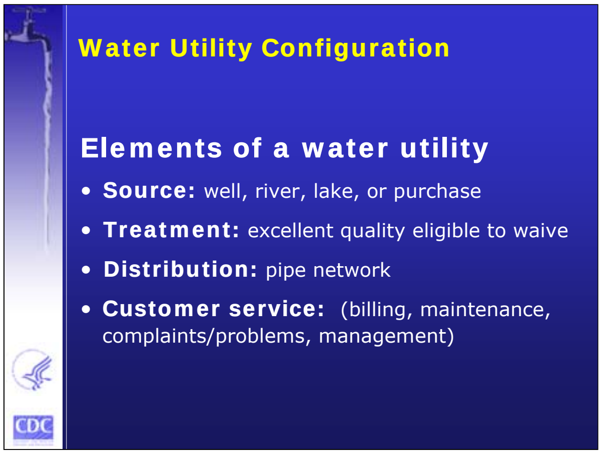
You have heard about the fluoride Additives and equipment , now we will try to put them together in the design process.

We will try to discuss the considerations on design of fluoridation systems. Since this class has a wide range of participants extending from program specialists who may not have a technical background, to practicing engineers, it is difficult to have a course that fully addresses everyone's knowledge level of needs. But we are going to try to include enough background information for the non-engineers so that you understand many of the issues involved, but also provide enough technical content so the engineers here have a basis for looking at the designs.



A water system infrastructure includes four essential elements.

The first thing to look at is the source of the water. Is it a well water, a surface river, a lake or impoundment, or does the water system purchase their water? All of these can influence the considerations on water fluoridation. As an example, a well water of excellent quality may not require any treatment, so adding fluoride might be more difficult for such a system not used to processing the water.

The treatment facility, or facilities, are another consideration. Are the facilities old or new. Is there a single facility or multiple facilities. What type of staffing is required?

The third element of a water system is the distribution pipe network which delivers the water to the customers.

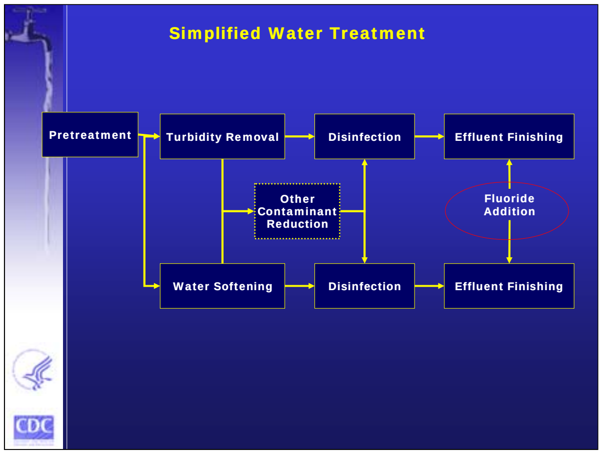
The objectives of water treatment are

•Disinfection, for pathogenic organisms

•Reduction of contaminants for health effects

•Oxidation of undesirable reduced compounds

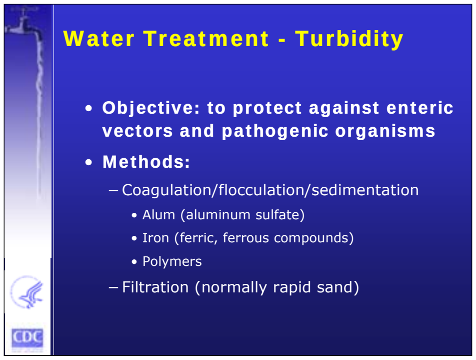
•Improvement of the aesthetics: taste, odor, and color

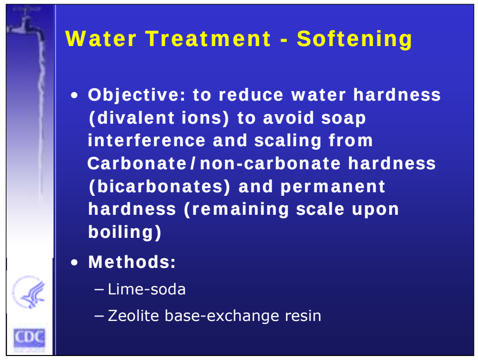


Here is a simplified schematic diagram of water treatment. The top line would be a conventional surface water treatment facility flow train, and the bottom one would be groundwater system that requires some processing of the extracted water. You will see that water fluoridation would be like corrosion control in that it would be done as part of effluent finishing as the water is delivered to the water system for distribution.

Water Treatment - Disinfection

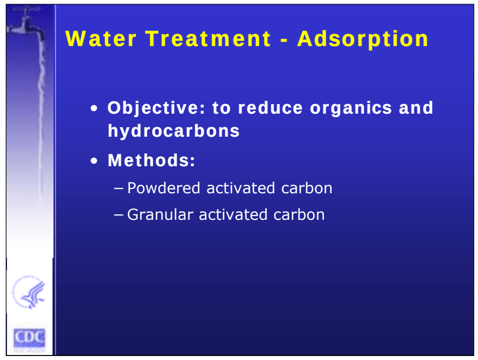
- **Objective: to protect against pathogenic organisms**
- **Methods:**
  - hypochlorous acid ($HClO$), Hypochlorite (ClO^-)
  - Sodium hypochlorite, calcium hypochlorite
  - Chloramines
  - UV (ultra-violet irradiation)
  - Ozone

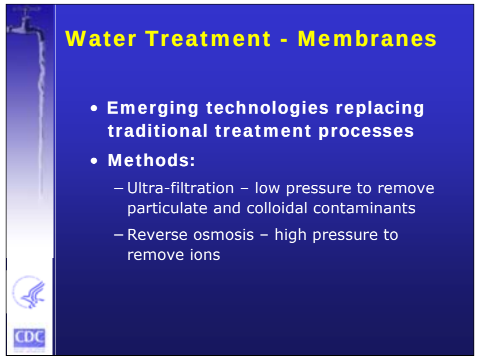

Water Treatment - Turbidity
• Objective: to protect against enteric vectors and pathogenic organisms
• Methods:
– Coagulation/flocculation/sedimentation
• Alum (aluminum sulfate)
• Iron (ferric, ferrous compounds)
• Polymers
– Filtration (normally rapid sand)
CDC

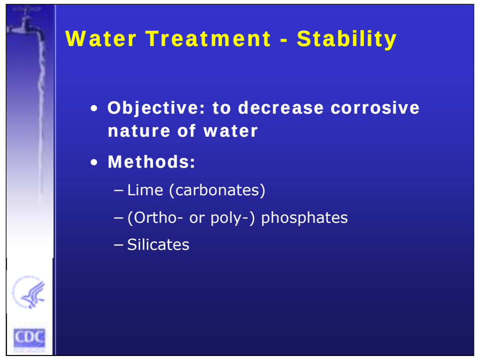

Water Treatment - Softening
Objective: to reduce water hardness (divalent ions) to avoid soap interference and scaling from Carbonate / non-carbonate hardness (bicarbonates) and permanent hardness (remaining scale upon boiling)
Methods:
– Lime-soda
– Zeolite base-exchange resin
CDC

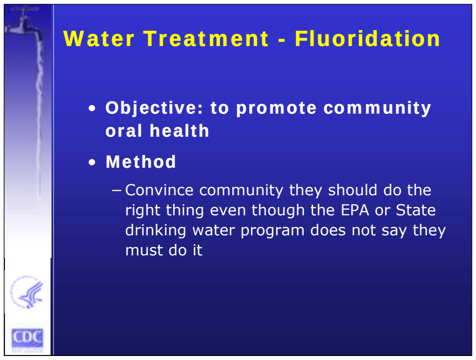
Water Treatment - Aesthetics

- **Objective: to improve characteristics for consumer satisfaction**
- **Methods:**
  - Aeration – volatile release such as H_2S
  - Oxidation – manganese/iron, etc, using potassium permanganate, chlorine, chlorine dioxide
  - Nuisance – color, algae, etc


Water Treatment - Adsorption
• Objective: to reduce organics and hydrocarbons
• Methods:
– Powdered activated carbon
– Granular activated carbon
CDC


Water Treatment - Membranes
• Emerging technologies replacing traditional treatment processes
• Methods:
– Ultra-filtration – low pressure to remove particulate and colloidal contaminants
– Reverse osmosis – high pressure to remove ions
CDC


Water Treatment - Stability
• Objective: to decrease corrosive nature of water
• Methods:
– Lime (carbonates)
– (Ortho- or poly-) phosphates
– Silicates
CDC



Water fluoridation requires a community to decide that it is the right thing to do, not because it is a requirement.

Before you begin, it is important that all parties clearly understand the project. Think about what is important, what is good, what would be bad, and issues to be addressed during design. Check on Fire Marshall requirements for handling hazardous wastes in the jurisdiction, which building codes will be used for issuing a construction permit, and ask the drinking water program if the facility had a previous facility review such as a sanitary survey, deficiencies, or compliance problems of which you should be aware. What types of facilities will be necessary? And you can often learn a lot by visiting other communities to learn about their successes and failures.

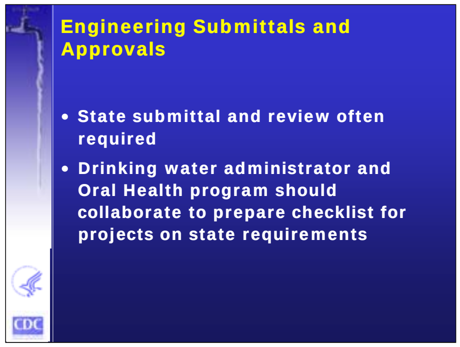
Permitting can be a very expensive and time consuming aspect of a project.

State permits could include permits to allow expansion or construction of improvements to drinking water facilities, and many locations now require erosion and drainage plans. Also, if you are using FSA and facility exceeds the thresholds for tank capacities, you may need to comply with SPCC requirements.

Air quality may be necessary if you are in California or in a metropolitan non-attainment area. Normally these have been avoided in the past, but you need to confirm that requirements have not changed.

Building permits have been known to slow or stop a project. Find out which government entity will issue a building permit (City, County, etc) and what their requirements might be (Standard Building Code or other). Check on if there are local rules or special requirements. What does the Plumbing Code require, and is the International Fire Code applicable (500 gallons storage without sprinklers and 1,000 gallons with storage)

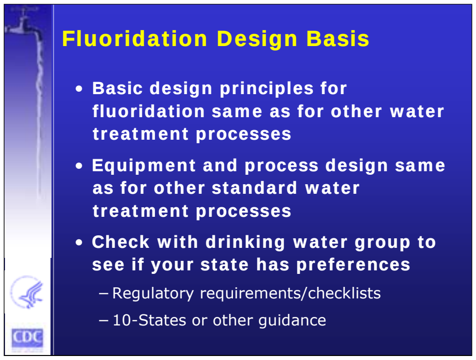
Neighborhood permits can sometimes also be necessary if you are in larger urban areas with neighborhood or planning group oversight.



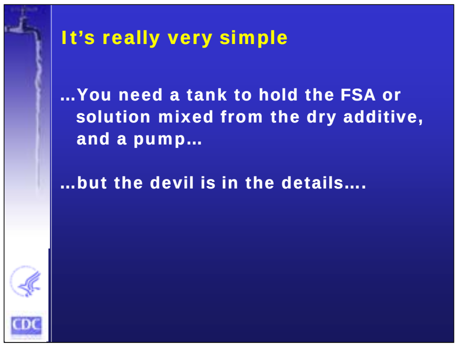
Improvements to water treatment facilities typically require state drinking water program review and approval. Check with the requirements of the state drinking water program on your state's requirements.

It is advisable that the oral health program and the drinking water administrator collaborate on preparing checklists and guidance on state requirements.

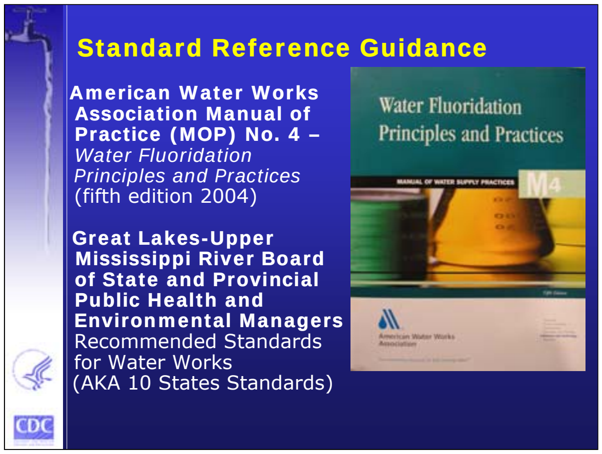

If Noah was asked to build an Ark today…
• Local building permit only allows structures conforming to zoning ordinance
• Soil Conservation requires drainage study
• Fire Marshall requires wood ark to have sprinklers even though it will be during a rainstorm
• DOT utility encroachment permits bogged done for clearance issues
• Wood availability poor due to timbering restrictions for spotted owl conservation requirements
• Legal injunction by animal rights group protesting collection of pairs of animals
• EPA requires EIS for flood impacts
• Immigration and Naturalization reviews of green card status of employees
• Trade union picketing of open labor policies
• IRS seizing assets to prevent illegally leaving country without declaring assets
CDC



The design principles for water fluoridation is the same as for other water treatment processes. The calculations are same as for other additives and the equipment and process design would be the same as for other standard water treatment processes.

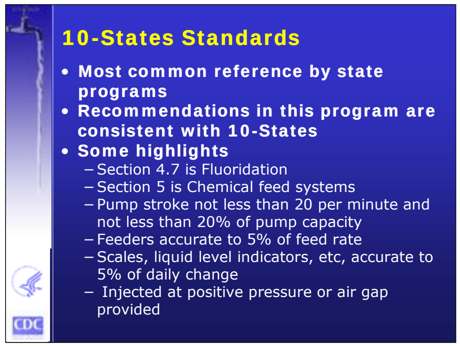


It's really very simple, you need a tank to hold the solution and a pump, but as with most things, there are certain details to get it right.



The standard reference guide is the AWWA Manual of Practice No. 4, Water Fluoridation principles and Practices. The current version is the Fifth Edition which was published in 2004. If you are adding fluoride to your system, you should purchase this manual of practice from AWWA as a reference. It contains a wealth of information on the practices and operations related to water fluoridation.

The other industry reference is 10-State Standards.



10-States is the most common reference used by state drinking water programs when reviewing designs. The materials in this CDC training are consistent with 10-States. Although Section 5 on chemical feed systems apply to fluoridation, there is also a Section 4.7 that is specific to fluoridation, so both sections must be checked. There are also certain specific requirements and a few of them include minimum pump strokes, minimum pump capacity, accuracy of measurement, and injection of solutions at positive pressure locations or with an air gap.

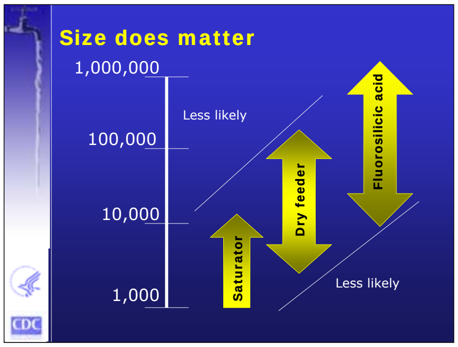
There is no one specific type of equipment that is used solely for one type of water system. All the fluoridation equipment, with the exception of a saturator, can be used on any system.

Historically, large water systems typically use FSA, a medium-sized system can use either FSA or dry additives with a feeder, and a very small system uses dry additives with either a saturator or a feeder.

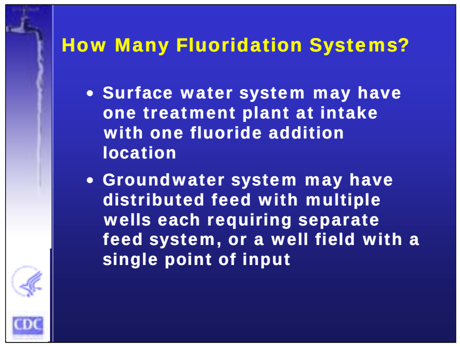
FSA systems are more frequently used because many utilities believe that because the acid is contained in tanks and pipes, there is less hazardous exposure to the operator and require less operator involvement and time. Larger systems typically have found FSA more cost-effective than dry additives in the larger delivery capacities. Some locations with hard water have found that using FSA avoids scaling and plugging from fluoride precipitation products.

Some utilities have chosen the dry additives because they have fewer impurities than FSA, or because they believe that exposure of personnel to dry additives and the resulting solutions present less hazardous conditions than FSA. So dry additives and FSA advocates can both argue that there is less resulting exposure, depending on assumptions, and they can both be right.

In fact, there are reasons to select any of the systems or additives, and a community should consider all the factors before deciding which system to use.



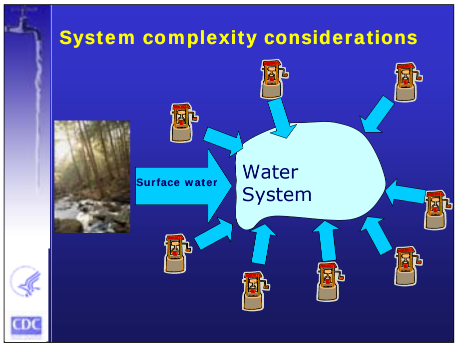
We have seen saturators used for large facilities where the saturator is used in a continuous flow basis to feed a day tank, and we have seen acid feed systems used in extremely small systems serving less than 100 people, but these are exceptions. Very small systems are typically going be least expensive as a saturator system, and very large systems will be least expensive as an acid feed. If a community desires to use a dry additive, then a dry feeder will become increasingly more cost effective as the size of the population served increases due to reduced labor costs.

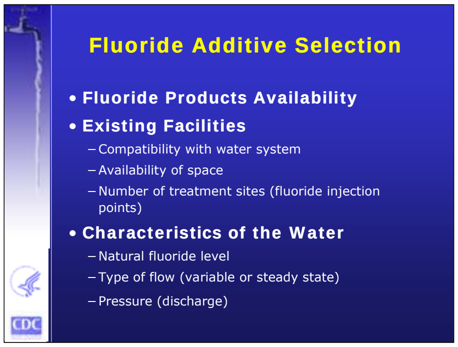


The number of fluoridation systems to serve a community depends on several factors. If the water system has a surface water supply, like a lake or a river, then there may be only one treatment facility, requiring a single fluoride addition location. If the community has two or more treatment facilities, then each location requires a separate feed system.

If the community is served with a groundwater system, then there may be multiple wells, resulting in a distributed feed to the distribution system. If that is the case, then each well requires a separate feed system.

Two equally sized communities, but one with a surface water plant and the other with a distributed well system, might have completely different fluoridation systems. The single surface water plant might use an FSA feed system, whereas the well system might be better off with a saturator or volumetric feeder for dry additive at each wellhead.


System complexity considerations
Surface water
Water System

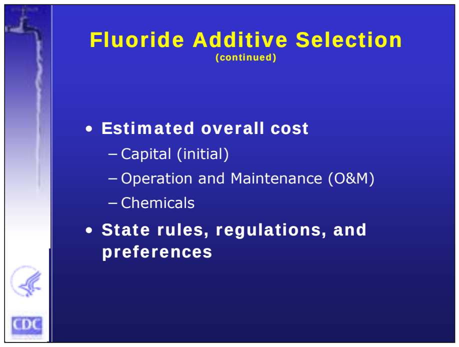


How do you design a water fluoridation system?

First, you select the additive and then select the equipment. The compatibility with the water system and other equipment may be a factor, such as using the same brand of metering pump or volumetric feeder that other chemical additive locations use in the facility. The type of flow, such as variable feed or steady state, and the pressure at the discharge point (gravity discharge into a tank or flume versus injection to a pipe) are other considerations. The number of treatment sites can also figure into the decision.

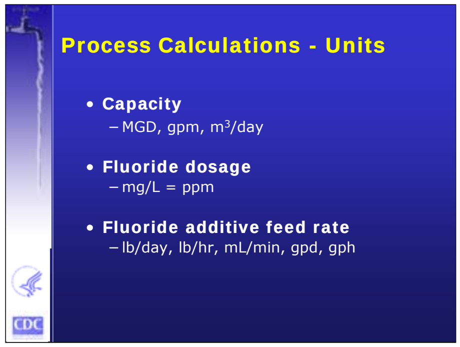
The natural fluoride level must be checked along with the optimum level for addition of fluoride.

Engineers earn their keep by considering the unique elements of each specific installation.



Cost is a major—and, in many cases, the deciding—factor in the design of a fluoridation system, especially capital costs.

Of course, state rules and regulations have to be followed and may affect the design a great deal. Sometimes there is a preference by state engineers for a certain additive or installation, so check with the drinking water program for the state for their opinion.

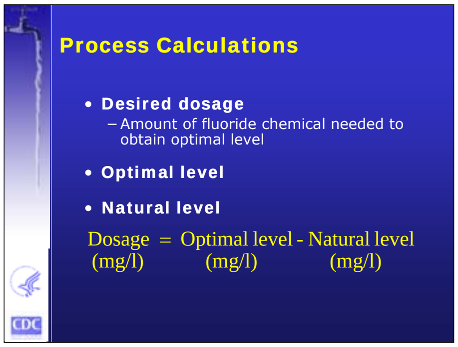


To get the right dosage of fluoride additive, it is necessary to know how much to add. This requires some math, but the calculations are the same type as those required for other chemical additives at a treatment facility. So let's review the simple math calculations that are needed for any process control in a water facility. As is the case with other calculations, it is normally necessary to express the calculations in units of measurement.

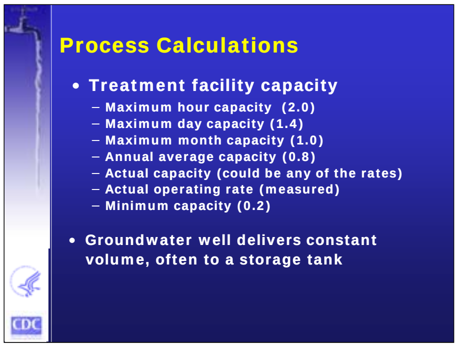
For the plant flow, million gallons per day (MGD), or gallons per day (gpd) for smaller facilities, and cubic meters per day (m^3/day) in the metric system.

For the dosage, either milligrams per liter (mg/L) or parts per million (ppm), which is approximately the same thing.

The additive feed rate is normally expressed as pounds per day (lb/day) or pounds per hour (lb/h) for dry additives, or as milliliters per minute (mL/min), gallons per day (gpd), or gallons per hour (gph) for FSA feed.



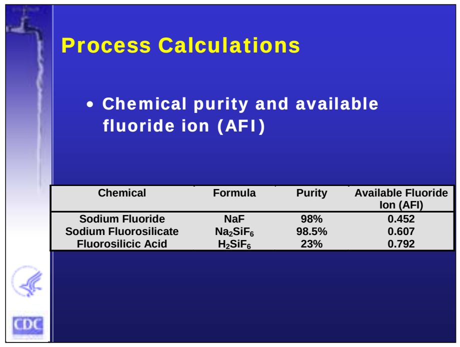
To determine the amount of fluoride additive, you need to know the optimal level for your location and what the natural fluoride level is for your source water. The optimal level can be determined by consulting with your state water fluoridation program, and the natural level must be measured. Some locations will find the natural level to be stable, but other locations will find it changes based on seasonal influences. Once you know the target optimal level and the natural level, you can determine the necessary dosage by simple subtraction. For example, if the optimal level is 0.8 mg/L, and the natural level is 0.2 mg/L, then the dosage is 0.6 mg/L.



Once the dosage has been calculated, then the quantity of fluoride additive can be calculated. This requires knowledge of the treatment facility capacity. Here is a listing of various capacity measurements for one treatment facility. Typically, a water facility is rated to have the capacity to produce the maximum month demand, and that is often the measurement we think of as a facility capacity. But, in fact, there are other measures of capacity including maximum hour, maximum day, annual average, and minimum capacity that the facility can operate; each is a factor of the capacity. On this list, the maximum month capacity is listed as a factor of 1, and the others have the factor you would multiply by to get that rating. So the annual average capacity is 80% of the maximum month capacity. When doing your calculations, you might need to run several calculations depending on what you are trying to determine. Often, the most important calculation is the actual operating rate, which is the measured flow through the facility.

Groundwater wells can present a unique case in that some groundwater pumps are constant speed pumps, so they deliver the amount of water only when they are pumping. Then you have a simpler calculation.

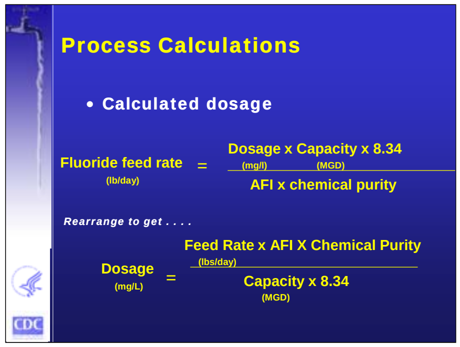
Please note that not all water treatment facilities operate on a 24-hour basis. If a water plant only operates 8 hours per day, then the calculations will need to be adjusted appropriately.



Chemical	Formula	Purity	Available Fluoride Ion (AFI)
Sodium Fluoride	NaF	98%	0.452
Sodium Fluorosilicate	Na_2SiF_6	98.5%	0.607
Fluorosilicic Acid	H_2SiF_6	23%	0.792

The chemical purity of the additive is also important. For the three fluoride products, the available fluoride ion depends on the chemical purity. However, some additives may not meet AWWA specifications and therefore would deliver a different quantity of available fluoride ion than shown in this table. One example is that FSA is nominally sold on a 23% purity basis, but, in fact, each batch might have a different purity. You need to verify the purity of your batch—is it 22% or 25% pure? And some dry additives can have a lower purity, such as excessive silica in sodium fluoride, which is often the case with imports from other counties that might not meet the AWWA specification. Make sure you verify the purity of each shipment. The supplier should be able to provide you with a certified test of the batch you receive; you can also run a test of the purity to verify what was delivered.

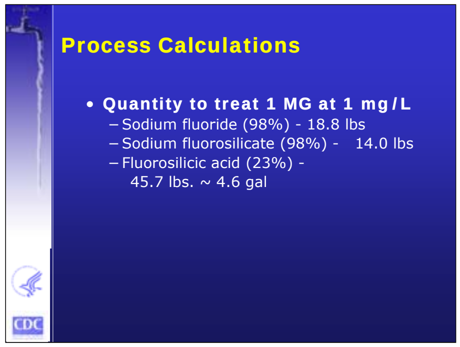
The available fluoride ion content is based on a 100% purity, so verify the purity of your additive using the AWWA test.



Here is an equation with which you should already be familiar. It's our old friend, the water formula. As you have learned in other courses, this equation is prepared to allow easy-to-use units, pounds per day, milligrams per liter, and million gallons per day, and the factor 8.34 includes all the conversion factors to make the units resolve. We also include the available fluoride ion and the chemical purity, which we saw on the previous slide.

The first time you run this calculation for your facility, it may take a while to get the calculation correct. But Best Practices for water plant operations are to document all your work in a Standard Operating Procedure, and once you do that, then a daily verification of the calculated feed rate should only take you minute to prepare.

If we rearrange this equation to calculate the dosage, we need to multiply both sides of the equation by the AFI and the chemical purity, and divide both sides by the capacity and the 8.34 conversion factor. This results in the lower equation.

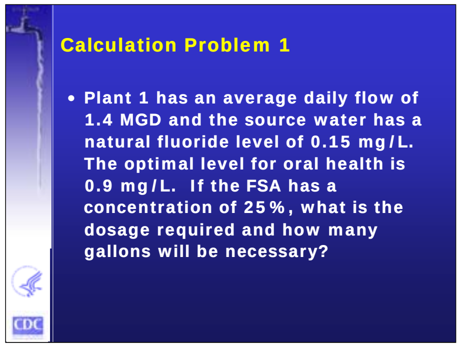


With this equation, which is a familiar friend, we can calculate how much additive is required to treat the flow. As a comparison, to treat 1 million gallons per day with 1 mg of fluoride per liter, presuming the water does not contain any naturally occurring fluoride, the following amount of additive is required:

Sodium fluoride (98% verify the purity, particularly if it is imported), 18.8 lb

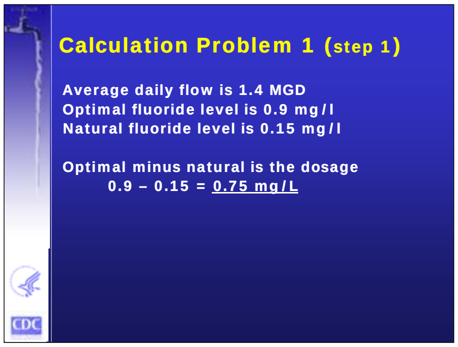
Sodium fluorosilicate (98%), 14.0 lb

FSA (23%, and this can vary from delivery to delivery), 45.7 lb/≈4.6 gallons.



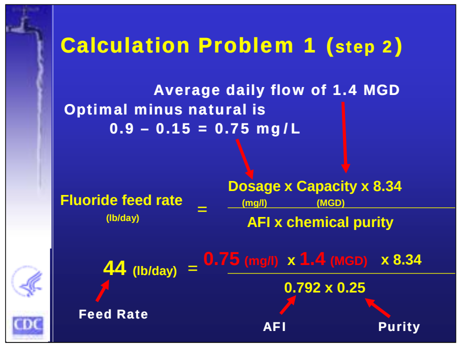
You will have to compute the usage of fluoride additive at your own facility for the flows and concentrations you will be dealing with. Let's take a little time to do a few sample calculations. We will do one calculation each for FSA, sodium fluorosilicate, and sodium fluoride, but even though you need to deal with only one of these at your plant, the practice of making the calculation for each example will help you in your management of fluoride levels in your plant.

For the first example, we have a plant that is treating 1.4 MGD. The natural fluoride in the source water is 0.15 mg/L and the optimal level for oral health for the state is 0.9 mg/L. The FSA has been evaluated by using the hydrogen titration method from the AWWA standard for FSA and has been determined to be 25%. Let's discuss how to calculate dosage and gallons of solution to be fed.



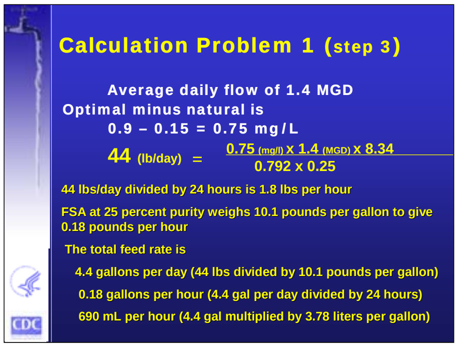
We have a plant that is treating 1.4 MGD. The natural fluoride in the source water is 0.15 mg/L and the optimal level for oral health for the state is 0.9 mg/L. So 0.9 minus 0.15 is 0.75 mg/L of fluoride to be added.

Now that we know how much fluoride product to add, we can calculate the number of gallons we need to add each day.



So we calculated that we needed a dosage of 0.9 minus 0.15 which is 0.75 mg/L of fluoride to be added. We put that dosage into the equation, and then substitute the capacity with 1.4 MGD. The FSA has a purity of 25%, which means it has 25% acid and 75% water. And from the earlier table, we know 0.792 mg of fluoride ion is available for each mg of pure acid (assuming 100% purity). Using the standard water treatment equation and substituting the known values in the equation, we can compute that we need to feed 44.22 lb of solution per day. From other math courses, you have probably learned the concept of significant figures in calculations; because the 1.4 MGD has only two significant figures, we can rely on only two significant figures in the final calculations, so we round it to 44 lb/day.

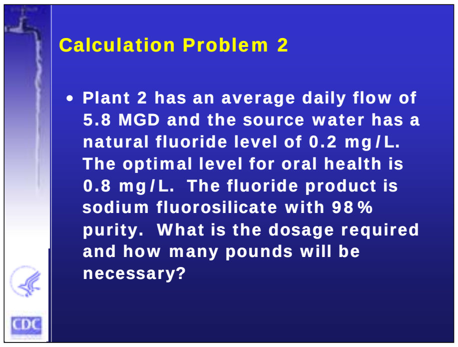
So that is how much fluoride additive is needed in one day.



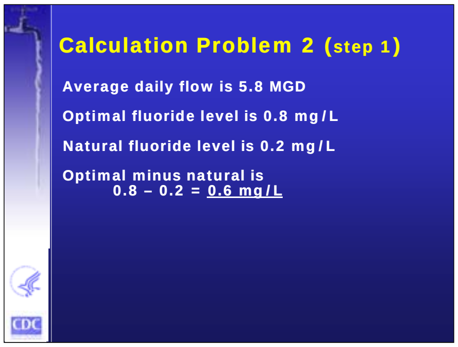
So we have calculated that we need 44 lb/day.

Pounds of solution may be difficult to use as a control amount because the pump is calibrated in gallons, so let's divide 44 by 10.1, which is how much each gallon of fluorosilicic acid at 25% purity weighs. This gives us 4.4 gallons, which is equal to 0.18 gallon per hour (dividing by 24 hours in a day). This is also 690 mL per hour. That is how much we need to set our pump to deliver.

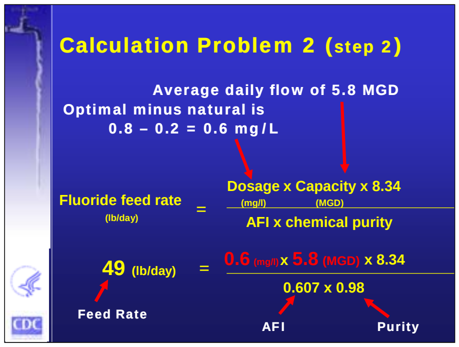
If the water facility does not operate 24-hours per day, then the calculation would need to be adjusted accordingly. If there is only an 8-hour operation, you would divide 4.4 gallons per day by 8 hours to get 0.55 gallons per hour.



For our second example, we have a plant that is treating 5.8 MGD. The natural fluoride in the source water is 0.2 mg/L, and the optimal level for oral health for the state is 0.8 mg/L. The sodium fluorosilicate purity has been evaluated by the specific ion electrode method from the AWWA standard and has been determined to be 98%. So let’s discuss how to calculate dosage and pounds to be fed.

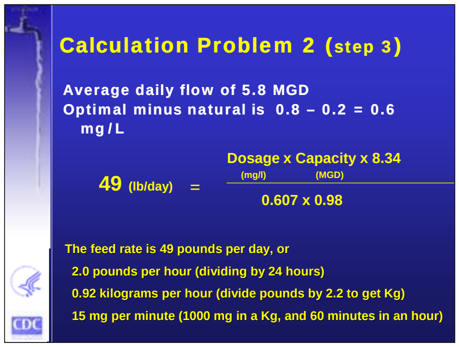


We have a plant that is treating 5.8 MGD. The natural fluoride in the source water is 0.2 mg/L and the optimal level for oral health for the state is 0.8 mg/L. So 0.8 minus 0.2 results in a dosage of 0.6 mg/L of fluoride to be added. Now, we can calculate the amount of additive to be added based on the dosage.



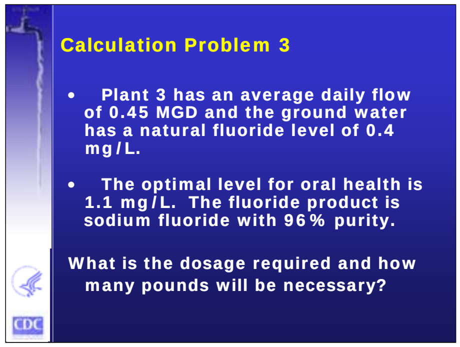
So we calculated that we needed a dosage of 0.8 minus 0.2 which is 0.6 mg/L of fluoride to be added. We put that dosage into the equation, and then substitute the capacity with 5.8 MGD. The NFSA has a purity of 98%. And from the earlier table, we know 0.607 mg of fluoride ion is available for each mg of additive. Using the standard water treatment equation and substituting the known values in the equation, we can compute that we need to feed 49 lb of solution per day. From other math courses, you have probably learned the concept of significant figures in calculations; because the 5.8 MGD has only two significant figures, we can rely on only two significant figures in the final calculations, so we round it to 49 lb/day.

So that is how much fluoride additive is needed in one day.

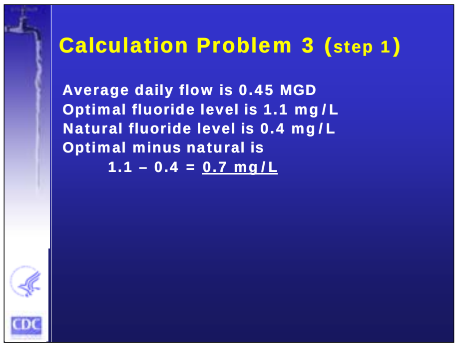


So we need to add 49 lb/day. That is how much we need to set our dry feeder to deliver. You can set it based on a calibration test to deliver the precise amount.

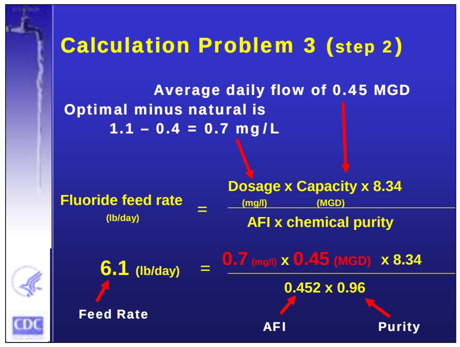
If the water facility does not operate 24-hours per day, then the calculation would need to be adjusted accordingly. If there is only an 8-hour operation, you would divide 49 pounds per day by 8 hours to get 6.1 pounds per hour.



For our last example, we have a plant that is treating 0.45 MGD. The natural fluoride in the source water is 0.4 mg/L and the optimal level for oral health for the state is 1.1 mg/L. The sodium fluoride purity has been evaluated by the specific ion electrode method from the AWWA standard and has been determined to be 96%. Let's discuss how to calculate dosage and pounds to be fed.

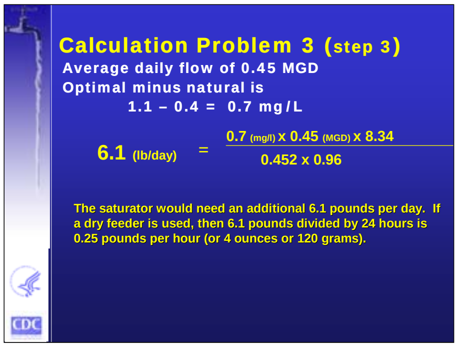


We have a plant that is treating 0.45 MGD. The natural fluoride in the source water is 0.4 mg/L and the optimal level for oral health for the state is 1.1 mg/L. So 1.1 minus 0.4 is 0.7 mg/L of fluoride to be added. So now we know the dosage we want, we can calculate the feed rate.



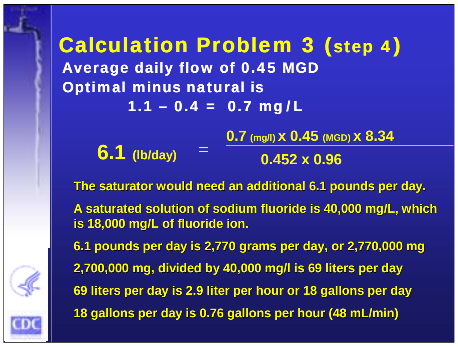
So we calculated that we needed a dosage of 1.1 minus 0.4 which is 0.7 mg/L of fluoride to be added. We put that dosage into the equation, and then substitute the capacity with 0.45 MGD. The sodium fluoride has a purity of 96%. And from the earlier table, we know 0.452 mg of fluoride ion is available for each mg of dry additive. Using the standard water treatment equation and substituting the known values in the equation, we can compute that we need to feed 6.1 lb of solution per day. From other math courses, you have probably learned the concept of significant figures in calculations; because the 0.45 MGD has only two significant figures, we can rely on only two significant figures in the final calculations, so we round it to 6.1 lb/day.

So that is how much fluoride additive is needed in one day.

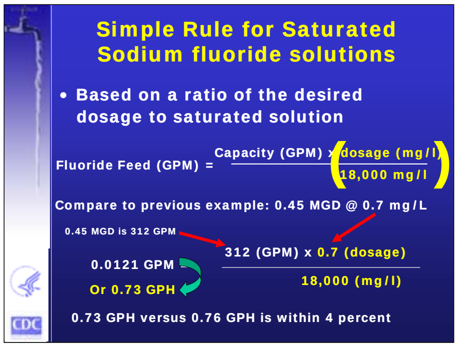


So we need to add 6.1 lb/day. That is how much we need to set our dry feeder to deliver, or the amount that would need to be added to a saturator each day. You would probably not add this much to a saturator each day, but if you don't maintain the additive bed, the material can be depleted in several days. You can set the dry feeder based on a calibration test to deliver the precise amount.

If the water facility does not operate 24-hours per day, then the calculation would need to be adjusted accordingly. If there is only an 8-hour operation, you would divide 6.1 pounds per day by 8 hours to get 0.76 pounds per hour.



With this being a saturator, we need to know how much solution to pump in addition to how much sodium fluoride to add to the saturator. 6.1 pounds per day can be multiplied by 454 to get grams per day, and with 1,000 mg per gram, we need 2,770,000 mg of sodium fluoride each day. Since the solution is 40,000 mg/L, if we divide by 40,000, we get 69 liters per day, or 2.9 liters each hour. This is also equal to 0.76 gallons per hour, or 48.3 mL/min depending on the pump rating.



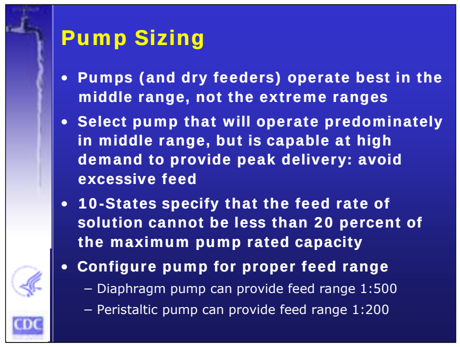
This is known as “Robert’s Rule. Robert was Robert Schieferstein who was a founder of LMI pumps.

There is a simple dosage calculation for saturated sodium fluoride solutions. The simple concept here is based on the fact that a saturated sodium fluoride solution will have a definite concentration of fluoride. So we use 1 gallon of saturated solution to treat 18,000 gallons of water to 1ppm. Remember that a saturated solution is 40,000 mg/L of NaF, but 18,000 mg/L of F.

If you want to know how much water you can treat to 1.2ppm its 18,000 / 1.2 = 15,000

If you want to know how much water you can treat to .8ppm its 18,000 / .8 = 22,500

For the previous example, the result is 0.73 GPH which is within 4 percent of the previous answer of 0.76 GPH. The 0.76 GPH answer is less accurate for it has several additional rounding errors through all the conversions (0.73 only had one rounding error, while 0.76 had 4 rounding errors). However, the more detailed calculation does give us additional information such as how much sodium fluoride make-up should be added.

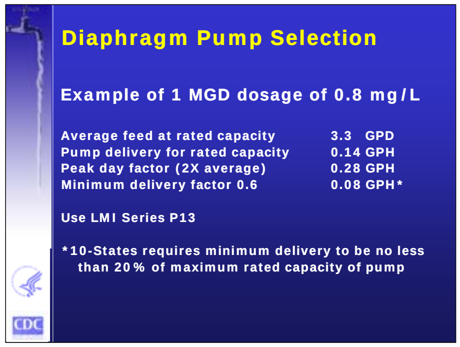


Pumps and dry feeders operate best in the middle of their capacity range, not at the extreme ends of their ranges.

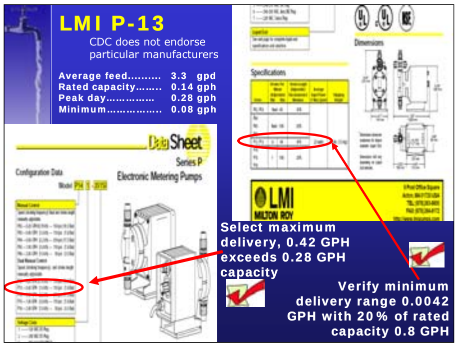
Select a pump that will operate predominately in the middle of its range, but is capable of high demand at peak delivery. 10-States require that the feed rate of the solution cannot be less than 20 percent of the maximum rated pump capacity.

Most of the chemical supply pumps can achieve a remarkable delivery range, diaphragm pumps can provide a feed from 1 up to 500, and peristaltic pumps can provide feed ranges from 1 up to 200. This is done by varying diaphragms or tubing sizes, pump stokes or rotation speed, and other techniques. Make sure that the pump is configured to operate in the range that you need for your facility, not necessarily at its maximum delivery.

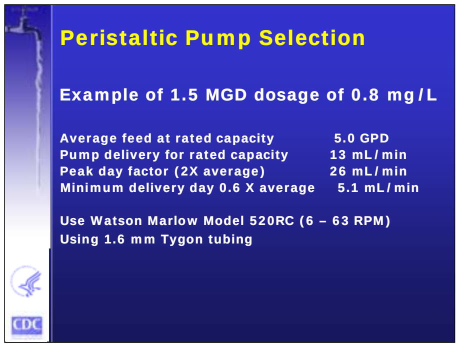
Dry feeders can also achieve a wide range of delivery by changing the auger or speed. Ensure that the right equipment is installed.



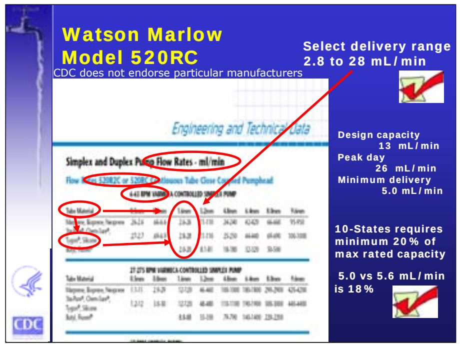
For purposes of instruction, let us look at a 1 MGD capacity with 0.8 mg/L dosage requiring 3.3 gallons per day, or 0.14 gph on average at design flow. Presuming maximum day rate of 2 times average design flow, and minimum rate of 60% of the average design flow to allow for lower plant flows in the early years of the system before it reaches the design demand basis, the pump would need to deliver 0.08 to 0.28 gph range. LMI Series P13 has range of 0.001 to 0.42 gph using minimum stroke of 0.6 and maximum stroke of 60, and minimum stroke length of 30 percent.



Checking the manufacturer's specification sheet, we verify that this pump model can deliver the maximum delivery of 0.42, and also meet the minimum delivery range. The true minimum delivery is actually less than this for the minimum of 0.0042 GPH is based on the number of strokes per minute, and the stroke length of the pump can be further adjusted to 30 percent of the length, so the pump can probably be adjusted to delivery only 0.0013 GPH.



For purposes of identifying a pump, let us look a 1 MGD capacity with 0.8 mg/L dosage requiring 3.3 gallons per day, or 0.14 gph on average at design flow. Presuming maximum day would be 2 times average for peak day, and minimum rate of 60% of the average rate for the early years when the plant was not at the future design capacity, the pump would need to deliver 3.4 to 19 mL/min range. Watson-Marlow has a model 520RC which delivers this range using a 1.6 mm Tygon tubing.



In this example, we have chosen a pump with a delivery pressure of up to 30 psi, having the delivery range from 2.8 to 28 mL/min to cover our range of 5.0 to 26 mL/min. We selected a tubing diameter to limit the delivery so that we will not over-dose the system. You can further increase or decrease the delivery of this pump by changing the tubing diameter.

10-States requires a minimum of 20% of maximum rated capacity, and in this case, we are slightly below. But it is 18% of maximum capacity, and would probably be considered reasonable.