**Section 391.APPENDIX D Sample Calculations of Sewage Sludge Application Rates**

I. Units and Conversions

 Laboratory analyses are reported on either a wet weight ("as-received") basis or on a dry weight basis. The units for a wet weight basis are millgrams per liter (mg/l – weight per volume). The units for a dry weight basis are milligrams per kilogram of solids (mg/kg – weight per weight). Sludge represents a material in which most of the solid matter is undissolved and the dissolved fraction is of minor importance. It is generally simpler to perform sludge calculations by using dry weight units. Furthermore, some calculations must ultimately be expressed in dry weight units to be correct. For these reasons all the sample calculations are worked on a dry weight basis. However, since may laboratories report results on a wet weight basis, conversion relationships are provided below. Be aware that some laboratories report results in mg/kg on an "as-received" basis. You should consult the laboratory to confirm this and then convert the units to a dry weight basis. Finally, note that the specific gravity of liquid and most dry sludges can be assumed to be 1.0 (equal to water) and sufficient accuracy in the calculations will be obtained.

A) The decimal equivalent (DE) of the percent total solids equals the percentage divided by 100.

|  |  |  |
| --- | --- | --- |
| % TS | = | DE of Total Solids |
| 100 |

|  |  |  |  |
| --- | --- | --- | --- |
| Example: | 5% TS | = | 0.05 DE  |
| 100 |

B) Wet Weight to Dry Weight Basis

|  |  |  |
| --- | --- | --- |
| mg/l | = | mg/kg (dry wt. basis) |
| DE |

|  |  |  |  |
| --- | --- | --- | --- |
| Example: | 1.5 mg/1 Cadmium | = | 30 mg/kg Cadmium (dwb) |
| 0.05 DE |

C) Dry Weight to Wet Weight Basis

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| (mg/kg) | x | (DE) | = | mg/l (wet wt. basis) |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Example: | (30,000 mg/kg TKN) | x | (0.05) | = | 1500 mg/1 TKN (wwb) |

D) Other useful conversions

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 1) | ppm (wet.) | x | 100 | = | ppm (dry) |
| %TS |

2) ppm x 0.002 = lb/ton

3) 10,000 ppm (or mg/l or mg/kg) = 1%

4) 1 acre = 43,560 square feet

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 5) | (dry tons sludge) | x | 100 | = | wet tons sludge |
| %TS |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 6) | Wet tons | x | 2000 | = | wet tons sludge |
| acre | 8.345 |

7) 1 cubic yard of drying bed sludge is approximately equal to 0.45 dry tons.

8) 1 mg/kg = 0.002 lb/ton

II. Assumptions for Sludge Calculations

A) Sludge will be surface applied with incorporation by disking or chisel plowing.

B) Soils are non-sandy at the application sites.

C) The sludge has been well stabilized by heat anaerobic digestion.

D) Laboratory analysis of sludge (dwb):

5% TS

Total Kjeldahl Nitrogen (TKN) = 30,000 mg/kg

Ammonia Nitrogen = 10,000 mg/kg

Phosphorus = 8,000 mg/kg

Potassium = 3,500 mg/kg

Cadmium = 30 mg/kg

Copper = 2000 mg/kg

Manganese = 1000 mg/kg

Nickel = 400 mg/kg

Lead = 1000 mg/kg

Zinc = 4000 mg/kg

E) Corn for grain is grown and the average yield is 110 bushels per acre per year.

III. Calculating Agronomic Nitrogen Application Rates of Sludge

A) Determine the availability of nitrogen forms by referring to Section 391.411.

1) Ammonia nitrogen plant availability is 80%.

2. Organic nitrogen plant availability is 20% for the first year and decreases as shown in Table I.

B) First Year Application Rate

1) Organic nitrogen is not a laboratory test. It is a calculated value as shown below.

 Organic N = Total Kjeldahl N - Ammonia N

 Organic N = 30,000 - 10,000 = 20,000 mg/kg

2) Calculate the plant available nitrogen (PAN) in the sludge as follows:

 Ammonia Nitrogen: 10,000 x 0.8 = 8,000 mg/kg

 Organic Nitrogen: 20,000 x 0.2 = 4,000 mg/kg

 PAN = 8,000 + 4,000 = 12,000 mg/kg

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| (12,000 mg/kg PAN) | x | (0.002) | = | 24 | 1b PAN |
| dry ton sludge |

This means that each dry ton of sludge solids will have 24 pounds of nitrogen available for utilization by plants when the sludge has been disked into the soil. Note that if the sludge has been injected into the soil there would have been 28 pounds of plant available nitrogen provided. If the sludge had been surface applied without incorporation there would have been only 18 pounds of plant available nitrogen provided.

3) Calculate the agronomic nitrogen requirement for the corn grain crop using the yield and the values from Appendix B – Table IV:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| 110 bushels | x | 1.3 lb. PAN | = | 143 1b. PAN |
| acre | bushel | acre |

 This means that each acre of corn with the stated yield requires 143 pounds of plant available nitrogen for proper growth.

4) Calculate the sludge application rate needed to provide the required plant available nitrogen.

|  |  |  |
| --- | --- | --- |
| 143 | = | 5.96 dry tons sludge |
| 24 | acre |

5) For convenience during the actual sludge application it is usually helpful to convert the application rate into gallons per acre.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 5.96  | dT | x | 2000 | x | 1 | = | 28,570 | gallons |
| acre | 8.345 | 0.05 DE | acre |

C) Second Year Application Rate

1) To simplify your calculations, assume that the laboratory analysis remains the same as used for the first year application rate calculations. However, note that nutrients and metal concentrations in sludge will vary, often considerably.

2) Determine the amount of organic nitrogen (O.N.) applied during the first year that is remaining for plant uptake during the second year by using Table I values and the first year application of organic nitrogen.

(20,000 mg/kg O.N.) x (0.20) = 4,000 mg/kg O.N. used up first year

20,000-4,000 = 16,000 mg/kg Organic N remains for second year use

(16,000 mg/kg) x (10%) = 1600 mg/kg O.N. available during second year

|  |  |  |  |
| --- | --- | --- | --- |
| (16,000 mg/kg) x (0.002) | = | 3.2 | lb Organic N available |
| dry ton sludge |

This represents:

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| 3.2  | lb. | x | 5.96 | dT | = | 19 | lb. PAN |
| dT | acre | acre |

Therefore, the second year crop will need:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| 143-19 | = | 124 | lb. PAN | of additional nitrogen is needed. |
| acre |

1. Calculate the second year sludge application rate.

|  |  |  |  |
| --- | --- | --- | --- |
| 125 | = | 5.17 | dry tons sludge |
| 24 | acre |

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 5.17  | dT | x | 2000 | x | 1 | = | 24,780 | gallons |
| acre | 8.345 | 0.05 DE | acre |

D) Third year application rate

1) In the third year some organic nitrogen applied during the first and second years will become available for plant utilization; 5% and 10% respectively from Table I.

2) Determine the amount of organic nitrogen applied during previous years that is available to plants during the third year.

a) From the first year application:

(16,000 mg/kg O.N.) x (0.10) = 1600 mg/kg O.N. used the second year

16,000-1600 = 14,400 mg/kg O.N. remaining from the first year sludge application.

(14,400 mg/kg O.N.) x (5%) = 720 mg/kg O.N. is available during the third year

This represents:

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| (720 mg/kg) x (0.002) | x | ( | 5.96  | dT | ) | = | 8.58 | lb. O.N. |
| acre | acre |

b) From the second year application:

(20,000 mg/kg O.N.) x (0.20) = 4,000 mg/kg O.N. used

20,000 - 4,000 = 16,000 mg/kg O.N. remains

(16,000 mg/kg) x (0.10) = 1600 mg/kg O.N. available

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| (16,000 mg/kg) | x | (0.002) | = | 3.2 | 1b. O.N. available |
| dry ton |

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| 3.2 | lb O.N. | x | 5.17 | dT | = | 16.5 | lb. O.N. available |
| dT | acre | acre |

c) Sum the available organic nitrogen from previous years application of sludge and subtract that sum from the crop nitrogen requirements.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| 143-(8.58 + 16.5) | = | 118 | lb. PAN | of additional nitrogen is needed. |
| acre |

d) Calculate the third year application rate.

|  |  |  |  |
| --- | --- | --- | --- |
| 118 | = | 4.92 | dry tons sludge |
| 24 | acre |

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 4.92  | dT | x | 2000 | x | 1 | = | 23,580 | gallons |
| acre | 8.345 | 0.05 DE | acre |

E) Fourth year application rate

1) In the fourth year some organic nitrogen applied during the previous three years will become available for plant utilization; 2.5%, 5%, and 10% respectively from Table I.

2) Determine the amount of organic nitrogen applied during previous years that is available to plants during the fourth year.

a) From the first year application:

14,400-mg/kg O.N.) x (0.05) = 720 mg/kg used during the third year.

14,400-720 = 13,680 mg/kg O.N. remaining

(13,680 mg/kg) x (2.5%) = 342 mg/kg O.N. available

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| (342 mg/kg) x (0.002) x  | ( | 5.96 | dT | ) | = 4 | lb. O.N. | available |
| acre | acre |

b) From the second year application:

(16,000 mg/kg O.N.) x (0.10) = 1600 mg/kg O.N. used

16,000-1600 = 14,400 mg/kg O.N. remains

(14,400 mg/kg) x (0.05) 720 mg/kg O.N. available

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| (720 mg/kg) x (0.002) x  | ( | 5.17 | dT | ) | = 7.4 | lb. O.N. | available |
| acre | acre |

c) From the third year application:

(20,000 mg/kg O.N.) x (0.20) = 4,000 mg/kg O.N. used

20,000-4,000 = 16,000 mg/kg O.N. remains

(16,000 mg/kg) x (0.10) = 1600 mg/kg O.N. available

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| (1600 mg/kg) x (0.002) x  | ( | 4.92 | dT | ) | = 15.7 | lb. O.N. | available |
| acre | acre |

d) Sum the available organic nitrogen from previous years application of sludge and subtract that sum from the crop nitrogen requirements.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| 143-(4 + 7.4 + 15.7) | = | 116 | lb. PAN | of additional nitrogen is needed. |
| acre |

e) Calculate the fourth year application rate.

|  |  |  |  |
| --- | --- | --- | --- |
| 116 | = | 4.83 | dry tons sludge |
| 24 | acre |

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 4.83  | dT | x | 2000 | x | 1 | = | 23,150 | gallons |
| acre | 8.345 | 0.05 DE | acre |

F. Fifth year application rate

1) In the fifth year some of the organic nitrogen applied during the previous four years will become available for plant utilization; 1.25%, 2.5%, 5%, and 10% respectively from Table I.

2) Determine the amount of organic nitrogen applied during previous years that is available to plants during the fifth year.

a) From the first year application:

(13,680 mg/kg) x (0.025) = 342 mg/kg used during the fourth year.

13,680-342 = 13,338 mg/kg O.N. remaining

(13,338 mg/kg) x (0.0125) = 167 mg/kg O.N. available

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| (167 mg/kg) x (0.002) x  | ( | 5.96 | dT | ) | = 2 | lb. O.N. | available |
| acre | acre |

b) From the second year application:

(14,400 mg/kg) x (0.05) = 720 mg/kg O.N. used

14,400-720 = 13,680 mg/kg O.N. remaining

(13,680 mg/kg) x (0.025) = 342 mg/kg O.N. available

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| (342 mg/kg) x (0.002) x  | ( | 5.17 | dT | ) | = 3.5 | lb. O.N. | available |
| acre | acre |

c) From the third year application:

(16,000 mg/kg) x (0.10) = 1600 mg/kg O.N. used

16,000-1600 = 14,400 mg/kg O.N. remaining

(14,400 mg/kg) x (0.05) = 720 mg/kg O.N. available

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| (720 mg/kg) x (0.002) x  | ( | 4.92 | dT | ) | = 7 | lb. O.N. | available |
| acre | acre |

d) From the fourth year application:

(20,000 mg/kg) x (0.20) = 4,000 mg/kg O.N. used

20,000-4,000 = 16,000 mg/kg O.N. remaining

(16,000 mg/kg) x (0.010) = 1600 mg/kg O.N. available

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| (1600 mg/kg) x (0.002) x  | ( | 4.83 | dT | ) | = 15.5 | lb. O.N. | available |
| acre | acre |

e) Sum the available organic nitrogen from previous years application of sludge and subtract that sum from the crop nitrogen requirements.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| 143-(2 + 3.5 +7 + 15.5) | = | 115 | lb. PAN | of additional nitrogen is needed. |
| acre |

f) Calculate the fifth year application rate.

|  |  |  |  |
| --- | --- | --- | --- |
| 115 | = | 4.79 | dry tons sludge |
| 24 | acre |

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 4.79  | dT | x | 2000 | x | 1 | = | 22,960 | gallons |
| acre | 8.345 | 0.05 DE | acre |

G) During and after the sixth year there will not be any significant amount of organic nitrogen available to the crop from sludge applied during the first year. An equilibrium situation was reached in this sample problem during the fourth year since there is practically no difference between the fourth and fifth year application rates. A conservative operating plan would be to apply sludge at approximately 4.8 dry tons per acre per year. Note, however, that this would mean that additional nitrogen would be needed from fertilizers during the first, second, and third years of sludge application to meet the nitrogen requirement for the crop grown.

IV. Metal Loading Rate Calculations

A) It is useful to estimate the lifetime of a site receiving sludge on the basis of metal loadings. The method for performing this estimation is given below assuming the sludge chemical analysis provided the following quantities.

|  |
| --- |
| Percent Solids = 5% (0.05 decimal equivalent) |
| Cadmium | 30 mg/kg |
| Copper | 2000 mg/kg |
| Nickel | 400 mg/kg |
| Lead | 1000 mg/kg |
| Zinc | 4000 mg/kg |
| Manganese | 1000 mg/kg |

Application rate 4.8 dry tons/acre/year

B) Set up and complete a table as follows:

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Metal | Sludge Analysis | Loading Factor | Annual Metal Loading (lb/acre/year) | Maximum Metal Loading (lb/acre) | Site Life (Years) |
| Cadmium | 30 mg/kg | 0.0096 | 0.29 | 10 | 34 |
| Nickel | 400 mg/kg | 0.0096 | 3.84 | 100 | 26 |
| Copper | 2000 mg/kg | 0.0096 | 19.2 | 250 | 13 |
| Zinc | 4000 mg/kg | 0.0096 | 38.4 | 500 | 13 |
| Manganese | 2000 mg/kg | 0.0096 | 19.2 | 900 | 46 |
| Lead | 1000 mg/kg | 0.0096 | 9.6 | 1000 | 104 |

C) The loading factor column will be the same for each metal and is calculated as follows:

|  |  |  |
| --- | --- | --- |
| 0.002 #/dry ton | x | (dry tons/acre/year) = 0.002 x 4.8 = 0.0096 |
| mg/kg |

D) Multiply the metal analysis value by the loading factor value (0.0096) to obtain the Annual Metal Loading (lb/acre/year) column.

Divide the maximum metal loading for each metal (from Table II, Section 391.420) by the annual metal loading rate (pounds/acre/year) to obtain the site lifetime.

E) This example indicates that the zinc and copper loading is the most restrictive to the site lifetime. Therefore a site should be used for no more than 13 years, however updated sludge analyses and different application rates may change these site lifetimes. Records should be kept on each site that sludge is applied to for each year's metal loading.