United States
Environmental Protection
Agency

Robert S. Kerr Environmental Research
Laboratory
Ada, OK 74820

Research and Development

EPA-600/S2-80-192 Jan. 1981

EPA

Project Summary

Predicting Cattle Feedlot Runoff and Retention Basin Quality

J. Ronald Miner, James K. Koelliker, and Marshall J. English

As a result of potential water and land pollution from cattle feedlots, a technology for control of feedlot runoff has evolved. This study describes a procedure for controlling runoff while recovering manure-laden water for use as fertilizer. When rain or melting snow reduces the surface holding capacity of a feedlot's runoff retention basin, manure-laden water, valuable as a cropland fertilizer, may be lost to soil surface and/or receiving streams near the basin. Accurate prediction of the quantity of runoff entering a retention basin or pond would permit design of a basin with a holding capacity sufficient to contain the runoff.

A procedure was devised which can predict, on a daily basis, the quality and quantity of feedlot runoff entering a retention basin. The predictions are based on climate, feedlot size, type of liquid-removal equipment, frequency of pumping and the needed level for land or water pollution control.

A cattle feedlot in Illinois was sampled to adjust the predictive model which measures the following parameters on a daily basis: chemical oxygen demand, total Kjeldahl nitrogen, ammonia nitrogen, total phosphorous, total solids, fixed dissolved solids, total coliforms, fecal coliforms, and fecal streptococcus. In order to determine quality changes between a runoff retention basin or other manure-laden water storage and the receiving soil surface, a separate study was conducted. Ammonia nitrogen is the major constituent lost. A technique was devised and tested for prediction of ammonia nitrogen loss as a function of wastewater quality, sprinkler equipment characteristics, and current weather data. Losses ranged from zero to 40 percent.

This project summary was developed by EPA's Robert S. Kerr Environmental Research Laboratory in Ada, OK, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Runoff from cattle feedlots was recognized as a potential water pollutant in 1962, following a series of fish kills in Kansas; since that time, a technology for control of feedlot runoff has evolved, accompanied by a variety of regulatory schemes. The strategy proven most feasible is the collection of stormwater runoff in a retention basin or pond. Following a storm, the manure-laden water is applied to cropland in a manner to avoid runoff. This approach recaptures plant nutrients, thereby reducing the cost of chemical fertilizer,

Table 1. *Cattle Feedlot Runoff Retention Basin Quality Parameters to be Predicted in the Developed Model.*

Parameter	*Abbreviation*	*Unit*
Chemical oxygen demand	*COD*	*mg/l*
Total Kjeldahl nitrogen	*TKN*	*mg/l*
Ammonia nitrogen $(NH_3+NH_4^+)$*-N*	NH_3*-N*	*mg/l*
Total phosphorus	*Total-P*	*mg/l*
Total volatile solids	*TVS*	*mg/l*
Fixed dissolved solids	*FDS*	*mg/l*
Total solids	*TS*	*mg/l*
Total coliforms	*TC*	*No./100 ml*
Fecal coliforms	*FC*	*No./100 ml*
Fecal streptococcus	*FS*	*No./100 ml*

some of which is replaced by the runoff water. The capacity of a runoff retention basin for a given location is a function of climate, feedlot size, availability of liquid-removal equipment, frequency of pumping and the required level of pollution control. Construction of a basin which could retain all runoff, even during the most extreme weather conditions, is unreasonably expensive and provides only minimal additional pollution control than a less expensive system for which well-defined limitations exist. Feedlot pollution control guidelines define the conditions under which a discharge will occur in a well-designed feedlot runoff control system during extreme weather conditions; typically, these are the 10-year, 24-hour storm and the 25-year, 24-hour storm.

Cattle feedlot runoff is a high-strength organic wastewater containing large numbers of enteric microorganisms. Quality of runoff water is highly variable, depending upon such parameters as rate of rainfall, temperature, and feedlot surface conditions. Quality is further modified by storage in the runoff control system; organic matter is stabilized, solids settle, ammonia volatilizes, and enteric bacteria die off. All of these changes influence the quality of basin contents; conversely, the rate of change is influenced by the quality of runoff water in the basin.

The quality and quantity of the discharged material must be known, if its impact on retention basin water is to be accurately predicted. When basin contents are to be applied to cropland, optimal application rates are a function of nitrogen concentration. Accurate quality predictions are critical if optimal nutritive values are to be fully realized.

Previous modeling efforts have provided techniques for predicting the size of runoff retention facilities to achieve various levels of runoff control or to predict the runoff retention achieved by various combinations of retention basin sizes and management strategies. No previous efforts have attempted to predict the quality of retention basin contents.

The initial plan for this effort was in two phases. The first phase was to develop a predictive model to estimate the pond volume, liquid temperature, and liquid constituent concentrations listed in Table 1.

Originally, a cattle feedlot runoff retention basin was to be sampled simultaneously to generate data for calibrating the model. In Phase II of the project, the model was to be verified by the collection of data in an intensive field study. Due to changing research priorities within the EPA, only Phase I of the project was funded: the development of a continuous water quality model which will predict, on a daily basis, the quality of feedlot runoff entering a runoff retention basin and contained in the basin. That runoff would be discharged in case of an uncontrolled event, or removed from the basin for subsequent treatment, or disposal on land. The predicted quality for basin contents will be compared with analytical data based upon sampling a cattle feedlot runoff retention basin in eastern Illinois during the summer of 1978.

In a separate but related effort, quality changes occurring during the sprinkler application of anaerobically stored liquid manure to cropland was investigated. Those data are also included in this report.

Conclusions

Originally, this project was to include two additional years of feedlot runoff and runoff retention basin sampling at several locations, to confirm the validity of the model and to better define variations in the derived coefficients as a function of site-specific variables. Due to changes in priorities within EPA, funding was not provided beyond the initial phase; therefore, a degree of uncertainty remains concerning the accuracy of the reported coefficients when applied to sites in different climatic and geographic regions.

A technique was developed to predict the quality of cattle feedlot runoff based upon the various parameters. Using this technique, it is possible to obtain a better estimate of this quality than by any other known procedure. Previous work by the authors of this report and others has provided a satisfactory method of estimating runoff quantity in response to climatic data and feedlot characteristics. The water quality model of a runoff retention basin developed in this project is based upon an analysis of previously published data and intensive sampling of a cattle feedlot in Illinois. The model represents the best available technique for predicting the quality of runoff water used for land application under specific climatic conditions, should runoff exceed the storage capacity of the retention basin. Daily calculation of liquid volume in a retention basin is possible with this technique. Also, the following water quality parameters can be predicted: COD, TS, FDS, TC, FC, and FS.

Water quality changes between a storage reservoir and the land surface during the process of sprinkler irrigation were analyzed to document that the only significant change was NH_3-N volatilization. Depending primarily on pH of the wastewater, volatilization of NH_3-N can range from nearly zero to over 40 percent. Other variables which influence NH_3-N loss are air temperature, wind velocity, relative humidity, droplet size and travel distance of the droplet. The predictive technique devised allows precise definition of this nutrient loss.

Hydrologic Model

The hydrologic model developed in this study can predict quality of runoff in the following stages: (1) entering the retention basin after running off a feedlot surface and passing through a solids trapping phase in a settling basin, a porous dam, or a grassed waterway, (2) contained in the retention basin, (3) discharged from the retention basin by uncontrolled events, (4) removed for subsequent application to land, and (5) deposited on the interception surface of the land treatment area. The hydrologic model and management scheme provided the input quantities to determine how long material has been in the basin and the extent of its degradation.

This water quality model complements the water quantity models developed previously under EPA grants to Oregon State University and Kansas State University. When completed, this water quality model will provide a complete quality and quantity model, to provide a tool for evaluating the impact of a cattle feedlot upon the water quality in a basin.

The continuous watershed model for the hydrologic portion of the feedlot runoff control system has previously been described by Zovne and Koelliker[1]. The reader is directed to that publication for a complete description of the model. Included herein is an abridged description. Figure 1 shows a process schematic of the feedlot runoff model. The three components of the model are the feedlot runoff generating surface, a runoff retention basin and a soil moisture budget model for the runoff disposal area.

[1] Zovne, J. J. and J. K. Koelliker. 1979. *Application of Continuous Watershed Modeling to Feedlot Runoff Management and Control*. EPA-600/2-79-065, U.S. Environmental Protection Agency, Washington, DC, 156 pp.

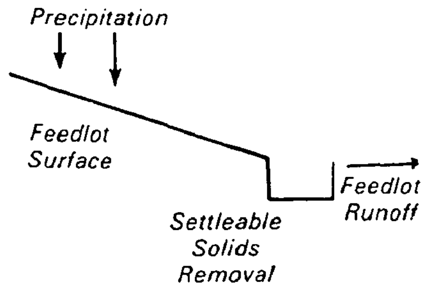

Figure 1. *Feedlot runoff generating system.*

For the purposes of the hydrologic model, the surface area of the feedlot must be defined so that the depth of runoff produced times the area of the feedlot will yield the runoff volume. Likewise, the total surface area of the retention pond at maximum depth must be defined since the amount of precipitation falling upon this surface is all added to the volume of the basin. The volume of precipitation added to the basin is then the daily depth of precipitation times the maximum surface area. To determine evaporation from the pond, the side slope, length, and width of a pond must be defined. Evaporation, considered to occur only from the actual surface area of the liquid within the pond, is equal to the actual surface area times the predicted daily depth on pond evaporation. The volume removed for disposal is a function of the area of the disposal field to which liquid can be applied by the disposal system times the depth of liquid that will be appliled in one day. Therefore, the physical capabilities of the disposal system must be defined in order to set the daily disposal volume. Discharge occurs when the retention pond volume is exceeded. Therefore, a maximum pond depth is also required.

The deterministic water budget model for the hydrology of the system is driven by daily values of minimum and maximum air temperature and daily precipitation from a continuous weather record for a particular station. Other meteorological inputs required are monthly mean values of air temperature, solar radiation, relative humidity, wind travel, percent sunshine, and A and B coefficients for the Brunt equation. Other input data needed for the feedlot include a soil type in the disposal area of only 12 classifications; crop to be grown on the disposal area; the management system for operation of disposal, if any; and the limitations of the amount of runoff applied in any one period, if any. These inputs are summarized in Table 2.

Table 2. *Inputs to the Hydrologic Model.*

Physical characteristics of the system
- *Feedlot surface area*
- *Surface area of retention basin at capacity*
- *Retention basin dimensions and interior slopes*
- *Disposal field*
  - *Area*
  - *Soil type (one of 12)*
  - *Crop to be grown*
  - *Management system*
  - *Maximum application rate*

Climatic data
- *Monthly mean data*
  - *Air temperature*
  - *Solar radiation*
  - *Relative humidity*
  - *Wind travel*
  - *Percent sunshine*
  - *Brunt equation coefficients A and B*
- *Daily values*
  - *Maximum temperature*
  - *Minimum temperature*
  - *Precipitation*

This model was developed as a technique to evaluate a particular feedlot in a particular location within the continental United States; it is considered to be the most rigorous hydrologic model that has yet been developed for a feedlot runoff control system. All masses of constituents will be reported in kg/ha and all concentrations in mg/l

Adaptation to Hydrologic Model for Water Quality Considerations

For purposes of the water quality model, a unit feedlot area is considered. To accommodate this approach with the hydrologic model, a runoff control system provides realistic runoff control at a particular location. Next, all volumes generated in the hydrologic model are divided by the feedlot area to provide values in terms of a depth per unit area of feedlot. Further, all depths are converted to SI units of cubic meters per hectare (m^3/ha). This approach allows for a simpler look at the quality of runoff without complicating the issue with the physical size of the feedlot runoff control system; i.e., the size of the feedlot has no influence upon the quality of the runoff water. However, such factors as the shape and depth of the pond may have some influence on water quality within the system at any given time. The model's prediction of feedlot runoff control quality is unlikely to be precise enough to separate such variables.

For the water quality model, the daily changes in liquid volume in the retention basin in m^3/ha, then is described by:

$$\Delta V = RUNOFF + PRECIP - SEVAP - DISVOL - DSCHRG \quad (1)$$

where,

ΔV = change in liquid volume,
RUNOFF = feedlot runoff into the basin,
PRECIP = precipitation onto the basin surface,
SEVAP = evaporation from basin surface,
DISVOL = amount of liquid removed by disposal operation, and
DSCHRG = amount of liquid discharged by uncontrolled events.

Infiltration through the bottom of the pond is assumed to be zero. Sludge is the volume of solids that accumulates within the retention pond as estimated in the COD portion of the model. The volume of liquid within the pond at any time per ha of feedlot is equal to the pond volume (PONVOL) yesterday, plus ΔV minus the increased volume occupied by the sludge.

Modeling Cattle Feedlot Runoff Quality

The cattle feedlot runoff process is a complex phenomenon controlled by a variety of physical, climatological, and environmental factors. An effective modeling effort requires that these factors are selectively handled to assure that the end product is useful as a planning tool even where in-depth local data are not available.

Although a fully satisfactory relationship between the factors influencing the cattle feedlot runoff process and runoff quality has not been achieved, nor is it likely to be achieved in the future, there are sufficient data available to use runoff quality as an input in calculating the quality of runoff retention basin contents. The structure of this process utilizes commonly available climatic and physical data to make the needed estimates. The following basic structure is inherent in the process being proposed:

1. Cattle feedlot runoff is an area-based phenomenon; hence, the constituent concentrations are independent of feedlot size.
2. Being an area-based process, the number of cattle on the lot is not an input to the process. This assumes the cattle are present in sufficient intensity to preclude the growth of vegetation, but not at such an intensity to inhibit efficient animal growth nor to result in unsuitable lot conditions. Typically, this translates into an animal density of between 350 and 850 head per ha (150 and 350 head/ac).
3. Some technique to remove easily settleable solids from runoff, prior tointroduction of the runoff into a retention basin, is a function of sound design; such a function is assumed to be part of this model. The technique might involve use of a debris basin, grassed waterway, sedimentation basin, porous dam, or any other device to provide short-term sedimentations.
4. This is a calendar-based model devised to estimate the average concentration of runoff produced by the precipitation occurring on a specific day. For a storm which occurs on two or more successive days, each day is treated separately.

The physical, chemical, and microbiological quality of cattle feedlot runoff is highly variable, not only among sites and separate storms but during the progress of a runoff event as well.

Field Sampling Program for Data Collection

The basis for selection of an ideal feedlot site from which to collect field data was that the site be representative of typical conditions in the major feeding areas of the United States; also, a site was needed which would insure several runoff events and disposal, from the retention pond during the testing period. As much variation as possible in pond volume and water quality as desired to assure that the model would be responsive to such changes. Since our sampling program was operated during the spring and summer, we chose a more humid region of the country where rainfall was likely to be more consistent. Previously, sampling programs had been run at several feedlot locations in Illinois. Also, previous data were available in a form which could be applied to evaluate the model's performance.

Incorporation of Field Data into Predictive Model

Occasionally, large discrepancies occurred between measured pond volumes and volumes predicted by the hydrologic model. The nature of these discrepancies indicated that substantial subsurface seepage was entering the pond, possibly originating in cultivated fields adjacent to the feedlot. These spurious flows rendered much of the data useless. As a consequence, only data collected during a single 45-day perod was considered reliable enough to be used for calibration of the model. The accepted procedure for a modeling effort of this sort calls for calibrating the model with one set of data, and then testing with a second set of data. However, because of the subsurface flow problem, the data collected were not sufficient for an independent test of the model. Because of the resultant data limitations, simple calibration of the model did not confirm the model, nor did it adequately represent the ideal situation upon which the model building effort was posited.

Demonstration of the Model

To demonstrate the model's ability to predict runoff and retention basin quality, a simplified weather pattern was adopted in which constant monthly temperatures were assumed and discrete rainfall events were specified. Those simplifying assumptions allow the influence of particular variables to be noted so that the function of the model can be viewed. A runoff retention basin having a surface area equal to 35 percent of the feedlot surface area was assumed.

Variations in cattle feedlot runoff quality were expected to occur with temperature, rainfall intensity and previous rainfall for various dates on which runoff was assumed to occur. The effect of precipitation occurring as accumulated snowfall is shown by the runoff which occurred on specific dates when no rainfall occurred. Januarv temperatures were assumed to be sufficiently low to maintain a snowpack; hence, a high concentrated runoff was noted as soon as the temperature increased. Subsequent storms of one, two and three days duration are shown for comparison purposes to note the effect of those variables on both runoff quality and quantity.

The impact that various runoff events have on the pond liquid concentrations were shown by measuring runoff retention basin quantity and quality. In all cases, the pond is assumed to have a completely mixed liquid layer overlying a sludge layer. Thus, a runoff event has an immediate effect upon the liquid concentration. The periods during which various constituents increased when no runoff was occurring reflects the degradation of the sludge layer releasing soluble materials into the liquid portion. Again, the model allows one to view the impact of temperature and precipitation on the rate of change of various constituents with time.

J. Ronald Miner and Marshall J. English are with the Department of Agricultural Engineering, Oregon State University, Corvallis, OR 97331, and James E. Koelliker is with the Agricultural Engineering Department, Kansas State University, Lawrence, KS 66044.

R. Douglas Kreis *is the EPA Project Officer (see below).*

The complete report, entitled "Predicting Cattle Feedlot Runoff and Retention Basin Quality," (Order No. PB 81-113045; Cost: $17.00, subject to change) will be available only from:

National Technical Information Service
5285 Port Royal Road
Springfield VA 22161
Telephone: 703-487-4650

The EPA Project Officer can be contacted at:

Robert S. Kerr Environmental Research Laboratory
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

☆ U.S. GOVERNMENT PRINTING OFFICE: 1981 -757-064/0238

United States
Environmental Protection
Agency

Center for Environmental Research
Information
Cincinnati OH 45268