Comparison of Evaporation Rates from Feedyard Pond Effluent and Clear Water as Applied to Seepage Predictions

D. B. Parker, B. W. Auvermann, D. L. Williams

Abstract. *Evaporation estimates are often used in water balance calculations to determine seepage rates from feedyard holding ponds and lagoons. These estimates have been made using empirical equations derived for clear water, Class A Pan evaporation measurements using clear water, and rule-of-thumb estimates. 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. Small evaporation pans were placed in a 4 × 4 Latin square design adjacent to a Class A Pan. Four experiments were conducted to compare evaporation rates at different concentrations of feedyard effluent, and a fifth experiment was conducted to compare clear water evaporation at different salt concentrations to test for potential vapor pressure effects. For the two experiments when freshly collected feedyard effluent from a holding pond was used, representing typical feedlot holding pond conditions with visible suspended sediment concentrations and dark colored effluent, the feedyard effluent evaporated 8.3 and 10.7% more than the clear water ($p = 0.001$ and $p = 0.0001$). When week-old feedyard effluent was used, representing clearer effluent with minimal suspended sediment, the differences were reduced to 3.2 and 0.0% ($p = 0.03$ and $p = 0.70$). For clay liners with hydraulic conductivities of 1×10^{-7} to 1×10^{-8} cm/s, we show that underestimating evaporation by 10% when actual evaporation is 1.1 cm/day results in seepage rate predictions of 3 to 20 times higher than actual seepage rates. Similarly, underestimating evaporation by 10% when actual evaporation is 2.2 cm/day results in seepage rate predictions of 5 to 40 times higher than actual seepage rates. This corresponds to 0.10 and 0.20 cm/day higher seepage rates for actual evaporation of 1.1 and 2.2 cm/day, respectively. Considering that some states have allowable seepage rates ranging from 0.08 to 0.63 cm/day, an overestimation of 0.1 to 0.2 cm/day could have serious ramifications with environmental regulators, thus demonstrating the importance of accurate evaporation estimates when predicting seepage using the water balance method.*

Keywords. *Evaporation, Seepage, Infiltration, Animal waste, Manure, Pond, Lagoon.*

There is evidence that seepage from feedyard holding ponds and lagoons can contaminate groundwater with nutrients, salts, and pathogens (Norstedt et al., 1971; Sewell, 1978; Hegg et al., 1979; Miller et al., 1985; Huffman and Westerman, 1995; Westerman et al., 1995; Parker et al., 1999). In the past, researchers have estimated seepage rates from existing 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 11.2 cm/day initially to 0.30 cm/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 0.50 cm/day four months after placing effluent and waste in the earthen pond. Cumba and Hamilton (1998) developed a swine lagoon water balance computer program to predict fluctuations in lagoon stage. For their lagoon evaporation estimates, they used 70% of the evaporation predicted using the Modified Penman Combination Method. They stated that evaporation was the most sensitive parameter in their model. 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

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equal to evaporation from the holding pond. Over a week-long period in September, evaporation averaged 0.60 cm/day and seepage rates averaged 0.87 cm/day.

In other related studies, Hegg et al. (1979) used a floating evaporation pan constructed of galvanized steel (61 cm × 183 cm × 30 cm depth) filled with water to estimate evaporation from a hog waste lagoon in South Carolina. Demmy et al. (1993) used an effluent-filled aluminum pan mounted within a dairy waste holding pond in Florida to measure evaporation and seepage rates. Demmy reported average evaporation rates of 0.05 cm/day (standard deviation = 0.04 cm/day) and average seepage rates of 2.24 cm/day. Demmy stated that the evaporation measurements were made at night, which might account for the low evaporation values.

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 in Randall County six miles east of Canyon, Texas. The experimental setup consisted of 36 translucent plastic pans (Rubbermaid Model 3863) of dimensions 33 cm length, 23 cm width, and 12 cm depth. The plastic pans were evenly distributed on two sheets of 1.9 cm (3/4 in.) thick plywood placed to form a square of dimensions 2.4 m × 2.4 m (8 ft × 8 ft). The plywood was supported 15 cm (6 in.) 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 2 m south of the 36 pans, and an automated weather station (Campbell Scientific Inc., Logan, Utah) was placed 50 m south of the 36 pans. At the beginning of each experiment, clear water or effluent was used to fill the pans to an initial depth of 10.2 cm. The water level was measured to the nearest 0.05 mm with a steel rule at the center of the pan at the beginning and end of each experiment, and averages over the three- to four-day monitoring periods were calculated to the nearest 0.01 mm.

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 4 × 4 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.

Four experiments were conducted to compare evaporation rates of effluent and clear water. A fifth experiment was conducted to compare evaporation rates of clear water with different salinities. For Experiments 1, 2, 3, and 4, the treatments consisted of 100% effluent (TRT 1), 50% effluent mixed with 50% groundwater (TRT 2), 25% effluent mixed with 75% groundwater (TRT 3), and 100% groundwater (TRT 4). Experiments 1 and 2 were conducted with the white side of the plywood facing upward. In Experiment 1 (duration 4 days), freshly collected effluent was used. The freshly collected effluent represents typical conditions in a feedyard runoff holding pond, in which the effluent has a high suspended solids concentration, is colored reddish to dark brown, and has a low dissolved oxygen content. These conditions are typical of shallow holding ponds in the Panhandle of Texas subject to mixing from wind and wave action. Experiment 2 (duration 4 days) was completed after Experiment 1. For Experiment 2, the existing effluent after Experiment 1 was replenished to its original volume with distilled water. Distilled water was used so that the salt content would be the same for Experiments 1 and 2 and the only difference would be the color and suspended sediment concentration of the effluent. This "aged effluent" represents conditions that might be found in a feedyard runoff holding pond with low organic loading, low suspended solids concentration, and higher dissolved oxygen content (aerobic conditions). Small feedyards with large holding ponds might fall into this category.

Experiments 3 and 4 were conducted with the dark brown side of the plywood facing upward. In Experiment 3 (duration 3 days), freshly collected effluent was used. Experiment 4 (duration 4 days) was similar to Experiment 2, in which the existing water at the completion of Experiment 3 was replenished to its original volume with distilled water (aged effluent). Water temperatures were measured at 1200 h at the completion of all experiments, except that water temperatures were not recorded for Experiment 1.

Experiment 5 was conducted to compare evaporation rates of clear water with electrical conductivities (salt contents) in the same range as at the start of Experiments 1-4. Sodium chloride (table salt) was added to groundwater to obtain an initial electric conductivity equal to that for 100% effluent (11.4 mS/cm) and 100% groundwater (0.60 mS/cm), with intermediate electrical conductivities of 5.7 and 2.8 mS/cm. Experiment 5 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 50,000 head beef cattle feedyard in Swisher County, Texas. 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 30 m. Laboratory analyses were performed to characterize the feedyard effluent (table 1) following EPA recommended procedures (USEPA, 1983). The following EPA methods were used:

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)	1575
Sulfate (mg/L)	50
TSS (mg/L)	669
Total coliform (colonies/100 mL)	9000
Fecal coliform (colonies/100 mL)	5600
pH	8.0
Total Kjeldahl nitrogen (mg/L)	210
Nitrate-N (mg/L)	1.0
Ammonium-N (mg/L)	108
Potassium (mg/L)	1625
Phosphorus (mg/L)	54
Boron (mg/L)	1.0
Calcium (mg/L)	265
Magnesium (mg/L)	213
Sodium (mg/L)	993

TKN (351.3); NH_4-N (350.2); Cl, NO_3-N, SO_4 (300.0); K, Mg, Ca, Na, P, and B (200.7).

The color of the effluent was characterized by measuring the spectral transmittance at wavelengths between 250 and 1100 nm with a Shimadzu UV-1601 spectrophotometer. Spectral curves were obtained for raw effluent, centrifuged effluent (centrifuged at 1000 g for 20 min), and clear groundwater (fig. 1). Also shown in figure 1 is an approximate solar irradiance spectrum prepared using Planck's radiation formula to simulate typical solar irradiance data (Boikess and Edelson, 1981; Rosenberg et al., 1983). It is evident from figure 1 that absorption occurs (as noted by low transmittance values) in spectral areas of significant solar energy. Because the transmittance of the centrifuged effluent was more than for the raw effluent but less than for the clear water, it was apparent that both the suspended and dissolved forms contributed to the color of the effluent.

Statistical analyses were performed using the GLM procedure in SAS (1996). Analyses from all five experiments were analyzed as a Latin square in addition to performing two-sample t-tests (LSD comparisons) between each treatment pair at $\alpha = 0.05$. The LSD method controls the type I comparison-wise error rate, not the experiment-wise error rate.

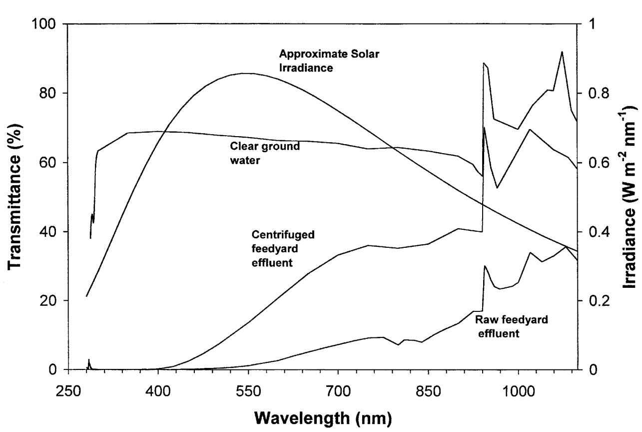

Figure 1–Spectral transmittance curves for raw feedyard effluent, centrifuged feedyard effluent, and clear ground water. Also shown is the approximate solar irradiance spectrum.

Results and Discussion

Evaporation from Freshly Collected Feedyard Effluent (Experiments 1 and 3)

When the white plywood background was used, the mean evaporation rates were significantly different (p = 0.001). The mean evaporation rate for clear water ($\bar{x}$ = 1.44 cm/day) was significantly less than evaporation from the three effluent treatments ($\bar{x}$ = 1.56 cm/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 rates were again significantly different (p = 0.0001). The mean evaporation rate for clear water ($\bar{x}$ = 1.21 cm/day) was again significantly less than evaporation from the three treatments of effluent ($\bar{x}$ = 1.34 cm/day for 100% feedyard effluent). There were no differences between evaporation rates for the 25% and 50% effluent treatments (TRT 2 and 3), but the 100% effluent treatment (TRT 1) was greater than TRT 2 and 3. The 100% effluent evaporation rates were 8.3 and 10.7% greater than the clear water evaporation rates for the white and dark brown backgrounds, respectively.

Table 2. Measured evaporation rates for evaporation experiments

	Effluent Experiments Mean Evaporation Rate (cm/day)*				
	TRT 1 100% Feedyard Effluent	TRT 2 50% Feedyard Effluent	TRT 3 25% Feedyard Effluent	TRT 4 100% Clear Groundwater	Class A Pan With Clear Groundwater
Experiment 1	1.56a	1.57a	1.58a	1.44b	1.28
(white plywood, fresh effluent) (p = 0.001)					
Experiment 2	1.59a	1.58a	1.61a	1.54b	1.57
(white plywood, aged effluent) (p = 0.028)					
Experiment 3	1.34a	1.32b	1.32b	1.21c	1.30
(brown plywood, fresh effluent) (p = 0.0001)					
Experiment 4	1.62a	1.62a	1.58a	1.62a	1.40
(brown plywood, aged effluent) (p = 0.702)					
	Saltwater Experiment Mean Evaporation Rate (cm/day)				
	TRT 1 11.4 mS/cm	TRT 2 5.7 mS/cm	TRT 3 2.8 mS/cm	TRT 4 (no salt added) 0.6 mS/cm	Class A Pan (no salt added) 0.6 mS/cm
Experiment 5	0.92a	0.93b	0.93b	0.93b	0.90
(brown plywood, clear water) (p = 0.117)					

* Means are averages of four observations. Only one Class A Pan was used.
NOTE: Row values followed by different letters are significantly different (α = 0.05).

Evaporation from Aged Feedyard Effluent (Experiments 2 and 4)

We observed that at about four days after collection, the effluent began to change physical characteristics. The effluent became clearer as suspended sediment settled or was degraded by aerobic activity, and small amounts of algae became visible. The result was smaller differences in evaporation between the effluent and the clear water (0.05 cm/day difference for Experiment 2 and no measured difference for Experiment 4).

Comparison of Clear Water Evaporation at Different Salinities

In Experiment 5, the mean daily evaporation rate for the clear water with the highest conductivity (0.917 cm/day) was significantly lower than the mean evaporation rate for the three other treatments (0.933 cm/day). The difference was smaller (only 1.8%) than differences measured with different concentrations of effluent (which ranged from 8.3 to 10.7%). No statistical differences were detected among Treatments 2, 3, and 4 (table 2).

Temperature at Completion of Experiments

In Experiment 3, which was with fresh feedyard effluent, the mean final temperatures were different (p = 0.0008). 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). In Experiments 2 and 4, which were with week-old effluent, there were no differences in final temperatures between the clear water (TRT 4) and the 25% and 50% effluent treatments (TRT 2 and 3). Only the 100% effluent (TRT 1) had significantly warmer mean temperatures than the clear water. In Experiment 5, there were no differences between any of the treatments (p = 0.47) (table 3).

Table 3. Measured water temperatures at completion of evaporation experiments

	Effluent Experiments Final Temperature (°C)*				
	TRT 1 100% Feedyard Effluent	TRT 2 50% Feedyard Effluent	TRT 3 25% Feedyard Effluent	TRT 4 100% Clear Groundwater	Class A Pan With Clear Groundwater
Experiment 1	NA	NA	NA	NA	NA
(white plywood, fresh effluent)					
Experiment 2	21.53a	21.35ab	21.33ab	20.70b	17.9
(white plywood, aged effluent) (p = 0.148)					
Experiment 3	28.92a	29.28a	29.40a	27.72b	25.6
(brown plywood, fresh effluent) (p = 0.0008)					
Experiment 4	31.40a	30.98ab	30.58b	30.58b	NA
(brown plywood, aged effluent) (p = 0.013)					
	Saltwater Experiment 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 added) 0.6 mS/cm	Class A Pan (no salt added) 0.6 mS/cm
Experiment 5	25.82a	25.70a	25.75a	25.68a	24.1
(p = 0.47)					

* Means are averages of four observations. Only one Class A Pan was used.
NOTE: NA = temperature data not recorded. Row values followed by different letters are significantly different (α = 0.05).

These findings suggest that temperature differences can be expected for fresh effluent, but as the water becomes clearer from settling and aerobic activity, the differences diminish. From the results of Experiment 5, we concluded that salinity differences did not significantly affect water temperature.

Comparison of Clear Water Evaporation Between Small Pans, Class A Pan, and Estimated Evaporation Formulas

In Experiment 1, evaporation from the clear water with the white background ($\bar{x}$ = 1.44 cm/day) was greater than evaporation from the Class A Pan (1.28 cm/day). In Experiment 2 also with the white background, the differences were minimal (1.54 and 1.57 cm/day). In Experiment 3, evaporation with the brown background ($\bar{x}$ = 1.21 cm/day) was less than evaporation from the Class A Pan (1.30 cm/day), while in Experiment 4 evaporation from the small pans ($\bar{x}$ = 1.62 cm/day) was greater than from the Class A Pan (1.40 cm/day). In Experiment 5, evaporation from the small pans ($\bar{x}$ = 0.93 cm/day) was slightly greater than evaporation from the Class A Pan (0.90 cm/day). There was no consistent relationship between the ratio of small pan evaporation to the Class A Pan for the white or brown backgrounds.

Average daily climatic values recorded during the experiments with an automated datalogging weather station are summarized in table 4. Evaporation estimates were made using the ASCE method and the Penman Method with the Wright wind function following the procedures outlined in Burman et al., 1983. A clear water albedo value of 0.12 was used in the calculations (Rosenberg et al., 1983). In all cases, evaporation estimates using the Penman method were slightly higher than those for the ASCE method (table 4). Evaporation estimates using the Penman method were similar to those measured in the Class A Pan, and were within 10% of measured Class A Pan evaporation values.

The Significance 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 5). 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 1.0 cm/day (Column 6),

Table 4. Weather conditions and evaporation estimates using Penman method with Wright wind function and ASCE method

	Daily Max. Temp. (°C)	Daily Min. Temp. (°C)	Daily Max. Rel. Hum. (%)	Daily Min. Rel. Hum. (%)	Wind Run (km/d)	Day/Night Wind Ratio	Solar Radiation ($cal/cm^2/d$)	Estimated Evaporation ASCE Method* (cm/d)	Estimated Evaporation Penman Method* (cm/d)
Experiment 1	33.6	13.3	52.5	9.6	456.5	1.5	726.1	1.11	1.34
Experiment 2	34.7	14.6	55.5	8.9	462.7	1.9	737.3	1.14	1.38
Experiment 3	37.2	19.0	79.8	19.9	345.5	1.2	641.0	0.99	1.19
Experiment 4	38.0	20.6	60.4	9.4	481.0	1.2	730.3	1.17	1.39
Experiment 5	36.4	17.2	85.8	16.7	220.5	2.0	540.8	0.81	0.97

* Evaporation estimation methods outlined in Burman et al., 1983.

Table 5. 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/s)	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/s)	Difference Between Predicted and Actual Seepage (cm/day)	Error in Seepage Rate Prediction (%)
1×10^{-4}	8.6	52.9	1.1	51.8	1.00	51.9	1.00×10^{-4}	0.10	0.19
1×10^{-5}	0.86	6.28	1.1	5.18	1.00	5.28	1.02×10^{-5}	0.10	1.9
1×10^{-6}	0.086	1.618	1.1	0.518	1.00	0.618	1.19×10^{-6}	0.10	19.3
1×10^{-7}	0.0086	1.152	1.1	0.0518	1.00	0.152	2.93×10^{-7}	0.10	193
1×10^{-8}	0.00086	1.105	1.1	0.00518	1.00	0.105	2.03×10^{-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

a typical summertime evaporation rate for the Southern High Plains, then our actual evaporation rate will be 10% greater than this, or 1.1 cm/day (Column 4). We assume a water depth of 1.5 m (5 ft) and clay liner thickness of 30.5 cm (12 in.) 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 1×10^{-4} to 1×10^{-8} cm/s (8.64 to 8.64×10^{-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:

$$\% \text{ Error} = \frac{\text{Predicted Seepage Rate} - \text{Actual Seepage Rate}}{\text{Actual Seepage Rate}} \times (100\%) \quad (1)$$

At a hydraulic conductivity (K) of 1×10^{-4} to 1×10^{-5} cm/s, which is characteristic of many silts and silty sands, the error in the seepage rate prediction is relatively small (0.19-1.9%). 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 = 1×10^{-6} cm/s, the error in seepage rate prediction is about 20%. A hydraulic conductivity value of 1×10^{-7} cm/s 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 = 1×10^{-7} cm/s, the error in the predicted seepage rate is nearly 200%. From another perspective, when K = 1×10^{-7} cm/s, 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 = 1×10^{-8} cm/s (almost 2,000%), with the predicted seepage rate and predicted K about 20 times as great as the actual seepage rate and actual K. The errors shown in table 5 are even higher if the estimated evaporation is 2.0 cm/day (table not shown). In this case, the seepage rate predictions are 5 to 40 times higher for hydraulic conductivities of 1×10^{-7} cm/s and 1×10^{-8} cm/s, respectively.

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 0.08 to 0.63 cm/day (CWQCC, 1997; IAC, 1992; NDEQ, 1995; KDHE, 1978), an overestimation of 0.1 to 0.2 cm/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 effluent freshly collected from a feedyard holding pond were 8.3 to 10.7% greater than clear water evaporation rates. As the effluent aged for about four days in the evaporation pans and settling and algae growth occurred, differences in evaporation rates between the effluent and clear water diminished. If seepage rates are determined by water balance with clear water evaporation estimates, then underestimating evaporation by 10% when actual evaporation is 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 1×10^{-7} cm/s, and up to 20 times the actual seepage rate if the hydraulic conductivity is 1×10^{-8} cm/s. These ratios increase to 5 to 40 times the actual seepage rate when actual evaporation is 2.2 cm/day. 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.

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