final report

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Prepared by: Dr Simon Lott
E. A. SYSTEMS Pty Limited

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Meat & Livestock Australia Limited
Locked Bag 991
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Modelling Feedlot Effluent Irrigation

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Overview

The Meat and Livestock Australia (MLA) Project 201 is a small project. It was funded over a three-year duration from 1 January 1997 to 30 December 1999. The project was started in April 1997 and at the request of MLA early completion of the project has been attempted. To this end data collection and collation ceased in May/June 1999.

The objective of the project was the completion of the holding pond and irrigation water balance component of the FSIM model. This is required so that simple design methods for holding pond capacities can be developed for industry in the future. Completion of the water balance equations required calibration and verification of the equations used to describe the loss of water from holding ponds by evaporation and draw off by irrigation.

The project was focused on the collection of data to define the water balance of feedlot holding ponds. The important data were inflows by rainfall runoff, loss of water by evaporation and the removal of waste water through irrigation. This required six commercial feedlots to collect the data on behalf of the project. Each site was visited once at the start of the project to initiate data collection. Two feedlots were in southern Queensland, one in Northern NSW, one in central NSW and two in Southern NSW. These feedlots covered a range of climates common to the lot feeding regions in Australia.

The following report has been drafted in the format of a scientific paper. This has ensured that the research has been written up to a standard where with some further honing it can be published and so provide the data it contains to the wider community.

Conclusions and Recommendations

- Current practice is to calculate holding pond evaporation as 70% of pan evaporation (ie. $E_{hp}=0.7\times E_{pan}$). Data presented in this report shows that the rate of evaporation from feedlot holding ponds is greater than previously thought.

- Without other data it is recommended that the determination of evaporative losses from feedlot holding ponds should be based on use of daily evaporation data (via pan evaporation) and an evaporative coefficient of **1.25**. (ie. $E_{hp}=1.25\times E_{pan}$) which is a significant increase over the coefficient currently used (0.7). The data used to obtain the coefficient showed some variation and its is suggested that this value may range from 1.0 to 1.4.

- Design guidelines need to acknowledge that evaporative loss of water from 'retention' holding ponds can be significant and may be greater than the draw off by irrigation.

- It is recommended that no further field based feedlot hydrological studies be undertaken and that no further calibration/verification of the hydrological equations in FSIM be undertaken.

- Modelling should be undertaken to develop simple design guidelines for all of eastern Australia **but** it must be based on a calibrated and verified programme that can be applied across climatic regimes.

- It is recommended that the information contained in the attached paper is published.

Special Note

The Australian Lot Feeders Association requested, through Meat and Livestock Australia (MLA), that the design criteria for holding ponds presented in the recently released guidelines (Skerman, 1999) be 'checked' using FSIM. A 'site' at Dalby was chosen for this task because a considerable amount of modelling has been performed in the past for this location. The standard design used by Skerman (1998) was adopted. Long-term meteorological data from MetAccess (CSIRO, 1998) were used in the modelling. It allows the user to compile high quality daily meteorological data in the format the user requires and also undertake comparative analyses of climate data. The FSIM model with revised evaporation coefficients and irrigation management criteria was used to simulate the water balance of the holding ponds.

Lott (1997) found that feedlot rainfall - runoff was most affected by rainfall quantity and intensity, antecedent catchment conditions (manure depth and moisture content), and pen slope. In subsequent modelling of holding pond dynamics for sites in Queensland, New South Wales and Victoria, Lott (1998) found that evaporative loss from ponds and irrigation demand influenced the size of holding ponds for a specific spill frequency. The impact of evaporation appears to be limited as shown in Figure A.

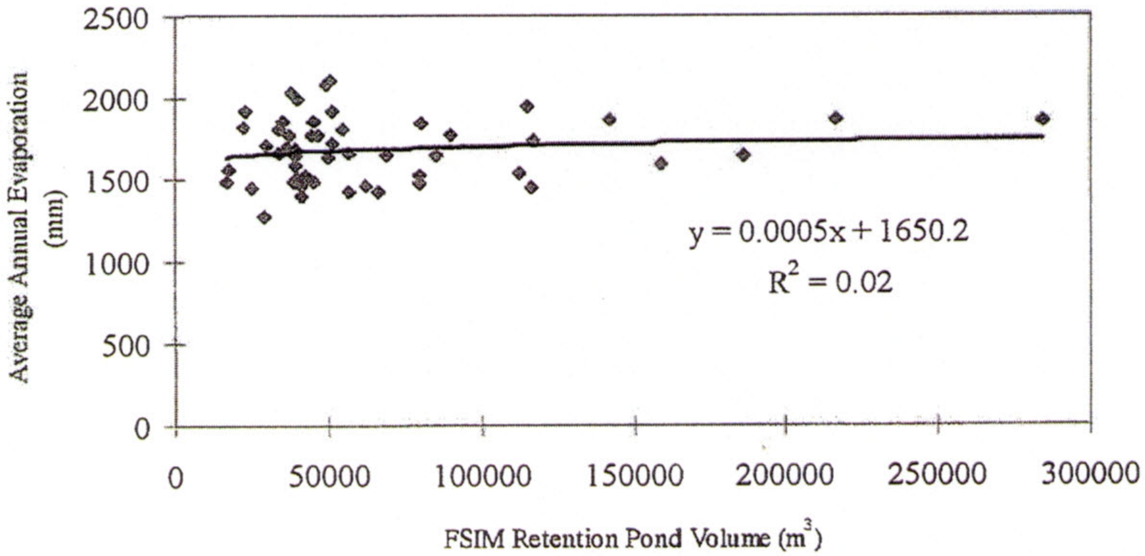


Figure A. FSIM Retention Pond Volume (m^3) versus the Average Annual Evaporation (mm)

Skerman (1998) also found that irrigation demand (as affected by area, crop type and irrigation practices) influenced pond sizing but evaporative losses had almost no effect. This finding is true in areas of high evaporation and summer dominant rainfall but not in more temperate environments which fall in the clump of data on the left hand end of the curve.

In Southern Queensland the determination of a holding capacity is primarily related to the capture of runoff from;

- a series of large storms in quick succession,

- a large monsoonal event (such as those that occur in a wet season) when a large amount of rainfall is received as a single event of a number of days, or
- a continuously wet season when irrigation is not possible and effluent must be stored.

For retention holding ponds in southern Queensland the influence of evaporative loss on the determination of holding pond capacity is comparatively small because in the first two cases rainfall-runoff capture occurs over just a few days when the loss of pond water by evaporation is comparatively minute. The opposite is true where pond capacity is required to store effluent for long periods of time.

Loss of holding pond water by evaporation has a significant bearing on the dynamics of some holding ponds and in particular areas where;

- 'evaporative' holding ponds are used in temperate climates,
- in wet climates and other climes where seasonal moisture surpluses occur (eg. south eastern Australia or the wet sub/tropical coast) and effluent must be held for extended periods until an irrigation demand occurs.

In these cases the magnitude of evaporative loss affects, required storage volume and the amount of water irrigated from the retention pond.

The modelling found that the proposed design method predicted a comparable capacity for the 'Dalby' site. The holding capacity determined by the guidelines (Skerman, 1999, 1998) was 30.2 ML. The capacity determined using FSIM and the parameters outlined by Skerman (1999, 1998) was 28.5 ML which is only 5% less than that proposed in the guideline. This difference is not significant and may be due to differences in;

- meteorological data used,
- the shape of the holding pond adopted for the simulations, and,
- the irrigation criteria that were used.

The design method proposed by QDPI has been developed as a conservative design method (Skerman, 1999). It has achieved this aim by producing a design outcome that should accommodate the worst case scenarios for feedlot catchment management and thus potential changes in the standard of feedlot management through time (ie. it assumes pen manure is managed at Class 1 standard). [Feedlot catchments yield the most runoff when the manure pack is well managed.]

Where feedlot manure management is not first class it is likely that runoff will be less and the holding pond capacity will be greater than would appear to be necessary. However, the additional capacity will accommodate any change to manure management (eg. an improvement which would induce more runoff), without addition capital cost nor additional risk to the environment. On this basis the proposed design is satisfactory for Southern Queensland.

In the southern regions the rainfall and catchment conditions are different to those in southern Queensland and as a consequence the runoff characteristics are also different. MLA Project 201 found that the amount of runoff generated from feed yards in central and southern New South Wales were less than those in Southern Queensland. This is most likely due to;

- the greater incidence of smaller rainfall events

- lower rainfall intensities, and most importantly,
- a greater incidence of pugged pen conditions where capture of rainfall is increased (see Lott, 1997).

The later case results from, a greater proportion of the rainfall occurring in cooler months and increased moisture accumulation in the pen manure through less evaporation and inputs of water from faeces and urine. Because the antecedent conditions and rainfall patterns vary from one region to another K values (used to develop the QDPI guidelines) derived in one region for the USDA SCS runoff can not be automatically transferred to another.

Recommendations Arising from Special Note

- The simple design method proposed by the Queensland Department of Primary Industry can be adopted for Southern Queensland **ONLY**.

- Any further modelling for the purpose of developing simple design methods should calculate evaporation using a coefficient of 1.25.

- Any further modelling for the purpose of developing simple design methods in areas other than Southern Queensland should include parameters that appropriately account for antecedent conditions and rainfall characteristics.

MODELLING FEEDLOT EFFLUENT IRRIGATION

Simon Lott

1 INTRODUCTION

Feedlot holding ponds are required to capture and hold effluent. The type of holding pond used depends upon the method of 'disposing of the effluent' (see Lott, 1995; Lott, 1998). Ponds are typically used as retention ponds where effluent is held pending its irrigation to land. Other holding ponds include evaporative ponds where 'disposal' is simply by evaporation of the water it contains, and treatment ponds where the waste water is held in ponds for sufficient time to allow significant removal of the suspended solids and nutrients by; precipitation, chemical reduction and precipitation, volatilisation and decomposition of the organic matter. Anaerobic and/or aerobic bacteria decompose organic matter and this then allows the preceding activities to occur.

1.1 Feedlot Holding Pond Design

Holdings ponds should be designed so that they spill infrequently. Current design criteria require that retention ponds be sized to spill 1 in 10 years (ANZSCC, 1997; Skerman, 1999) using a water balance calculation. These criteria have been introduced because Lott (1997) demonstrated using field data and a calibrated and verified rainfall-runoff model that the use of the catastrophic storm design criteria resulted in pond capacities that spilled frequently as the result of persistent rainfall events, sequential summer storms and very wet seasons.

Lott (1997) found that the 'retention' pond volume for a 'standard' 5000 head feedlot could be described as a simple function of annual rainfall (see Figure 1). Equations 1 and 2 can describe the relationship. The first equation is shown in Figure 1.

$$HP = 15.216 e^{0.0016 P_a} \qquad (r^2 = 0.82) \qquad \mathbf{(1)}$$

$$HP = 0.1312 P_a - 40.18 \qquad (r^2 = 0.80) \qquad \mathbf{(2)}$$

Where; HP = Holding pond volume (Ml)
P_a = Mean Annual Precipitation (mm)

These equations show that simple guidelines can potentially be developed for sizing feedlot holding ponds for all of eastern Australia. However, while the FSIM model (Lott, 1998) used statistically verified equations for calculation of rainfall-runoff, it used empirical methods for the calculation of effluent evaporation and set criteria for scheduling of irrigation. Lott (1997) and Lott and Skerman (1995) showed that the determination of holding pond capacity was sensitive to holding pond evaporative loss and effluent irrigation demand whether that be influenced by crop water demand, irrigation area, or different soil types. The variation of data about the line plotted in Figure 1 can be attributed to variance caused by temporal variability in rainfall patterns and evaporation.

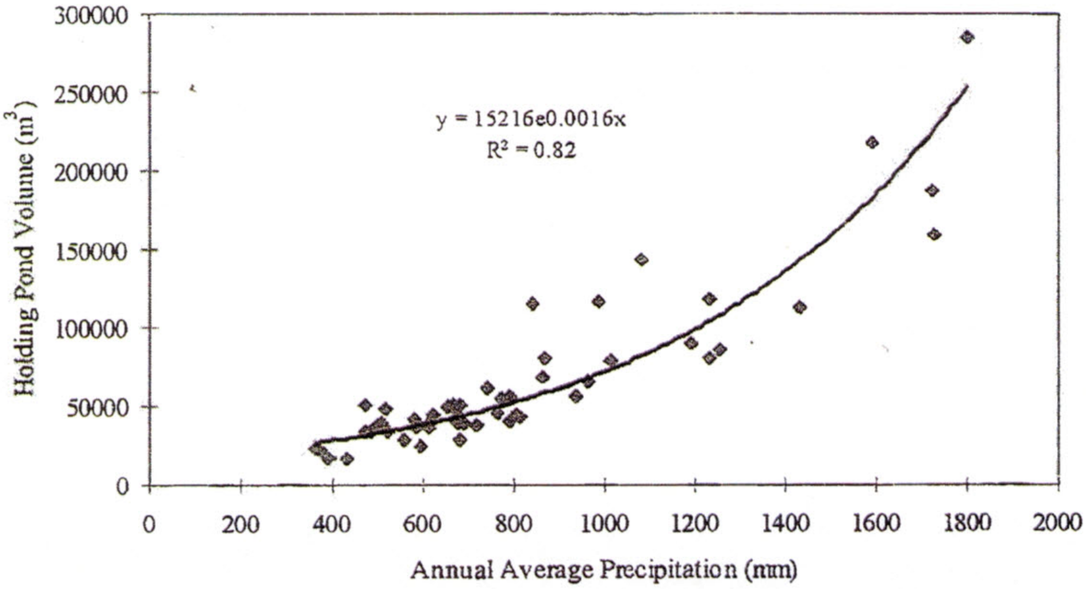


Figure 1. Retention Holding Pond Volume (m^3)

Apart from rainfall-runoff entering holding ponds, evaporation is the most crucial to determining holding pond capacity (Lott, 1998). Therefore the design of the holding pond capacity is dependant upon accurate calculation of holding pond evaporation. Lott (1997) showed that actual daily evaporation values can vary markedly above and below mean values and actual annual evaporation can vary as much as 30% from estimated average annual values. Therefore, accurate calculation of the holding pond water balance requires use of both daily rainfall and evaporation data.

The inputs and outputs from a feedlot holding pond are shown in Figure 2. Little research has been undertaken on the evaporative loss from effluent holding ponds and the determination of evaporative loss from holding ponds has typically been based on a pan evaporation coefficient of **0.7 (ie. E_{hp}=0.7×E_{pan})** which was derived for water loss by evaporation from large clear water surfaces (eg. Gardner et al., 1993; Watts and McKay, 1986).

1.2 Measurement of Evaporation

Lott (1986) discusses in detail methods of measuring potential evaporation. Two methods are in common use;

- loss of water from an evaporation pan multiplied by a pan factor,
- calculation using an equation/s based on an energy balance.

Potential evaporation is described as the loss of water from a free water body given an available energy (Penman, 1948). Other works manipulate this concept to include that evaporation from any surface given that water is freely available (eg. bare soils, crops).

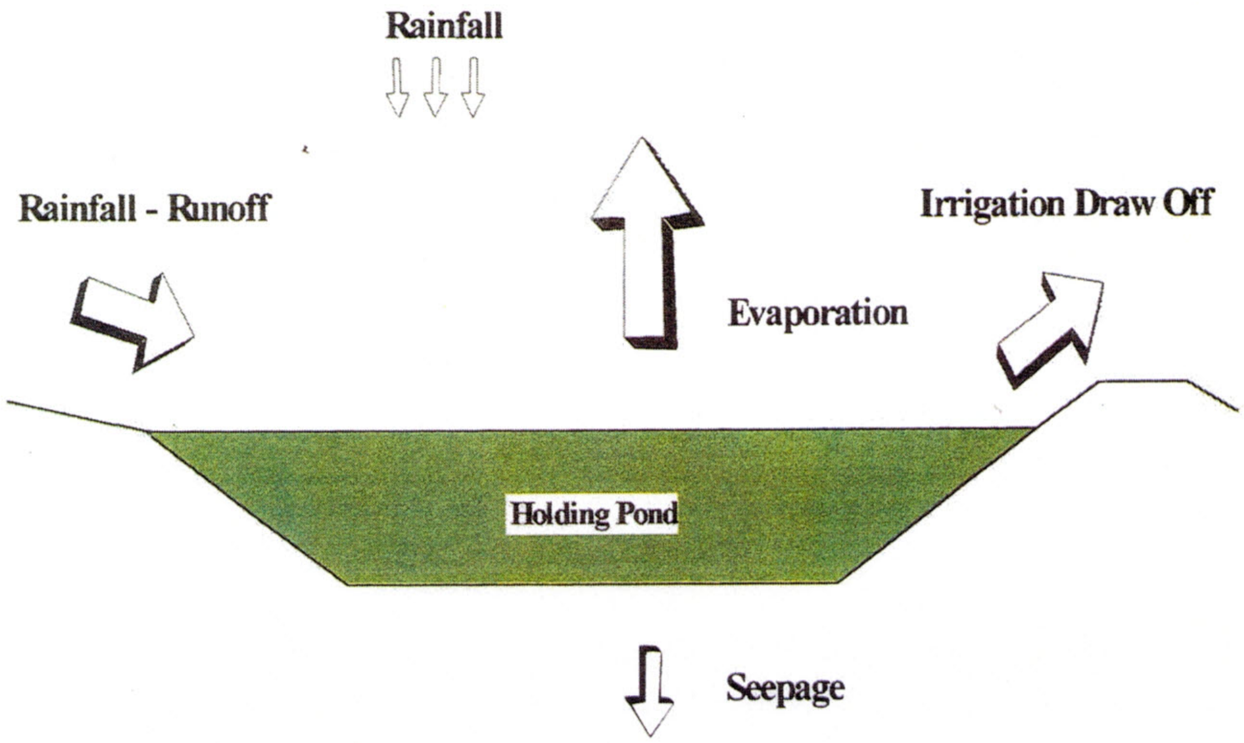


Figure 2. Inputs and Outputs from an Effluent Holding Pond

Evaporation pans are a device where the loss of water per day is considered to be a measure of evaporation or more precisely potential evaporation. The US Class A pan has been accepted as the standard device. It gives a measure of free water evaporation from a 1.2 m diameter 0.3 m deep tank. The maintenance and siting of these devices varies from site to site (see Pruitt, 1966; Doorenbos and Pruitt, 1977; Burman et al., 1980). A measure of potential evaporation (E_{To}) is derived via 'pan factors' ($E_{To} = K_p \times ET_{pan}$). Penman (1948) carefully outlines the true guidelines for the siting and management of evaporation pans. Weeks (1983) compared pan and calculated potential evaporation to develop pan factors for Queensland. The values ranged from 0.63 to 1.03. There was no obvious geographical or topographic relationship with K_p. Doorenbos and Pruitt (1977) show that the evaporation pan is an awkward means of obtaining reliable evaporation readings. The installation of the pan requires that they be elevated above the natural ground surface and as a result some ventilation occurs beneath the tank. The tank is maintained at a set level with clean water. Most tanks are fabricated with Galva-bond and are light grey in colour.

Potential evaporation is typically calculated with equations using radiation as the key parameter. The equations vary from simple equations such as the Priestley-Taylor equation (Priestley and Taylor, 1972) through to the Penman Monteith equation (Penman, 1948 and Monteith, 1965). In the latter case the equation considers that evaporation is derived by two mechanisms. The first results from the energy input from radiation and the second, the aerodynamic function is driven by the energy input from passage of a wind across the surface. Calculated values of potential evaporation vary because of the number of means that can be computed. It is also dependant upon the values of albedo used.

2 MATERIALS AND METHODS

2.1 Description of Sites

To define the water balance of holding ponds data were collected from six commercial feedlots. The characteristics of each feedlot were defined through an initial site visit and site appraisal where information on the management of the feedlot and the physical attributes of the feedlot and its irrigation areas were determined. Plans of the yard areas, holding ponds and irrigation areas were obtained. Surveys of the holding ponds were undertaken so that a depth, surface area and volume relationship could be obtained. An example of the depth, surface area, and volume curves obtained from a site is presented in Figure 3.

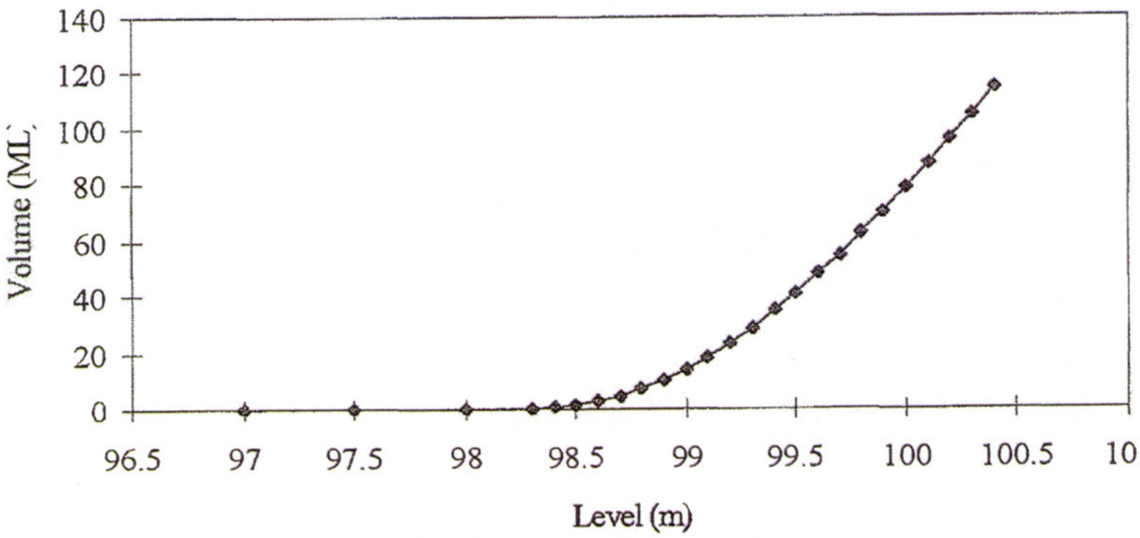


Figure 3. Holding Pond Curve for Feedlot B

A careful visual inspection of the feed yards, holding ponds, soil types and cropping regime at each location was undertaken and features of each feedlot noted. The design and management of waste management facilities varied across the feedlots. The level of feedlot staff involvement varied from site to site and as a result the data collected also varied in quantity and quality.

Data were collected over the period January 1997 to June 1999. Insufficient data were collected from Feedlot A which prevented its inclusion in the modelling. This site was also atypical in nature because it had a large permanent effluent storage capacity in the sedimentation pond and combined effluent and clean water storage. Data from feedlot C was set aside because of a lack of stock and the lack of precise effluent irrigation data. At this site measurement of the loss of holding pond water was also confounded by the clumps of trees that surrounded the pond and its extremely shallow nature and ill defined extents when full.

Data from Feedlots B, C, E and F were used in the study. They had similar design features and waste management processes. Data collected included; daily rainfall data and other meteorological information, and records of effluent irrigation quantities and holding pond levels over time. Rainfall was measured on a daily basis and in all cases manual and electronic recordings of rainfall data were available. Automatic weather stations were located at Feedlots B, D, and F. In each case the Priestly

-Taylor formula was used calculate potential evaporation. The calculation ignored aerodynamic effects and used an albedo of 0.2. The basic form of the formula is;

$$E=1.26.(\frac{s}{s+g}).(R_n-G) \quad \textbf{(3)}$$

R_n is nett radiation, G is ground heat flux, s is the slope of the saturation vapour pressure curve at temperature T, and g is the psychrometric constant (0.66). (s / s + g) was approximated by the quadratic :-

$$\frac{s}{s+g}=0.3978+0.01733.T-1.46135E-4.T^2 \quad \textbf{(4)}$$

Nett Radiation (kilojoules) was calculated from :-

$$R_n=R_g(1-A)+Q_l \quad \textbf{(5)}$$

where A is the Albedo or reflection coefficient, R_g is global short wave radiation, and Q_l is the nett long wave radiation (atmospheric - terrestrial or Q_a - Q_t).

Daily climate and evaporation data were also obtained from a NSW agricultural experimental station 8km from Feedlot E. Similarly climate data were obtained from a CSIRO research station near Feedlot F. These data were compared with the calculated potential evaporation data and screened daily evaporation data in MetAccess (CSIRO, 1998). Other data were sourced from MetAccess (1998) to use for a comparative analyses of the supplied data.

Each holding pond was carefully inspected and data on the construction methods and, where possible, soil permeability and ground water monitoring were obtained. The soils used in the construction of Feedlot B holding pond is a heavy black earth. Southcott et al., (1998) undertook permeability tests on the soils from this site and found that the permeability was so low that only the top cm of the compacted sample was wet after a week of saturation. The soils used to construct the holding pond at Feedlot D are similar. The pond has been recently constructed and the permeability of the soils exceed those required by the NSW EPA.

At Feedlot E and F the subsoil material used to construct the holding ponds is sodic and again the permeabilities are very low. Insitu permeabilities are greater than the maximum permeability of 1×10^{-9} m/s required by the NSW EPA for pond linings (Coffey, 1997) and the construction of the ponds followed engineering specifications. Ground water monitoring data have demonstrated that there has been no appreciable change to ground water conditions as a result of leakage from the holding ponds at Sites E and F. While it appears that seepage from the holding ponds is less than 1×10^{-9} m/s, this valued was assumed for the purposes of this study.

In all cases the feedlots had large irrigation areas and large pumps to irrigate effluent quickly. The amount of water pumped for irrigation was measured by either flow meters, or through calculation of volumes using a pump curve and the duration of pumping. The irrigation practices varied from site to site. For instance, at Feedlot F effluent was passed to land areas almost as soon as a moisture deficit existed, whereas, at Feedlot E waste water collected in the winter and spring was held over into the summer period to meet peak irrigation demands.

At Feedlot B some process generated waste waters were passed to the holding pond. This was measured with a low degree of precision by a large San Dimas flume. This additional variable in the pond water balance created difficulties in the determination of the other variables in the holding pond water balance.

Loss of water by evaporation was not measured directly. The depth in the holding ponds were measured through time and where no inflows or irrigation occurred evaporation could be determined but on the basis that the loss by seepage was assumed.

Table 2.1 Characteristics of the Feedlots

Feedlot	B	D	E	F
Capacity	25000	28000	40000	28000
Location				
Longitude	151.60	150.63	146.49	145.75
Latitude	27.53	31.35	34.63	34.33
Elevation	410	390	140	105
Mean Annual Rainfall (mm)	585	665	415	395
Mean Annual Evaporation (mm)	1935	2010	1615	1730
Land Use				
Pens	381900	393500	800000	442000
Drains	31300	46840	33000	28100
Extraneous Grass Areas	43000	454900	148000	30800
Roads	69000	95450	102000	57630
Manure Stockpile	27600	5200	251000	-
Sedimentation Pond	24300	32900	80000	22000
Effluent Retention Pond	93579	150200	91200	92000
Total Controlled Drainage Area (ha)	67.0679	117.899	150.52	67.253
Effluent Irrigation Area (ha)*	383	115.3	150	250

* Area over which effluent was applied during the study.

2.2 Data Collection and Collation

The cooperating feedlots collected the data on standard collection sheets. The time between recordings varied across the sites. Some feedlot staff collected data on an ad hoc basis and at the times of rainfall, runoff and irrigation events. Other yards collected data as events occurred and also on a daily, weekly or monthly basis. These data were passed to the author in either hard copy or electronic format. The raw data provided by the cooperating feedlots were collated in a number of ways. This included digital mapping of the catchment and irrigation area plans to determine the areas of land use; and manual entry of weather data, pond depth, and irrigation records. All data once entered were organised into a common format.

2.3 Raw Data Analysis

The collated raw data were analysed once they were in common format. This required entry of other meteorological data into spreadsheets so that a full daily record was developed for each site.

A comparison of meteorological data against data obtained from MetAccess (CSIRO, 1998) was undertaken to check the integrity of the data. In most cases the data collected by the cooperating feedlot were sound and little patching of data was required. Additional data were obtained from MetAccess and added to form a continuous meteorological data set.

Actual evaporation data was obtained directly from the site or from a nearby Bureau of Meteorology station. The type of evaporation measurement varied. Some data were calculated potential evaporation as opposed to pan evaporation data. The evaporation data were normalised across the sites by comparing potential evaporation data with pan evaporation data and determining a coefficient for calculating a 'pan' data set. An example of this is shown in Figures 4 and 5.

This approach ensured that comparable evaporation values could be used in the modelling of holding pond and irrigation area performance. Once a full set of data had been obtained for each site these data were imported into MetAccess (CSIRO, 1998) where statistical information on each site were obtained.

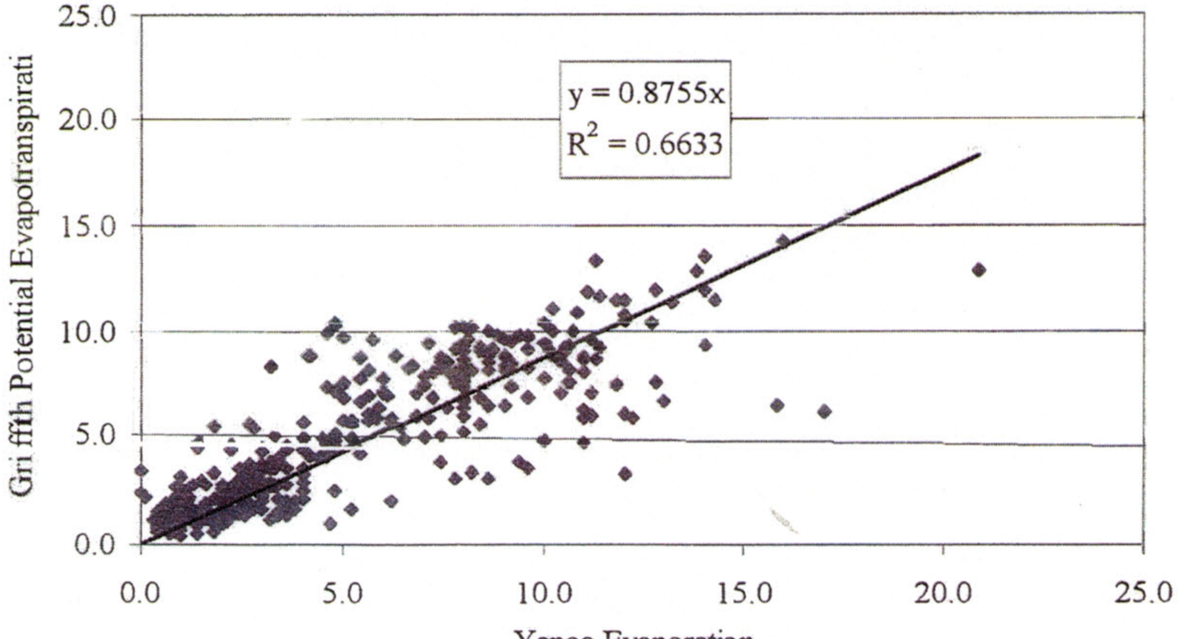


Figure 4. Comparison of Yanco and Griffith Evaporation Data

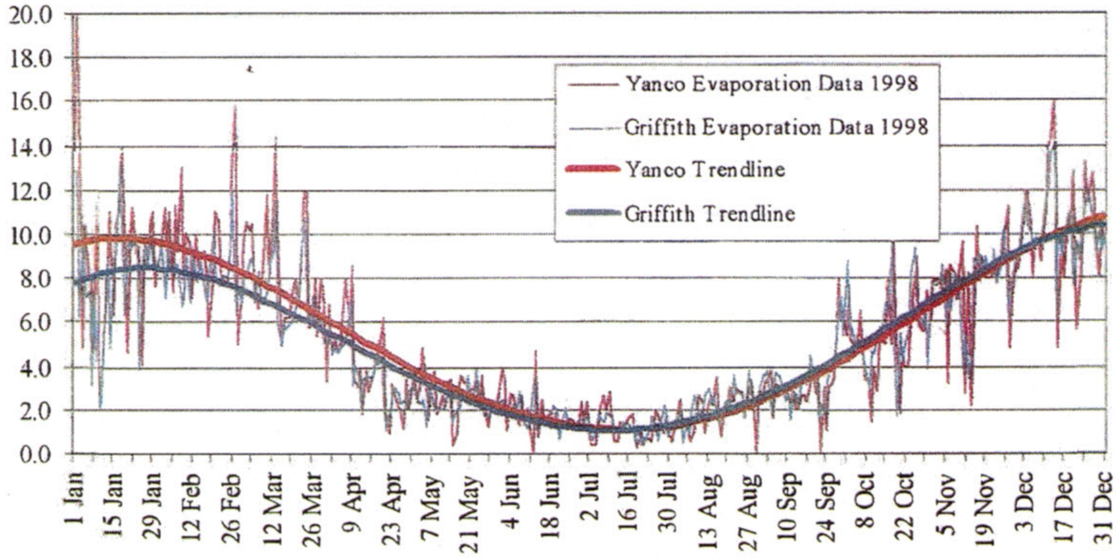


Figure 5. Yanco and Griffith Evaporation Data for 1998

2.4 Modelling

Modelling of the feedlot catchment and holding pond performance was undertaken using FSIM (see Lott, 1998). The structure of the model and its calibration and verification has been described by Lott (1997). The model was developed as research tool for investigation of feedlot catchments.

The physical description of each site was defined using Environmental Management Plans, maps, and any other information defining the physical characteristics of the complex. This information was entered into an input file. Initial conditions were set so that the simulation started with the feedlot being in full operation. It also ensured that from the first day of computations the feedlot was stocked, the pens had a pen manure depth of 50 mm and the pond volume was equal to the actual volume at the commencement of the study.

The model was run for the time frame covered by the study period using the initial conditions and the actual weather data for the site. The output from the model included, runoff from the catchment (mm), pond volumes, loss of pond water by evaporation and seepage, and the amount of effluent applied as irrigation water. These data were compared to the actual values recorded by the feedlots.

3 RESULTS

3.1 Raw data analysis

The annual average rainfall, runoff, evaporative loss, and effluent irrigated data are presented in Table 3.1. The average yields of runoff over the study period were 23.1%, 22% and 18% for Feedlots D, E and F respectively. It was not possible to obtain an accurate measure of annual runoff yield for Feedlot B.

The average pen and catchment slopes varied across the sites. The slopes were: 2 and 2.3% at Feedlot B; 3.8 and 4.4% at Feedlot D; 3.8 and 4% at Feedlot E; and, 2 and 2.5% at Feedlot F.

Table 3.1. Actual rainfall, runoff, potential evaporation and effluent irrigation data for each site

Site / Year	Annual rainfall (mm)	Runoff (% of Rainfall)	Annual potential evaporation (mm)	Effluent Irrigation (ML/yr)
Site B				
1997	n/a	n/a	n/a	98.5
1998	n/a	n/a	n/a	199.1
1999 (6 months)	n/a	n/a	n/a	80.1
Average	-	-	-	*125.9*
Site D				
1997	697.3	28.8	1437.4	15.4
1998	859.5	15.4	1444.2	15.5
1999 (5.3 months)	297.5	25.1	641.8	87.5
Average	*618.1*	*23.1*	*1174.5*	*39.4*
Site E				
1997	324.5	16.0	2263.8	44.6
1998	379.0	18.0	1974.0	5.2
1999 (5 months)	269.0	32.9	1022.2	48.6
Average	*324.2*	*22.3*	*1753.3*	*32.8*
Site F				
1997	336.0	19.6	1981.1	-
1998	406.3	9.2	1870.5	-
1999 (6 months)	289.8	25.4	934.5	-
*Average (*Total)*	*344.0*	*18.0*	*1595.4*	*129.6**

The actual evaporative loss from Holding Pond D over weekly or fortnightly periods was matched against the pan evaporation data compiled for the site. From these data a value of K_p was derived. This is shown in Figure 6 and it can be seen that the value of K_p was 1.25. This value was then used in the modelling of feedlot holding pond performance at the other feedlots.

These data were derived from pond depth measurements. Measurements from week to week varied The variation is most probably due to the difficulty in precise measurement of depth given wave action against the depth gauge. The measurements are most probably responsible for much of the variance in the data set shown in Figure 6.

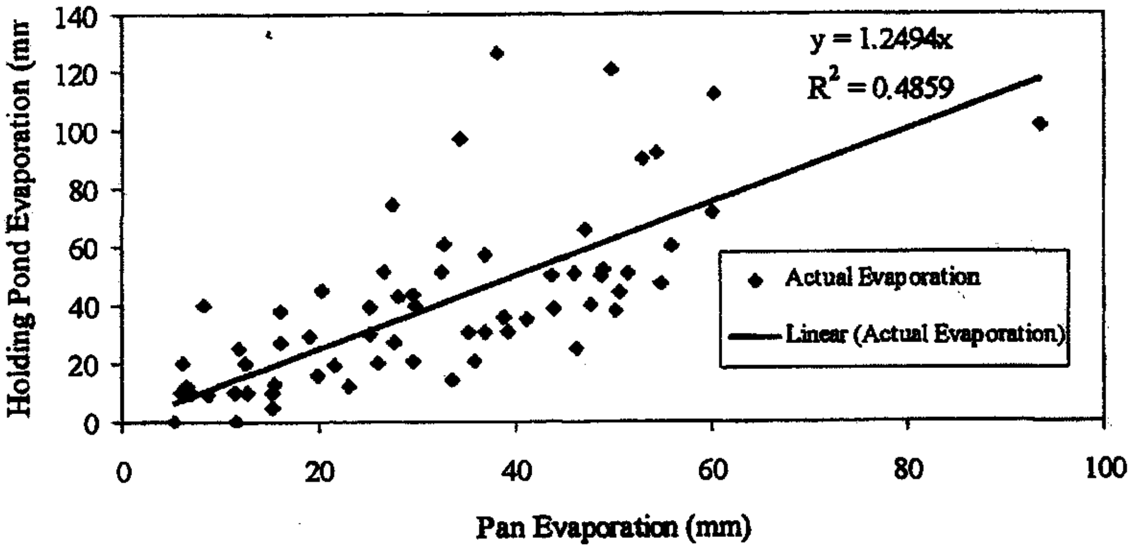


Figure 6. Holding Pond Evaporation Versus Potential Evaporation

Lott (1997) developed a predictive equation for the calculation of annual feedlot runoff. The equation is;

$$R_{ann} = 0.573 \, . \, P_{ann} . \, S_p^{0.1723} - 181.4. \quad (r^2 = 0.96) \qquad (6)$$

Where S_p is expressed as a percentage. The annual yields calculated from this equation were compared with the actual yields for Feedlots D, E and F. The results compared favourably with the value computed using the equation. The above equation shows that feedlot runoff and holding pond capacities can be determined using simple equations for eastern Australia.

3.2 Modelling

The equations calculating rainfall-runoff from feedlots have been previously calibrated and verified (see Lott, 1998). A check of the predicted rainfall-runoff versus the actual changes in holding pond volume for Site B was undertaken. This was difficult because the continuous but variable flow of process generated waste waters (eg. from cattle washing etc) into the holding pond made the differentiation of inflows difficult. The predicted inflows to the holding ponds were matched with the actual increases in volumes determined by the changes in holding pond capacity (recorded by their depth gauge and subsequent determination of volume based on the surveyed depth versus volume curve).

No changes were made to the parameters defining the rainfall-runoff equations. The pan evaporation coefficient previously determined was used in the modelling of the catchment and holding pond performance in Feedlots D, E and F. Figures 7 and 8 shows the plot of predicted holding pond volume and irrigation volume over the study period for Feedlots D and E.

The modelling found that while inflows and evaporation could be predicted with a reasonable degree of accuracy, the prediction of effluent irrigation concurrent with actual irrigation was not possible. Figure 7 shows that waste water was held in the pond at a time when the model was reducing pond capacity by irrigation draw offs. In this case the lack of draw off caused the pond to overtop because insufficient capacity was available for rainfall-runoff from several significant events. In Feedlot E waste water collected in winter and spring is deliberately stored until peak irrigation demand is achieved in late summer (ie. the follow year).

The modelling did show that from time to time through the study period the predicted volume did concur with the actual pond volumes. The deviations in between these times is solely due to irrigation practices which the model can not emulate. Based on a qualitative assessment the best fits were obtained when K_p was held at 1.25.

The model did not predict the timing of all irrigation activities well, and it demonstrated a very aggressive irrigation strategy. This is due to the fact that the model schedules irrigation by a soil water conditions and it does not take into account other management factors the irrigation operator must consider or accommodate. This approach to the irrigation resulted in predicted annual irrigation volumes generally greater than the actual volume of effluent irrigated (see Table 3.2). This occurred because every possible opportunity to irrigate effluent was used and as a result less pond water was lost through additional evaporative loss.

Table 3.2. Modelling results for the January 1997 to May/June 1999 periods with K_p = 1.25

		Feedlot D	Feedlot E	Feedlot F
Total Rainfall	mm	1854.3	972.5	1032.1
Total Evaporation	mm	3523.4	5260.0	4786.1
Total Inflow to Pond	mm	407.5	208.5	176.6
Average Runoff Yield	%	23.1	22.3	18.0
Total Evaporation from Pond	ML	308.3	82.0	32.0
Total Modelled Irrigation	ML	265.5	174.2	99.7
Total Actual Irrigation	ML	118.3	98.4	129.6
Total Modelled Seepage	ML	5.87	1.24	0.57

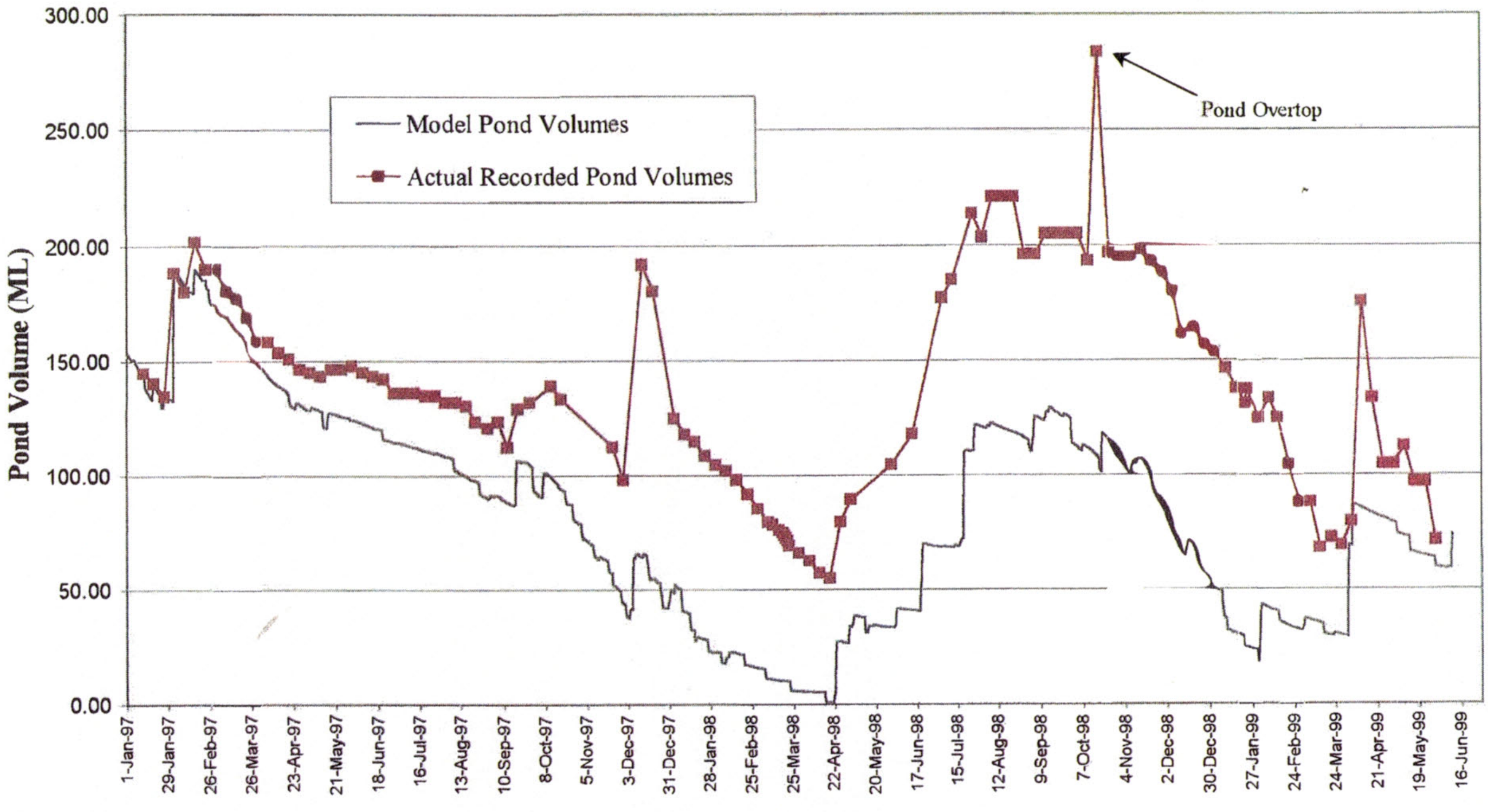


Figure 7. Actual and Predicted Pond Volumes for Feedlot D

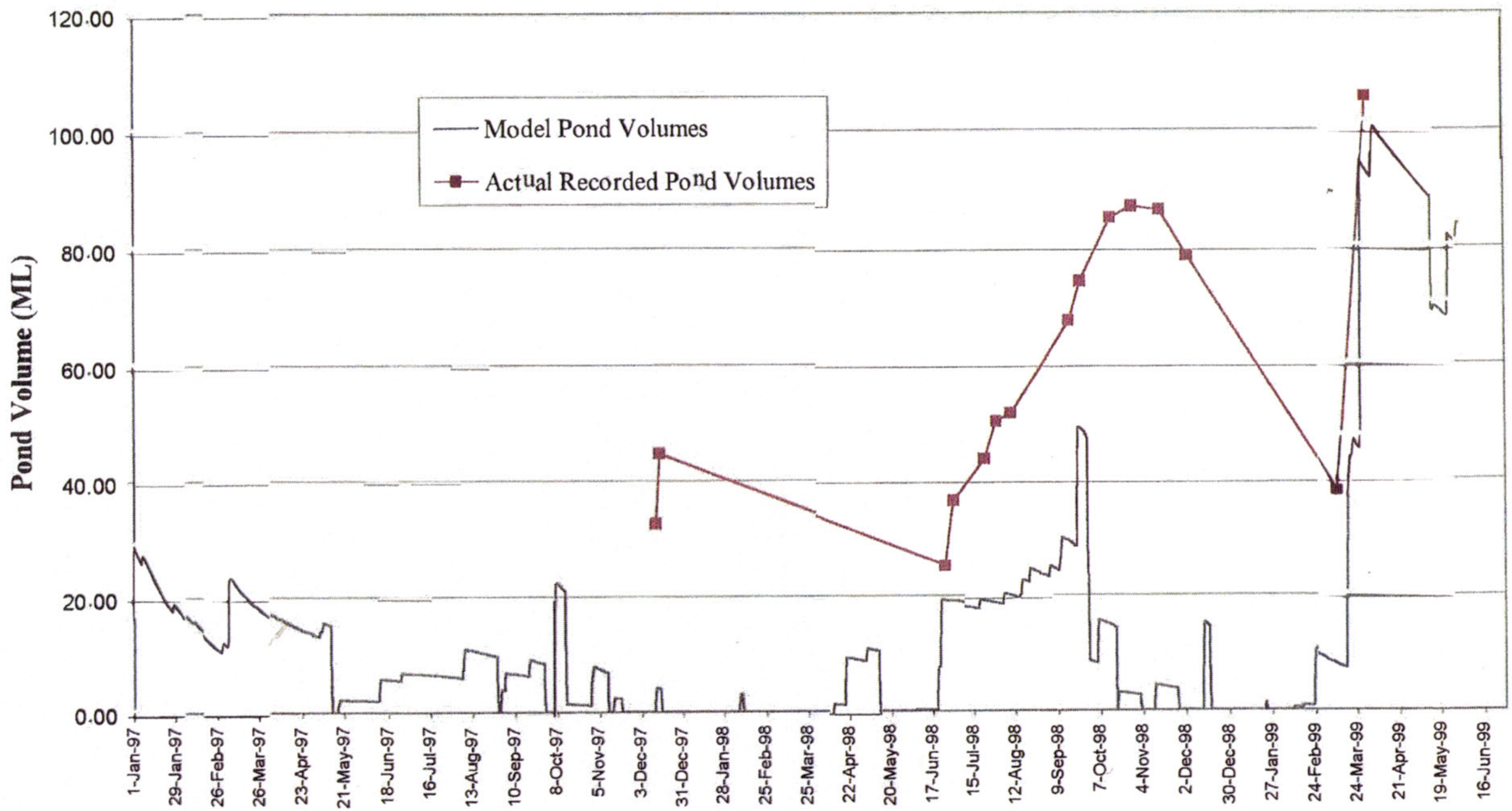


Figure 8. Actual and Predicted Pond Volumes for Feedlot E

Modelling of the individual feedlots showed that the average pond depth was quite shallow. The average and maximum depths of the holding ponds through time are presented in the Table 3.3. Data from Feedlot B were excluded from this table because the constant inflow from process generated waters caused the pond to be almost full at times when it should have been nearly empty.

Table 3.3. Pond characteristics

Site	Max pond depth (m)	Average pond depth (m)
Feedlot D	1.7	1.0
Feedlot E	1.8	0.3
Feedlot F	1.1	0.6

4 DISCUSSION

4.1 Evaporation from Effluent Holding Ponds

Lott (1997) found for feedlots in Eastern Australia that holding pond shape and thus evaporative loss, irrigation practices, soil and crop types, all affected the water balance of the holding pond and thus the volume required to contain runoff whilst obtaining a 1 in 10 year spill.

The results have shown that the holding ponds used by the cooperating feedlots are essentially large shallow impoundments with maximum depths of 3 metres and average depths of less than 2 metres. Over the reporting period the average depth of the water contained in the holding ponds was less than 1 metre. In all cases the effluent stored in the feedlot holding ponds has been black in colour and containing suspended solids.

The properties of water make them important stores and transmitters of energy. The exchanges occurring at the air/water interface are complicated by the fact that water is a fluid. Heat transfer in water can occur by both, conduction and radiation, and also convection and advection. These processes facilitate mixing of water and thus the transfer of heat throughout the body.

Short wave radiation can be transmitted by water. The extinction rate is dependant upon the nature of the water and the radiation wavelength. The extinction coefficient increases with turbidity and wavelength towards the infra-red. The greater the adsorption surfaces in the water the greater the extinction coefficient, and the less penetration of radiation occurs. In turbid waters short wave radiation will be adsorbed by the uppermost layers.

Some short wave radiation will be reflected. The ratio between total incident radiation and the outgoing radiation is described by the term 'albedo'. The albedo of a clear water surface is not constant (see Oke, 1978). With cloudless skies and the sun at least 30° above the horizon, water is one of the most effective absorbing surfaces (albedo = 0.03 to 0.10). However, at low angles the surface can be highly reflective. The condition of the surface is also important. The presence of waves increases reflection when the sun is overhead, but it will cause an increase in adsorption when the sun is at low angles. Because the areas of holding ponds are relatively small, they tend not to be ruffled. This increases the probability that the albedo will be low and more radiation will be adsorbed.

Radiation is an energy source. The energy balance of a water body can be described by the following simple equation;

$$Q=Q_H+Q_E+\Delta Q_S \qquad (7)$$

where;
- Q = energy in incoming radiation.
- Q_H = energy lost by long wave radiation
- Q_E = energy lost in evaporation of water
- ΔQ_S = change of heat storage in water layer

The ratios between input and output energy from a surface are discussed by Lott (1986) (after Watts, 1983). In large clear water bodies about 90% of Q is used is used to evaporate water.

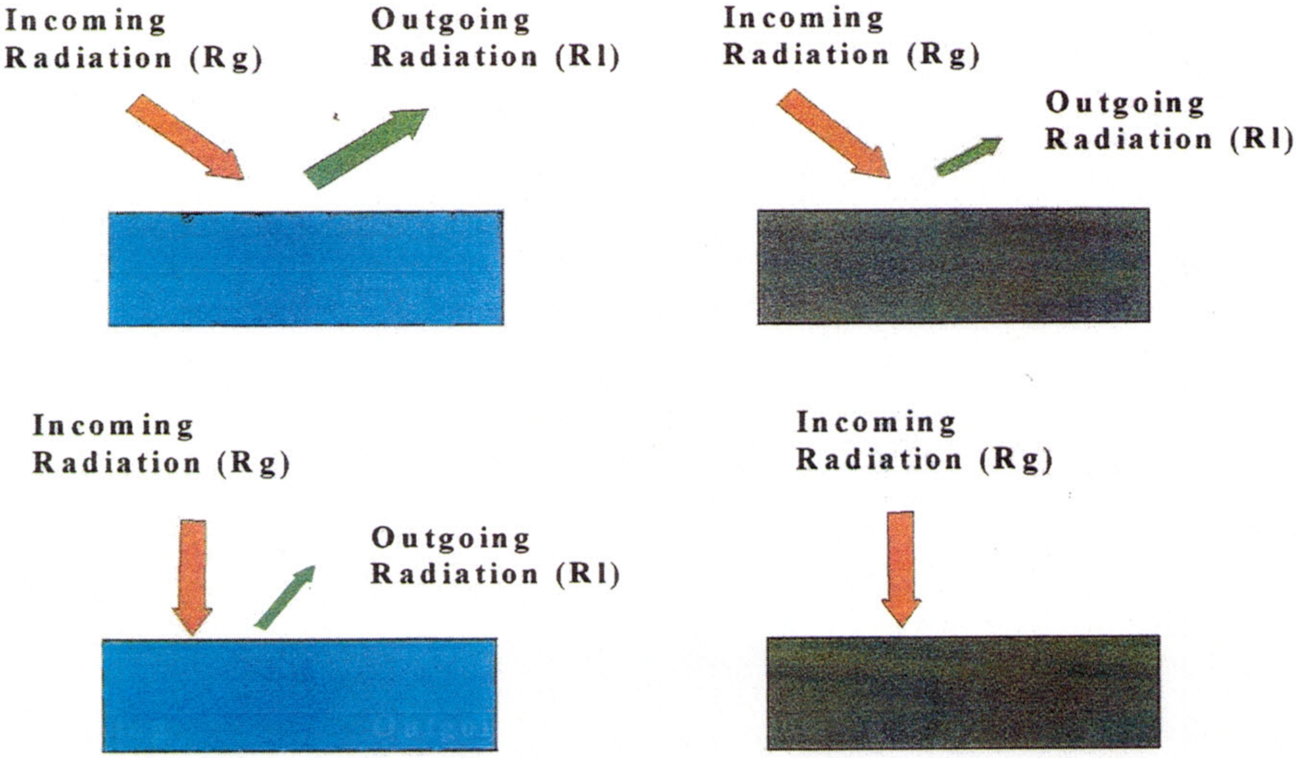
In the case of Equation 7 other terms may have to be added in. Where the water body is shallow and radiation passes through the water and heats the underlying soil, then Q_G must be added to the equation. Q_G is the energy related to heat conduction into and out of the soil. In smaller storages some of this input can come from soils surrounding the edge of storage (Oke, 1978).

Effluent may contain a significant amount of nutrient in ionic and organic forms. The exothermic reduction of some of these compounds will release heat while endothermic reduction will require heat. It is not clear whether these two reduction process balance each other out. However the organic matter in effluent is a food source for bacteria. Decomposition of the food provides a mechanism for the release of heat. Q_D is the net amount of heat that is transferred to the water body through the reduction and decomposition of matter in the effluent. This is an unknown entity in feedlot holding ponds.

The dark nature of the effluent contained in the ponds results in a greater proportion of incident radiation being adsorbed, and thus the heating of the effluent water body is significant. The holding pond effluent is warmed because the radiation is intercepted by suspended material. This is quite different from clear water bodies where the short wave radiation is adsorbed over a considerable volume of water. Therefore, it is suggested that holding pond effluent adsorbs more energy per unit volume than clear water and that ΔQ_S is a significant parameter.

Oke (1978) found that in rice paddies the heating of the large shallow water body and the underlying soil supported release of heat sufficient to offset the radiation loss at the water surface, and then continued to support evaporation through the night. Oke (1978) points out that the energy sources and sinks would approximately balance throughout the day, and demonstrates that the evaporation from the paddy is high.

Due to evaporative cooling, an isolated moisture source always finds itself somewhat cooler than its surrounds. This is especially the case with water bodies in arid areas. Oke (1978) demonstrates that the evaporative losses from oases require more energy than that supplied by Q (ie. QE is greater than Q). In this situation the atmosphere provides the sensible heat to the surface because the oasis water surface is cooler than the regional air in which it is embedded. Therefore there is a continual air-to-oasis inversion temperature gradient driving a downward directed heat flux, and the process is aided by air subsidence over the oasis (Oke, 1978). Oke (1978) points out that the ratio QE/Q is 1.37 and that values of 2.5 are possible for the ratio in cases of irrigated cotton (Lemon et al., 1957).



It is clear that there are two driving forces for large evaporative losses from the holding ponds; additional direct heating of the water and the soil beneath or surrounding the storage, and, the transfer of heat through the 'oasis' effect. These explain why the evaporative coefficient is much greater than that used for open water surfaces. Clearly the evaporation coefficient of 0.7 currently used in the calculation of holding pond evaporative loss is too low and must be increased. It is acknowledged that the value of K_p obtained in this project needs to be verified. At the moment it is however the best available data that can be used for determining evaporative losses.

4.2 Irrigation of Feedlot Effluent

Lott (1997) found through modelling that the average annual effluent application rates from simulations of feedlot performance from sites throughout eastern Australia ranged from 25 to 175 mm. The annual average depth of effluent applied each year at the cooperating feedlots ranged from about 39 to 86 mm.

Each feedlot involved in the study had other sources of clean water to ensure an irrigation supply to growing crops. As a result the potential for stress is reduced and crops at each site yielded well. This also may have caused the irrigation practices to be focused on storing effluent until there was sufficient volumes available to undertake full irrigation of a block. While this may have been convenient for the management of the farm, it also proved that 'available' storage capacity in the ponds were reduced and on at least one occasion this caused the ponds to overtop.

These research findings support those of Lott (1997) and Skerman (1998) who found that irrigation demand/practices do have a profound influence on the performance of holding ponds.

5 CONCLUSIONS

Rainfall-runoff from the feedlot controlled drainage area is captured in holding ponds. Holding ponds must be sized to store the effluent until it is disposed of, and spill only at an acceptable frequency. The results presented in Lott (1997) show that if holding ponds are required to spill only once in 10 years, then they will be larger than those sized using the design storm method. This occurs because feedlots produce more runoff than originally thought, and a significant storage capacity is required to capture runoff from a sequence of storms in quick succession, persistent rainfall, or to store runoff during extended periods having a low moisture deficit.

Evaporative loss of water from the holding pond and the rate of draw off for irrigation also influence the pond volume required to limit spill to an acceptable frequency. The effects of evaporative loss are most noticeable in situations where effluent is stored for prolonged periods of time.

The study found that the amount of runoff generated from feed yards in central and southern Australia were less than those in Southern Queensland. This is most likely due to the greater incidence of smaller rainfall events and most probably lower rainfall intensities. The amount of water lost from holding ponds was also greater than that calculated using a pan factor of 0.7. This resulted in less effluent being available for irrigation.

The size of holding capacity is primarily related to; the capture of runoff from a series of large storms in quick succession single catastrophic events, a large monsoonal event (such as those that occur in a wet season) when a large amount of rainfall is received as a single event of a number of days, or, a continuously wet season when irrigation is not possible and effluent must be stored. For holding ponds in southern Queensland the influence of evaporative loss on the determination of holding pond capacity is comparatively small. This is because most rainfall-runoff capture occurs over just a few days when the comparative loss by evaporation is minute. The opposite is true where pond capacity is required to store effluent for long periods of time.

Irrigation with effluent is a common method of using liquid waste from cattle feedlots. The management of the irrigation area is dependant on; the application system, application rate, crop type, soil type and depth, and, the availability of clean irrigation water. These factors influence the irrigation demand for effluent and thus the holding pond capacity because reduced demand means more effluent must be stored for longer periods which limits space to capture further rainfall-runoff.

Modelling of the hydrologic performance of holding ponds can be used to develop simple relationships suitable for guidelines. These guidelines need to accommodate the effect of evaporation, irrigation practices, and feedlot design.

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