Chapter 13

# Agricultural Waste Management Systems and Software Tools

John J. Classen and Harbans Lal

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/50484

## 1. Introduction

As the demand for animal products such a milk, meat, etc. has increased, producers have found ways to increase productivity and decrease the unit cost of production. Fossil fuels, inorganic fertilizer, pesticides, improved genetics of production species, better management techniques, and mechanization allowed productivity to increase to meet these demands. This has also meant concentration of more animals at each location. Confining some types of animals to houses or barns through all or most of their life cycle protects them from the weather and from predators and facilitates feeding, animal movement, and materials handling. Producers have benefited from economies of scale and product uniformity to provide the consumer with low-cost, high-quality meat and animal products.

These housing and confinement facilities employ specialized systems for materials handling, feed distribution, and, in the case of dairy, product collection and processing. Because of the large scale of these facilities, specialized waste collection and management systems are required. The manure, litter and process wastewater contains nitrogen, phosphorus, and potassium that are useful to plants if managed properly but, along with other pollutants such as pathogens, metals, and pharmaceuticals, could pollute the environment or harm human health if not handled properly. When properly applied to crop land as fertilizer, nutrients are used by crops, and other materials are generally rendered harmless in the soil. The purpose of waste management is to protect the environment and the public by keeping manure and contaminated waters out of surface and ground water and controlling application of manure nutrients to crop land such that nutrients are available in the right quantity, at the right time and at the right place.

This chapter describes the purpose and design of manure management systems and demonstrates how two software tools (AWM and SPAW) can be used to assist with the design and evaluation process.

## 2. Manure management systems

Manure is the collection of feces, urine, spilled feed and water from animal production and is collected in different forms, depending on the animal species. Swine and cattle produce thick liquid manure called slurry while manure from broilers and laying hens is much dryer. Storage systems depend on the animal species, how manure is collected, and local practices. Swine and dairy production in some areas collect and store slurry manure in storage ponds or tanks while some systems use liquid from anaerobic treatment lagoons to flush manure from collection pits or alleys. Although beef cattle excrete very wet manure, many of the concentrated feedlots are in dry regions where excessive rainfall and runoff do not create large storage requirements.

Selection of a manure management system is largely up to the producer based on the needs and goals of the individual operation. Slurry can be stored in earthen storage ponds or in above-ground glass-lined steel tanks. Earthen storage ponds can be less expensive to construct than steel tanks but will use more space than a steel tank of the same capacity. Storage tanks are more expensive and require installation by specifically trained teams. Storage tanks are installed with a central drain pipe through which manure can be loaded to slurry wagons or pumped back into the top of the tank for mixing. Such mixing prior to loading gives the applied manure a more consistent nutrient concentration and makes complete emptying and cleaning of the tank easier. A major concern with both ponds and tanks is odor emission, especially during mixing and land application.

Lagoons combine the storage capacity of ponds and tanks with a functional anaerobic treatment capacity [1]. By having a larger structure with more dilute contents, naturally occurring organisms convert manure organic matter to methane and carbon dioxide and transform organic nutrients into plant-available mineral forms [2]. This dilute liquid can be applied to crop land by irrigation, a less expensive and less labor-intensive operation than applying slurry. Drawbacks to lagoons include significant amounts of ammonia volatilization from lagoon surfaces and during spray irrigation, higher construction costs due to the larger size, and the need to irrigate lagoon effluent frequently during the growing season. Effluent irrigation requires a careful balance of preventing ponding on and runoff from the application fields with the proper timing and rate of nutrient application. Although odor reduction is a consequence of anaerobic treatment and odor from lagoon effluent is not as intense as that of slurry manure, odor emissions and neighbor complaints are still problems for producers using lagoon treatment systems [3,4].

Manure management facility design includes consideration of the amount and type of manure, requirements of any treatment system that will be used, any wash water or bedding that is added to the manure, and any limitations on land application such as applying when the ground is not frozen to allow infiltration and only when a crop is actively growing (or within 30 days prior to emergence in some cases). Expected manure mass and volume production of different species are available from the Manure

Production and Characteristics Standard produced by the American Society of Agricultural and Biological Engineers (ASABE) [5]. The data and procedures needed to calculate these volume components are available from the Animal Waste Management Field Handbook published by the United States Department of Agriculture (USDA) Natural Resource Conservation Service (NRCS) [6]. The Animal Waste Management Field Handbook also provides additional information needed for system design such as bedding characteristics and typical use rates, lagoon loading rates, sludge accumulation ratios for different species, expected depth of storms of different intensities, typical wash water requirements, and other guidelines regarding accepted practices of animal waste management. Typical rainfall and evaporation numbers must be obtained from local sources or national databases such as the National Climatic Data Center at the National Oceanic and Atmospheric Administration in the United States. National and state or provincial regulations must also be considered for requirements or limitations on facility siting or design.

Any design calculation or model depends on accurate data and sound procedures for reliable results; the critical data needs for manure management system design are weather data and manure production characteristics. The United States government took on the task of collecting and organizing weather data, assured the quality of these data, and has made these available to the general public. Animal manure production and characteristic data have been collected and verified primarily through university research efforts and reported in peer reviewed journals. These data have been checked for quality and organized by both the ASABE and the NRCS and are proven through frequent user designs and verification.

Collecting and manipulating these data are time consuming and require a great deal of care to obtain an acceptable facility design. Changing that design or comparing two or more designs takes almost as much time as creating the first design. In addition, it is highly recommended that liquid animal waste storage structures – especially ponds and lagoons should be adequately designed and frequently evaluated for the changing operational scenarios and for long term weather conditions. Changes in animal population and management style of a CAFO coupled with unexpected weather event(s) can significantly impact the waste generation and the need for the storage volume even for a well-defined storage period. Design software permits users to carry out such tasks in a fraction of the time.

AWM and SPAW are two such tools that have been developed to facilitate the design process. The capabilities of these tools have been recognized nationally by regulatory and non-regulatory agencies and private entrepreneurs. The United States Environmental Protection Agency (USEPA) CAFO Rules suggest using AWM and SPAW for evaluating liquid animal waste storage structures with respect to adequate storage for various storm events. This chapter describes these two tools and how they can be used for evaluating liquid waste storage structures using a hypothetical example scenario.

## 3. Animal Waste Management (AWM)

AWM is the NRCS national software tool for designing storage and treatment facilities for liquid and solid animal waste using site-specific characteristics and monthly weather data [7-9]. Key AWM components include: 1) Manure production; 2) Adjustments: bedding, wash water, runoff; 3) Withdrawals; 4) Storage Design/Analysis (Figure 1).

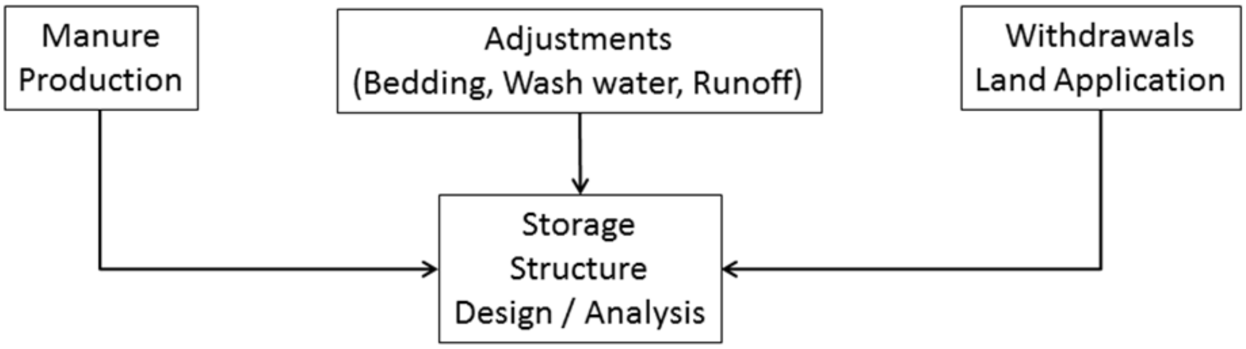


**Figure 1.** Key components of the AWM (Animal Waste Management) Software

The AWM production component estimates the quantity of manure based upon the type and size of the animal herd. The adjustments component adjusts the quantity and consistency of manure due to wash water, flush water, bedding etc. It also accounts for the amount of contaminated runoff from the pervious and impervious areas from the normal rainfall and design storm events (25 year-24 hour return period) contributing to the waste stream from the operation. It uses a database of monthly rainfall averages for the specific location in estimating runoff from the contributing area(s) but the rainfall amounts can be modified if more accurate values are available to the user.

The storage facility design is the key AWM output based upon the waste produced and withdrawal schedule for on-farm uses or off-farm disposal to meet regulatory requirements which are generally defined by months of waste removal or by the storage period.

The AWM software has the capability to evaluate existing waste storage structures in addition to designing new facilities. This feature permits evaluating dimensional adequacy for storing the waste flowing into the structure for the defined storage period or for the withdrawal schedule and can be used to determine if planned expansion of an animal operation will require additional storage capacity. The waste flowing into the structure includes: animal manure with additions, normal runoff, and the runoff from the 25 year-24 hour storm events, if applicable. Figure 2 shows the screen shot of the Evaluate function of AWM for a dairy operation used as an example in this chapter.

The AWM generates standard and customized reports that document the information furnished by the user, design and evaluation features of storage facilities and an estimate of land area needed to effectively utilize the available nutrients (N, P, and K) for the current or proposed cropping systems.

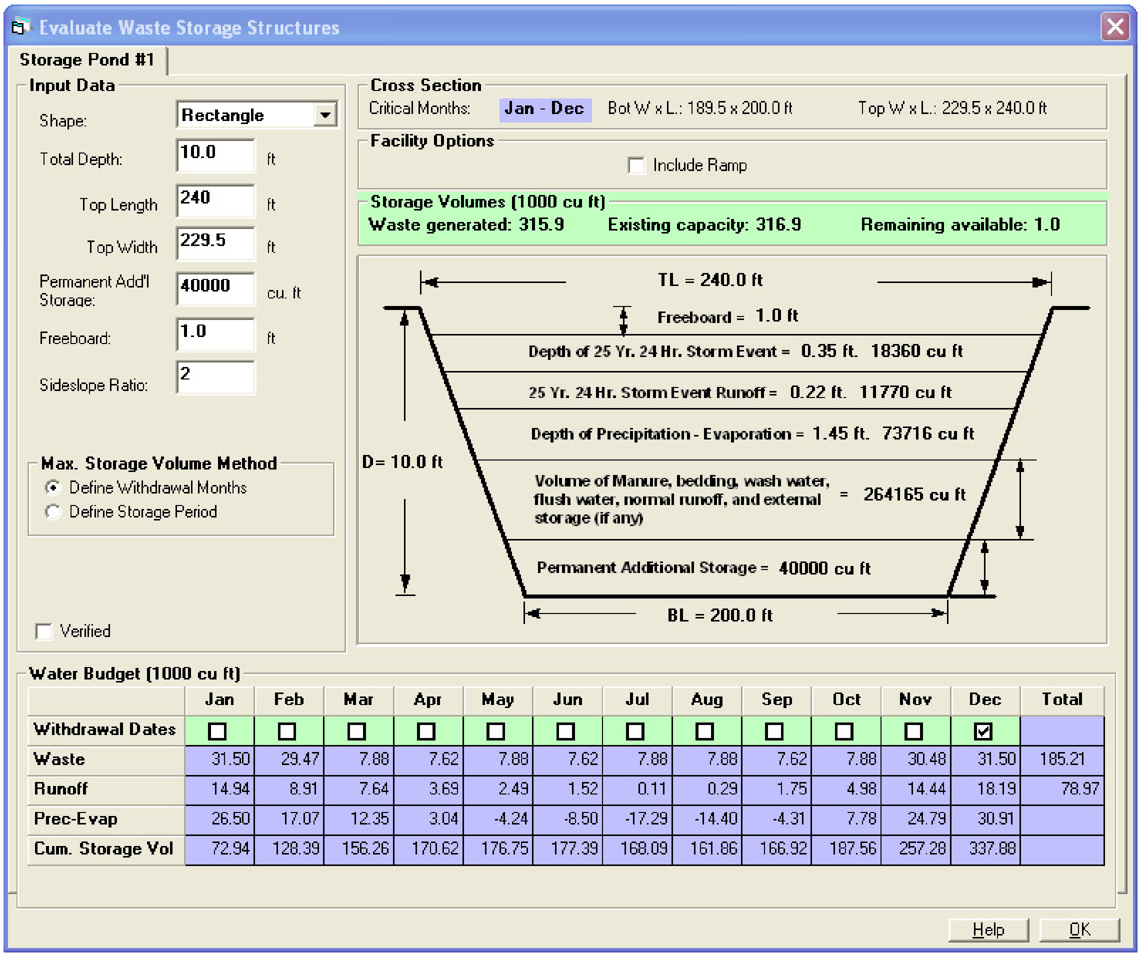


**Figure 2.** The "Eval" Screen of AWM for the example pond. This function evaluates an existing storage pond design against information about the farm operation. Note that in this example only a small storage volume is considered available.

## 4. Soil-Plant-Air-Water (SPAW)

SPAW (Soil-Plant-Air-Water) is a hydrologic water budget model that consists of two main connected routines: one for farm fields and the second for impoundments such as wetland ponds, lagoons or reservoirs [10, 11, 12].

The "Field" module of the SPAW simulates daily vertical, one-dimensional water budget depth of all major hydrologic processes such as runoff, infiltration, evapo-transpiration, and percolation occurring on a field. Input to this budget include: 1) daily rainfall, temperature and evaporation; 2) a soil profile of interacting layers, each with unique water holding characteristics; 3) annual crop growth and target yields with management options for rotations, irrigation and fertilization. The volumes for different water budget components are estimated by multiplying the component depth by the associated field area.

The "Pond" module simulates the hydrology of impoundments such as wetland ponds, lagoons or reservoirs (Figure 3). These simulations are based upon multiple input sources and depletion processes affecting the impoundment such as runoff from agricultural fields, irrigation and other water related operations. Typical applications of a SPAW simulation could include analyses of wetland inundation duration and frequency, wastewater storage design evaluation, and reliability of water supply reservoirs [11]. This is helpful in evaluation of liquid animal waste storage facilities when open lot runoff must be included.

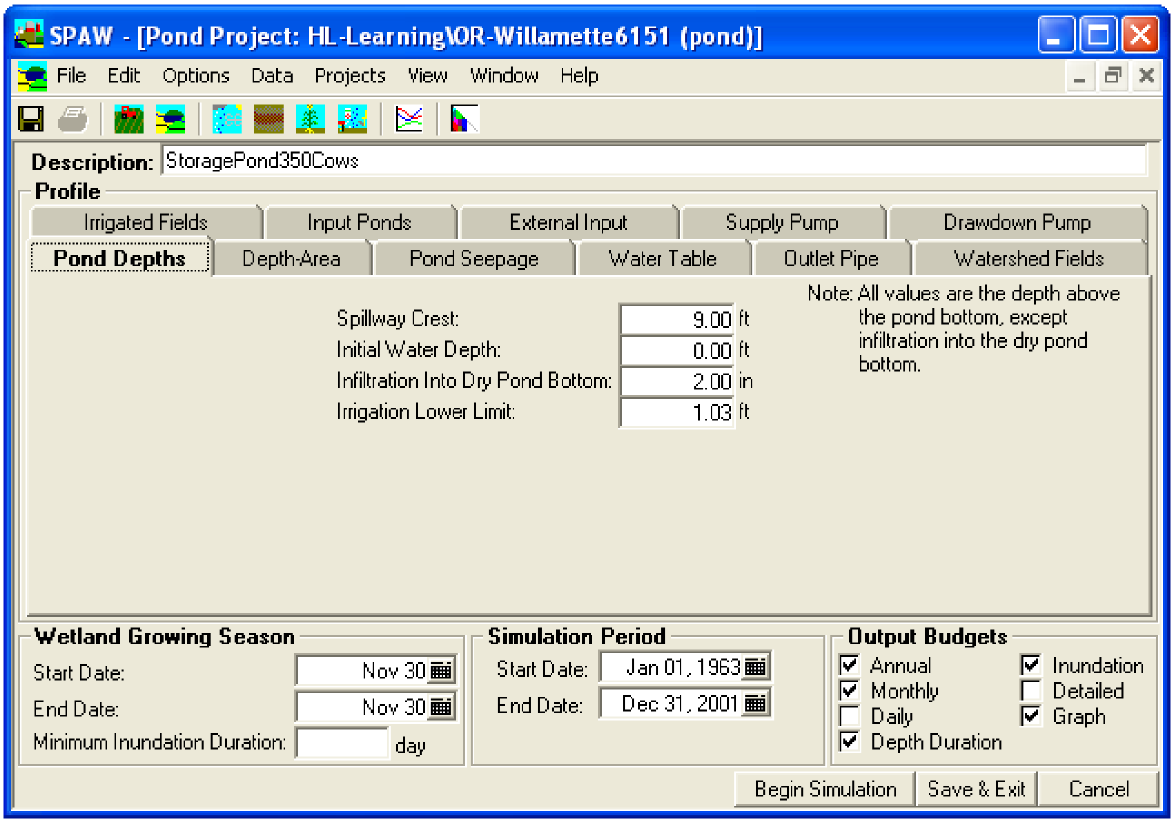


**Figure 3.** SPAW Screen for pond evaluation project

In this chapter AWM and SPAW have been used to evaluate an existing waste storage structure on a dairy farm (referred to as An Example Dairy). The AWM verifies the design parameters of the structure and the SPAW evaluates the operational characteristics of the structure.

## 5. An example dairy operation

The example is a hypothetical dairy operation located in Clackamas County, Oregon close to the N. Willamette Ext STN OR6151 weather station. The operation has a capacity to milk 350 animals and includes dry cows, heifers and calves as shown in Table 1. Animal barns have a total of 3,730 $ft^2$ of roof area and the animals have access to a 1-acre un-surfaced open exercise lot except during the coldest part of the winter. This farm follows typical practices of housing the calves in the barn at all times but the larger animals have access to the pasture during the warmer months of the year but are kept in the freestall barn during the months of November to February (Table 2). In this example all the waste collected from the operation is directed to a storage pond which is designed for a storage period of 12 months and the pond is emptied in the month of December.

| Animal Type | Animal | Quantity | Body Weight (lbs) |
|---|---|---|---|
| Dairy | Calf | 90 | 150 |
| Dairy | Dry Cow | 50 | 1000 |
| Dairy | Heifer | 12 | 900 |
| Dairy | Milker 60 Lbs | 350 | 1000 |

**Table 1.** Animal herd size and characteristics of the example dairy.

| Location | Calf | Dry Cows | Heifer | Milker (60 lb Milk) |
|---|---|---|---|---|
| *1st Operating Period (November – February)* | | | | |
| Freestall Barn | 100 | 100 | 100 | 80 |
| Milking Parlor | 0 | 0 | 0 | 20 |
| Pasture | 0 | 0 | 0 | 0 |
| *2nd Operating Period (March – October)* | | | | |
| Freestall Barn | 100 | 0 | 0 | 0 |
| Milking Parlor | 0 | 0 | 0 | 20 |
| Pasture | 0 | 100 | 100 | 80 |

**Table 2.** Percentage of manure deposited by animals at different locations during two operating periods.

The as-built dimensions of the storage pond are shown in Table 3. It stores the waste generated from the operation and also the runoff from a pervious watershed of 1 acre and an impervious area of 3,730 (0.09 acres) sq. ft of roofs, slabs and walkways.

| Key Parameter (s) | Units | Value(s) |
|---|---|---|
| Top Length × Width | ft × ft | 240 × 229.5 |
| Side-slope ratio | $ft/ft$ | 2 |
| Bottom Length × Width | ft × ft | 200 × 189.5 |
| Total Depth | ft | 10 |
| Freeboard | ft | 1 |
| Permanent Storage Volume | $ft^3$ | 40,000 |
| Storage Period | months | 12 |
| Withdrawal Month | | December |

**Table 3.** Key characteristics of the existing storage pond for the example farm

## 6. Evaluating the design with AWM

To evaluate the storage structure on the example farm, we entered and/or selected all the operational characteristics of the farm in the AWM as described by Lal [9]. With the complete set of AWM inputs, the evaluation function becomes active and shows the existing capacity is 1,000 $ft^3$ larger than the waste generated (see the green strip just above the pond graphic, Figure 2). This indicates that the storage pond is appropriately designed and has enough capacity to store the waste based on the waste generated and monthly averages of rainfall and evaporation. The user can also produce a separate report (Figure 4) with these parameters for inclusion in the overall pond report or as a component of a Comprehensive Nutrient Management Plan (CNMP) report.

AWM uses long term monthly rainfall averages and provides estimate of the storage volume required for the critical months [7]. AWM cannot evaluate the impact of what is known as "chronic" rainfall events, or a series of rainfall events that in total exceed the depth of a 25 year – 24 hour rainfall event. For such an evaluation, the SPAW model, which is based upon a daily time step of historical rainfall, is considered more appropriate and is discussed in the next section.

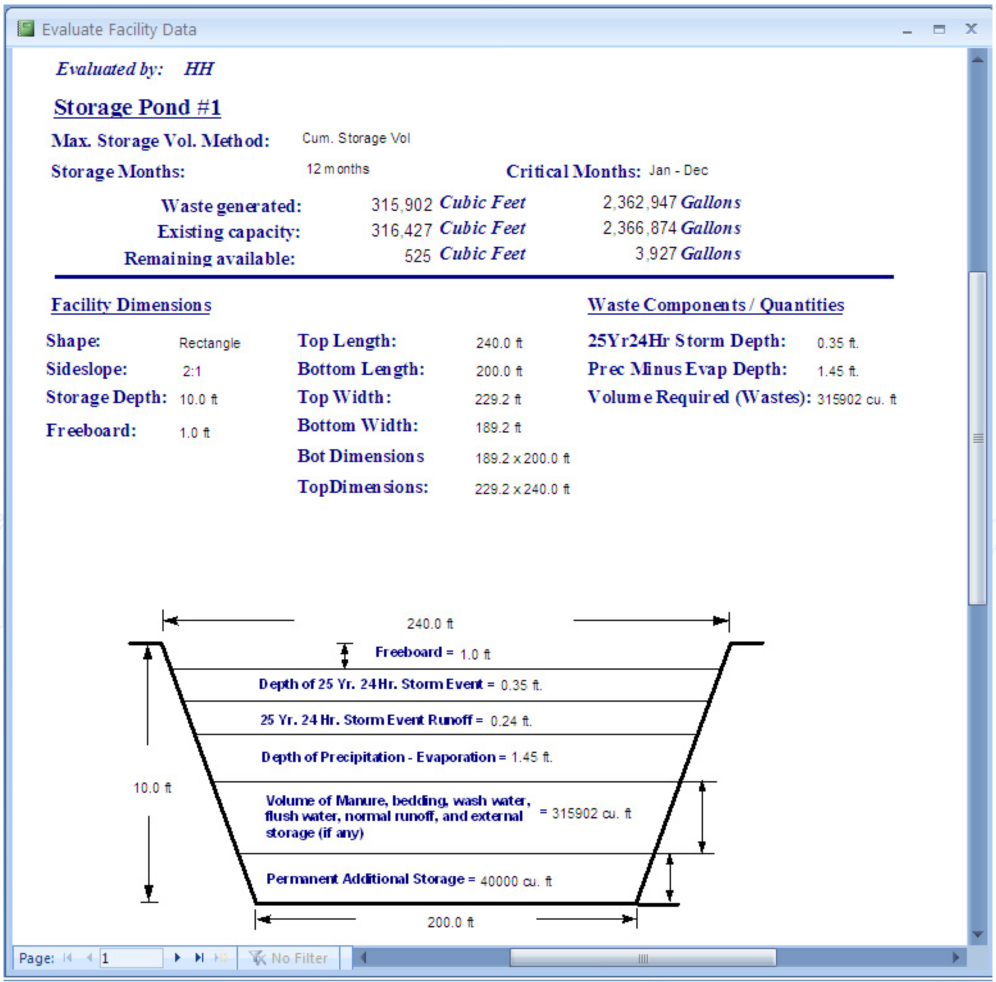


**Figure 4.** The pond evaluation report by AWM

## 7. Evaluating the design with SPAW

The hydrological analysis of a pond using SPAW is carried out in two linked simulations: the "Field" simulation and the "Pond" simulation. The Field simulation is performed to estimate the runoff that will be generated from the field and is routed to the pond and/or for the application of irrigation of the pond water to the field. A field represents any surface receiving rainfall that can be modeled by the SCS Runoff Curve Number hydrology method. Fields can be vegetated areas (defined as pervious watershed in AWM) or impervious areas such as rock outcrops, roofs, parking lots, and feedlots. Fields are further characterized by their soil type, crop, and management.

The "Pond" hydrology is simulated by accounting for the water entering and exiting the pond. Input sources include runoff, rainfall, evaporation, pumped inflows, and outflows such as irrigation and seepage. The user defines one or more fields that supply runoff to the "pond" based upon the site-specific climatic data for the simulation period. The user also defines the rules for wastewater withdrawals with an irrigation schedule and/or pumping rates and durations.

In the example scenario, there are three sources of wastewater to the storage pond: 1) runoff from the pervious area of 1 acre, 2) runoff from the impervious area of 3730 sq. ft (0.09 acre), and the waste from the waste producing locations such as free stall barn and milking parlor. Waste flow includes manure, flush water, wash water, etc. which are accounted as an "External Input" for SPAW pond simulation. A depth/volume curve for the example pond is created and entered in SPAW. Other information such as spillway crest height and lower limit for withdrawal are defined which were set respectively at 9 ft and 1.03 ft in the example. The spillway crest limit is found by subtracting the freeboard (1 ft.) from the total depth of 10 ft. The lower limit 1.03 ft the depth of the minimum treatment volume.

SPAW simulates removal of water/waste from the storage pond at scheduled irrigations and/or withdrawal events. The withdrawal is specified by the dates and rates of withdrawal. SPAW removes wastewater from the pond on the scheduled date regardless of the current climate conditions. The withdrawal (drawdown) removes liquids from the pond defined by the upper and lower limits and creates storage space for the future rainfall events. The two limits define the total volume of water to be removed during the drawdown period. If the upper limit is set to "zero", the SPAW starts pumping on the start date irrespective of depth of water in the pond. Otherwise, it starts at the next scheduled irrigation event or between the start date and end date whenever the pond depth exceeds the upper limit and it runs until either the end date is reached or the pond depth drops below the lower limit.

Table 4 shows the mapping of AWM parameters to SPAW inputs and also sources of additional data for SPAW simulations. These include: the location file (daily climatic data, monthly evaporation values), soils, pond volume/surface area relationship, external input of waste flow, and the pond depths including spillway and irrigation lower limit depth.

| Parameter | AWM Value | SPAW Value |
|---|---|---|
| Location file<br>Precipitation<br>Evaporation | <br>Built-in Monthly Averages<br>Built-in Monthly Averages | <br>Daily precipitation file from either of the following two source<br>USDA/NRCS High Resolution Climate Extractor website (http://199.133.175.81/HCEWebT/)<br>USDA/NRCS Water & Climate Center fttp site (ftp://ftp.wcc.nrcs.usda.gov/support/climate/daily-data/)<br>Transferred from AWM monthly averages |
| Soil | Not Required | Layered information on<br>Soil Texture (percentage Sand, Silt, Clay)<br>% Organic Matter (OM)<br>% Gravel<br>Bulk Density<br>USDA/NRCS Web Soil Survey Website ( http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx) ( Also special SQL query for accessing attribute data at http://sdmdataaccess.nrcs.usda.gov/Query.aspx) |
| Runoff<br>1.Pervious Surface<br>2. Impervious Surface | <br>Area (1 acre) and SCS curve number of 90<br>Area (3730 sq. ft) and SCS curve number of 98 | <br>Management files with appropriate selection of cropping, irrigation and fertilizer files both for pervious and impervious layer |
| Pond Depth | Total Depth = 10 ft<br>Free Board = 1 ft<br>Permanent Additional Volume (40,000 cu. ft) = 1.03 ft<br>Waste Volume (264, 165 cu. ft) = 5.95 ft<br>Preci-Evap (73,703 cu. ft) = 1.45 ft<br>On-site and runoff from 25 yr-24 Hr Storm (30,126 cu. ft) = 0.56 ft | <br>Spillway Crest = 9 ft<br>Irrigation Lower Limit = 1.03 ft |

<table>
<tr>
<td>Pond Dimensions</td>
<td>Top Length * Width (240*229.5 ft)<br>Bottom Length *Width (200*1189.5)<br>Side Slope Ratio = 2:1</td>
<td>
<table>
<tr><th>Depth (ft)</th><th>Area (Ac)</th><th>Volume (ac-ft)</th></tr>
<tr><td>0</td><td>0.87</td><td>0.00</td></tr>
<tr><td>1</td><td>0.91</td><td>0.89</td></tr>
<tr><td>3</td><td>0.99</td><td>2.78</td></tr>
<tr><td>5</td><td>1.06</td><td>4.82</td></tr>
<tr><td>7</td><td>1.14</td><td>7.02</td></tr>
<tr><td>9</td><td>1.22</td><td>9.38</td></tr>
<tr><td>10</td><td>1.26</td><td>10.62</td></tr>
</table>
</td>
</tr>
<tr>
<td>Pond Withdrawal</td>
<td>Emptying once every year in the month of December</td>
<td>Drawdown to the Lower limit (1.03 ft) every December irrespective the upper level (set upper Level = 0)</td>
</tr>
<tr>
<td>Waste Flow</td>
<td>Internally estimated based upon the herd size, bedding, waste water and flush water, etc. (values from the AWM Eval Screen)
<table>
<tr><th>Mon</th><th>Waste (1,000 cu. ft)</th></tr>
<tr><td>Jan</td><td>31.50</td></tr>
<tr><td>Feb</td><td>29.47</td></tr>
<tr><td>Mar</td><td>7.88</td></tr>
<tr><td>Apr</td><td>7.62</td></tr>
<tr><td>May</td><td>7.88</td></tr>
<tr><td>Jun</td><td>7.62</td></tr>
<tr><td>Jul</td><td>7.88</td></tr>
<tr><td>Aug</td><td>7.88</td></tr>
<tr><td>Sep</td><td>7.62</td></tr>
<tr><td>Oct</td><td>7.88</td></tr>
<tr><td>Nov</td><td>30.48</td></tr>
<tr><td>Dec</td><td>31.50</td></tr>
</table>
</td>
<td>Calculated based upon the monthly waste flow estimated in AWM pumping rate of 15 gal/min (equal to a Nelson Model 70 sprinkler with 5/16 inch nozzle at 30 psi)
<table>
<tr><th>Start Date</th><th>End Date</th><th>Duration (hrs/day)</th></tr>
<tr><td>Jan 1</td><td>Jan 31</td><td>9</td></tr>
<tr><td>Feb 1</td><td>Feb 29</td><td>8</td></tr>
<tr><td>Mar 1</td><td>Mar 31</td><td>2</td></tr>
<tr><td>Apr 1</td><td>Apr 30</td><td>2</td></tr>
<tr><td>May 1</td><td>May 31</td><td>2</td></tr>
<tr><td>Jun 1</td><td>Jun 30</td><td>2</td></tr>
<tr><td>Jul 1</td><td>Jul 31</td><td>3</td></tr>
<tr><td>Aug1</td><td>Aug 31</td><td>2</td></tr>
<tr><td>Sep 1</td><td>Sep 30</td><td>2</td></tr>
<tr><td>Oct 1</td><td>Oct 31</td><td>2</td></tr>
<tr><td>Nov1</td><td>Nov 30</td><td>9</td></tr>
<tr><td>Dec 1</td><td>Dec 31</td><td>9</td></tr>
</table>
</td>
</tr>
</table>

**Table 4.** Mapping of AWM data value to SPAW input parameters and also source of additional information needed for running SPAW model (Numerical values shown are for the example dairy)

Once all the input data files have been created, simulations in SPAW are run initially for the two fields (pervious surface and impervious surface) and then for the pond by selecting the appropriate project files. The field simulations are made prior to the pond simulation because they provide runoff and climate data for the pond simulation. The simulation period (Jan 01, 1963 to Dec. 31, 2001) is selected within the dates of available climatic data with appropriate selection of output files. Each simulation generates the specified output files which can be viewed in a tabular or graphic form for analysis. Budget summaries for annual, monthly and daily time periods are provided. Average data for each time period (annual, monthly or daily) are shown at the end of each summary table. The graphical routine provides a visual representation of the daily hydrologic values within the field and pond budgets. Daily and cumulative values for most variables are selectable. The pond graph is similar to that of the field of both daily and cumulative variables over each calendar year. The flexibility in selecting the time-period for displaying graphs is a unique SPAW feature. It enables analyzing SPAW results over a variable time period by months (1-24) and years. The graphs can be saved using the "File/Save As" option.

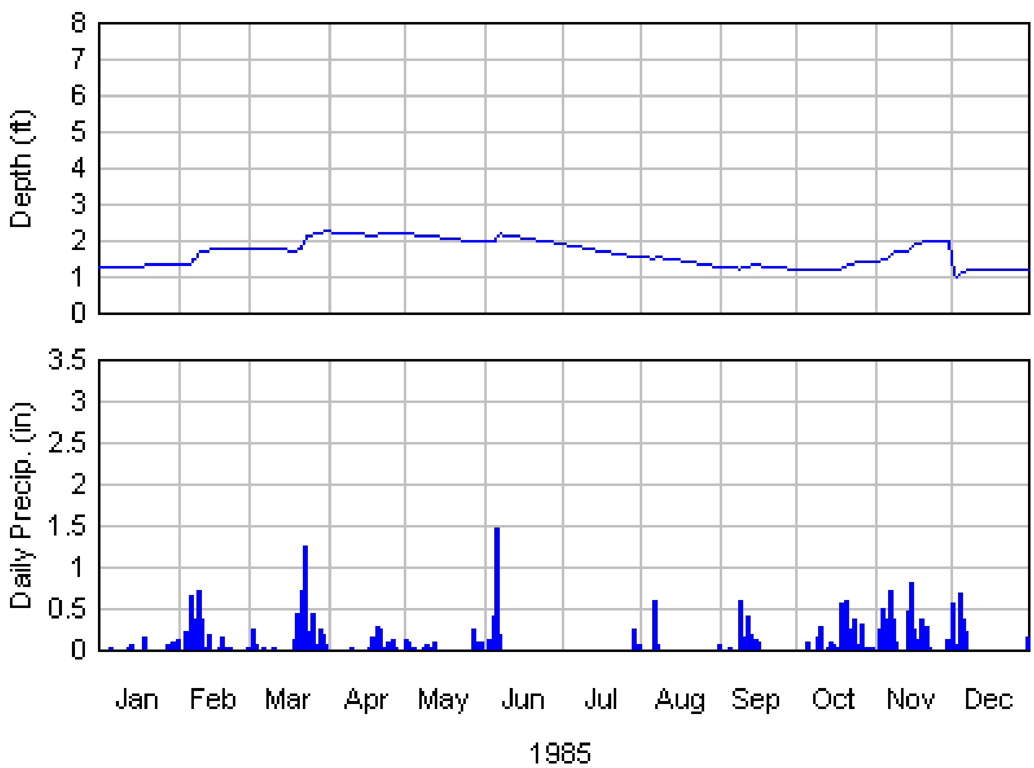


**Figure 5.** Pond storage depth and daily precipitation for the example dairy for 1985 -- the driest year of the simulation period. Annual precipitation was 26.45 inches with impervious layer runoff from 3730 ft².

The primary objective of the SPAW example simulation is to evaluate the daily variation of the pond's depth during the simulation period. Figures 5 and 6 present the daily precipitation and pond depth for the two extreme weather years (1985 and 1996), respectively. The year of 1985 was the driest year with the total annual precipitation of 26.4

inches. On the other hand, 1996 was the wettest year with the precipitation of 72.94 inches. During the dry year of 1985 the maximum depth of wastewater in the pond was 2.26 ft on Mar. 30th as compared to 7.20 ft during the wet year of 1996. It was satisfying to note that the storage pond designed and evaluated as being "satisfactory" using AWM was confirmed through SPAW simulation to be able to withstand the waste flow during one of the wettest years on record.

To validate the sensitivity of the SPAW model to input changes, another simulation was made by changing the area of impervious layer considerably from 0.09 acre to 1 acre. Figures 7 and 8 show the daily storage depth and spillway volume from the smaller impervious area for the same two extreme years as shown above. The maximum depth with the increased impervious area increased to 3.37 ft compared to 2.26 ft for the dry year (1985) and to 9 ft for wet year 1996. As the spillway crest was set at 9 ft (Figure 3), the pond started flowing soon after the pond depth reached 9 ft on Nov 17 and continued until Nov. 30th with the total spill amount of 1.16 acre-ft. This shows that the SPAW model is sensitive to the runoff generating areas which are clearly reflected in the variation of the waste storage depths in the pond. In the event a producer wanted to implement a modification that resulted in such an increase in impervious area, additional pond capacity would be required; the calculation and design of that capacity would easily be completed with the AWM software.

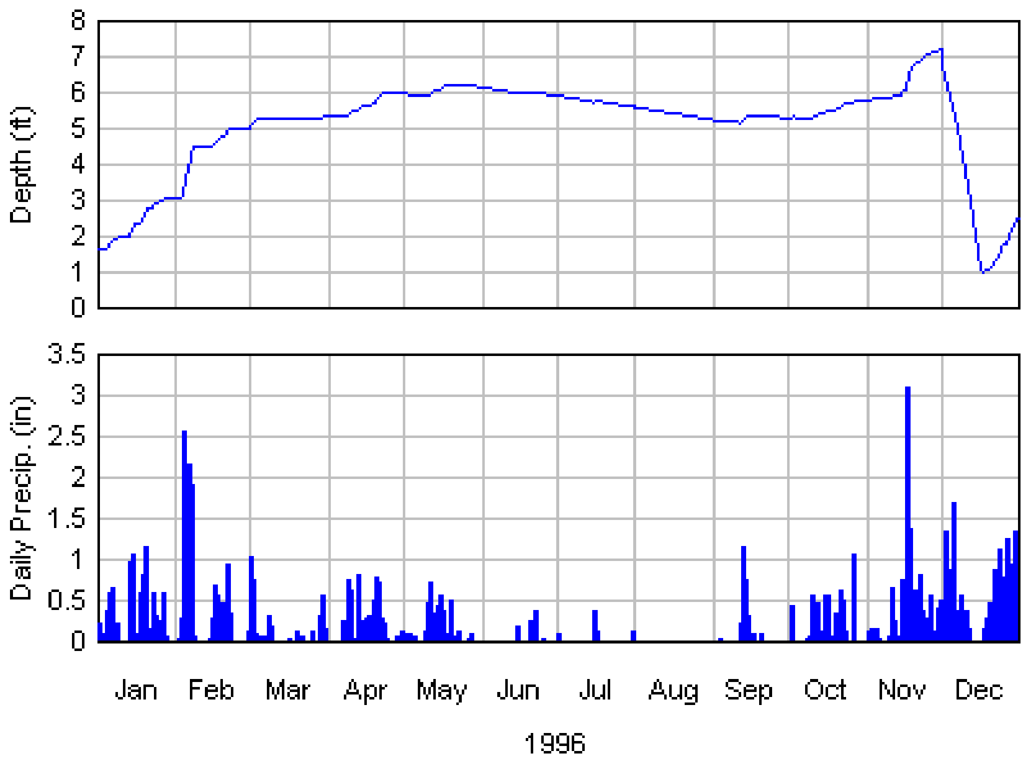


**Figure 6.** Pond storage depth and daily precipitation for the example dairy for 1996 -- the wettest year of the simulation period. Annual precipitation was 74.94 inches with impervious surface runoff area of 3730 ft$^2$.

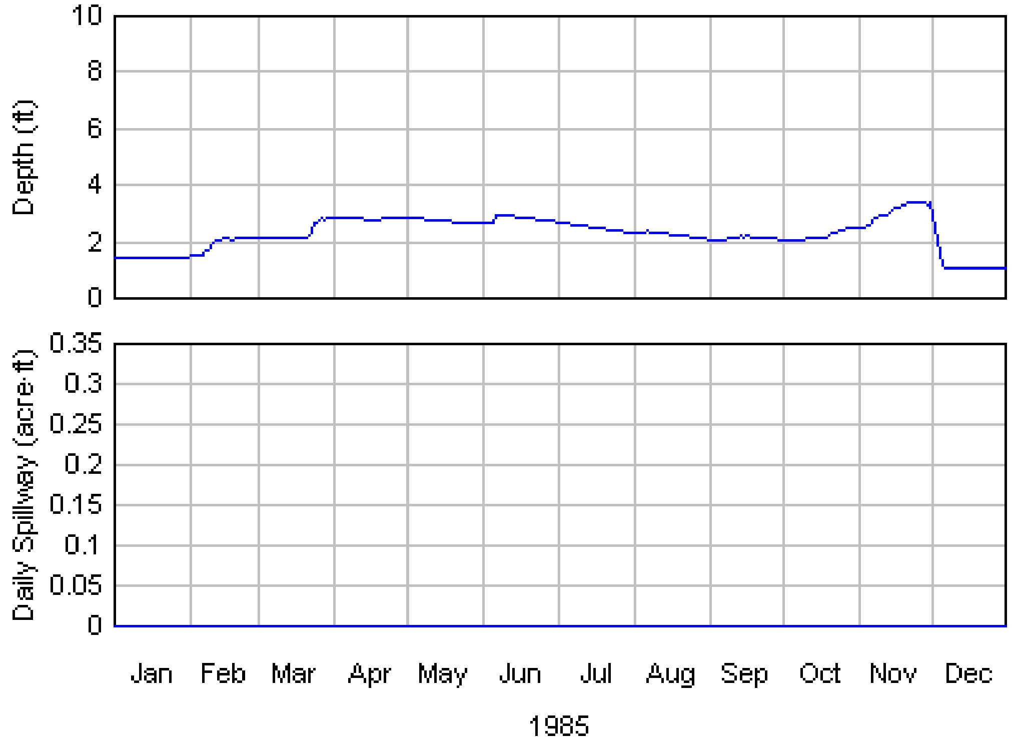


**Figure 7.** Storage pond depth and spillway dicharge during 1985 – the driest year with total precipitation of 26.45 inches from the enlarged impervious surface area of 1 acre. Please note there was no spillway discharge during the year.

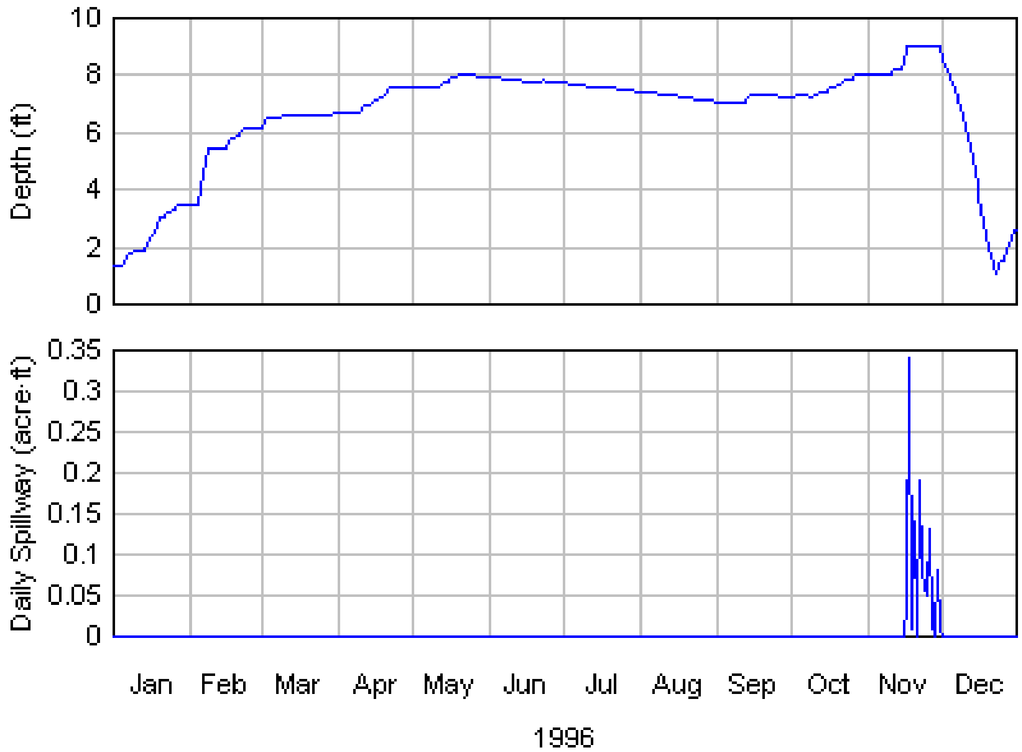


**Figure 8.** Storage pond depth and spillway discharge volume during 1996 – the wettest year with total precipitation of 72.94 inches from the enlarged impervious surface area of 1 acre.

## 8. Concluding remarks

This chapter described the basics of animal production systems as related to liquid animal waste storage. Design of storage and treatment facilities on the farm requires accurate data about the manure production characteristics, the size and operation of the farm, local weather conditions, and regulatory requirements and procedures. Liquid storage structures must provide sufficient capacity for manure, wash water, bedding, contaminated runoff and any additional inputs for that period of time during which land application operations do not normally occur. For some operations, that period may be a year and for others, it may be only several months. Local conditions and practices are critical to a successful design.

It was successfully demonstrated how two engineering software packages, namely AWM (Animal Waste Management) and SPAW (Soil-Plant-Air-Water), supported by the NRCS can be used to design and evaluate waste storage ponds and treatment lagoons. They serve evaluation processes that are complementary to each other. AWM evaluates the design of the storage pond while SPAW evaluates the operation of the pond, identifying how the pond will behave for extreme events. The test example demonstrated the pond designed and successfully evaluated by AWM was also able to withstand the wettest year (1996) when evaluated using SPAW model. However, when the impervious surface area contributing runoff to the pond was increased to 1 acre from 0.09 acre, the pond reached the maximum storage height of 9 ft on Nov. 17 and spilled continuously till Nov. 30$^{th}$.

## Author details

John J. Classen
*Biological and Agricultural Engineering Department, North Carolina State University, Raleigh, NC, USA*

Harbans Lal
*National Water Quality and Quantity Team, NRCS/USDA, Portland, OR, USA*

## 9. References

[1] Bicudo JR, Westerman PW, Safley LMJ. (1999) Nutrient content and sludge volumes in single-cell recycle anaerobic swine lagoons in North Carolina. Trans ASAE ;42: 1087-1093.

[2] Burns JC, King LD, Westerman PW. (1990) Long term swine lagoon effluent applications on to coastal bermudagrass: I. yield, quality, and elemental removal. Journal of environmental quality ;19: 749-756.

[3] Lim T, Heber, A J, Ni, J, Sutton, A L, Shao, P. (2003) Odor and Gas Release from Anaerobic Treatment Lagoons for Swine Manure. J Environ Qual /3;32(2):406-416.

[4] Mukhtar S, Borhan MS, Rahman S, Zhu J. (2010) Evaluation of a field-scale surface aeration system in an anaerobic poultry lagoon. Appl eng agric ;26: 307-318.

[5] ASAE. (MAR2005) D384.2 Manure Production and Characteristics. ASAE: St. Joseph, MI.

[6] USDA NRCS. National Engineering Handbook - Part 651 - Agricultural Waste Management Field Handbook. United States Department of Agriculture: Washington, D.C.

[7] Moffitt, DC, Wilson, B, and Wiley, P. (2003) Evaluating the design and management of waste storage ponds receiving lot runoff. ; ASAE Paper 034129; St. Joseph, Mich.: ASAE.

[8] Moffitt, DC, and Wilson, B. (2004) Evaluating the design and management of waste storage ponds - Part II. ; ASAE Paper 044072; St. Joseph, Mich.: ASAE.

[9] Lal H. (2011) Animal Waste Management (AWM) System New and Improved - A tool for evaluating and designing waste storage facilities. Resource May/June 2011;18(3):16-19.

[10] Saxton K.E. (2002) SPAW Soil-Plant-Atmosphere-Water Field and Pond Hydrology Model. United States Department of Agriculture-Agricultural Research Service: .

[11] Saxton, KE, Wiley, P, and Rawls, WJ. (2006) Field and pond hydrologic analysis with the SPAW model. ; ASAE Paper 062108; St. Joseph, Mich.: ASAE.

[12] Lal, H, Wiley, P, and Khanal, P. 2011. Using AWM and SPAW for Evaluating Animal Waste Storage Structures, presented at the Southern Regional Water Conference, USDA, Athens, GA, September 13-16, 2011.