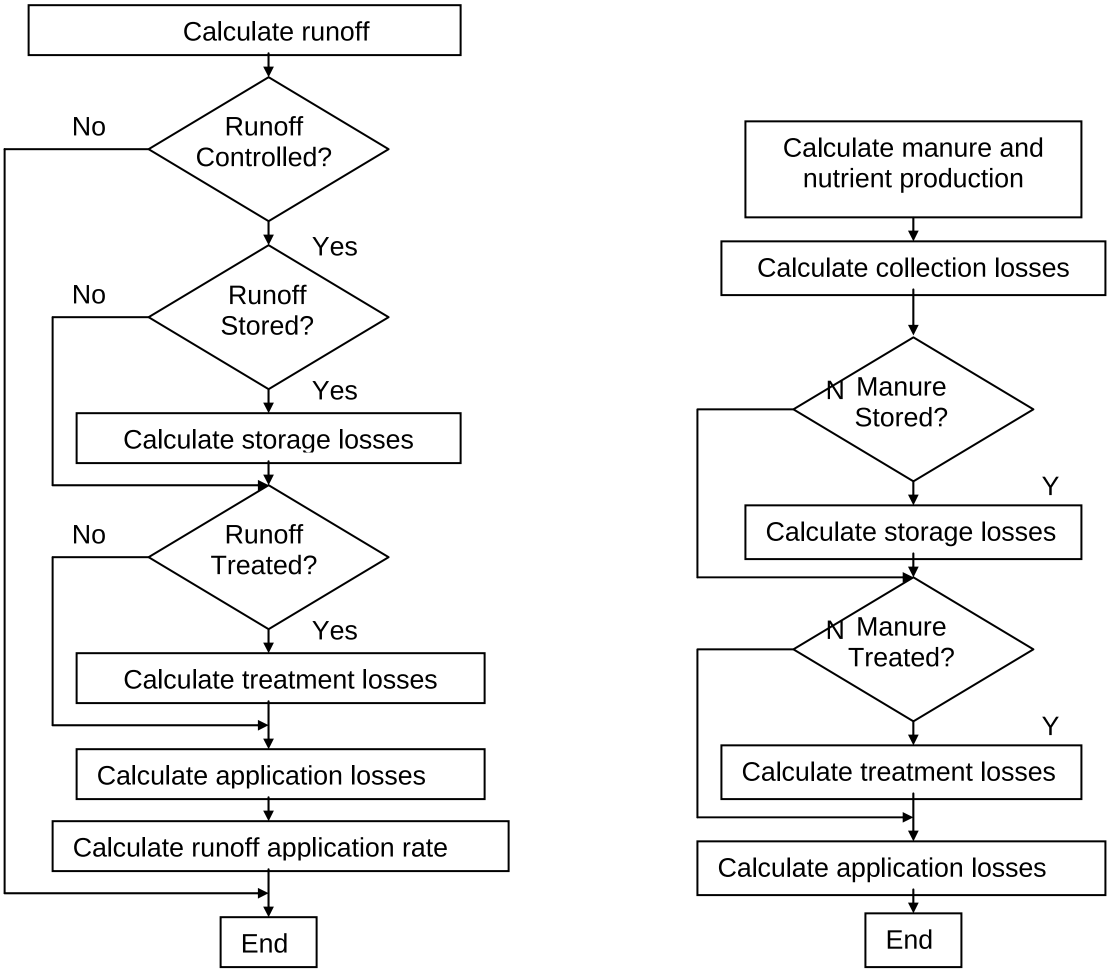


Figure 3. Runoff and manure management options.

User Interface

Required data are asked from the user through seven different data windows. These data windows are General, Animal, Feedlot, Crop/Land, Weather, Management, and Design.

The general data window asks the user information such as hours per day when animals are not in the feedlot, days per year when the manure is not produced, and estimated prices of commercial fertilizers. The animal data window provides the general information about the animals housed in the

operation. The number of animals and average animal weights were asked. Daily default manure, total solids, volatile solids, BOD production rates, and nutrient concentrations are provided to the user.
In the feedlot data window, the runoff curve number and surface area for feedlot and contributing area are asked. Also, default feedlot soil characteristics are provided to the user. Since it might have been conservative, a default curve number for the contributing area was provided.

In the crop/land data window, the proposed crop to be planted, typical manure and fertilizer application rates, and information about manure history for up to five lands are asked. Phosphorus requirement for the selected plant were calculated considering Bray-1 and Olsen recommendations. In the calculation of P and K recommendation, soil test results and yield goal were asked from the user. Nitrogen recommendation requires soil test results, yield goal, sampling day adjustment and previous crop credit. Sampling day adjustment and previous crop N credit were explained and the tabular data was provided in Franzen and Cihacek (1996).

The weather database covers the data such as monthly rainfall and evaporation, 25-year and 24-hour rainfall data, 10-year and 1-hour rainfall intensity, lagoon volatile solids loading rate, and lagoon BOD loading rate. Volatile solids loading rate and BOD loading rate data were obtained from AWMFH (1992). The default database includes all this information for all the stations in North Dakota. Also, the weather data window enables the user to run the program for a single rainfall event.

In the management data window, manure application techniques and options for manure/runoff storage and treatment are provided. Broadcasting, incorporation, sprinkling, and injection are the possible techniques provided to the user for manure/runoff application. Based on the season, default nutrient loss factors are provided.

Finally, in the design data window, some preferred structural/management information are asked to design runoff and manure storage ponds, runoff settling basin, runoff settling tank, circular and rectangular manure tanks, manure stacking structure, and anaerobic and aerobic treatment ponds.

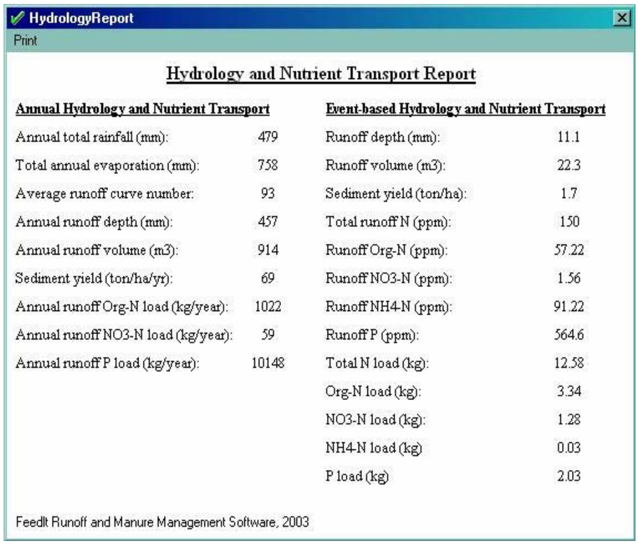
Since each module requires data from the previous module, after entering the data, one should run the models for hydrology, manure management, and design modules, respectively. Reports are generated for each module. Estimated runoff characteristics, runoff volume, manure and runoff nutrient fates, and dimensions of the storage/treatment structures are provided in printable forms.

Results

A complete example for a beef feedlot was run for the following conditions using default data.

- Days per year when manure is not produced = 20.
- Total days manure is produced = 345.
- Commercial values of N, P, and K, respectively = 0.45, 0.47, and 0.28 $/kg.
- Number and average weight of animal = 150 beef cow weighing 500 kg/each.
- Feedlot area = 2000 m^2.
- Location = Cass County, ND.
- Application type and season = Broadcasting, summer.

The hydrology/nutrient transport, nutrient budget, and design reports are given in Figure 4, 5, and 6, respectively.



Hydrology and Nutrient Transport Report

Annual Hydrology and Nutrient Transport

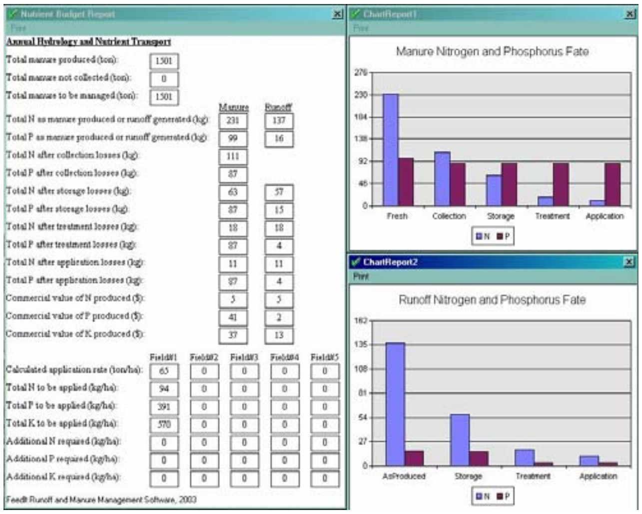
Annual total rainfall (mm):	479
Total annual evaporation (mm):	758
Average runoff curve number:	93
Annual runoff depth (mm):	457
Annual runoff volume (m3):	914
Sediment yield (ton/ha/yr):	69
Annual runoff Org-N load (kg/year):	1022
Annual runoff NO3-N load (kg/year):	59
Annual runoff P load (kg/year):	10148

Event-based Hydrology and Nutrient Transport

Runoff depth (mm):	11.1
Runoff volume (m3):	22.3
Sediment yield (ton/ha):	1.7
Total runoff N (ppm):	150
Runoff Org-N (ppm):	57.22
Runoff NO3-N (ppm):	1.56
Runoff NH4-N (ppm):	91.22
Runoff P (ppm):	564.6
Total N load (kg):	12.58
Org-N load (kg):	3.34
NO3-N load (kg):	1.28
NH4-N load (kg)	0.03
P load (kg)	2.03

FeedIt Runoff and Manure Management Software, 2003

Figure 4. Sample hydrology/nutrient transport report



Annual Hydrology and Nutrient Transport

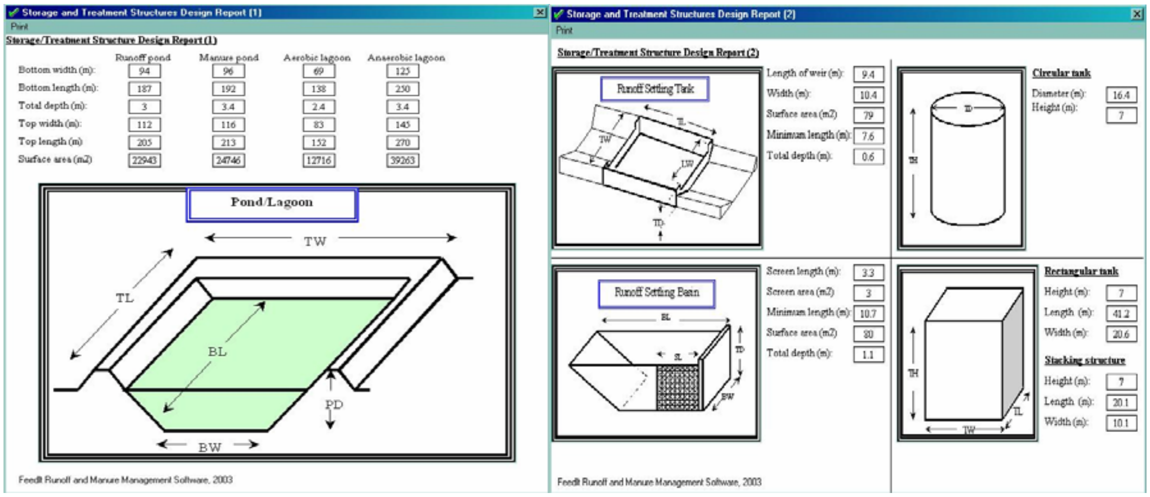
Total manure produced (ton):	1501
Total manure not collected (ton):	0
Total manure to be managed (ton):	1501

	Manure	Runoff
Total N as manure produced or runoff generated (kg):	231	137
Total P as manure produced or runoff generated (kg):	99	16
Total N after collection losses (kg):	111	
Total P after collection losses (kg):	87	
Total N after storage losses (kg):	63	57
Total P after storage losses (kg):	87	15
Total N after treatment losses (kg):	18	18
Total P after treatment losses (kg):	87	4
Total N after application losses (kg):	11	11
Total P after application losses (kg):	87	4
Commercial value of N produced ($):	5	5
Commercial value of P produced ($):	41	2
Commercial value of K produced ($):	37	13

	Field#1	Field#2	Field#3	Field#4	Field#5
Calculated application rate (ton/ha):	65	0	0	0	0
Total N to be applied (kg/ha):	94	0	0	0	0
Total P to be applied (kg/ha):	391	0	0	0	0
Total K to be applied (kg/ha):	570	0	0	0	0
Additional N required (kg/ha):	0	0	0	0	0
Additional P required (kg/ha):	0	0	0	0	0
Additional K required (kg/ha):	0	0	0	0	0

FeedIt Runoff and Manure Management Software, 2003

Figure 5. Sample nutrient budget reports.



Storage/Treatment Structure Design Report (1)

	Runoff pond	Manure pond	Aerobic lagoon	Anaerobic lagoon
Bottom width (m):	94	96	69	125
Bottom length (m):	187	192	138	250
Total depth (m):	3	3.4	2.4	3.4
Top width (m):	112	116	83	145
Top length (m)	205	213	152	270
Surface area (m2)	22943	24746	12716	39263

FeedIt Runoff and Manure Management Software, 2003

Storage/Treatment Structure Design Report (2)

Length of weir (m):	9.4
Width (m):	10.4
Surface area (m2)	79
Minimum length (m):	7.6
Total depth (m):	0.6

Circular tank

Diameter (m):	16.4
Height (m):	7

Screen length (m):	3.3
Screen area (m2)	3
Minimum length (m):	10.7
Surface area (m2)	80
Total depth (m):	1.1

Rectangular tank

Height (m):	7
Length (m):	41.2
Width (m):	20.6

Stacking structure

Height (m):	7
Length (m):	20.1
Width (m):	10.1

FeedIt Runoff and Manure Management Software, 2003

Figure 6. Sample design report.

Figure 6 shows that collection, storage, and treatment has a significant impact on manure N content while the P content remains almost same. The chart demonstrates the importance of a runoff containment/treatment system. Stored and treated runoff N decreased dramatically during these periods. In the absence or failure of a runoff control system significant pollutant discharge may happen. The commercial values and pollution potential of manure and runoff will help user to observe the importance of manure/runoff management.

In the design module of the program structural specifications for different storage/treatment facilities are reported. Based on the available land one can see the different alternatives and make the best decision for his/her operation.

Summary and Conclusions

It is essential that the producers be familiar with manure nutrient management (Van Horn et al., 1991, 1996, 1998, Powers and Van Horn, 2001). Manure is often considered a waste problem; however, it can be used to provide crop nutrients (Kessel et al., 1999). Manure nutrient management is also a part of proposed federal regulations for Concentrated Animal Feeding Operations (CAFOs) to control water resources quality (EPA, 2000). Therefore, there was a need for a computer program that can be used to estimate the pollution potential of feedlot operations, to design manure/runoff treatment structures, and make nutrient management plans. Prediction of waste produced, including manure and runoff; making manure management plans; and designing control structures make the software complete.

Hydrology output, including annual and event-based calculations, lets the user see the long- and short-term pollution potential from his/her feedlot. The nutrient budgeting module gives a good estimation of manure and runoff nutrient fate. For different management options, the program can be run, and change in nutrient fate could be observed for different options.

Since the program designs all possible manure and runoff treatment/storage structures, one can observe and decide the appropriate treatment/storage structure for his/her operations. The program can also be used to see effects of these structures on the pollution potential of the feedlot. For example, nutrient concentrations of manure or runoff at the time of application could be observed if there was a treatment facility.

It has been aimed to provide as much default data as possible to the user to make the use of the program easy. Also, the program provides a flexibility to change the default data when the observed or real data available. The use of manure, runoff, and soil test results will increase the precision of the results and avoid over and under application of nutrients.

As the new models and programming languages are released, this study should be updated. One challenge might be the distribution of this software and database. With the collection of more default data such as manure characteristics for each animal species and feedlot soil characteristics for North Dakota operations, it may be more helpful and might increase the precision of model results.

Future work may involve collection of the mentioned data. Also, nutrient loss factors that are given as default values are not determined for North Dakota conditions. Seasonal nutrient loss factors should be determined for different application types.

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Nomenclature

Acont = Contributing area, (m2)
Afeedlot = Feedlot surface area, (m2)
ActualAppRate = Actual manure application rate, (t/ha)
AU= Animal unit
$AvailableN$ = Available N, (kg/t)
$AvailableP$ = Available P, (kg/t)
$AvNut$ = Available N or P, (kg/t)
BL = Bottom length, (m)
BW = Bottom width, (m)
CN_{avr} = Average runoff curve number
DMP = Daily manure production rate, (kg/day/AU)
ER = Enrichment ratio
k_d = P concentration in the sediment divided by that of the water, (175 ppm)
LD = Liquid depth, (m)
$MappNut$ = Manure nutrient contents at the time of application, (kg)
N = Runoff total-N concentration, (ppm)
$N_{default}$ = Default runoff total-N concentration, (ppm)
$NetNReq$ = Net N requirement, (kg/ha)
$NetPReq$ = Net P requirement, (kg/ha)
$NH_4 - N$ = Runoff ammonium-N concentration, (ppm)
$NO3 - N$ = Runoff nitrate-N concentration, (ppm)
$NO3_{sur}$ = Feedlot surface nitrate-N concentration, (ppm)
$NRate$ = N balanced manure application rate, (t/ha)
ON_{sur} = Feedlot surface organic-N concentration, (ppm)
$OrgN$= Runoff organic-N concentration, (ppm)
P_{sed} = Sediment phase of runoff P concentration, (ppm)
P_{sol} = Soluble phase of runoff P concentration, (ppm)
P_{sur} = Feedlot surface P concentration, (ppm)
P_{total} = Total P concentration, (ppm)
PMP = Percentage of manure pack
PMR = Percent manure received
$PRate$ = P balanced manure application rate, (t/ha)
PRR = Percent runoff received
Q = Runoff depth, (mm)
R= Net rainfall depth, (mm)
$RappNut$ = Runoff nutrient contents at the time of application, (kg)
s = Retention parameter, (mm)
S_y = Sediment yield, (t/ha)

SS = Side slope, (1/n)
TDMP = Total days manure is produced
TMP = Total manure production, (t)
TMTM =Total manure to be managed, (t)
V = Runoff volume, (m3)
Vol = Pond volume, (m3)

Subscription

i = Animal group

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