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Injection of Chemicals Into Irrigation Systems: Rates, Volumes, and Injection Periods[1]

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Irrigation systems can be used to transport soluble chemicals to the crop. Depending on the type of irrigation system, chemicals may be applied to the root zone, the aerial part of the plant, or both. The process of chemical transport using the irrigation system is referred to as chemigation. Specific terms may be used to refer to specialized applications of chemigation, such as nematigation and fertigation.

Irrigation systems designed or adapted for chemigation require specialized equipment for the injection of the chemical solution into the irrigation system at a controlled rate. Several injection methods are possible and are discussed in detail in other publications (Nakayama and Bucks, 1986; Smajstrla et al., 1987; and Yeager and Henley, 1987). The cost, accuracy, reliability, and longevity of the equipment varies greatly among manufacturers.

It is important to select adequate equipment, maintain it regularly, and properly operate it to insure a successful chemigation system. New irrigation system designs must consider which chemicals are to be injected while selecting the system components to insure compatibility. Uniformity of chemical application cannot exceed that of the irrigation system. Therefore, it is very important to have a well designed and well maintained irrigation system to provide the greatest potential for a high level of application uniformity. When existing irrigation systems are to be adapted for chemigation, they should be thoroughly examined for uniformity of application as well as compatibility of the chemicals to be injected with existing components.

Water quality is another factor to consider in the design or adaptation of an irrigation system for chemigation. Some water supplies require chemical amendment to prevent bacterial growths or chemical precipitants from clogging the system. This publication will concentrate on the management aspects of chemigation and how chemigation influences other aspects of irrigation management.

Chemical Mixtures and Injections

Chemicals may be applied as a precisely managed level of concentration or as a bulk mass of chemical with possibly varying concentration levels. Concentration management requires a precise injection system and is more involved than bulk injection. The injection system must be specifically calibrated for the irrigation system it is to be operated on and under the operating conditions that will exist when chemicals are to be injected. Variations in operating pressure, system flow rate, and at times even temperature can influence the calibration of the system. Bulk injection simply involves the injection of a desired volume or amount of chemical into the system. The injection rate does not need to be precisely controlled. However, it should not be damaging to any part of the system or crop, should not exceed manufacturers' recommended application rates, and should apply the chemical in a time period which does not result in over-irrigation or leaching of previously applied chemicals.

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Concentration Mixtures of a Stock Solution

Some chemical applications require that a certain concentration level be maintained for proper use of that chemical in that situation. Concentrations are generally expressed in parts per million (ppm), which is not a convenient term for mixing purposes. Chemicals may be supplied in dry form or liquid form; however, the end result is a liquid mixture of a desired concentration. The following equation can be used to determine the mass of chemical required to achieve a particular ppm level. (Equation 1)

$$lb\ of\ raw\ chemical\ per\ 100\ gal = \frac{desired\ ppm}{1205} \quad \textbf{(1)}$$

This provides the mass of actual chemical that must be dissolved per 100 gallons of water. For example, a 200 ppm concentration level of nitrogen as a fertilizer solution will require as shown in Equation 2:

$$\frac{200\ ppm}{1205} = 0.17\ lb\ of\ N\ per\ 100\ gal.\ of\ water \quad \textbf{(2)}$$

This is pounds of actual nitrogen required and not pounds of fertilizer mix as either a dry or liquid source.

Many chemicals are supplied as either a percentage by weight of a dry or liquid mixture. Therefore the mass of chemical mixture required will depend on the concentration of raw chemical in the mixture. Equation 3 can be used to determine the mass of chemical mixture required to provide the necessary level of raw chemical.

$$M(mixture) = \frac{(M_x)(100)}{\%X} \quad \textbf{(3)}$$

where

M(mixture) = the required mass of chemical mixture (lb.),

M_x = the desired mass of chemical X (lb.), and

%X = the percentage of chemical X in the mixture.

If in the above example a 16-4-8 (N-P_2O_5-K_2O) dry fertilizer mix was used, then the required mass of fertilizer mix for 100 gallons of solution is shown in equation 4:

$$\frac{(0.17\ pounds)(100)}{16\%} = 1.1\ pounds \quad \textbf{(4)}$$

Therefore 1. 1 pounds of 16-4-8 fertilizer source mix are required to supply 0.17 pounds of nitrogen.

Table 1 combines both Equations (1) and (3) to provide the mass of chemical mixture (for example, fertilizer mix) to add to 100 gallons of water to obtain a certain ppm level for the desired chemical. An example using Table 1 is included in the Appendix.

It is important to remember that the A-B-C analysis of a fertilizer label refers to the nitrogen (N), phosphorus oxide (P_2O_5), and potash (K_2O). Therefore only 44% of the B factor (P_2O_5) refers to actual phosphorous (P), and only 83% of the C factor (K_20) refers to actual potassium (K). Equation (3) can be slightly rearranged to solve for M_x based on M(mixture), and used to determine the mass of actual P or K contained in a fertilizer mix. For example, in 50 pounds of 16-4-8 fertilizer the mass of P_2O_5 is shown in Equation 5:

$$\frac{(50\ pounds)(4\%)}{100} = 2.0\ pounds\ of\ P_2O_5 \quad \textbf{(5)}$$

Similarly, the mass of actual P is shown in Equation 6:

$$\frac{(2.0\ pounds)(44\%)}{100} = 0.88\ pounds\ of\ P. \quad \textbf{(6)}$$

Therefore 50 pounds of a 16-4-8 fertilizer mixture contains only 0.88 pounds of actual P. The same procedure can be used to determine that the amount of actual K is 3.32 lbs.

When chemicals are supplied in liquid form, it is more convenient to measure volumes rather than masses or weights. This requires the specific density or specific weight (S_x) of the liquid mixture such as pounds of chemical per gallon of liquid. This property should be provided by the manufacturer or chemical supplier and can be used to simply convert from required lbs. to required gallons. For example a liquid fertilizer provided as a 4-0-8 solution has 4%

nitrogen by weight. However, the amount of nitrogen is not known unless the specific weight of the chemical (fertilizer) solution is known, such as 9.6 lb. per gallon. As was previously mentioned, this value varies among chemical mixtures and should be on the chemical label, but may be obtained from the chemical supplier.

Concentration Injection Rates

The previous section described the procedure for mixing particular concentrations of a stock solution. However, many systems will have flowing water with a requirement to maintain a desired concentration of a chemical in that system. This requires injecting a supply mixture at the proper rate to maintain the desired concentration level. The following equation or Tables 2 and 3 can be used to determine the injection rate necessary to maintain the desired concentration of a chemical X. (Equation 7)

$$Q_i = \frac{(ppm_x)(Q_w)(8.3)}{[(\%X)(S_x)(10000)] - [(ppm_x)(S_x)]} \qquad \textbf{(7)}$$

where
Q_i = Injection rate in gallons per minute (gpm),
Q_w = Water supply flow rate (gpm),
8.3 = Specific weight of water (lb./gal.),
ppm_x = Desired ppm level of chemical X,
%X = Percentage of chemical X in the stock solution, and
S_x = Specific weight of the stock solution mix (lb. /gal.).

For example, chlorine is to be injected to provide 10 ppm of free chlorine into a micro-irrigation system which has a system flow rate of 550 gpm. (Equation 8) The chlorine stock solution contains 5% free chlorine (sodium hypochlorite source, NaOCl) and has a specific weight of 9.1 lbs. per gallon. Therefore,

$$\begin{gathered} Q_w = 550;\ ppm_x = 10;\ \%X = 5;\ S_x = 9.1;\ and \\ Q_i = \frac{(10)(550)(8.3)}{[(5)(9.1)(10000)] - [(10)(9.1)]} = 0.100\ gpm \end{gathered} \qquad \textbf{(8)}$$

Therefore, the injector should be set to provide 0.10 gallons per minute of stock solution into the irrigation system in order to maintain an injected free chlorine level of 10 ppm. The actual ppm of free chlorine throughout the system will depend on how much free chlorine is used by organics in the water supply and in the irrigation system.

If the specific weight of the chemical is close to that of water, Equation (7) can be simplified. The simplified approximation to Equation (7) is shown in Equation 9:

$$Q_i = \frac{(ppm_x)(Q_w)}{(\%X)(10000)} \qquad \textbf{(9)}$$

where
Q_i = Injection rate in gallons per minute (gpm),
Q_w = Water supply flow rate (gpm),
ppm_x = Desired ppm level of chemical X, and
%X = Percentage of chemical X in the stock solution.

In repeating the above chlorine example we get as shown in Equation 10:

$$\begin{gathered} Q_w = 550\ gpm;\ ppm_x = 10;\ and\ \%X = 5;\ and \\ Q_i = \frac{(10)(550)}{(5)(10000)} = 0.10\ gpm \end{gathered} \qquad \textbf{(10)}$$

This result is consistent with the previous example. In most cases, Equation (9) may be used. However, if greater accuracy is needed, then use Equation (7). Some injectors are operated to inject on a gallons-per-hour (gph) basis. Therefore, the injector rate determined above must be converted using Equation 11:

$$Q_i(gph) = (60)(Q_i\ [gpm]) \qquad \textbf{(11)}$$

For example, a flow rate of 0.10 gpm is equal to a flow rate of 6.0 gph.

Injection Volumes and Periods

Chemical mixtures may be injected directly from the stock supply tank or from an injector feeder tank. Injector feeder tanks are useful for injecting a specific volume of liquid, regardless of the injection rate. When the tank is empty the desired volume of chemical mixture has been injected. This procedure eliminates excess applications of chemicals which may occur due to pump or controller failure.

The size of the required feeder tank will depend on the volume of chemical mixture to be injected, which in turn will depend on either the total amount or volume of chemical to be applied or on the length of the injection period. Volumetric applications can be based on area applications or the sum of individual applications. For example, a pesticide may require that X pounds of a chemical be applied per acre; a vegetable grower may want to apply a certain mass of fertilizer per acre or per 1000 bedded feet of plant row; or a citrus or nursery operator may want to supply a certain amount of fertilizer per irrigated plant. In addition to the desired level of fertilization, these situations require knowledge of the irrigated acreage per set, total feet of bedded production area irrigated per set, or the number of plants or trees irrigated in each set.

Injection Volumes

To determine the required injection volume for bulk applications, the mass of the desired chemical or compound dissolved per gallon of stock solution must be known. This can be determined by using Table 4 or Equation (12) as follows:

$$Sm_x = \frac{(\%X)(S_x)}{100} \qquad \textbf{(12)}$$

where
S_{mx} = Mass of chemical X per gallon of stock solution (lb/gal),
%X = Percentage of chemical X in the solution (%), and
S_x = Specific weight of the stock solution (lb/gal).

Then by knowing the mass of that chemical contained per gallon of stock solution, the required volume can be determined using Table 5 or equation 13:

$$V_m = \frac{(M_x)}{(S_{mx})} \qquad \textbf{(13)}$$

where
V_m = Required mixture volume (gal),
M_x = Mass of chemical required (lb), and
S_{mx} = Mass of chemical per gallon of mixture, (lb/gal; from Table 4 or Equation 12).

For example, a vegetable grower wishes to apply 4 lb. of N per 1000 bedded feet of plant row each week; the N is to be applied in 3 applications per week; 20 acres are to be irrigated per set; and the system has 4500 bedded feet per acre. What size feeder tank is necessary for injecting a 4-0-8 fertilizer solution which has a specific weight of 9.55 lb per gallon?

The weekly production requirement of total N is:

> (20 acres) (4500 ft/acre) (4 lb of N/1000 feet) = 360 lb of N per week.
>
> The application requirement of N (3 applications) is:
>
> (360 lb of N per week) / (3 applications per week) = 120 lbs of N per application.

Using Equation (12) as shown in Equation 14:

$$S_{mx} = \frac{(4)(9.55)}{100} = 0.38 \ \textit{lb of N per gallon of solution} \qquad \textbf{(14)}$$

The injection volume per application is (Equation 15):

$$V_m = \frac{120 \ \textit{lb of N per application}}{0.38 \ \textit{lb of N per gallon of solution}} = 316 \ \textit{gallons} \qquad \textbf{(15)}$$

Therefore, the feeder tank must be at least 316 gallons to provide room for this fertilizer application.

Sometimes chemicals are injected on a periodic basis to maintain a certain injected concentration of that chemical during that period. In this case, the required injection volume of stock solution depends on the length of the injection period, and the injection rate. The required stock solution volume can be determined from Equation 16 as follows:

$$V_m = (Q_i)(T_i) \qquad \textbf{(16)}$$

where
V_m = Required mixture injection volume (gal),
Q_i = Injector flow rate (gpm), and
T_i = Injection period (minutes).

For example, a micro irrigation system manager desires to inject 10 ppm of free chlorine into his irrigation system for a period of 40 minutes. The irrigation system delivers water at a rate of 550 gpm, the chlorine stock solution weighs 9.1 lbs. per gallon and contains 5% of free chlorine. From a previous example using Equation (7), the required injector flow rate was 0.10 gpm. Therefore, the required injection volume is:

V_m = (0.10 gpm) (40 minutes)
= 4 gallons of stock solution.

Therefore, only a small feeder tank is required for this application.

Injection Periods and Calibration

The length of the injection cycle is important from an irrigation management viewpoint. With respect to the injection period, several criteria may need to be addressed, such as the frequency of chemical application (daily, semi-weekly, weekly, etc.) and the maximum time allocated per irrigation zone. For example, for daily chemical applications the number of irrigation zones multiplied by the injection period per zone cannot exceed 24 hours. Furthermore, if the injection period exceeds the maximum irrigation period which results in over-irrigation and leaching, then split chemical applications are necessary.

The injection period is generally determined from the volume of chemical to be applied and the rate of injection. As was previously mentioned, some chemical applications require that a specific concentration be maintained for a particular application or injection period. In this case the injection period is already pre-set.

The injection volume was discussed in the previous section. Injection rate may be provided by the supplier of the injection system. However, whether the injection rate is already available or not, calibration is required. Calibration should be performed on the irrigation system which is to be used with the injection system. Also, because irrigation system operating pressures and flow characteristics may influence injection rates, calibration should be performed while the irrigation system is operating.

One simple calibration procedure involves placing a flow meter on the injection line and then measuring the volume of chemical injected in a specific period. A measurement period of 2 to 5 minutes should suffice; however longer measurement periods provide better results. Also, three or more replications of the measurement should be performed to obtain an accurate calibration and to eliminate measurement error or discrepancies. The quality of the flow meter will influence the quality of the calibration. Therefore, use a good flow meter sized to operate in the estimated flow range of the injection system and manufactured for use with the chemicals being injected. Corrosion of the flow meter could alter the injection rate and possibly result in damage to some other part of the irrigation system. Also, be sure that the flow meter can operate under the higher pressures associated with some injectors.

A second calibration procedure involves physical measurement of the injected volume during the measurement period. This procedure can be performed using one of two methods. In each method a container is filled with a known volume of the chemical to be injected. Water or colored water may be substituted for the chemical but may not provide accurate results with some injectors if the viscosity is very different from that of the chemical.

The first method measures the time required to inject all of the known chemical volume and then uses the following formula to determine the injection rate shown in Equation 17:

$$Q_i = \frac{V_i}{T_i} \qquad \textbf{(17)}$$

where
Q_i = Injection rate (gpm),
V_i = Injected volume (gal), and
T_i = Time required (min) to inject volume V_i.

The second method measures the initial volume and the final volume after a specified injection period. The injection period should be at least several minutes but short enough that all of the chemical has not been injected. Calculation of the injection rate is similar to the above procedure with a slight modification of Equation (17) as follows in Equation 18:

$$Q_i = \frac{V1 - V2}{T_i} \qquad \textbf{(18)}$$

where
Q_i = Injection rate (gpm),
V1 = Initial chemical volume (gal),
V2 = Final chemical volume (gal), and
T_i = Injection measurement period (min).

If a positive displacement type of pump is used, the injected volume can be determined by counting the number of piston strokes in the measurement period and then multiplying the number of strokes by the displacement volume per stroke. The displacement volume per stroke should be measured periodically to insure proper operation.

Once the injection rate is known, the injection period for any chemical volume can be determined from rearranging Equation (17) as follows in Equation 19:

$$T_i = \frac{V_i}{Q_i} \qquad \textbf{(19)}$$

where
T_i = Required injection period (min),
V_i = Volume of chemical to be injected (gal),and
Q_i = Injection rate (gpm) of the system.

For example, the vegetable grower in the previous fertilizer example has a piston injection pump which was measured to give 42 piston strokes in a three-minute period. Each piston stroke of the pump corresponds to 0.10 gallons. Therefore, the injection rate is shown in Equation 20:

$$Q_i = \frac{(42\ strokes)(0.10\ gallons/strokes)}{3\ minutes} = 1.40\ gpm \qquad \textbf{(20)}$$

In the previous example the grower needed to apply 316 gallons of fertilizer mix three times each week. The required injection period for this volume of fertilizer is shown in Equation 21:

$$T_i = \frac{316\ gallons}{1.40\ gpm} = 225\ minutes \qquad \textbf{(21)}$$

Therefore the system must be operated for about 225 minutes on each of the three fertilizer injection days to apply the required level of fertilizer. If the crop is shallow rooted and the soil is sandy, it may be best to apply the fertilizer in three 75 minute cycles (i.e. morning, mid-day and afternoon) to avoid moving fertilizer out of the root zone of the crop. If this injection schedule is a problem, it may be better to inject fertilizer every day or upgrade the capacity of the injection system to reduce the total injection period.

Summary

Information pertaining to the injection of chemicals into irrigation systems was discussed in terms of concentration injections, bulk injections, quantity of chemicals to be injected, injection system calibration and injection periods. The information was provided to assist irrigation system designers and operators with the chemigation aspects of irrigation system design, scheduling and management.

TABLE EXAMPLES

1) How much 10-10-10 soluble fertilizer mix is required to mix with water to make a 100 ppm solution of actual nitrogen? From Table 1 a value of **0.83** lb of soluble fertilizer is required per 100 gallons of water (solution) to provide a 100 ppm solution of nitrogen.

2) Chlorine is to be injected into an irrigation system which has a water delivery (supply) rate of 400 gpm. The chlorine stock solution contains 8% of "free" chlorine. What stock solution injection rate is necessary to provide 20 ppm of "free" chlorine to the irrigation supply water? Table 2 (or Table 3) indicates that to provide a 20 ppm concentration level with an 8% stock solution, approximately **0.025 gpm (1.50 gph)** of stock solution injection is necessary per 100 gpm of water delivery rate. Therefore, a 400 gpm water delivery rate requires a stock solution injection rate of:

(0.025 gpm/100 gpm) (400 gpm) = **0.10 gpm**.
or
(1.50 gph/100 gpm)(400 gpm) = **6.0 gph**.

Therefore injecting an 8% stock solution of chlorine at 0.10 gpm (6.0 gph) into an irrigation system with a system flow rate of 400 gpm will provide approximately 20 ppm of "free" chlorine into the system.

3) A vegetable field is to be fertigated (have fertilizer injected) on a weekly basis with three pounds of nitrogen (N) per 1000 feet of plant bed per week. The field is 25 acres in area with 6000 bedded feet per acre. What size of feeder tank is necessary to hold the required volume of fertilizer mixture if the mixture is a 4-0-8 solution with a specific weight of 10 lb/gal?

The required amount of fertilizer is:

=(3 lb/1000 ft) (6000 ft/acre) = 18 lb/acre

=(18 lb/acre) (25 acres)

=**450 lb** of N per week.

Table 4 is used to determine the amount of chemical (nitrogen) per gallon of solution. A 4-0-8 solution of fertilizer (S_x = 10) has 4% nitrogen.

From Table 4 read the actual amount of N as **0.40 lb** per gallon of solution.

Next use Table 5 to determine the required volume of mixture. For a 0.40 lb/gal chemical (nitrogen) density and 450 lb requirement, read **1125 gallons** of fertilizer mixture required. Therefore, the supply tank must have a minimum capacity of 1125 gallons to hold the weekly supply of fertilizer.

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Table 1. The mass (lb) of chemical mixture (i.e., fertilizer mix) to add to 100 gallons of water for different ppm level solutions.

PPM Level	Percent Analysis of the Mixture							
	5	10	15	20	25	30	40	50
	(lb per 100 gallons)							
10	0.17	0.08	0.06	0.04	0.03	0.03	0.02	0.02
20	0.33	0.17	0.11	0.08	0.07	0.06	0.04	0.03
30	0.50	0.25	0.17	0.12	0.10	0.08	0.06	0.05
40	0.66	0.33	0.22	0.17	0.13	0.11	0.08	0.07
50	0.83	0.41	0.28	0.21	0.17	0.14	0.10	0.08
60	1.00	0.50	0.33	0.25	0.20	0.17	0.12	0.10
70	1.16	0.58	0.39	0.29	0.23	0.19	0.15	0.12
80	1.33	0.66	0.44	0.33	0.27	0.22	0.17	0.13
90	1.49	0.75	0.50	0.37	0.30	0.25	0.19	0.15
100	1.66	0.83	0.55	0.41	0.33	0.28	0.21	0.17
200	3.32	1.66	1.11	0.83	0.66	0.55	0.41	0.33
400	6.64	3.32	2.21	1.66	1.33	1.11	0.83	0.66
600	9.96	4.98	3.32	2.49	1.99	1.66	1.24	1.00
800	13.28	6.64	4.43	3.32	2.66	2.21	1.66	1.33
1000	16.60	8.30	5.53	4.15	3.32	2.77	2.07	1.66

Table 2. Chemical injection rate expressed in gpm of injection rate per 100 gpm of irrigation system flow rate for different desired concentration levels (ppm) and different stock solution concentration levels.[1]

Desired PPM Level	Percent Analysis of the Chemical in the Stock Solution							
	4	8	12	16	20	30	40	50
	(gpm of injection per 100 gpm of irrigation rate)							
10	0.025	0.013	0.008	0.006	0.005	0.003	0.003	0.002
20	0.050	0.025	0.017	0.013	0.010	0.007	0.005	0.004
30	0.075	0.038	0.025	0.019	0.015	0.010	0.008	0.006
40	0.100	0.050	0.033	0.025	0.020	0.013	0.010	0.008
50	0.125	0.063	0.042	0.031	0.025	0.017	0.013	0.010
60	0.150	0.075	0.050	0.038	0.030	0.020	0.015	0.012
70	0.175	0.088	0.058	0.044	0.035	0.023	0.018	0.014
80	0.200	0.100	0.067	0.050	0.040	0.027	0.020	0.016
90	0.225	0.113	0.075	0.056	0.045	0.030	0.023	0.018
100	0.250	0.125	0.083	0.063	0.050	0.033	0.025	0.020
200	0.500	0.250	0.167	0.125	0.100	0.067	0.050	0.040
400	1.000	0.500	0.333	0.250	0.200	0.133	0.100	0.080
600	1.500	0.750	0.500	0.375	0.300	0.200	0.150	0.120
800	2.000	1.000	0.667	0.500	0.400	0.267	0.200	0.160
1000	2.500	1.250	0.833	0.625	0.500	0.333	0.250	0.200

1. (Caution: these values assume a stock solution specific weight equal to water. If necessary, these numbers may be adjusted by multiplying by the ratio of the specific weight of the chemical solution to the specific weight of water.)

Table 3. Chemical injection rate expressed in gph of injection rate per 100 gpm of irrigation system flow rate for different desired concentration levels (ppm) and different stock solution concentration levels.[1]

Desired PPM Level	Percent Analysis of the Chemical in the Stock Solution							
	4	8	12	16	20	30	40	50
	(gph of injection per 100 gpm of irrigation rate)							
10	1.50	0.75	0.50	0.38	0.30	0.20	0.15	0.12
20	3.00	1.50	1.00	0.75	0.60	0.40	0.30	0.24
30	4.50	2.25	1.50	1.13	0.90	0.60	0.45	0.36
40	6.00	3.00	2.00	1.50	1.20	0.80	0.60	0.48
50	7.50	3.75	2.50	1.88	1.50	1.00	0.75	0.60
60	9.00	4.50	3.00	2.25	1.80	1.20	0.90	0.72
70	10.50	5.25	3.50	2.63	2.10	1.40	1.05	0.84
80	12.00	6.00	4.00	3.00	2.40	1.60	1.20	0.96
90	13.50	6.75	4.50	3.38	2.70	1.80	1.35	1.08
100	15.00	7.50	5.00	3.75	3.00	2.00	1.50	1.20
200	30.00	15.00	10.00	7.50	6.00	4.00	3.00	2.40
400	60.00	30.00	20.00	15.00	12.00	8.00	6.00	4.80
600	90.00	45.00	30.00	22.50	18.00	12.00	9.00	7.20
800	120.00	60.00	40.00	30.00	24.00	16.00	12.00	9.60
1000	150.00	75.00	50.00	37.50	30.00	20.00	15.00	12.00

1. (Caution: these values assume a stock solution specific weight equal to water. If necessary, these numbers may be adjusted by multiplying by the ratio of the specific weight of the chemical solution to the specific weight of water.)

Table 4. The mass (lb) of active chemical contained per gallon of stock solution (Sm_x) for different combinations of specific weight and chemical concentration.

Specific Weight (lb/gal)	Percent Concentration of the Active Chemical							
	4	8	12	16	20	30	40	50
8.0	0.32	0.64	0.96	1.28	1.60	2.40	3.20	4.00
8.5	0.34	0.68	1.02	1.36	1.70	2.55	3.40	4.25
9.0	0.36	0.72	1.08	1.44	1.80	2.70	3.60	4.50
9.5	0.38	0.76	1.14	1.52	1.90	2.85	3.80	4.75
10.0	0.40	0.80	1.20	1.60	2.00	3.00	4.00	5.00
10.5	0.42	0.84	1.26	1.68	2.10	3.15	4.20	5.25
11.0	0.44	0.88	1.32	1.76	2.20	3.30	4.40	5.50
11.5	0.46	0.92	1.38	1.84	2.30	3.45	4.60	5.75

Table 5. Required volume (gal) of chemical mixture to provide a desired level of an active chemical for different concentrations (lb/gal) of the chemical in the stock solution from Table 4.

Mass of Chemical Desired (lb)	S_{mx} Mass of Chemical (lb) per gallon of Stock Solution							
	0.2	0.4	0.6	0.8	1.0	2.0	3.0	4.0
	(gallons of stock solution)							
20	100	50	33	25	20	10	7	5
40	200	100	67	50	40	20	13	10
60	300	150	100	75	60	30	20	15
80	400	200	133	100	80	40	27	20
100	500	250	167	125	100	50	33	25
150	750	375	250	188	150	75	50	38
200	1000	500	333	250	200	100	67	50
250	1250	625	417	313	250	125	83	63
300	1500	750	500	375	300	150	100	75
350	1750	875	583	438	350	175	117	88
400	2000	1000	667	500	400	200	133	100
450	2250	1125	750	563	450	225	150	113
500	2500	1250	833	625	500	250	167	125