# Differences in Evaporation Between Feedyard Effluent and Clear Water Cause Overprediction of Seepage Estimates

David B. Parker, West Texas A&M University
Brent W. Auvermann, Texas A&M Research and Extension Center
Darren L. Williams, West Texas A&M University

## ABSTRACT

Clear water evaporation estimates are often used in water balance calculations to determine seepage rates from feedyard holding ponds and lagoons. However, feedyard effluent has different physical and chemical characteristics than clear water. The objectives of this research were to compare clear water and feedyard effluent evaporation rates and to determine how inaccuracies in evaporation estimates affect seepage predictions. Experiments were conducted using small evaporation pans and a Class A Pan, using different concentrations of feedyard effluent. The 100% feedyard effluent evaporated 8.3 to 10.7 percent faster than the clear water, which means that seepage will be overestimated if clear water evaporation estimates are used in water balance calculations. For clay liners with hydraulic conductivities of $2.8\times10^{-4}$ to $2.8\times10^{-5}$ ft/day ($1.0\times10^{-7}$ to $1.0\times10^{-8}$ cm/sec), we show that underestimating evaporation by 10 percent when actual evaporation is 0.44 inches/day results in seepage rate predictions of 3 to 20 times higher than actual seepage rates. Considering that some states have allowable seepage rates ranging from 0.03 to 0.25 inches/day, an overestimation of 0.04 inches/day could cause problems with environmental regulations, thus demonstrating the importance of accurate evaporation estimates when predicting seepage using the water balance method. Errors in evaporation estimates could also cause errors in long-term water balance calculations used for sizing ponds and lagoons.

## INTRODUCTION

In the past, researchers have estimated seepage rates from animal waste holding ponds and lagoons using a water balance. Assuming no inflow into a pond during the measurement period, seepage rates for the period of interest are determined by subtracting the estimated amount of evaporation from the total decline in pond stage. Thus, the accuracy of the seepage measurement is only as accurate as the evaporation estimate.

The use of a coefficient applied to monthly pan evaporation to obtain open water (lake surface) evaporation rates has been a long accepted practice (Kane, 1967). In studies conducted in Texas, monthly pan coefficients for the Class A Pan were reported to range from 0.64 in April to 0.92 in November (Kane, 1967), meaning that monthly lake surface evaporation was 64 to 92% of the monthly Class A Pan evaporation rates.

Several researchers have used pan coefficients and Class A Pan evaporation rates to estimate evaporation from animal waste ponds and lagoons. Robinson (1973) used 70% of the clear water-filled Class A Pan evaporation rate to estimate evaporation and seepage from a beef cattle holding pond in California. He found that seepage rates were reduced from 4.4 inches/day initially to 0.12 inches/day when effluent was placed in the earthen pond. Davis et al. (1973) used 100% of the clear water-filled Class A Pan evaporation rate for seepage studies on a newly constructed dairy waste pond in California. Davis estimated seepage rates of 0.20 inches/day four months after placing effluent and waste in the earthen pond. At a Nebraska beef cattle feedyard holding pond, Parker et al. (1999) used an effluent-filled plastic pan placed in an excavation on the pond sidewall to measure evaporation and seepage rates. Parker assumed that evaporation from the small pan was equal to evaporation from the holding pond. Over a week long period in September, evaporation averaged 0.24 inches/day and seepage rates averaged 0.34 inches/day.

A question arises as to the accuracy of estimating feedyard holding pond evaporation using clear water evaporation rates. There are several factors that could cause potential evaporation differences between the two liquids. Wastewater in holding ponds and lagoons is typically dark brown to reddish brown, a result of suspended sediment and bacteria (Wenke and Vogt, 1981; Freedman et al., 1983). Dark colored water absorbs more radiation, which could cause greater evaporation rates than from clear water. Also, high ammonia concentrations in feedyard effluent could increase the vapor pressure of the solution, resulting in higher evaporation rates than from pure water. Conversely, the high salinity of the feedyard effluent could cause a decreased vapor pressure resulting in less evaporation.

The objectives of this research were to 1) compare feedyard effluent and clear water evaporation rates and 2) determine how inaccuracies in evaporation estimates affect water-balance-based seepage rate predictions.

## MATERIALS AND METHODS

Evaporation experiments were conducted at West Texas A&M University's Research Feedyard located six miles east of Canyon, Texas. The experimental setup consisted of 36 translucent plastic pans (Rubbermaid Model 3863) of dimensions 13 inches length, 9 inches width, and 4.75 inches depth. The plastic pans were evenly distributed on two sheets of ¾ inch thick plywood placed to form a square of dimensions 8 ft x 8 ft. The plywood was supported 6 inches above the ground surface on cinder blocks. The plywood was painted white on one side and dark brown on the other. A Class A Pan was placed 6 ft south of the 36 pans, and an automated weather station (Campbell Scientific Inc., Logan, UT) was placed 50 yards south of the 36 pans. At the beginning of each experiment, clear water or effluent was filled to an initial depth of 4.0 inches.

We were concerned that evaporation rates could vary with location on the plywood because of wind and temperature effects. To minimize the effect of location, only the inner 16 pans were used in the experiments, with the outer ring of 20 pans placed to reduce the effects of wind and location. To further account for the effect of location, the experimental design consisted of a 4x4 Latin square (Hoshmand, 1998), with four treatments and two blocking variables (row and column). The treatments were randomly assigned so that each treatment occurred once in each column and once in each row.

Experiments were conducted to compare evaporation rates of effluent and clear water. The treatments consisted of 100% effluent (TRT 1), 50% effluent mixed with 50% ground water (TRT 2), 25% effluent mixed with 75% ground water (TRT 3), and 100% ground water (TRT 4). Experiment 1 was conducted with the white side of the plywood facing upward. Experiment 2 was conducted with the dark brown side of the plywood facing upward. Water temperatures were measured at 1200 hrs at the completion of Experiment 2. Experiment 3 was conducted to compare evaporation rates of clear water with electrical conductivities (salt contents) in the same range as at the start of Experiments 1-2. Sodium chloride (table salt) was added to ground water to obtain an initial electric conductivity equal to that for 100% effluent (11.4 mS/cm) and 100% ground water (0.60 mS/cm), with intermediate electrical conductivities of 5.7 and 2.8 mS/cm. Experiment 3 was conducted with the dark brown side of the plywood facing upward.

The effluent used in the experiments was collected from a runoff holding pond at a commercial feedyard. Clear water was collected from a ground water well near the West Texas A&M Research Feedyard in Randall County, Texas, which pumps water from the Ogallala aquifer at a depth of 100 ft.

Statistical analyses were performed using the GLM procedure in SAS (1996). Analyses from all experiments were analyzed as a Latin square in addition to performing two-sample t-tests (LSD comparisons) between each treatment pair at $\alpha$=0.05.

## RESULTS AND DISCUSSION

### Evaporation From Feedyard Effluent

When the white plywood background was used, the mean evaporation rate for clear water ($\bar{X}$=0.57 inches/day) was significantly less than evaporation from the three effluent treatments ($\bar{X}$=0.61 inches/day for 100% feedyard effluent), and there were no significant differences in evaporation for the three effluent treatments (Table 2). When the dark brown plywood background was used, the mean evaporation rate for clear water ($\bar{X}$=0.48 inches/day) was again significantly less than evaporation from the three treatments of effluent ($\bar{X}$=0.53 inches/day for 100% feedyard effluent). The 100% effluent evaporation rates were 8.3 and 10.7 percent greater than the clear water evaporation rates for the white and dark brown backgrounds, respectively.

### Comparison of Clear Water Evaporation at Different Salinities

In Experiment 3, the mean daily evaporation rate for the clear water with the highest conductivity (0.36 inches/day) was significantly lower than the mean evaporation rate for the three other treatments (0.37 inches/day). The difference was smaller (only 1.8 percent) than differences measured with different concentrations of effluent (which ranged from 8.3 to 10.7 percent). No statistical differences were detected among Treatments 2, 3, and 4 (Table 2).

### Temperature at Completion of Experiments

In Experiment 2, the mean clear water temperature (TRT 4) was significantly cooler than the three feedyard effluent temperatures (TRT 1-3), but no differences were observed among the effluent treatments (TRT 1-3). Experiment 3, there were no differences between any of the treatments (Table 3). From the results of Experiment 3, we concluded that salinity differences did not significantly affect water temperature.

### The Significant of Error in Evaporation Prediction

To illustrate the significance in evaporation estimation and measurement when predicting seepage from earthen-lined feedyard holding ponds, we present a hypothetical example for a typical feedyard holding pond (Table 4). In our example, we assume that actual evaporation is ten percent greater than predicted evaporation, which is on the same order as the results from this research. If our predicted evaporation rate is 0.4 inches/day (Column 6), a typical summertime evaporation rate for the Southern High Plains, then our actual evaporation rate will be ten percent greater than this, or 0.44 cm/day (Column 4). We assume a water depth of 5 ft and clay liner thickness of 12 inches for a hydraulic gradient of 6.0. We calculate the "actual" seepage (Column 5) using Darcy's law by multiplying the hydraulic conductivity (Column 2) times the hydraulic gradient (six in this case), and do this for hydraulic conductivities covering five orders of magnitude of 0.28 ft/day to $2.8\times10^{-5}$ ft/day (8.64 to $8.64\times10^{-4}$ cm/day). Our "measured" or "actual" decline in pond stage (Column 3) is calculated by adding the actual evaporation (Column 4) and the actual seepage (Column 5).

The predicted seepage (Column 7) is determined by subtracting predicted evaporation (Column 6) from the decline in pond stage (Column 3). The error in the seepage rate prediction was determined using the following equation:

$$\%\ \text{Error} = \frac{\text{Predicted Seepage Rate} - \text{Actual Seepage Rate}}{\text{Actual Seepage Rate}} * (100\%) \qquad [1]$$

At a hydraulic conductivity (K) of 0.28 to 0.028 ft/day ($1\times10^{-4}$ to $1\times10^{-5}$ cm/sec), which is characteristic of many silts and silty sands, the error in the seepage rate prediction is relatively small (0.19 to 1.9%). This is because the evaporation rate is small relative to the seepage rate for hydraulic conductivites in this range. As the hydraulic conductivity becomes smaller, the error in seepage prediction increases. At $K=2.8 \times 10^{-3}$ ft/day ($1\times10^{-6}$ cm/sec), the error in seepage rate prediction is about 20%. A hydraulic conductivity value of $2.8\times10^{-4}$ ft/day ($1\times10^{-7}$ cm/sec) is often considered a critical value because several states including New Mexico, North Carolina, Oklahoma, South Dakota, and *Texas* use this value as a maximum for animal waste pond and lagoon liners, as do federal regulations for solid waste landfill liners (NMED, 1995; NCDEHNR, 1997; ODA, 1997; SDDENR, 1997; TNRCC, 1995). At $K=2.8\times10^{-4}$ ft/day, the error in the predicted seepage rate is nearly 200%. From another perspective, when $K=2.8\times10^{-4}$ ft/day, the predicted seepage rate and predicted K are about three times as great as the actual seepage rate and actual K. The error is higher at $K=2.8\times10^{-5}$ ft/day (almost 2,000%), with the predicted seepage rate and predicted K about 20 times as great as the actual seepage rate and actual K.

These overestimations in the seepage rate or K could have a negative impact on a feedyard in the case where the estimated seepage rate or K was greater than that allowed by state or federal regulations. Considering that several states (Colorado, Iowa, Nebraska, Kansas) have allowable seepage rates ranging from 0.03 to 0.25 inches/day (CWQCC, 1997; IAC, 1992; NDEQ, 1995; KDHE, 1978), an overestimation of 0.04 inches/day could cause unwarranted fines or penalties, or require construction of a new pond or liner for an existing pond.

## CONCLUSIONS

Our research results showed that evaporation rates for 100% effluent were 8.3 to 10.7 percent greater than clear water evaporation rates. If seepage rates are determined by water balance with clear water evaporation estimates, then underestimating evaporation by 10 percent when actual evaporation is 0.44 inch/day (1.1 cm/day) causes the predicted seepage rate to be about three times the actual rate for a clay liner with hydraulic conductivity on the order of $2.8\times10^{-4}$ ft/day ($1\times10^{-7}$ cm/sec), and up to 20 times the actual seepage rate if the hydraulic conductivity is $2.8\times10^{-5}$ ft/day ($1\times10^{-8}$ cm/sec). We demonstrated how errors in evaporation estimation could be large enough to pose potential problems with meeting state regulatory requirements for allowable seepage rates. The results of these experiments demonstrate the importance of an accurate evaporation estimate when measuring seepage using the water balance approach. Also, because of the sensitivity of the water balance method for estimating seepage and evaporation rates from feedlot holding ponds, we recommend that readings be taken over a period of several days or longer to account for measurement error.

## REFERENCES

Burman, R.D., R.H. Cuenca, and A. Weiss. 1983. Techniques for estimating irrigation water requirements. In Daniel Hillel, Ed. Advances in Irrigation, Volume 2. pp. 335-394. Academic Press Inc., New York, NY.

CWQCC. 1997. Confined animal feeding operations control regulation No. 81 (5CCR 1002-81). Colorado Department of Publich Health and Environment, Water Quality Control Commission. Denver, CO.

Davis, S., W. Fairbank, and H. Weisheit. 1973. Dairy waste ponds effectively self-sealing. *Transactions of the ASAE* 16(1):69-71.

Freedman, D., B. Koopman, and E. P. Lincoln. 1983. Chemical and biological flocculation of purple sulfur bacteria in anaerobic lagoon effluent. *J. Agric. Engng. Res.* 28:115-125.

Hoshmand, A.R. 1998. Statistical methods for environmental and agricultural sciences. 2nd Ed. CRC Press:New York.

IAC. 1992. Environmental regulations and guidelines for animal feeding operations in Iowa. Iowa Administrative Code, Chapter 65 of the Environmental Protection Commission, Section 567. Des Moines, IA.

Kane, J.W. 1967. Monthly reservoir evaporation rates for Texas 1940 through 1965. Texas Water Development Board Report 64. Austin, TX.

KDHE. 1978. Minimum standards of design for water pollution control facilities. Kansas Department of Health and Environment. Topeka, KS.

NCDEHNR. 1997. North Carolina Administrative Code Section 15A NCAC 2H .0200 "Waste Not Discharged to Surface Waters." State of North Carolina Department of Environment, Health and Natural Resources. Raleigh, NC.

NDEQ. 1995. Rules and regulations pertaining to livestock waste control, Title 130, Ch. 1-19. Nebraska Department of Environmental Quality. Lincoln, NE.

NMED. 1995. Guidelines for liner material and construction of clay-lined lagoons. New Mexico Environment Department Ground Water Pollution Prevention Section. Santa Fe, NM.

ODA. 1997. Rules for concentrated animal feeding operations. Oklahoma Department of Agriculture. Title 35, Chapter 17, Subchapter 3. Oklahoma City, OK.

Parker, D.B., D.E. Eisenhauer, D. D. Schulte, and J.A. Nienaber. 1999. Seepage characteristics and hydraulic properties of a feedlot runoff storage pond. Transactions of the ASAE, 42(2):369-380.

Robinson, F. E. 1973. Changes in seepage rate from an unlined cattle waste digestion pond. *Transactions of the ASAE* 16(1):95-96.

SAS. 1996. SAS Software, SAS Institute Inc., Cary, N.C.

SDDENR. 1997. Draft general water pollution control permit for concentrated animal feeding operations. South Dakota Department of Environment and Natural Resources. Pierre, South Dakota.

TNRCC. 1995. Animal Waste Management Rules - Subchapter B: Livestock and Poultry Production Operations. Chapter 321. Texas Natural Resource Conservation Commission. Austin, TX.

Wenke, T.L. and J.C. Vogt. 1981. Temporal changes in a pink feedlot lagoon. *Applied and Environmental Microbiology* 41(2):381-385.

**Table 1. Chemical and physical characteristics of the feedyard effluent used in the experiments.**

| Parameter | Concentration |
|---|---|
| Electrical Conductivity (mmhos/cm) | 8.0 |
| Chloride (mg/l) | 1,575 |
| Sulfate (mg/l) | 50 |
| TSS (mg/l) | 669 |
| Total Coliform (colonies/100 ml) | 9,000 |
| Fecal Coliform (colonies/100 ml) | 5,600 |
| pH | 8.0 |
| Total Kjeldahl Nitrogen (mg/l) | 210 |
| Nitrate-N (mg/l) | 1.0 |
| Ammonium-N (mg/l) | 108 |
| Potassium (mg/l) | 1,625 |
| Phosphorus (mg/l) | 54 |
| Boron (mg/l) | 1.0 |
| Calcium (mg/l) | 265 |
| Magnesium (mg/l) | 213 |
| Sodium (mg/l) | 993 |

**Table 2. Measured evaporation rates for evaporation experiments.**

| | Effluent Experiments<br>Mean Evaporation Rate (inches/day) † | | | | |
|---|---|---|---|---|---|
| | TRT 1 100% Feedyard Effluent | TRT 2 50% Feedyard Effluent | TRT 3 25% Feedyard Effluent | TRT 4 100% Clear Ground Water | Class A Pan With Clear Ground Water |
| Experiment 1 (white plywood) | 0.61a | 0.62a | 0.62a | 0.57b | 0.50 |
| Experiment 2 (brown plywood) | 0.53a | 0..52b | 0.52b | 0.48c | 0.51 |
| | Saltwater Experiment<br>Mean Evaporation Rate (inches/day) | | | | |
| | TRT 1 11.4 mS/cm | TRT 2 5.7 mS/cm | TRT 3 2.8 mS/cm | TRT 4 (no salt) 0.6 mS/cm | Class A Pan (no salt) 0.6 mS/cm |
| Experiment 3 (brown plywood, clear water) | 0.36a | 0.37b | 0.37b | 0.37b | 0.35 |

Row values followed by different letters are significantly different ($\alpha=0.05$).
†Means are averages of four observations. Only one Class A Pan was used.

**Table 3. Measured water temperatures at completion of evaporation experiments.**

| | Effluent Experiments<br>Final Temperature (°F)† | | | | |
|---|---|---|---|---|---|
| | TRT 1 100% Feedyard Effluent | TRT 2 50% Feedyard Effluent | TRT 3 25% Feedyard Effluent | TRT 4 100% Clear Ground Water | Class A Pan With Clear Ground Water |
| Experiment 1 (white plywood) | NA | NA | NA | NA | NA |
| Experiment 2 (brown plywood) | 84.0a | 84.7a | 84.9a | 81.9b | 78.1 |
| | Saltwater Experiment<br>Final Temperature (°C) † | | | | |
| | TRT 1 11.4 mS/cm | TRT 2 5.7 mS/cm | TRT 3 2.8 mS/cm | TRT 4 (no salt) 0.6 mS/cm | Class A Pan (no salt) 0.6 mS/cm |
| Experiment 3 | 78.5a | 78.3a | 78.3a | 78.2a | 75.4 |

Row values followed by different letters are significantly different ($\alpha=0.05$).
†Means are averages of four observations. Only one Class A Pan was used. NA=temperature data not recorded.

**Table 4. Evaluation of Error in Seepage Prediction if Actual Evaporation is 10% Greater Than Predicted Evaporation**

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|
| Actual Hydraulic Conductivity (cm/sec) | Actual Hydraulic Conductivity (cm/day) | Actual Stage Decline (cm/day) | Actual Evaporation Rate (cm/day) | Actual Seepage Rate (cm/day) | Predicted Evaporation Rate (cm/day) | Predicted Seepage Rate (cm/day) | Predicted Hydraulic Conductivity (cm/sec) | Difference Between Predicted and Actual Seepage (cm/day) | Error in Seepage Rate Prediction (%) |
| $1x10^{-4}$ | 8.6 | 52.9 | 1.1 | 51.8 | 1.00 | 51.9 | $1.00x10^{-4}$ | 0.10 | 0.19 |
| $1x10^{-5}$ | 0.86 | 6.28 | 1.1 | 5.18 | 1.00 | 5.28 | $1.02x10^{-5}$ | 0.10 | 1.9 |
| $1x10^{-6}$ | 0.086 | 1.618 | 1.1 | 0.518 | 1.00 | 0.618 | $1.19x10^{-6}$ | 0.10 | 19.3 |
| $1x10^{-7}$ | 0.0086 | 1.152 | 1.1 | 0.0518 | 1.00 | 0.152 | $2.93x10^{-7}$ | 0.10 | 193 |
| $1x10^{-8}$ | 0.00086 | 1.105 | 1.1 | 0.00518 | 1.00 | 0.105 | $2.03x10^{-7}$ | 0.10 | 1930 |

Notes: Calculations assume hydraulic gradient of 6.0.
Col. 4=Col.6 * 110%
Col. 5=Col.2 * 6.0
Col. 3=Col.4 + Col.5
Col. 7=Col.3 - Col.6
Col. 8=Col.7 / 6.0 / 86,400
Col. 9=Col.7 - Col.5