C. MANURE GENERATION AND STORAGE

Manure Generation Calculations

The standard procedure in manure generation calculations is to consider manure to be animal waste plus bedding.

\[ Manure = Waste + Bedding \]

Waste is defined as feces plus urine.

\[ Waste = Feces + Urine \]

Total Annual Volume of Waste:

On a volumetric rate, each 750-pound Finishing Beef animal produces 0.59 ft³ of waste per day and each 1,100-pound Finishing Beef animal produces 0.86 ft³ of waste per day (MWPS-18, 2004, Table 6). This operation will house a maximum of 6,999 animals comprised of 3,500 finishing cattle with an average weight of 750 pounds and 3,499 finishing cattle with an average weight of 1,100 pounds.

\[ V_{750} \] is the daily volume of waste produced by the 750-lb cattle.

\[ V_{750} = 3,500 \text{ animals} \times \frac{0.59 \text{ ft}^3 \text{ waste}}{\text{animal}(\text{day})} = \frac{2,065.00 \text{ ft}^3 \text{ waste}}{\text{day}} \]

\[ V_{1100} \] is the daily volume of waste produced by the 1,100-lb cattle.

\[ V_{1100} = 3,499 \text{ animals} \times \frac{0.86 \text{ ft}^3 \text{ waste}}{\text{animal}(\text{day})} = \frac{3,009.14 \text{ ft}^3 \text{ waste}}{\text{day}} \]

Thus, the daily volume of waste produced, \( V_W \), can be expressed as the volume produced by the 750-lb cattle plus the volume produced by the 1,100-lb cattle.

\[ V_W = V_{750} + V_{1100} \]

\[ V_W = 2,065.00 \text{ ft}^3 + 3,009.14 \text{ ft}^3 = 5,074.14 \text{ ft}^3 \]

The mass of waste, \( M_W \), produced daily is the daily volume of waste generated multiplied by the waste’s density, which is 63 lb/ft³ (MWPS-18, Table 6).

\[ M_W = 5,074.14 \text{ ft}^3 \times 63 \frac{\text{lb}}{\text{ft}^3} = 319,670.82 \text{ lb} = 159.83 \text{ tons} \]

On an annual basis, the total waste produced is the daily amount times 365 days. Therefore, the annual volume of waste is 1,852,061.10 ft³ and the annual mass of waste is 58,339.92 tons.
Total Annual Volume of Bedding:
The waste produced by Finishing Beef Cattle is 92% water (8% solids) (From MWPS-18, Table 6). This percentage will be reduced to 74.5% moisture (above 25.5% solids) to ensure that the manure will act as a solid and be moveable and stackable.

To calculate the amount of bedding required to achieve the desired percent moisture of the manure requires a weighted average of the waste and bedding percent moisture.

\[ M_W \times %S_W + M_B \times %S_B = (M_W + M_B) \times %S_M \]

\( M_W \) is the mass of waste, \( M_B \) is the mass of bedding, \( %S_W \) is the percent solids of the waste, \( %S_B \) is the percent solids of the bedding, and \( %S_M \) is the percent solids of the manure.

The above equation can be rewritten for 100 lb. of waste and bedding with 7.5% moisture (92.5% solids).

\[ (100 \times 0.08) + M_B \times 0.925 = (100 + M_B) \times 0.255 \]

Solving for \( M_B \) yields 26.1 lb. of bedding needed for 100 lb. of waste.

The bedding mass per day is the ratio of bedding per manure times the weight of manure generated per day.

\[ \frac{26.1 \text{ lb bedding}}{100 \text{ lb waste}} \times \frac{319,670.82 \text{ lb waste}}{\text{day}} = 83,434.08 \text{ lb bedding day} \]

On a per animal basis the amount of bedding is 11.92 lb/animal/day.

The annual mass of bedding is the daily mass of bedding times 365, or 30,453,440.67 lb.

The daily bedding mass needs to be converted to volume, \( V_B \), by dividing by the density of the bedding, 7 pounds/ft\(^3\) (TN SD2011-1).

\[ V_B = \frac{83,434.08 \text{ lb bedding day}}{7 \text{ lb bedding}} = 11,919.15 \text{ ft}^3 \text{ bedding day} \]

The annual volume of bedding is the daily volume of bedding times 365, or 4,350,489.75 ft\(^3\).

Total Annual Volume of Manure:
The total manure volume generated, \( V_T \), is estimated to be the volume of waste plus half the volume of bedding (MWPS-18, Eqn. 6, page 17).

\[ V_T = V_W + 0.5 \times V_B \]

The daily manure volume can be calculated from the daily waste volume and daily bedding volume calculated above.
5,074.14 $ft^3 + 0.5 \times 11,919.15 \, ft^3 = 11,033.72 \, ft^3$

The annual manure volume can be calculated from the annual waste volume and annual bedding volume calculated above.

$1,852,061.10 \, ft^3 + 0.5 \times 4,350,489.75 \, ft^3 = 4,027,310.48 \, ft^3$

The density of the manure is expressed as the weighted mean of the densities of the waste and bedding.

$$\rho_T = \frac{100 \, lb}{100 \, lb + 26.1 \, lb} \times \left(63 \, \frac{lb}{ft^3}\right) + \frac{26.1 \, lb}{100 \, lb + 26.1 \, lb} \times \left(7 \, \frac{lb}{ft^3}\right) = 51.4092 \, \frac{lb}{ft^3}$$

The daily manure mass produced is the daily manure volume times the manure density.

$$11,033.72 \, ft^3 \times 51.4092 \, \frac{lb}{ft^3} = 567,234.72 \, lb = 283.62 \, tons$$

The annual manure mass produced is the annual manure volume times the manure density.

$$4,027,306.86 \, ft^3 \times 51.4092 \, \frac{lb}{ft^3} = 207,040,809.93 \, lb = 103,520.40 \, tons$$

**Manure Storage Volume Calculations**

**Total Volume of Animal Confinement Barns:**

Manure will be stored in three designated manure storage barns as well as in each of the six animal confinement barns, which will be operated as bedded pack barns. The animal confinement barns are summarized in Table 1 and the manure storage barns are summarized in Table 2.

Each animal confinement barns has a 12’ wide aisle along each long wall and an 18’ wide aisle down the center of the barn. For the 138’ wide barns, this leaves two 48’ wide (96’ total) areas the length of the barn for animal confinement that will contain manure as shown in Figure 1 below. For the 150’ wide barn there are two 54’ wide (108’ total) containment areas. Thus, the area available for manure storage within each barn (the Manure Storage Area in Table 1 below) is 96’ times the length of the barn for the 138’ wide barns and 108’ times the length of the barn for the 150’ wide barn.
The animal confinement barns have solid concrete floors and 27” solid concrete containment walls surrounding the animal confinement areas. Manure will be stored at a maximum height of 1’ in the animal confinement areas. Thus the Maximum Storage Volume for manure in each barn, shown in Table 1, is given by the Manure Storage Area times the 1’ storage height. The total maximum storage volume available in the animal containment buildings is 512,700 ft³.

Table 1. Animal Confinement Barns Storage Volume Calculations

<table>
<thead>
<tr>
<th>Building</th>
<th>Building Footprint</th>
<th>Manure Storage Footprint</th>
<th>Manure Storage Area (ft²)*</th>
<th>Storage Height (ft)</th>
<th>Maximum Storage Volume (ft³) [Area x Height]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Animal Confinement Barn A</td>
<td>205’ x 150’</td>
<td>205’ x 108’</td>
<td>22,140</td>
<td>1.0</td>
<td>22,140</td>
</tr>
<tr>
<td>Animal Confinement Barn B</td>
<td>470’ x 138’</td>
<td>470’ x 96’</td>
<td>45,120</td>
<td>1.0</td>
<td>45,120</td>
</tr>
<tr>
<td>Animal Confinement Barn C</td>
<td>720’ x 138’</td>
<td>720’ x 96’</td>
<td>69,120</td>
<td>1.0</td>
<td>69,120</td>
</tr>
<tr>
<td>Animal Confinement Barn D</td>
<td>720’ x 138’</td>
<td>720’ x 96’</td>
<td>69,120</td>
<td>1.0</td>
<td>69,120</td>
</tr>
<tr>
<td>Animal Confinement Barn E</td>
<td>1600’ x 138’</td>
<td>1600’ x 96’</td>
<td>153,600</td>
<td>1.0</td>
<td>153,600</td>
</tr>
<tr>
<td>Animal Confinement Barn F</td>
<td>1600’ x 138’</td>
<td>1600’ x 96’</td>
<td>153,600</td>
<td>1.0</td>
<td>153,600</td>
</tr>
</tbody>
</table>

**TOTAL = 512,700**
Total Volume of Manure Barns:
In the 200’ long x 60’ wide manure barn, manure will be stacked in the shape of a rectangular solid the length and width of the barn to the height of the containment wall. Above the containment wall the manure will be stacked in the shape of a trapezoidal solid with a footprint the length and width of the barn, with side slopes of 2H:1V, and a flat top at a height of 18 feet. The total cross-sectional area of the manure stack is the cross-sectional area of the rectangular solid plus the cross-sectional area of the trapezoidal solid. The cross-sectional area of the 200’ long x 60’ wide manure barn is shown in Figure 2 and is 880 ft$^2$.

![Figure 2- Cross-sectional Area of Manure Stack for 200' long x 60' wide Manure Barn A](image)

For the 300’ long x 150’ wide manure barn, a floor space of 100’ long x 50’ wide may be used for a manure dryer for the manure export operation. A 100’ long x 15’ wide aisle may be left for equipment movement. In the remaining 100’ long by 85’ wide area, the manure will be stacked in a semi-triangular cross section with area 1,111 ft$^2$. In the remaining 200’ long x 150’ wide area of the barn, manure will be stacked in a trapezoidal solid, similar to the 200’ long x 60’ wide barn, but up to a height of 30’. That section of the barn will have a cross-sectional area of 3,532 ft$^2$. The two cross sections of manure in the barn are shown in Figure 3.
In the 350’ long x 100’ wide manure barn, manure will be stacked in a trapezoidal solid, similar to the 200’ long x 60’ wide barn, with side slopes of 2H:1V, and a flat top at a height of 18 feet. The total cross-sectional area of the manure stack in the 350’ long x 100’ wide manure barn is shown in Figure 4 and is 1604 ft².
The volume of the manure to be stored in each manure barn can be calculated by multiplying the cross-sectional area of each manure pile times the length of the pile. The storage capacity of each manure storage barn and the total maximum storage volume available in the manure barns is given in Table 1 and is 1,554,900 ft$^3$.

### Table 1 - Manure Barns Storage Volume Calculations

<table>
<thead>
<tr>
<th>Building</th>
<th>Building Footprint</th>
<th>Manure Cross-Sectional Area (ft$^2$)*</th>
<th>Storage Length (ft)</th>
<th>Maximum Storage Volume (ft$^3$) [Area x Length]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manure Storage Barn A</td>
<td>200’ x 60’</td>
<td>880</td>
<td>200</td>
<td>176,000</td>
</tr>
<tr>
<td>Manure Storage Barn B</td>
<td>200’ x 150’</td>
<td>3532</td>
<td>200</td>
<td>706,400</td>
</tr>
<tr>
<td></td>
<td>100’ x 85’</td>
<td>1111</td>
<td>100</td>
<td>111,100</td>
</tr>
<tr>
<td>Manure Storage Barn C</td>
<td>350’ x 100’</td>
<td>1604</td>
<td>350</td>
<td>561,400</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td></td>
<td></td>
<td><strong>1,554,900</strong></td>
</tr>
</tbody>
</table>

**Total Volume Storage:**

As stated in Tables 1 and 2, the total manure storage volume of this operation is 512,700 ft$^3$ plus 1,554,900 ft$^3$ for a total of 2,076,600 ft$^3$. 

![Figure 4- Cross-sectional Area of Manure Stack for 350' long x 100' wide Manure Barn C](image-url)
**Mass Storage:**

The total manure storage mass is the manure storage volume times the density of the manure.

\[
2,076,600 \text{ ft}^3 \times \frac{51.4092 \text{ lb}}{\text{ft}^3} = 106,293,662 \text{ lb} = 53,146 \text{ tons}
\]

**Days of Storage:**

A portion of the total manure generated by the operation will be exported and a portion of the manure will be land applied. The operation is required by 10 CSR 20-8.300 to provide 90 days of storage for the portion of manure that will be exported and 180 days of storage for the portion of manure that will be land applied by the operation on fields identified in the Nutrient Management Plan.

Of the manure generated, 80% will be exported. The daily volume for export is calculated by multiplying the daily manure volume by 0.8.

\[
11,033.72 \text{ ft}^3 \times 0.8 = 8,826.98 \text{ ft}^3
\]

The 90-day volume is the daily rate times 90 days, or 794,427.84 ft³.

The remaining 20% or the manure generated will be land applied by the operation calculated by multiplying the daily manure volume by 0.2.

\[
11,033.72 \text{ ft}^3 \times 0.2 = 2,206.74 \text{ ft}^3
\]

The 180-day volume is the daily rate times 180 days, or 397,213.92 ft³.

Thus the total required storage volume to accommodate the manure as required by 10 CSR 20-8.300 is the 90-day volume plus the 180-day volume.

\[
794,427.84 \text{ ft}^3 + 397,213.92 \text{ ft}^3 = 1,191,641.76 \text{ ft}^3
\]

The storage volume of the operation is 2,076,600 ft³, which is 1.74 times the required storage volume of 1,191,641.76 ft³, thus satisfying the requirements of 10 CSR 20-8.300.

To calculate the days of storage provided by the animal confinement barns and the manure barns requires dividing the total storage volume by the daily volumetric rate of manure production.

\[
\frac{2,076,600 \text{ ft}^3}{11,033.72 \frac{\text{ft}^3}{\text{day}}} = 188 \text{ days}
\]
Therefore, if the operation were storing all of the manure generated, there would be 188 days of storage.

**Calculations for 6,999 Cattle Weighing 1,100 pounds**

If all 6,999 cattle on the operation had an average weight of 1,100 pounds, the amount of manure produced would be greater and the necessary storage volume would change. Using the same methodology as outlined above, the daily volume of waste produced, $V_w$, can be expressed by multiplying the 6,999 animals times the $0.86 \text{ ft}^3$ of waste per day that each 1,100-pound Finishing Beef animal produces (MWPS-18, 2004, Table 6).

$$V_w = 6,999 \text{ animals} \times \frac{0.86 \text{ ft}^3 \text{ waste}}{\text{animal}(\text{day})} = \frac{6,019.14 \text{ ft}^3 \text{ waste}}{\text{day}}$$

At a waste density of 63 lb/ft$^3$ (MWPS-18, Table 6), the mass of waste, $M_w$, produced daily is the volume of waste times the density.

$$M_w = 6,019.14 \text{ ft}^3 \times 63 \frac{\text{lb}}{\text{ft}^3} = 379,205.82 \text{ lb} = 189.60 \text{ tons}$$

On an annual basis, the total waste produced is the daily amount times 365 days. Therefore, the annual volume of waste is 2,196,986.10 ft$^3$ and the mass of waste is 69,204 tons.

The required bedding mass per day is the bedding rate per 100 lb of waste times the mass of waste produced.

$$\frac{26.1 \text{ lb bedding}}{100 \text{ lb waste}} \times \frac{379,205.82 \text{ lb waste}}{\text{(day)}} = \frac{98,972.72 \text{ lb bedding}}{\text{day}}$$

On a per animal basis the amount of bedding is 14.14 lb/animal/day.

The annual mass of bedding is 36,125,042.44 lb.

This bedding mass needs to be converted to volume. If the density of bedding is 7 pounds/ft$^3$ (SD, 2011), then the volume of bedding, $V_b$, is the daily mass of bedding divided by the density of bedding.

$$V_b = \frac{98,972.72 \text{ lb bedding}}{\text{day}} \times \frac{1 \text{ ft}^3}{7 \text{ lb bedding}} = \frac{14,138.96 \text{ ft}^3 \text{ bedding}}{\text{day}}$$

The annual volume of bedding is 5,160,720.40 ft$^3$.

The total manure volume generated, $V_T$, is the volume of waste plus half the volume of bedding (MWPS-18, Eqn. 6, page 17).

$$V_T = V_w + 0.5 \times V_b$$
The daily manure volume can be calculated from the daily waste volume and daily bedding volume calculated above.

The annual manure volume can be calculated from the annual waste volume and annual bedding volume calculated above.

\[ 6,019.14 \, ft^3 + 0.5 \times 14,138.96 \, ft^3 = 13,088.62 \, ft^3 \]

The annual manure volume can be calculated from the annual waste volume and annual bedding volume calculated above.

\[ 2,196,986.10 \, ft^3 + 0.5 \times 5,160,720.40 \, ft^3 = 4,777,346.30 \, ft^3 \]

The daily mass of manure produced is the daily manure volume times the density of manure.

\[ 13,088.62 \, ft^3 \times 51.4092 \, \frac{lb}{ft^3} = 672,875.48 \, lb = 336.44 \, tons \]

The annual manure mass produced is the annual manure volume times the manure density.

\[ 4,777,346.30 \, ft^3 \times 51.4092 \, \frac{lb}{ft^3} = 245,599,551.41 \, lb = 122,799.78 \, tons \]

Of the manure generated, 80% will be exported. The daily volume for export is calculated by multiplying the daily manure volume by 0.8.

\[ 13,088.62 \, ft^3 \times 0.8 = 10,470.90 \, ft^3 \]

The 90-day volume is the daily rate times 90 days, or 942,381 ft³.

The remaining 20% or the manure generated will be land applied by the operation. The daily volume for land application is calculated by multiplying the daily manure volume by 0.2.

\[ 13,088.62 \, ft^3 \times 0.2 = 2,617.72 \, ft^3 \]

The 180-day volume is the daily rate times 180 days, or 471,189.60 ft³.

Thus the total required storage volume to accommodate the manure as required by 10 CSR 20-8.300 is the 90-day volume for export plus the 180-day volume for land application.

\[ 942,381 \, ft^3 + 471,190 \, ft^3 = 1,413,570 \, ft^3 \]

The storage volume of the operation is 2,076,600 ft³, which is 1.47 times the required storage volume of 1,413,570 ft³, thus satisfying the requirements of 10 CSR 20-8.300.
**Conservative Calculations**

These manure generation and storage calculations are conservative because of several factors.

- Because the manure is stored under roof but exposed to the air, moisture in the manure piles is in equilibrium with atmospheric humidity. Moisture from the piles regularly evaporates into the air, and this evaporation is hastened by the fans installed in the animal confinement barns.
- The manure pile is biologically active and the material in it is being acted upon by bacteria and fungi. The composting process as the manure ages reduces its volume.
- Manure samples that have been analyzed to date (see Nutrient Management Plan Appendix B) have percent solids ranging from 29.1% to 83.1%. This indicates the operation is achieving a drier manure product than assumed for these calculations.
- The calculation used to calculate the volume of manure (MWPS-18, Eqn. 6, page 17) is known to overestimate the total volume of manure (TN SD2011-1).

**References**
