New York State
Maple Tubing and
Vacuum System
Notebook

Cornell Maple Program,
County Cornell Cooperative Extension and the
New York State Farm Viability Institute

Cornell University
Cooperative Extension

New York State Maple Tubing and Vacuum System Notebook
6th Edition

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Section 1 Introduction

Summary:

Tubing systems have become the most common method to collect maple sap for two reasons. The first is the significant time and labor reduction required to collect sap during the production season. The second is the significant increase in sap yield obtainable through use of vacuum. There are weather conditions where sap can be collected only under vacuum and even when sap is flowing without vacuum, vacuum will boost production and increase sap yields.

Proper design of a vacuum and tubing collection system is moving from an art or guessing to more of a science, though there is still much to be learned. This notebook will expand on the basic information provided in the *North American Maple Syrup Producers Manual* to provide you with a deeper, practical understanding of what you need to think about in designing an effective collection system.

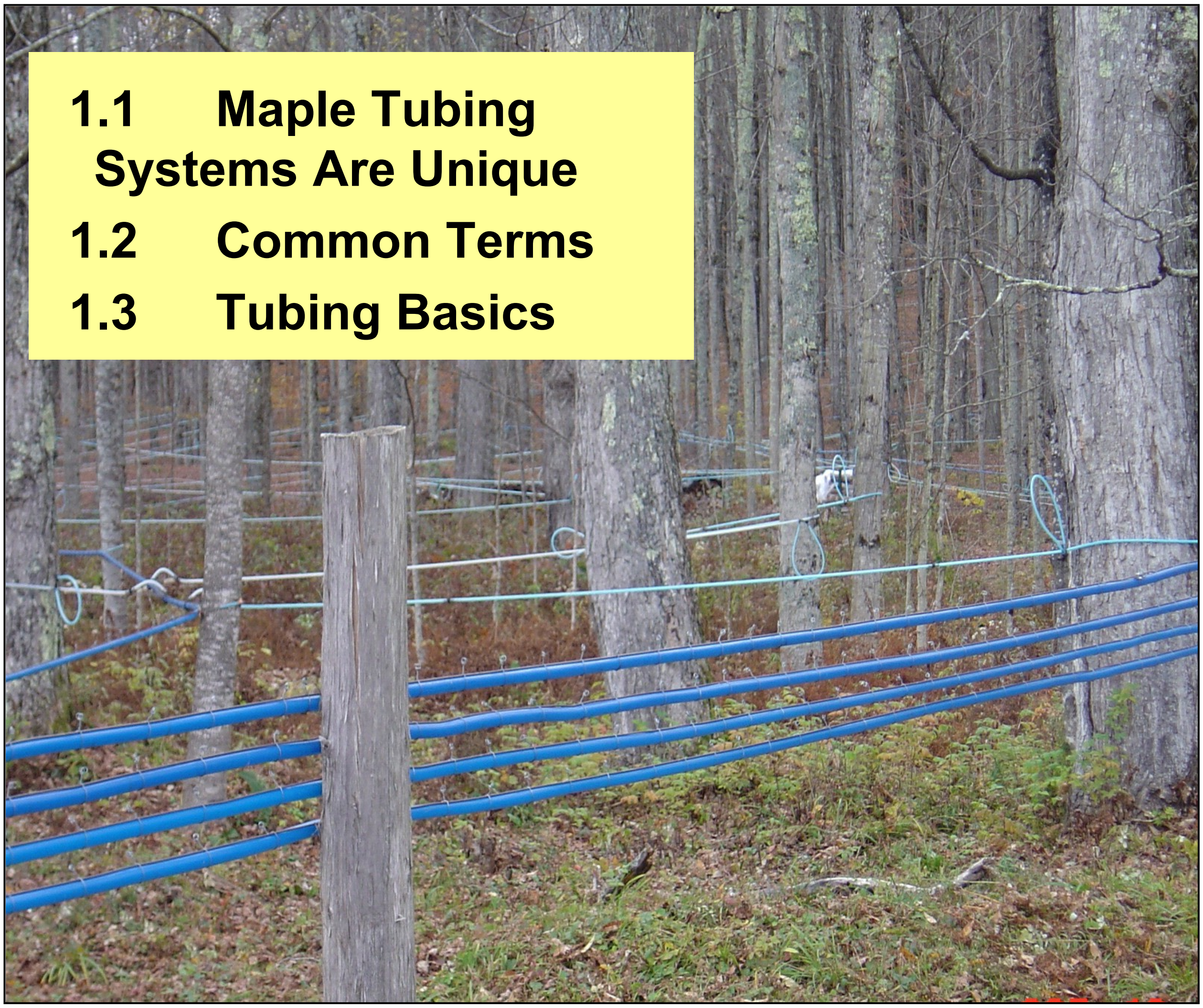
The rate of movement of liquids or air in tubing is affected by three factors: the diameter of the tube, the length of the tube, and the pressure difference between the ends of the tube. The volume of flow is faster in larger, shorter tubes under high pressure. Rate of sap flow decreases in smaller, longer tubes and with a lower pressure differential between the ends of the tube. German and French scientists working separately in 1838-39 discovered these relationships. The resulting equation is called the Hagen-Pousielle Law. This relationship is key to understanding how tubing systems work and how sap flows inside the tree.

Under appropriate freezing and thawing temperatures, maple trees will develop reasonably high internal pressures. From the tree’s perspective, the function of this is to squeeze air out of the xylem tubes so they are filled with sap ready to supply expanding leaves. Air bubbles will occur under freezing and thawing conditions and will produce vapor lock that prevents the movement of sap up the tree.

When you drill a tap hole into the tree, sap comes out when there is positive internal pressure. In this case, the tree is pushing against air pressure. This internal pressure builds during the thawing phase and then decreases as sap leaves the tree. The mechanisms behind the pressure buildup are described in the North American Manual. The microscopic diameters of the xylem elements limit the flow rate of sap into the tap hole so that sap flow can occur for many hours before the tree looses pressure. If you think about air loss from a tire, a big hole can produce near instant pressure loss. A small hole will cause a tire to loose pressure over time. The rate of pressure loss in the tree also is affected by the fact that the pressure mechanisms are internal so that the tree can increase in pressure even when sap is leaving the tree, something that a tire can’t do. During periods of below freezing temperature the internal pressures in the tree become negative, developing in essence a vacuum of its own creating the mechanism by which the tree is refilled with sap by pulling water in through the roots. This period of negative internal pressure also allows the tree to pull sap back into the tap hole from the spout and tubing. It is a better understanding of this mechanism that has lead to the recent development of tap hole sanitation procedures such as check valves, imbedded silver spouts, tap extenders and regular replacement of spouts and droplines. The value of these tap hole sanitation techniques will be covered in Section 8.

The effect of vacuum in increasing sap yields can be calculated with the Hagen-Pousielle Law. Putting the tubing system under vacuum has the tree pressure pushing against a much lower external pressure. This increases the pressure difference causing the sap to flow much faster through the xylem elements and into the tubing. Sap can be collected even with low pressures inside the tree. Also, a greater volume of sap can be collected in the same time period compared with a bucket or non-vacuum collection system where the tree is pushing against atmospheric pressure. Creating this pressure difference with vacuum also allows the sap to be extracted from the tree at lower temperatures thus it begins running sooner and can continue running longer as the temperature drops down at night or during a weather change.

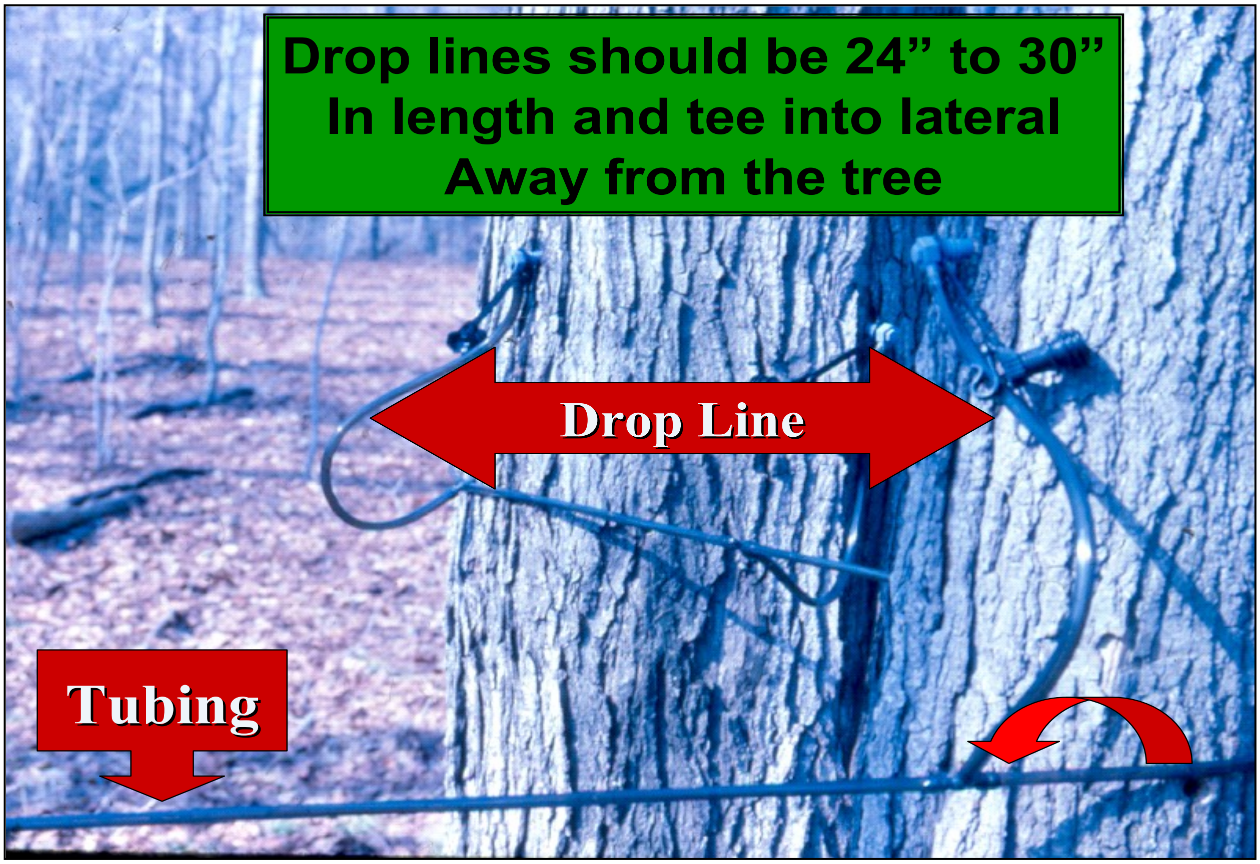
If we apply the Hagen-Pousielle Law to tubing systems, a larger volume of air and sap can move through the larger diameter tubes. The diameter of the tubing will affect the volume of sap that can be delivered to the collecting tanks. The tubing diameters typically increase from the tree to the collecting tank as more and more sap is put into the system. More about the way these systems function and how to properly size the tubing will be covered in Sections 11-13.



1.1 Maple Tubing Systems Are Unique
1.2 Common Terms
1.3 Tubing Basics

1.1 Maple Tubing Systems Are Unique

Maple tubing systems are a unique application of vacuum and collection technology. There are very few other applications where miles of main lines and lateral lines are strung out in nature. We have been learning slowly how to make such a system work to maximum productivity with the most efficient cost and return. There has been a lot of trial and error and very little system engineering applied. The vacuum systems installed in medical or dental facilities are probably the closest in design and offer maple production a wealth of information. Misconceptions about “natural” vacuum in tubing systems have perpetuated many systems being installed with significantly undersized capacity. Recommendations for how many taps per lateral line or main lines have changed dramatically over the years. Research has clearly shown the value of vacuum and closed tubing systems. Research has demonstrated that getting good vacuum levels at the tree result in significantly improved yields. Most recently, research has shown the importance of tap hole sanitation using check valve spouts or replacing taps and drop lines on a regular schedule. Washing maple tubing systems remains an ongoing challenge as to the most effective methods and materials and whether currently used procedures accomplish much.



1.2 Common Terms

An understanding of some common terms may be helpful as the discussion progresses. The tubing that runs from tree to tree is called the lateral line and consists of plastic 5/16th" tubing. The drop line is the same size and connects the spout to the lateral line. The plastic or medal spout is driven into the tap hole and is often called the tap, spout or spile. The lateral line collects sap from a series of trees. In most newer installations, lateral lines collect from 5 or 6 taps before empting into a larger main line. Where there is just a single mainline it is commonly called a conductor line. Since these mainlines carry both sap and vacuum they are a dual purpose line. Where two lines are installed together in the tubing system the one to primarily conduct sap is called the wet line and the one to primarily conduct vacuum air is called the dry line.

1.3 Tubing Basics

Drop lines are usually 24" to 30" long so that a tap hole can be placed anywhere around the tree. Smaller trees may be fine with a shorter drop line while larger trees may need a longer drop line. The drop line connection with the lateral line should be placed 4 to 6" away for the tree as illustrated by the arrow in the picture above. This placement helps avoid rodent damage and makes replacement much easier than when the connection is tight to the bark of the tree. With the exception of a sap ladder, which is covered in section 15 of this notebook, all tubing, the drop line, the lateral line or the main lines should always be graded to flow down hill. Sap should not be allowed to sit in a dip in the line as this will led to sap fermentation on warm days and reduced sap quality.

Section 2 Why does sap flow and what can we do about it?

Summary
A basic understanding of how and why sap runs can be helpful in making decisions about how to tap a tree, how many taps to put in a tree, how many taps to put on a line, how vacuum can increase yield and how tap hole sanitation can make a season last longer.

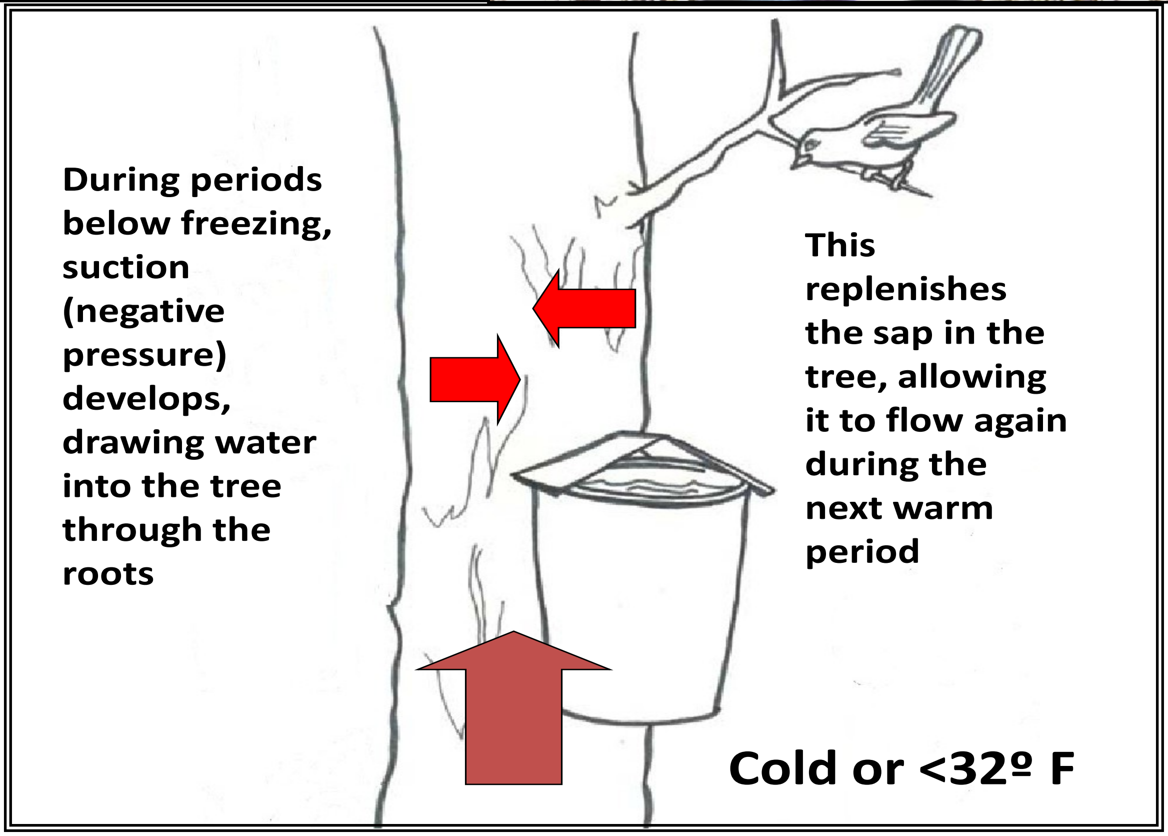
2.1 Internal Maple Tree Pressures

During warm periods when temperatures rise above freezing, pressure (positive pressure) develops in the tree

This pressure causes the sap to flow out of the tree through a wound or tap hole

Early in the spring, when the maple trees are still dormant, temperatures often rise above freezing during the day but drop back below freezing at night. This fluctuation in air temperature is vital to the flow of sap in sugar maple trees. Although sap generally flows during the day when temperatures are warm, it will also flow at night if temperatures remain above freezing.

Sap will only continue to flow for 30 to 72 hours if the temperature does not fall below freezing again. Note the 25 psi positive pressure exhibited by the pressure gauge connected to a maple tree tap. This picture was taken on a warm spring day following a freeze the night before. This pressure forces or pushes sap from the tree through any wound or tap hole.


During periods below freezing, suction (negative pressure) develops, drawing water into the tree through the roots

This replenishes the sap in the tree, allowing it to flow again during the next warm period

Cold or <32º F

During the period of negative tree pressure or suction the tree pulls water in from the roots. There is a limited volume of sap in the tree. If a warm up is fairly long most of the sap would be drained out through a single tap no mater what the tree size. Adding a second tap would remove the sap faster but would not be able to extract more sap as long as the time available for the run was sufficiently long. Adding many taps to a tree will not get more sap, it will just drain it faster. Therefore, if the sap runs are very short, just a few hours, more taps will net more sap. Extra taps in a tree or even extreme over tapping only gain sap volume during short warm ups. An interesting problem is created by the tree surging between positive and negative pressures. When the tree drops back to a negative pressure when temperatures cool it pulls sap in from the roots but it will also pull sap back in from the spout and drop line. If that sap is contaminated from bacteria and yeast residing in the spout or drop line the tap hole will more rapidly become plugged with the growth of these microbes.

2.2 The Value of Vacuum

Vacuum allows sap to begin running at a lower temperature, generally just a couple of degrees, depending on how high the vacuum pressure is. So the vacuum affect on internal tree pressure lengthens the sap run both at the beginning of the flow and at the end of the flow as temperature fall back to below freezing. This is one way that vacuum increases yields. It lengthens a flow as well as allows the sugarbush to have a flow when it is still a little to cool for trees not on vacuum to run at all. Vacuum also increases the flow rate during a flow. The higher the vacuum the higher the flow rate tends to be. Vacuum increases the pressure differential making it easier for the tree to push out sap. This is basic physics as described in the Hagen-Pousielle relationship. There is a point where the cost of adding more vacuum will be greater than the value of the increase in sap yield. This will be true for all maple operations. However, because each maple operation manage capital, installation and maintenance cost differently, the most profitable vacuum level will be different for each farm. There is much greater detail about vacuum in Sections 7,11 and 12.

2.3 Size of Tapholes

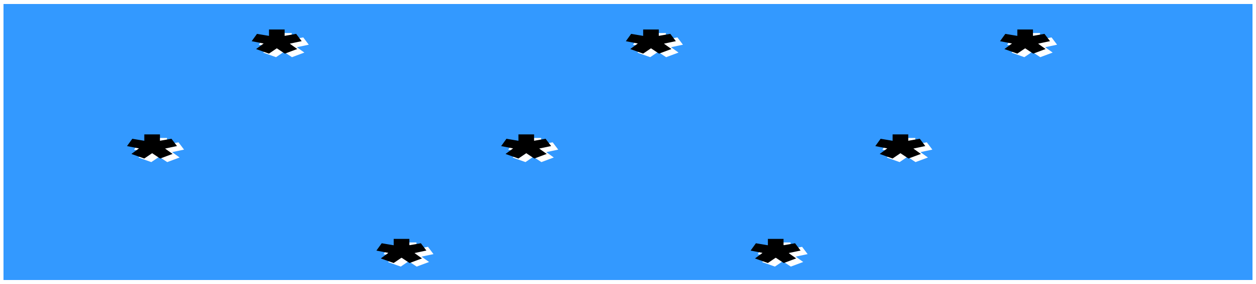
Research has shown that using the 5/16 health spout without vacuum often cuts the sap flow by about 20%. That would be due to the fact that it simply takes more time for a sap flow to be pushed out of the smaller hole. This was especially noted during fairly short runs. During runs with more extended time, the yield from a health spout would be more similar to the yield from the traditional 7/16 sized spouts. Under vacuum the difference between the 5/16 and the 7/16 sized spout was found to be about equal. The depth of the sap wood in a maple tree is usually 1″ to 3″ deep depending on how fast the tree has been growing. Very slow growing trees will have a narrower band of sap wood and fast growing trees a wider band of sap wood. Drilling tap holes deeper than 2″ has not been shown to increase sap yield but it does increase the chances of drilling into old partitioned (darker brown) wood from previous tap holes. Drilling into partitioned wood will reduce sap yield and can result in poorer quality sap. In the old days some of the taps used on trees were much larger than today leaving extensive scarring and partitioning in the trees. The health spouts leave a significantly smaller partitioned zone than even the 7/16″ spouts.

2.4 Tree Size and Tapping

The volume of sap wood in a tree relates directly to the volume of sap that the tree can hold following a freezing period. Therefore tapping trees that have a small diameter results in small runs of sap but will create partitioned zones in the tree that are large relative to the size of the tree. Unless a tree is scheduled for removal for thinning purposes in the near future, it is recommended that trees not be taped until they reach at least 10″ in diameter at about 4′ above the ground. Even then the tree needs to have a fairly good growth rate to be able to reduce your chances of drilling into the partitioned zones of old taps in future years.

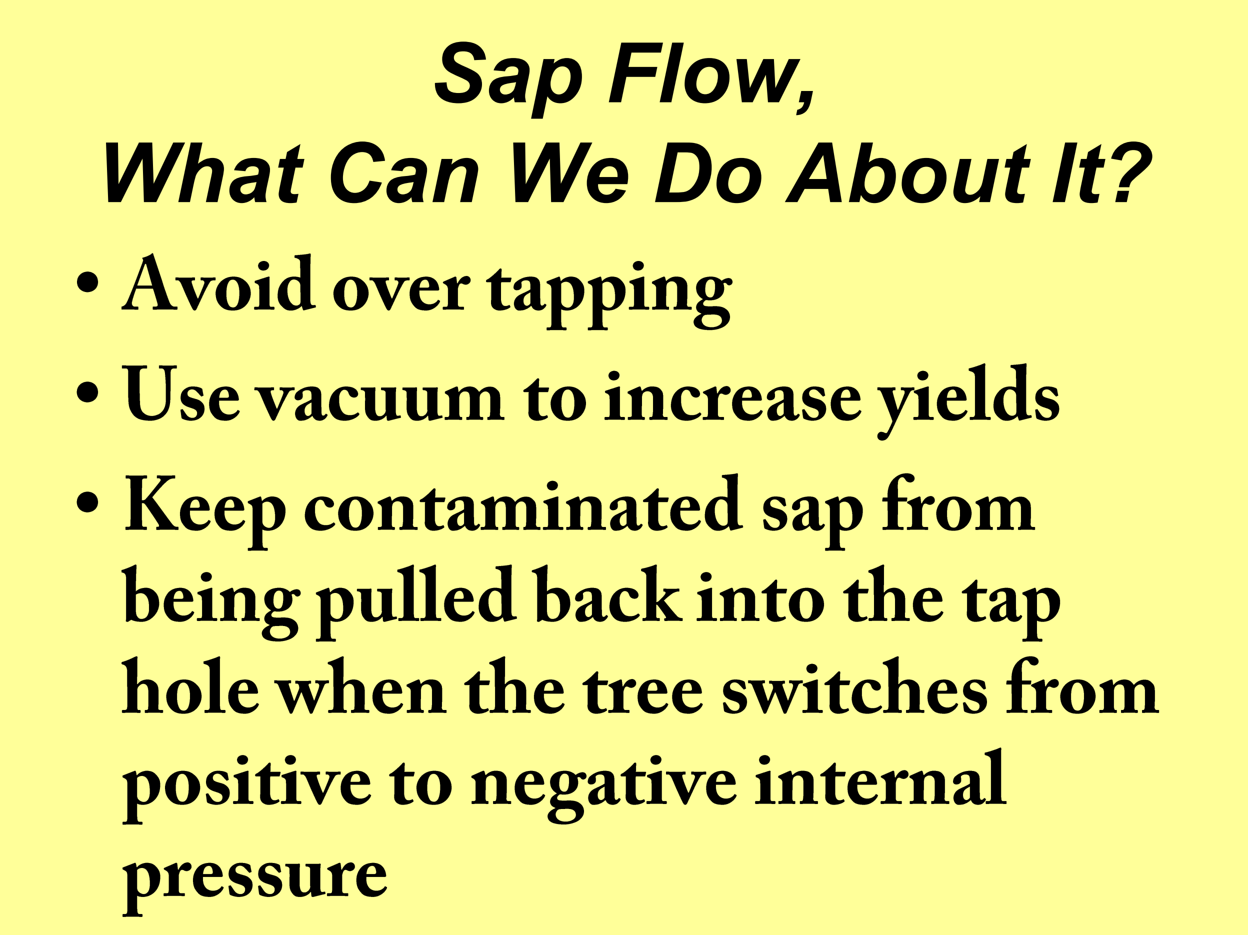
2.5 Pattern Tapping

When starting to tap a new tree it is recommended that you pattern tap to avoid hitting into old partitioned zones. To pattern tap, drill the next tap hole 1″ to ″ to the side of last years tap as well as moving the taps up and down around the tree in a vertical span of 10 to 14 inches. Drilling the holes in a straight line around the tree can create a weakened area in the wood of the tree. It is recommended to pattern tap on all trees but it especially makes sense when beginning with a new tree where there are no old taps to confuse the system. Many times maple producers are confused by a temperature reading they see at the house or even at the trunk of the tree when the important conditions are what is happening up in the tree branches 50 or more feet higher than where reading are being observed.



2.6 Other Tapping Considerations

Having more than one tap in a tree would allow the tree to be drained of sap more quickly. It does not increase the total sap available but by draining the tree more quickly there is more potential for extracting more sap over the whole season. During fairly short periods of sap flow, because the time above freezing is short, more sap will be extracted during the time available where there are more taps on the tree. On the other hand having more taps on the tree during a longer warm spell cannot improve sap yield at all. The tree can only yield the sap that is in the sap wood above the tap hole. Having vacuum that allows the sap run to begin at a slightly cooler temperature means it begins sooner and runs later allowing for a better overall extraction of the available sap. With vacuum a producer can have less taps per tree and still extract the extra sap. Any time a new tap is drilled into the partitioned (darker brown) wood from a previous tap the new tap will result in reduced yield. Therefore the less old tap holes in a tree the less likely a new tap will be drilled into an old tap partitioned zone. Over tapping generally does not result in more sap but can create so much partitioned areas in the tree that it becomes very common for new tap holes to be drilled into old partitioned wood making it likely that many more new taps will be poor yielders. Adding vacuum and reducing the rate of taps per tree makes more sense than adding extra taps or over tapping to have the best yield both now and especially in the long run.



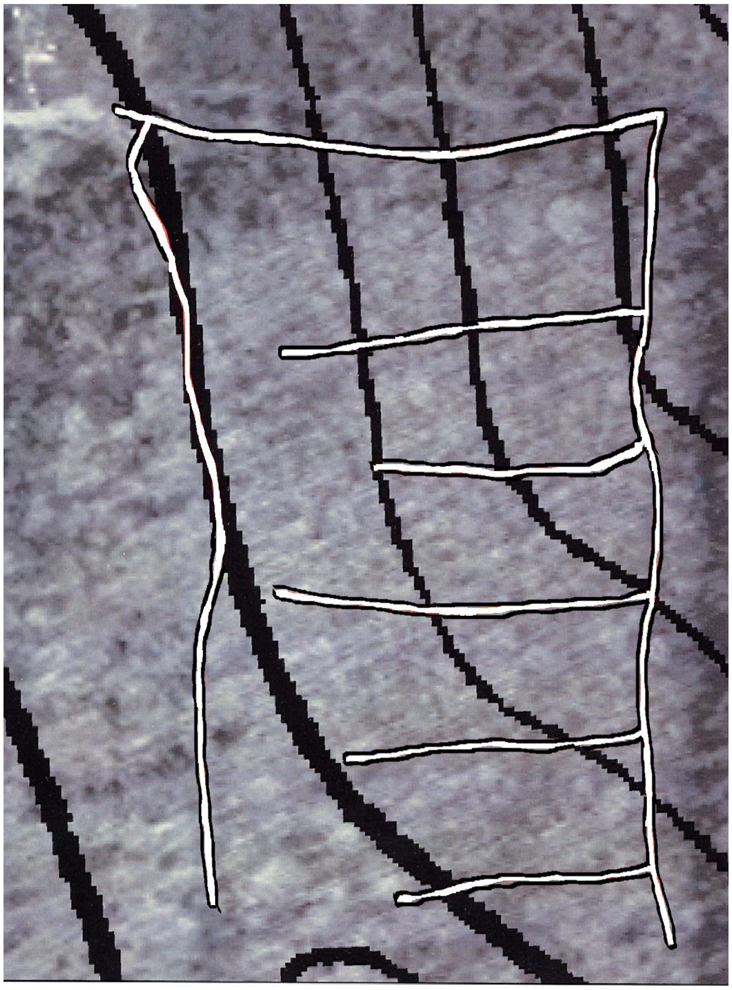
Sap Flow,
What Can We Do About It?

- **Avoid over tapping**
- **Use vacuum to increase yields**
- **Keep contaminated sap from being pulled back into the tap hole when the tree switches from positive to negative internal pressure**

Section 3 Planning and layout of a maple tubing system

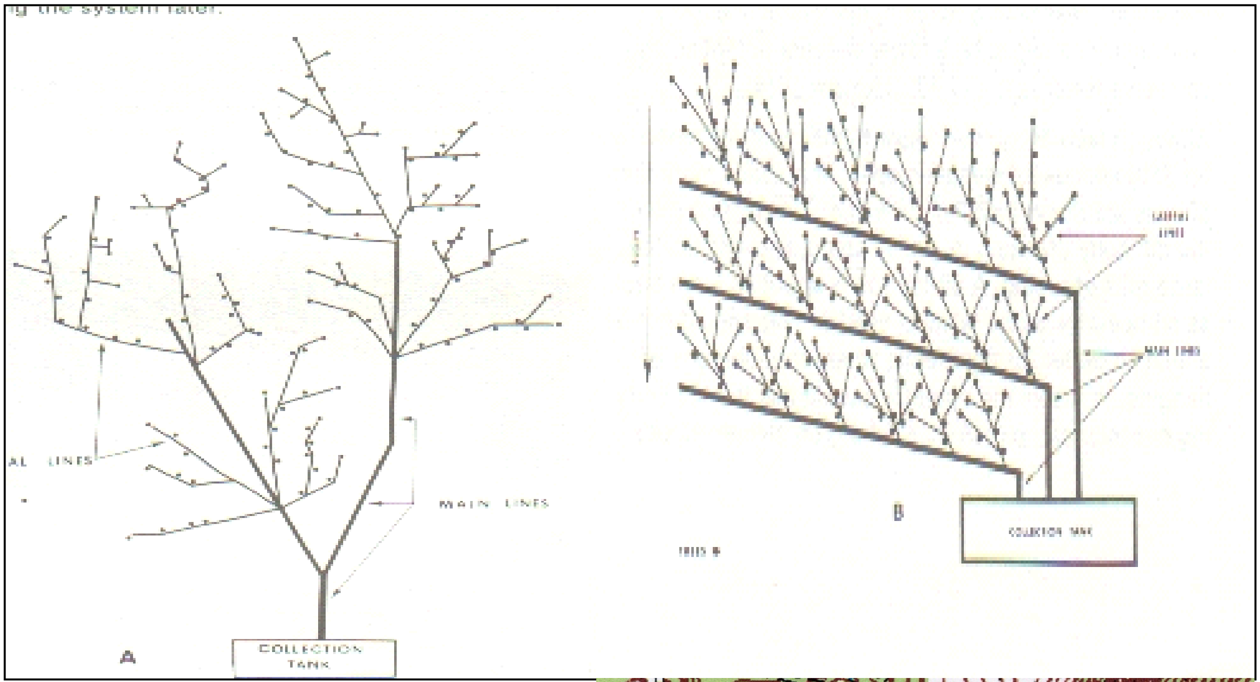
Summary:

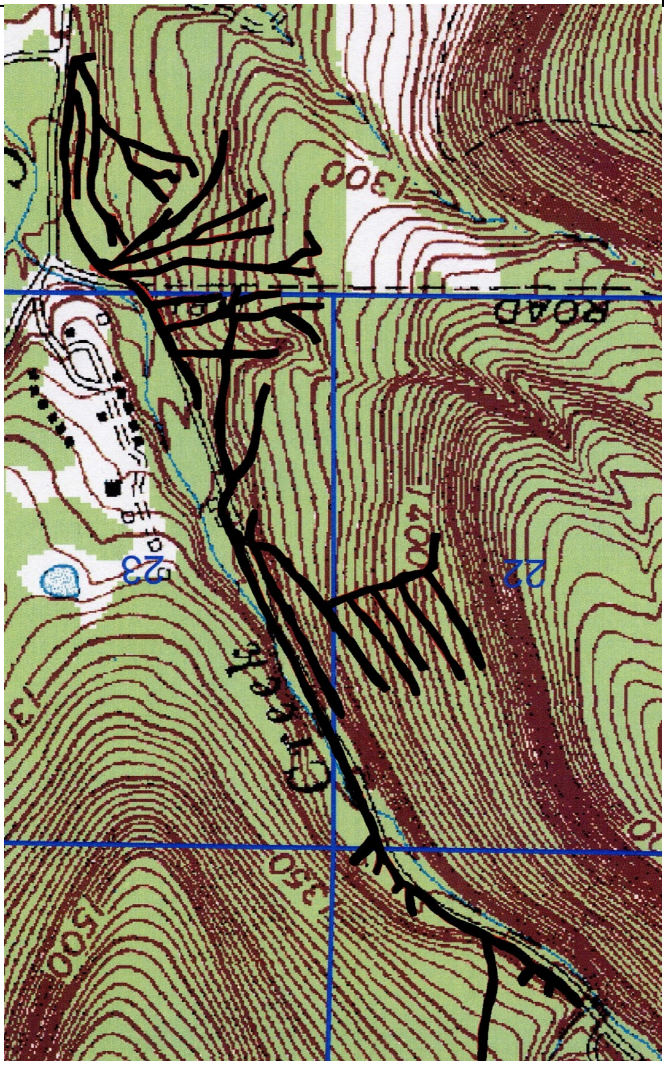
A maple tubing system is expensive and time consuming to install. Once installed it will likely stay as constructed for the next 10 to 25 years. Planning the system so that it will be efficient to maintain, easy to access the collected sap and result in excellent sap yield is of significant value. The location of the sugarbush and its topography dictate many of the system characteristics and many long term problems can be avoided with a well thought out plan. Here are just a few of the tools available to assist with developing your plan.



3.1 Planning Tools

This picture shows an existing maple tubing system. It includes several layers of helpful planning information. First there is an over head photo of the property showing buildings, roads and trees. Such photos can be helpful in thinking through a system layout and are generally available on line, as part of county soil maps, or at your local FSA office. Second there is a topographical map represented by the thicker black lines. These can also be helpful in planning with the understanding that there will be mounds and valleys important to your system which are too small to be reflected on the map. Third, the location of the main lines (no lateral lines), represented by the white lines with black edges, have been mapped using a GPS system. Such maps can be helpful when keeping track of maintenance and improvements over time.





3.2 Tubing System Configurations

Tubing can be laid out in different configurations. The first example above is like a tree with the mainlines following the lower ravines in the woods and lateral lines coming off on both sides. This can work well especially in woods with distinct valleys. When checking mainlines, however, the maple producer is constantly ducking or stepping over lines which can make for slow going and eliminates the use of a four wheeler or snow mobile. Setting main lines on a contour at even intervals of between 80 and 150′ and then always running the 5/16th lines up hill (as in the second example above) make for a system that is convenient to walk or ride next to for maintenance or pleasure. Often a combination of these styles is common as we see in the map of main lines at the right. This map is of the system at the Arnot Forest and was made by taking GPS readings at regular intervals on each main line then superimposing the data onto a topographical map.

Mainline set up on the contour, all lateral lines directed to the up hill side

3.3 Establish Main Collection Points

When establishing a maple tubing system there are several considerations to start with. First, channel as much sap directly to the sugar house as possible. Not having to move sap with a truck or tractor can save labor as well as investment. Second, design the system with sap ladders or remote pumping stations to move sap directly to the sugarhouse to save labor where direct flow to the sugar house is not feasible. Third, locate remote collection tanks where they can be easily accessed by truck or tractor . Where vacuum pumps or transfer pumps are part of the plan, site them where there is access to electricity. Finally, if none of the options listed above will make for an efficient tubing layout, placing the collection tank where it will collect the most sap the most efficiently and then building an access road for pick up may be your best option.

3.4 Designing a Mainline Network

Once the main collection points have been established the next step is to lay out a plan for main lines to access the maple trees. Main lines can often follow the natural surface drainage pattern in the sugarbush. Where the topography of the land allows the main lines should rise at a fairly even grade of between 2 and 6% slope. Lines with changing slopes will easily develop slugs of sap coming through the line which temporarily block the movement of air being pulled to the vacuum pump making the vacuum available at the tree inconsistent and lower than expected. It is generally considered better to have lateral lines be steep and mainlines more gradual to avoid slugs of sap. Consider how to make checking and maintaining the mainlines as efficient as possible when designing the system layout.

Section 4 Installing mainlines

Summary:
Once the collection points and the basic configuration of the tubing has been decided, the next step is to install the mainlines. Determine the distance between main lines. Using an eye level or slope gauge you set the slope with flagging or paint marks on the tree to mark out the slope of the main lines. Install the wire that suspends the mainline to the marked slope, secure the ends and install side ties. Then the mainline is pulled out and attached to the support wire. Hardware to assist with washing, draining, securing, connecting and maintaining lines is added next. Lateral lines would then be put in place before their connections to the mainline are installed.

4.1 Determine the distance between mainlines.
4.2 Flagging the mainline trail
4.3 Installing the mainline wire
4.4 Installing the mainline
4.5 Mainline hardware

4.1 Determine the distance between mainlines.

To determine the space to be left between main lines a couple of questions must be answered. How long do I want the lateral lines to be and how many taps would I like to average per lateral line. If the tubing system is set up like a tree as illustrated in the last chapter the distance between mainlines usually continues to get wider as the tubing goes further from the collection point. As the gap becomes too wide a branch will be added to the mainline to keep the length of lateral lines more reasonable. Many maple producers will simply pick a distance that they think is reasonable and add mainlines to maintain that maximum distance. Many producers limit the distance to between 70' and 150'. Long lateral lines offer a couple of potential disadvantages. First, sap moves slowly through lateral lines where leaks are well controlled and faster through the mainline. So very long lateral lines can allow sap to warm in the sun. Second, long lateral lines may restrict the vacuum from reaching the tap. Some very steep, leak tight lateral lines have been observed to add to the pull of vacuum. Generally it is observed that mainlines do a better job of extending vacuum capacity into the woods than lateral lines do.

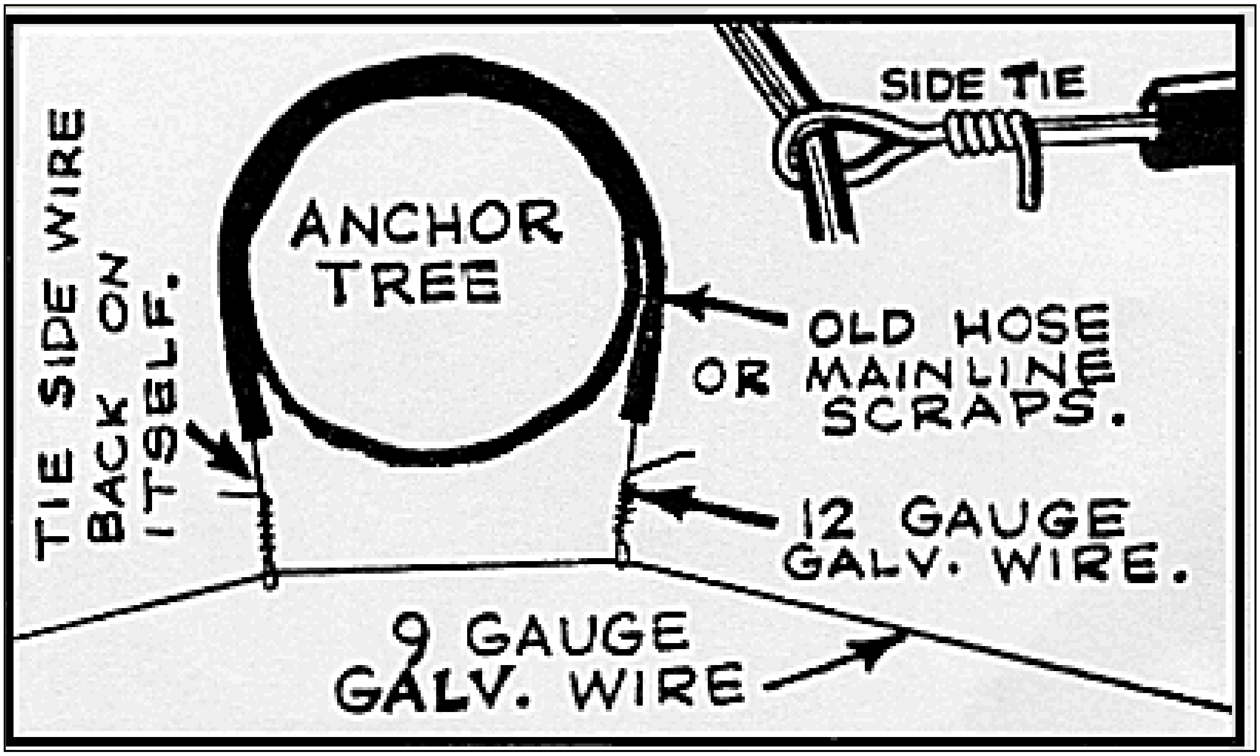
In a tubing system on a fairly even contour an experienced maple tubing installer may make a visual estimate of the density of the taps in the woods and make a reasonable estimate of the distance it will take to have between 5 and 6 taps per lateral line. The second mainline is then measured that distance uphill from the first and then adjusted to follow an even slope.

Another approach, especially for an installer with less experience, is to do a tap density measurement in the woods from which an average distance between trees in that section of the sugarbush can be calculated and used to set the distance. Tree density and number of taps per acre can be calculated by measuring out 26' 4" from a center point and marking a circle around the center point at that distance. This distance is the radius of a 1/20th of an acre circle. Count the number of tappable trees inside the circle and multiply by 20. Take several samples and then average the results to estimate the taps per acre. Number of taps can depend on tree size. Start with one per tree and add a tap for trees greater than 18 inches DBH. If areas of the woods differ significantly from others you would want to do separate density estimates for each area. Once you have estimates of average taps per acre and average taps per lateral line you can calculate how long these lateral lines will be.

For example, if a density evaluation is conducted and an average density of 120 taps per acre is determined, from this density the average distance between trees can be calculated. This is done by dividing the square footage in an acre of sugar bush by tap density. In this case 43,560 square feet per acre divided by 120 is 363 square feet. The square root of the 363 feet gives the average distance between two trees, in this case it is 19.1 feet. Use a calculator with a square root function for this. To determine the average length of a lateral line, multiply the average distance between trees by the number of taps you would like to average per lateral line minus .5. Where 6 taps per lateral line is desired, multiply by 5.5. Where 7 taps per lateral line is desired multiply by 6.5. For a 6 tap lateral line the lateral line includes the whole width for the first five trees on a lateral line but only half of the distance for the final tree on the lateral line. If you imagine each tree sitting in the middle of the 363 square foot area this makes sense. This makes the average lateral line 104.8 feet long in this example with 6 taps per lateral. It would be reasonable in this case to round that distance off to 100' or 110' as these are rough estimates not exact spacing.

4.2 Flagging the mainline trail

Mainline tubing is supported by a system of support wire and side tensioning wires. Using an eye level, an Abney level, laser level or a transit, set the elevations of the main line support wire using plastic ribbon down the intended path. Start at the bottom of the mainline and set the height of the main line support wire based on how high it needs to be to enter a tank, vacuum releaser or the sugar house. Next site a level line down the intended path and install a ribbon on a tree or shrub out 50 to 300 feet at this level line, with some estimation of the distance (either measure it, pace it or use a range finder) place a second ribbon on the tree that will give you the intended slope or final height of the main line support wire. If you are planning to have the mainline drop at 2% slope you need to place the second ribbon two feet above the level ribbon for each 100 feet of distance. If you were intending a 5% slope then you would need to place the second ribbon five feet above the level ribbon for each 100 feet. Now repeat this procedure as many times as necessary to get the whole mainline elevation set with the ribbons. You are then ready to set up the main line support wire to the height of the higher ribbon or use the procedure listed below. If using a more advanced tool that can be set to a specific slope, the flag to mark the level line will be unnecessary. If you use an Abney level, transit or a laser leveling device which can be set to the desired slope, the ribbon setting can be applied directly to the desired height on the marker trees without determining the level line. Slope does not need to be set to an even number like 2% or 4%, rather set the slope to stay as even as possible without the mainline getting too high to make tapping a problem or too low to where parts of the mainline may remain under snow because it is too close to the ground. One more point to consider when marking out the mainline trail. A well supported mainline will need to have side ties from both sides. The trail may be adjusted to the right or left to accommodate having trees fairly close by on both sides. Often this can be accomplished with minor adjustments as long as it is always being considered. Laying out the wire then discovering that this was not considered can be problematic.

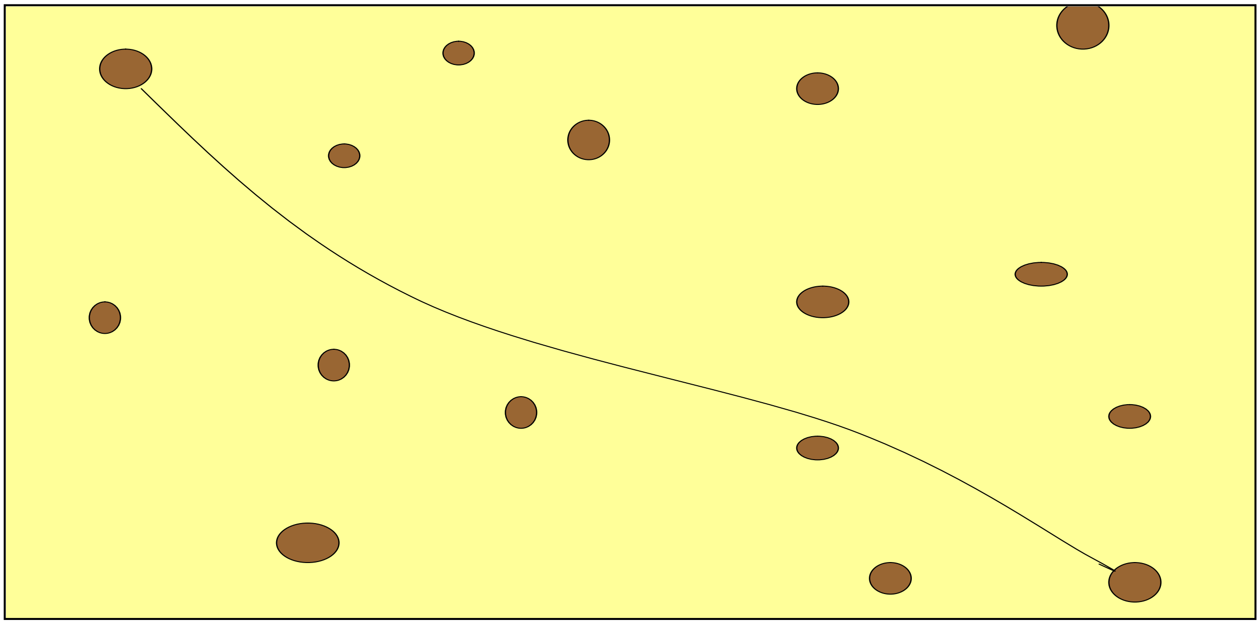


4.3 Installing the mainline wire

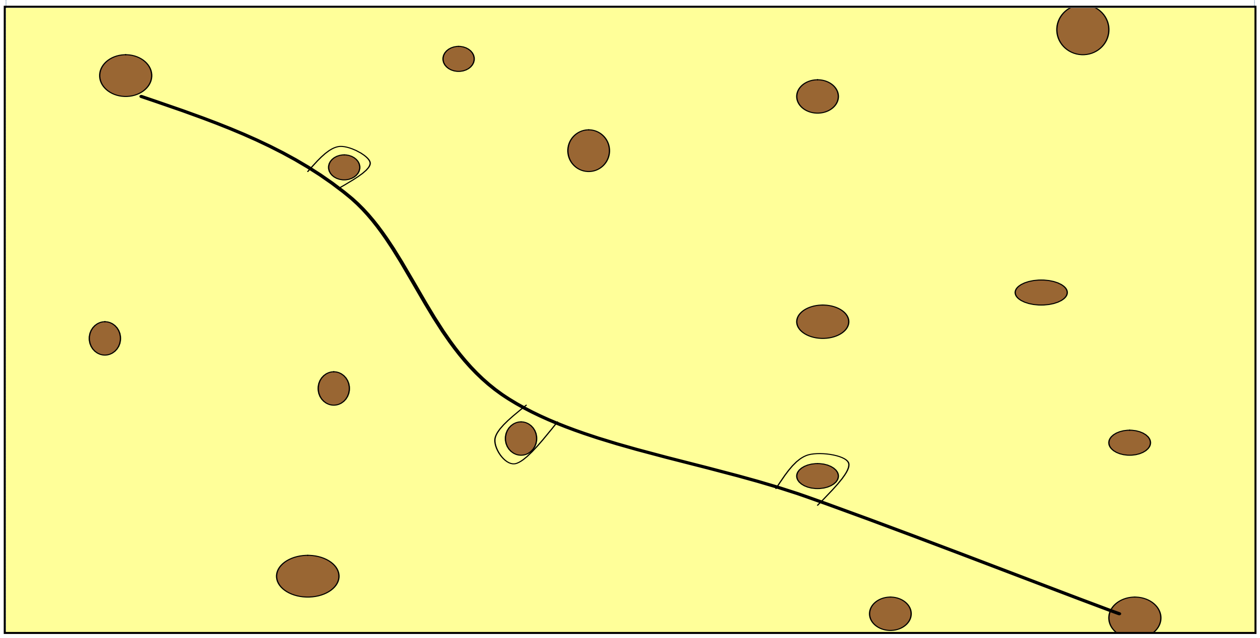
Installing the mainline wire requires the use of two different galvanized wires. #9 or #12.5gauge wire is used to support mainline tubing and #12 or #14 gauge wire is used to tension the mainline support wire with side ties. To make the installation go well the heavier mainline support wire should be placed in a spooler if not already on a spool that can be set up to rotate as the wire is pulled along the previously marked trail. A controlled unwinding of the wire from a spool as it is pulled along the trail solves the issues of kinks and tangles that can be time consuming, very aggravating, and create weak spots.

Both ends of the mainline support wire need a substantial anchor such as a tree or well-secured post. Wires can be tied around the starting and ending tree preferably something other than a maple. To tie the wire you will need a wire connecting device, or twist the wire by hand. A lag bolt with eye or a J can be placed into the tree to hook the mainline support wire. If wire is wrapped around a tree use wire protection such as tubing or rubber hose. This allows for some protection of the bark but this method has proven to be inferior to using a lag in the tree.

Wire should be connected to the end trees and pulled up at least hand tight or pulled up moderately with a tensioner, fence jack or wire puller but leaving enough slack so that the wire can be side tied to trees along it's path. Overly tight wires before installing the side ties will be more likely to break in the event of being hit by a falling limb or tree. Where the side ties provide more of the tension the main line wire is more likely to be pushed down or have some of the side ties break with are much more easily repaired.



The heavier gauge mainline support wire has to be tensioned to keep a uniform slope and eliminate sags. Start by tensioning pronounced curves first, by using trees on either side of the mainline support wire. The lighter #12 or #14 gauge support wires are used to tension the mainline support wire. It is tied around the main line support wire then looped around a tree and tied back around the main line support wire. Use plastic hose to run the wire through on the backside of the trees, this will protect the bark and allow for easy height adjustment. The advantage in using #9 or #12.5 high tensile wire for main line support and #12 or #14 wire for side ties is to give protection to the mainlines. In the event a tree or a branch should fall on the mainline the side tie wire should break, in most cases, avoiding damage to the mainline. When all support wires are installed and well tensioned it is now time for mainline installation.



Wire twist ties and twist tie tools

4.4 Installing the mainline

Mainline wires and tubing can be installed any time of year. In cold weather install everything very tight. In hot weather leave some slack and retighten if needed when it gets cold. Pull the mainline pipe through woods in the same path the main line support wire follows, staying under the main line wires at all times. Again pulling from a stationary spool or spooler will make this part of the project work much better than trying to roll tubing out. Secure the end of tube to the main line support wire by installing and clamping an end plug then clamping with the use of a standard stainless pipe clamp or with the side tie 12 gauge wire to the loop which secures the main line support wire to the tree.

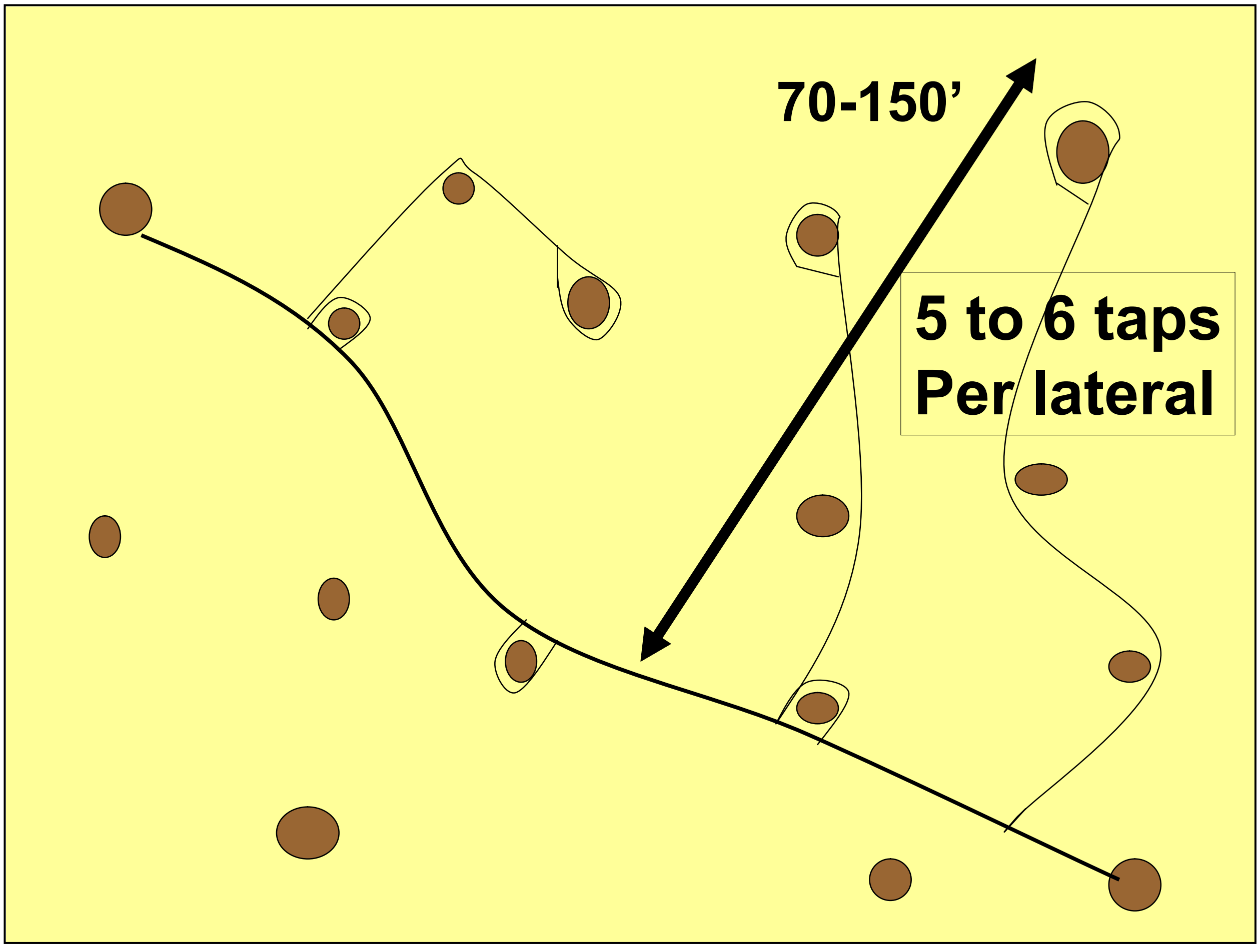
While pulling the mainline tight and working towards the opposite end, temporarily tape mainline to wire approximately every 8' to 10' apart or install a wire tie but do not make it too tight for the mainline to be able to move on the support wire.. After this is done one person is now able to install the wire twist ties every 10" to 18" apart. When attaching the mainline to the support wire keep the orientation of the two the same as much as possible. Allowing the mainline to at times be below the support wire and other times above the support wire will make an even grade impossible to maintain.

At the bottom end of the mainline take a 4" piece of tubing, slice and slip it over the tube near bottom of the tree. This is to double up the thickness of the line. Install 1 stainless steel clamp over the 4" piece and with a wire looped through the clamp tie to end wire loop or J in the lag in the tree, as done at the other end. This will help to hold the mainline tight and keep it straight as it expands with heat. The procedure for setting up a dry line tubing system is the same as described here. To avoid problems of crossing wires and pipes along the mainline path first install the dry line support wire, then the dry mainline followed by the wet line wire then the wet mainline. Boosters and other connecting hardware would be added last. The distance between these two wire and mainline systems depends on the method used to connect them.

4.5 Mainline hardware

Once the mainline is installed and secured to the mainline wire there are several other options to finish the line. The simplest is to finish the upper end by installing the appropriate sized plug. For the purpose of cleaning mainlines a valve may be installed instead. Many producers install a valve and then a plug in the end of the valve. When washing the plug would need to be removed and the valve opened. The plug provides an extra seal against vacuum leak. To assist with evaluating the maintenance needs of individual mainlines a vacuum gauge can also be installed at or near the end of the mainline. When a wet and dry line are the method used in the tubing system design additional hardware is needed to transfer vacuum capacity and sap flow to dual purpose mainlines and lateral lines. Many hardware combinations have been used to accomplish this function. This connection is typically called a manifold or booster. In many of the older wet/dry line installations the manifold was plumbed directly between the wet and dry line with PVC pipe and fittings. Though these performed well separating sap and vacuum and providing excellent capacity, they were somewhat expensive to build and were subject to breaking when the lines were hit with limbs or trees falling on the lines because there was no give in the manifold connection. Connecting the manifold to the mainlines with a short piece of tubing has proven to reduce this kind of breakage as demonstrated in the photo below. An even more durable method is to loop the connection to the dry line up one to three feet as well as over several feet to create a very flexible connection between the two mainlines with lower cost materials. Often maple producers will include valves and vacuum gauges in the manifolds to assist with cleaning and efficient maintenance of the system.

The tree in this picture shows some of the long term problems of trying to secure a mainline to a tree. Unprotected wire has cut and grown deep into the tree. The partly protected chain was better, but the protection needed to include all the contact surface between the tree and chain. The fully protected wire seems to be working better but if too tight and not moved at all over time can become grown in. The currently recommended end tree connection is in the upper left hand corner. A hook end lag bolt seen at the very top of the picture seems to offer the better solution for long term tree health.



Lateral lines should be installed in the woods next, but not the lateral line connection hardware to the mainline. The connectors or saddles that connect the lateral lines to the main line should be added after the lateral lines have been installed. It is important to have the connectors in the best place to input a lateral line without the line having to cover un-necessary distance.

When the length of a main line exceeds the length of your tubing roll a connection needs to be made. Connecting the main lines through heat fusion, electro welding or butt fusion is ideal. Mainlines are most commonly connected using a straight connector and the stainless steel clamps or bands. There are special tools made to accomplish the compression needed to push the tubing onto the connector that can make the work go with much less effort. The tubing can also be warmed in hot water or warmed with a portable torch. Heating with a torch can make pulling the connection together much easier but can make it difficult to reseal the connection if for some reason it needs to be pulled apart and reconnected in the future.

Section 5 Installing lateral lines

Summary:
The recommendations for how many taps to place on lateral lines have changed dramatically over the years. The materials used to make these lines and the variety of colors and flexibility have also changed. Lateral lines used to lie on the ground but now are suspended tree to tree. There is an extensive array of fittings that allows for a variety of lateral line installation styles. This section will not attempt to take an in-depth look at all the options but will attempt to provide a framework from which a maple producer can make reasonable decisions planning a system of lateral lines.

5.1 History of lateral line installations.
5.2 Installing lateral lines to the end tree
5.3 Basic rules for lateral lines
5.4 Connecting lateral lines to the mainline
5.5 Tools for installing lateral lines

Four wheeler loaded with tools and materials for installing lateral lines.

History of Taps per Lateral Line

- **1960’s to 1980’s First level gravity flow research suggested up to 80**
- **1980’s – suggested limiting to 35**
- **1990 Old Maple Manual – 25 on steep slopes and 15 on flat systems**
- **Late 90’s max of 10**
- **2000 and current recommendation 5 to 6**

5.1 History of lateral line installations.

Tubing systems have dramatically changed since the introduction of plastic tubing in the middle of the last century. Early systems had the main and lateral lines all staying on the ground where snow and ice could be a major hindrance to sap flow. Early systems were nearly always taken down and reinstalled each year. Many early systems were vented at each spout. Gradually, suspending systems with the mainlines on support wires and lateral lines held up with tension became the norm with many producers leaving the main lines up permanently. Most of these systems did not have vacuum and were looking to gain some advantage from gravity induced vacuum by keeping the lines full of sap. Many of these systems then had 25 to as many as 80 taps on a 5/16″ line. Many mainlines were 1/2″ or 3/4″. The chart above shows the fairly rapid reduction in suggested taps per lateral line. These changes were spurred on by the superior production experienced where mechanical vacuum was added and taps on lateral lines reduced. Research also has shown that closed systems yield better than vented systems. Where the system was designed to extend the vacuum capacity to the tree, yields increased by 100% or even as much as 150%. Now the common recommendation is for there to be 5-6 taps on a 5/16″ line for vacuum to be the most beneficial. Research at the University of Vermont has shown that the fewer taps per lateral line the better the yield per tap so that one tap per line gives the highest yield per tap. However the extra cost and the relatively small increase in yield from having less that 5 or 6 taps on the lateral line has led to the 5 to 6 tap per lateral line recommendation.

(left) End ring commonly used on the end tree, (middle) typical double tee method, (right) dead end loop fitting with straight through drop line to lateral line connection

5.2 Installing lateral lines to the end tree

The 5/16th lateral line ends by forming a loop around the end tree along with a tap. It is the loop on the end tree that allows the tubing to be suspended. There are a number of ways of accomplishing the loop and tap, each with it's own advantages and disadvantages. The method used in the picture above is probably the least effective. It is using one T to allow the tubing to go around the tree and a second T to connect the drop line to the loop. The disadvantage here is that sap can move into the loop around the tree and does not drain out cleanly. This then becomes a place where sap can ferment on warm days during the season. It can be a difficult area to get a good cleaning or rinse accomplished when cleaning the system.

There are Ts available that are only open on the front and one side connector. If two of these Ts were used correctly in the system shown above the sap would be eliminated from the loop and a fairly short path for the sap to travel from the drop line to the lateral line could be created. The third and most direct way is to use a connector like the one pictured in the smaller right side photo above. This connects the lateral line and the drop line directly and the loop around the tree is not open to sap flow. This kind of connector is generally more expensive than two Ts and can be more of a challenge to attach the loop tubing with some kinds of tubing tools. The other method commonly used uses one T which can be a T with one side closed off. A ring, like the left photo above, is placed over the lateral line and then plugged into the end of the lateral line after going around the tree. This is the least expensive method as the ring is less expensive than a T and the ring can be pulled along the lateral line allowing the tension on the lateral line to be adjusted.

5.3 Basic rules for lateral lines

For the best results lateral lines should be completely off the ground and suspended from tree to tree between 2 and 5 feet above the ground. The tubing is held there by keeping it tight between the end tree and mainline wire. Tubing must be tight and must always run down hill to the mainline to avoid creating sites in the tubing where sap sits and ferments, reducing the sap quality in the tubing system. Tubing that is suspended too low can be buried in the snow during years with severe winters. Lines under the snow will remain frozen during early runs preventing sap from trees further up hill from passing through. Suspending tubing too high can make it difficult and tiring to drill the tap holes so high. There is also some uncollectable sap left in the tree below those high taps during each run. Even the drop lines need to be arranged so that they only drain down hill. There should be no loops or traps where sap would not freely flow on down the line.

5.4 Connecting lateral lines to the mainline

The 5/16th lateral line is connected to larger ¾", 1" or larger main lines and directed to the sugar house or the collection tank. This connection can be made in a variety of ways but is most commonly done with an attachment saddle. A hole is drilled in the top of the mainline of the correct size to accommodate the saddle type you have purchased. Most saddles have a groove where the main line wire is to go. In the photo above the lateral line is first connected to a hooked connector that allows the lateral line to be very tightly connected to the main line wire. Then a short loop connects the lateral line and hooked connector to the saddle connector. This loop allows the mainline wire to take all the stress of keeping the lateral line tight to the trees and connecting to the saddle connector with nearly no pressure or connection stress on the saddle. In the picture above the location of the main line wire and the angle the saddle is positioned results in a slight rise in the loop. This can create a spot where sap will not easily drain out when the sap stops flowing during warm spells allowing a small amount of sap to ferment and add bacteria, yeast and invert sugars to the next run. When vacuum is used in the tubing system the loop into the saddle can be pushed down creating a small trap where it is easy to see if air is entering through a leak in the lateral line system. This loop allows for a quick check for leaks as you walk along the mainline.

5.5 Tools for installing lateral lines

There are a number of tools available from maple equipment suppliers or that could be created by the maple producer that make the job of installing lateral lines go much better. A spooler that hangs on the mainline wire is used to hold the roll of lateral line allowing the installer to pull the lateral line out from the mainline without having to carry the roll around. This method also dramatically reduces the chances that the line will kink and coil. In a fairly level woods the eye level can be use to assure the lateral lines follow an uphill grade from the mainline. The double vise tool, like the one in the upper right hand picture, allows the producer to install a T in the lateral line to connect the drop line at each tree or tap. The single vise tool like the one pictured in the lower right hand photo above works well to install the spout and T to a drop line. Either can be used to install end Y fittings, install plugs, hooked or straight connecters or end rings. Depending on the supplier of the main line attachment saddles and depending on if the saddles have one or two attachments, the choice of the best tool to attach lateral line to the mainline will vary. There are also tools for cutting lines from a T, drilling holes for saddles, removing taps and other miscellaneous tubing jobs.

The double vice tool being used to insert the drop line T into the lateral line

Section 6 The cost of installing a maple tubing system

Summary:
Managing costs is an important part of profitability in a maple business. Getting good estimates of what it will cost to install a maple tubing system can be important to seeking financing, estimating a payback period or just good enterprise decision making and management. The Cornell Maple Program has put together an Excel spreadsheet that can assist the maple producer in estimating tubing system installation costs. The spreadsheet is limited to estimating the cost for only the tapped area of the sugarbush. The cost of mainlines, releaser and the vacuum system that are not directly in the tapped section of the woods need to be calculated separately. By separating out these components a much more accurate estimate can be generated. The distance between the sugarbush and the vacuum pump and releaser will affect the sizing as well cost estimates dramatically so including them in the spreadsheet would have jeopardized the accuracy of the estimates. Prices of fittings, hardware, and tubing should be updated by the user to reflect their choices of supplier and styles. If a good estimate of tap density is accomplished in the prospective woods then the details of how many fittings, length of wire and mainline and lateral line will be very close and the cost will be as well. Installation cost for labor also is not part of this estimate. Additional research is needed to complete that part of the picture. This section explains how to use the spreadsheet. It is available at the www.cornellmaple.com Webpage. Click on publication and it is listed about 8 lines down and is titled “Excel spread sheet for use with the above article”

Evaluation of the costs when installing a maple tubing system.

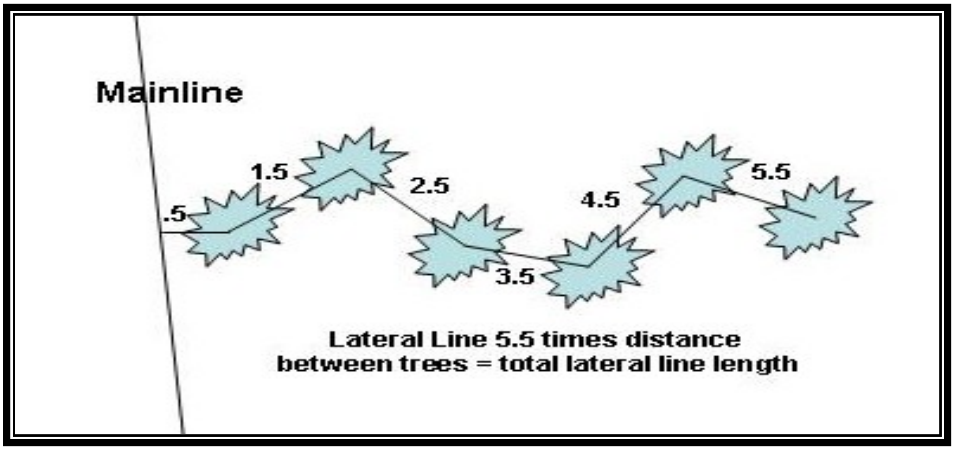
Stephen Childs, NYS Maple Specialist with Cornell University

An important part of beginning or improving the tubing system in a maple enterprise is to have a good estimate of just how much the project will cost. Though there are many variables in installing a new or replacing an old system, the basic cost of materials should be fairly predictable. To develop a good cost estimate first get an approximation of just how many trees and taps you have available and an estimate of how dense or close together the target trees are. These two factors allow you to make reasonable estimates of what a sap collection system will cost in materials. A valuation of tree density can be made in a prospective sugarbush by measuring out 26' 4" from a center point in a circle. This distance is the radius of a 1/20th of an acre circle. Count the # of tappable trees inside the circle and multiply by 20. Take several samples and then average the results to estimate the usable trees per acre. If areas of the woods differ significantly from others you would want to do separate valuations and estimate how big of an area the differing densities represented. If you don't have any idea how large a wood lot is, your county Farm Service Agency or Soil and Water Conservation Office may be able to assist you from aerial photos.

The calculations here will be based on one tap per tree, using 5/16th spouts, all main lines connecting the 5/16 lateral lines are 1" in diameter. This cost estimate will only include mainlines used to collect sap from the lateral lines within an acre. It does not include the mainline connections to the sugar house or collection tank. Those would need to be added based on total system size and distances. I decided not to include them in this sheet as putting in an automatic estimate of it would make the overall result much less accurate.

The number of taps you wish to have on the average lateral line is an important decision. Current recommendations suggest an average of 6 taps per lateral line works very well in most situations. The recommendation for the number of taps on a lateral line tries to balance the overall system cost vs. getting vacuum effectively to the tree. Research at the University of Vermont indicates that the fewer taps on a lateral line the more sap is yielded per tree. In the early days of tubing much larger numbers were suggested. Six taps seems to be a reasonable compromise.

Once there is an estimate of average trees per acre and it is determined how many taps will be installed per lateral line, we can estimate how long lateral and main lines will be. In this example we use an average density of 120 trees per acre. From this density we calculate the average distance between trees. This is done by dividing the square footage in an acre of sugar bush by the number of trees present in this case 43,560 square feet per acre is divided by 120 to grant each tree 363 square feet. The square root of the 363 feet gives us the average distance between two trees, in this case is 19.1 feet. Now to see the average length of a lateral line we multiply the average distance between trees by 5.5. 5.5 because we chose 6 taps per lateral line. The lateral line includes the whole width for the first five trees on a lateral line but only half of the distance for the final tree on the lateral line. This makes our average lateral line 104.8 feet long.



For the number of lateral lines in one acre divide the density of 120 trees per acre by the number of trees or taps per lateral line, in this case 6 giving us 20. Now determine the total length of lateral line by multiplying 20 lateral lines by 104.8 feet each for a total of 2095.8 feet. To calculate the total length of mainline needed to connect all of the lateral lines we multiply the total number of lateral lines in the acre by the average distance between trees as the average distance between trees will also be the average distance between lateral lines where we let the distance between lateral lines fall at its most efficient distance. This calculation sets the distance between mainlines as the average distance between 6 trees or 6 times 19.1 feet or 114.6 feet. If were decided we wanted the distance between main lines to be less and decided 80 feet would somehow be better, the lateral lines would stay the same 104.8 feet to capture the sap from 6 trees but the distance between lateral lines would become greater so we would be adding more main line to accomplish the same task. This would not in any way make this system more efficient. Lateral lines are the same length and we now would have more mainline to add to vacuum loss due to more air friction from air passing through more main line. At this given density, if we wanted mainlines to be closer than 114.6 feet we should consider reducing the number of taps per lateral line. This change would reduce total lateral line length in the acre by 38 feet and increase main line length by 76 feet.

To determine the length of 5/16 tubing that will go into uses other than lateral lines we multiply the number of taps by 2 feet to total the tubing used in drop lines. In this example we are using end Y fittings to end the upper end of lateral lines which also need about 3 feet of tubing to go around each end tree. This could be one place where a maple producer could use old lateral lines rather than new since sap never enters this part of the line. However at a cost of about $4 to $5 per acre to use new tubing for this loop, the labor to handle a separate batch of tubing may not be worth the effort to get old tubing to each of the end trees.

To determine the number of wire ties it will take to secure the mainline to the mainline wire, we assume a wire tie every 18 inches or dividing the mainline length by 1.5. Side tie wire to tighten and secure the main line is estimated at placing a wire tie every 30 feet and using an average of 5 feet of wire for each side tie. Protection for the side tied trees is needed but here we assumed old materials would be used. In this example side tie wire amounted to a little over 60 feet per acre.

Number of trees per acre (one tap per tree)	120
Number of trees per lateral line	6
Average distance between trees	19.1
Average length of a lateral line	104.8
Number of lateral lines per acre	20.0
Main line length per acre	381.1
Total length of lateral lines	2095.8
Length of 5/16 lines end tree loop (3' each)	60.0
Length of 5/16 in drop lines (24" each)	240.0
Number of wire ties (one every 18")	254.0
Length of side tie wire	63.5

Next we put a price on each of the materials needed.

Costs:		
Spouts - use spouts or stubs not both	0.39	$46.80
Stubs -use spouts or stubs not both, must include one kind of adapter	0.29	
Stub adapter - use adapter or check valve not both, must also include stub	0.21	
Check Valve adapter - use adapter or check valve not both	0.5	
Saddles, all single connect	2.95	$59.00
T's	0.24	$24.00
Y's	0.77	$15.40
Hooked connector	0.33	$6.60
Lateral end tree loop (leave this blank if you use old tubing here)	0.09	$5.40
Drop lines	0.09	$21.60
Lateral Lines	0.09	$188.62
Main Lines (1") Black use black or blue not both	0.383	$145.94
Main Lines Blue (1") use black or blue not both	0.42	
Main Line Wire same length as mainline	0.055	$20.96
Wire ties	0.014	$3.56
Wire grips estimated at 3 per acre	1.75	$5.25
Tree hooks estimated at 2 per acre	3.5	$7.00
Tensioners estimated at 1 per acre	5.95	$5.95
Side tie wire	0.07	$4.45
Mainline valves one on each end(1 for each 3 acres) brass plus fitting and clamp	52	$17.33
Total material cost per acre		$577.86
Cost per tap		$4.82

All of the prices are based on a 2009 catalogue and are subject to change and subject to variation depending on source. The first item is the spout. Listed first is the health or tree saver 5/16th inch spout. It would be used alone on the drop line. If a producer was planning to use the new check valve adapter or the regular stub adapter, the stub spout would need to be purchased along with one of these adapters. A T is used to connect the drop line to the lateral line on all taps that are not end trees. To get the number subtract the number of lateral lines listed above from the total number of taps and then multiply times the cost each. There is an end Y and a hooked connector for each lateral line again times cost each.

Next the total length of 5/16th tubing from lateral lines, drop lines and end tree lines is multiplied by the cost of 5/16th line at 9 cents per foot. The price for mainline per foot was based on purchasing the largest rolls listed and calculated out to a per foot cost. The chart includes a place to figure either black or colored mainlines, choose one or the other or use the chart to compare costs. The mainline wire is based on purchasing a 2000’ roll of 12.5 gauge wire priced out on a per foot basis. We calculated the number of wire ties above, now we multiply that times the calculated cost each. Finally, we advise having a shut off valve where a mainline that connects to the lateral lines meets the main line that connects a number of mainlines and the holding tank or sugar house. We also recommend a valve at the upper end of this mainline. These valves can be very helpful when washing mainlines and when finding and solving vacuum leaks in the line. Here we estimated that the system would need one valve for each 3 acres of installation.

Now we can sum up all of the material costs for a total per acre and divide this by the number of taps. This will give the material cost per tap for the tubing system only on that given acre. Remember this number does not include the mainline needed to transfer the sap to the holding tank or the sugarhouse. It does not include the costs of a releaser, vacuum pump or other components related directly to the vacuum system. All of those costs will vary significantly depending on the size of the whole system and the distances between the woods and the rest of the collection and vacuum system. These other costs can be estimated in a fashion similar to what we have done here once the additional information is provided.

Now that you see how the calculations are done, provided below is second example of how the costs work out on a woods with less tapable maple per acre.

Number of trees per acre (one tap per tree)	50
Number of trees per lateral line	6
Average distance between trees	29.5
Average length of a lateral line	162.3
Number of lateral lines per acre	8.3
Main line length per acre	246.0
Total length of lateral lines	1352.8
Length of 5/16 lines end tree loop (3' each)	25.0
Length of 5/16 in drop lines (24" each)	100.0
Number of wire ties (one every 18")	164.0
Length of side tie wire	41.0

Costs:		
Spouts - use spouts or stubs not both	0.39	$19.50
Stubs -use spouts or stubs not both, must include one kind of adapter	0.29	
Stub adapter - use adapter or check valve not both, must also include stub	0.21	
Check Valve adapter - use adapter or check valve not both	0.5	
Saddles, all single connect	2.95	$24.58
T's	0.24	$10.00
Y's	0.77	$6.42
Hooked connector	0.33	$2.75
Lateral end tree loop (leave this blank if you use old tubing here)	0.09	$2.25
Drop lines	0.09	$9.00
Lateral Lines	0.09	$121.75
Main Lines (1") Black use black or blue not both	0.383	$94.21
Main Lines Blue (1") use black or blue not both	0.42	
Main Line Wire same length as mainline	0.055	$13.53
Wire ties	0.014	$2.30
Wire grips estimated at 3 per acre	1.75	$5.25
Tree hooks estimated at 2 per acre	3.5	$7.00
Tensioners estimated at 1 per acre	5.95	$5.95
Side tie wire	0.07	$2.87
Mainline valves one on each end(1 for each 3 acres) brass plus fitting and clamp	52	$17.33
Total material cost per acre		$344.69
Cost per tap		$6.89

A spread sheet is available in Excel format to actually do all of these calculations for you. You need to provide a good estimate of your forest density as described earlier in this article and the desired number of taps per lateral line. It is a great tool to compare how costs and distances change with changes in these details. It comes loaded with the 2009 material prices but you can also adjust these depending on your supplier or other ways you may choose to change your set up. It is available at no cost from the Cornell Maple Program at cornellmaple.com

Estimating Taps Per Acre Using the Angle Gauge

Summary

Maple producers may wish to estimate the potential number of taps per acre to assess the productive capacity of an area, and to aid in estimating the costs for installing tubing systems or buckets. Once you know the number of taps per acre, you can compare sites and estimate costs using the tapping and tubing cost estimator available at www.CornellMaple.com (look at publications" and then "tools"). Two methods allow producers to collect data that estimates the number of taps. One method uses a tape measure to establish 1/20th acre plots as previously described. The other method uses an angle gauge to estimate the number of taps per acre from a series of sample points. Both methods are valid and useful, but use different mathematical principles. The data will be recorded and tabulated using the table at the end of this article. Use three to five sample points for each area of the sugarbush that has very similar characteristics of trees size and stand density.

Variable Radius Plot

An **angle gauge** is the tool used to determine which trees to measure when using this variable radius plot method. Using this method makes measuring out the plot area unnecessary saving significant time. Using the angle gauge a maple producer can quickly identify the trees that are in or out of the plot. The angle gauge must be held a fixed distance from your eye for it to work properly and the surveyor's eye is kept over plot center or "the point" when using an angle gauge.

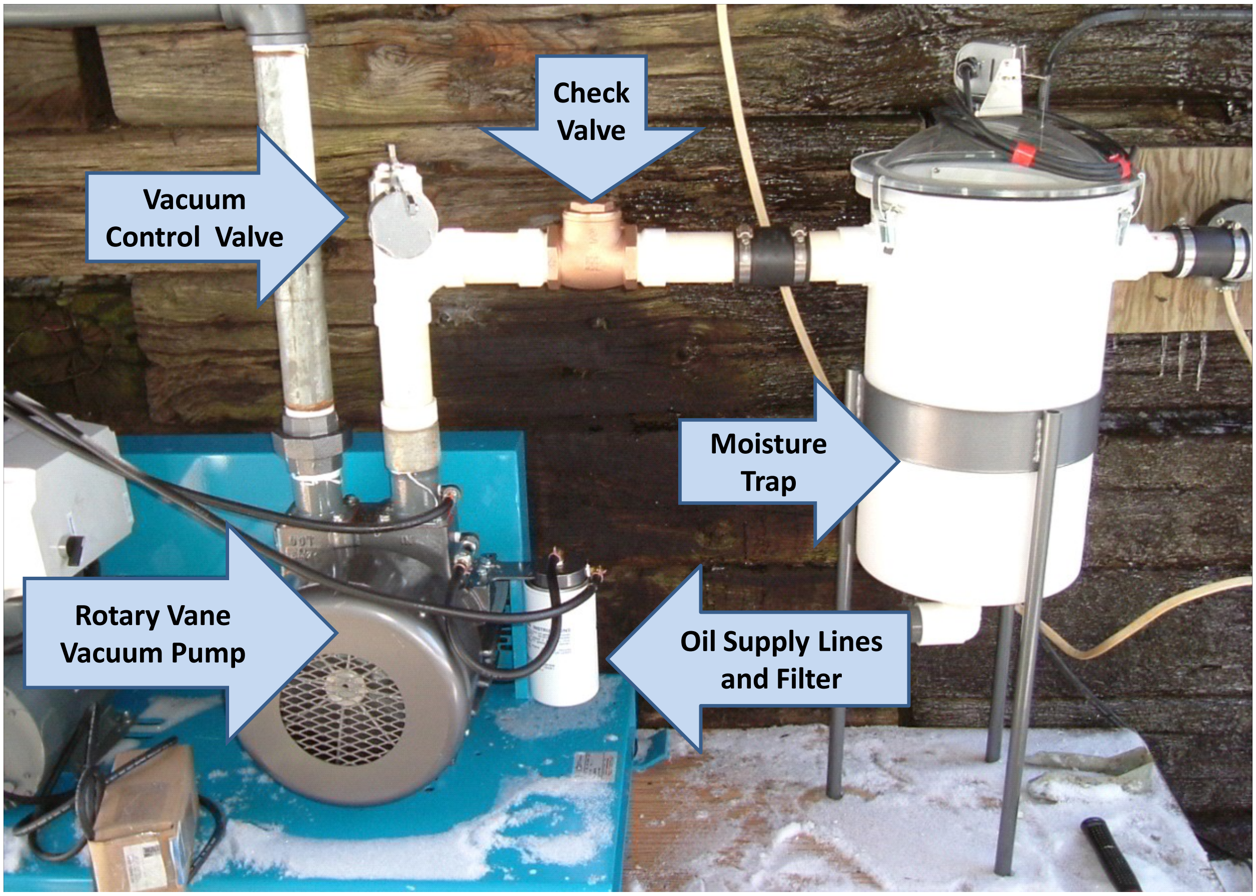
When using an angle gauge the user must count trees that are large enough to fill the width of the angle gauge window, as viewed from the "point", the center of the plot. Randomly select a spot in the sugarbush. At this spot, called the point, hold the angle gauge at arms length, at eye height, 25" or as prescribed by the manufacturer from your eye as demonstrated in the photo-graphs. Many angle gauges have a string or chain that lets the user know the set distance. Keeping your feet on the same point rotate your whole body 360º or in a complete circle while you identify which trees fill the gauge window while in the 10 BAF direction. Having a second person measure each tree as they are identified can make this project even easier. Ignore all trees that do not fill the window no matter how big they are. Each angle gauge is set at a certain basal area factor, or BAF, the table below is calculated to use with the 10 BAF window. Each tree that fills the gauge window is in the plot and needs to be measured and added to the tally.

Use the angle gauge at each point to count all red or sugar maple trees that fill the 10 BAF window and record them as TPP or "taps per point". In the table, assign each tree to the appropriate DBH class by having a second person measure each in or window filling tree with a circumference tape or tree scale stick. Place a dot or dash in the box under the appropriate DBH category for each tree that filled the window when inspected at 4.5' above ground. For each point on the table, multiply the number of taps per point (TPP) in each DBH category by the "tree per acre" multiplier (*TPA), the average of each DBH category. *TPP* *(times)*TPA equals taps per acre for that DBH category*. Sum a row of TPA= to estimate taps/acre. Finally, sum and calculate average for all the points to find the average taps per acre to the section of sugarbush included in this evaluation. For example from one plot point as you rotate the full 360 degrees you identify 2 trees between 10 and 11.9 DBH, 5 trees 12-13.9 DBH and one tree 18-19.9 DBH. In the DBH category 10-11.9 place two dots under that category and beside the TTP box. Multiply this by the 15.2 and list 30.4 in the TPA (Taps per acre) box. Under 12-13.9 mark 5 dots in the TPP line and multiply the 10.8 times 5 and list 54 in the TPA box. Under 18-19.9 place one dot and multiply times the 5.1 multiplier and list 5.1 in the TPA box. Add all the TPA boxes for an estimate of 89.5 taps per acre at this point. Continue with 2 to 4 more points in similar woods to get a more complete estimate.

		DBH Category											
		10-11.9	12-13.9	14-15.9	16-17.9	18-19.9	20-21.9	22-23.9	24-25.9	26-27.9	28-29.9	30+	Sum
POINT	**TPA >*	*15.2*	*10.8*	*8.1*	*6.3*	*5.1*	*4.2*	*3.5*	*2.9*	*2.5*2*	*2.2*2*	*1.8*2*	
1	TPP												
	TPA =												
2	TPP												
	TPA =												
3	TPP												
	TPA =												
4	TPP												
	TPA =												
5	TPP												
	TPA =												
6	TPP												
	TPA =												
7	TPP												
	TPA =												
8	TPP												
	TPA =												
Average	TPA												

Section 7 Installing Vacuum

Summary: To add vacuum to a maple tubing mainline system requires a vacuum pump along with several additional pieces of equipment and hardware. First, you need to separate the vacuum pressure from the sap. This is commonly accomplished with a releaser or extractor or by having a sap holding tank that can tolerate vacuum pressure. Most vacuum pumps need protection from having sap enter the pump. There is a variety of equipment designed to accomplish this protection but it is most commonly done with a moisture trap installed between the vacuum pump and the extractor. Most systems would want to include a vacuum pressure control valve and one way valves to reduce back surging in the tubing system during break downs or shut down. Many vacuum systems include automated electronic systems that turn the system on or off based on weather conditions suitable for sap collection. Some kinds of vacuum pumps also need to be fitted with specific equipment to recover oil or to supply cool water. Each of these components should be considered when planning for a successful vacuum installation.



Vacuum advantage

Research has shown that adding vacuum to a maple tubing system can increase sap production 50% to over 200% over a maple season. The higher the vacuum pressure at the tree the greater the yield response. Research has also shown that vacuum does not significantly alter the level of sugar and minerals in sap. Vacuum does not cause identifiable damage to the tree. To accomplish these positive results, a vacuum and tubing system must be properly planned and installed. Information on sizing the vacuum pump and sizing and installing mainlines to match the number of taps and site conditions are covered in sections 12 and 13.

Types of vacuum pumps

Choosing a vacuum pump is an important step. Each kind of pump has its benefits and drawbacks. The specific capacity and limitations of each kind of pump can also vary significantly between different manufacturers. The dealer or manufacturer's representative should be able to provide the potential purchaser with details about a pump's performance at various vacuum levels, its durability and price so that appropriate comparisons can be made. Several types of vacuum pumps have been commonly used by the maple industry including rotary vane, piston pumps, diaphragm pumps and liquid ring. Rotary vane and piston pumps must have a continuous supply of oil. Letting the oil run out will cause damage to the pump. Liquid ring pumps must have a steady supply of oil, water or water and anti-freeze in order to function properly. Oil recovery systems connected to the exhaust side of the vacuum pump have been proven effective. Oil based vacuum pumps have less concern with placing the pump where the temperatures commonly fall below freezing. Liquid ring pumps are often capable of reaching higher vacuum levels but need a system in place to supply water (where freezing is a major concern) or anti-freeze (where freezing is not such a concern but anti-freeze recovery can become important). Variable drive systems can be used to reduce energy use and equipment wear in a vacuum system. Whatever kind of vacuum pump is selected, take the time to become very familiar with the details of operating that pump. When using a gas powered vacuum pump be sure to understand the rpm of the engine necessary for the pump to operate at its rated capacity. Idling a pump that requires a much higher rpm to be at rated capacity will not result in the desired performance.

Vacuum pump location

The noise produced by a vacuum pump should also be considered when locating the pump. A vacuum pump in the sugarhouse can be convenient for protection and maintenance but can make so much noise that it is very obnoxious there. For this reason many vacuum pumps are located in a closable side room, outside or in a remote pump house. . It is also important that the exhaust air from the vacuum pump not be pulled into the intake air stream of a bubbler or any air injection system. This could cause serious off flavors to be imparted to the syrup. Exhausting the vacuum air into a closed room can at times fill the room with oil vapor or oily smoke which should not be inhaled by sugarhouse workers. Vacuum pumps run on electricity will require significant electrical service. Locating the pump in close proximity to the electrical service can be helpful.

Moisture traps

A device to trap any moisture in the vacuum line, and protect the pump from a failure of the extractor must be installed between the vacuum pump and the extractor or releaser. Most vacuum pumps are not made to handle anything but air flow and a liquid flow into the pump can be damaging. It is common for a relief valve or a pressure control valve be installed at the vacuum pump. A pressure control valve will allow you to set the vacuum pressure at a level that works well with your vacuum pump. Running the vacuum too high for extended time with a rotary vane or piston pump can cause them to over heat and burn oil. The control valve allows just the right amount of air to enter next to the pump to hold a steady vacuum. If there are leaks in the tubing system holding the vacuum level down, the control valve will remain closed and not take away from the pump's capacity

Typical moisture trap, pressure control valve and one way valve

Controls

A vacuum pump can be equipped with sensors that will turn the pump on or off when the weather conditions are right for those changes. This can be especially helpful when the sugarhouse or pump house is not in the common traffic area of the producer. There are other options available that will allow a maple producer to control or at least be notified of the vacuum pumps status from remote locations. These options can increase the efficient use of a maple producer's time, especially where a number of systems are being managed by one person.

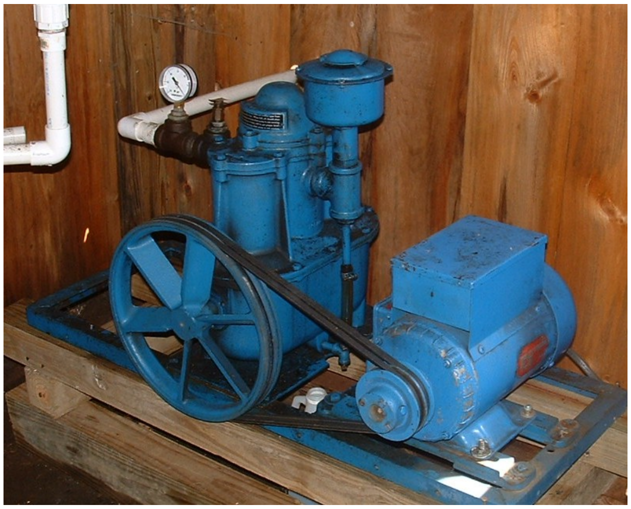
Locating a one way valve between the vacuum pump and the sugarbush can moderate vacuum surges in the tubing system when the vacuum pump is shut down or fails during operation. Surges in the tubing system can drive sap that has become contaminated with bacteria and yeast in the tubing system back into the taphole. This contamination of the taphole has been associated with reduced yield as the hole becomes plugged with the microbe growth. A one way valve must be large enough so as to not restrict the airflow between the pump and sugarbush. An undersized valve could eliminate a significant part of the pump's capacity to pull from the tubing.

Extractors

The extractor, or releaser, or dump unit collects the sap from the mainlines and allows it to be directed to a collection or holding tank without disrupting the vacuum. This is accomplished several ways. A mechanical extractor has two containers where the vacuum is present. When sap triggers a valve the vacuum is shut off and air allowed to enter the space where most of the sap has collected allowing it to push out through a flap valve by gravity while the second space in the extractor maintains vacuum on the lines. This can all be accomplished with the power provided by the vacuum and gravity. A similar extractor can be set up where the valves are controlled by sensors and electricity.

A second type of extractor is connected to a liquid pump so when the sap reaches a given depth, a sensor turns on the pump and the sap is pumped out of the extractor. Where a pump is used a small vacuum line must also be connected to the exit side of the pump so that the pump is not pulling against the vacuum when pumping. Pumping against the vacuum would seriously reduce the capacity or even over ride the ability of the liquid pump to move the sap from the extractor. Extractors come in a variety of sizes. A vacuum gauge is a must at the releaser, this is an important place to know how the system is functioning. Under sizing the extractor unit can reduce the vacuum capacity of the system. See the section titled bottle neck evaluation for more information on this topic.

In place of an extractor, some maple producers use a sap collection tank that can withstand the vacuum pressure . Most tanks cannot. The vacuum pump is set up to pull vacuum in the collection tank and the mainlines are connected to the top of the collection tank. The ends of the mainlines must not be below the sap level in the tank or no vacuum will be developed in the tubing system. The sap is then pumped from the holding tank as needed to supply the evaporator or at some point the vacuum is shut off so the tank can be emptied by gravity. One drawback of this system occurs where the vacuum pump is mounted directly on the holding tank. This seems to warm the sap in the tank leading to degraded sap quality. Especially if significant time is involved.

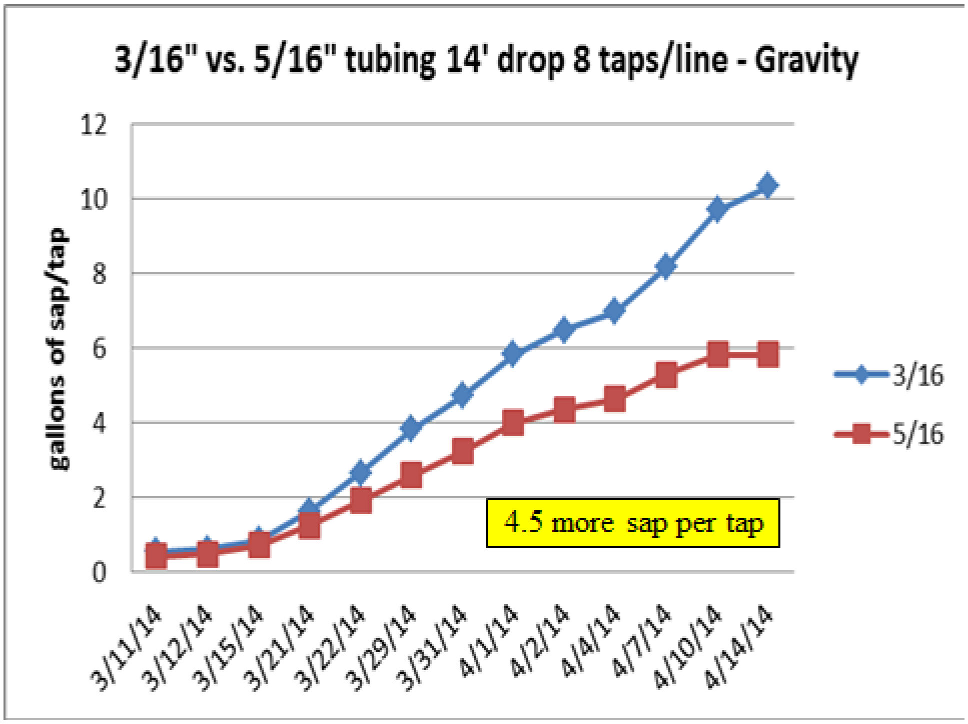


Section 8 Natural Vacuum Using 3/16" Tubing

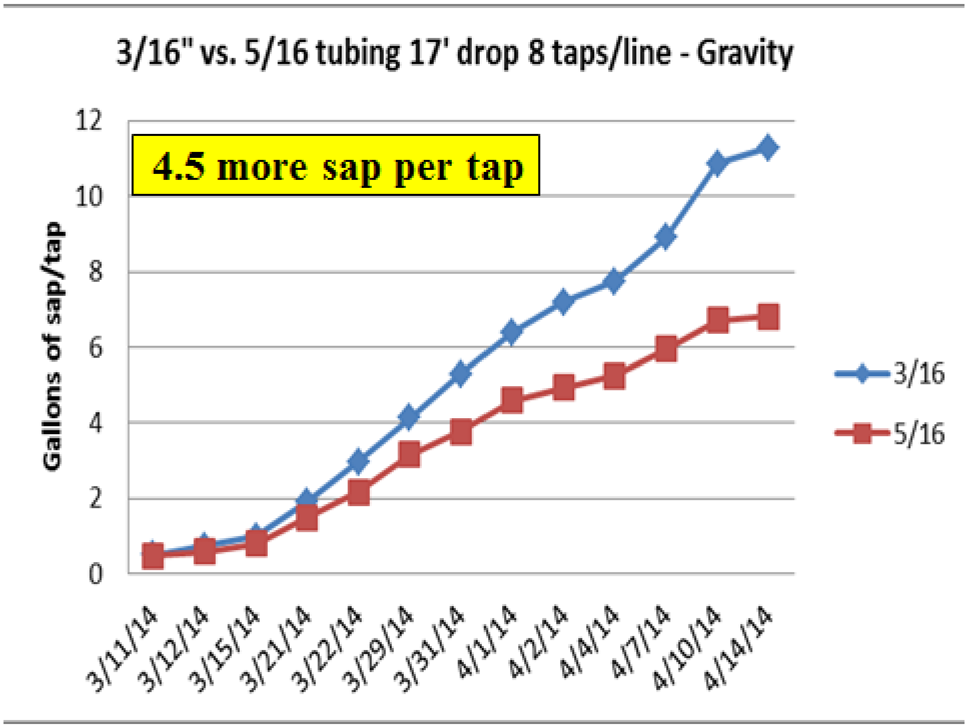
Cornell Maple Program tests on 3/16" maple tubing
By Stephen Childs, NYS Maple Specialist

During the 2014 maple season the Cornell Maple Program conducted three demonstration sites using 3/16" maple tubing. Each demonstration site was set up in the month of February and tapped the last week of February. The first sap run occurred on March 10th. The demonstrations were set up to compare sap yield from a new 5/16" lateral line with 8 taps using 5/16" standard black check valve spouts on new 5/16" drop lines with sap yield from a new 3/16" lateral line with 8 taps using 5/16" standard black check valve spouts on a new 5/16" drop lines for 8 inches then fitted to 3/16" drop line.

Eight trees were tapped in each demonstration with the two treatments tapped in the same tree, about 7 inches apart, in the same basic orientation. The first demonstration had 14' of drop from the highest tap on the highest tree to the top of the collection tank. Sap yield was collected following each run starting on March 11th. The graph below shows the sap yield difference between the 5/16" lateral line and 3/16" lateral line each with 8 taps in gallons of sap per tap. The 3/16" lateral line yielded 10.3 gallons of sap per tap over the season and the 5/15" lateral line yielded 5.8 gallons of sap per tap or an increase of 4.5 gallons of sap per tap.

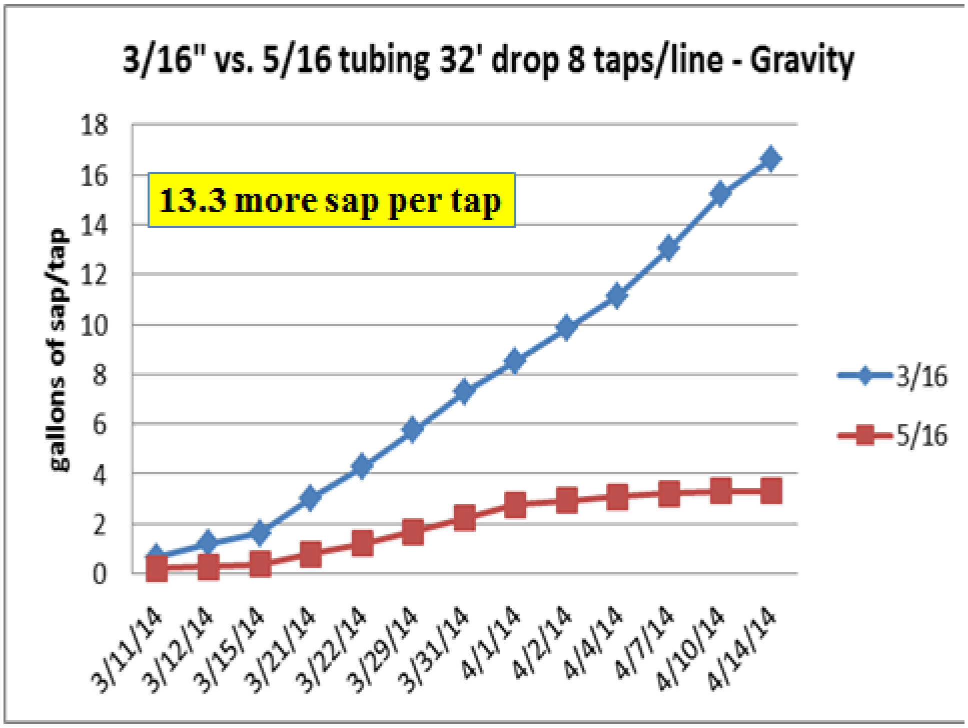


The second demonstration was set up exactly like the first except with 17 feet of drop from the spouts on the highest tree to the top of the collection tank. The graph below illustrates the results of this demonstration and showing a very similar increase of 4.5 gallons of sap per tap.



The third demonstration was again the same set up as the first and second except with 32 feet of drop.

In this case the vacuum created by the 3/16" lateral line appears to have stolen sap from the spouts hooked to the 5/16" line with the 3/16" line yielding 16.6 gallons of sap per tap while the 5/16" lateral line yielded just 3.3 gallons of sap per tap for a difference of 13.3 gallons of sap per tap more in the 3/16".



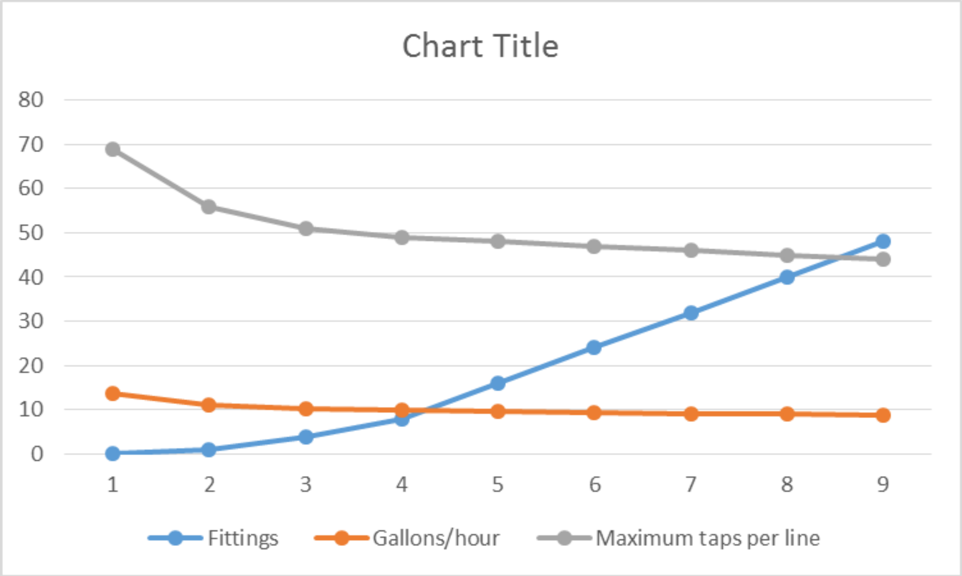
Results from this kind of demonstration create many new questions such as how many taps are needed on a 3/16" line to result in good vacuum and how many taps can a 3/16" line support. This demonstration demonstrates that 8 taps is sufficient to generate significant vacuum though vacuum tests were not included in this demonstration. It was simply a yield comparison. Testing the number of taps necessary to generate excellent vacuum will need to be conducted during the maple season as testing that with a simulated set up would generate many more questions.

To try to answer the question of how many taps can a 3/16" line support, a series of experiments were conducted in the summer of 2014. A site was located where we had easy access to the top of the elevation and a drop of 35’ was measureable. Water was transported to the site in 15 gallons jugs. 270’ of 3/16” maple tubing was laid on the ground to obtain the drop of 35’ on about a 13% slope. The line siphoned water from the jugs to establish the volume of water that could be conducted through the 3/16” lines over time. A vacuum gauge was plumbed in at the top of the line to measure vacuum pull on the line. Fittings were added to the line in increments to assess how adding T’s would influence the flow level. The flow rate of .2 gallons of sap per hours per tap is used to estimate how many taps the 3/16” tubing could support. The first chart below indicates just how many fittings were in the line, followed by how much water was siphoned through the line per hour, followed by the number of taps the 3/16” line could support if taps were contributing .2 gallons of sap per hour. The next column lists the number of leaks in the line and the vacuum measured at the top. The number of taps that the calculations say can be supported is much larger than I would have anticipated ranging between 47 where 24 fittings were in the line to 56 where only a fitting for the vacuum gauge was in the line.

Flow rates of 3/16 tubing at various number of fittings

	gallons per hour	taps supported	leaks	vacuum at top
1 fitting	11.2	55.8	0	24"
4 fittings	10.2	51.1	0	24"
8 fittings	9.8	49.0	0	24"
16 fittings	9.6	48.1	0	24"
24 fittings	9.4	46.8	0	24"

By graphing this data we can estimate what the flow rate would be when putting more fittings and taps on the line. The graph below would estimate that a maximum number of fitting and taps comes together at about 45 taps per line. This would suggest that if you had excellent flow conditions the line could support up to 45 taps before resistance in the line would cause the vacuum to drop in the tubing system. It is important to note that this is with 35” of drop on a 13% slope. The chart will change with either a change in drop or a change in slope and should only be used as an example.



Data points	Fittings	Gallons/hour	Maximum taps per line
1	0	13.8	69
2	1	11.2	56
3	4	10.2	51
4	8	9.8	49
5	16	9.6	48
6	24	9.4	47
7	32	9.2	46
8	40	9	45
9	48	8.8	44

It is important to recognize that it is not necessary to have many taps on the 3/16” line to develop the vacuum. In these tests 8 taps per line generated excellent vacuum. I’m not suggesting producers consider going to such high numbers but it is interesting that it appears the line can support them. From a line maintenance perspective it is a significant benefit to have shorter lines when seeking to find and fix leaks. The 3/16” tubing systems need to be kept leak free if they are to yield the added benefit.

The remaining factor that was tested in 2014 was the influence of leaks in a 3/16” tubing system. To look at this, leaks were created in the line as it was siphoning water from the jug at the top by drilling several 1/16” holes in the line. The first hole was drilled 20’ of elevation below the tank, the second hole 10’ below and the third hole 5’ below the elevation of the water tank. The leaks both reduced flow rate and significantly reduced vacuum at the top. As suspected leaks will significantly reduce the vacuum advantage provided by the 3/16” tubing. A 1/16” hole is very small compared to the average squire damage typically seen in maple tubing systems.

Flow rates of 3/16 tubing at various leak rates				
no fittings	13.8	68.8	0	24.2"
no fittings	12.6	63.1	1	16"
no fittings	10.9	54.5	2	11"
no fittings	10.3	51.6	3	5"

In the fall of 2014 two demonstration plots were set up. One with 47’ of drop and one with 34’ of drop. Vacuum gauges were installed on every other tap to observe the influence of location in the line on the level of vacuum at the tap. The line with 47’ of drop consistently showed 27” of vacuum on the top tap with declining vacuum at each gauge depending on the elevation drop below that tap. The bottom tap, right next to the end of the line showed 0” vacuum. With the 34’ of drop the top tap showed 24” of vacuum. These reading were consistent even when the sap was frozen and when there had been no freeze of several days.

During the 2015 maple sap season the Cornell Maple Program conducted a small trial of sap yield from 5/16” tubing vs. 3/16” tubing. This trial was not conducted at the Arnot Research forest but with a small maple operation cooperator. The tubing system consisted of six lateral lines, three 5/16” and three 3/16” alternating between the two treatments across the hill side. The lines were set up on a previously untapped forest with a north facing slope with tapped trees ranging from 10” to 19” in diameter. Each line had between 8 and 11 taps per line and averaged about 220 feet in length. The slope of the woods was very consistent with a drop of about 23’ from the tops of the lines to the collection tanks. The three 3/16” lines had a total of 32 taps and the 5/16” lines had a total of 26 taps. The spouts were all new black 5/16” plastic with 3/16” fittings for the 3/16” tubing and 5/16” fittings for the 5/16” tubing. Trees were tapped on March 11, 2015 in deep snow. The total yield per tap with the 5/16” was 11.25 gallons of sap per tap and the yield from the 3/16” tubing was 18.2 gallons of sap per tap. There was one problem with the collection tanks used as on several occasions the tanks collecting from the 3/16" were running over when the cooperators arrived to collect the sap. The 5/16" tanks did not have this problem. Sap collection was finished on April 9th. The installation time for setting up the 3/16" lines verses the 5/16" lines was identical. The yield difference between the 3/16" setup and the 5/16" set up is at least 6.95 more gallons of sap per tap or an increase of 62%. That would represent a little more than an increase of one pint of syrup per tap or a total increase of four gallons of syrup from the 32 taps. A special thanks to Bob Beil, Gordon Putman, Dave Norton and the Upper Hudson Maple Producers for their support for this study.

Further Questions and Answers on the installation of 3/16" tubing

Should 5/16 tubing be replaced with 3/16 tubing in current tubing systems?

Where there is fall of 15 feet or more and at least a 6 to 10% slope it seems obvious from research conducted so far that sap yield would be increased in both gravity and mechanical vacuum systems. Before I would recommend using 3/16 at less slope or less drop I would want to see it tested with several year of research.

How many taps should be the goal on a 3/16 tubing system?

The research above would indicate that up to 30 to 40 taps can be place on a line with more than 10% slope before the sap flow would exceed the tubing capacity. There is no need to put more than 3 or 4 taps on a line as that seems to produce enough sap to create the desired vacuum. When seeking to solve leaks the shorter the lines the more efficient the search within reason. I would rather find where a leak is on a ten or twelve tap line vs. a 40 tap line. Installing a system that is easily maintainable is more important than if the tubing can handle the sap load.

How can vacuum be maximized in a gravity 3/16 tubing system?

In the 3/16 system the vacuum at the tap is directly related to the elevation drop of 3/16 tubing that is filled with sap below that tap. So taps near the top of the system have the best vacuum and taps near the bottom may not have much vacuum at all. To get more vacuum on the taps in the middle and towards the bottom is to extend the 3/16 tubing on down the hill to get as close to 35’ of drop below the lowest tap to get maximum vacuum on all the taps. These can give the better yield from all taps but the trade off in the increased exposure to wildlife and other damaging factors and extra hiking when seeking for leaks. For each inch of vacuum increase at the tap the usual result is 5 to 8% increase in sap yield. So the decision is easier maintenance or some reduction in yield. Conditions in a sugarbush should help guide that decision.

Is there a good way to wash 3/16” tubing

Pushing a sanitizer up through 3/16 tubing from the bottom is likely to be a slow process and using vacuum to pull sanitizer in through the spouts will require a little more technique. To use the natural vacuum to pull sanitizer into the system a pair of vice grips, with tubing or tape over the grip teeth or take off the sharp edges with a grinder, to close off the drop line near the spout. The properly set vice grips will keep much air from entering the tubing while the spout is pulled from the taphole and the spout opening held in the sanitizer solution or connected to a sanitizer dispenser. Once the spout is in contact with the sanitizer solution release the vice grip and the natural vacuum in the line should pull the sanitizer solution into the line. Nest secure the spout onto the spout holder part of the T. Repeat this procedure at each spout on the line. Depending on the sanitizer used you may want to come back though in a few days and let the system drain.

Section 8 Tap hole sanitation and check valves

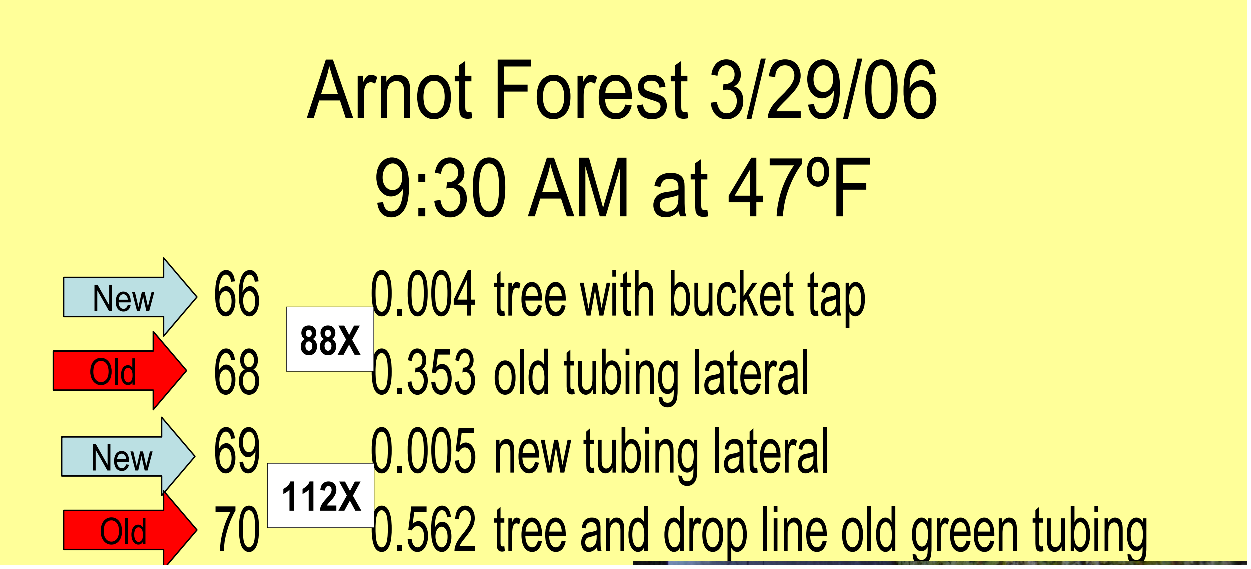
Summary:

Research at Cornell and Proctor over the last nine years has shown that significant increases in sap yield can be obtained by keeping the tap hole from contamination by bacteria and yeast. This contamination usually comes from an old spout or an old drop line. By replacing the spout, and the 20 to 30 inch drop line or by protecting the tap hole with a check valve, proper cleaning or anti-microbial spout very significant increases in tap productivity are experienced. Because of the suction pressure created in the tree as the tree falls below freezing temperatures, sap is pulled back into the tree from the spout and drop line. If these are contaminated with bacteria and yeast, the tap hole becomes contaminated and "dries out" earlier in the season than where the tap hole is kept sanitary. Studies have been conducted both on vacuum and gravity tubing systems showing positive results of maintaining some form of tap hole sanitation.

8.1 2006 Cornell maple sap collection system sap fermentation study
8.2 2007 Cornell tap hole sanitation research results
8.3 2008 Cornell tap hole sanitation research results
8.4 2009 Cornell tap hole sanitation research results
8.5 2010 Cornell tap hole sanitation research results
8.6 2011 Cornell tap hole sanitation research results
8.7 2012 Cornell tap hole sanitation research results
8.8 2013 Cornell tap hole sanitation research results
8.9 2014-15 Tap hole Sanitation Research

8.1 2006 Cornell maple sap collection system sap fermentation study

Research conducted in 2006 examining over 200 samples from 10 maple operations clearly showed that old tubing, even when rinsed or washed held a significant load of bacteria and yeast that acted rapidly on sap to begin the fermentation of sucrose to the invert sugars glucose and fructose. The numbers below are an example of the results obtained showing the level of microbe activity in sap by measuring the level of glucose present in the sap under various conditions. Sap tested from new tubing show very little microbe activity as seen in the readings of .004 and .005 grams of glucose per liter of sap. Under the same sugarbush and weather conditions old tubing show levels 88 and 112 times greater. These studies raised concerns about the closeness of this contamination to the tap hole. Microbe contamination of the tap hole has been shown to be a major contributor to season ending tap holes drying up. This finding led to the studies in 2007-2010 that showed that having a new spout and drop line in the tubing system resulted from 80% to over 200% increases in sap production in recorded trials.

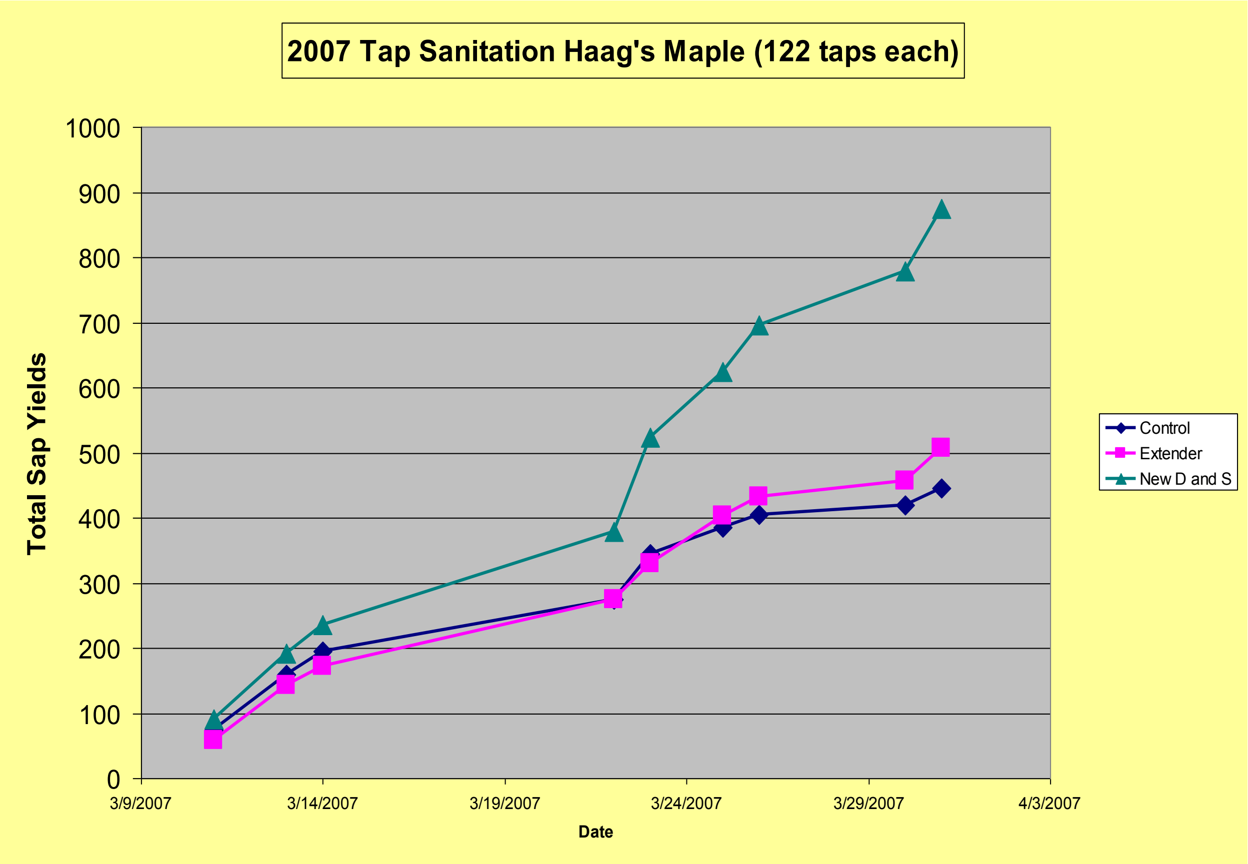


Arnot Forest 3/29/06
9:30 AM at 47°F

New 66 0.004 tree with bucket tap
88X
Old 68 0.353 old tubing lateral
New 69 0.005 new tubing lateral
112X
Old 70 0.562 tree and drop line old green tubing

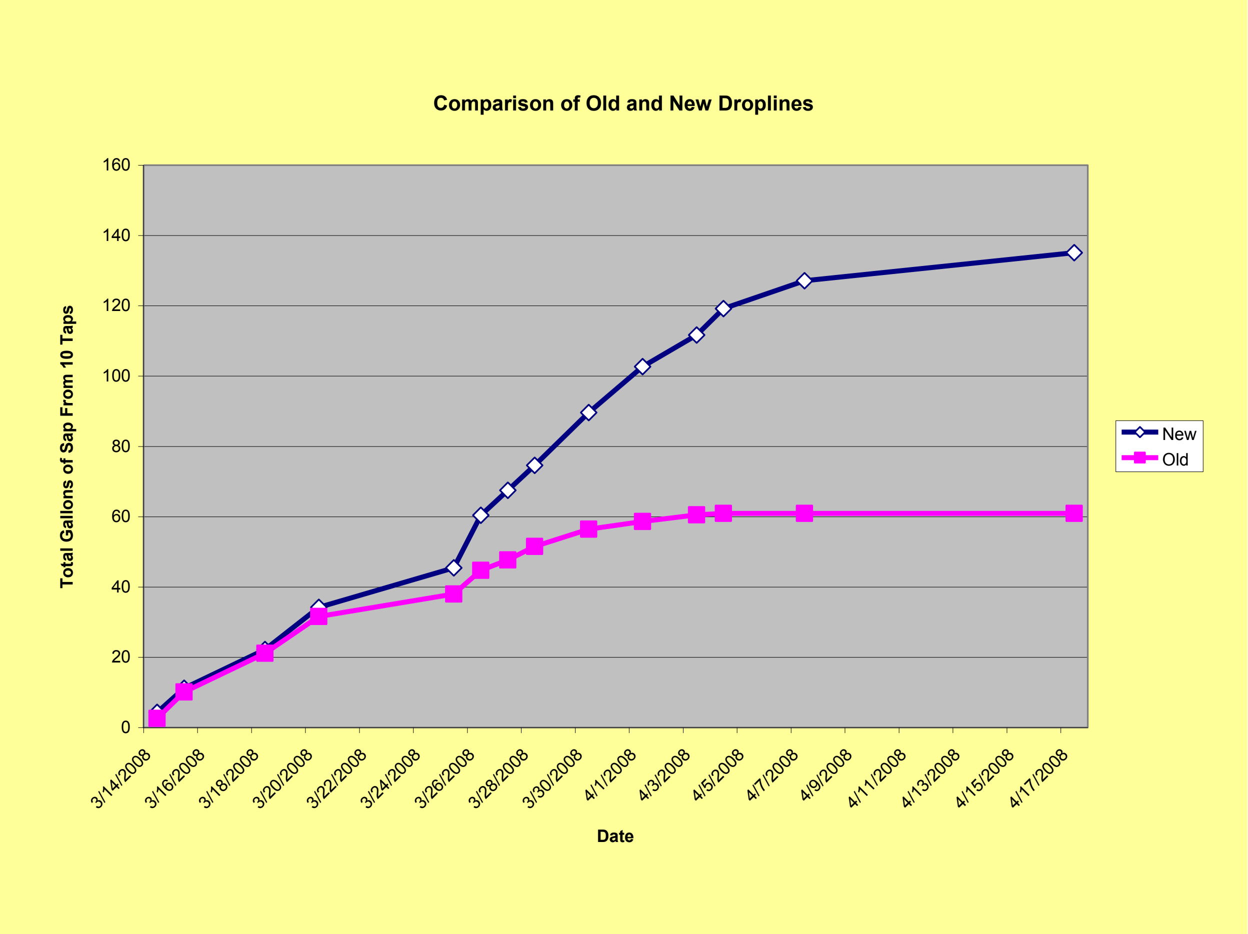
8.2 2007 Cornell tap hole sanitation research results

A trial was run in 2007 with Haag Maple in Allegany County where three treatments were installed on the existing tubing system which had been in the woods for 7 seasons. The tubing system had three collection tanks each servicing 122 taps. In the first section to serve as the check, no changes were made. In the second section tap extenders, sometimes called tree savers were installed onto the existing spouts to provide a clean new spout in the taphole. In the third section the old spout and dropline were replaced with new spout and dropline. The results were dramatic. Where the new spout and dropline were installed sap yield was twice the production of the check. While the clean spout adapter showed only a 15% increase in yield. See the yield graph on the next page. The early sap runs were very similar but as the season progressed the yield difference expanded. This trial was conducted under gravity flow conditions.



8.3 2008 Cornell tap hole sanitation research results

In 2008 a trial was set up at the Cornell Arnot Forest to see if the 2007 results with Haag Maple could be repeated under very controlled experimental conditions. In this test ten trees were selected and a double lateral line system was installed. One lateral line was totally new including drop lines and stainless steel spouts. The second lateral line was all new except for a 10" droplines that were removed from active sites in the Arnot tubing system. These drop lines had been in continuous use for over 15 years. New stainless steel spouts were used in this treatment as well. The only difference between the two treatments was one had new droplines and the other had droplines in continuous use for 15 years. The two taps were place in each of the ten trees at the same elevation and about 10 inches apart to maintain similar orientation to the sun. Each lateral line emptied into its own collection barrel and measured during and after each sap run. This research on a gravity system again showed over a 100% increase in sap yield where the new spout and drop was used vs. a new spout and old drop. A second small experiment was conducted at the Uihlein Maple Research Forest where trees were tapped and a spout and dropline installed. The dropline was looped so that when sap ran it would fill and remain filled with sap. When the temperature dropped below freezing and the internal tree pressure became negative the flow of sap back into the taphole was measured. The results here showed an average back flow of between 8 and 9 inches and as much as 13 inches. Together these two results suggest that contaminated sap pulled back into the taphole from old droplines is responsible for loss of yield in mid and late season.


Comparison of Old and New Droplines
Total Gallons of Sap From 10 Taps
160
140
120
100
80
60
40
20
0
3/14/2008
3/16/2008
3/18/2008
3/20/2008
3/22/2008
3/24/2008
3/26/2008
3/28/2008
3/30/2008
4/1/2008
4/3/2008
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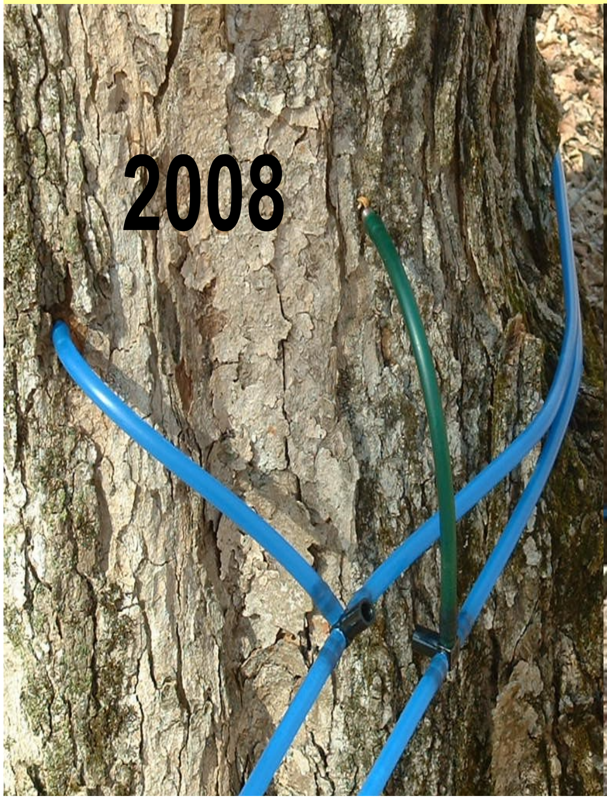
4/15/2008
4/17/2008
Date
New
Old


2008

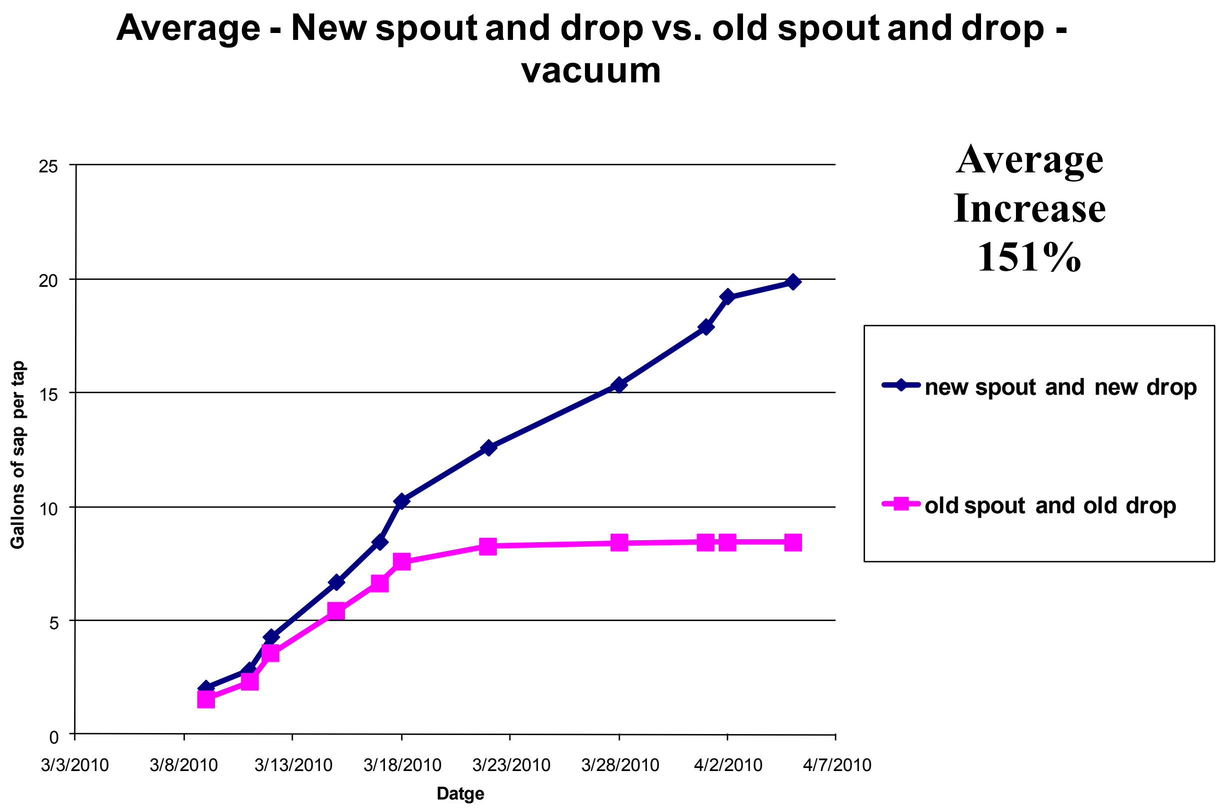
8.4 2009 Cornell tap hole sanitation research results

Research at Cornell by 2009 had shown that significant increases in sap yield can be obtained by keeping the tap hole free of contamination by bacteria and yeast in a gravity tubing system. This contamination usually comes from an old spout and old drop line. By replacing the spout and the 20 to 30 inch drop line in a tubing system, experiments had shown over 100% increase or doubling of yield in both 2007, a generally poor sap year, and 2008, an excellent sap year. These experiments were conducted with a tubing system that had been in place for 5 or more years. This would represent the current status of over 65% of the maple tubing systems in New York. In 2009 replicated tests were run on gravity systems where new spouts and drops were compared to old spouts and drops. The new spouts and drops produced 88% more sap in the season than the old spouts and drops. Old spouts and drops averaged 6.4 gallons of sap per tap while the new spouts and drops averaged 12 gallons of sap per tap. In 2009, check valves were installed into drop lines where both treatments had new spouts, then a check valve followed by either a new drop line or an old drop line. In this case the check valve seemed to keep the tap hole free of contamination and both treatments had the same yield of about 10 gallons of sap per tap but two gallons less than just the new spout and drop.

Also in 2009 a larger study was done with Breezie Maples Farm in Otsego County. Here about 2700 spouts and drops were replaced in one woods to compare with older spouts and drops in woods nearby on the same farm where vacuum held at about 21 inches and with the vacuum being shut off when sap in the system became frozen. In this case the updated woods out yielded neighbor woods by producing 2.4 times more sap. When compared with the yield in the same woods the year before, the new spouts and drops produced 2.2 times more sap. In 2009 the updated woods produced 22 gallons of sap per tap while surrounding woods with old spouts and drops produced just 10.5 gallons of sap per tap. Records were also kept on the material and labor cost involved in updating the woods resulting in a total cost of about $2.12 to install each new tap and drop. Though this cost may seem high, the additional sap resulted in the production of an extra quart of syrup per tap or a retail value of between $10 to $18 per tap depending on syrup grade and sale price. This clearly showed that taphole sanitation is also very important where vacuum is used on the collection system.

8.5 2010 Cornell tap hole sanitation research results

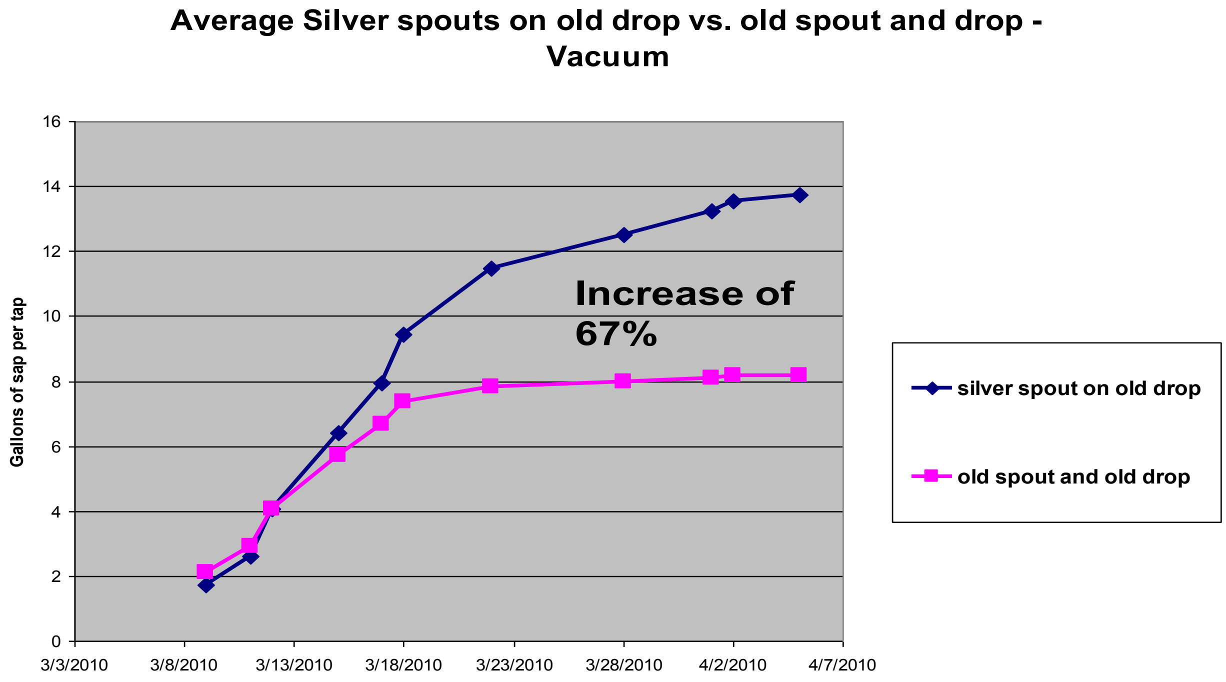
In 2010 replicated studies were done with both vacuum and gravity systems using drop and spout replacement, Leader Evaporator check valve spouts and imbedded silver spouts. With about 15 inches of vacuum at the lateral line, a new spout and drop out produced old spouts and drops by 151%. Old spouts and drops averaging about 7.9 gallons of sap per tap while new spouts and drops averaged 19.8 gallons of sap per tap.



Average - New spout and drop vs. old spout and drop - vacuum

Average Increase 151%

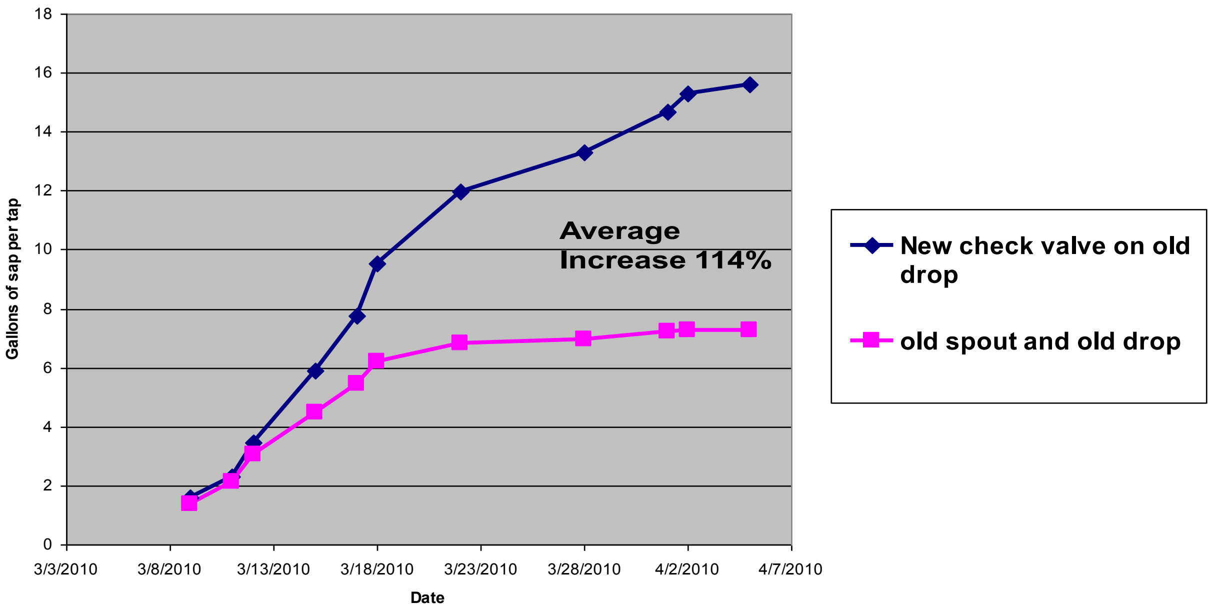
Where a new silver spout on an old drop was compared to an old spout and drop the difference was 13.7 gallons of sap with the silver spout and 8.1 gallons from the old spout for an increase of 69% in sap yield.



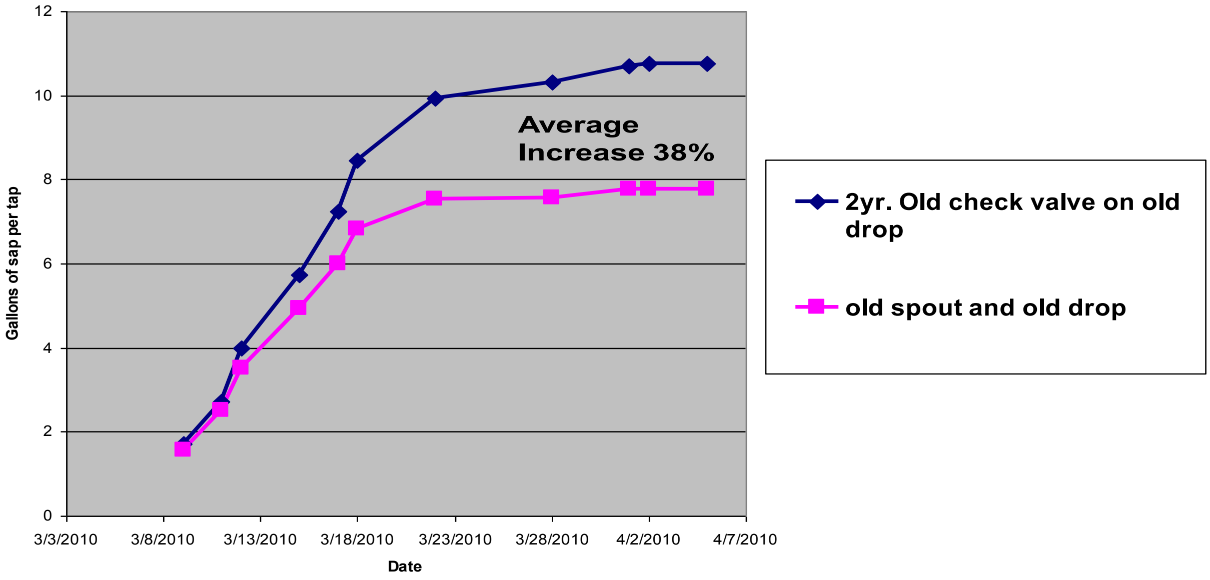
Average Silver spouts on old drop vs. old spout and drop - Vacuum

Increase of 67%

Tests with new check valve spouts on an old drop verses old spouts on old drops showed the check valve producing 114% more sap than an old spout and drop. Check valve treatments averaged 15.6 gallons of sap per tap while the old tap and drop averaged 7.9 gallons.

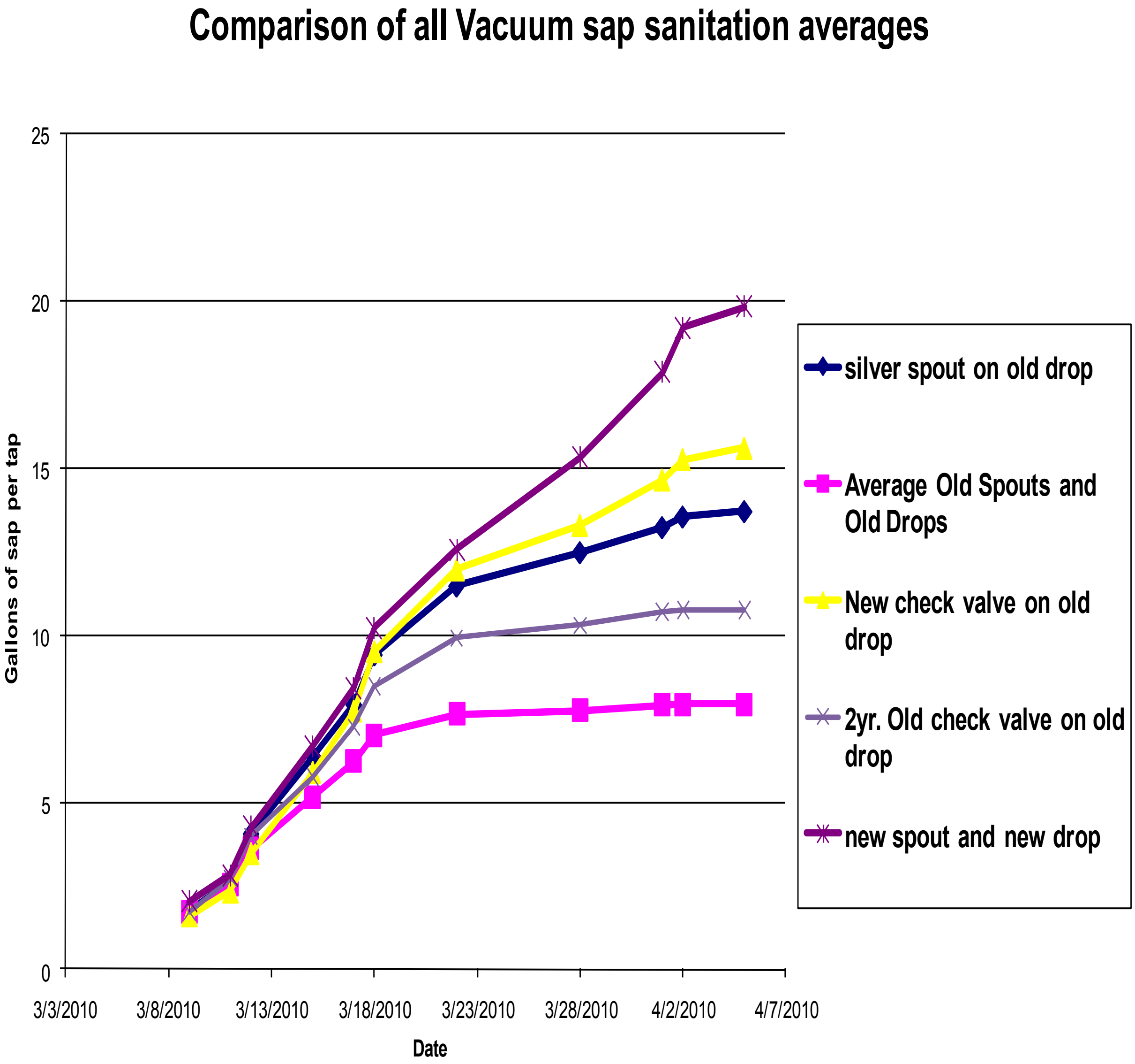

New check valve on old drop vs. old spout and drop Vacuum

The final vacuum test was to compare a Leader check valve spout that had been used the previous year and then rinsed in water as a cleaning and compared with an old spout and drop. In this case only a 38% increase in yield was observed.


2nd year check valve vs. old tap and drop - vacuum

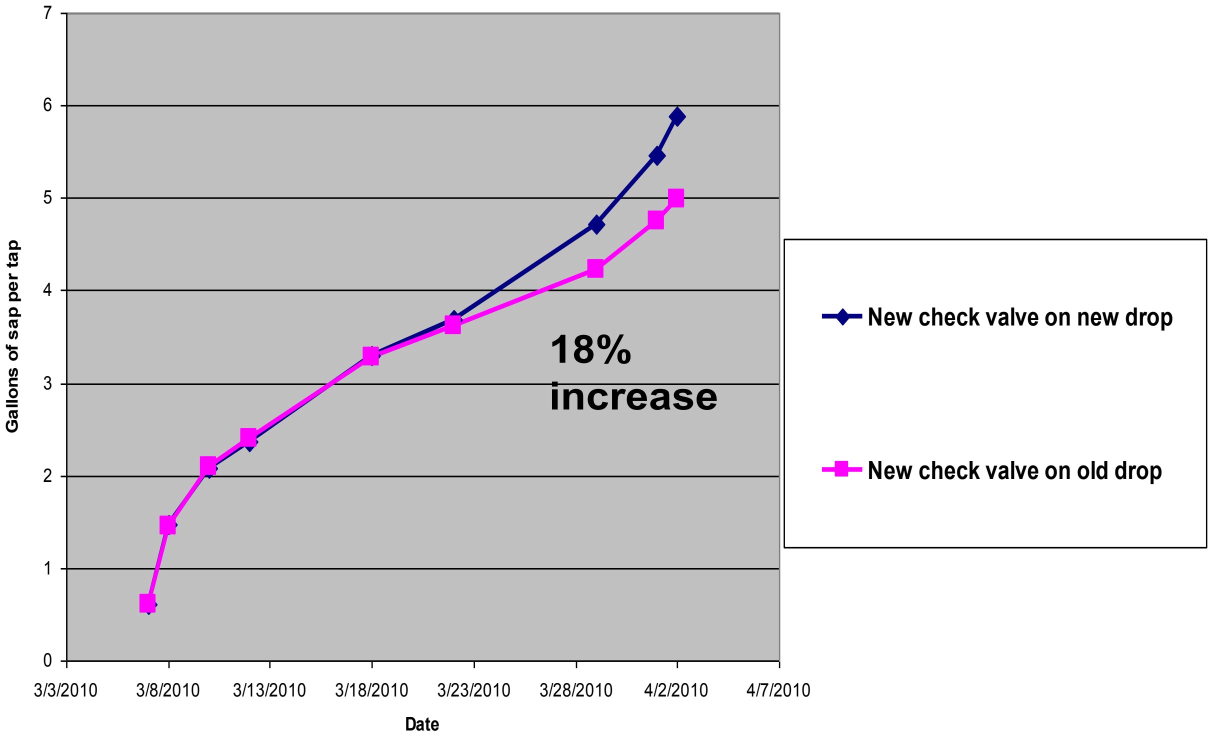
These photos clearly show the design of the tubing research. Two taps are placed into each tree on separate lateral lines. Each lateral line connects to a vacuum canister where sap from a lateral line is collected and measured while maintaining vacuum. The spout and dropline on the left are old, both have been used each year to collect sap for over 15 years. The spout on the right is a new silver spout, available commercially for the first time in 2010, on a dropline that has collected sap each season for over 15 years.

The chart below compares the sap yield of all of the five different vacuum treatments.

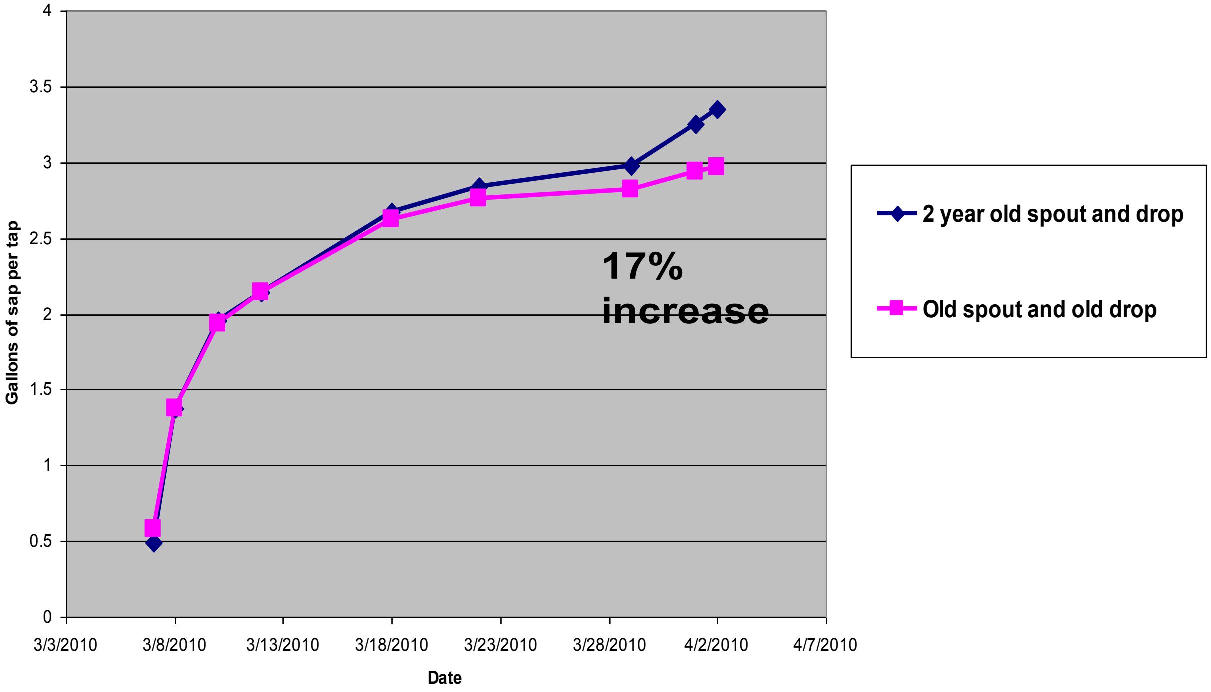


In 2010, replicated tests were also conducted on gravity systems. When a new check valve spout on an old drop line was compared to a new check valve on a new drop line the difference was a 18% yield improvement where the new drop was used. This would indicate that on the gravity system the check valve is giving the tap hole a lot of protection, but the protection is not perfect. With a new dropline, the check valve produced 5.9 gallons of sap per tap while the check valve on an old drop line produced just 5 gallons per tap. Where a new spout and drop were compared to old spout and drop the result was 76% more sap. The new spout and drop yielded 6 gallons of sap per tap vs. the old spout and drop which produced 3.4 gallons of sap per tap. The graphs for these are on the next page.

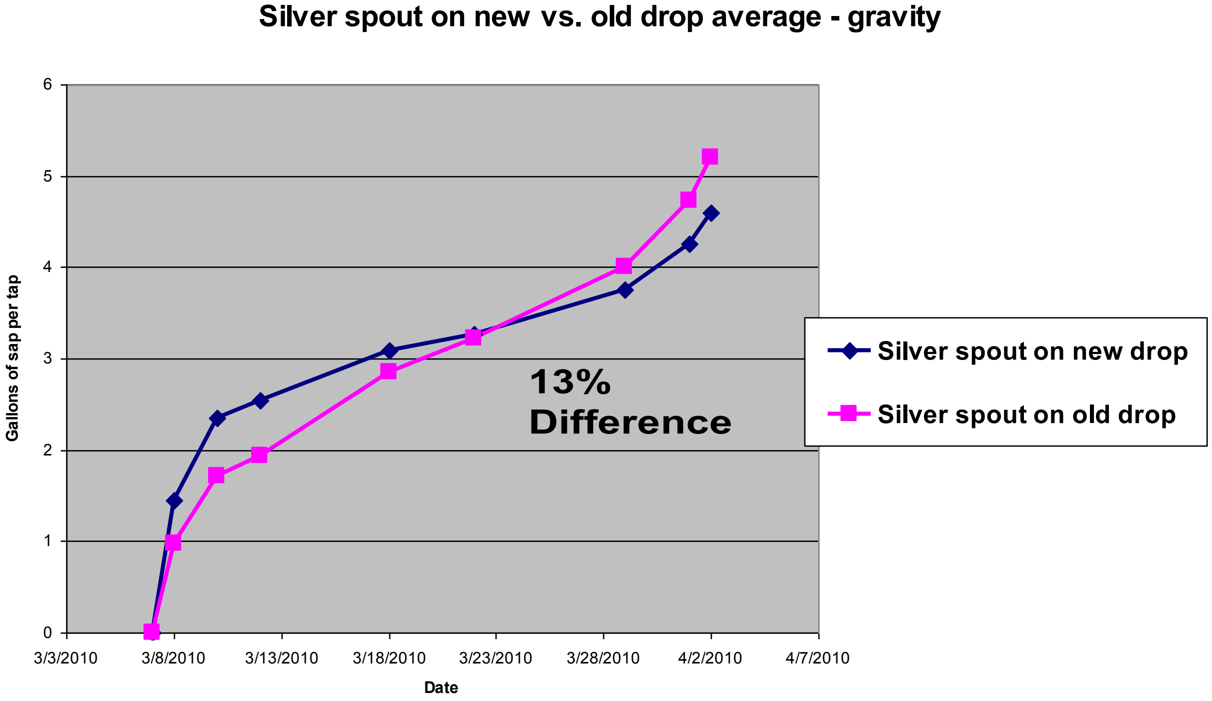
New check valve on new drop vs. old drop - Gravity



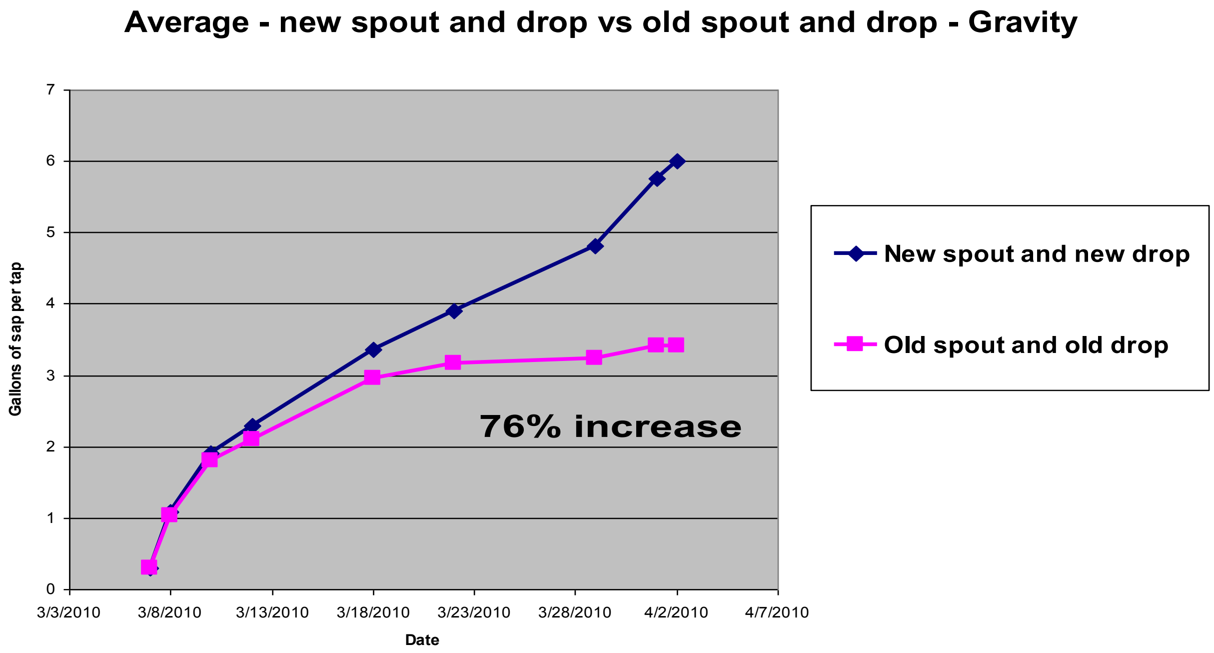
2 year old spout and tap vs. old tap and drop - gravity



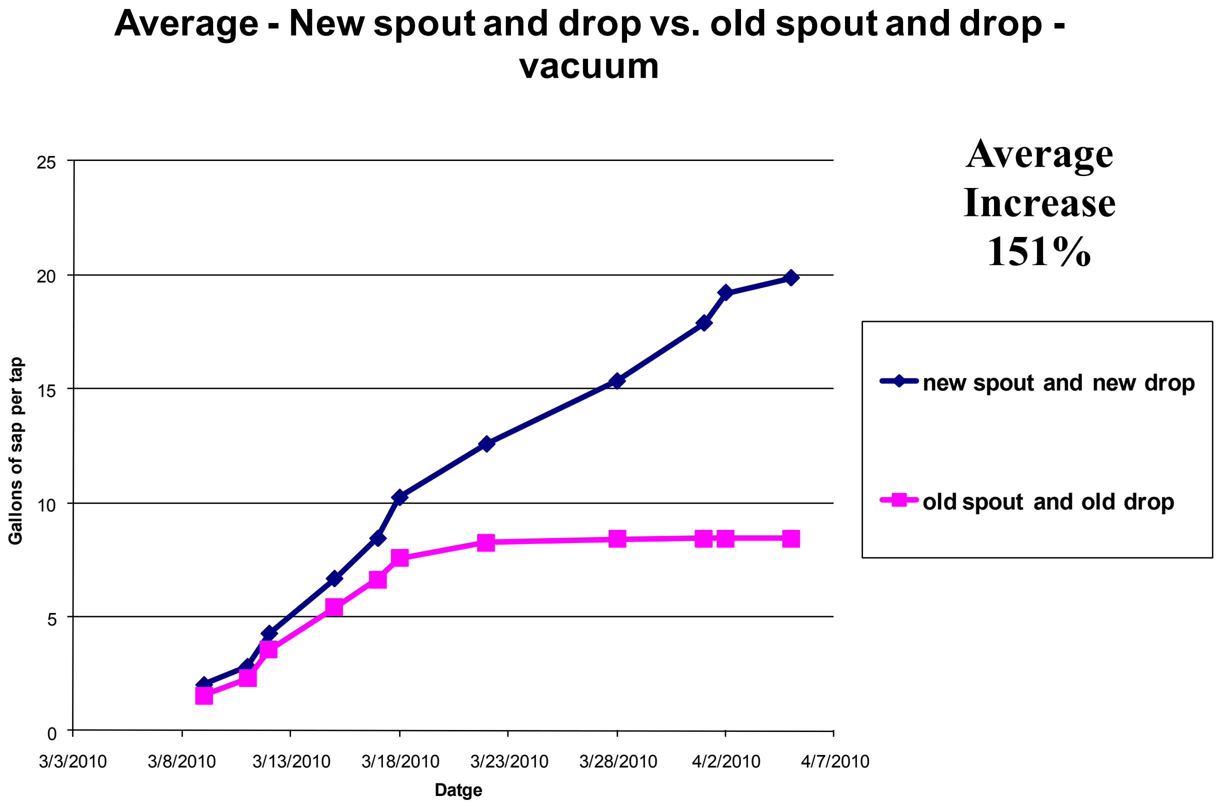
In the gravity flow system where a new silver spout on a new drop was compared with a new silver spout and old drop, the difference was just 13% indicating that the silver spout provided significant protection against tap hole contamination from the old drop line. The new drop with silver spout resulted in 4.6 gallons of sap per tap while the old drop with a silver spout yielded 5.2 gallons of sap.



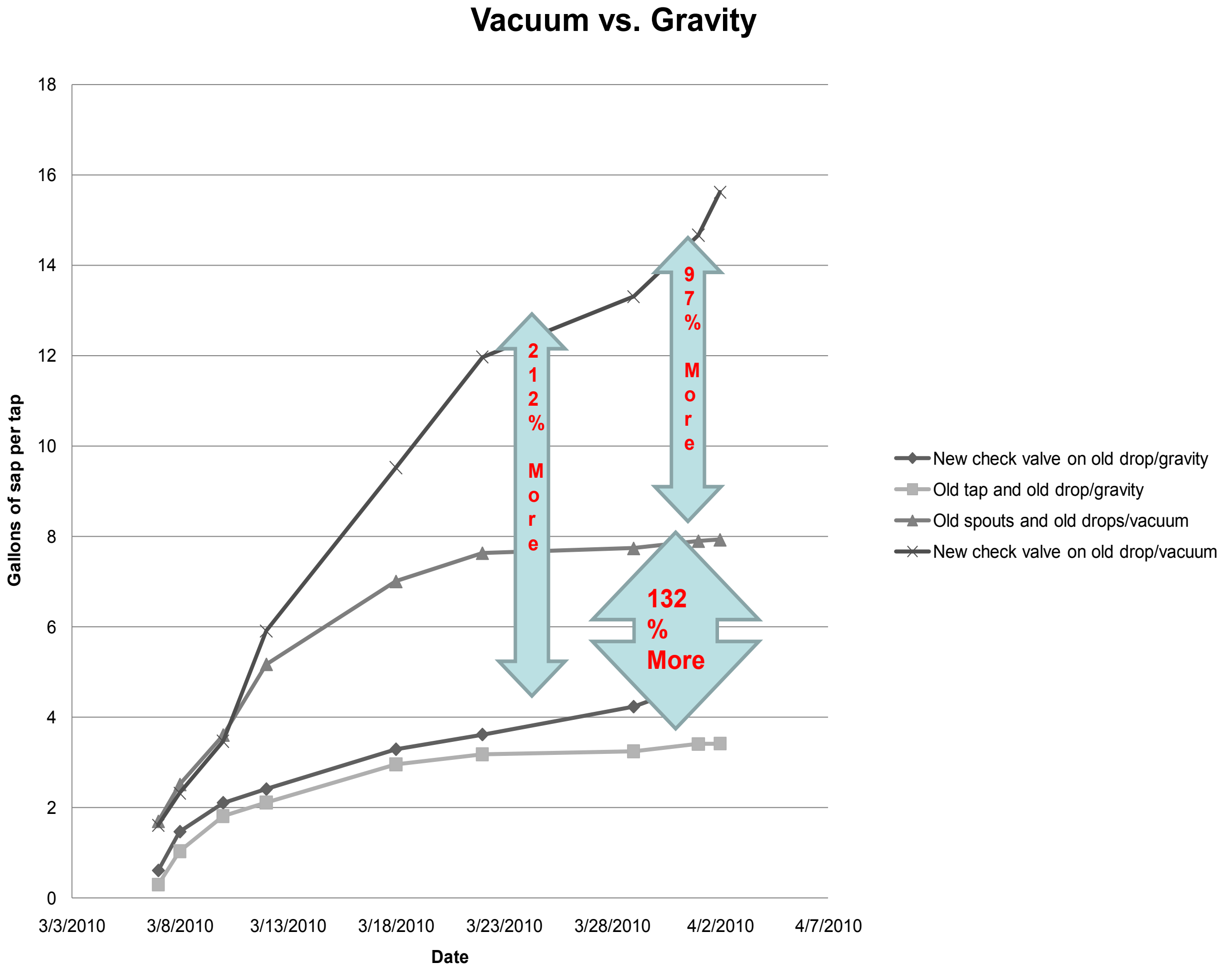
This photo shows the set up in a gravity treatment. Each tree has a treatment and a check with separate lateral lines to collect the sap into holding tank for measuring the yield of each treatment.



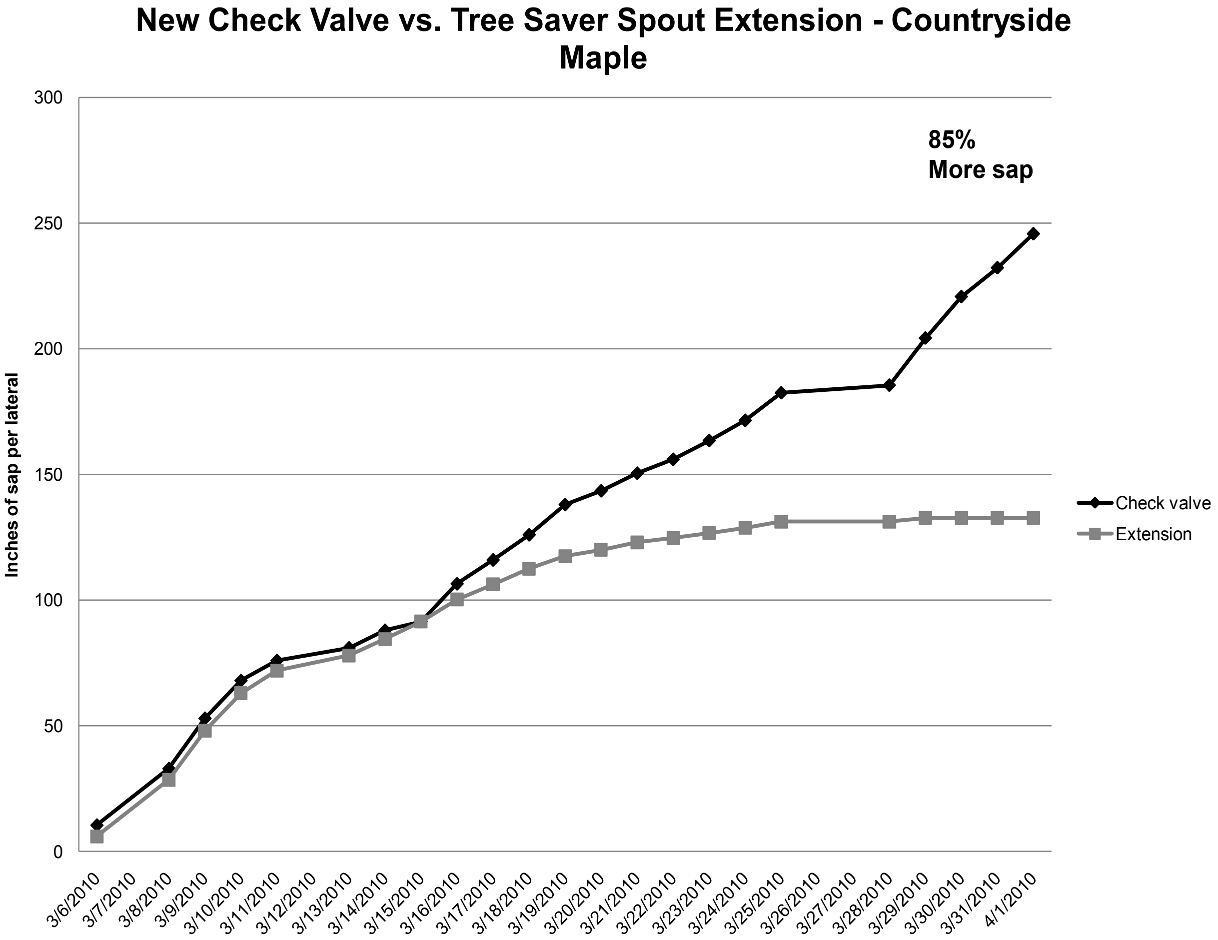
In the gravity system a new spout and drop showed 76% greater yield than replicates with old spout and drop. See the graph above. In a vacuum system a new spout and drop showed an average increase of 151% over the old taps and spout as reflected in the graph below.



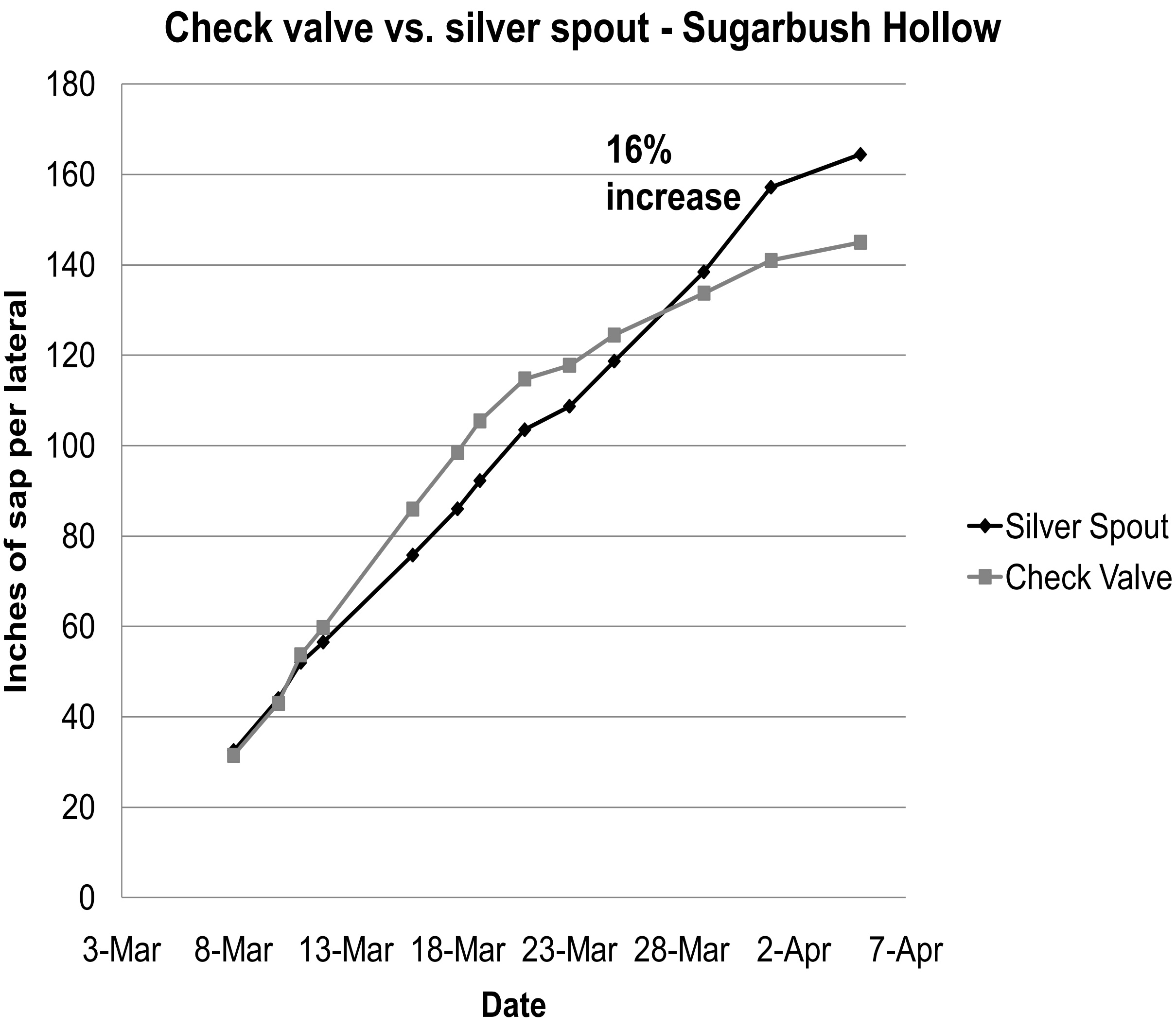
Though the gravity and vacuum tests were done in different woodlots, they are in the same valley, similar elevation, trees tend to be slightly bigger in the gravity woods and the two woods are within sight of each other. A very interesting comparison comes to light when we compare sap yield from similar treatments in the two nearby woodlots. The old tap and drop on gravity yielded an average 3.4 gallons of sap per tap while the same treatment with an average of 15" of vacuum yielded 7.9 gallons of sap per tap. That would represent a 132% increase in sap due to the use of vacuum. A new check valve on an old drop line yielded 5 gallons of sap with gravity but 15.6 gallons of sap with the same treatment with 15" of vacuum, more than three times the production or a 212% increase. A new tap and drop on gravity had a yield of 6 gallons of sap per tap and the same treatment with 15" of vacuum produced an average of 19.8 gallons of sap per tap, a 230% increase or more than three times the production with vacuum. The lesson here is that moving from gravity to vacuum can be very valuable for increasing production per tap. Also practices that keep the tap hole sanitary result in greater yield improvement where vacuum is in use than with a gravity system making such investments of even greater value.



In 2010 several trials were also conducted with maple producers who cooperated with demonstration systems. Here trees were again tapped with two treatments with separate lateral line collection systems and vacuum canisters so that sap yields could be measured and recorded. The first graph below shows the results where new check valves on old droplines was compared to a new tree saver tap extension on an old spout and drop. The results indicate an 85% increase in sap yield with the check valves.


New Check Valve vs. Tree Saver Spout Extension - Countryside Maple

In 2010 several trials were also conducted with maple producers who cooperated with demonstration systems. Here trees were again tapped with two treatments with separate lateral line collection systems and vacuum canisters so that sap yields could be measured and recorded. This second graph below shows the results where new check valves on old droplines was compared to new silver spouts on old droplines. In this demonstration the silver spouts out performed the check valve spouts by 16%



8.6 2011 Report Update of Maple Tubing and Taphole Sanitation Research

Stephen Childs, New York State Maple Specialist

During the 2011 maple sap season a variety of research trials were conducted at the Arnot Forest of Cornell University and in the woods of a number of cooperators both with vacuum and gravity systems. This research is primarily funded by the New York State Farm Viability Institute. Research conducted over the last five years has shown that significant increases in sap yield can be obtained by keeping the tap hole from contamination by bacteria and yeast. This contamination usually comes from an old spout or an old drop line. By replacing the spout and the 20 to 30 inch drop line in a tubing system, experiments have shown significant increase in yield each year regardless of seasonal conditions. These experiments were conducted with tubing that had been in place for 5 or more years. This condition of using aging tubing systems represents the current status of over 65% of the maple tubing systems in New York. Testing in 2007 and 2008 were only conducted on gravity systems.

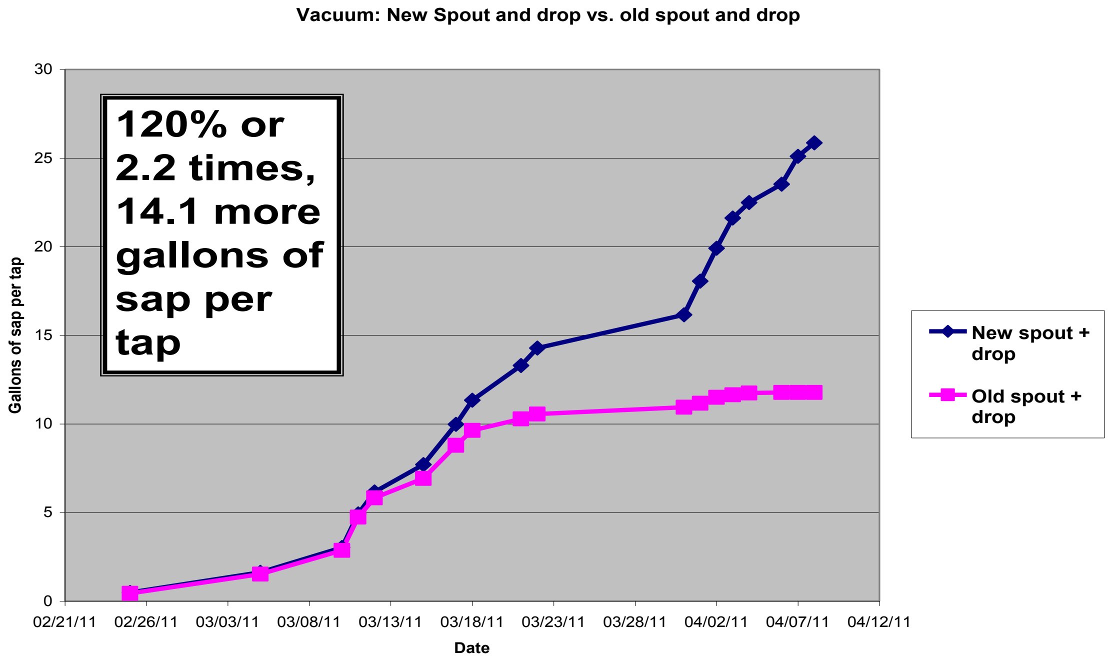
In 2009 tests were again run on gravity systems where new spouts and drops were compared to old spouts and drops. The new spouts and drops produced 88% more sap in the season than the old spouts and drops. Old spouts and drops averaged 6.4 gallons of sap per tap while the new spouts and drops averaged 12 gallons of sap per tap. In 2009, check valves were installed into drop lines where both treatments had new spouts, then a check valve followed by either a new drop line or an old drop line. In this case the check valve seemed to keep the tap hole from contamination and both treatments had the same yield of about 10 gallons of sap per tap but two gallons less than the new spout and drop. Also in 2009 a larger study was done with Breezie Maples Farm in Otsego County. Here about 2700 spouts and drops were replaced in one woods to compare with older spouts and drops in woods nearby on the same farm where vacuum held at about 21 inches and with the vacuum being shut off when sap in the system became frozen. In this case the updated woods out yielded neighbor woods in the same area on the same farm by producing 2.4 times more sap. When compared with the yield in the same woods the year before, the new spouts and drops produced 2.2 times more sap. In 2009 the updated woods produced 22 gallons of sap per tap while surrounding woods with old spouts and drops produced just 10.5 gallons of sap per tap. Records were also kept on the material and labor cost involved in updating the woods resulting in a total cost of about $2.12 cost to install each new tap and drop. Though this cost may seem high, the additional sap resulted in the production of an extra quart of syrup per tap or a retail value of about $10 to $18 per tap depending on sale price.

In 2010 replicated studies were done with both vacuum and gravity systems using drop and spout replacement, Leader Evaporator check valve spouts and imbedded silver spouts. With vacuum operating at about 15 inches Hg at the lateral line, a new spout and drop out produced old spouts and drops by 151%. Old spouts and drops averaging about 7.9 gallons of sap per tap while new spouts and drops averaged 19.8 gallons of sap per tap. Tests with a new check valve spout on an old drop verses an old spout on an old drop showed the check valve producing 114% more sap than an old spout and drop. Check valve treatments averaged 15.6 gallons of sap per tap while the old tap and drop averaged 7.9 gallons. Where a new silver spout on and old drop was compared to an old spout and drop the difference was 13.7 gallons of sap with the silver spout and 8.1 gallons from the old spout for an increase of 69% in sap yield. The final test was to compare a Leader check valve spout that had been used the previous year and then rinsed in water as a cleaning and compared with an old spout and drop. In this case only a 38% increase in yield was observed.

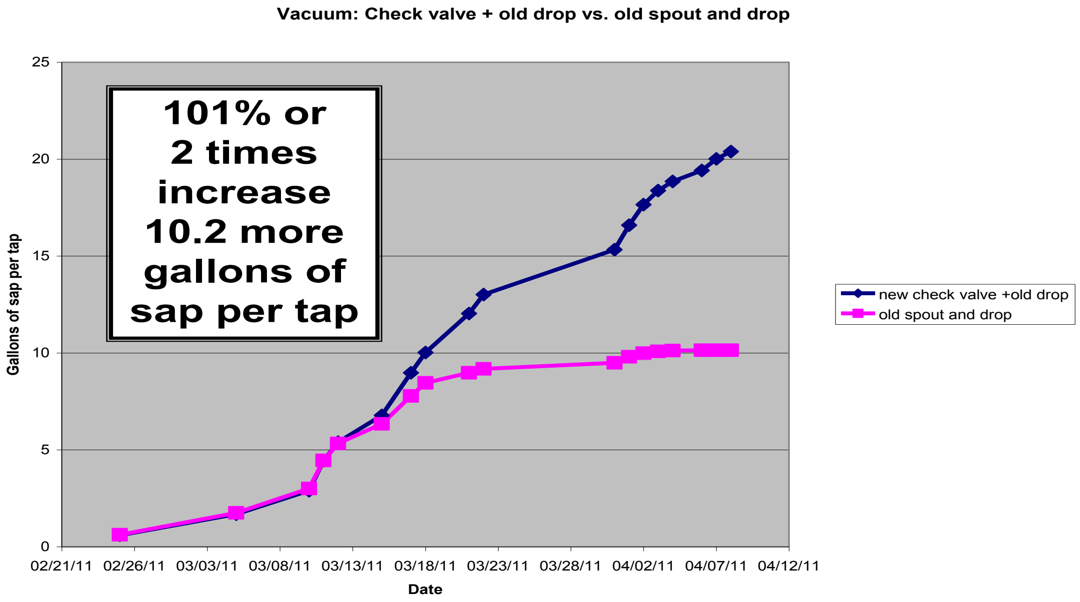
In 2010 replicated tests were also conducted on gravity systems. When a new check valve spout on an old drop line was compared to a new check valve on a new drop line the difference was an 18% yield improvement where the new drop was used. This would indicate that on the gravity system the check valve is giving the tap hole a lot of protection but the protection is not perfect. With a new drop line the check valve produced 5.9 gallons of sap per tap while the check valve on an old drop line produced just 5 gallons per tap. Where a new spout and drop were compared to old spout and drop the result was 76% more sap. The new spout and drop yielded 6 gallons of sap per tap vs. the old spout and drop which produced 3.4 gallons of sap per tap. Where a silver spout on a new drop was compared with a silver spout and old drop the difference was just 13% indicating that the silver spout provided significant protections against tap hole contamination from the old drop line. The new drop with silver spout resulted in 4.6 gallons of sap per tap while the old drop with a silver spout yielded 5.2 gallons of sap.

The replicated tests run in 2011 used the same two taps per tree, each tap with a different treatment system used in prior years. The following picture shows a typical tapping set up, in this case a new spout and drop next to an old spout and drop located 8” to 10” apart to keep the orientation of the two taps about the same.

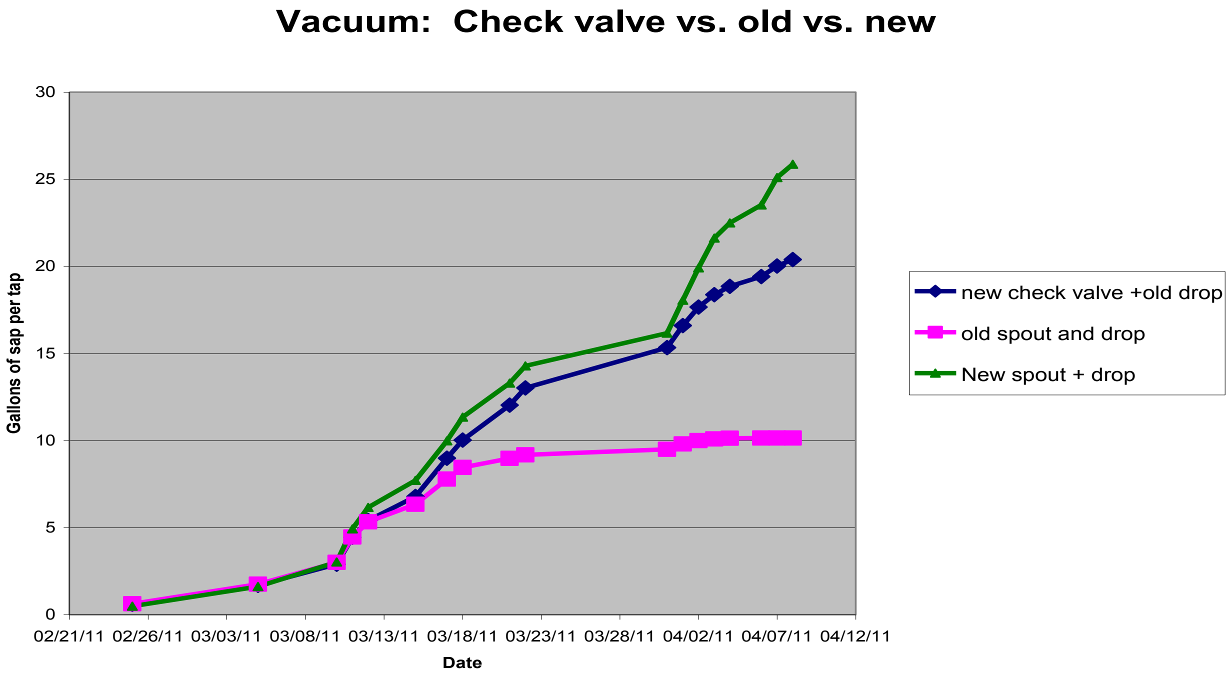
With vacuum held at about 16” to 17” Hg at the lateral line the following results were measured. Where the test was new spouts and new drops vs. old spouts and old drops, the new spout and drop out yielded the old by 120% or 2.2 times or 14.1more gallons of sap per tap than the old spout and drops. The season long flow of the two treatments is reflected in the graph below.



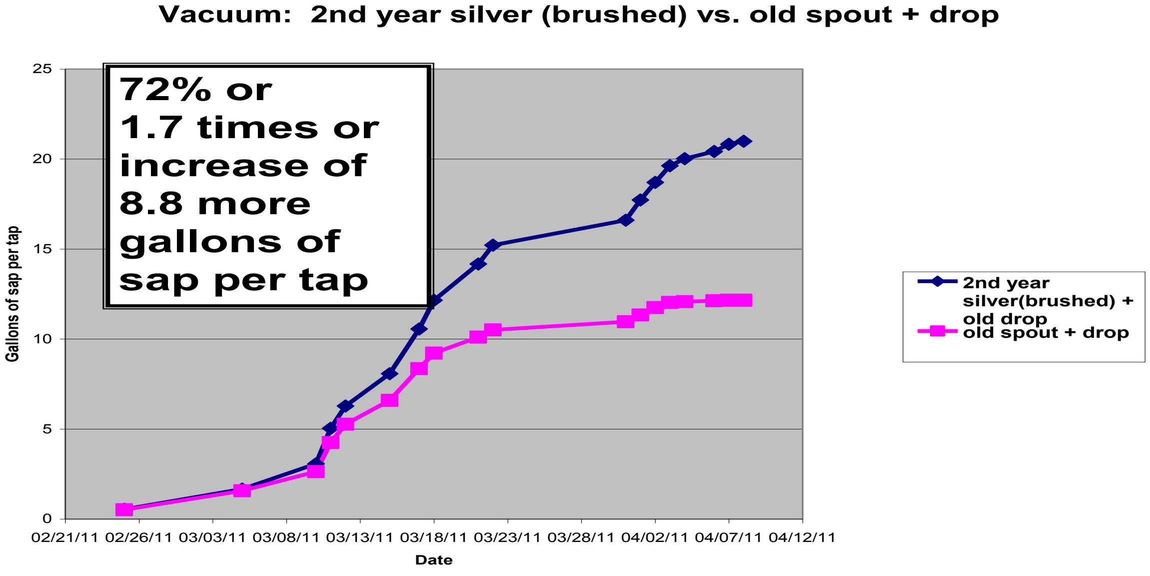
In another test a new check valve spout and old drop was compared with an old spout and old drop, the check valve treatment produced 101% or 2 times or 10.2 more gallons of sap per tap than the old spout and drop as reflected in the graph below.



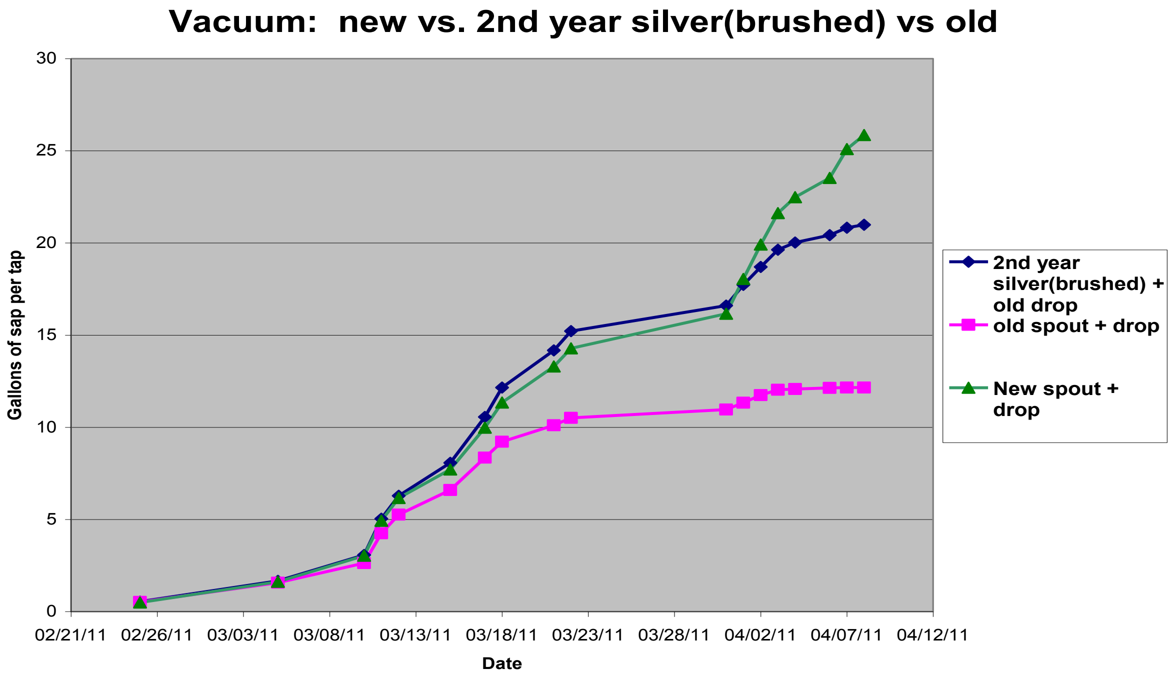
For the sake of a broader comparison, if we take the graph above and add the average of all the replications in the trail of new spout and drops, they produced more than the new check vale on an old drop as reflected in the graph below.



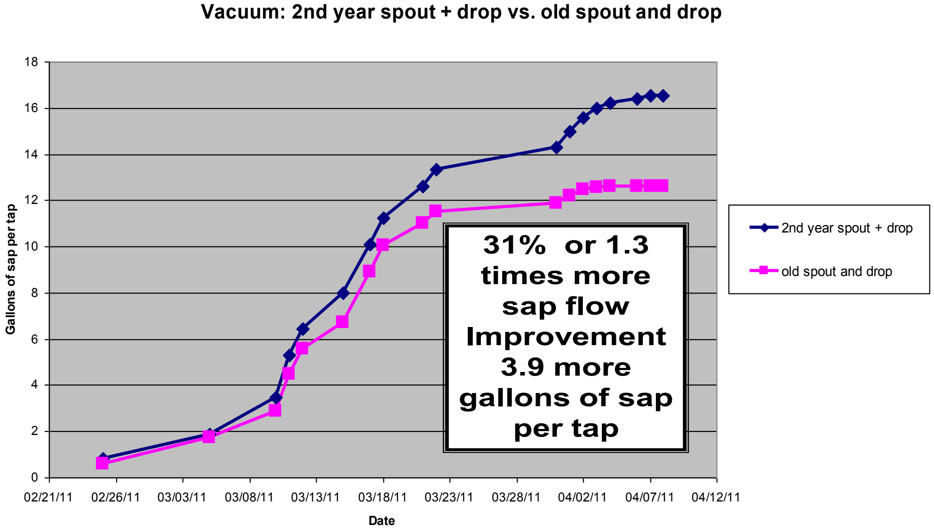
In 2010 a treatment was set up using a new silver spout on an old drop compared to an old spout and drop with the result showing a 69% increase in sap flow over the season. In 2011 the same systems were used only a stiff 5/16" brush was scrubbed into the silver spout. So the silver spouts were being used for the second year with the same old droplines that were used in 2010 still in place. In this case the second season brushed silver spouts and old drops produced 72% or 1.7 times or 8.8 more gallons of sap per tap than the old spout and old drops.



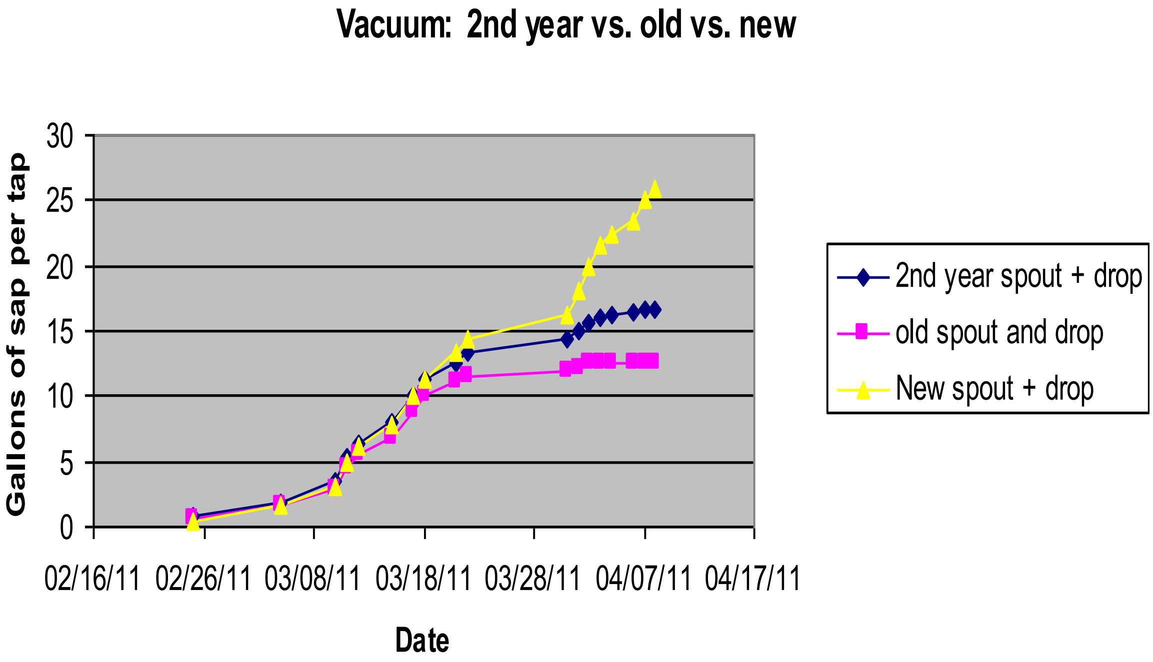
Again for the sake of comparison the average results of new spouts and new drops is added to the graph for comparison.



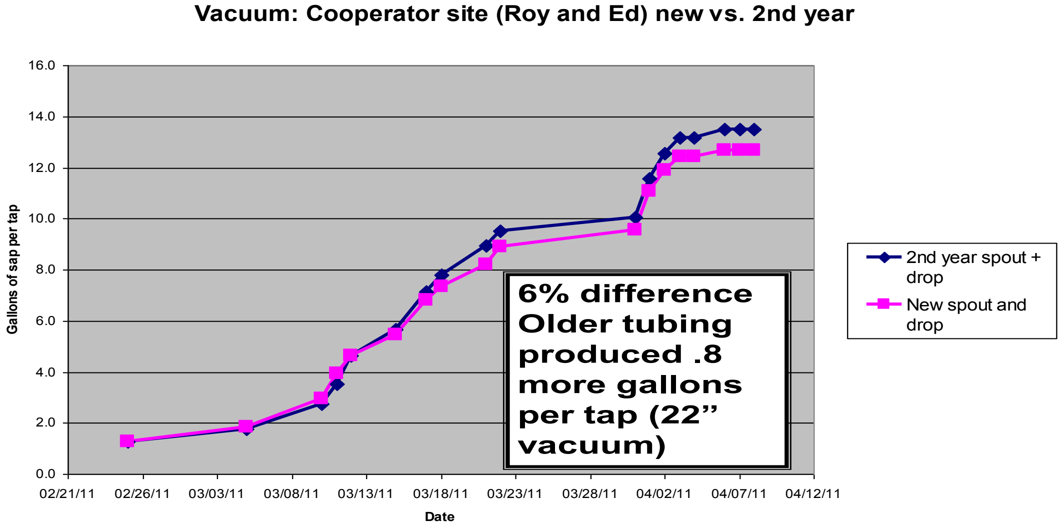
Once a maple producer has updated his tubing system by replacing spouts and drops the key question is how soon does that need to be done again to maintain the highest profitability of that tubing system. For how many years is there a production benefit and how big is that benefit? In 2011 under vacuum a treatment of old spouts and drops was compared with spouts and drops in their second season. The second year spout and drops produced just 31% or 1.3 times or 3.9 gallons of sap more than the old spout and drops.


31% or 1.3 times more sap flow Improvement 3.9 more gallons of sap per tap

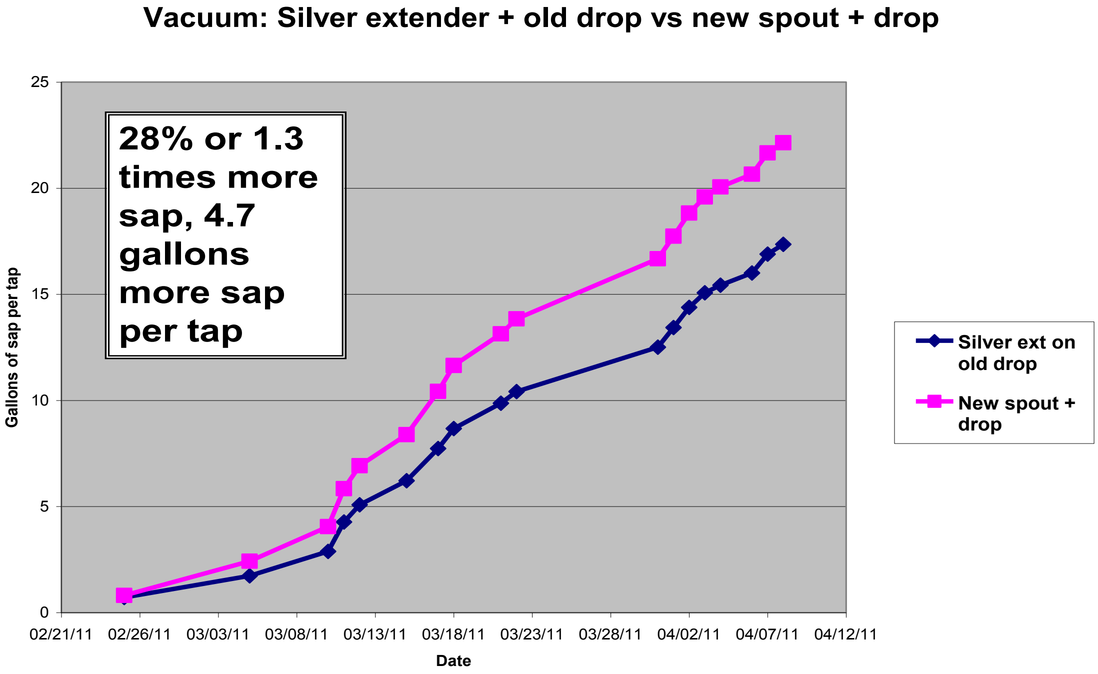
When compared to the average new spout and drop results from nearby tests we see that the second year spouts and drops have lost significant productivity in just the second season of use.

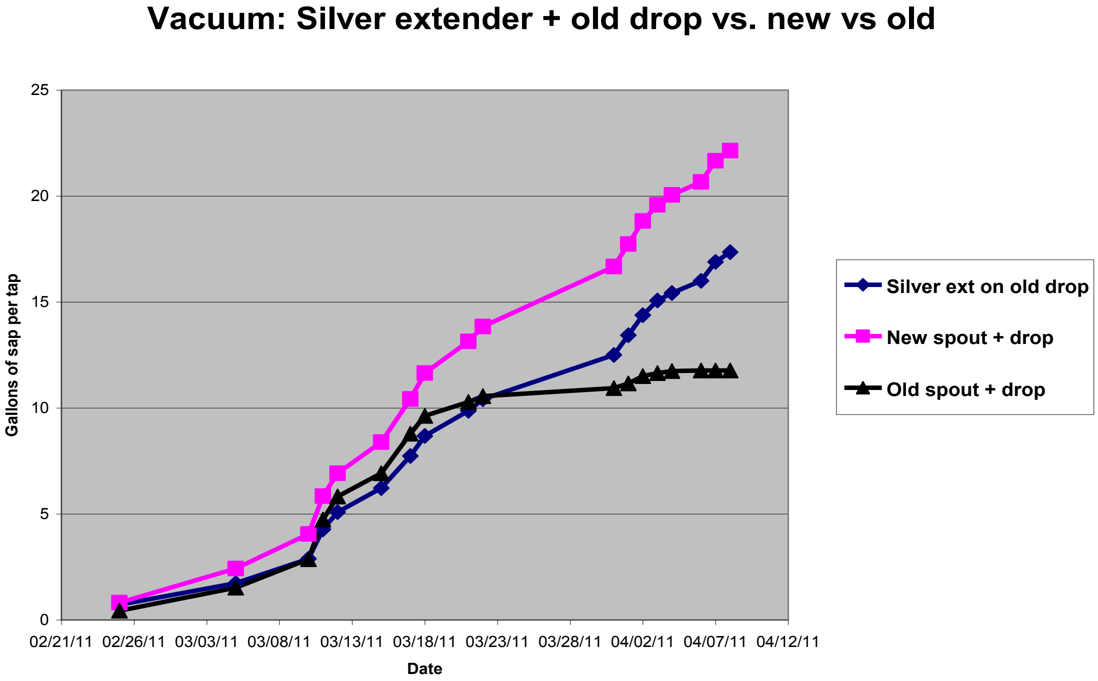


In the 2010 season this same test was run only in the gravity treatments. The results were even more disappointing for those looking for lasting yield improvement. In 2011, a similar treatment was conducted with one replication on one of the cooperator sites with interesting results. At this cooperator the vacuum was held at 22” Hg and second season spouts and drops were compared with a treatment of new spouts and new drops. In this case the second year spout and drops slightly outperformed the new spout and drops.



In 2011 tests were conducted comparing a new silver extender spout on old drops vs new spout and new drops. In this case the new spouts produced 28% or 1.3 times or 4.7 more gallons of sap per tap than the silver extender spout on old drops. When compared to the average of old spouts and old drops in the same area the silver extender would fall a little better than half way between new spout and drop and old spouts and drops as seen in the second chart below.

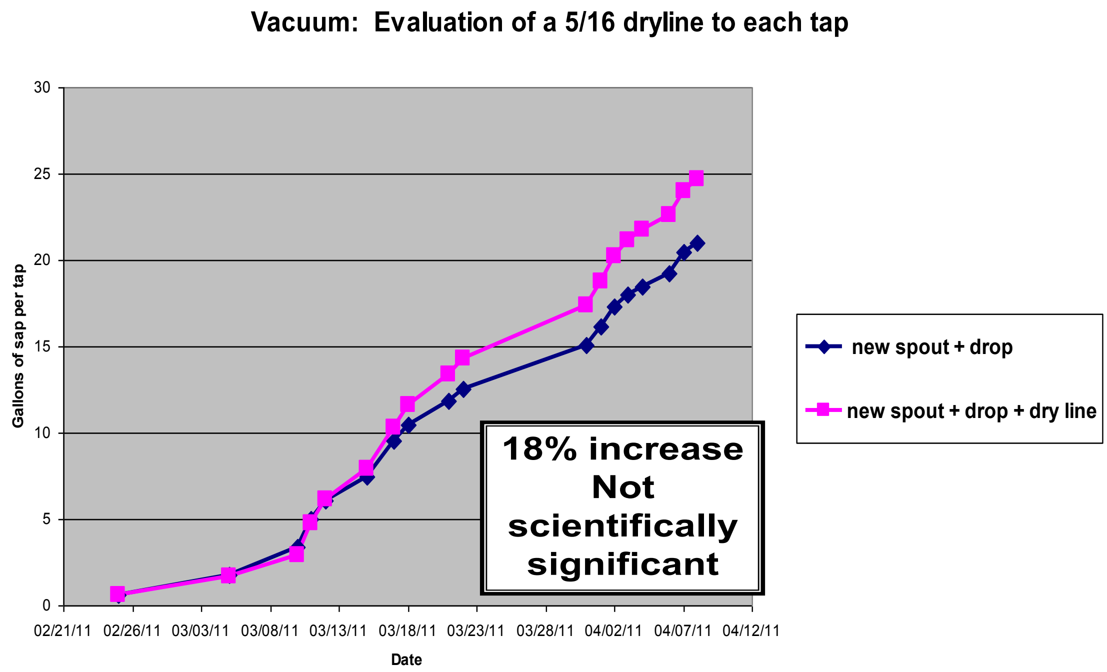




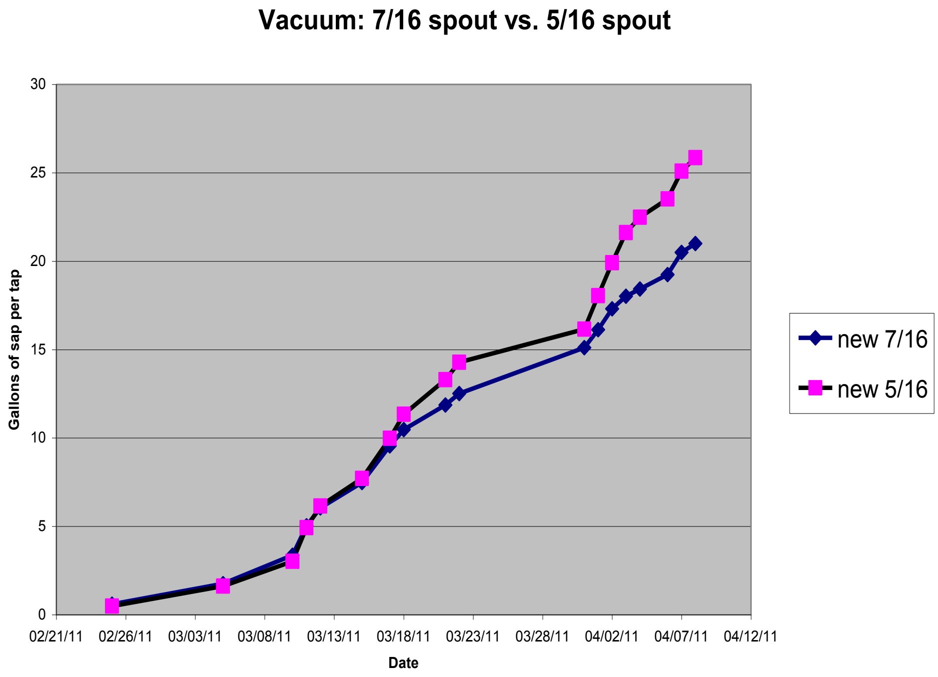
A general conclusion to the tests with the various spout and drop combinations is that most any action taken to protect the tap hole from bacteria and yeast being pulled back in during freezing weather when the tree is experiencing internal negative or vacuum pressure results in significant production increases. Figuring out which system pays best under given conditions is the maple producer's challenge.

In 2011 a test was run to see if having a clear dry line for vacuum directly to the tap would significantly improve sap yield vs. getting vacuum to the tap through the same lateral line through which sap is passing. To conduct this test new dual connection taps were obtained. These taps were often used back in the 70's when vented tubing systems were common practice. These taps were all 7/16" as well. For the regular drop and lateral line treatment an air tight cap was placed on the second spout connection. For the dry line treatment a drop and lateral line was connected to the lower spout connection and then to the vacuum canister and a second line was connected to the tops of the spout connection and connected to a second lateral line that extended directly to the vacuum canister. Vacuum was consistently held in the 16" to 17" Hg range. Both treatments were on the same trees as reflected in the picture below.

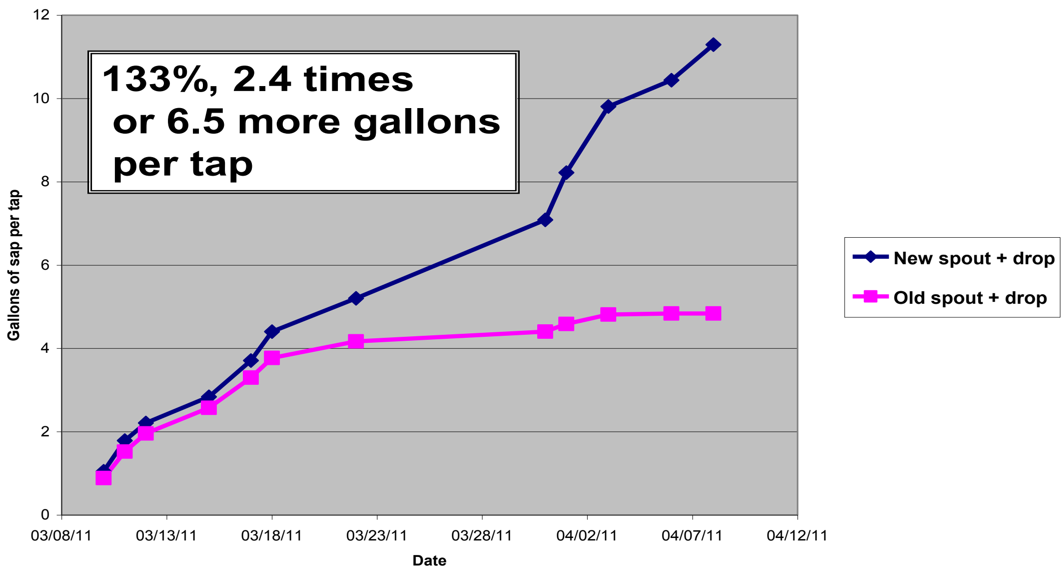
The results here were not consistent between the three replications clearly indicating that the results are not scientifically significant. On average the dry line treatment resulted in 18% more sap. Another year of tests will be conducted on this but at this point it is not high on the list of systems that are likely to give an excellent payback if any at all.



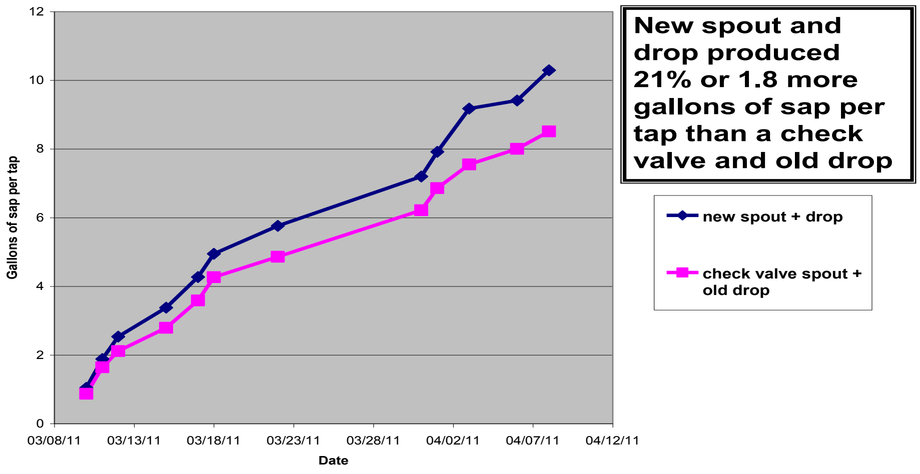
Just for comparison sake, since there are replicated treatments of new 7/16” spouts on new drops in the same wood as replicated treatments of new 5/16” spouts on new drops the following chart was assembled. It indicates as much of the research back in the 90’s that under good vacuum the smaller 5/16” spout performs as well as or better that the larger 7/16” spout.



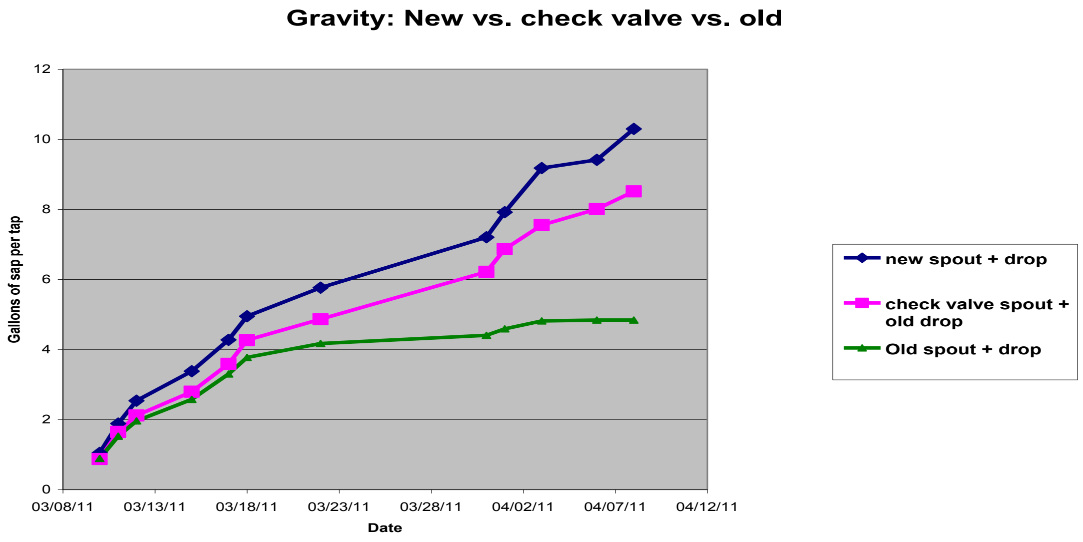
In 2011 a number of tests were run comparing sap yields from different spout and drop combinations in gravity systems. These tests were set up with the same two treatments per tree system described for the vacuum treatments with the exception that lateral lines empty into a collection barrel rather than a vacuum canister. Where new spouts and new drops were compared with old spouts and drops the new produced 133%, or 2.4 times or 6.5 more gallons of sap per tap than old spouts and drops. These results are reflected in the chart below.


Gravity: New spout + drop vs. old spout + drop

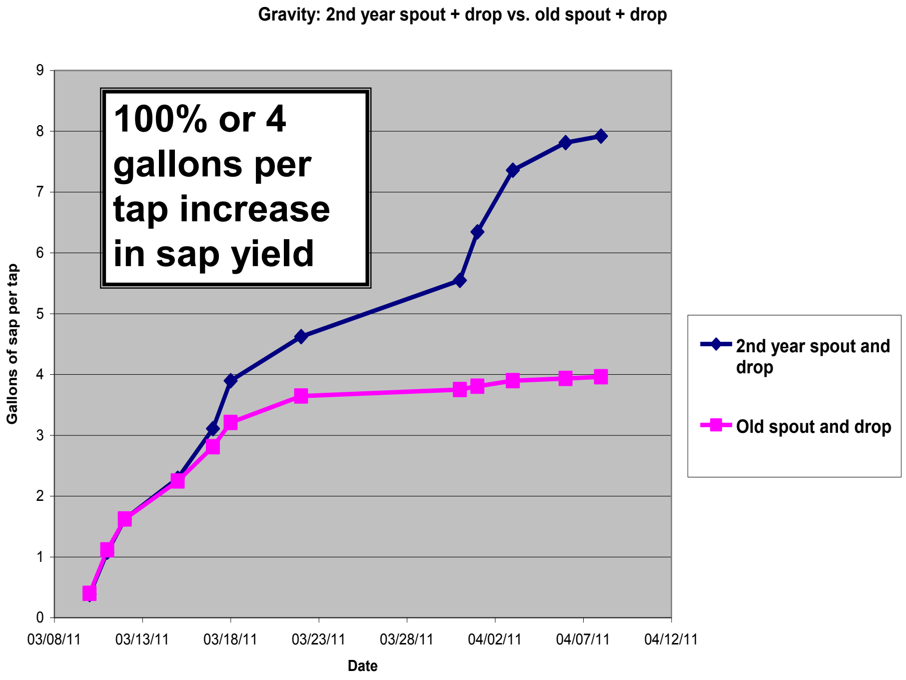
A new check valve on old drop lines was tested against a new spout and drop line. The new spout and drops yielded 21% or 1.8 times or 1.8 more gallons of sap per tap than a check valve with old drops.


Gravity: Check valve spout + old drop vs. new spout and drop

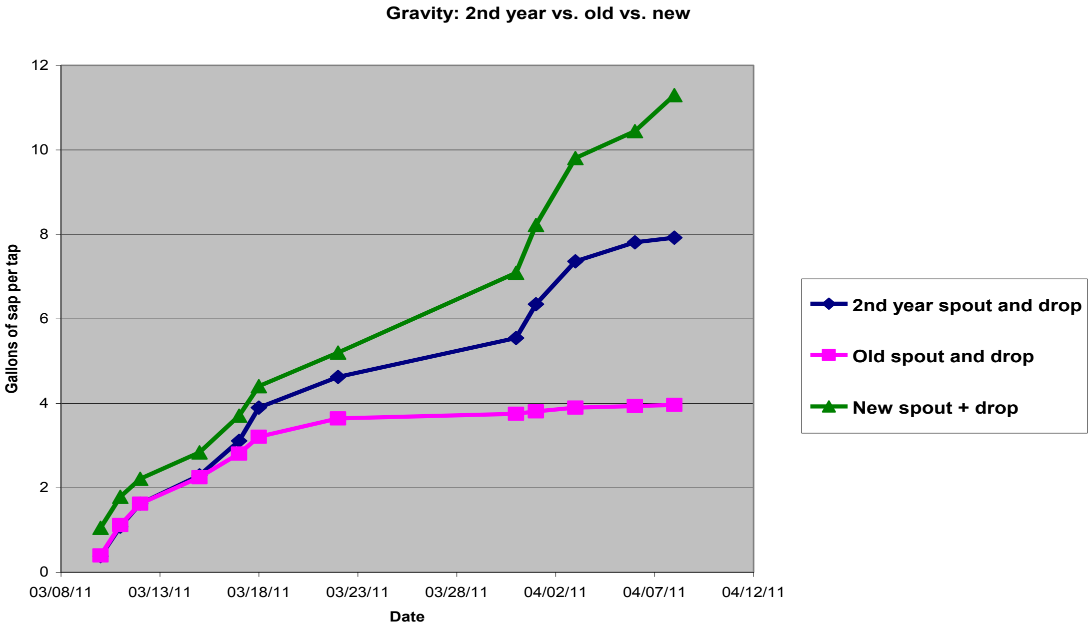
This would actually represent fairly good protection of the tap hole on the part of the check valve spout. This is fairly easy to see if we include the average yield from old spouts and drops from the replications in the same area. This is reflected in the chart below.



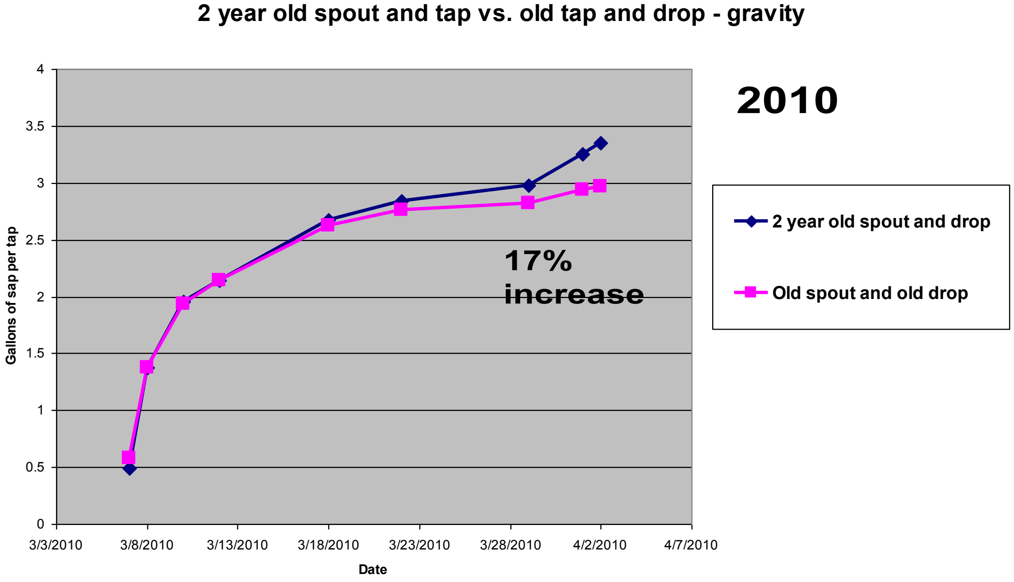
Spouts and drops that were new in 2010 were used for the second year in 2011 and compared with old spouts and drops. In this case the second year spout and drops yielded 100% or 2times or 4 gallons more sap than the old spouts and drops did as is reflected in the chart below.



This seems like an excellent result except when we compare it with the yield result experienced with new spout and new drop from nearby replicates. By adding that data to the chart below it is easy to see that the two year old spout and drops were just a little better than half the yield improvement experienced with the new spout and drop.

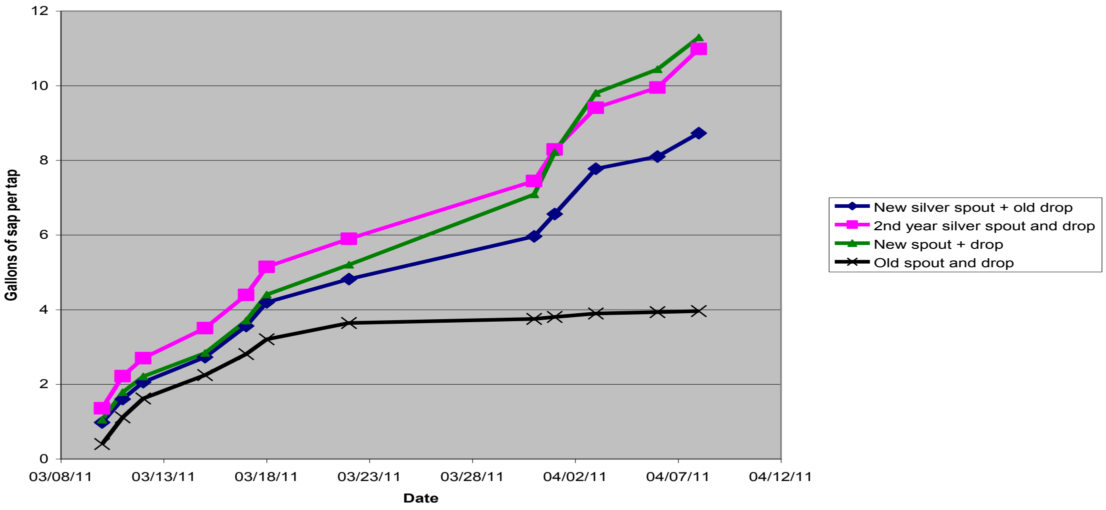


The performance of the second year spout and drop was much better in 2011 than what was recorded in 2010 as reflected in the chart below. The weather in 2010 warmed into the 50's and warmer much earlier than it did in 2011. That may be a key factor in the kind of results one could expect experience with second year collection equipment.



Silver spouts were tested in a gravity system where a second year silver spout on a second year drop was compared with a new silver spout on old drops. From the chart below it is clear that the second year silver spout and second year drop yield was comparable to a new spout and drop. In this case the second year silver spout was not brushed or cleaned in any way. A new silver spout on an old drop yielded about two gallons or 22% less sap per tap than a new spout and drop, but 2.2 times or 125% more sap than an old spout and drop.

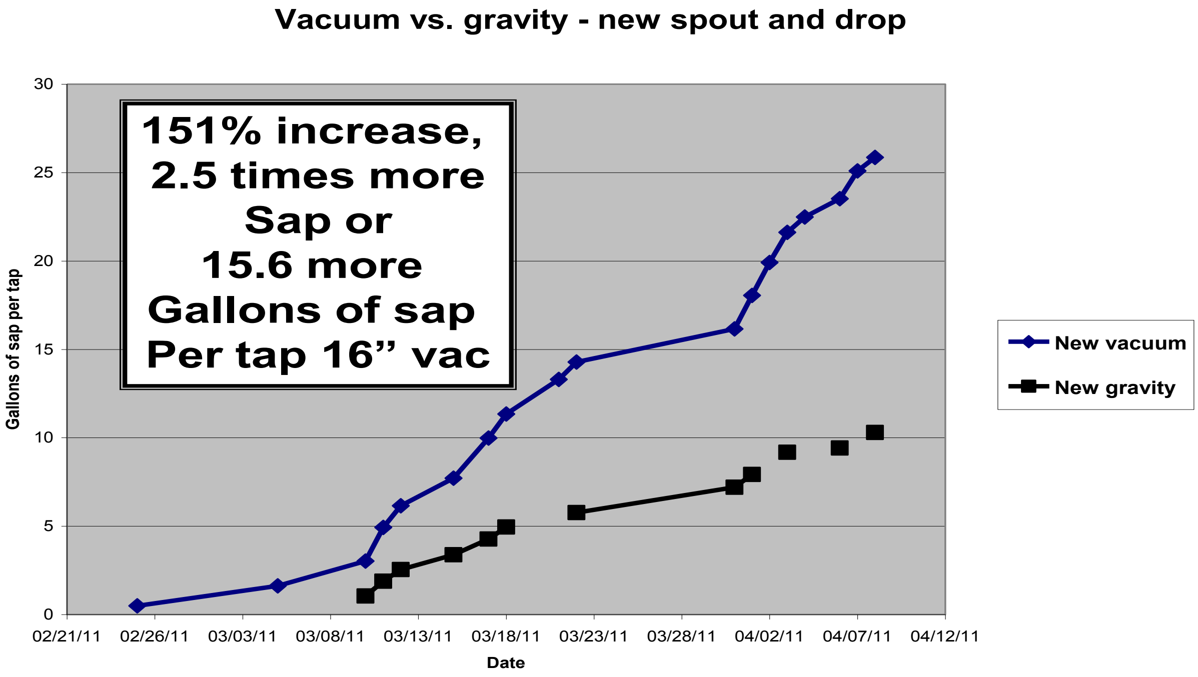
Gravity: Siver spout comparison



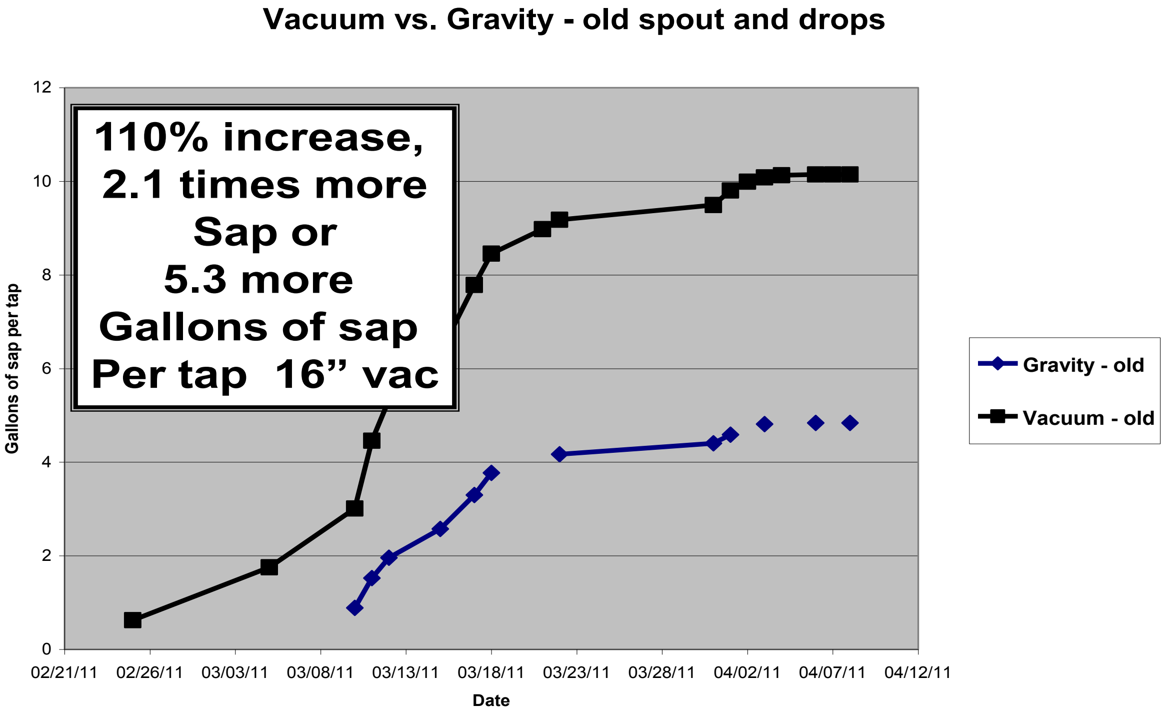
As was observed in the vacuum tests, with gravity systems all attempts to protect the tap from contamination from old spouts or sap flowing back from contaminated spouts and drops resulted in significant improvements to sap production. The challenge is for the maple producer to determine with practice is most cost effective for them and implement a taps hole sanitation practice.

Vacuum vs. Gravity

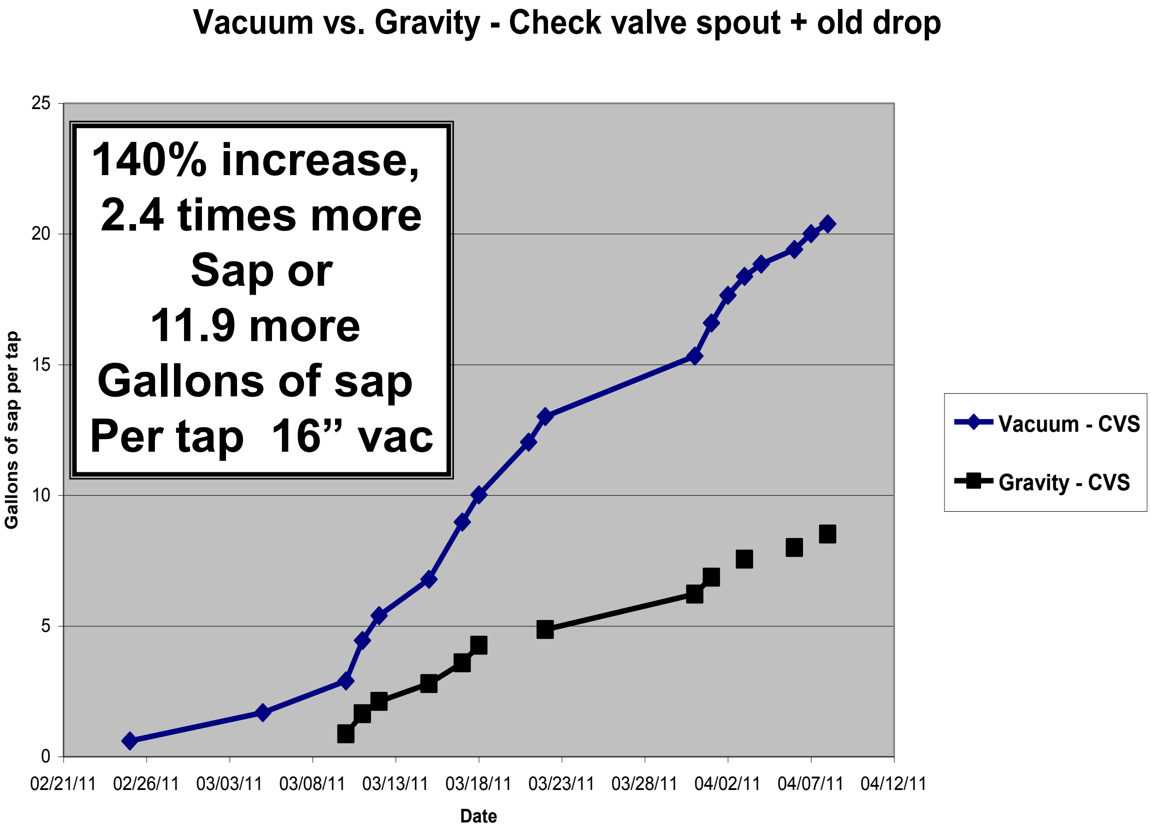
Since a great deal of data from these tests is available from a single location, the Arnot Forest, making a few comparisons between treatments with vacuum and treatments without vacuum can be interesting though not perfect as the two areas have some differences. The soils where the gravity tests are run are somewhat better drained. The trees average a little bigger in the gravity testing area. Yet the weather and elevation are about the same being about 700 yards apart. With the vacuum at 16”-17”the lines with new spouts and drops are compared to the gravity treatment of new spouts and drops. The taps under vacuum produce 151% or 2.5 times or 15.6 more gallons of sap per tap than new spouts and drops without vacuum. See the chart below.



When old spouts and old drops under vacuum are compared with old spouts and old drops in a gravity collection system the vacuum taps produce 110%, or 2.1 times or 5.3 more gallons of sap per tap. See the chart below.



When a check valve on old drops with vacuum is compared with check valve on old drops with gravity collection, the vacuum taps produce 140% or 2.4 times or 11.9 more gallons of sap per tap. See the chart below.



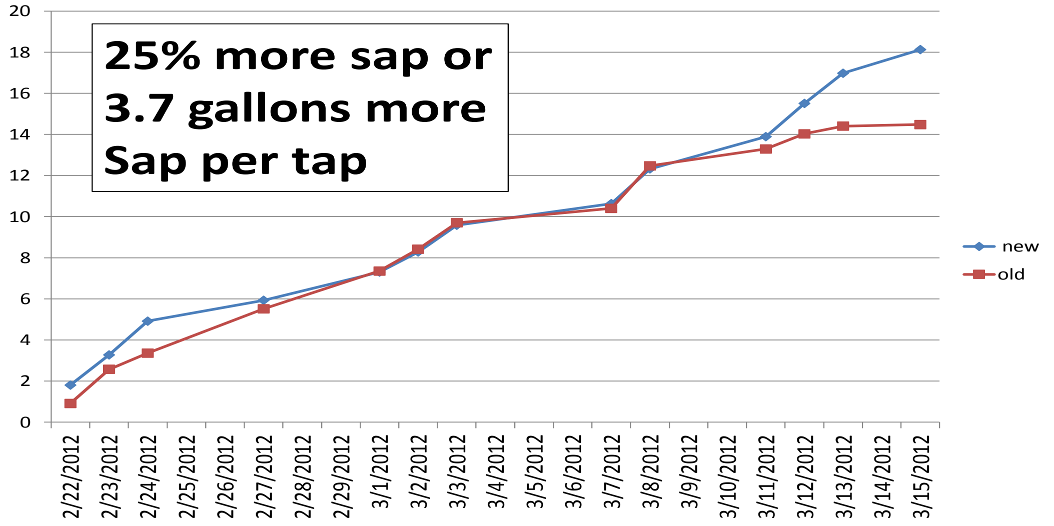
The conclusion to be observed here is that investments in tap sanitation equipment such as a new spout and drop, check valve or silver spout all return more when enhanced by vacuum. And the yield of a vacuum system is enhanced by taphole sanitation practices.

8.6 2012 Maple Tubing Research
by Stephen Childs, NYS Maple Specialist

In 2012 a variety of spout and tubing cleaning and replacement options were tested to determine the extent of sap yield changes. These tests were done at the Cornell Arnot Research Forest. Treatments except where noted were a direct comparison between a check and a described treatment each with three replications, each replication with 4 to 6 taps, both treatments in the same tree, spaced about 10 inches apart at the same elevation and same basic orientation. The check was usually represented by an old spout and old drop, having been used each season for at least 10 years or in a few cases by a new spout and new drop. The 2012 season started early with our first measureable sap run occurring on February 21^{st} followed by many small runs and temperatures only reaching 50 º F one day until March 13^{th} which was followed by 15 days without a freeze and daily temperatures commonly in the 70s and 80s. Once the sap stopped running on the15th there was no sap run during this warm weather and none of the treatments ran any sap when it finally did freeze again. In the vacuum systems tests the vacuum level was consistently between 21" and 22" Hg. This is 5" to 6" Hg higher than prior years.

The research goal for 2012 was to first test some rather extreme tubing cleaning or sanitizing techniques to see if buy going to extremes we could get old tubing to perform like new. If going to an extreme does not produce significant results then treatments that go just part way will not likely be effective. These extreme treatments include concentrated alcohol washing, boiling spouts in vegetable oil where much higher temperatures can be achieved than when boiling in water and dry heating drop lines to 180ºF for two hours. Second there have been some fairly common spout and tubing combinations that we have not had a chance to try in prior years of testing. These included testing clear spouts and copper spouts.

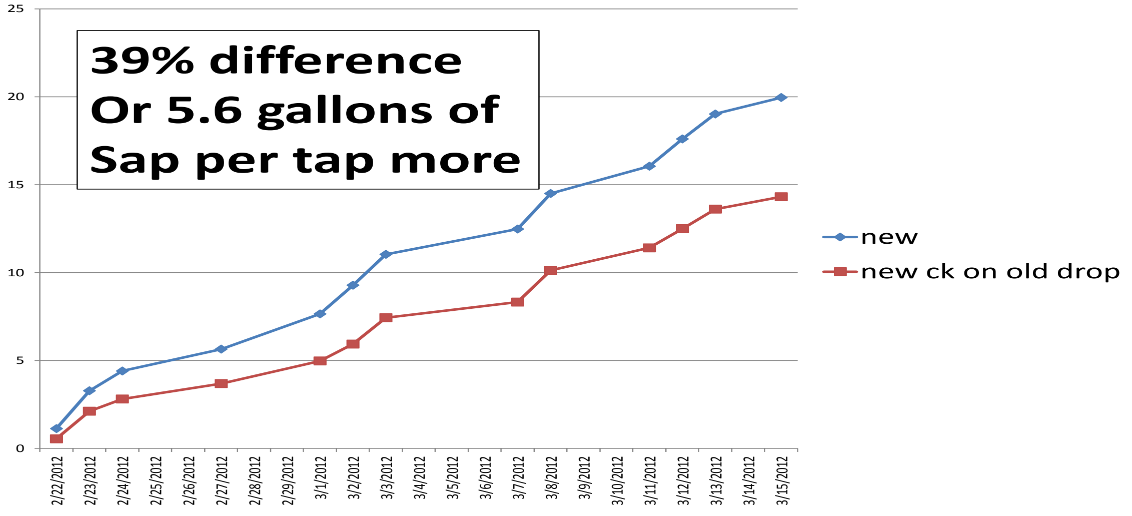
The standard test of comparing yield from a new spout and drop vs. an old spout and drop (used for at least ten years) was also used as a comparison this year. In all the prior seasons the new spout and drop showed at least an 80% increase in sap yield over the old spout and drop and usually over 100%. With this season ending abruptly with no significant warm weather (greater than 50 º F) between tapping and the unseasonal warm up that started on March 13^{th} the old spout and drop had just begun to drop in yield performance resulting in just a 25% or 3.7 more sap from the new spout and drop. The new spout and drop yielded 18 gallons of sap per tap and the old spout and drop 14.3 gallons of sap per tap. This test was conducted at between 21" and 22" of Hg. Both the old and new spouts were black plastic.



Vacuum – new spout and drop vs. old spout and drop

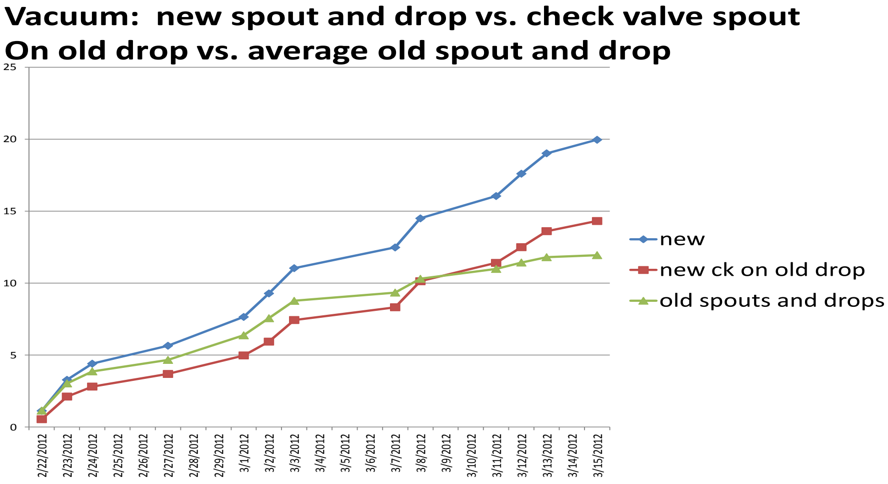
25% more sap or 3.7 gallons more Sap per tap

A new spout and drop was compared with a new check valve spout on an old drop (in use more than 10 continuous seasons) at the 21” to 22” Hg vacuum, new spouts were black plastic. Here the average yield of the new spout and drop was 20 gallons of sap per tap and the check valve on the old drop yielded 14.8 gallons of sap per tap for a difference of 39% or 5.6 gallons of sap per tap more with the new spout and drop. In these replications the difference between treatments started right from the beginning of the season which is not what we have consistently seen in most all comparisons which are normally the same early in the season followed by the spouts that best protect the taphole from bacteria and yeast sustaining sap yield while old equipment contaminated with bacteria and yeast begins to reduce sap yield once temperatures above 50ºF are observed. This difference from the normal pattern of results make me suspect that this treatment had some poor tap holes or restriction issues that I was not able to identify.



Vacuum – New spout and drop vs. new check valve spout on old drop

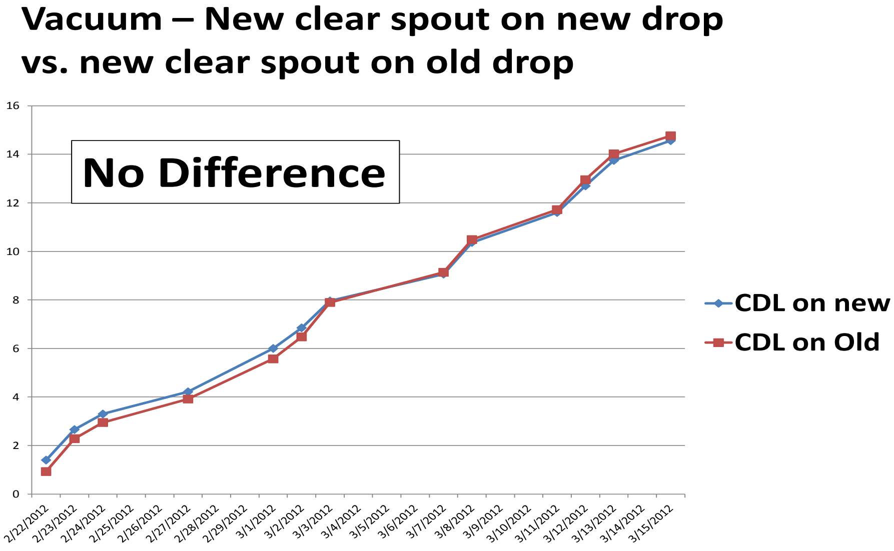
39% difference Or 5.6 gallons of Sap per tap more


Vacuum: new spout and drop vs. check valve spout On old drop vs. average old spout and drop

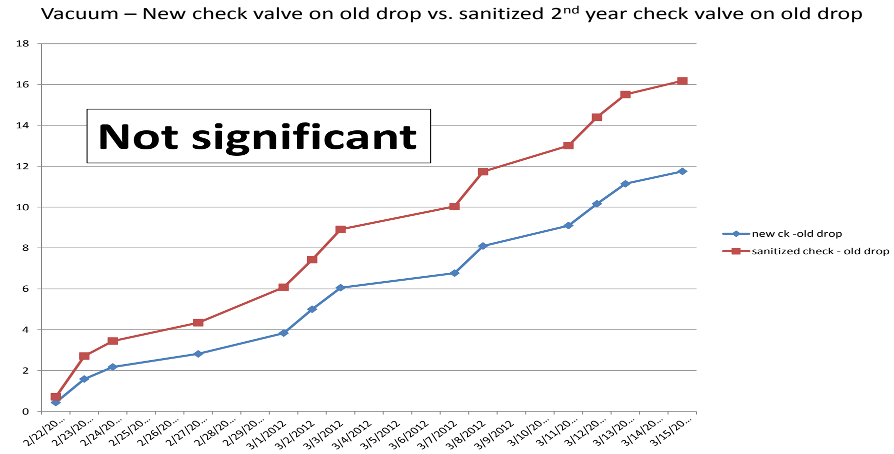
When the new check valve is also compared to the average of new spout and drop results and the average old spout and drop for all the treatments and replications in the sugarbush check valve treatments yielded about a 3 gallons of sap per tap advantage over the old spout and drop treatments.

Treating maple tubing with an alcohol wash prior to the season did not show any yield improvement under vacuum or on a gravity system.

A new clear poly carbonate spout with new drop was compared to a new clear poly carbonate spout on an old drop with no difference. Both treatments yielded about 14.5 gallons of sap per tap. The problem here is that both of these treatments averaged only 14.5 gallons of sap per tap or very near what the old spout and drop yielded in other tests, less than where the black spouts were used with new tubing. It is obvious that more tests and more seasons are needed to examine these differences to conclude if clear spouts or black spouts offer some kind of clear advantage.

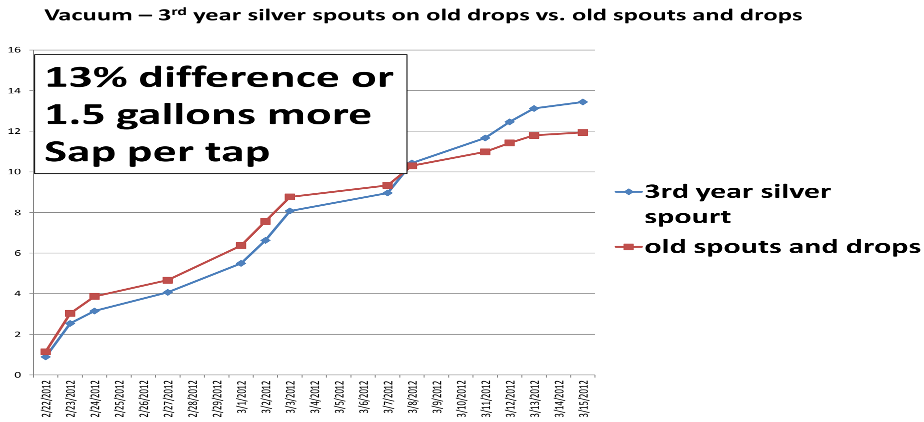

Vacuum – New clear spout on new drop vs. new clear spout on old drop

One of the questions that consistently comes from maple producers is can the check valves be cleaned and reused? Traditionally the results of trying to clean plastics in the field have not been successful at getting like new response. In the case of check valves they can be transported back to the sugarhouse and handled more easily than trying to return the whole tubing system. In the sugarhouse or at the farm there are more cleaning and sanitizing options available. In this next test check valves that had been used in the 2011 maple season were cooked in vegetable oil at 300ºF for 15 minutes then washed with soap and, completely rinsed, dried then checked to be sure the check valve ball was in place and able to move freely in the channel. The hot oil was used to get to a hotter temperature than would be offered by boiling water. It was also to test what physical characteristics would change in the spout when exposed to the higher heat. The higher temperature did release some of the check valve balls from the spout at about 15% rate. Otherwise the spouts showed no negative results of being boiled in the hot oil. The results are surprising. The sanitized check valve spouts averaged about 4 gallons of sap more than the new check valve spouts but the reps were not consistent indicating that this test would not be significant or this average difference would not be expected consistently. Again with the unusual season no conclusion can be drawn from this one set of tests. More seasons of testing are needed to draw any realistic conclusion. Again the differences started right in the beginning of the season rather than being time and temperature induce so sanitation is not the likely cause.


Vacuum – New check valve on old drop vs. sanitized 2nd year check valve on old drop

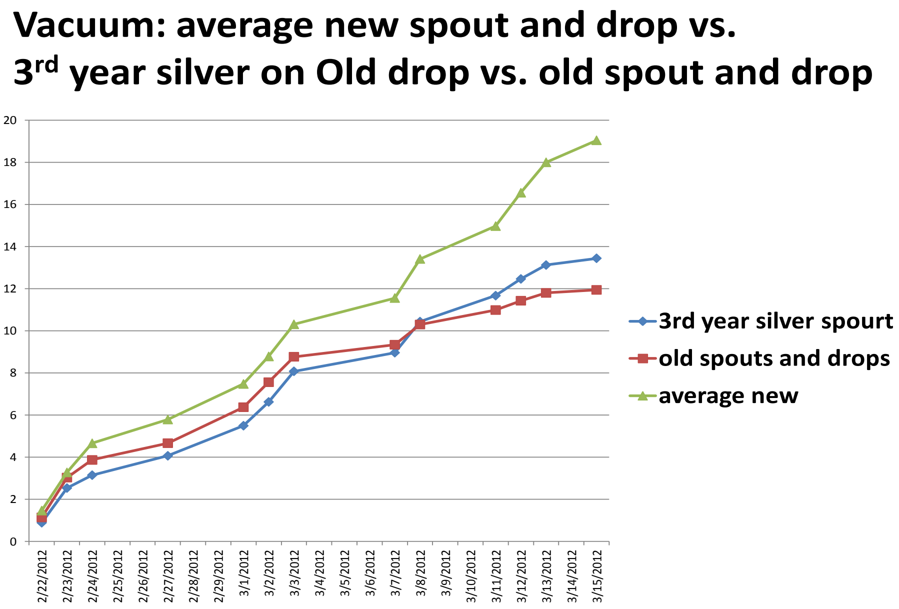
Not significant

For two years the silver spouts have given about a 70% increase in sap yield in their first and second year of use. In 2012 they were used for the third year in a row and produced a difference of just 13% or 1.5 more gallons of sap per tap. Testing in the fourth year should better indicated if the spouts have lost much of their effectiveness or the sudden end of season was the reason for the smaller result.


Vacuum – 3rd year silver spouts on old drops vs. old spouts and drops

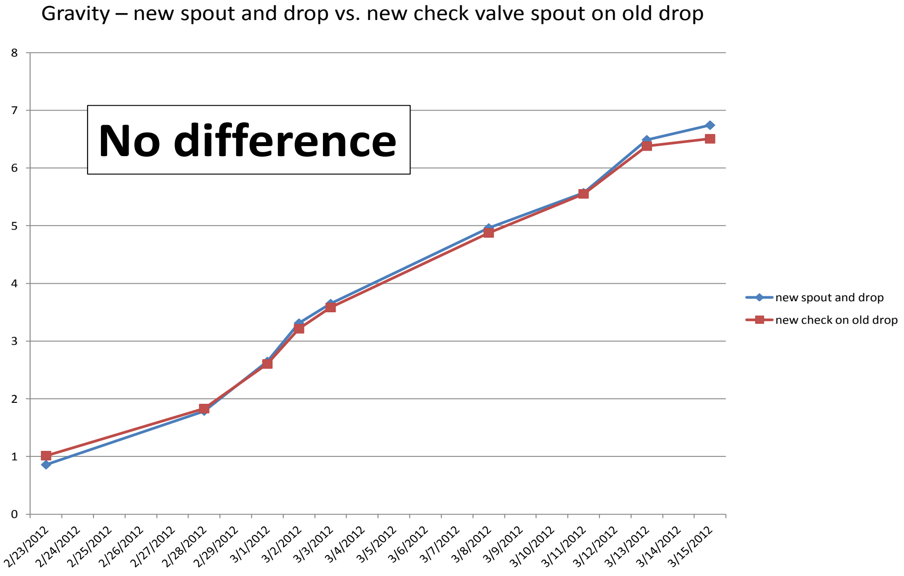
13% difference or 1.5 gallons more Sap per tap

When compared with the average of new spouts and drops in the sugarbush would indicate that it was not all due to the unusual season. The new spout and drop averaged 19 gallons of sap per tap, 3rd year silver averaged 13.8 gallons of sap per tap and old spouts and drops averaged just 12 gallons of sap per tap as seen in the chart below.



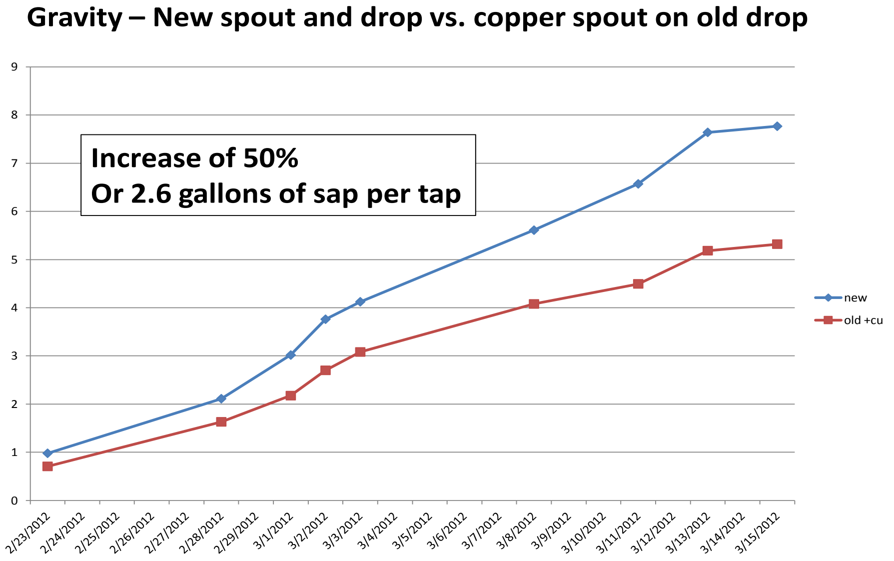
Vacuum: average new spout and drop vs.
3rd year silver on Old drop vs. old spout and drop

A series of tubing without vacuum tests were also conducted in 2012
Under gravity the new spout and drop vs. a check valve on an old drop resulted in no difference in the yield.

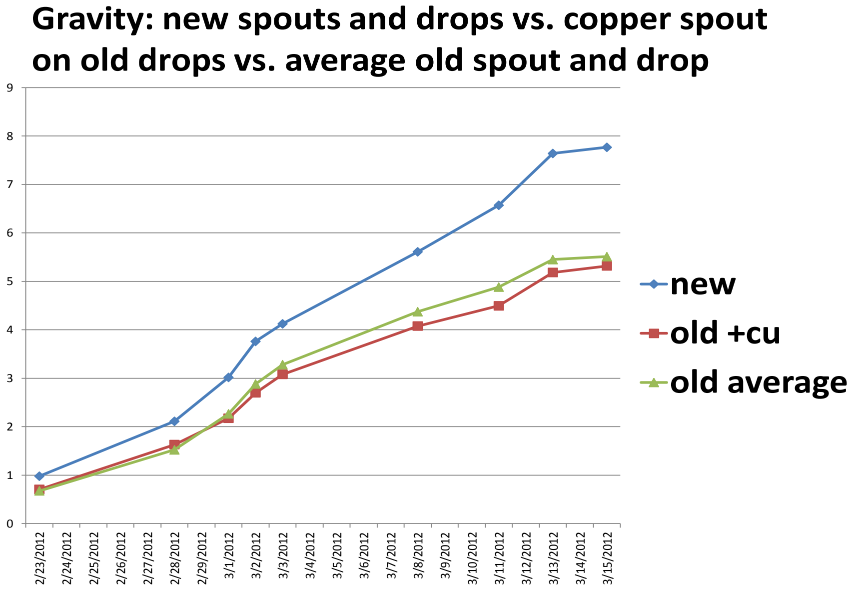


Gravity – new spout and drop vs. new check valve spout on old drop

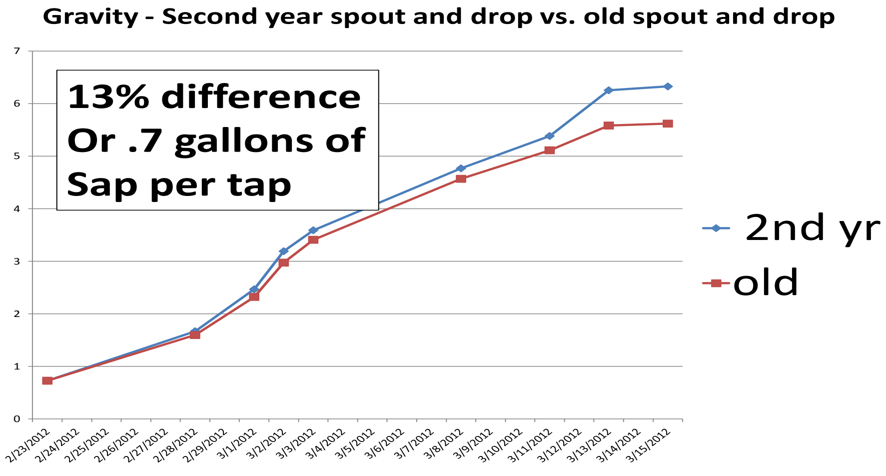
A test was run where a new black spout and new drop was compared to a new copper spout with an old drop. The copper spouts performed the poorest of all treatments resulting in just 5.2 gallons of sap per tap for the season while the new spout and drop produced 7.8 gallons of sap from the same tree.

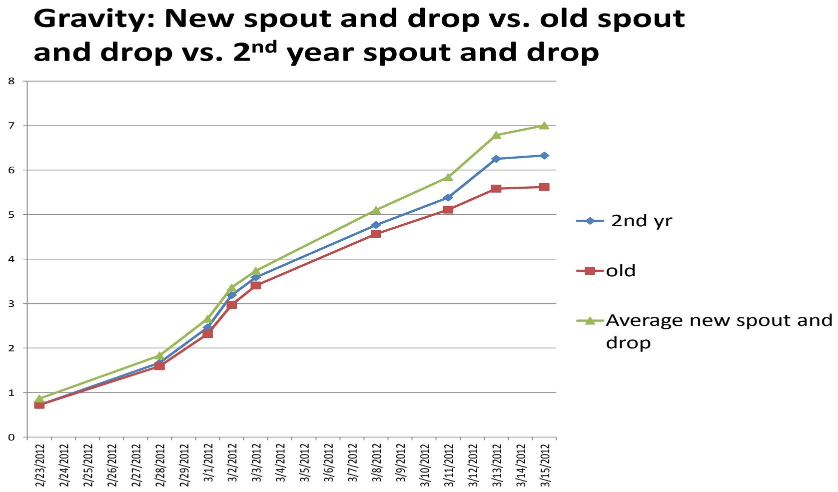

Gravity – New spout and drop vs. copper spout on old drop

Increase of 50%
Or 2.6 gallons of sap per tap

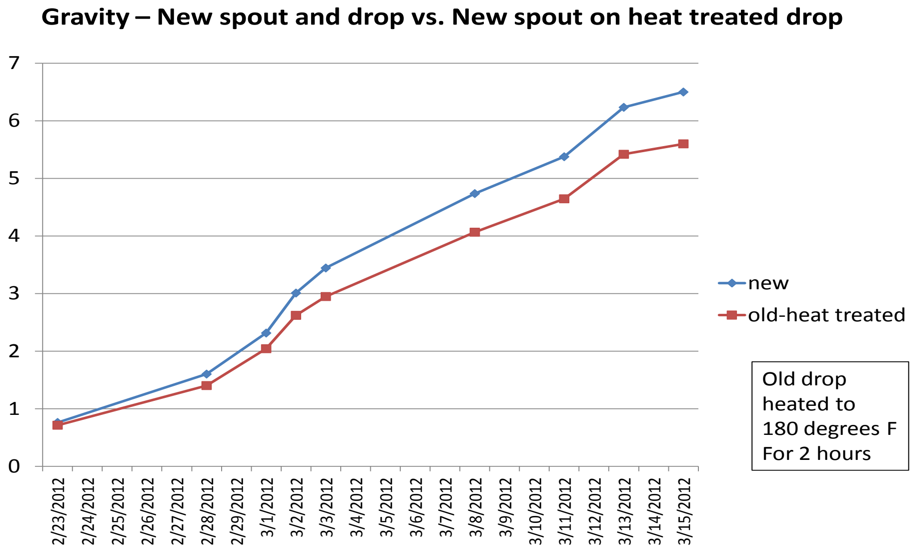

Gravity: new spouts and drops vs. copper spout on old drops vs. average old spout and drop

The question of how long does the effect of a new spout and drop last was again tested in 2012 where a second year spout and drop was compared with an old spout and drop with only a gain of .7 gallons of sap per tap or 13%. Over the years this has been tested this difference is the most inconsistent of all the tests tried. Generally a second year spout and drop is much less than new but still better than old.





In looking for ways to clean and sanitize used tubing so that the tap will yield like it would with new spout and drop has lead to some extreme attempts at finding what the limits are on tubing treatments. In this experiment droplines that have been in continuous use for over 10 years were baked in an oven at 180°F for two hours were compared with new droplines. In this case both the new droplines and the heated droplines were connected with the taphole with a new black plastic spout. In this test the new droplines with new spout yielded about 6.5 gallons of sap per tap while the heat treated droplines with new spout yielded about 5.6 gallons of sap per tap or about 16% less yield. In order to accomplish this kind of treatment the maple producer would have to remove all of the droplines and take them to a treatment site then return them to the trees. For this amount of work a bigger difference would be necessary in order to be financially profitable. This test should be conducted again as many of the taphole sanitation practices did not have a chance to enhance yield due to the unusual weather as they have in all the other years testing.



This research was supported in part by the North American Maple Syrup Council Research Fund.

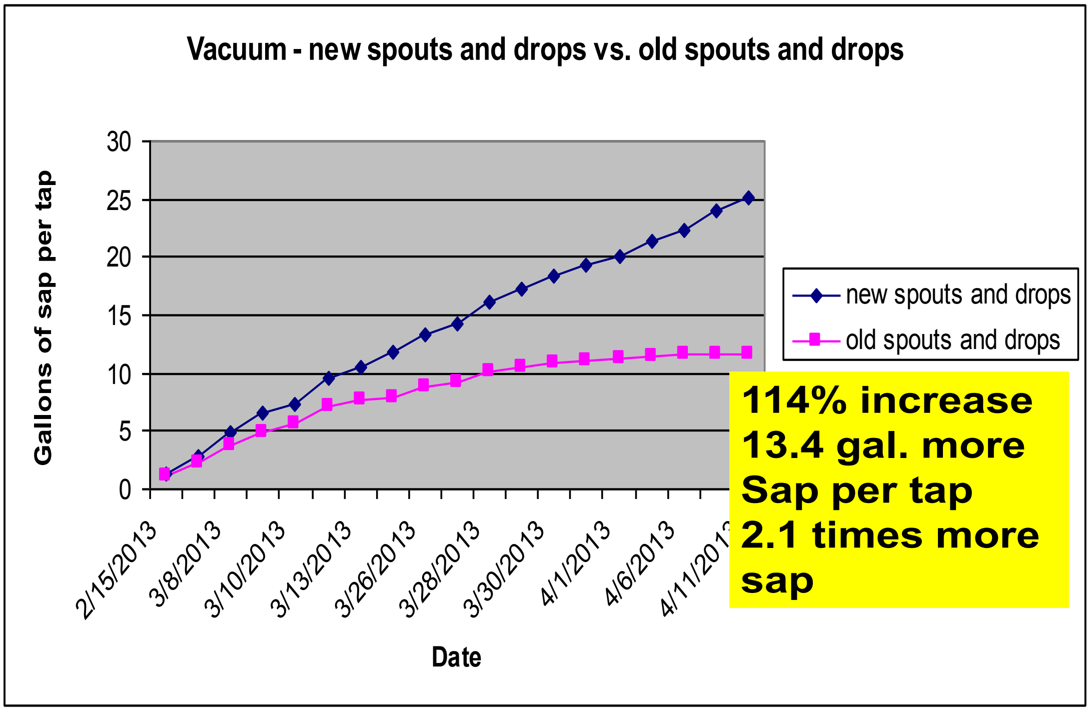
8.8 2013 Cornell tap hole sanitation research results

2013 Maple Tubing Research
by Stephen Childs, NYS Maple Specialist

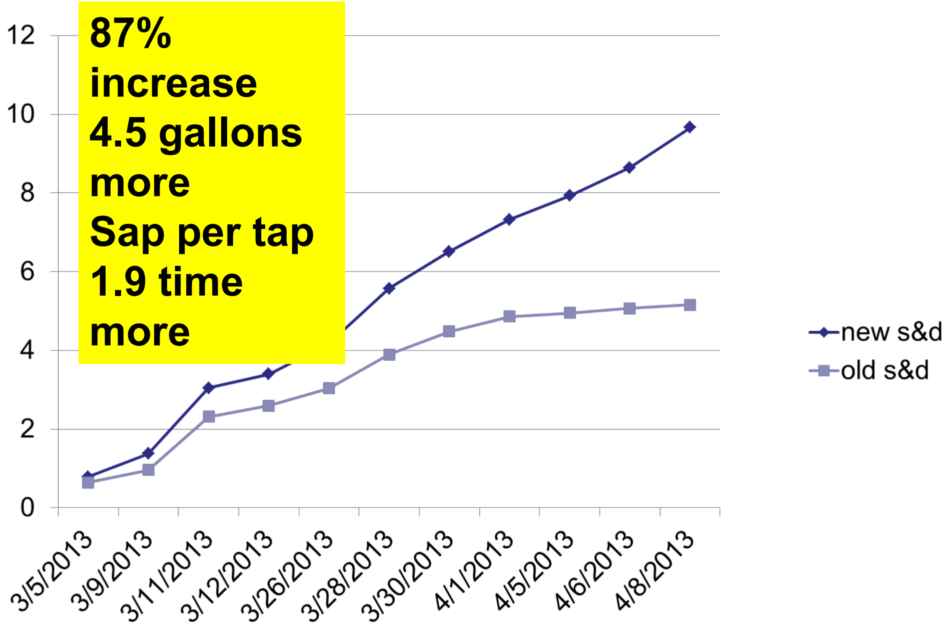
In 2013 a variety of spout and tubing cleaning and replacement options were tested to determine the extent of sap yield changes that would result. Most of these tests were done at the Cornell Arnot Research Forest. Treatments except where noted were a direct comparison between a check and a described treatment each with three replications, each replication with 4 to 6 taps, both treatments in the same tree, spaced about 10 inches apart at the same elevation and same basic orientation. The check was usually represented by an old spout and old drop, having been used each season for at least 10 years or in a few cases by a new spout and new drop. The 2013 season started early with our first measureable sap run occurring on February 15th followed by a long cool season lasting well into April. In the vacuum systems tests the vacuum level was consistently between 21” and 22” Hg.

It is important to remember some of the factors in maple production that make the maple taphole subject to season ending taphole drying. Sap stops running at the end of the season for one of two reasons. First, the weather no longer provides any more freeze thaw cycles necessary for sap flow. Second, the very small vessels in the wood in the tap hole become plugged with bacteria and yeast blocking the flow of sap. There seem to be two important means by which tap holes become contaminated with bacteria and yeast that a maple producer can have some reasonable method of control. First, the spout that is driven into the freshly drilled taphole must be sanitary. Sanitary meaning that it is either new or been completely sanitized with a chemical sanitizer, heat or other sanitizing action. Second, as the tree alternates between positive internal pressure when it is above freezing and negative (vacuum) internal pressure then it first drops below freezing, sap is sucked back into the tree through the spout and out of the tubing which if it has been in use for more than a season or two is often loaded with a population of bacteria and yeast. To avoid tap hole contamination due to this pulling of sap back into the tree either the back flow must be blocked as with a check valve or the inside of the spout and dropline must be sanitary. The inside of tubing could be sanitary due to being new or having been sanitized with chemicals, heat or other method of cleaning. Below are photos of the pressure changes in a maple tree do to temperature changes. The first shows about 26 psi positive pressure when the temperature was above 40 degrees F the morning after a freeze. The second picture shows about 10 inches of vacuum developed in the tree during a period of freezing during the maple season.

The standard test of comparing yield from a new spout and drop vs. an old spout and drop (used for at least ten years) was also used as a comparison this year. This test was conducted at between 21” and 22” of Hg and the old and new spouts were black plastic. In 2013 the new spout and drop produced about 25 gallons of sap per tap while the old spout and drop yielded about 12 gallons of sap per tap for an increase of 114% or 13.4 more gallons of sap per tap with the new spout and drop. On the gravity system with the same test we did not see measureable sap flow until March 5th. Here the new spout and drop yielded 87% or 4.5 more gallons of sap per tap than the old spout and drop.



114% increase
13.4 gal. more
Sap per tap
2.1 times more
sap



Gravity – new spout and drop vs. old spout and drop

87%
increase
4.5 gallons
more
Sap per tap
1.9 time
more

The chart below shows how these treatments have compared over the last 7 years of testing both on gravity and vacuum.

Record of new spout and drop vs. old spout and drop

Gravity

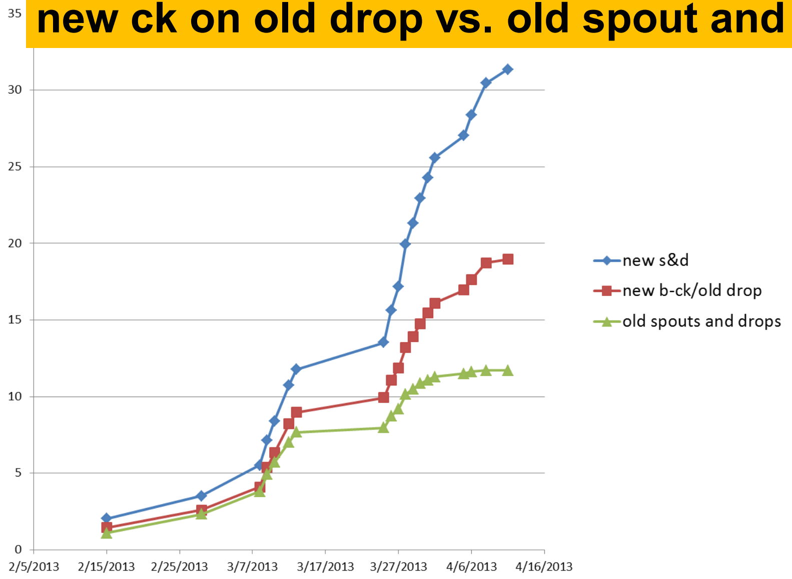
- **2007 – Haag field study 100% increase**
- **2008 – Arnot 100% inc.**
- **2009 – Arnot 160% inc.**
- **2010 – Arnot 76% inc.**
- **2011 – Arnot 133% inc.**
- **2012 – Arnot 42% inc.**
- **2013 – Arnot 87% inc.**

Vacuum

- **2009 – Breezie Maple field study 110% increase**
- **2010 – Arnot 151% inc.**
- **2011 – Arnot 120% inc.**
- **2012 – Arnot 25% inc.**
- **2013 – Arnot 114% inc.**

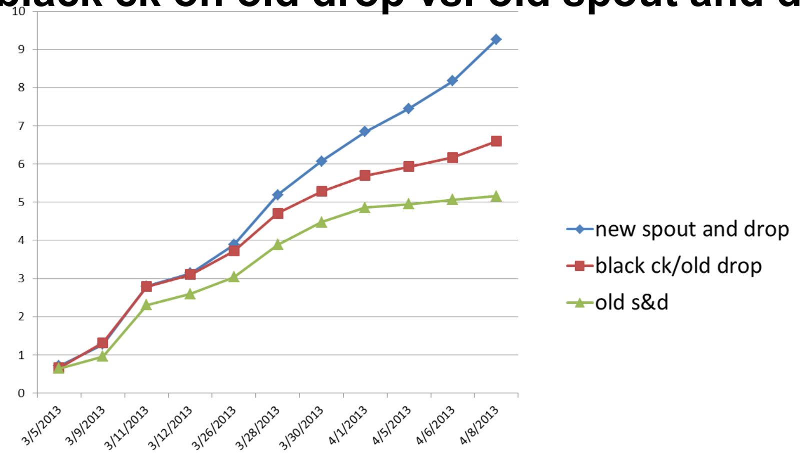
In 2013 several tests were conducted using check valve spouts. A new spout and drop was compared with a new check valve spout on an old drop (in use more than 10 continuous seasons) at the 21” to 22” Hg vacuum, new spouts were black plastic. Here the average yield of the new spout and drop was about 32 gallons of sap per tap and the check valve on the old drop yielded about 19 gallons of sap per tap for a difference of 65% or 12.4 gallons of sap per tap more with the new spout and drop. The new black check valve out yielded the average old spout and drop in the same woods by 7 gallons of sap per tap for an increase of 63%.

Vacuum – new spout and drop vs. new ck on old drop vs. old spout and drop



The results with the same treatments on gravity were simular. With the new spout and drop out performing the new check valve on an old drop by 35% and the new black check valve spout on an old drop out performing the average old spout and drop by 33%

Gravity – new spout and drop vs. black ck on old drop vs. old spout and drop

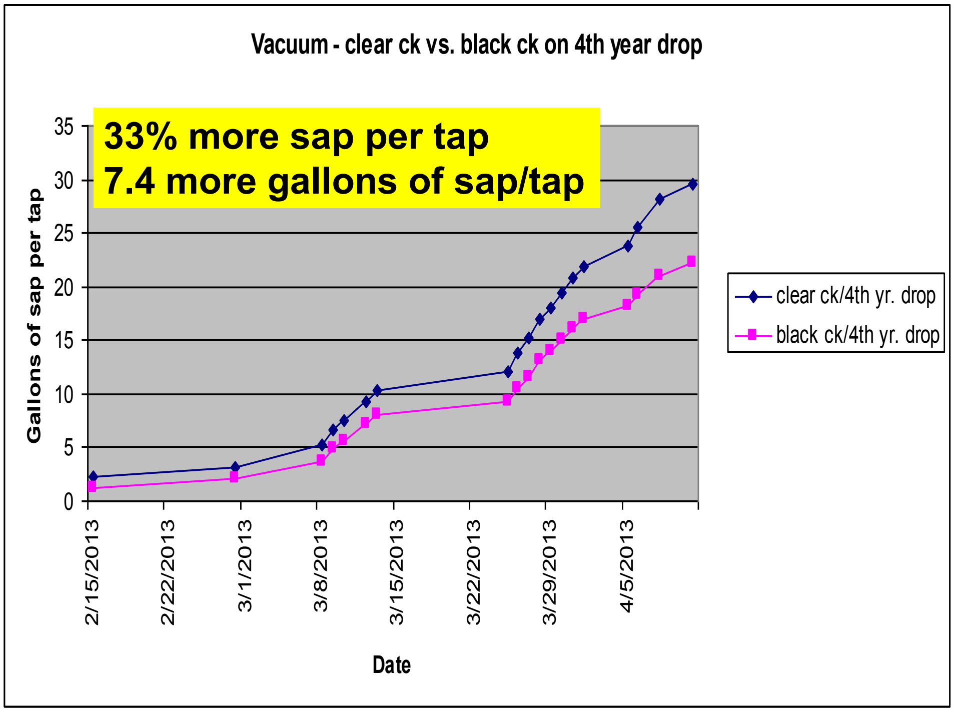


History of Check Valve Tests

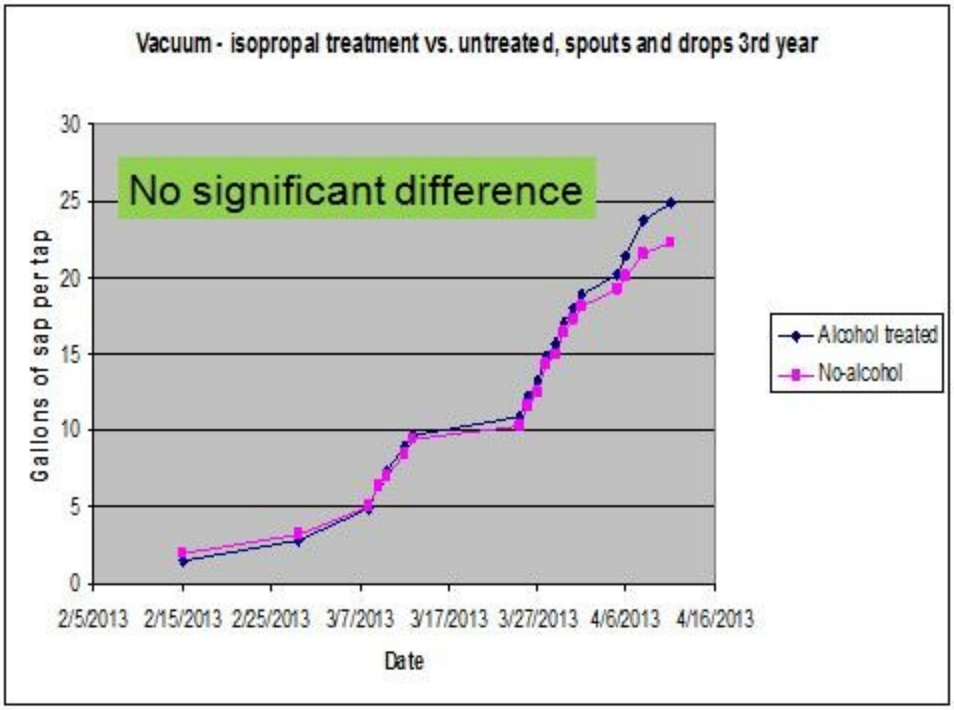
- **Vacuum**
- **2013 65% increase**
- **2012 20%**
- **2011 101%**
- **2010 114%**

- **Gravity**
- **2013 33% increase**
- **2012 18%**
- **2011 77%**
- **2010 47%**
- **2009 43%**

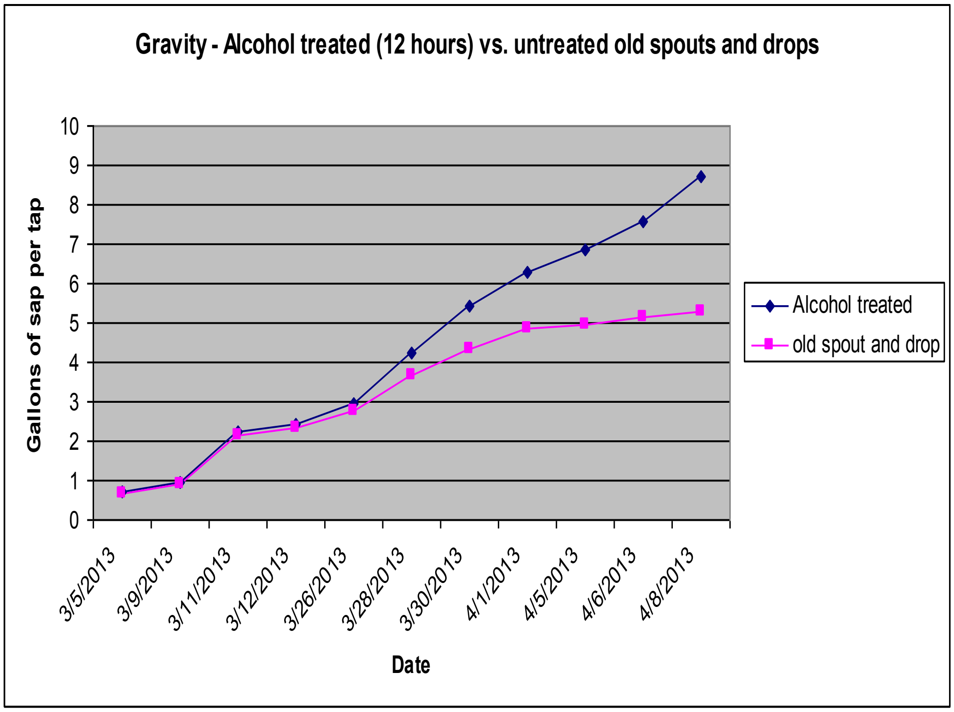
Also the new clear check valve was tested against new black check valves. In this test both new check valves were on fourth season drop lines. In this case the new clear check valve treatment outperformed the new black check valves by 33% yielding an average 7.4 more sap per tap.



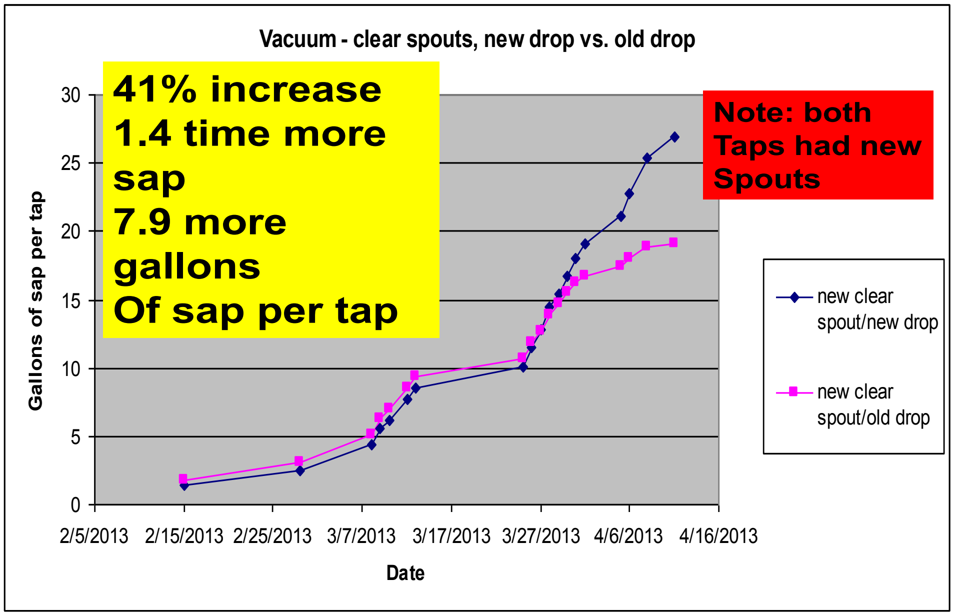
Maple tubing on vacuum was sanitized with isopropyl alcohol. On February 14th 3-4 ounces of 50% Isopropyl alcohol was sucked up by vacuum into each spout and the spout wiped with it as well. Spouts and drops were in use for the third year. Treating maple tubing this way with an alcohol wash prior to the season did not show any yield improvement under vacuum.



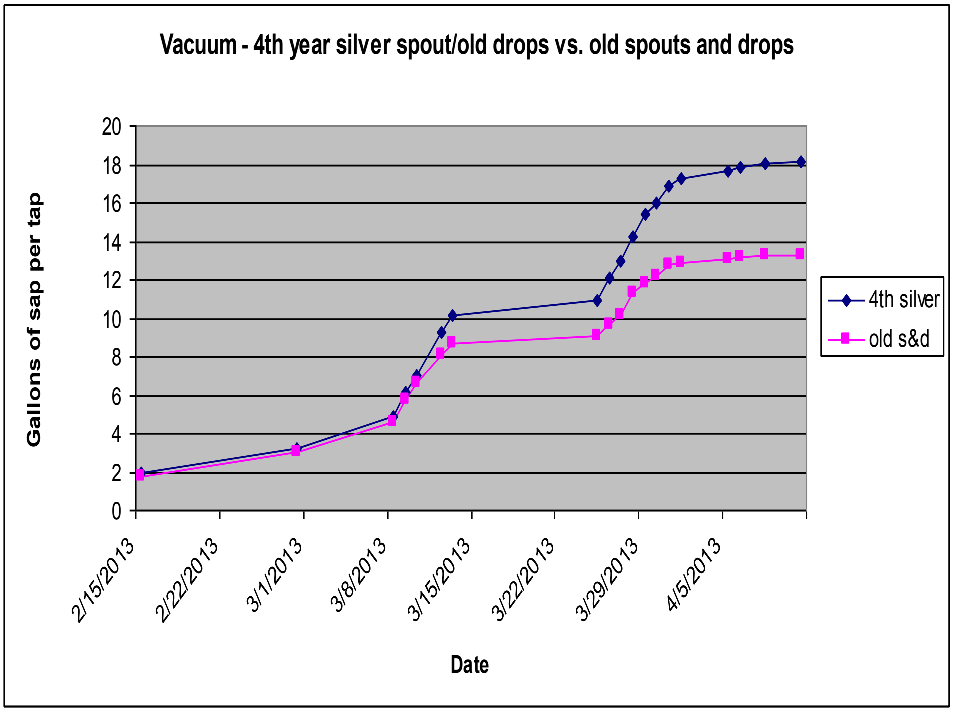
On the gravity system more aggressive treatments were conducted. On February 13th spouts and drops were removed from the trees and submersed in 50% Isopropyl alcohol over night for 12 hours, drained and replaced on the lateral lines and tapped into the trees. Spouts in 3rd season, drops were at least ten years old. In this case a difference of 3.5 gallons per tap was recorded for an increase of 66%. Please note these tests are for comparison only as washing a porous food contact surface with isopropyl alcohol is not approved in New York State though it is widely used in Canada.



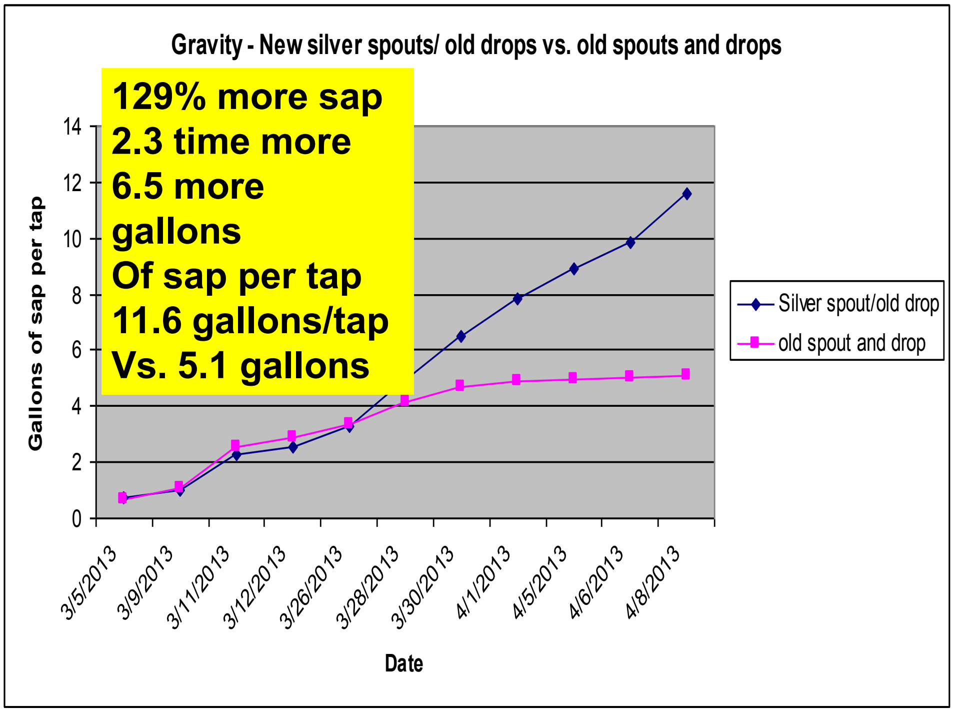
A new clear poly carbonate spout with new tubing was compared to a new clear poly carbonate spout on an old drop. In this test the new clear spout on a new drop out performed the new clear spout on an old drop by 41% or 7.9 more gallons of sap per tap.



In 2013 fourth season silver spouts on old drops on vacuum were compared to old spouts and drops. The four year silver spouts still out performed old spouts and drops by 32% or 4.4 more gallons of sap per tap. In the gravity test the first year silver spouts on old drops out yielded old spouts and drops by 129% or 6.5 more gallons of sap per tap. The history of silver spout results is also posted below.



Vacuum - 4th year silver spout/old drops vs. old spouts and drops



Gravity - New silver spouts/ old drops vs. old spouts and drops

129% more sap
2.3 time more
6.5 more
gallons
Of sap per tap
11.6 gallons/tap
Vs. 5.1 gallons

Silver spouts – production history

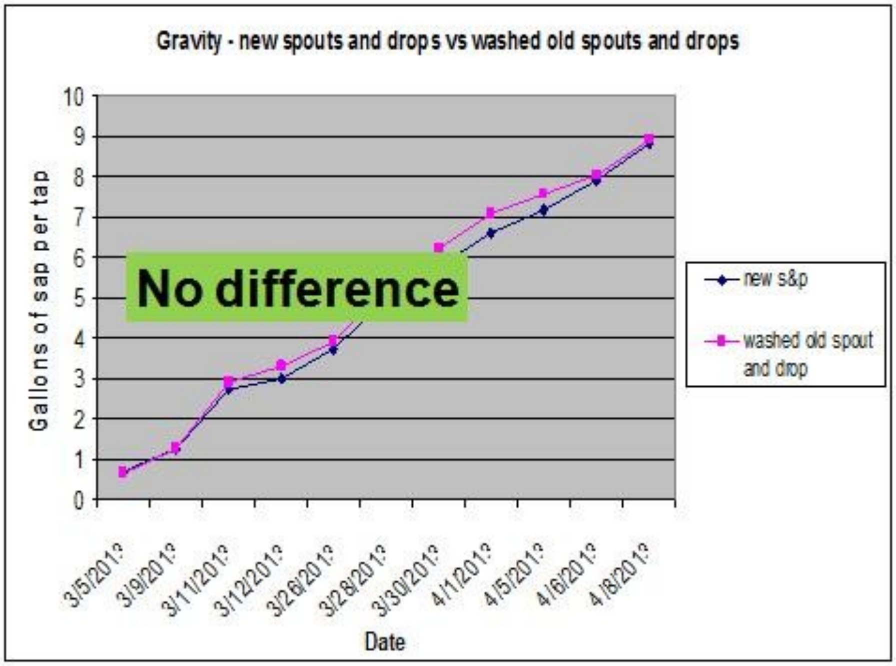
Gravity

- 2013 – Arnot 129% increase

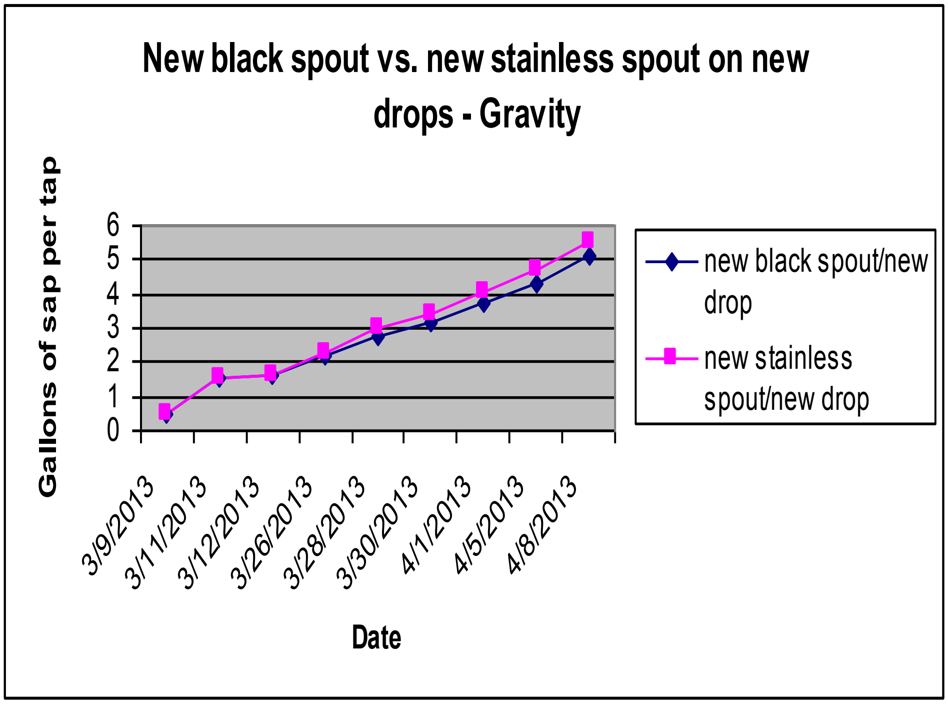
Vacuum

- 2010 – Arnot, 1st year silver spout 67% increase over old s&d.
- 2010 – Sugar Bush Hollow -16% increase over new check valve
- 2011 – Arnot, 2nd year silver spout, 72 % increase over old s&d
- 2012 – Arnot, 3rd year silver spout 13 % inc.
- 2013 – Arnot, 4th year silver spout 36% inc.

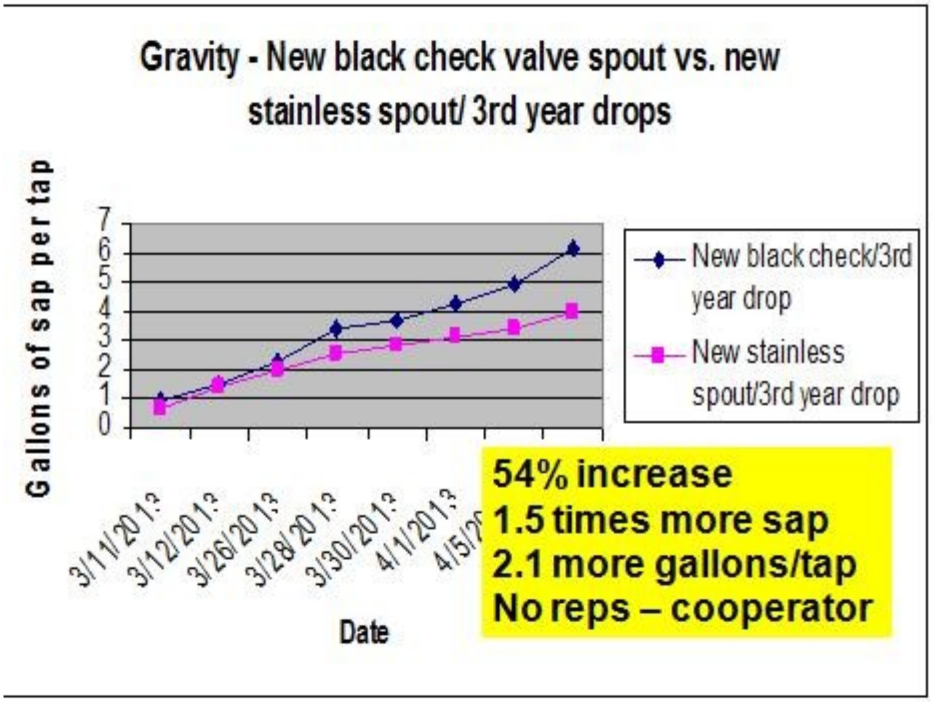
In 2013 a test was conducted to compare a new spout and drop with old tubing which had an extensive cleaning and sanitizing. Old spouts and drops had been in continuous use for 15+ years and they were washed first with detergent and water, then rinsed, followed by 10 minutes of 10% chlorine treatment, rinsed and followed by a 20 minute, hydrogen peroxide treatment and finally rinsed and drained. The result showed the washed old tubing to perform as well as the new spout and tubing with the new yielding 8.8 gallons sap per tap, washed yielded 8.9 gallons of sap per tap.



A couple of additional tests were conducted to evaluate stainless steel spouts. First new stainless spouts on new drops were compared with new black spouts on new drops. The result was no production difference.

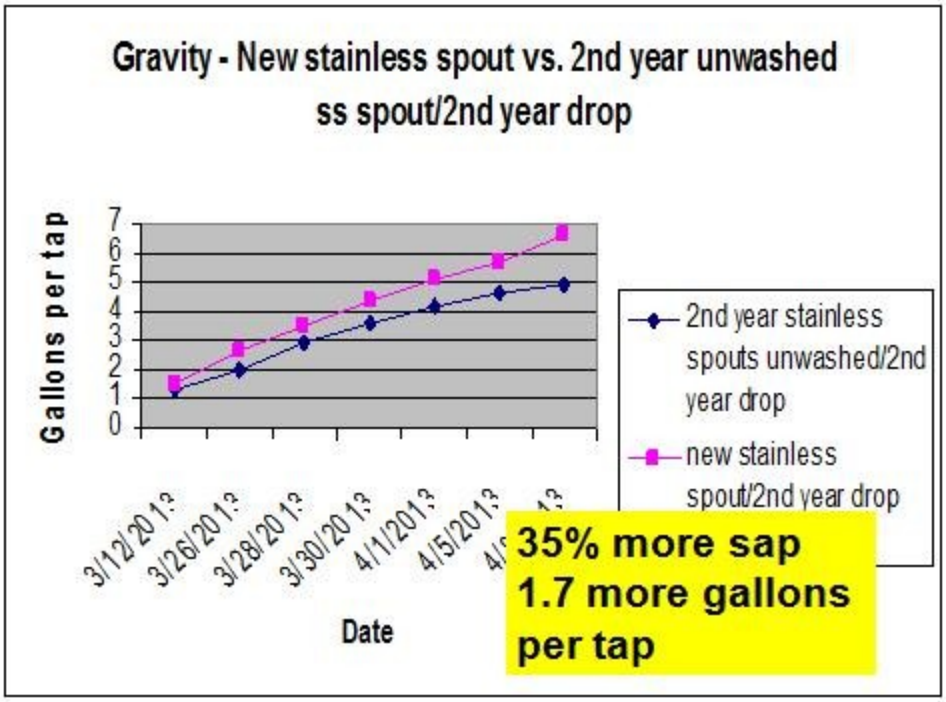


In another gravity test new black check valves were compared to new stainless steel spouts both on third year drops. In this case the new black check valves on third year drops out performed new stainless spouts on third year spouts by 54% or 2.1 more gallons of sap per tap. This test was conducted on a cooperator site and was not replicated.



54% increase
1.5 times more sap
2.1 more gallons/tap
No reps – cooperator

Finally new stainless spouts on second year drops were compared to second year stainless spouts that had only been rinsed with water and not sanitized on second year drops. New spouts out performed unsanitized stainless spouts by 35% or 1.7 more gallons of sap per tap. This shows the value of a clean sanitary spout vs. a water rinsed used stainless spout.



35% more sap 1.7 more gallons per tap

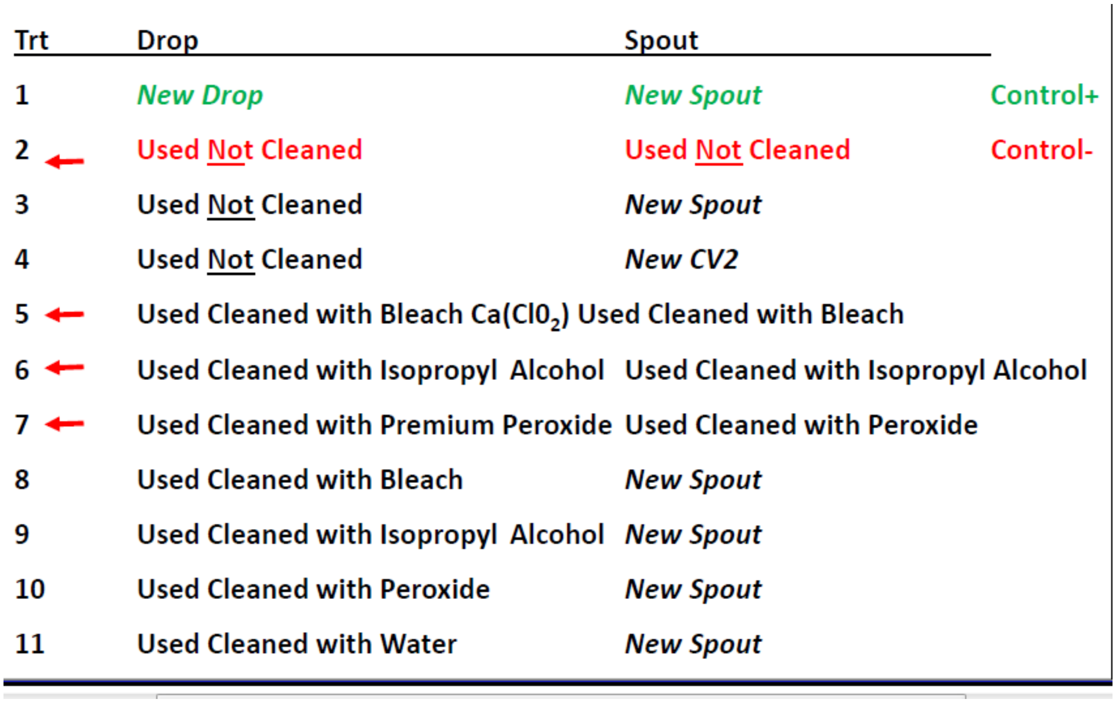
In conclusion, these kinds of tests continue to show clearly that a variety of tap hole sanitation practices significantly increase sap production per tap. Each sanitation practice creates its own level of added investment and labor. Each producer must decide which practice if any fits that operations production goals, available labor and available capital to add this value to their operation. Plans are to have more tests conducted in the 2014 maple season. Industry support for this kind of work is also welcome.

Finally new stainless spouts on second year drops were compared to second year stainless spouts that had only been rinsed with water and not sanitized on second year drops. New spouts out performed unsanitized stainless spouts by 35% or 1.7 more gallons of sap per tap. This shows the value of a clean sanitary spout vs. a water rinsed used stainless spout.

8.9 2014-15 Taphole Sanitation Research

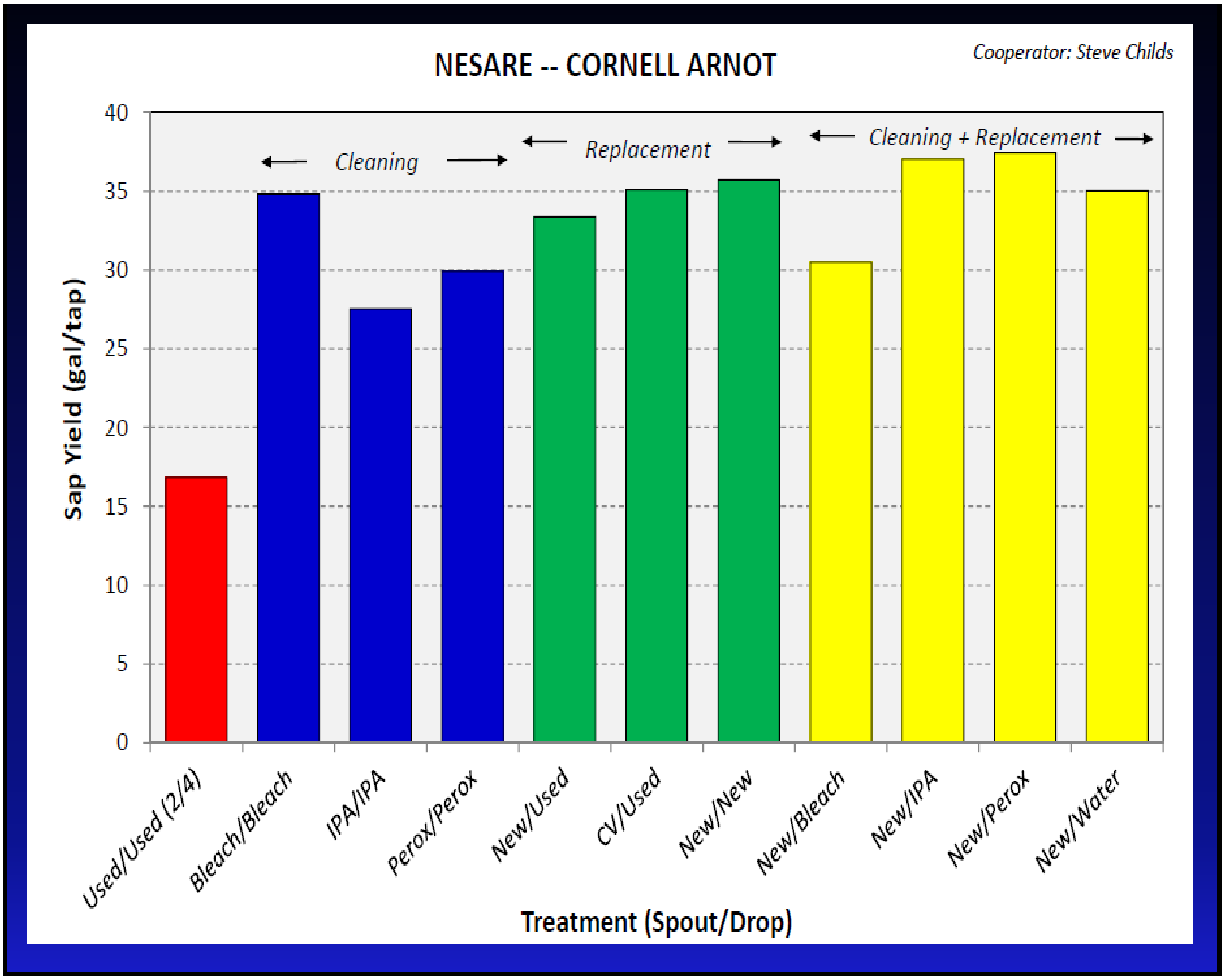
2014 -15 Maple Tubing Research
by Stephen Childs, NYS Maple Specialist

In 2014 and 2015 the focus of the tubing and taphole sanitation research changed dramatically. Tests conducted in 2013 showed that if the spout and drop line were adequately sanitized sap yield comparable to a new spout and drop could be obtained. With the assistance of a grant from the Northeast Sustainable Agriculture Research and Extension program of the USDA and in cooperation with the Proctor Maple Research Center in Vermont, a variety of spout and drop cleaning and replacement options were tested to determine the extent of sap yield changes. All of these tests were conducted at the Cornell Arnot Research Forest. All treatments had four replications, each replication with 4 taps on a lateral line. The 2014 season was slow starting with just a few flows in March and the season lasting well into April. The vacuum level was consistently between 21" and 22" Hg. Treatments are listed in the chart below:



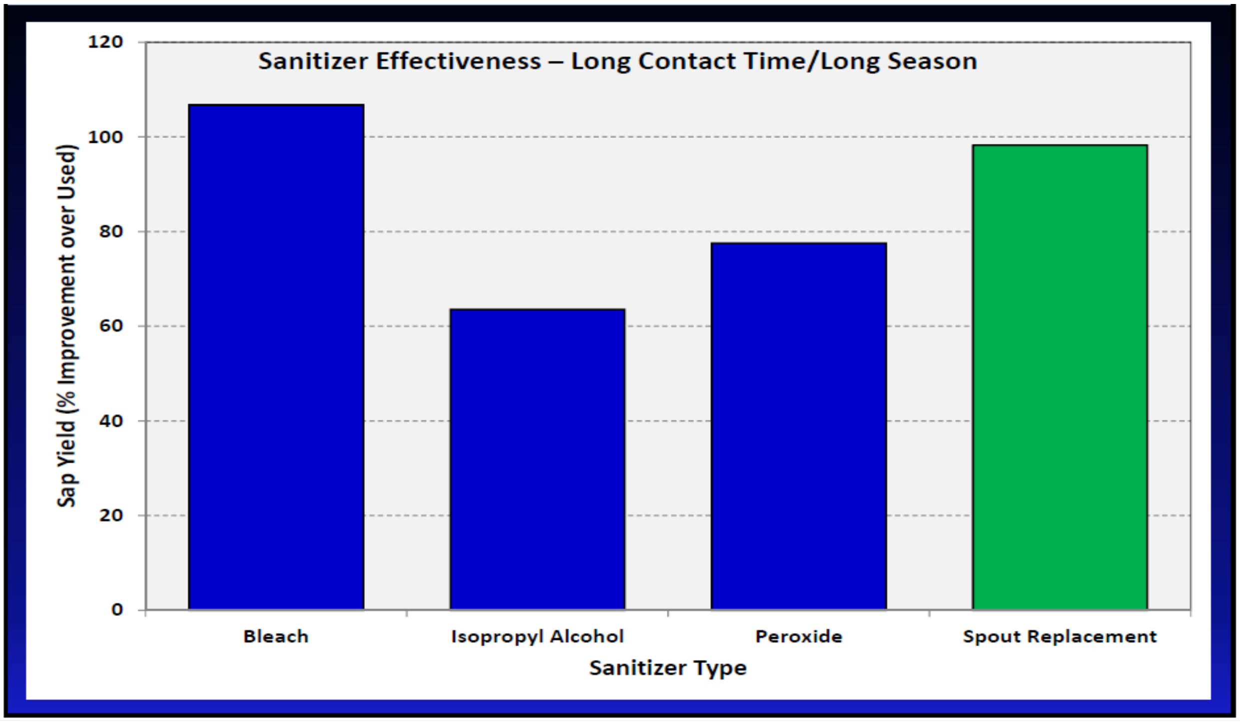
Trt	Drop	Spout	
1	*New Drop*	*New Spout*	Control+
2 ←	Used Not Cleaned	Used Not Cleaned	Control-
3	Used Not Cleaned	*New Spout*	
4	Used Not Cleaned	*New CV2*	
5 ←	Used Cleaned with Bleach Ca(Cl0$_2$)	Used Cleaned with Bleach	
6 ←	Used Cleaned with Isopropyl Alcohol	Used Cleaned with Isopropyl Alcohol	
7 ←	Used Cleaned with Premium Peroxide	Used Cleaned with Peroxide	
8	Used Cleaned with Bleach	*New Spout*	
9	Used Cleaned with Isopropyl Alcohol	*New Spout*	
10	Used Cleaned with Peroxide	*New Spout*	
11	Used Cleaned with Water	*New Spout*	

In every case where a sanitizer such as bleach, peroxide or isopropyl alcohol were used the treated spout and drop were brought from the sugarbush where they had been in prior use and sanitized with at least 30 minutes of contact time in the sanitizer. Following sanitizer treatment they were rinsed, dried, and reinstalled in the tubing system. All the drops in these tests were in the sugarbush for their 4th season and spouts for their 2nd season. All treatments were made in February and installed by the middle of February. Sap yields are reported in the following graph prepared by Dr. Tim Perkins at Proctor:

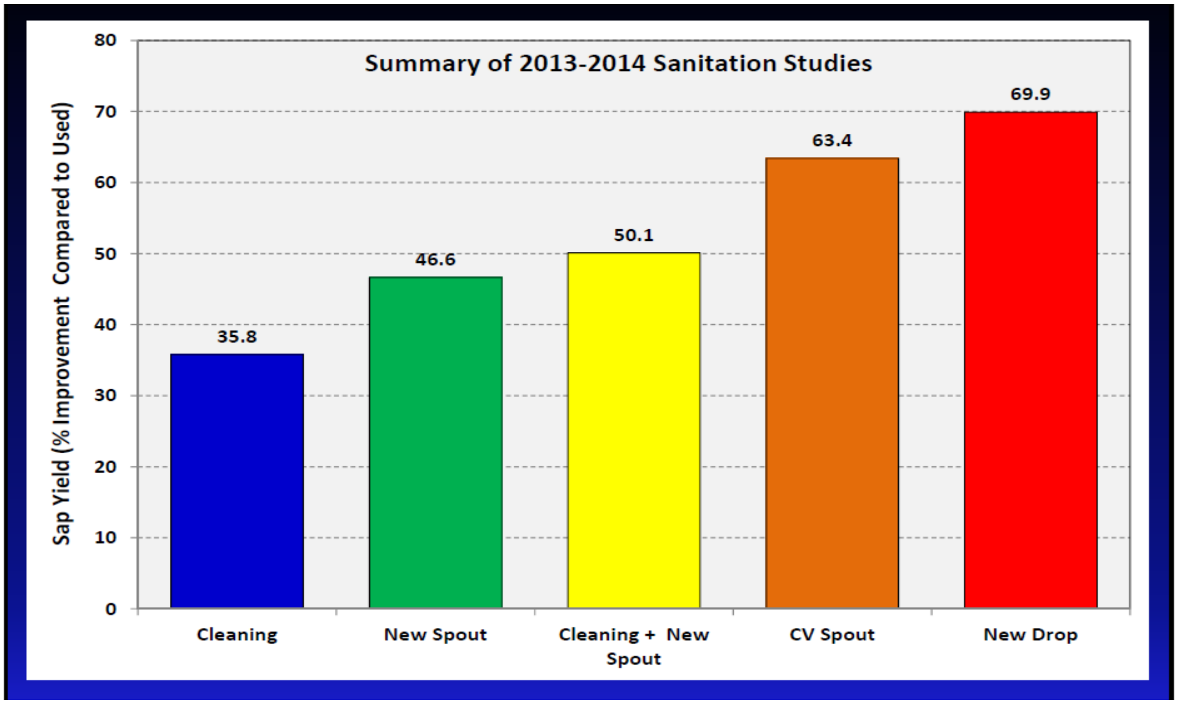


The used spout and drop with no cleaning treatment yielded an average of about 17 gallons of sap per tap. All other treatments show production between 27 and 37 gallons of sap per tap, yields were increased between 59% and 118% depending on the sanitizer used and the spout or drop replaced. The new clear check valve on a used drop line also showed results nearly equal to the new spout and drop. The new spout and drop yielded 106% more or an increase of 18 gallons of sap per tap more than the old spout and drop. Providing proper contact time with the sanitizer clearly provides significant yield improvement similar to replacement of the spout and drop. It is important to point out that Isopropyl alcohol is not approved for cleaning plastic tubing in New York as it is in Canada and is included only to see the Canadian claims of its superiority are true under New York conditions. Most cleaning and sanitation systems maple producers currently use in New York do not provide the necessary contact time with the sanitizer to obtain these kinds of sap yield improvement.

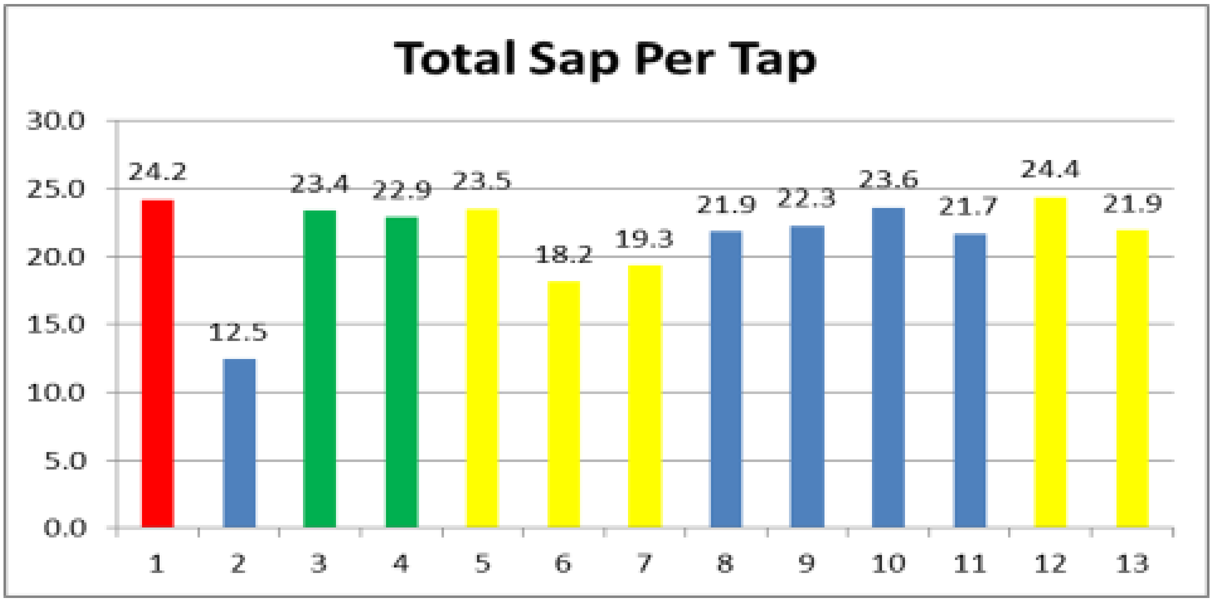
The following chart shows the relative effectiveness of the various sanitizers used in this study. It appears that bleach and spout replacement with a new spout provided the best results while isopropyl alcohol provided the least.



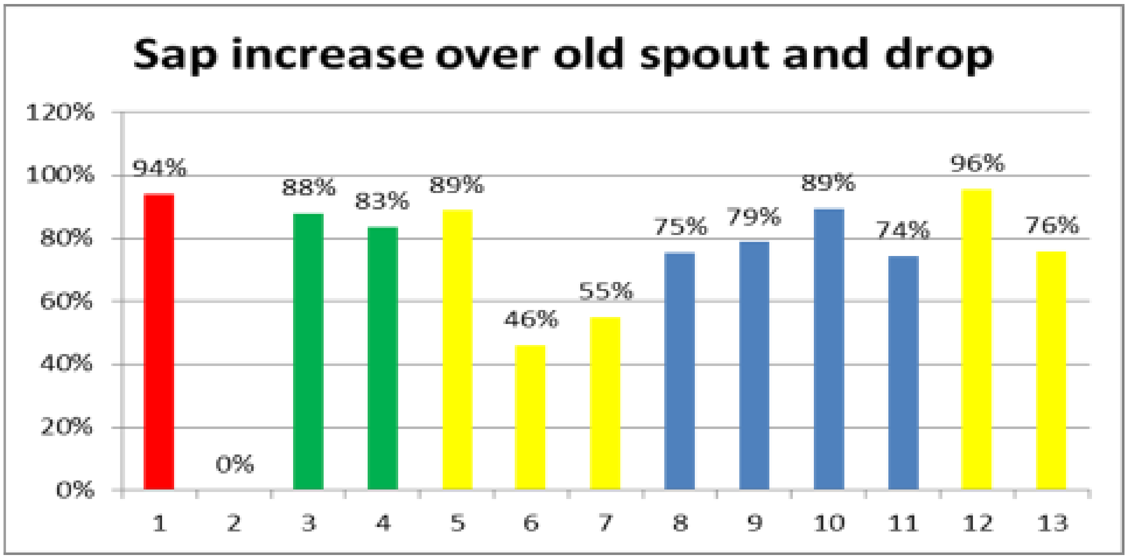
The next chart compares results from all tests conducted at Cornell and Proctor in the 2013 and 2014 maple seasons. The summary shows the relative value of the different styles of treatment with new spout and drop performing the best, followed by check valves followed by new spouts placed on sanitized drops then new spouts and last sanitizing both spout and drop. In the Proctor tests drops and spouts were treated using techniques common in the industry which provide only very short sanitizer contact time.



The 2015 season was very similar to the 2014 season where the season started late in March and much of the syrup made in April. The primary change made in 2015 compared to 2014 was that most of the treatments, 1-11 were conducted in the sugarbush in mid-September to see if working in the woods without the issues of snow and demands of taping time would still be effective. In the case of the sanitizers, drop lines were filled with sanitizer and capped so that they would have sufficient contact time then drained at tapping time in mid-February. Treatments with bleach(12) and peroxide(13) were also conducted at tapping time by removing them from the sugarbush and providing at least 30 minutes of contact time with the sanitizer solution followed by a rinse and dryed. These treatments were then returned to the sugarbush at tapping time in mid-February and installed. Results were very similar to those in 2014 with the new spout and drop out performing the old spout (3rd season in use) and old drop (5th season in use) by 94% yielding 11.7 more gallons of sap per tap. Treatments ranged from yield increases of 46% to a high of 96%. Treating in the fall performed only slightly less that the treatments at tapping time. Sanitizing with proper contact time again proves to very effective to producing excellent sap yield. To make removing the spout and drop convenient quick connects were added just above the drop line T as is pictured below.



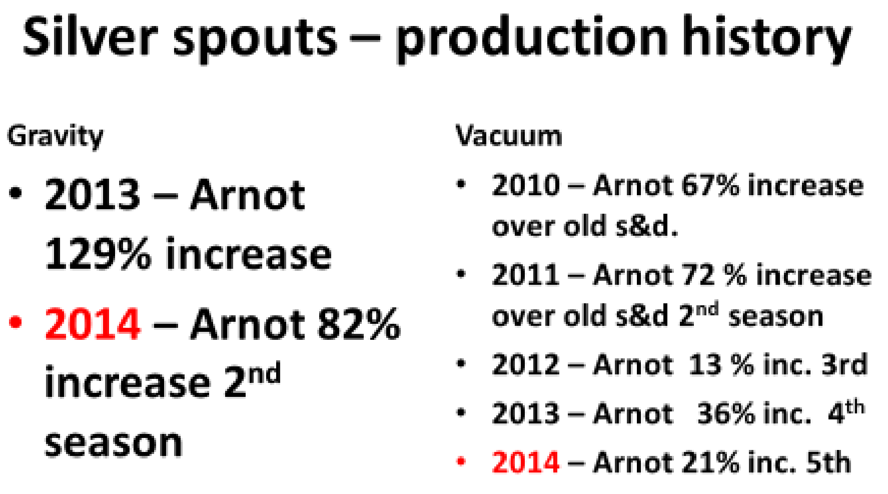
1. New spout/new drop
2. Old spout/old drop
3. New spout/old drop
4. New ck spout/old drop
5. Bleach/Bleach -Fall
6. Iso/Iso Fall
7. Peroxide/Peroxide Fall
8. New/Bleach Fall
9. New/Iso Fall
10. New/Peroxide Fall
11. New/Water wash
12. Bleach/Bleach Spring
13. Peroxide/Peroxide Spring



1. New spout/new drop
2. Old spout/old drop
3. New spout/old drop
4. New ck spout/old drop
5. Bleach/Bleach -Fall
6. Iso/Iso Fall
7. Peroxide/Peroxide Fall
8. New/Bleach Fall
9. New/Iso Fall
10. New/Peroxide Fall
11. New/Water wash
12. Bleach/Bleach Spring
13. Peroxide/Peroxide Spring

In 2014 trials were also run to follow up testing of silver spouts started in 2013 and 2010. In 2013 new silver spouts on old drops on gravity were compared with old spouts and drop showing a 129% increase.

At the end of the season when these were pulled from the tap holes they were simply hung on the drop line T and the lines vacuumed dry, no other cleaning was provided. Then in 2014 they were removed from the T holder and placed in the new tap hole. This second season silver spout test showed they yielded 82% better than the old spout and drop. In the second 2014 silver spout trial, on vacuum, silver spouts were first used in 2010 as well as each year since so that this year was 5th season of use without any other washing or sanitizing other than vacuuming the lines dry after each season. The silver spout on an old drop still out performed the old spout and drop by 21%.



Silver spouts – production history

Gravity

- 2013 – Arnot 129% increase
- 2014 – Arnot 82% increase 2nd season

Vacuum

- 2010 – Arnot 67% increase over old s&d.
- 2011 – Arnot 72 % increase over old s&d 2nd season
- 2012 – Arnot 13 % inc. 3rd
- 2013 – Arnot 36% inc. 4th
- 2014 – Arnot 21% inc. 5th

Section 9 Washing maple tubing systems

Summary:

The Cornell Maple Program has not yet conducted significant research on cleaning maple tubing systems. This is a project we expect to pursue in the near future. This section deals mostly with issues of various cleaners that have been used or questioned by maple producers. For additional up to date information on cleaning tubing systems see the North American Maple Syrup Producers Manual beginning on page 109.

Pickup truck with water tank, air compressor and water pump set up to rinse mainlines.

Washing Maple Tubing Systems

Washing all food contact surfaces is an important part of all food processing facilities including maple tubing systems. The sooner a maple tubing system can be cleaned following the last sap flow the less time bacteria and yeast will have to grow on sap remaining in the lines. Lines are washed to remove any remaining sap and the mass of bacteria and yeast that built up in the late season sap. The standard procedure for most food contact surfaces would be to rinse with hot water to remove residue, wash with a cleaner, rinse out the cleaner, treat with a sanitizer, rinse again with hot water and dry. A cleaner is a product that is good at removing microbes and debris from the tubing but not necessarily good at actually killing the bacteria and yeast. A sanitizer is generally not good at removing microbes and debris from the tubing but is good at killing the bacteria and yeast. Due to the fact that sap is such a weak solution of sugar water, such an extensive protocol of cleaning has been seen as un-necessary. However, a maple producer needs to be careful which parts of the washing protocol are utilized and the implications of their choices of cleaners and or sanitizers. Residues of cleaners and sanitizers can be associated with off flavors in syrup or even with health concerns with tainted syrup. Maple producers must be familiar with the conditions that may lead to tainted syrup.

Besides flavor issues in syrup associated with cleaner and sanitizer residues, research has not been able to show clear improvements to syrup quality based on the tubing cleaning method used. Research in Canada conducted between 1998 and 2000 could not clearly link the number of bacteria present in sap with mid-season tubing treatments with air and water, bleach, hydrogen peroxide and acid cleaners. Not one of these treatments was found to be consistently better than the others at reducing bacteria counts. This would raise the question of why maple producers would risk handling, storing and disposing of chemical treatments for tubing if they cannot provide a definable benefit.

The difficulty seeing the benefit of chemical cleaners and sanitizers is likely due to a combination of factors. First is the very large area of contact surface present in a maple tubing system. There is about one square foot of internal surface area for each 12′ of 5/16″ tubing. One inch mainline has about one square foot for each 4′ of tubing. An acre of sugarbush with 60 taps per acre would average about 148′ of dropline, 1480′ of lateral line and about 270′ of one inch mainline. That would represent a total of 203 square feet of surface area that needs to be cleaned. 6000 taps would have 20,300 square feet of surface area to wash. Second, many sanitizers need a certain contact time at a given concentration to actually kill the bacteria and yeast present. Often the contact time of fresh sanitizer solution flowing through the droplines of the system during washing is just a few seconds. Third, many times maple producers do not rinse the lines before the sanitizer is added. When the lines are not rinsed the sanitizer comes into direct contact with a volume of bacteria and yeast bodies, both dead and alive, in the line at the end of the season and the sanitizing effect is rapidly exhausted. If the lines were well rinsed prior to the sanitizer being introduced the sanitizer would be much more effective. Fourth, often there are bacteria and yeast that form a bio-film on the inside surface of the tubing. In a bio-film the bacteria and yeast are glued to the tubing surface in a protective coating that is not easily penetrated with a sanitizer. The bio-film must be removed or disrupted with a cleaner before the microbes can be accessed by the sanitizer.

The most common method of washing maple tubing is with a combination of pressurized air and water fed into the bottom of the mainlines and the spouts removed from the trees when the air and water are being pushed into the line so the cleaning water is forced out thorough the spouts for several seconds before being placed securely into the spout holder. Some producers then leave the system full of water, others let the system drain and some will follow up by vacuuming the line dry. In my experience, leaving the lines full of water results in very foul smelling water, often with algae to start the following season. This water must be disposed of along with a significant amount of new sap that it takes to purge the lines.

Chemical cleaners and sanitizers are strictly regulated in food processing operations. They are regulated by the Federal Food and Drug Administration's Code of Federal Regulations Title 21, Chapter I, Part 178 – Indirect Food Additives: Adjuvants, Production Aids, and Sanitizers. This document gives the suitable materials along with accepted concentrations. These regulations are available on line through the government printing office. The Environmental Protection Agency is also involved in providing the businesses that make the cleaners and sanitizers with regulations for what must be listed on the label for the legal use of the chemicals titled Label Requirements for Pesticides Used for Sanitation of Food Contact Surfaces. This is also available on line at http://epa.gov/oppad001/dis_tss_docs/dis-17.htm. This instructs the company to specify many important details of how a material can legally be used. Of particular importance to a maple producer who is planning to treat maple tubing is the term porous surface. Plastic is one of the food contact surfaces that is considered porous. Many labels specify that the chemicals are only for use on non-porous surfaces. This is true of most of the labels for several sanitizers that some maple producers have shown an interest in trying, including quaternary ammonium compounds and per-oxyacetic acid. These labels do not allow their use in cleaning a plastic food contact surface. Using a cleaning chemical in ways either not mentioned on the label or forbidden on the label or at concentrations other than listed in the label is not acceptable. The label is the legal document, even if the use is permitted by the Food and Drug Administration, the label may limit the use. Experimenting with materials without a label or with uses not listed on the label is also not acceptable.

Only two sanitizers are recommended for sanitizing the tubing system, sodium hypochlorite (the active ingredient in bleach) or food-grade hydrogen peroxide. Where the bleach is used maple produces often complain of more rodent damage to tubing. The bleach should be drained, vacuumed or rinsed from the tubing. Leaving it in the lines can lead to off flavors or saltiness of the next season's maple syrup if not completely purged by sap the following season. The food grade hydrogen peroxide breaks down without leaving any residue and is not reported to attract rodents.

Hydrogen peroxide that is not food grade often has a second sanitizer present called peroxyacetic acid. This product should be avoided in the maple tubing system. Acid cleaners and peroxyacetic acid do not break down, do not boil away and can be toxic. They would only be used where the protocol is a true and complete rinse following the acid and following the sanitizer, followed by drying the food contact surface. The actual product purchased would also need the label allowing them to be used to treat a porous food contact surface. These and other products not recommended can have residues that are actually concentrated by the sap boiling process and as a result a health concern.

To determine the correct concentration of a sanitizer to use in maple tubing read and follow label directions. These products are available in a variety of formulations and concentrations; therefore to list a potential dilution rate here may not match the products you purchase. Always read and follow the label.

An alternative to washing the tubing system by pushing the water, air and associated cleaners or sanitizers into the system from the bottom end of mainlines is to wash the system from the top down. This method is more common in systems of small or medium size. This method is used for both gravity and vacuum systems. In a system with vacuum, it is left on during the cleaning. The operator carries a container or backpack filled with clean hot water or water plus sanitizer and injects the solution into each tap as they are removed from the tree. The solution is then pulled down through the system either by gravity or by the vacuum. This method may do a fair job of cleaning out drops and lateral lines but is not likely to provide the volume necessary to clean out the larger mainlines. Some producers have overcome this shortfall by also washing mainlines from the top. After cleaning the lateral lines as just described the maple produce brings an adequate supply of water and pump to the top of the mainline with a tractor or four-wheeler and continues washing down the mainline from the top. Some woods do not provide adequate access to the tops of mainlines for this system to be used. One advantage of this cleaning method is that less pressure is required to push the solution through the lines. A disadvantage is that there is likely to be less turbulence to assist in a good cleaning of the mainline.

Another cleaning opportunity is available for cleaning mainlines where vacuum with dry lines and wet lines are part of the tubing system. With some additional plumbing near the releaser, a dry line and wet line can be washed with a minimum of effort. By shutting off the dry line from the vacuum of the releaser and injecting air and water under pressure into that dry line, the wash water will be forced out through the dry line and pulled back to the releaser through the wet line that is still under vacuum. From the releaser the wash water can be discarded. This would likely only provide a good cleaning out to the first few manifolds connecting the wet and dry lines. If the manifolds were constructed so that a shut off valve was in place between the wet and dry line the washing could be complete as far as the dry line extends into the system if the producers were to close all of those manifold valves along the line, except the one at the furthest point. This method allows the producer to wash mainlines from the sugarhouse or pump station. Producers with this system often will wash mainlines several times throughout the sap season or even following each sap run. The main effort is in closing and then reopening the manifold valves if there are more than just a few in the dry line system.

Section 10 Managing Wildlife

Summary:

Wildlife damage to maple tubing systems impacts the maple producer in three key areas; the labor to repair damage, the cost of materials that need replacing and the loss of sap due to direct sap leakage or loss of sap yield due to vacuum loss. When sap was gathered in metal buckets losses to wildlife were minimal. Tubing systems can be substantially damaged by wildlife or damaged just enough to be a continuous maintenance problem. Rodents usually are the cause of most tubing damage including squirrels, chipmunks, mice, voles, porcupines, and rabbits. Occasional damage has also been caused by deer, moose, woodpeckers foxes, bears, raccoon, coyotes, bobcats, dogs and even humans. Squirrels are particularly known to severely damage and destroy maple tubing systems especially where the tubing is left up year round and where bleach has been used to sanitize the lines. Specific control measures may be unavailable for the sugarbush, or techniques are very strictly regulated. A thorough understanding of the habits, life cycle, and habitat requirements for each of the potential wildlife pests can aid the maple producer in making the changes in the sugarbush that will alleviate the most persistent problems.

This publication contains pesticide recommendations. Changes in pesticide regulations occur constantly, some materials mentioned may no longer be available, and some uses may no longer be legal. All pesticides distributed, sold, and/or applied in New York State must be registered with the New York State Department of Environmental Conservation (DEC). Questions concerning the legality and/or registration status for pesticide use in New York State should be directed to the appropriate Cornell Cooperative Extension Specialist or your regional DEC office. **READ THE LABEL BEFORE APPLYING ANY PESTICIDE.**

Section 10.1 Introduction

Because a sugarbush is considered an agricultural production area, or more specifically a food production area, any chemicals, pesticides, repellents, or even toxic baits used in the area must have been approved by the EPA and the NYSDEC for that use. Pesticide use in a maple sugarbush must also be listed on the product label for it to be legally used there. This severely limits materials that can be applied in a sugarbush that may be available for use in a forest, woodlot, orchard, or vineyard, but may not be used for maple syrup production.

There may be several reasons why rodents are attracted to chew on tubing. A primary reason appears to be that they are attracted to the salt deposits left when bleach is used to sanitize the tubing. They also may be attracted to the sap or water left in tubing during dry spells. The damage may also reflect their territorial behavior or just the general tendency of rodents to gnaw most anything chewable. The primary pests of maple tubing systems and associated control methods will be reviewed next, along with the steps most likely to reduce damage to maple tubing systems.

Attraction to sap in tubing

General tendency of rodents to gnaw

Attraction to salt deposits left by bleach tubing wash

Territorial behavior

Why Rodents Damage Maple Tubing

Rodent Damage Information. Provided by USDA-Wildlife Services.

10.2 Tree squirrels

Four species of squirrels, the gray squirrel, fox squirrel, red squirrel, and northern flying squirrel, reside in New York State. Each of these species inhabits wooded areas in both rural and suburban landscapes and play an important role in forest ecosystems.

Gray squirrels typically are grizzled gray on the top of the body and have a white underside. Most adult gray squirrels first breed in mid- December or early January, and 5 to 10 percent of older females may breed again in June. The gestation period is 42 to 45 days, after which gray squirrels typically give birth to three young. The young spend their first 10 to 12 weeks in the den cavity. Gray squirrels typically live about two to three years. Hawks, owls, and foxes occasionally prey on young squirrels, but adults are not frequently taken. Predation does not greatly affect squirrel populations in areas that have good food and cover.

Fox squirrels are tawny-brown to reddish-gray above, and buff to pale orange-brown on the underside. They live primarily in the south and western regions New York State. They are larger than gray squirrels, mate in January and give birth to two to four young in late February or early March. Fox squirrels have only one litter per year.

Red squirrels, also known as barking squirrels, boomers, chickarees, and chatterboxes, are alert, noisy, and energetic. They spend most of their time in trees and are extremely agile, sometimes leaping 10 feet between branches or 30 feet to the ground. They are about half the size of the gray squirrel. In the summer, its fur is a rich, rusty brown color, turning grayer in winter when the squirrel also develops prominent ear tufts. The undersides are off-white. Breeding season for red squirrels begins in late winter; three to six young are born in April, May, or June. Red squirrels are strongly territorial and will defend their food sources and den trees against intruders.

The northern flying squirrel is New York's only nocturnal squirrel. Its large, round eyes are adapted for night vision. The fur of the flying squirrel is soft grayish-brown above and white on the underside. The flying membrane is a loose flap of skin between the front and hind legs on either side of the body. The membrane is stretched tight when the legs are extended, allowing the squirrel to soar or glide but not to fly in the true sense of the word. The broad, flat tail is used as a rudder to guide the animal while it is soaring. Flying squirrels can sail up to 40 yards in a downward direction, often soaring from tree to tree. Two to six young are born in April or May.

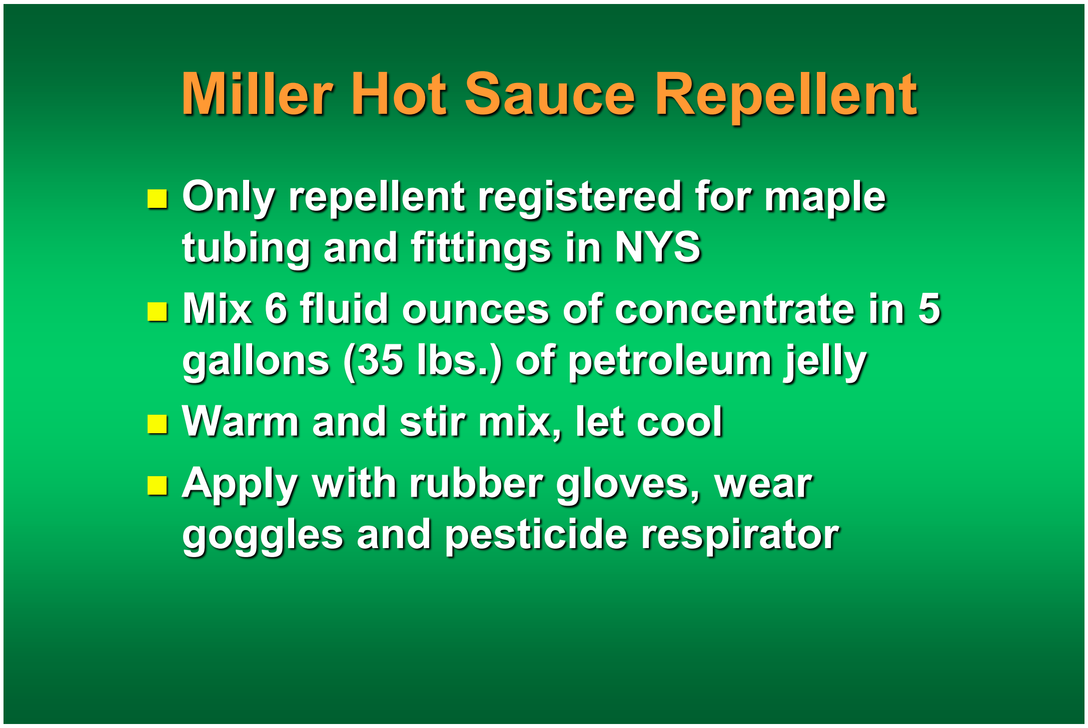
Tree squirrels inhabit woodland areas. Fox squirrels prefer the forest edge, where trees border crop fields or other open areas. Red squirrels favor coniferous or mixed deciduous and coniferous forest, but will inhabit mature deciduous forests where coniferous habitat is unavailable. Although the gray squirrel is the most common and adaptable species, all three species regularly live in cities and suburbs as well as forests. Good squirrel habitat contains many mature fruit- and nut-producing trees, and a mixture of other tree and shrub species to provide a variety of food throughout the year. Natural dens and tree cavities are used for escape and breeding cover. In addition, gray and fox squirrels build and use leaf nests in trees during summer and fall. Leaf nests are typically 12 x 16 inches and are built of twigs, leaves, grass, bark, and other plant materials. Red and flying squirrels prefer to nest in hollow tree limbs and woodpecker cavities. Fox and gray squirrels share similar food preferences. They typically feed on mast (fruits and nuts) in fall and early winter. They favor acorns, hickory nuts, and walnuts, and often store them for use in the winter. In late winter and early spring they prefer tree buds and in the summer they eat fruits, berries, and succulent plant materials. Fungi, corn, and cultivated fruits are taken when available. When populations peak, these squirrels may chew bark from a variety of trees. They will also feed on insects and other animal matter such as bird eggs. Red squirrels prefer pine seeds and buds but will also eat a variety of other foods common to the gray and fox squirrels. Flying squirrels feed on items similar to other squirrels, but they are the most carnivorous of all tree squirrels, feeding on bird eggs and nestlings, insects, and other animal matter when available. All tree squirrels cache, or hide, food to be eaten during the winter. Red squirrels cache large amounts of food at a single location such as a hollow log. Gray and fox squirrels, however, bury nuts singly at numerous locations. Removing these favorite food sources from the sugarbush can result in lower populations over the long run. White oak acorns, walnuts, and bitternut hickory nuts are preferred foods of squirrels. Removal of these trees along with other nut producing species such as beech and butternut will reduce the squirrel population in the bush.

Squirrels can become a nuisance when their feeding and nesting habits conflict with human interests. Squirrels may chew holes through the tubing used in maple syrup production. Tree squirrels can also become a problem when they gnaw on wires, enter buildings, and build nests in the sugarhouse. Squirrels may damage siding, insulation, electrical wiring, or contents when they take up residence in homes or a sugarhouse.

Gray and fox squirrels are considered small game species in New York State and can be taken during the established hunting season for these species. Red and flying squirrels are considered unprotected species and can be taken at any time with a valid hunting license. New York State Environmental Conservation Law (section 11-0523) specifies that whenever gray, fox, red, or flying squirrels are injuring property on occupied farms or lands or dwellings, they may be taken at any time in any manner by the owners or occupants thereof or by a person authorized in writing by such owner or occupant. By law, any animal taken outside the regular hunting season by the landowner must be killed or released alive on site. Nuisance wildlife control operators, licensed by the New York State Department of Environmental Conservation, are authorized to trap and transport animals off-site and will do so for a fee.

Gray, fox, and red squirrel numbers can be reduced by shooting, but the results are often short-lived. Squirrels also can be trapped using snap-back rat traps, box traps, or cage traps. Cage traps should have a 6-x-6-inch opening and be 24 inches long. Effective baits include apple slices, walnuts removed from the shell, peanut butter, corn, or sunflower seeds. When using box or cage traps, tie the trap doors open for two to three days to allow squirrels to become accustomed to feeding there. Then set the traps and check them twice a day.

Capsaicin (the active ingredient in hot peppers) has been found to have repellent properties for mammals. Miller Hot Sauce Animal Repellent is registered in New York State for use on maple sap collection equipment, including plastic tubing, lines, and fittings. This repellent can be used to prevent squirrel damage to maple sap collection equipment. Follow label instructions for applying this product to sap collection lines.



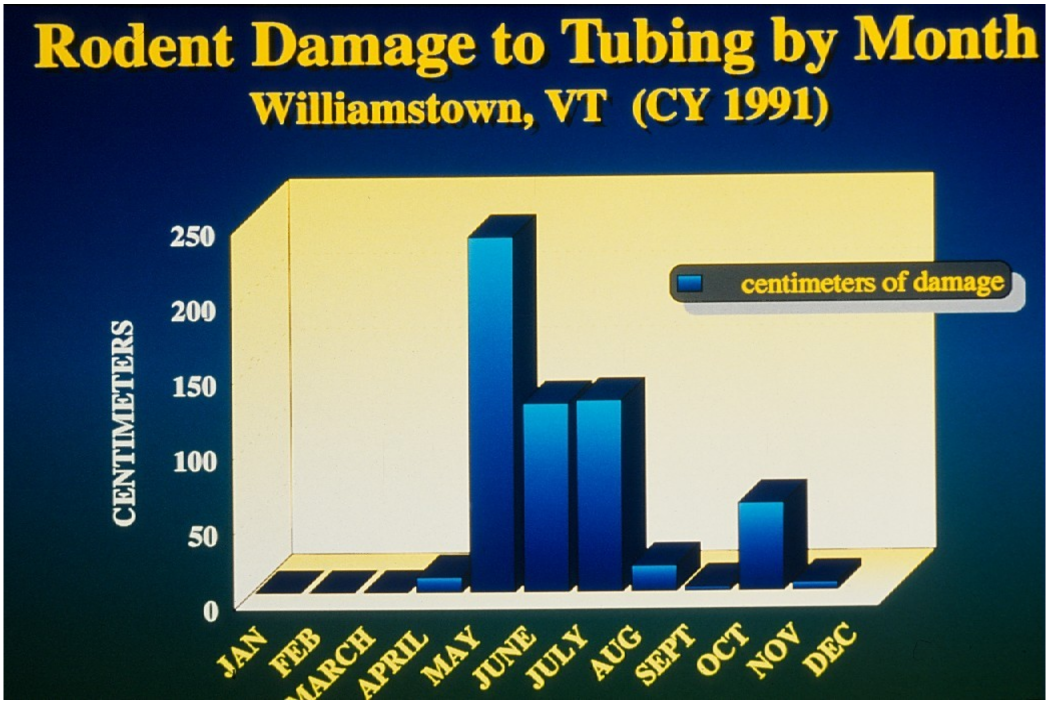
Miller Hot Sauce Repellent

- Only repellent registered for maple tubing and fittings in NYS
- Mix 6 fluid ounces of concentrate in 5 gallons (35 lbs.) of petroleum jelly
- Warm and stir mix, let cool
- Apply with rubber gloves, wear goggles and pesticide respirator

Squirrels can be excluded from the sugarhouse and other buildings by securely fastening hardware cloth over attic vents, which are a common entry point into buildings. Also seal openings at joints of siding and overhanging eaves. In addition, seal openings where utility cables or pipes enter buildings. Install chimney caps on all chimneys, and check for gaps in the flashing at the chimney base. Be sure not to trap squirrels inside. A squirrel excluder can be constructed by mounting an 18-inch section of 4-inch diameter plastic pipe over the building opening used by squirrels. The pipe should point down at a 45-degree angle to allow squirrels to exit but prevent them from reentering. Alternatively, if squirrels are located inside an attic, traps may be set to ensure that any squirrels left inside are removed. To prevent squirrels from climbing up trees to gain access to buildings, taking fruit or nuts, or stripping bark from a tree, fasten a 2-foot band of sheet metal around the trunk 6 to 8 feet above ground. Sheet metal can be fastened by wrapping wires around the trunk and attaching them together with springs. This method allows the sheet metal to spread as the tree grows. All trees that need protection, plus all trees within jumping distance (branches within 6 to 8 feet), should be protected with a sheet metal band. Tree limbs also should be trimmed to 6 to 8 feet from buildings to prevent squirrels from leaping onto buildings.

The time of year that squirrels and other rodents do the most damage has been studied. It appears that the majority of rodent damage occurs May through August, and again in November. These are times when many maple producers are not observing the conditions of the maple tubing system. When the maple producer begins getting the tubing system ready for the season in January and February, it is too late to do anything but make the repairs. If the system had been examined during the key times reflected in the chart, action could have been taken to control some of the damage.

Constant monitoring and population management are the most effective ways to reduce tubing system damage.



Finally protecting key locations of the tubing system with tubing protectors or wire coils has reduced the most severe chewing damage. Current sources of these coil protectors are not known.

Recommendations

- Reduce use of chlorine solution
- Modify habitat, remove conifers
- Coiled-wire tubing covers
- Repellent applications
- Lethal control- trapping, shooting

Section 10.3 Other rodents

Eastern chipmunk

After squirrels, the eastern chipmunk is the rodent most often blamed for maple tubing damage. The presence of chipmunks can be readily identified by the sounds they make. They use a sharp repetitive chirp to alert others of danger. When startled, they'll often respond with a single chirp followed by a short burst of chatter (1–2 seconds). Chipmunks inhabit holes that are about 2" in diameter. These holes usually go straight down, with no dirt mound in front. Evidence of their chewing is similar to squirrels, chipmunks leave gnawed cuts and holes in maple tubing. Occasionally, chipmunks will damage buildings, but not nearly as often as other rodents.

Chipmunks are primarily herbivores. Their favorite foods are nuts, seeds, and fruits. Chipmunks eat nuts (acorns, hazel nuts, beechnuts), seeds (from many ornamental trees, wildflowers, clover, ragweed, and sunflowers, and birdseed), flower bulbs, berries (such as raspberries, strawberries, black berries, and chokecherries), fruit (watermelon, apples, pears, peaches, cantaloupe, cherries), and wild mushrooms. They will occasionally eat corn, wheat, oats, grass seed, insects, worms, snails, slugs, bird eggs, nestlings, mice, moles, frogs, salamanders, small snakes, and carrion. Although they spend most of their time on the ground, they will climb trees to take nuts, fruits, and seeds. Chipmunks cache food in a storage chamber in their burrow. During the breeding season, they must drink up to a quarter of their body weight in water each day.

Chipmunks are generally solitary, except for females with dependant young. They can be fairly aggressive to each other. They are known to be active both during the day and at night. Chipmunks do not hibernate or migrate. They'll stay in their burrows for days at a time during the winter, in a sleepy state. Chipmunks rely on their food caches during the winter. They may come out on warm days, often to travel to another food cache.

They adapt to a variety of habitats, but are usually found in areas with at least a few mature trees. Chipmunks are common in rural, suburban, and urban areas, including yards, gardens, campgrounds, parks, urban lots. Chipmunks often burrow under old stone walls bordering pastures or woods; under piles of brush, rocks, or garbage; among a tree's roots, or near buildings. The only places you're not likely to find them are marshy areas with very dense undergrowth. The home range varies from 1/10 to 3 acres, but most don't venture across more than an acre. Males have larger home ranges than females. Densities may be as high as 10 chipmunks per acre. They will defend an area of about 50 feet around burrow entrance.

Female chipmunks raise their young alone in underground burrows. They produce two litters annually, one in May and one in August. Each litter will contain 2-7 young, and they will leave the burrow at about 6–8 weeks old. They usually don't raise their young in buildings. Very young chipmunks might enter a building on their own, leading someone to believe there's a "nest" inside.

Chipmunks are not protected by federal or state laws. Suggested control measures include limiting easy access to food. If anyone is feeding the chipmunks, persuade them to stop. "Squirrel-proof" bird feeders that use the animal's weight to close the feeder won't stop chipmunks unless the feeder's set so it will close when a very light weight is applied. Unfortunately, at that setting, you’ll also stop all but the smallest birds from using the feeder. Hang bird feeders on a rope between two pulleys. Ideally, feeders should be 15–30 feet away from the building so any seed that collects below doesn’t lead the chipmunks right to the foundation. Keep the area underneath the feeder clean. Feed pets indoors. Store food, birdseed, and pet food in metal, glass, or ceramic, containers. Because of the wide range of food that the chipmunk can survive on changing the mix of trees in the forest to reduce the food source is less effective than with squirrels.

Live traps can be used to capture chipmunks. Suggested baits include nuts, peanut butter, and sunflower seeds. Place the trap near the tunnel's entrance or along their travel route.

Lethal traps such as the rat-sized, snap-back traps can be very effective. There are now models that have built-in safety catches. The bait's under a cover, which must be lifted before the trap will fire. This means that an animal that's just investigating won't set off the trap. The design also helps ensure proper positioning, which is more humane. If using a traditional snap-back trap, place it within a cage trap, a box, a coffee can with both ends cut out, or in PVC pipe, to prevent the capture of songbirds. If the trap is next to a foundation or large rock, you could lean a board over it.

There are no pesticides, chemicals, or treated baits that are registered for controlling chipmunks in the sugarbush..

Mice and Voles

Mice and voles, though not implicated in damage to tubing as often as squirrels and chipmunks, can contribute to the problem. Voles and mice are prolific breeders, and their populations have the potential to increase rapidly unless the carrying capacity of the habitat is reduced. White-footed and deer mice are agile climbers, and very abundant in deciduous forests. They may damage tubing systems at any height above ground. Damage is often most severe where tubing systems contact trees or posts where these rodents can easily climb and gain a foot-hold.

Meadow voles occur throughout most of the northern and eastern United States and Canada in low wetlands, open grasslands, and orchards. Meadow voles are most active above the ground, as evidenced by surface trails often littered with droppings and grass cuttings in the ground vegetation where they live. They sometimes live underground where the soil has been cultivated or where a burrow system is already present. Tubing systems in woods adjacent to open fields and especially abandoned fields would be most subject to vole damage.

Damage to maple tubing takes the form of gnawing cuts and small holes up to large sections of tubing chewed away. These larger damaged areas are most likely where tubing has been laying on the ground for an extended period of time. Damage to mainlines has been noted where mainlines are sited directly next to trees, on support poles or when a stick or tree limb provides access to the mainline. Properly constructed and maintained mainline systems, suspended on a support wire held in place by side ties, do not offer much access to mice or voles.

For voles and mice there are no pesticides, chemicals or treated baits that are approved for use in a sugarbush. Trapping is the only option.

Rabbits

Rabbits have been implicated in occasionally damaging maple tubing systems. This has been noted mainly under conditions of deep snow when the rabbits have access to the suspended tubing.

Rabbits are protected game animals in New York, and sport hunting can be used to effectively lower rabbit numbers. Rabbits causing property damage may be destroyed without a permit under existing New York State Environmental Conservation Law (Title 5, Section 11-0523). In more suburban locations where hunting may not be possible, rabbits can be captured in box traps or commercial wire cage traps. Permits from DEC will be required to trap and transport live rabbits, and it is best to contact your Regional DEC office before capturing or killing rabbits. Live traps can be baited with apples or corn, and once a rabbit is caught in a trap, its lingering scent will often attract other rabbits. Putting a few rabbit droppings in a trap along with the bait will enhance the trap's effectiveness. Rabbits are usually most active just after sunset and just before sunrise. Live traps should be set prior to these peak activity periods.

Rabbits require dense vegetation near feeding areas for protection from predators.

Overgrown ditches, stream banks, fence rows, or brush piles within or near the sugar bush may harbor abundant rabbits. Mowing, cutting brush, and removing brush piles or overgrown areas may effectively control this problem.

Porcupines

Although porcupines are known for causing extensive damage to maple trees in the sugarbush, they are only known to cause occasional damage to tubing systems. A trapping program may be warranted for tree damage, but repairing the tubing system damage when it happens is the most reasonable tubing management program for porcupines.

Section 10.4 Other mammals

Other mammals known to have damaged maple tubing systems include deer, moose, foxes, bears, raccoon, coyotes, bobcats, and dogs. Losses typically include punctures in the tubing from chewing, or larger animals tearing down lines while traveling through the stand. The damage is usually infrequent, and replacement of the tubing is less expensive than the intensity of observation and control that would be required to stop the damage. Many of these species can be controlled or reduced through regulated sport hunting or trapping.

Often maple producers who contemplate installing a tubing system for the first time question how much damage to anticipate from deer moving through the sugarbush. Complaints of damage from deer are nearly non-existent among maple producers who have had tubing systems in the woods for many years, along with a healthy deer population. Deer are also suspected of occasionally chewing on the 5/16th tubing giving it a very damaged appearance but not often puncturing through it. Moose are a different story. Moose have a reputation for causing extensive damage to tubing systems when passing through the sugarbush. Fortunately, moose are not present in the majority of the maple production areas of New York. Damage done to tubing systems by humans can be some of the most frustrating repairs to deal with, knowing that it is completely intentional.

Section 10.5 Other wildlife

Woodpeckers have occasionally been blamed for holes that occur in maple tubing. Although holes in mainlines are not known to be caused directly by woodpeckers, they have been known to damage spouts and in particular the bark and tree around maple spouts. The damage is primarily to the tree as the woodpecker attempts to expand the tap hole, even with the spout in place. The species often responsible for this kind of damage are the Downy and Hairy Woodpeckers. These are both protected species and no lethal control measures are legal. In areas where damage becomes extensive, placing a metal plate, such as a large washer, on the spout between the tree and the elbow or expansion of the spout may completely control the damage.

Woodpecker Damage

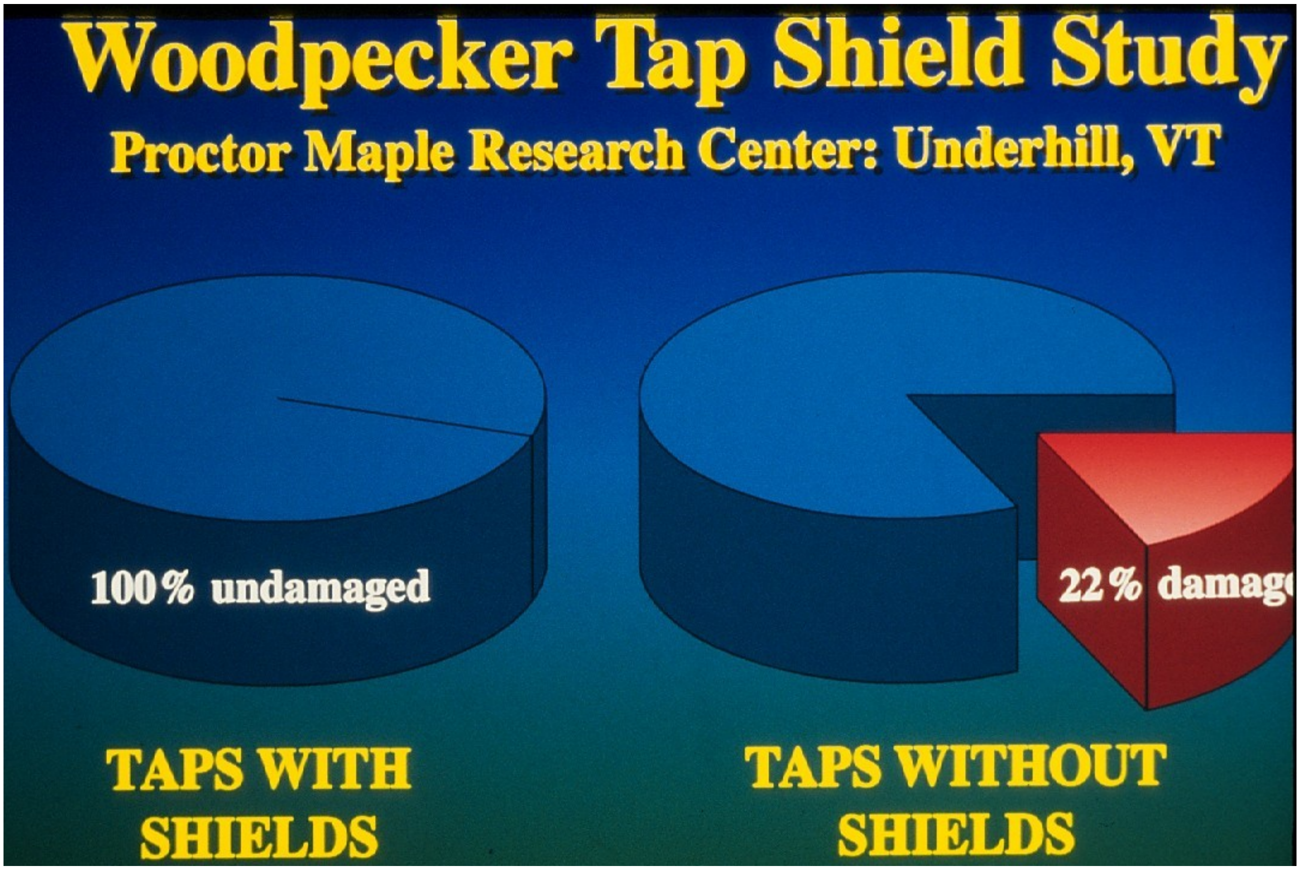
Downy Woodpecker

The Downy Woodpecker is a familiar sight at backyard feeders and in woodlots, where it joins flocks of chickadees and nuthatches. The bill tends to look smaller for the bird's size than with other woodpeckers. The Downy Woodpecker is the smallest woodpecker in North America. Adults are mainly black on the upper parts and wings, with a white back, throat and belly and white spotting on the wings. There is a white bar above the eye and one below. They have a black tail with white outer feathers barred with black. Adult males have a red patch on the back of the head whereas juvenile birds display a red cap. The female lacks the red patch on the back of the head. They make lots of noise, both with their shrill calls, and by drumming on trees.

It is virtually identical in plumage pattern to the larger Hairy Woodpecker, but it can be distinguished from the Hairy by the presence of black spots on its white tail feathers. Their breeding habitat is deciduous forested areas across most of North America. They nest in a tree cavity excavated by the nesting pair in a dead tree or limb. These birds are mostly permanent residents, though there is some migration. Downy Woodpeckers roost in tree cavities in the winter. They mainly eat insects, along with some seeds and berries. Especially in winter, Downy Woodpeckers can often be found in suburban backyards with trees, and will feed on suet at birdfeeders.

Hairy woodpecker

The Hairy Woodpecker is virtually identical in plumage to the much smaller Downy Woodpecker, but with a longer bill. The best way to tell the two species apart other than the size is the lack of spots on its white tail feathers (which the Downy has). Hairy Woodpeckers are birds of mature forests. They are also found in woodlots, suburbs, parks, and cemeteries, as well as forest edges, open woodlands of oak and pine, recently burned forests, and stands infested by bark beetles. Mating pairs will excavate a hole in a tree, where they will usually produce four white eggs. These birds are mostly permanent residents, and eat mainly insects, but will also consume <u>fruits</u>, berries, nuts, suet, and sometimes <u>tree sap</u>.



Woodpecker Tap Shield Study

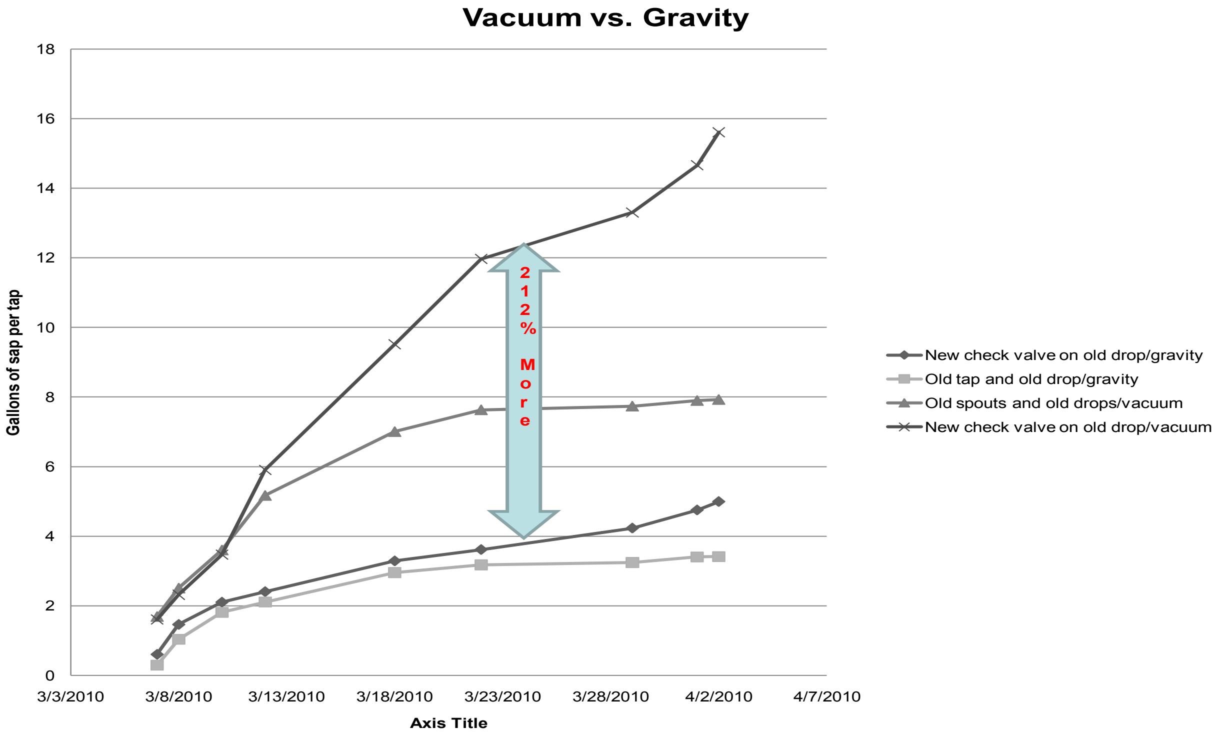
Proctor Maple Research Center: Underhill, VT

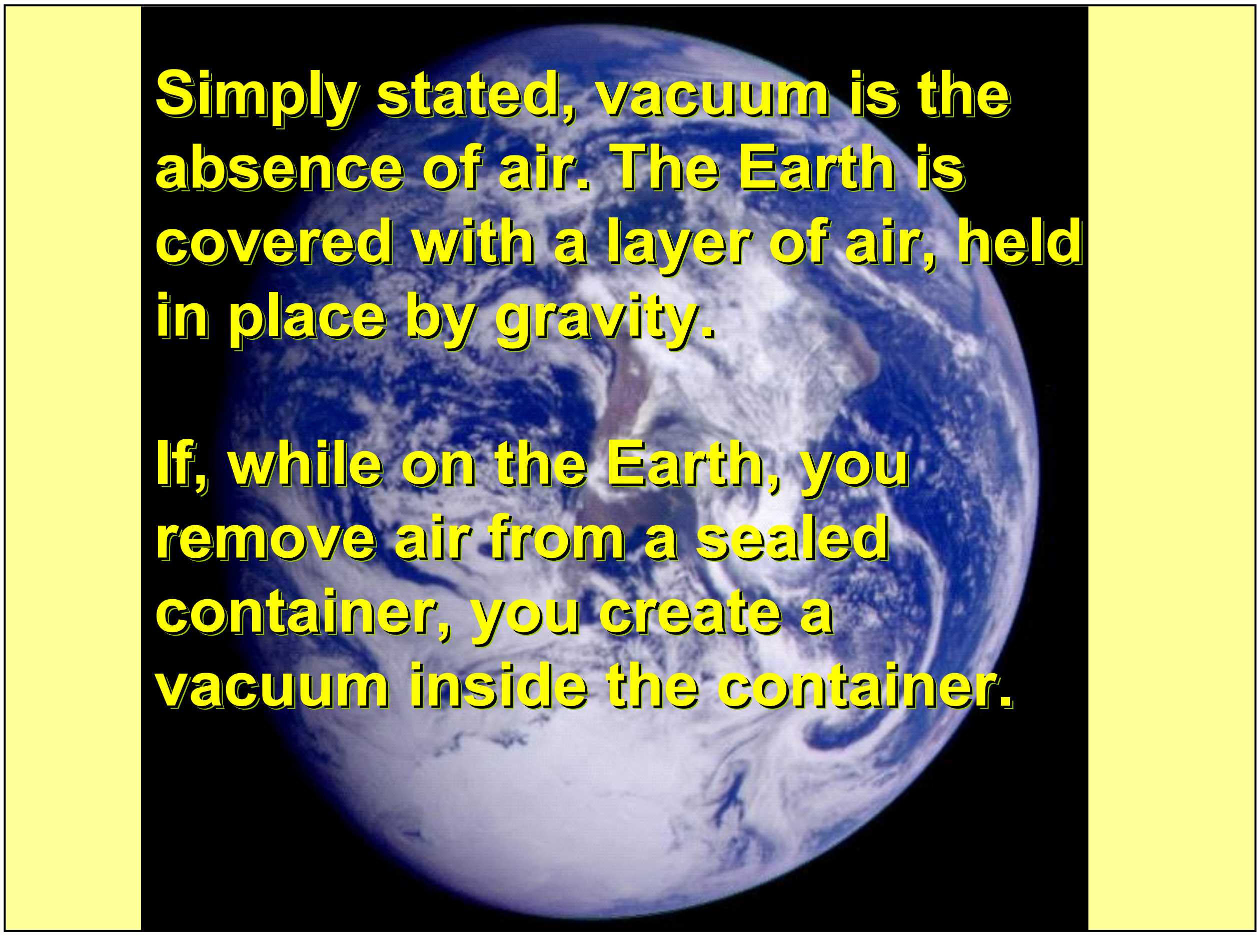
Section 11 Vacuum Basics

Summary:
Vacuum is simply the reduction of air in a closed or nearly closed system. Maple producers have been using vacuum as a tool to increase production of sap for over 50 years. Vacuum interacts with the pressure dynamic within the maple tree allowing sap to run at a lower tree pressure and temperature as well as to run faster from the tree. Research in the past has shown an increase in sap yield of between 50% and 150% when vacuum is added to the maple tubing system. In the generally poor sap year 2010 Maple Vacuum and Gravity Research at the Arnot Forest showed a 212% increase in sap yield between treatments with 15" of vacuum and check valve spout vs. a gravity tubing system with check valve spouts. See the graph lower on this page. Research also has shown that the higher the vacuum the higher the sap yield.

There is a great variety of vacuum equipment used by maple producers each with its own advantages and disadvantages. This section will look at the basics of vacuum, how vacuum level influences the pump capacity, and how vacuum is measured and calculated in the maple tubing system.

11.1 Vacuum Basics
11.2 Using vacuum in a maple sap collection system
11.3 Changes in vacuum pump capacity
11.4 Measurements of air flow in a vacuum systems
  CFM
  SCFM
  ACFM





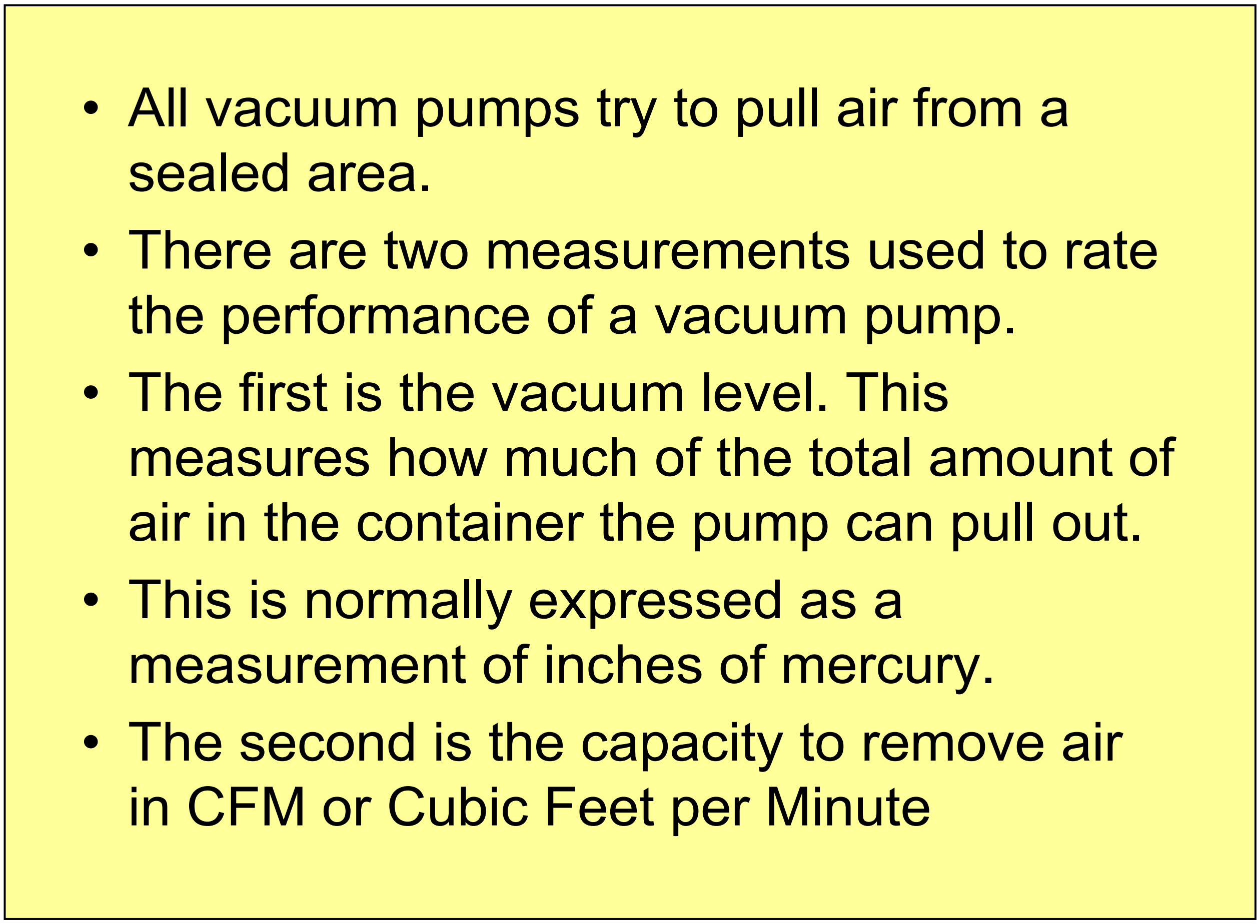
Simply stated, vacuum is the absence of air. The Earth is covered with a layer of air, held in place by gravity.

If, while on the Earth, you remove air from a sealed container, you create a vacuum inside the container.

11.1 Vacuum Basics

Simply stated, vacuum is the absence of air. The Earth is covered with a layer of air, held in place by gravity. This layer of air has weight that produces barometric pressure and amounts to about 15 pounds per square inch or 29 inches of mercury. If, while on the Earth, you remove air from a sealed container, you create a vacuum inside the container. In our case the sealed container is the maple tubing system and absence of air is created by attaching a vacuum pump to the tubing system and pumping out part of the air. At the same time as air is being pumped out of the tubing by the vacuum pump, air is leaking into the tubing through small holes, connections that have a poor seal, the connection between the spout and the wood of the tree, and from the tree itself. The higher the vacuum, the greater the difference between the air pressure outside the tubing and the pressure inside the tubing which forces even more air into the tubing through the leaks.

Tubing conducts both air and sap toward the vacuum pump. There must be airspace above the sap for air to be removed from the tubing. In a tubing system that is undersized there is a competition between the air from leaks being pulled through the tubing to the pump and the sap being pulled through the system mainly by gravity. Where the competition becomes too great the liquid sap wins out and effectively blocks the movement of air needed to maintain vacuum at the tap, even though the vacuum pump is working very hard at the end of the line.

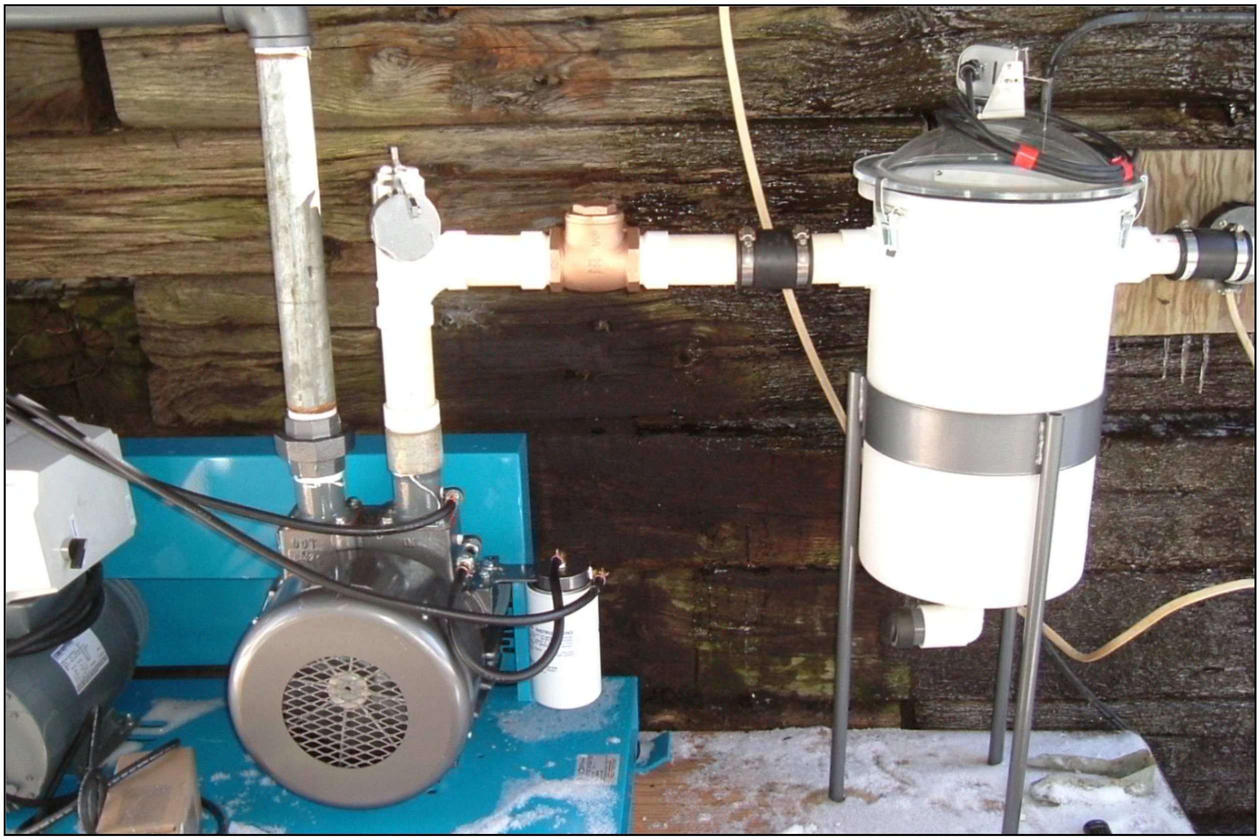


- All vacuum pumps try to pull air from a sealed area.
- There are two measurements used to rate the performance of a vacuum pump.
- The first is the vacuum level. This measures how much of the total amount of air in the container the pump can pull out.
- This is normally expressed as a measurement of inches of mercury.
- The second is the capacity to remove air in CFM or Cubic Feet per Minute

All vacuum pumps work to pull air from a sealed area, in this case the maple tubing system which is a somewhat leaky sealed area. There are two measurements used to rate the performance of a vacuum pump.

The first is the vacuum pressure level. This measures how much of the total amount of air in the container the pump can pull out. This is normally expressed as a measurement in inches of mercury and will range between 0 and about 30 inches or topping out at the current barometric pressure where the tubing system is. With the kinds of pumps used in an application like milking cows or drawing vacuum on a maple tubing system, all of the air is not removed resulting in a vacuum gauge reading typically in the 10 to 24 inches of mercury range .

The second rating used on vacuum pumps is the capacity to remove a volume of air in a unit of time, typically cubic feet per minute (cfm). This rating is used to calculate the capacity of the pump to hold the vacuum pressure required to counter act the amount of air flowing into the system from leaks. If the air flow into the tubing through leaks exceeds or equals the capacity of the vacuum pump to remove leaked air, no vacuum pressure can be established. If the air flow into the tubing through leaks is less than the capacity of the pump, a level of vacuum pressure can be established where the greater the difference between the leak rate and the pump capacity the higher the vacuum can be.



Vacuum pump and moisture trap set up outside the sugarhouse at the Arnot Forest

Vacuum pumps come in a variety of sizes and capacities. They have significant differences in their ability to move a volume of air and how high a vacuum level they can sustain. Vacuum pumps are typically rated for the cubic feet of air they can remove from a system per minute at standard atmospheric conditions while operating at 15 inches of vacuum. If the inches of vacuum is decreased from 15 inches the capacity to move air in cubic feet per minute will increase. If the inches of vacuum is increased above 15 inches the capacity to move air in cubic feet per minute will decrease. Just how much the capacity of the pump decreases as the vacuum is increased also depends on the type of pump. The horse power rating of the motor running the vacuum pump is not a good indicator of the vacuum pump's performance potential. The speed at which the pump is spinning can have an important influence on its performance. For instance a vacuum pump connected to a gas powered engine will perform very differently depending on if the motor is idling or if it is running at a high rpm level. Sometimes when a vacuum system is purchased from a dairy operation the motor and pulleys may have been changed in the past altering the pump's performance. The only sure way of knowing a vacuum pump's output is to have the cfm tested at your desired vacuum level. If a pump is purchased outside of the maple or dairy industry, it may be rated based on what is called free air or the cfm of air the pump moves when not under vacuum. Free air rating on a pump will appear to be higher than when rated at 15" of vacuum, usually somewhere near twice as high.

Portable vacuum pump and gas motor set up for remote locations away from electric

11.2 Using vacuum in a maple sap collection system

In a maple sap collection system, getting the vacuum pump close to the sugarbush can be an advantage as vacuum capacity is easily lost in long or undersized lengths of mainline tubing. Providing properly sized tubing for extended distances can be expensive compared to the size of tubing that would be required to pump sap out from a distant site. The picture above illustrates a portable vacuum system that can be taken to a remote location to provide vacuum to a maple tubing system. Providing fuel and oversight of remote vacuum pumps can be difficult and time consuming. On long runs of tubing a significant percentage of the vacuum pumps capacity can be consumed by friction in the line resulting in what is called line loss. This can be an important part of calculating the vacuum pump capacity needed to successfully operate a maple tubing vacuum system and properly size the vacuum pump.

Vacuum can be used to move sap over long distances as well as lift sap, but it is inefficient compared to pumping the sap over the same distance with positive pump pressure. Estimates are that pumping is four times more efficient at moving sap over a long distance than pulling with vacuum is. The problem with pumping from these remote sites is the availability of electricity or the difficulties of managing a pump system automatically with a power source other than electricity. Some producers have added a generator to a motorized remote vacuum pump allowing them to use pumps, uv lights, electric releasers or even ROs at these remote sites.

Percent of air in the tubing	Percent air removed from tubing	Vacuum gauge reading in the tubing (inches Hg)	Air pressure gauge reading in the tubing (psi)
100	0	0	0
90	10	3	-1.5
80	20	6	-2.9
70	30	9	-4.4
60	40	12	-5.9
50	50	15	-7.4
40	60	18	-8.8
30	70	21	-10.3
20	80	24	-11.8
10	90	27	-13.2
0	100	30	-14.7

There is a direct link between the percentage of air removed from a maple tubing system and the vacuum measurement in inches of mercury or the pounds of pressure per square inch. When the vacuum gauge reading is just half of the current barometric pressure then half of the air has been removed from the tubing system. The chart on this page reflects how this typically looks on a day when the barometric pressure is 30 inches of mercury. The first column shows the percentage of air that is in the tubing starting with no vacuum applied and falling as higher vacuum is applied until no air remains. The second column shows the percentage of air that has been removed from the tubing starting with no vacuum and no air has been removed increasing with higher vacuum until all of the air is removed. The third column is what the vacuum gauge would show in inches of mercury measuring the vacuum level inside the tubing. The fourth column shows the pressure inside the tubing in standard pounds per square inch. So when the vacuum gauge is reading about 10 inches of mercury about a third of the air has been removed from the tubing system. When the gauge is reading 15 inches of mercury about half of the air is removed from the tubing and at 24 inches of mercury about 80% of the air in the tubing has been removed. Just because there is a certain vacuum pressure reading at one location in a tubing system does not mean that the whole system is at the same level. As air travels through a tubing system, friction between the moving air and the walls of the tubing will diminish the flow of air. The result of this friction loss will result in lower vacuum gauge readings (less vacuum) at a reading further out the mainline, further from the pump. Always assume that the vacuum gauge reading near the pump is not the same through out the tubing system. Taking readings at distant points from the vacuum pump and especially when the system is under a normal flow of sap will give a more accurate picture of how well the system is actually performing.

When taking a vacuum reading at a spout during a sap run it is a mistake to simply pull the spout and then take the reading. When the spout is pulled the vacuum will immediately suck in air and purge the lateral line and even some of the mainline of sap removing it as an obstruction to vacuum air flow. The reading may give a better vacuum reading than occurs under normal sap flow conditions. First, block the line using a pair of vice grips so sap is not instantly sucked out. Then pull the spout, attach the vacuum gauge and release the vise grip. This will give you a more accurate reading. Permanently installed vacuum gauges are another way to go.

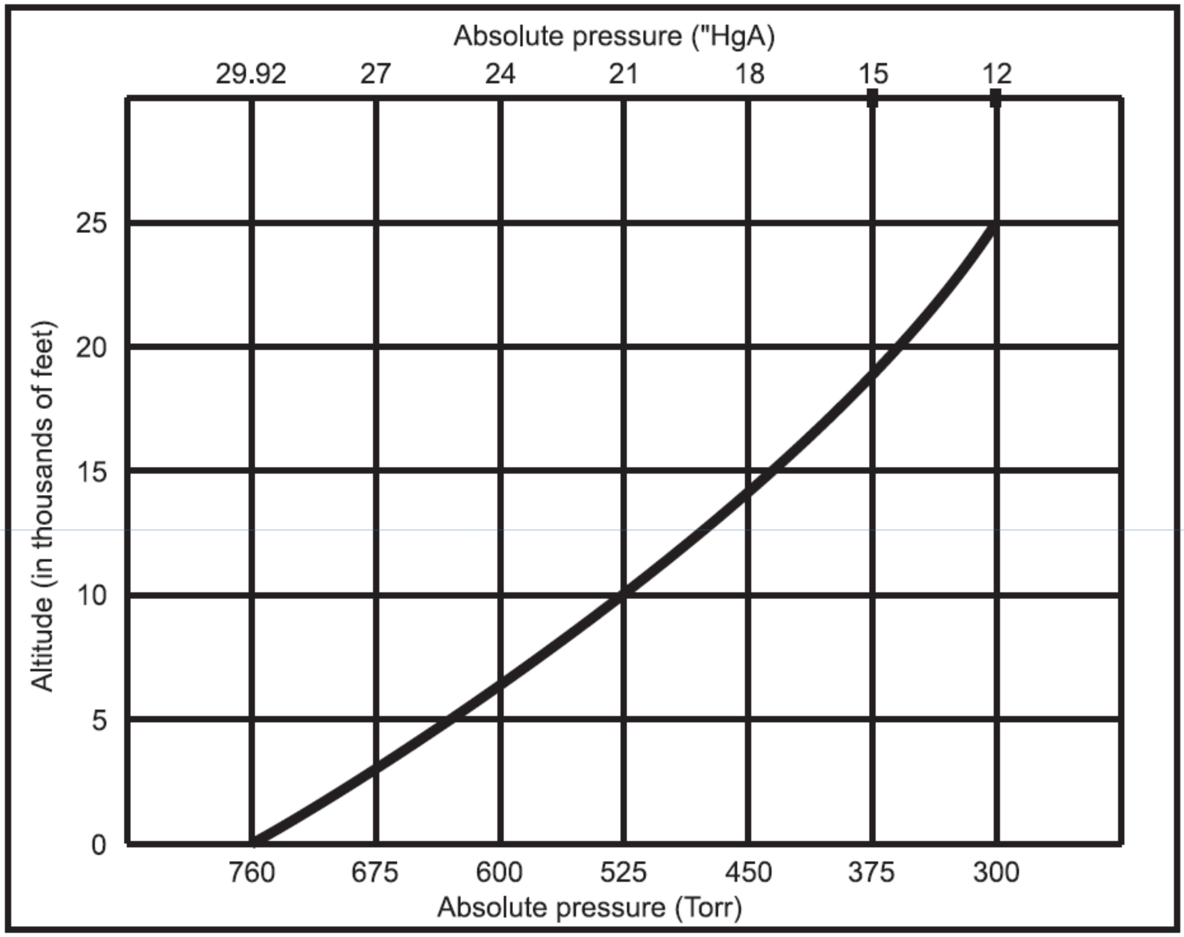
There are two objectives in using vacuum in maple sap collection, . First is to induce additional sap flow at the tap hole. Higher vacuum results in a higher yield per tap. The first objective is best served by maintaining as high a vacuum level as practical and by not having leaks in the system. To increase the level of vacuum at the tap you must either reduce the rate of leakage into the tubing, increase the output flow of the pump or increase the size of the tubing where it is preventing the leaked air from reaching the pump. The leak rate into the tubing can be reduced by plugging cracks, fixing holes, replacing poor fittings and tightening loose taps. Increasing the flow rate at the pump can be accomplished by increasing the setting on the vacuum controller, speeding up the rate of rotation or simply using a higher capacity pump. Improving the ability of the tubing to move the leakage air to the pump can be accomplished by increasing the size of tubing at key locations, adding mainlines, adding a dry line or reducing the length of lateral lines.

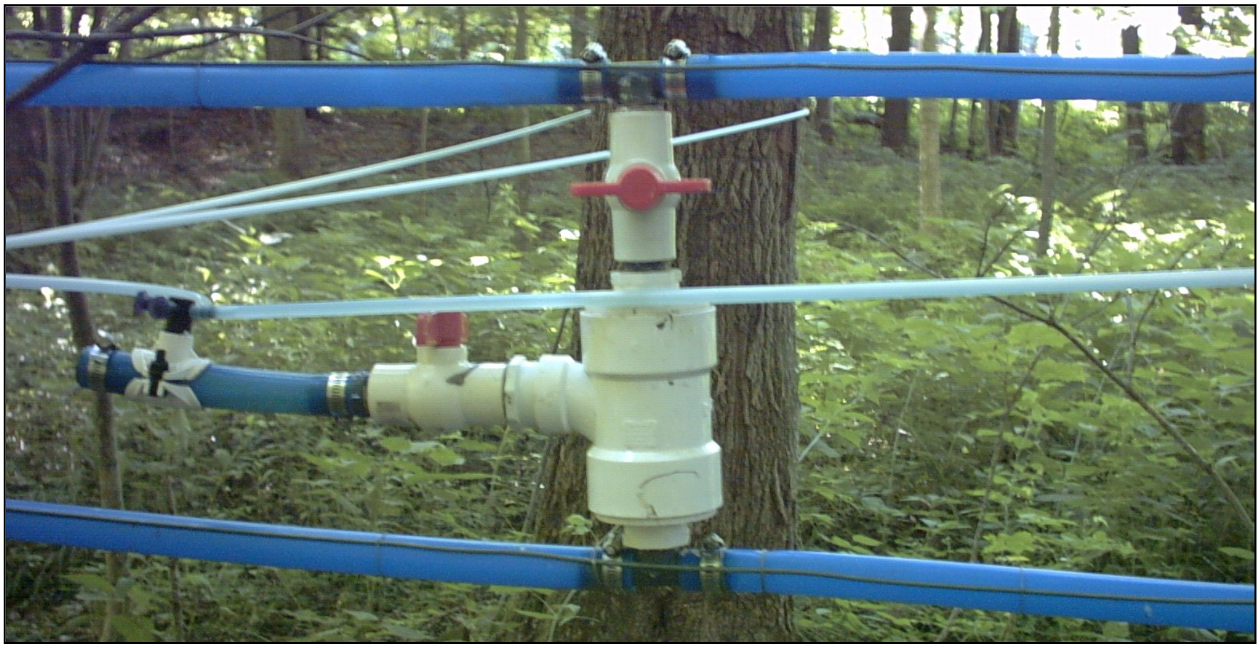
The second objective of having vacuum on a maple tubing system is to facilitate a rapid sap movement through tubing. This objective requires air moving in the tubing network that is supplied by very small leaks in fittings or at tap holes. Getting the sap out of the tubing and into an insulated holding tank or directly into the evaporator as soon as possible reduces sap warming and the associated reduction of sap quality. However, the leaks that enhance rapid sap flow in the tubing system also use additional capacity both from the vacuum pump and line loss in the mainlines and may hinder getting the desired vacuum pressure

This is a picture of a typical vacuum gauge with a reading of about 10" of Hg. The dial also includes a second scale in millimeters of Hg. There are many different scales used to measure vacuum pressure. The two on this meter are very common as is pounds per square inch shown on the previous page. Conversion charts are available on line. For the purposes of this book inches of Hg will be used consistently.

Vacuum performance is influenced by a number of natural conditions, such as moisture level in the air, air temperature and elevation. Though these conditions are not thought of as important hindrances to a typical maple operation, they can help explain why people with the same equipment many not see the same performance when compared with a different location.

As a general rule of thumb, you lose one inch of mercury in the barometric pressure reading for every 1000 feet of elevation. This is do to the fact that at the higher elevation there is less air above you. 1000 feet of air less and the weight of that air is what creates barometric pressure. Barometric pressure is directly linked to the efficiency of a vacuum pump. In this thinner higher elevation air with lower barometric pressure the vacuum pump will loose about 3% of its rated capacity. That is 3% for each 1000 feet of elevation, so at 2000′ of elevation you would expect the vacuum pump to operate at 6% less than its rated capacity. For example a vacuum pump rated at 30 cfm at 15″ of mercury at sea level would actually perform at 28 cfm at an elevation of 2000′. A vacuum pump rated at 60 cfm at 15″ of mercury at sea level would actually perform at about 55 cfm at an elevation of 3000′.

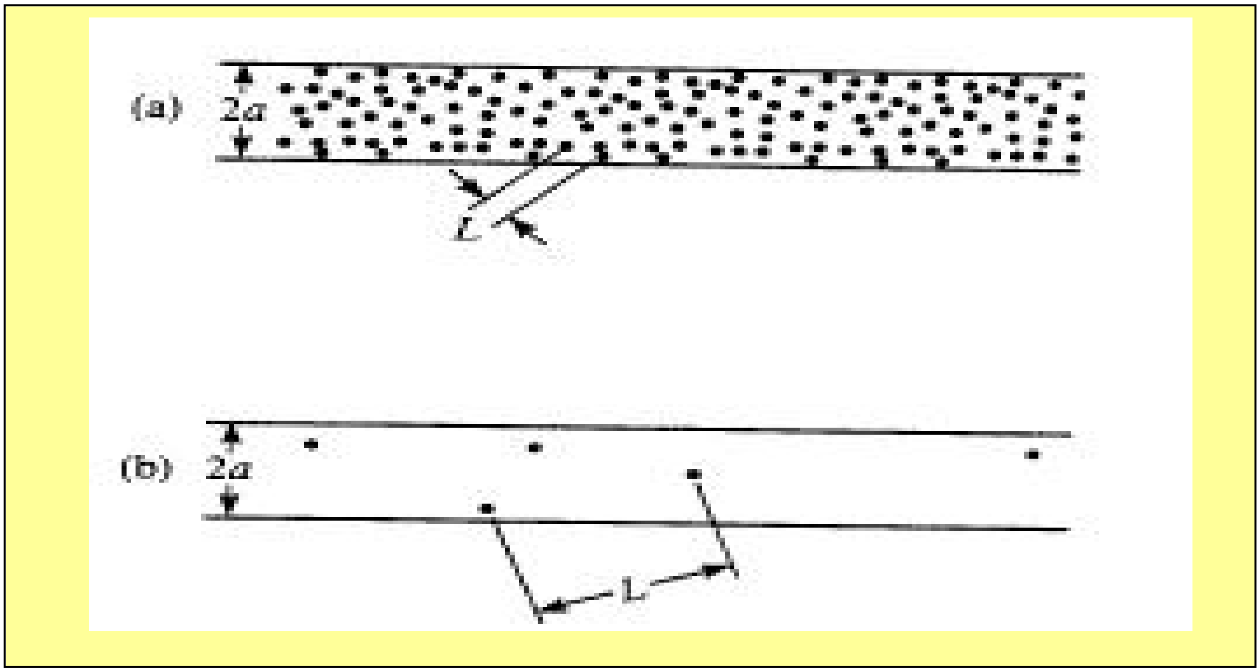




Typical dry line wet line manifold

The use of a dry line has become common in recent years as a way of increasing the vacuum capacity in the woods. A dry line system simply designates one mainline to only conduct air or vacuum and a second line to primarily conduct sap. The spout in the tree collects sap and creates vacuum pressure at the tree. The dropline connects the spout to the lateral line. The lateral line is connected to a mainline conducting both sap and air. This dual purpose mainline connects to the manifold or booster where air is pulled through the upper dry line and sap is pulled by gravity thru the lower wet line. This connection has been called a booster by many maple producers because it increased the air removal capacity provided to the single dual purpose main lines .

A dry line can be added to an existing system to improve vacuum capacity in the sugarbush. New systems can also be set up using the wet and dry line system. Advantages include such things as: it keeps more sap together in a smaller line which may allow it to stay cooler. Air can move freely in the dry line without slugs of sap temporarily blocking its movement. The dry line allows vacuum air to be removed effectively even if sap is frozen in sections of the wet line. Some producers have developed ways of washing the wet sap lines and the dry lines during warm spells in the season when sap stops flowing. They leave the vacuum on the wet line and send air and water out the dry line. At the manifold the cleaning water is pulled down into the wet line and returned to the sugarhouse. This allows the main lines to be washed without tearing things apart or without much labor on the part of the maple producer. It also is much easier to calculate the correct vacuum capacity of an open dry line vs. calculating the correct capacity of a line that will sometimes be carrying a light load of sap and other times a heavy load of sap. The negatives of the wet line dry line system includes the extra lines and wires required. The manifolds or boosters can be expensive and a maintenance problem.

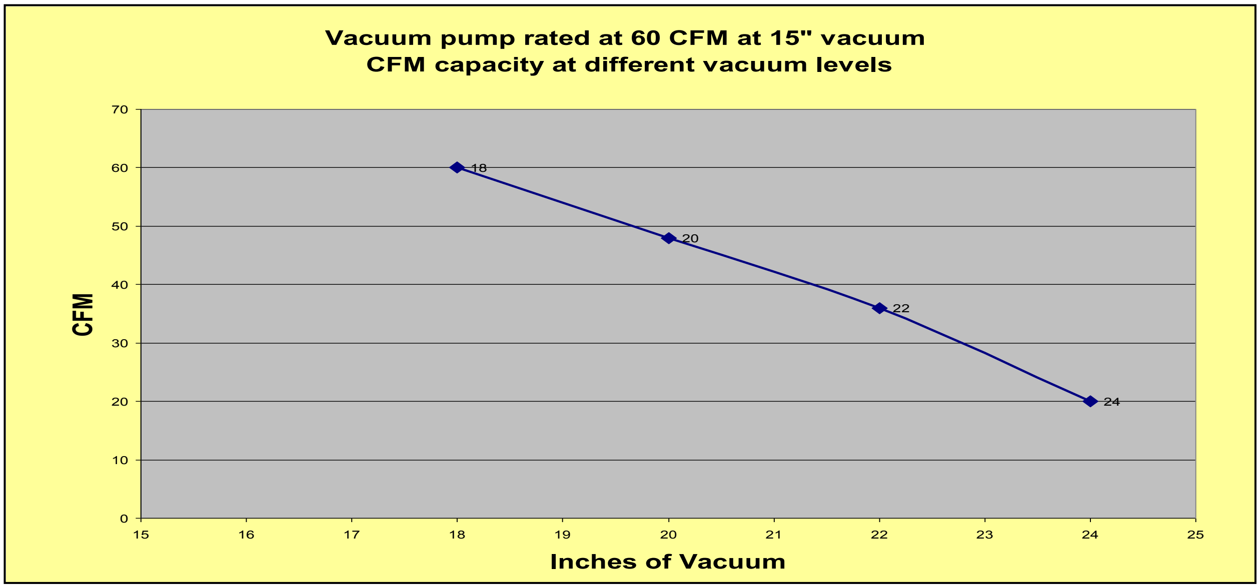


As the vacuum pump increases the level of vacuum, its capacity to remove more air decreases.

11.3 Changes in vacuum pump capacity

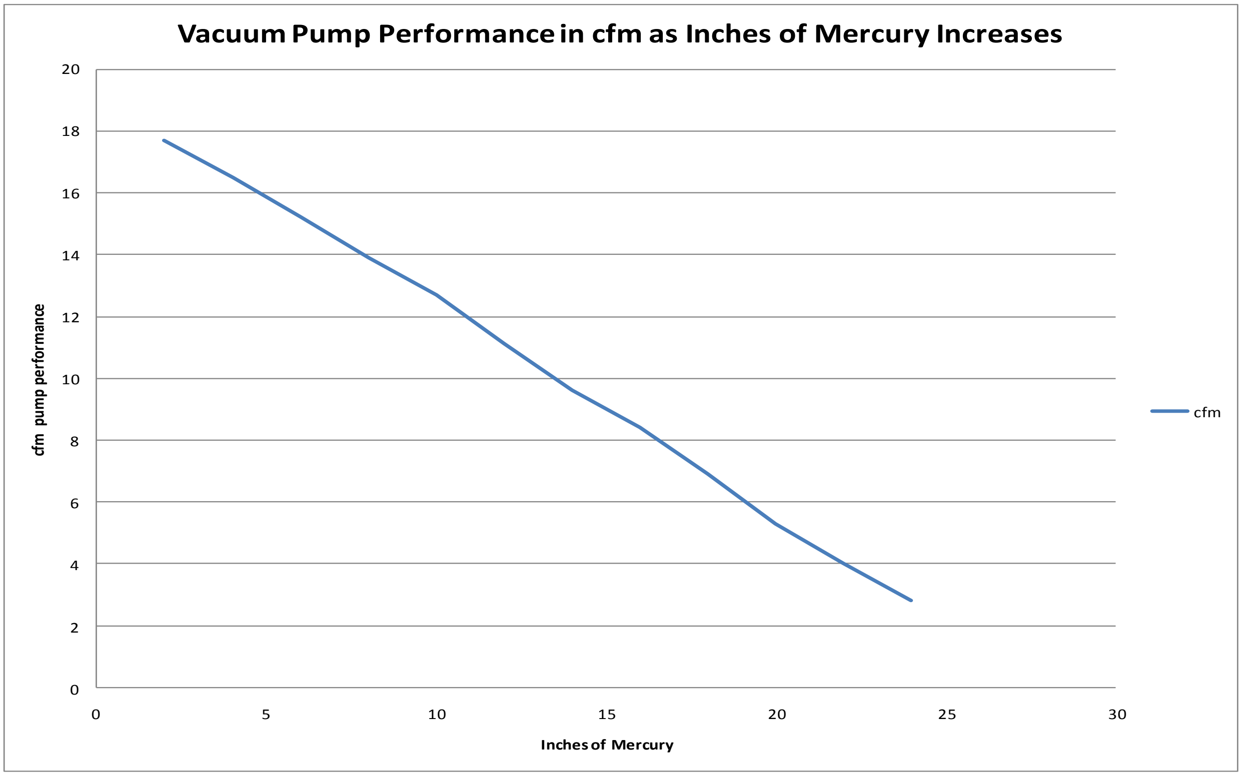
The illustration above shows the upper line filled with air with the dots representing air molecules and the lines showing the average gap between the molecules. The lower pipe illustrates a line with high vacuum. There is a large gap between molecules because most air molecules have been removed by vacuum. As the space between molecules gets larger the pump takes longer to get the same number of molecules of air out of the system. Research conducted on several vacuum systems in 2006 and 2007 showed that the air removal capacity of a vacuum pump decreases significantly as the level of vacuum in the tubing system increases. Vacuum pump capacity decreased from between 9% and 23% for each inch of vacuum increase at the pump. At first this can be hard to understand as the impression is that the line with the higher vacuum level sucks leak air harder. As the vacuum level increases there is less air in the tubing and in the pump so that the molecules of air become further and further apart as the vacuum increases. As the molecules become further and further apart it becomes more and more difficult for the vacuum pump to remove as much air in the same amount of time as it did at the lower vacuum level when the molecules were closer together.

Also, as you increase the vacuum level in the tubing system, the leak rate also will tend to increase as more air is pulled into the tubing through the tap and small holes when the vacuum pressure is higher. The usual result is that you simply cannot attain the high levels of vacuum you were hoping to reach unless you add more vacuum pump capacity and do an exceptional job of correcting leaks.



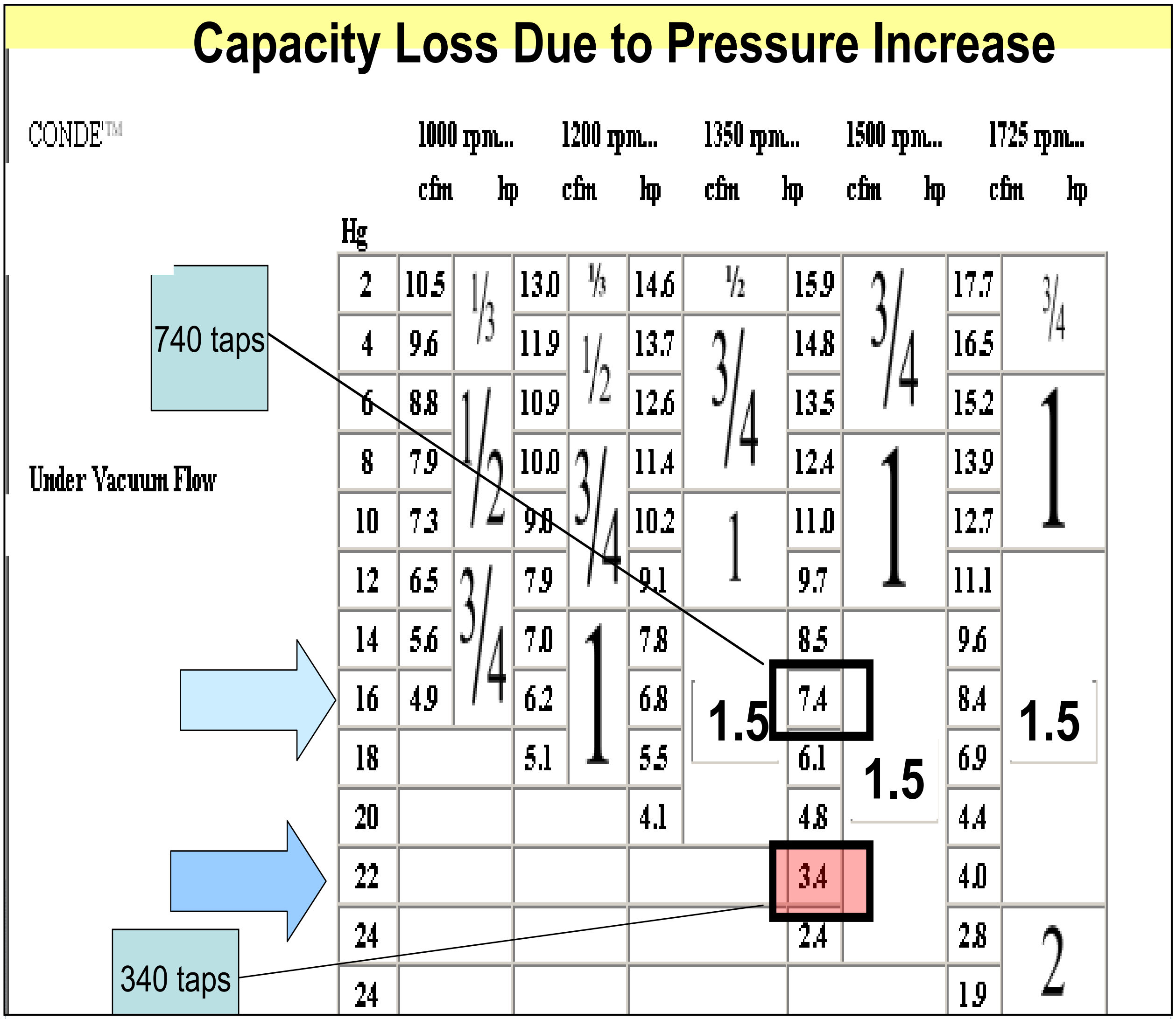
The chart above was made taking samples of air flow with a rotameter and vacuum gauge on a rotary vane vacuum pump rated for 60 cfm at 15″ of vacuum. It shows the decline in vacuum pump capacity in terms of the cubic feet of air the pump can remove from the system as the vacuum measurement in inches of Hg in the system increases. The readings were taken at 18, 20, 22 and 24 inches of Hg. Between the readings of 18″ and 24″ of Hg the capacity of the pump fell from 60 cfm to 20 cfm. What might this mean in a typical sugarbush? Based on this chart, and a common leak rate in a tubing system of 1 cfm per 100 taps, a maple tubing system with 5000 taps could operate fine at 15 or 18″ of vacuum with this pump rated at 60 cfm at 15″ vacuum. The pump we tested was actually functioning over its rated capacity with 60 cfm at 18″ of vacuum. The 5000 taps require a capacity of 50 cfm. However, if the maple producer decided to operate at 22 inches of vacuum he would need to adjust the air flow controller on the pump to increase the vacuum. From the chart we see the pump would not reach 22 inches. We can see on the chart that at 22 inches this pump could only remove about 36 cfm, just enough to keep up with 3600 taps. It could only keep up with 5000 taps up to about 19.5 inches of vacuum. To reach the desired 22 inches, at least another 14 cubic feet per minute pumping capacity would have to be added to the system. To increase to 24 inches of vacuum would reduce the capacity of this pump to 20 cfm, making it good for only 2000 taps. To function with 5000 taps it would need 30cfm added to the system to work at 24 inches. That would take one and a half more vacuum pumps of this size to get the system to operate at 24″ of vacuum. That would more than double the investment in pumps and energy to operate the vacuum system.

Sometimes maple producers are deceived about the ability of their pump to provide high levels of vacuum to the tap. An under sized tubing system, one that is not big enough to deliver all the leakage in the system to the vacuum pump will allow the vacuum gauge at the pump to have a high reading but the vacuum reading at the tap is much less. It looks good because you get a high vacuum reading at the pump but you do not accomplish the goal of higher vacuum at the tree.



The chart above demonstrates with a different vacuum pump how a vacuum pump loses capacity to move a volume of air when the level of vacuum is increased. Various kinds of vacuum pumps will react differently depending on whether they are single or two stage pumps, liquid seal, rotary vane or a piston pump. Often a chart of how well a given pump performs at various vacuum levels is available with the purchase or in descriptions on line. Where those charts are available they should be used to estimate how a pump will perform at a given vacuum level. These estimates will be very important in planning or improving a system.

There are meters that are fairly common in the dairy industry for measuring the cfm performance of a vacuum pump. A rotameter is a common tool for measuring vacuum pump capacity in cfm. Rotameters are fairly expensive in the capacity range of most maple vacuum systems. If a chart for your pump is not available the rated capacity is often marked on a pump sticker or metal stamp. If the pump will be operated at a level higher or lower than the inches of vacuum for which it is rated, an estimated adjustment must be made. For this a rule of thumb would be to deduct 10% of the rated capacity for each additional inch of mercury increase in vacuum pressure. For instance if you have a pump rated for 15 cfm at 15″ of mercury and the plan is to operate the system at 22 “, the increase from 15″ to 22″ is 7″ Hg. 10% of 15 cfm is 1.5 so 1.5 times 7 = 10.5 cfm reduction in pump capacity, 15 cfm—10.5 cfm leaves just 4.5 cfm of vacuum pump capacity at 22″ Hg. From the chart above the cfm output of the pump actually measured about the same as the rule of thumb predicted. To install a vacuum pump with a capacity of 15 cfm at 22″ would require a pump three times bigger in cfm capacity than the original vacuum pump that was rated at 15 cfm at 15″ of Hg.



Capacity Loss Due to Pressure Increase

CONDE™

Under Vacuum Flow

Hg	1000 rpm... cfm	hp	1200 rpm... cfm	hp	1350 rpm... cfm	hp	1500 rpm... cfm	hp	1725 rpm... cfm	hp
2	10.5	1/3	13.0	1/3	14.6	1/2	15.9	3/4	17.7	3/4
4	9.6		11.9	1/2	13.7	3/4	14.8		16.5	
6	8.8	1/2	10.9		12.6		13.5		15.2	1
8	7.9		10.0	3/4	11.4		12.4	1	13.9	
10	7.3		9.0		10.2	1	11.0		12.7	
12	6.5	3/4	7.9		9.1		9.7		11.1	
14	5.6		7.0	1	7.8		8.5		9.6	
16	4.9		6.2		6.8	1.5	7.4		8.4	1.5
18			5.1		5.5		6.1	1.5	6.9	
20					4.1		4.8		4.4	
22							3.4		4.0	
24							2.4		2.8	2
24									1.9	

740 taps

340 taps

Another way of looking at vacuum pump capacity loss is to base it on the number of taps the pump can service at a given vacuum level. In the chart above the top square indicates that a vacuum pump spinning at 1500 rpm on a 1.5 horse electric motor has the capacity at 16" Hg to service 740 taps with 7.4 cfm. The very same vacuum pump, spin speed, and motor but operating at 22" Hg has only enough capacity to service 340 taps with 3.4 cfm.

Are all cfm exactly the same? No. The weight of air in a cubic foot of air is influenced by many factors. The temperature of the air, the current barometric pressure, the current humidity, and the elevation all contribute to making the weight of a cubic foot of air somewhat variable. Many of these differences are fairly small so we ignore them in working with maple vacuum systems. Knowing this however can explain why the rated vacuum capacity of a pump and the actual output of the vacuum pump at a given location and under certain weather conditions are not the same.

SCFM vs ACFM

- SCFM
- **S**tandard **C**ubic **F**eet per **M**inute defines mass flow. Volume is calculated at prescribed set of conditions. The specifier must state standard conditions. The most prevalent standard conditions used in North America is 14.7 psia (barometric pressure at sea level), 68°F and 36% relative humidity. These are the conditions set forth by the ASME (American Society of Mechanical Engineers. API (American Petroleum Institute) is 14.7 psia, 60°F and 0% Relative Humidity.

ACFM

- **A**ctual **C**ubic **F**eet per **M**inute defines volumetric flow at specific conditions. A mass flow must be known so that it can be converted into the actual flow rate.

11.4 Measurements of air flow in a vacuum systems

CFM

The term cfm means cubic feet per minute. This terminology is used in many applications where air is being moved mechanically. It is used when referring to the capacity of a vacuum pump but it is used to describe the capacity of fans and air compressors as well. The term can create confusion because air is a compressible or expandable gas. A cubic foot may have more air molecules (more weight) in a cubic foot when compressed or less when under vacuum conditions. Because of this pressure effect, the mass or weight of the air moving through the pump will change with changes in barometric pressure, temperature or relative humidity. The pump may move the same volume, but not the same weight, at a different air density. This means that the air velocity in a system is the same even though mass flow rate through the pump is not. This is where additional terms to identify the weight of air being moved vs. the volume of air being moved in a strict sense are introduced. Therefore cfm is a confusing term because it has no single definition that applies to all instances.

The term SCFM stands for Standard Cubic Feet per Minute and standardizes the pressure, temperature and moisture level of air being pumped or vacuumed so that you can compare a given weight of air being moved in that given volume of one cubic foot. The ACFM stands for Actual Cubic Feet per Minute and simply indicates the actual volume of air being moved no matter how much vacuum or pressure the air is under. ACFM is an effective measure when evaluating fans but must be understood when dealing with a maple vacuum and tubing system. Manufacturer's information on a vacuum pump will likely include charts that compare the SCFM with the ACFM. The ACFM chart will make the pump look like it has a great deal of capacity even at very high vacuum levels. This information has meaning in some vacuum applications but with maple we are trying to remove air leaking into the tubing system that is somewhere near a Standard Cubic Foot. When evaluating the capacity of a vacuum pump you may be purchasing, pay a great deal of attention to the stated SCFM capacity at the vacuum level at which you plan to operate. All of the worksheets in this book deal with estimates close to the SCFM and not the ACFM. Using ACFM in the worksheets will result in very distorted estimates of capacity.

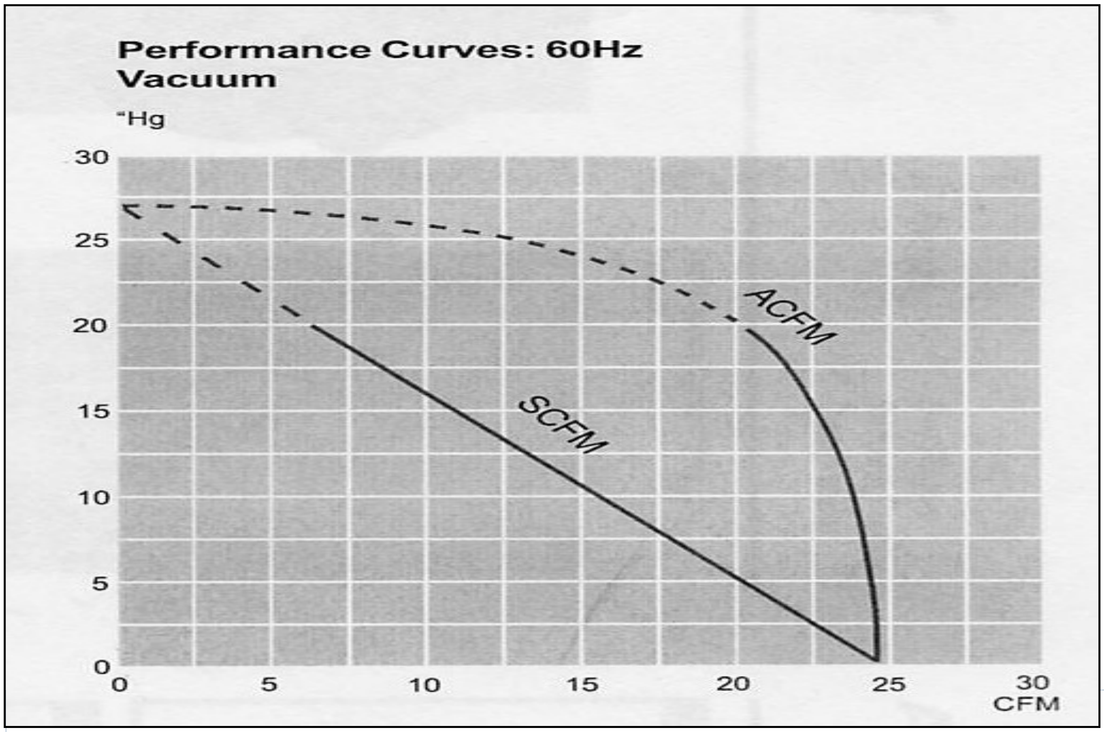
Weight Based vs. Volume Based Measurement

SCFM

SCFM (Standard Cubic Feet per Minute) is the volumetric flow rate of a gas corrected to "standardized" conditions of temperature, pressure and relative humidity, thus representing a precise mass flow rate or a flow at a standard weight of air. Unfortunately the "standard" condition for pressure is variously defined as an absolute pressure at 14.73 psia, or 14.696 psia and the "standard" temperature is variously defined as 68°F, 60°F, 0°C, 15°C, 20°C or 25°C. The relative humidity is also included in some definitions of standard conditions and can range from 0% to 36% from different sources. There is, in fact, no universally accepted set of standard conditions.

The temperature variation is the most important. In the United States, the standard temperature is most commonly defined as 60°F, but again not always. A variation in standard temperature can result in a significant volumetric variation for the same mass flow rate. For example, a mass flow rate of 1000 kg/hr of air at 1 atmosphere of absolute pressure is 455 SCFM at 0°C (32°F), but 481 SCFM at 60°F (15.56°C). So under real world conditions the performance of the vacuum system will vary with the temperature, pressure and humidity.

Generally the only time a maple producer would need to pay attention to a SCFM rating is when shopping for the right vacuum pump for your system. The ratings would be given in a standardized format, not for your location on a given day. Generally when planning a tubing system or evaluating problems in an existing tubing system we simply deal with cfm. To test the actual capacity of your pump or what cfm capacity is available in your tubing system at some location, you would use a rotameter. This is a fairly simple meter where the flow of air lifts a ball or metal weight giving a reading in cubic feet per minute. Because the ball or cylinder in the rotameter takes a given weight of air to hold it suspended, its reading comes very close to a standard cubic foot per minute. The readings can be mathematically adjusted to the SCFM, but the differences when working with a system as imprecise as a maple tubing system make the extra calculations unnecessary. The measurement with the rotameter shows how much air in cubic feet per minute the vacuum pump is capable of removing at the given point in the tubing system where the test is being conducted under the conditions of that day and location.



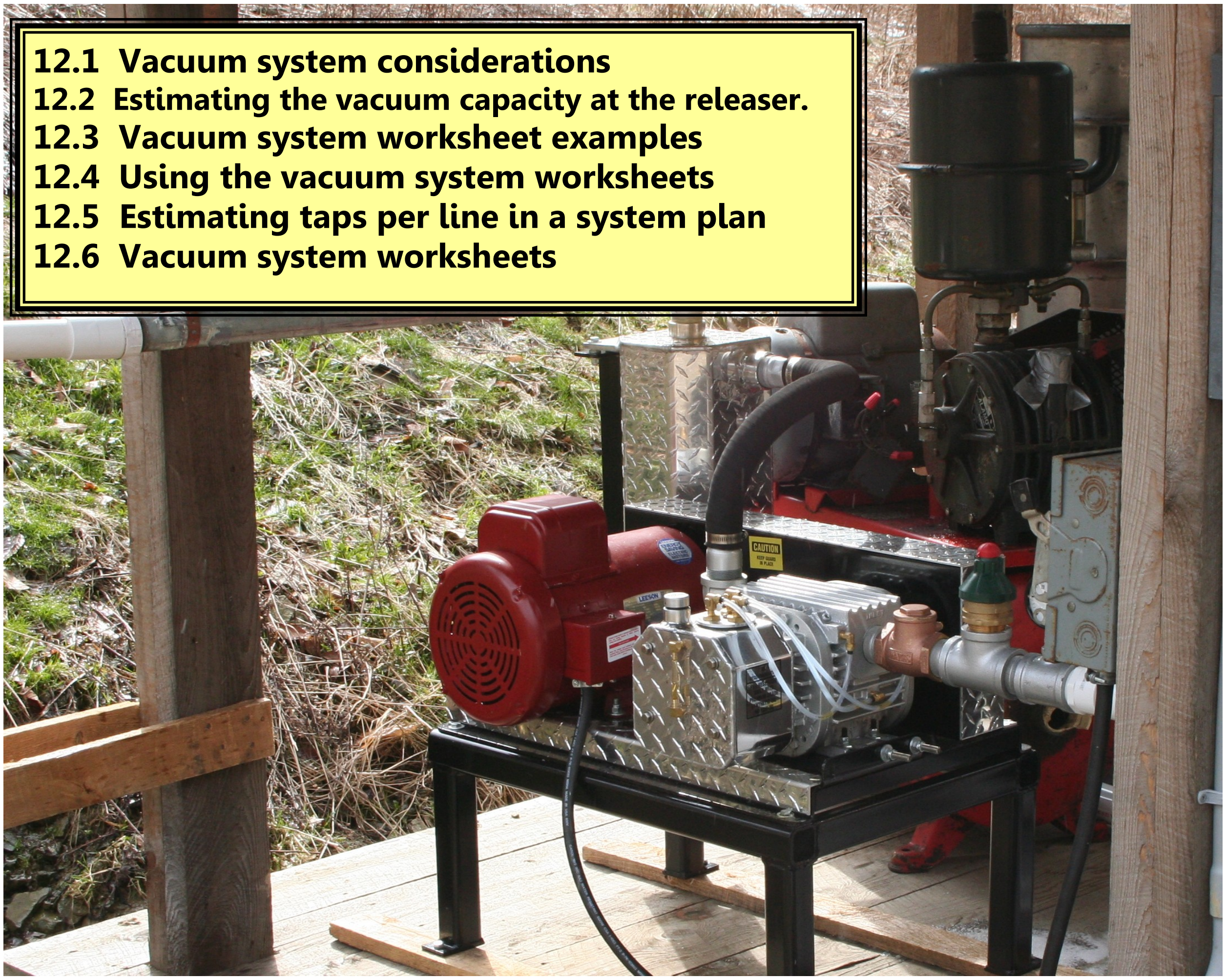
ACFM

Actual Cubic Feet per Minute (ACFM) is the volume of gas flowing anywhere in a system, independent of its temperature and pressure. If the system were moving a gas at exactly the "standard" condition, then ACFM would equal SCFM. Unfortunately, this usually is not the case as the most important change between these two definitions is the pressure. To move a gas, a positive pressure or a vacuum must be created. When positive pressure is applied to a standard cubic foot of gas, it is compressed. When a vacuum is applied to a standard cubic foot of gas, it expands. The volume of gas after it is pressurized or rarefied (under vacuum) is referred to as its "actual" volume. Knowledge of the temperature, pressure and relative humidity of the gas will allow the calculation of SCFM from the ACFM or from the ACFM to the SCFM. Generally the ACFM should be ignored by maple producers in dealing with their vacuum systems as it adds more to the confusion rather than being helpful with this application. Maple producers are often working with colder air during the maple season than the Standard CFM so that a vacuum pump may be slightly more effective than the SCFM chart would indicate but many sugar bushes are at fairly high elevations so the barometric pressure will be slightly lower making the vacuum pump operate slightly less efficiently than a SCFM chart for the unit would indicate. With pressure being the main difference, applying the % of vacuum or air removed from a closed space like a tubing system makes estimating the difference between SCFM and ACFM easy. For instance at about 15" of vacuum 50% of the air is removed, so one ACFM would have about half the weight of air of a SCFM. That seems to be close to true in the vacuum pump chart above. With 20 " 2/3rds of the air is removed so ACFM would be about 3 times more.

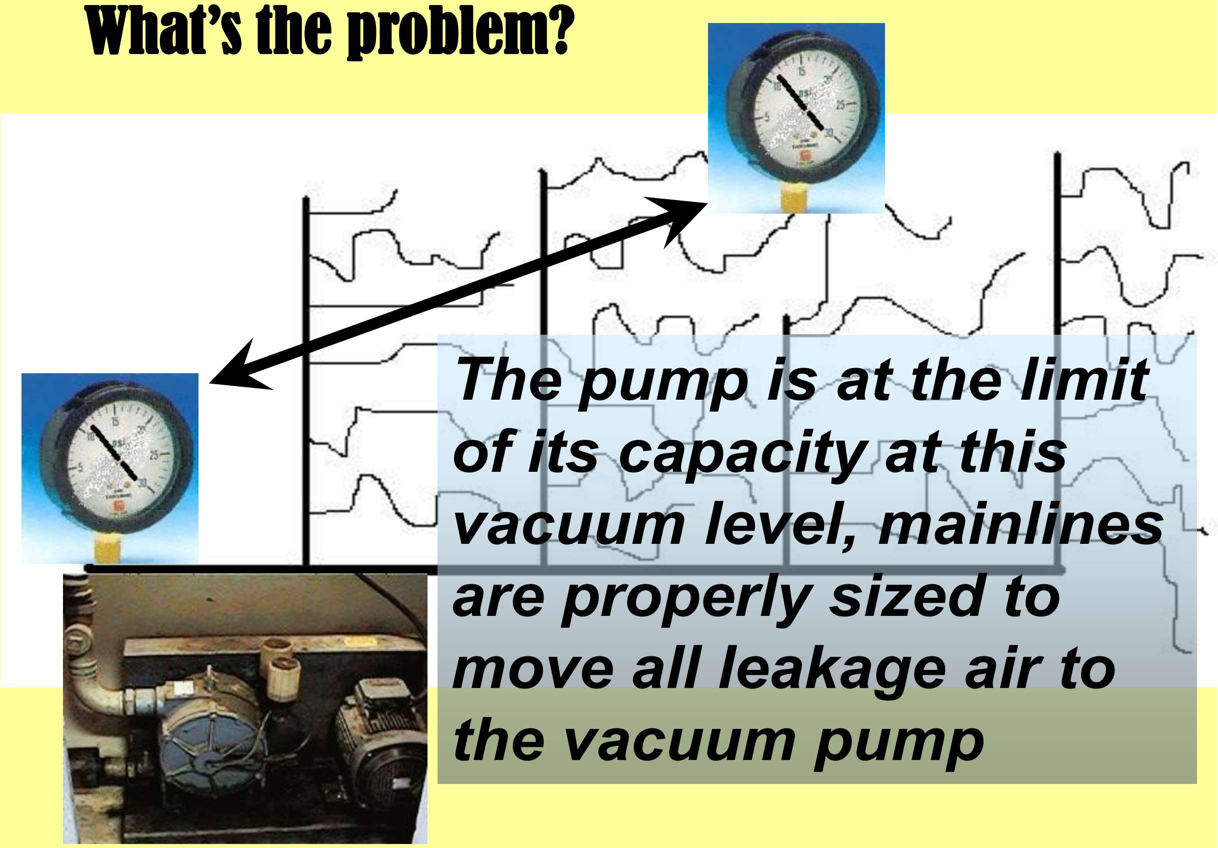
Above 20" the vacuum pump's ability to remove air either falls as noted in the illustration above and becomes an estimate rather than a true measurement.

Section 12 Sizing Your Vacuum System

Summary: When designing a new maple sap collection system or seeking to improve an existing one, matching the vacuum pump with the variety of demands placed on the pump is critical. An undersized pump will simply not perform to expectations. An over sized pump uses up capital investment money that would likely return a better profit elsewhere in the business. It is important to plan for and calculate the various factors involved with a maple vacuum system. Those factors include the leak rate, especially air leaking into the system that you cannot control. Another factor is the capacity loss to friction or line loss. As was just highlighted in the last section, the vacuum level you intend to operate the system alters the capacity needs dramatically. Some of these factors are fairly simple to estimate while other can be quite complex. Some can be evaluated using general rules of thumb while others really should be based on manufacturers measurements.



What's the problem?

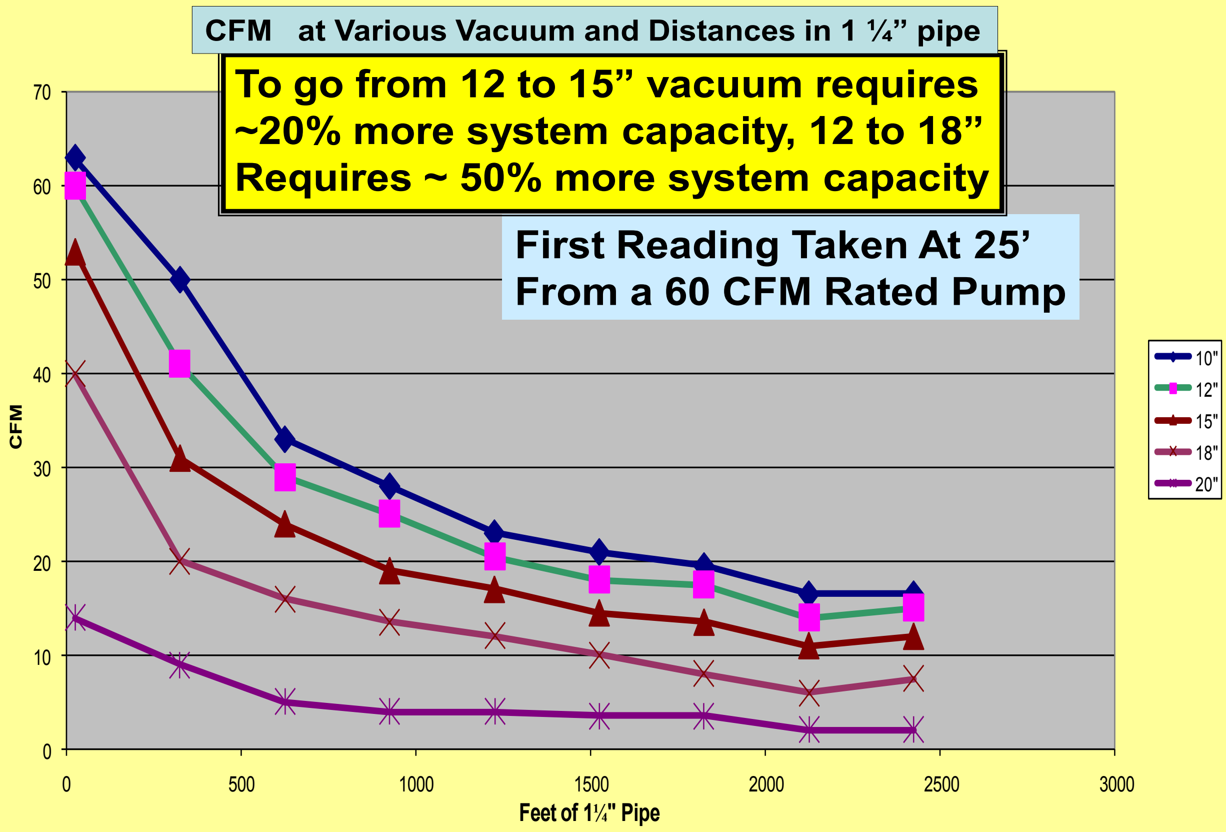


The pump is at the limit of its capacity at this vacuum level, mainlines are properly sized to move all leakage air to the vacuum pump

12.1 Vacuum system considerations

The key to sizing a vacuum system is to account for the three main factors influencing vacuum capacity. As discussed in the last section, the capacity of the vacuum pump, usually rated at 15″ Hg, must be adjusted to match its capacity at the vacuum pressure it is intended to operate. The capacity of the vacuum pump then needs to be adequate to match the leak rate and friction loss in the sap collection system. In the illustration above the pump shows 11″ of vacuum and the vacuum at the tap shows 11″. This indicates that the leak rate plus friction loss and the pump capacity are in perfect balance. It also shows that the tubing systems has sufficient capacity to deliver the leaked air to the vacuum pump without any restriction or bottle neck. The problem here is that many producers would prefer to operate at a higher vacuum pressure level to obtain a higher sap yield. In this example there are two options to increase vacuum level. One is to further reduce the leak rate. Should that be accomplished, the vacuum pressure would increase if the pump has the ability to operate at a higher vacuum pressure. Each pump, based on what type it is, and how worn important parts in the pump may be, has a functional limit as to what vacuum pressure it can generate. When purchasing a pump it is important to understand what the functional vacuum pressure limits for that type of pump are. These vary with the manufacturer and the set up. Information from the vacuum pump maker should be helpful in determining this. Second, the capacity of a worn pump or a pump that has been altered in some way can only be determined by testing with an air flow meter or rotameter combined with a vacuum gauge.

Determining the size of the vacuum pump is a balancing act. There are rules of thumb that can be helpful. These typically suggest 1 to 1.5 cfm for each 100 taps. Use the larger number when extended distances are involved. Use a common rule of thumb as a starting point. Then run through the calculations laid out for more accurate pump sizing in this book. The calculations will estimate the cfm capacity at the releaser. Then assign vacuum capacity to the mainlines and see how that works out with line loss and leak estimates. This will show if the rule of thumb is near the full calculated need for your system. It may take working through the program several times to come up with the balance that works best. It is usually an advantage to have some excess capacity to allow for minor expansion or temporary maintenance issues. Under sizing a vacuum pump will leave you working hard to improve vacuum but only minor improvement to vacuum pressure will result. Over sizing by too much means capital investment and operating cost that simply do not pay back.
The chart below illustrates the huge variation in system capacity that can result with a single vacuum pump rated at 60 cfm at 15″ Hg connected to a 1¼″ mainline. It shows graphically the capacity differences at different vacuum pressure levels and how friction in the mainline reduces the capacity as the distance between the vacuum pump and the end of the mainline is extended. The loss of capacity due to the friction between the air moving through the pipe and the walls of the pipe is commonly called line loss. Line loss will be covered extensively in the next section of this book.
The worksheets on the next few pages are designed to assist with sizing a vacuum pump in an existing maple sap collection system or designing a new system.



CFM at Various Vacuum and Distances in 1 ¼” pipe

To go from 12 to 15” vacuum requires ~20% more system capacity, 12 to 18” Requires ~ 50% more system capacity

First Reading Taken At 25’ From a 60 CFM Rated Pump

12.2 Estimating the vacuum capacity at the releaser.

The vacuum releaser or extractor is the equipment that distributes the vacuum coming from the vacuum pump to the mainlines. It also functions to separate the sap from the vacuum system and direct it to a holding tank or to the evaporator. The vacuum capacity that reaches the releaser is the capacity that is available to the tubing system. Since it is actually the releaser that connects the vacuum system to the mainlines and since the pipe connecting the vacuum pump to the releaser is one of the most undersized installations in vacuum systems, it is important that this be considered at this point. Under sizing the pipe between the vacuum pump and the releaser can be a source of significant system capacity loss in cfm and will influence the inches of vacuum experienced at the tap. The lower section of the Evaluating and Assigning Vacuum Pump Capacity to the Sap Collection System Worksheet provides a framework to estimate capacity loss between the vacuum pump and releaser. To complete the worksheet it will be important to be familiar with the principles and charts relating to friction or line loss in tubing. These are covered in the next section of this book titled Sizing mainlines. The charts and worksheets for the various sizes of mainlines are distributed through the next section beginning with 3/4″ lines and proceeding through 3″ lines. It would be good to be very familiar with both this and the next section before attempting to proceed with planning or evaluating a complete maple sap collection system. First, identify the pipe diameter and length between the vacuum pump and the releaser. Second, identify the presence and number of any 90º elbows that are common in these installations. For each elbow add 25feet to the length of the line prior to locating it's estimated line loss on the charts. On the chart for the diameter of pipe being used find in the second column where the cfm capacity for your vacuum pump as calculated in the top half of the worksheet is first listed. There will be a length in the first column associated with that cfm capacity. Add the length you determined between the vacuum pump and the releaser to the length on the chart and note the cfm in column two next to the added length. This is the cfm capacity at the releaser. The difference between the two cfm readings is the loss experienced from friction in the line connecting the two pieces of equipment. See the worksheet examples.

12.3 Vacuum system worksheet examples

In this example there is a 60 cfm vacuum pump, operating at 20″ of vacuum, connected to the releaser with 25′ of 1.5″ pipe with 2 90 degree elbows, the releaser is connected to 4 one inch lines each 500′ long and each with 500 taps. To do a complete evaluation of the system, complete the next section on sizing mainlines and work through the worksheets that evaluate the sizing of the main lines in the sap collection system.

Evaluating and Assigning Vacuum Pump Capacity to the Sap Collection System Worksheet (Example)

Vacuum pump functional capacity estimate in cubic feet per minute (cfm):

1. Make of pump __Green_________ Electric or gas? __E_____ Horse power __5____
2. Vacuum pump cfm rating at 15” of vacuum ____60_____cfm
3. Inches of vacuum at which you intend to operate this pump ___20___“
4. From your vacuum pump capacity chart for various vacuum levels, find the estimated cfm output at your intended operation vacuum level ________**cfm**
    - **Or**, your intended vacuum level _20” - rated vacuum level (ususlly 15”) __15” = increase in “ of vacuum __5_”, take this times 10 = _50_% pump capacity loss, take this times the vacuum pump rated capacity to estimate of your pump capacity at the intended higher vacuum level. __60__ cfm x 50_% = **__30_ cfm,** pump capacity at vacuum level you intend the system to function. Use this cfm number when estimating line loss in your tubing system, not the pump rating at 15” or the free air rating of the pump. With some pumps this loss many be lower, only 8% or 9%. If this % can be determined in the manufactures information, use the more accurate estimate. The loss rate can also be higher with some vacuum pumps.

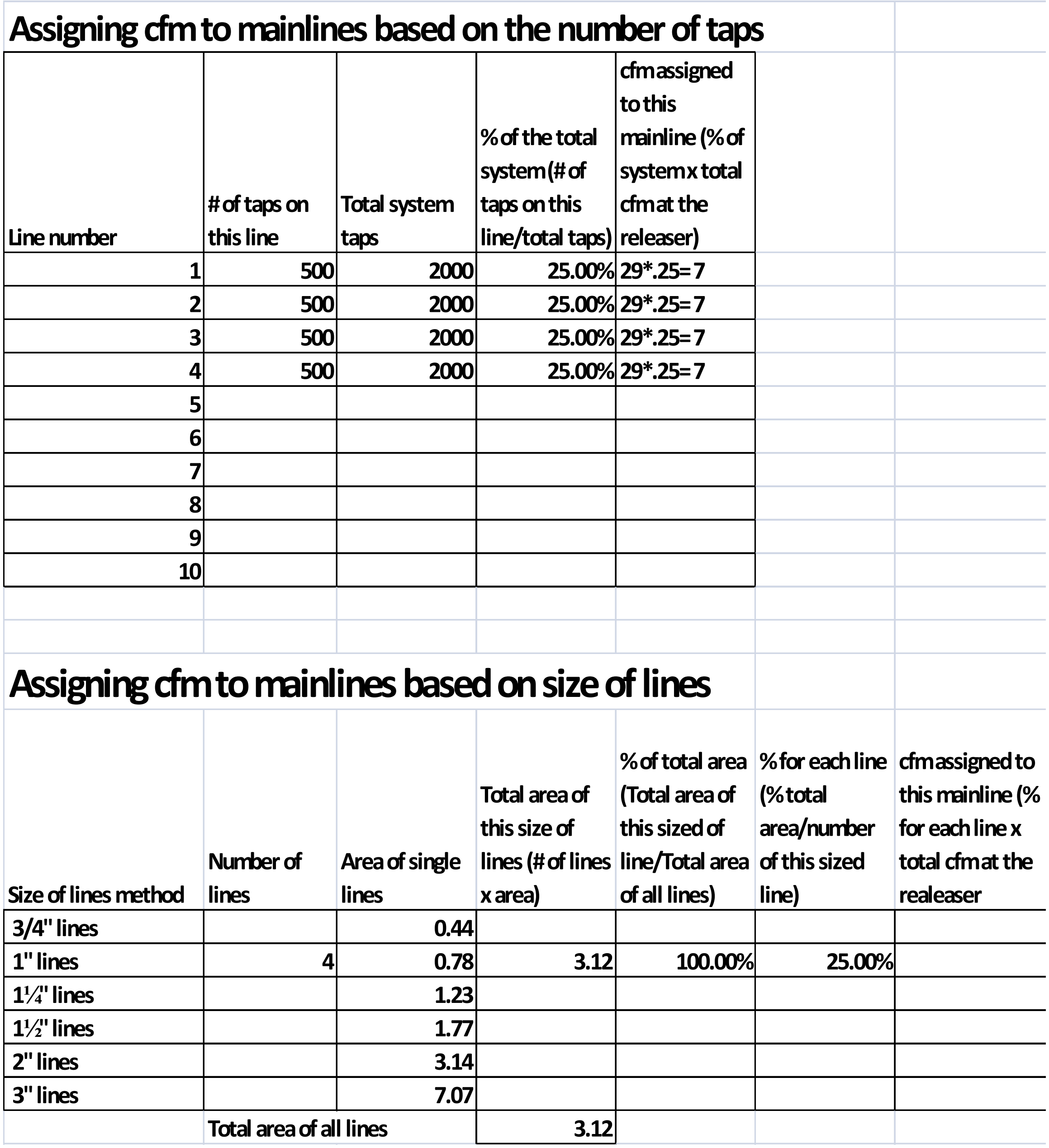
Estimate of cubic feet per minute (cfm) vacuum capacity at the vacuum releaser:

Under sizing the pipe between the vacuum pump and the releaser can be a source of significant system capacity loss in cfm and influencing the inches of vacuum experienced at the tap.

5. Pipe size between the vacuum pump and the releaser. __1.5”__
6. Length of pipe between the vacuum pump and the releaser. __25’____
7. For each 90^{o} elbow add 25’ to the total length of pipe. ___75’___ pipe length equivalent
8. From the line loss chart for this size of pipe, how many cfm are lost between the pump and the releaser? ____1__ cfm
9. Subtract line 8 __1__ from the results of line 4 __30_. This is the estimated cfm capacity available to the sap collection system at the releaser ___29__cfm

Estimating the vacuum capacity in cubic feet per minute (cfm) distributed to each main line in the tubing system:

1. At the releaser list the tubing sizes or tap numbers of each pipe in one of the tables below.
2. Do not count or add in wet lines, only dry lines and dual purpose lines. Wet lines can be considered dual purpose lines if they have sufficient size to be less than half full of sap during an exceptional sap run. This concept is more completely explained in the sizing main lines section of this book.



Assigning cfm to mainlines based on the number of taps

Line number	# of taps on this line	Total system taps	% of the total system (# of taps on this line/total taps)	cfm assigned to this mainline (% of system x total cfm at the releaser)
1	500	2000	25.00%	29*.25=7
2	500	2000	25.00%	29*.25=7
3	500	2000	25.00%	29*.25=7
4	500	2000	25.00%	29*.25=7
5				
6				
7				
8				
9				
10				

Assigning cfm to mainlines based on size of lines

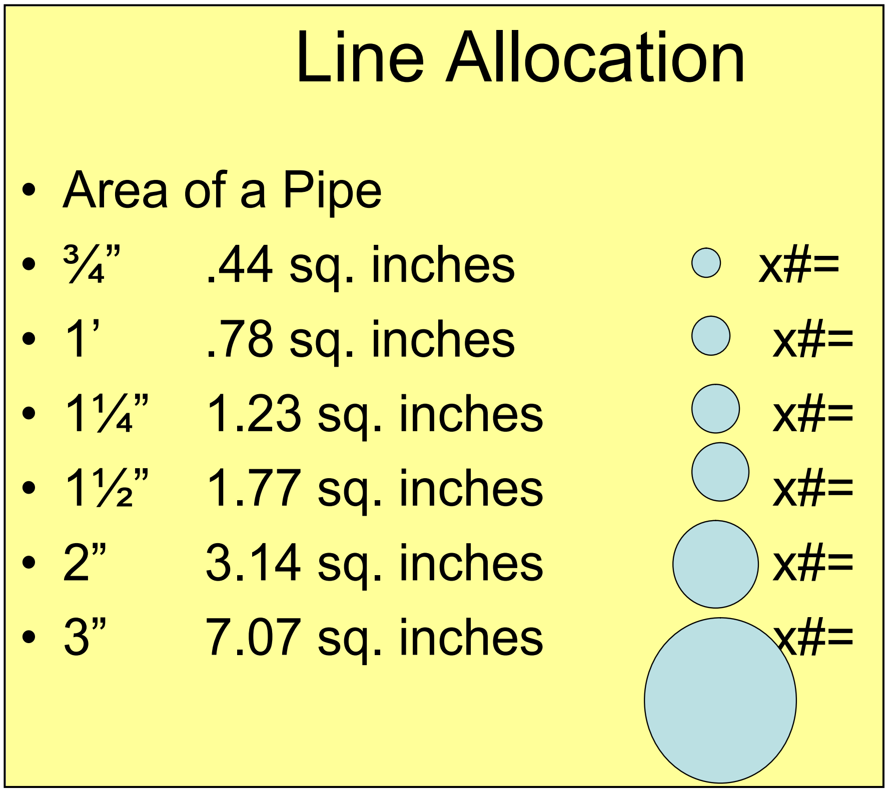
Size of lines method	Number of lines	Area of single lines	Total area of this size of lines (# of lines x area)	% of total area (Total area of this sized of line/Total area of all lines)	% for each line (% total area/number of this sized line)	cfm assigned to this mainline (% for each line x total cfm at the realeaser
3/4" lines		0.44				
1" lines	4	0.78	3.12	100.00%	25.00%	
1¼" lines		1.23				
1½" lines		1.77				
2" lines		3.14				
3" lines		7.07				
	Total area of all lines		3.12			

What if I have a number of different sized lines going into the sugarbush?

12.4 Using the vacuum system worksheets

Calculating vacuum system needs involves estimating line loss. The next pages of instruction and examples along with the associated worksheets will provide greater detail of methods to correctly estimate the distribution of vacuum capacity between mainlines. Having mainlines of different sizes complicates dividing the capacity of the vacuum pump between all the mainlines. Estimating vacuum capacity in a mainline is necessary for good planning. Estimating the amount of cfm available from the vacuum pump designated to each mainline allows for a line loss estimate or for identifying the number of taps recommended in the guidelines for that mainline. Where the number of taps on each line are known, the allocation of cfm from the pump can be made on that basis as seen in the upper table of the worksheet. Other- wise, an appropriation can be made based on the number and diameters of the various mainlines as outlined in the bottom table of the worksheet. Use only the bottom of the worksheet if the number of taps per line is not available. Line loss should be evaluated at each change in the mainline system. For instance line loss between the vacuum pump and the releaser should be deducted before distribution out of the releaser is allocated. This is also outlined on the bottom of the first page of the worksheet. When lines T or Y after the releaser this influences, usually reduces, the line loss occurring and would need to be estimated in addition to the lines provided in the worksheet.

For example, a tubing system has 400 taps connected to a single vacuum pump and a releaser with two 3/4″ lines and one 1″ line. Each 3/4″ line with 100 taps and the 1″ line with 200 taps. The allocation of vacuum capacity is fairly simple; 1/2 of the capacity is allocated to the 1″ line and 25% of the capacity at the releaser to each 3/4″ line. If the capacity at the releaser were 5 cfm, 2.5 cfm is allocated to the 1″ line and 1.25 cfm to each of the 3/4″ lines. Next you would follow the instruction given in the next section to estimate the line loss in each line and see if they have been allocated sufficient capacity to adequately service the taps with vacuum air flow and sap flow capacity.



Line Allocation

- Area of a Pipe
- ¾” .44 sq. inches x#=
- 1’ .78 sq. inches x#=
- 1¼” 1.23 sq. inches x#=
- 1½” 1.77 sq. inches x#=
- 2” 3.14 sq. inches x#=
- 3” 7.07 sq. inches x#=

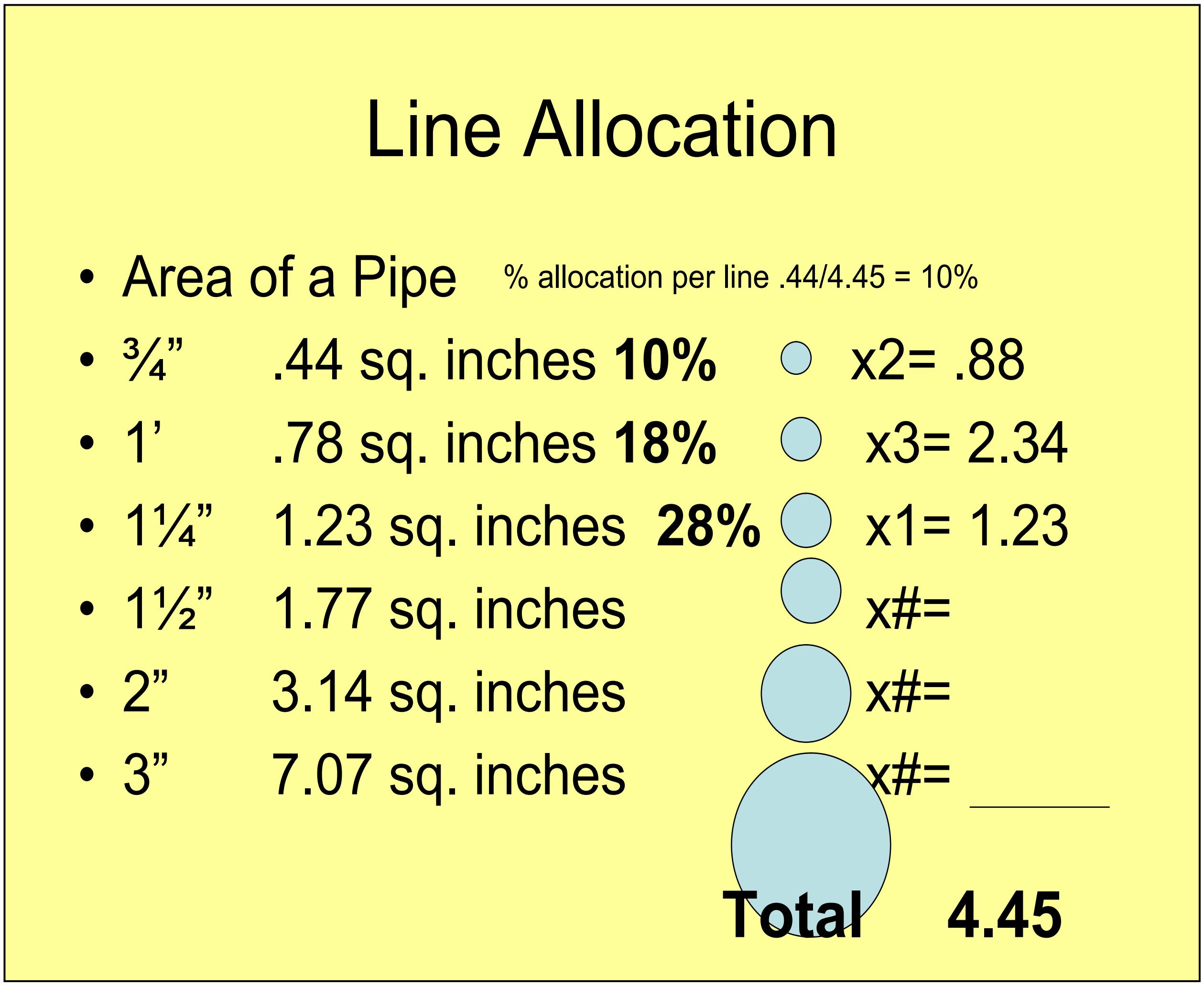
When the number of taps on each mainline is not known, the alternative way to allocate the vacuum system capacity to the tubing system uses the area of the various sizes of tubing to make an estimated allocation. This method may be better if you are designing a system but do not know just how many taps there will be on each line.
Knowing the cross section areas of the various sizes of tubing allows an estimated cubic feet per minute capacity of the vacuum pump to be assigned to each size of line. The areas are as follows:
Area of a Pipe

¾″	.44 sq. inches
1′	.78 sq. inches
1¼″	1.23 sq. inches
1½″	1.77 sq. inches
2″	3.14 sq. inches
3″	7.07 sq. inches

The area of a 5/16th lateral line is .077 sq. inches so it takes 6.3 lateral lines to equal the capacity of one three quarter inch line. It takes ten to equal the capacity of one 1″ line. These figures can be especially important when designing a sap ladder and you want it to carry through the capacity of the system rather than have it act as a bottle neck.

To work through our previous example of two 3/4″ lines and one 1″ line connected to the releaser using this method, use the mainline diameters when the number of taps is unknown. Multiply the 3/4″ area of .44 square inches by 2 to = .88 and add the 1″ area of .78 = 1.66 total area. Divide the area of a 3/4″ pipe by the total area, .44/1.66 = 26.5% so the two 3/4″ pipes would be allocated 53% of the capacity and the one inch 47% of the capacity based on tubing size alone. If the pump capacity again was 5 cfm, each 3/4″ line would be estimated to be using 5 cfm x 26.5% or 1.3 cfm and the one inch line 2.4 cfm.

For example, a tubing system has 3000 taps connected to a single vacuum pump and a releaser with two one inch lines, one with 400 taps and one with 700 taps, one inch and a quarter line with 800 taps and an inch and a half line with 1100 taps. 25% of the pump capacity could be assigned to each line because there are four lines. That would be simple but not very accurate as both the number of taps and tubing sizes vary. To estimate on a per tap basis would require dividing the 400 taps on the first one inch line by the total of 3000 taps (13.3%) and assign 13.3 % of the cfm to that line. Where using a 45 cfm pump, the first line would be assigned 13.3% of that or 6 cfm. The second 1″ line is 700 divided by 3000 = 23.3% or 10.5 cfm of the total 45 cfm. The 800 tap inch and a quarter line is 800 taps divided by 3000 = 26.7% or 12 cfm. The final line would have 1100 divided by 3000 = 36.7% or 16.5 cfm. Now, if line length is known, line loss can be calculated to see if there is sufficient capacity for this system to function as desired.



Line Allocation

- Area of a Pipe % allocation per line .44/4.45 = 10%
- ¾” .44 sq. inches **10%** x2= .88
- 1’ .78 sq. inches **18%** x3= 2.34
- 1¼” 1.23 sq. inches **28%** x1= 1.23
- 1½” 1.77 sq. inches x#=
- 2” 3.14 sq. inches x#=
- 3” 7.07 sq. inches x#= ______

Total 4.45

For example, where six main lines leave the releaser where two are ¾″, 3 are 1″ and one is an 1¼″, multiply two times the area of a ¾″ line or 2 x .44 = .88 square inches, and three times .78, the area of 1″ tubing, or 3 x .78 = 2.34 and one times the area of 1¼″ tubing or 1.23 square inches for a sum total of 4.45 square inches through which the leakage from the taps and tubing will flow to the vacuum pump. Next, estimate what percentage of the air flowing to the vacuum pump from leaks will likely flow through each sized tubing by dividing the square inches of each size of tubing by the total. Divide the total square inches of ¾″ tubing .88 by the total of 4.45 square inches and the result is 20% of the total capacity is assigned to the ¾″ lines. Since there are two ¾″ lines, 10% or half is assigned to each of the two ¾″ pipes. There are three 1″ main lines with each having an area of .78 square inches so multiply the .78 times three for a total of 2.34 square inches for each 1″ pipe. Divide the total square inches of 1″ tubing, 2.34 by the total 4.45 square inches equals 53% of the cubic feet of leakage air passing through the 1″ tubing or about 18% of the total in each of the three 1″ pipes. Finally, with just one 1¼″ line, divide these square inches 1.23 by the total 4.45 square inches and get 28% of the leakage passing through this pipe.

Line Allocation

- Area of a Pipe % allocation per line .44/4.45 = 10%
- ¾” .44 sq. inches **10%** ○ x2= .88
- 1’ .78 sq. inches **18%** ○ x3= 2.34
- 1¼” 1.23 sq. inches **28%** ○ x1= 1.23

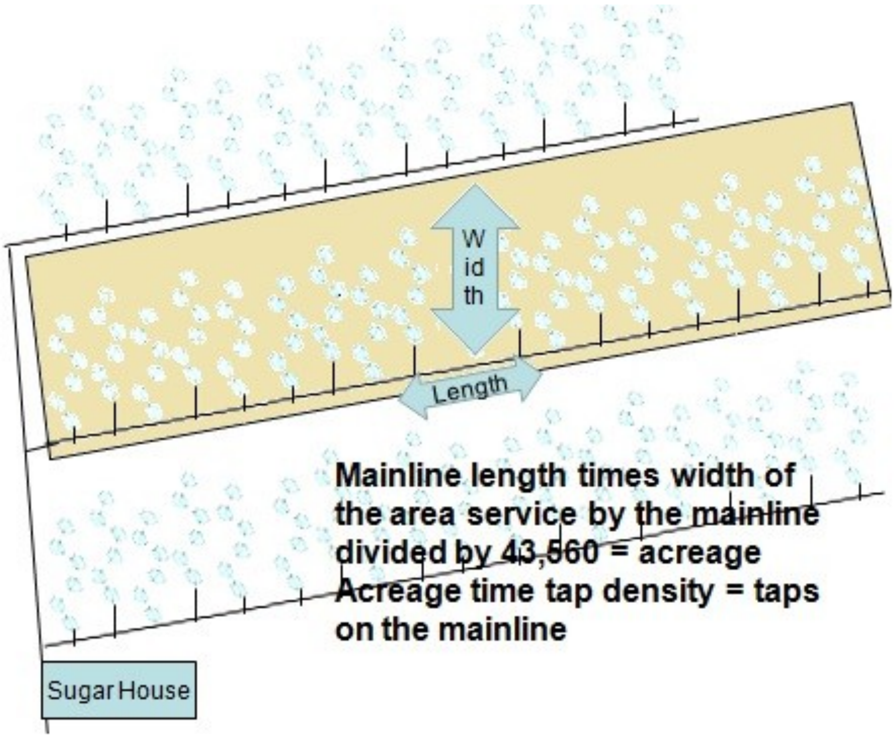
Total CFM capacity of vacuum pump on this dumper is 30 cfm, so each ¾” line gets 3 cfm, each 1” line gets 5.4 cfm and the last line gets 8.4 Now go back to the chart to estimate line loss

Total 4.45

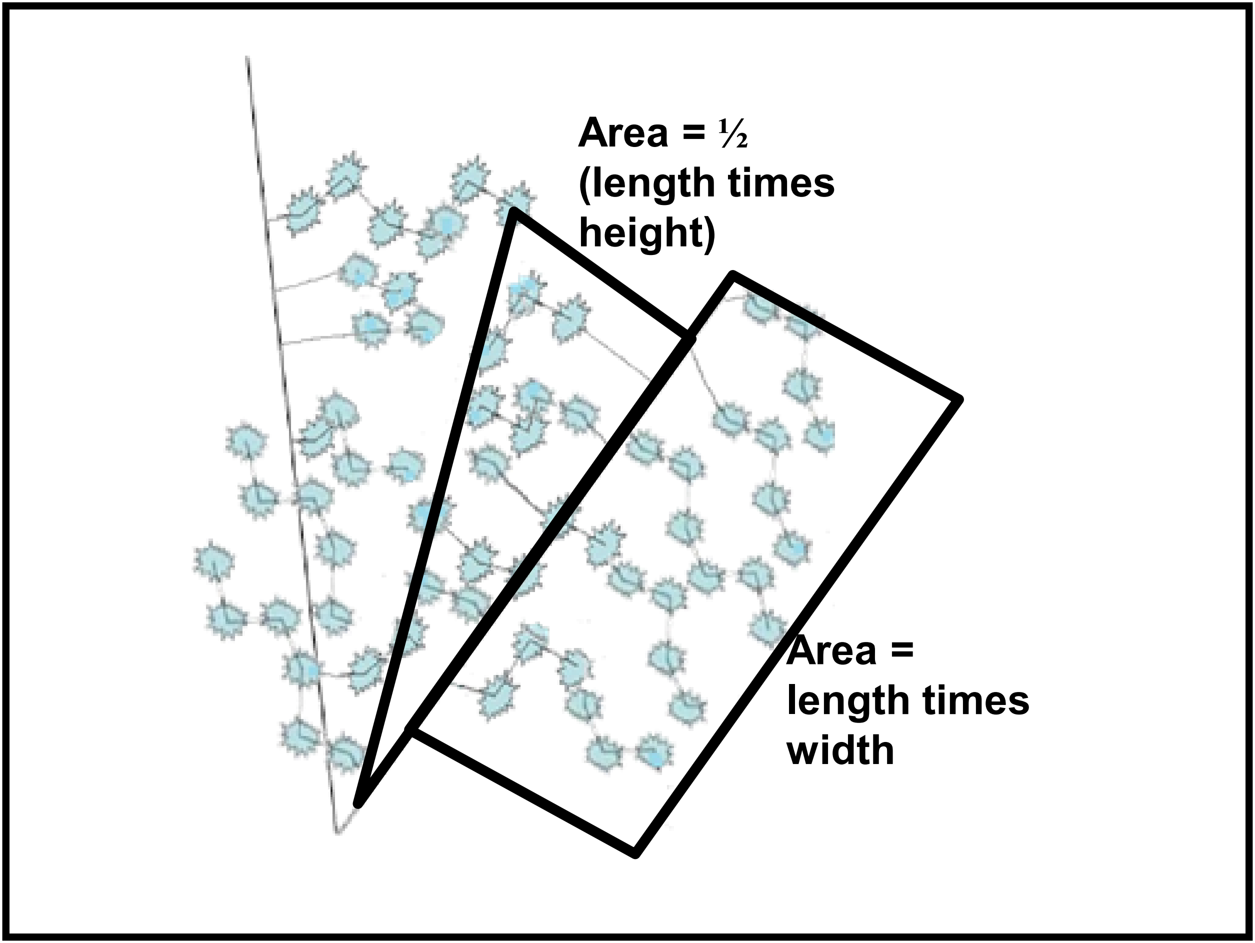
In this example, if the vacuum pump has a capacity of 30 cfm calculate the main line assignments to see what the capacity assigned to each line will be. Each 3/4″ line has 10% based on its size so each would be assigned 3 cfm. The one inch lines each have 18% of the flow area and would be assigned 5.4 cfm each and the one 1¼″ line would be assigned 28% of the capacity or 8.4 cfm. If each line was 800 feet long how many taps could each be expected to handle? If we use the line loss charts in the next chapter at 6% slope each 3/4″ line with a beginning capacity of 3 cfm could support 208 taps. On the 3/4″ chart we looked down the second column to where 3 cfm was first listed at 1800′, add the 800′ over which the line loss will be experienced and look across to 6% slope and the number of taps suggested by the guideline is 208 taps. The 1″ lines with 6% slope assigned 5.4 cfm could support 440 taps. Understand that on the guidelines charts sap flow and flow of leakage air have both been accounted for. The 1¼″ line at 6% slope has 8.4 cfm. It will work for 674 taps. More detail on using the line loss charts is available in the next section. Now add the guideline tap recommendations to see if this pump has enough capacity for this number of taps over this great of a distance on these sizes of lines at 15″ of vacuum. 3/4″ lines can support 208 taps each for a total of 416. One inch lines can support 440 taps each for a total of 1320 taps and the one 1¼ inch line 674 taps for a total of 2434 taps that this system is designed to handle. If the plan was to have 3000 taps in the system it would not likely function at the expected capacity. This system would need to be re-evaluated using a bigger pump and possibly some bigger mainlines. Use the worksheets provided at the end of this section to evaluate the vacuum system with the charts and worksheets in the next chapter.

12.5 Estimating taps per line in a system plan

When planning a maple tubing system it can be helpful to make a count or an estimate of the number of taps that will be on a mainline. If the proposed mainline runs have been flagged, a rough count of tappable trees in the area to supply the mainline would be sufficient. If the area is large and counting very difficult, several measurements will be necessary for an accurate estimate. The estimated length of the mainline, the average distance between mainlines and an estimate of the tap density in that section of the woods together can provide a reasonable estimate of the number of taps on a potential mainline. The length of the mainline and distance between mainlines should be measured out or at leased paced off. An estimate of tap density can be made in the perspective wood lot by measuring out 26' 4" from a center point in a circle, this distance is the radius of a 1/20th of an acre circle, count the # of tappable trees inside the circle and multiply by 20. Take several samples and then average the results to estimate the taps per acre. If areas of the woods differ significantly from others you would want to do separate valuations and estimate how big of an area the differing densities represented. Next, using the mainline length and the distance between mainlines calculate the acreage the mainline will service. For example if the mainline is 815′ long and the distance between mainlines is 150′ the area serviced would be 815 x 150 = 122,250′. Divide this by the number of square feet in an acre (43,560). 122,250/43,560 = 2.8 acres. Multiply this by the estimated tap density. For this example use 72 taps per acre, so 2.8 acres times 72 taps per acre results in 202 taps on the proposed mainline. An important consideration here is if lateral lines end with the mainline or extend out past the end of the main line. It the lateral extends 150′ beyond the end of the mainline that would need to be calculated. In this example multiply 815′ + 150′ times 150′ or 965′ x 150′ = 144,750′. Again divide 144,750 by 43,560 results in 3.3 acres serviced by the mainline. 3.3 acres time 72 taps per acre



Mainline length times width of the area service by the mainline divided by 43,560 = acreage Acreage time tap density = taps on the mainline



Where the tubing system is to be set up in the "branching tree" styled layout rather than on a contour, calculating the area serviced by the tubing becomes more complicated. In the illustration above the mainlines split at an angle so that the area between the two lines must be measured off as a triangle. In the illustration the mainline being measured runs along the base of the triangle and the left side of the rectangle. The formula for calculating the area of a triangle is 1/2 of the longer side or base times the height of the shortest side or 1/2(base X height). The area away from the Y would need to be calculated based on it's shape. In many cases this would be a rectangle as in the illustration above but variations occur in different locations.

For example if the mainline coming off the Y were 220′ long and lateral lines extended 150′ in both directions at the far end, the area of the rectangle would be calculated and added to the area of the triangle. 220′ times 150′ = 33,000 square feet plus 1/2 (220′ times 150′)= 16,500 square feet for a combined total of 49,500 square feet. To convert this to acreage divide the total by 43,560. 49,500/43,560 = 1.1 acres. If the density of the taps per acre was determined to be 72 this mainline would service 1.1 acres times 72 taps per acre = 79 taps on this Y of the mainline. It rapidly becomes obvious that going through the woods once mainline flags are in place and doing actual tree counts may be preferred to these area and density calculations when designing a mainline system plan and getting the mainlines sized correctly is the intent.

12.6 Vacuum system worksheets

Evaluating and Assigning Vacuum Pump Capacity to the Sap Collection System Worksheet

Vacuum pump functional capacity estimate in cubic feet per minute (cfm):

1. Make of pump ________________ Electric or gas? _______ Horse power ______
2. Vacuum pump cfm rating at 15" of vacuum ___________cfm
3. Inches of vacuum at which you intend to operate this pump ________"
4. From your vacuum pump capacity chart for various vacuum levels, find the estimated cfm output at your intended operation vacuum level ________**cfm**
    - **Or**, your intended vacuum level ___" - rated vacuum level (ususlly 15") ____" = increase in " of vacuum ____", take this times 10 = ____% pump capacity loss, take this times the vacuum pump rated capacity to estimate of your pump capacity at the intended higher vacuum level. ____ cfm x ___% = **____ cfm,** pump capacity at vacuum level you intend the system to function. Use this cfm number when estimating line loss in your tubing system, not the pump rating at 15" or the free air rating of the pump. With some pumps this loss many be lower, only 8% or 9%. If this % can be determined in the manufactures information, use the more accurate estimate. The loss rate can also be higher with some vacuum pumps.

Estimate of cubic feet per minute (cfm) vacuum capacity at the vacuum releaser:

Under sizing the pipe between the vacuum pump and the releaser can be a source of significant system capacity loss in cfm and influencing the inches of vacuum experienced at the tap.

5. Pipe size between the vacuum pump and the releaser. _____
6. Length of pipe between the vacuum pump and the releaser. ______
7. For each 90° elbow add 25' to the total length of pipe. ______ pipe length equivalent
8. From the line loss chart for this size of pipe, how many cfm are lost between the pump and the releaser? _________
9. Subtract line 8 ____ from the results of line 4 ____. This is the estimated cfm capacity available to the sap collection system at the releaser _______cfm

Estimating the vacuum capacity in cubic feet per minute (cfm) distributed to each main line in the tubing system:

1. At the releaser list the tubing sizes or tap numbers of each pipe in one of the tables below.
2. Do not count or add in wet lines, only dry lines and dual purpose lines. Wet lines can be considered dual purpose lines if they have sufficient size to be less than half full of sap during an exceptional sap run. This concept is more completely explained in the sizing main lines section of this book.

Assigning cfm to mainlines based on the number of taps

Line number	# of taps on this line	Total system taps	% of the total system (# of taps on this line/total taps)	cfm assigned to this mainline (% of system x total cfm at the releaser)
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

Assigning cfm to mainlines based on size of lines

Size of lines method	Number of lines	Area of single lines	Total area of this size of lines (# of lines x area)	% of total area (Total area of this sized of line/Total area of all lines)	% for each line (% total area/number of this sized line)	cfm assigned to this mainline (% for each line x total cfm at the realeaser
3/4" lines		0.44				
1" lines		0.78				
1¼" lines		1.23				
1½" lines		1.77				
2" lines		3.14				
3" lines		7.07				
		Total area of all lines				

Section 13 Sizing mainlines

Summary:
Designing a tubing system with mainlines that have sufficient capacity to provide both excellent vacuum to the tap and high quality sap to the sugarhouse should be the goal of the system designer. Sizing the vacuum system and the tubing system is an issue of calculating the balance between the systems capacity to remove leakage air and high quality sap from the system at the same time. Over sizing is expensive and can reduce the sap quality by allowing it to be warmed while in the tubing. Under sizing will reduce sap yield as the vacuum capacity is blocked by sap reducing vacuum to the tap. Even with the best possible plan and design, tubing systems must be managed. Regular monitoring of the tubing system for leaks due to breakage or damage is critical. Designing the system so that it is as quick and easy as possible to diagnose where leaks are in the system is as important as getting the system properly sized. Spending the time necessary to maintain a tight system can be a problem for maple producers already doing many jobs. This section attempts to walk you progressively through the concepts of air and sap flow in tubing. Many tools have been developed to assist with the sizing and planning a new tubing system as well as evaluating an existing system.

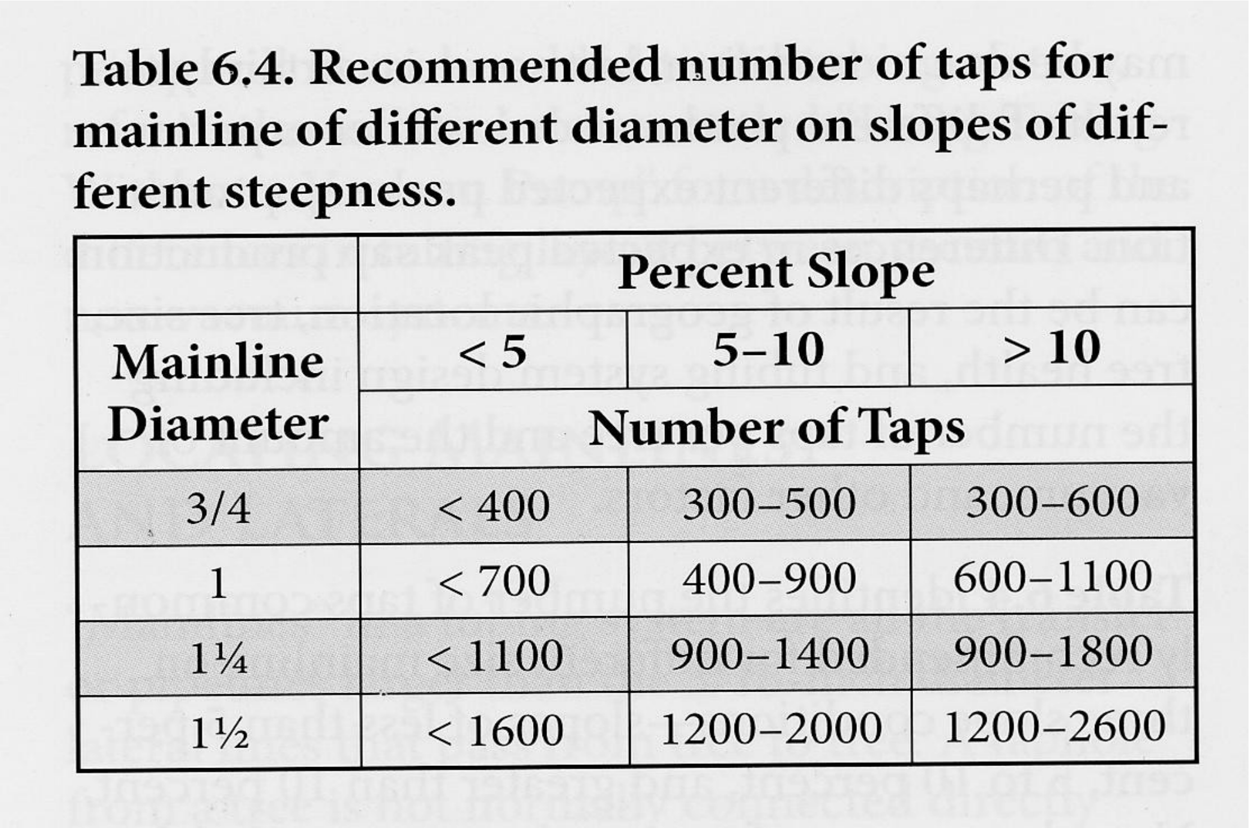
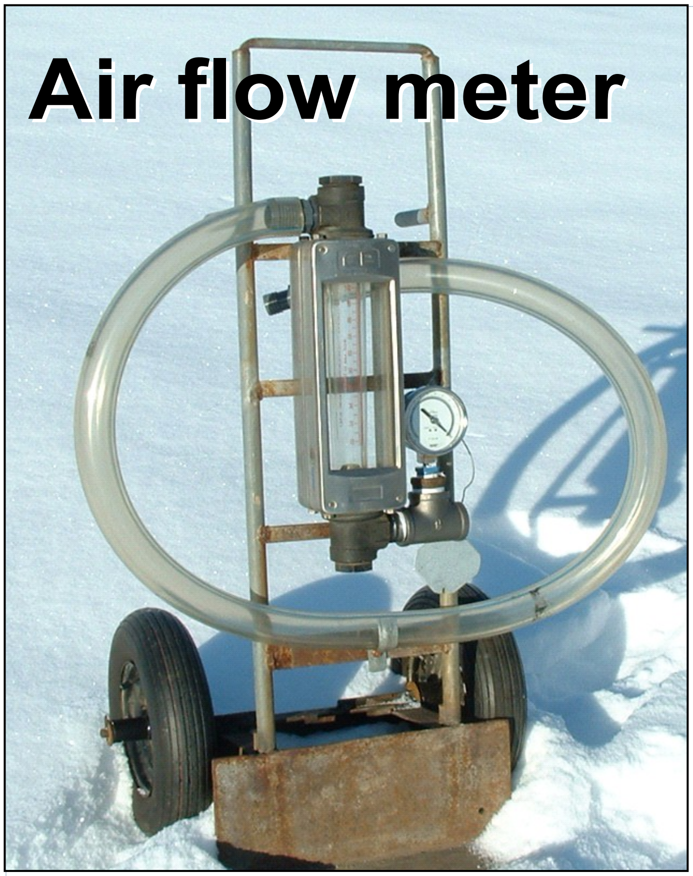


Table 6.4. Recommended number of taps for mainline of different diameter on slopes of different steepness.

Mainline Diameter	Percent Slope		
	< 5	5–10	> 10
	Number of Taps		
3/4	< 400	300–500	300–600
1	< 700	400–900	600–1100
1¼	< 1100	900–1400	900–1800
1½	< 1600	1200–2000	1200–2600

13.1 Mainline basics

A maple tubing system should have the capacity to move the sap from the tree to the tank without restricting the flow. When under vacuum it should have the capacity to move the sap to the collection tank and air from all the taps and leaks to the vacuum pump while keeping the desired vacuum pressure at the tap. Decisions regarding the size and number of main lines to install in the sugar bush are made by installers and producers in a variety of ways. One way is to follow one of the tables of the number of recommended taps to put on a given sized line that are available from various sources. The 2006 North American Maple Syrup Producers Manual suggests the levels in the above chart. These charts are helpful but there are fairly large ranges suggested. A chart like this works best if the tubing system planner understands the purpose of the large range. That you go to the lower end of the range if the slope is on the lower side of the range. You go to the higher side of the range if your vacuum pump is close to the woods and the main lines are short. Where mainlines are long you must stay with the lower range of the suggested tap numbers. This becomes more complicated if the system has several different sizes of mainline, or uneven slopes which tend to create blockage to the movement of the vacuum air. If installing a tubing system where the vacuum pump is a long distance from the taps, it can make following this chart less reliable. Getting out and seeing what other producers have done setting up their tubing systems is a common way of making design decisions. Research in the past, along with recent work of the Cornell Maple Program is described in this section relating to balancing air and sap flow in maple tubing vacuum systems. All new installations should be built with the capacity to add vacuum in the future.



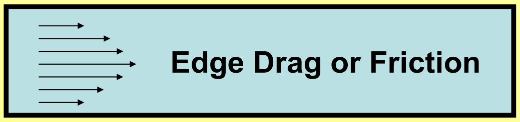
Planning and installing maple tubing systems has involved a lot of guessing and very general rules of thumb. In order to move planning and designing maple tubing vacuum systems to a new level of accuracy, additional information needed to be located or created.

13.2 Sources of information

Drawing up guidelines and worksheets for just how big the mainlines and vacuum pump in a tubing system need to be required locating and proving some existing data. This was the case with friction or line loss that occurs in mainlines. The line loss in tubing is dependant on three primary factors, the pipe diameter, the length, and the volume of air being forced through the pipe by the suction of a vacuum at one end of the line. The volume of air needing to be moved is the result of air leaking into the pipe. There is a line loss chart for tubing under vacuum available from Quebec and a second chart available as part of the New York State building code for vacuum used in medical facilities. The Cornell Maple program also ran many tests checking line loss at a variety of vacuum pressures on a variety of mainline sizes and lengths using the rotameter and vacuum gauge as shown in the picture above. These sources show excellent agreement and serve as the bases for much of this section. The same equipment was used to test several vacuum pumps at various vacuum pressures to gain specific insight into how vacuum pumps perform under a variety of conditions. These were compared with information provided by vacuum pump companies and from these various sources the information in the last section on sizing vacuum pumps was developed. These two factors, the loss of vacuum capacity to friction and the capacity loss that occurs when operating a pump at a vacuum level other than the level at which it is rated are critical to improving design accuracy.

Another key that seemed to be completely missing in past research is the normal leak rate that occurs in well maintained lateral lines. Besides leaks that can be corrected with good tubing system maintenance, how much air naturally leaks into the tubing? Using a much smaller rotameter than in the above photo many lateral lines were tested at a variety of vacuum pressures to determine this natural leak rate. For tubing system design purposes, determining the system capacity requirements based on what is needed where the mainline connects to the lateral line is much more accurate than determining the capacity need for the whole system where the mainline

Air Flow Resistance in the Maple Tubing



How Important Is It?
and
What information is available about It?

connects with the vacuum pump. There is just too much variation in systems between these two points in a maple tubing system to not take it into consideration. Cornell Maple Program research has established that about 1 cfm for each 100 taps where the lateral line connects to the mainline is an average leak rate.

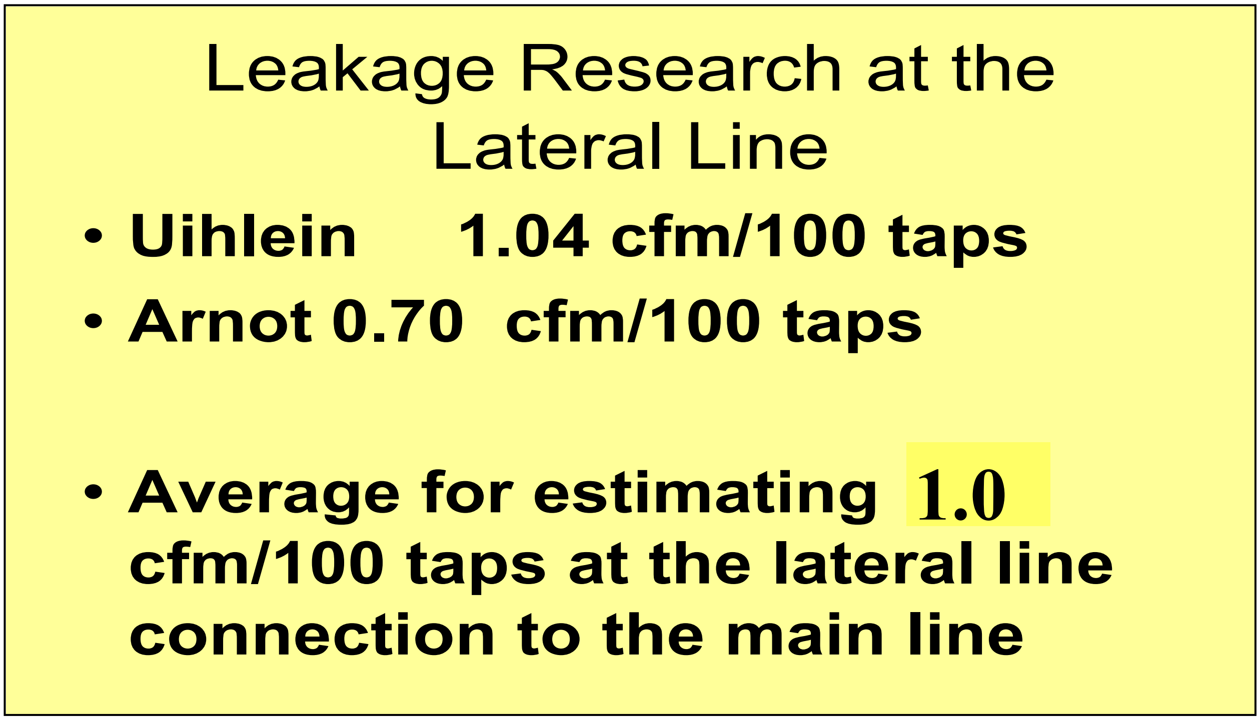
Finally, the fourth factor was to estimate an average sap flow per tap under excellent flow conditions. This estimate of .2 gallons of sap per tap per hour was arrived at by checking flow rates in numerous sap flow research papers and records kept by several maple producers. With these four key data sources now in hand, the calculations necessary for more accurate sizing are developed using charts, worksheets, maps and explanations in the rest of this section.

For accurate line loss estimates a good estimate of how long and at what slope the mainlines will be and how many taps the mainlines will service are key. An estimate of how much tubing system capacity will be obstructed by the sap moving through the main lines is calculated into the Guidelines that are available in this section for each of the common sizes of mainline. The bigger a tubing system is the more complex the calculations become. There is nothing particularly difficult about doing this kind of in-depth planning. It is important to know and follow all the steps to be certain in the end that you have the best system you can plan with the information available.

For many years the industry has estimated a common leak rate of 1 to 1.5 cubic feet per minute for each 100 taps. This estimate has been made at the pump and assumed at 15 inches of vacuum. It has been somewhat effective when estimating how to size a vacuum pump for a system but did not take into account several important factors such as the size of the mainline tubing between the taps and the pump or the distance the air needed to be moved from the taps and leaks to the pump. Each of these factors can significantly influence how the capacity of the vacuum pump must be sized to function at the desired vacuum level at the tap.

Leakage Estimates

- 1 to 1.5 cubic feet of air per minute (CFM) per 100 taps
- Assumed at the vacuum pump
- Assumed at 15” of vacuum



Leakage Research at the Lateral Line

- **Uihlein 1.04 cfm/100 taps**
- **Arnot 0.70 cfm/100 taps**

- **Average for estimating 1.0 cfm/100 taps at the lateral line connection to the main line**

13.3 Estimating the leak rate

After measuring the air flow in many lateral lines in two different locations at a variety of vacuum levels we determined an average leak rate of .7 cfm per 100 taps at Cornell's Arnot Forest and 1.04 cfm/100 taps at Cornell's Uihlein Maple Research Forest. This figure is different than the estimate at the pump. This figure represents the flow requirements where the lateral lines leave the main line. This allows you to calculate the losses in vacuum system capacity getting the leakage air from the lateral line to the pump when planning a system. For calculations in this notebook an average of 1 cfm per 100 taps at the lateral line will be used. This would place the system at the Arnot over sized by 30% and the system at the Uihlein undersized by about 4%. It is also important to note that spouts that are not well secured in the taphole were found to have much higher leak rates than this average. Since most maple producers cannot conduct these measurements on their own lateral lines, using an average like this gets us close to a realistic estimate. It should also be pointed out that this research was attempting to determine the leak rate due to what would be considered normal air leakage from around the taps in the tree and from the tree itself. Lines which had other obvious leak problems due to wildlife damage, broken connections or other tubing system failures were either fixed before the reading was accepted or not included in the data. These kinds of leaks are a tubing system maintenance issue and were outside of what is considered the natural leak rate. In designing a tubing system it is wise to account for a certain amount of these maintenance correctable leaks as they always occur and you want the system to operate efficiently even when some are present. Producers who are diligent at repairing leaks will experience better sap yields while producers who understand line maintance will be a problem for them may want to build in a little bigger capacity to make up for the maintenance issues. Planning a tubing system to be over sized is costly and creates the potential for sap quality loss due to sap warming.

Air that leaks into the maple tubing system must be transported through the system to be expelled by the vacuum pump

With an average leak rate of 1 cfm per 100 taps

The vacuum pump must have the capacity to remove this much air from the system each minute

The tubing system must be designed to deliver it to the pump

When a leak rate of 1 cubic feet of air per minute (cfm) per 100 taps at the lateral line connection to the main line is estimated, then the vacuum pump must have the capacity to remove this much air from the system each minute. The system of mainlines must have the capacity to deliver that airflow to the pump each minute while at the same time providing for the friction or line loss in those lines.

The size in terms of diameter of the tubing becomes very important. The bigger the tubing the more air that can pass through without significant resistance. The bigger the leaks or the greater volume of air passing through the tubing the more resistance develops between the air and the tubing. High volumes of air forced through small diameter tubing will suffer tremendous friction loss wasting a significant amount of a vacuum pumps capacity. The length of the mainline is also an important factor. The longer the line the greater the accumulated capacity loss to friction. The more taps on a given main line, the larger the volume of air that must pass through the tubing due to this natural leak rate which occurs in all systems. The result is that more taps on a line results in greater line loss or capacity loss to that line. The presence of additional leaks due to maintenance issues further increases friction loss and further reduces the capacity of the mainline to maintain the desired vacuum pressure level to taps on the line. The result is reduced production of sap per tap in the system.

The volume of gas flowing through a pipe is called Flow Rate.

Flow rate is the product of the speed at which a gas flows and the area of cross-section of the pipe through which it flows.

Flow Rate = Speed of flow x Area of cross-section

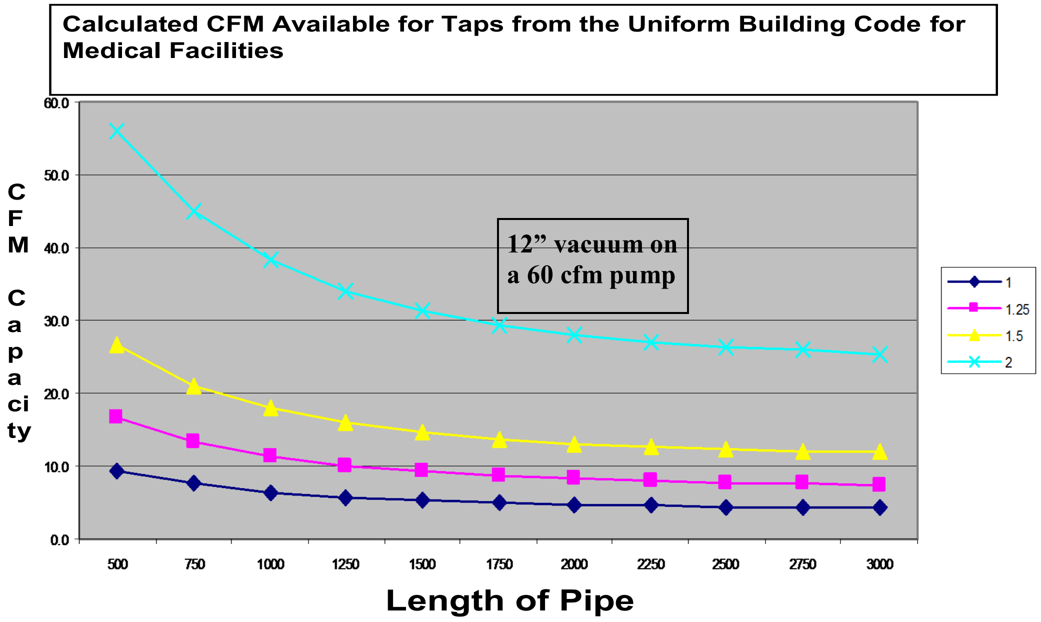
Line loss is the reduction in volume of gas flowing through the pipe due to friction between the flowing gas and the walls of the pipe over a given length of the pipe

13.4 Line loss and line loss charts

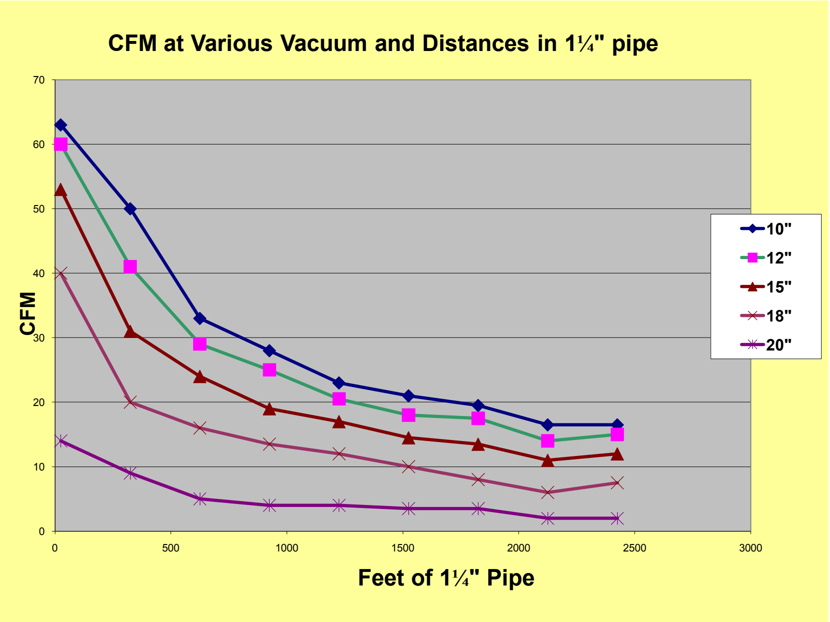
The volume of gas flowing through a pipe is called the flow rate. Flow rate is the product of the speed at which a gas flows and the area of cross section of the pipe through which it flows. Flow rate throughout this book is usually referred to as cfm or the cubic feet of air passing through a point in the pipe in one minute. Line loss is the reduction in volume of gas flowing through the pipe due to friction between the flowing gas and the walls of the pipe over a given length of the pipe. For example a vacuum pump with the capacity at 15″ of vacuum to pull 10 cubic feet of air through 1′ of 1″ pipe can only pull 9 cubic feet of air per minute through a 200′ 1″ pipe.

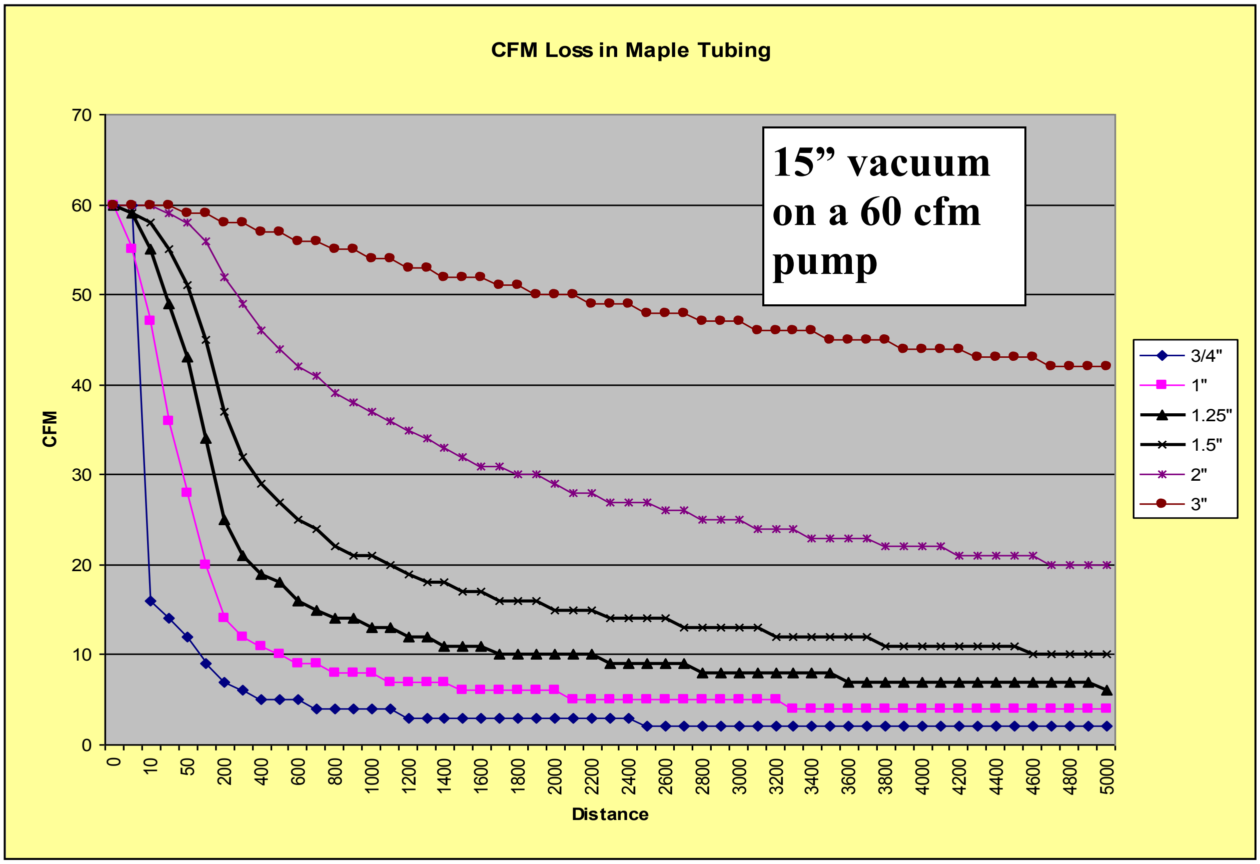
Many times the tubing and vacuum system have the capacity to deal with the natural leak rate but not with leaks due to the lack of maintenance. The extra leaks cause significant line loss due to friction in the line because excessive vacuum pump capacity is attempting to pull air through the line

In planning the maple tubing system several key pieces of information are critical. First is how many taps will be on the system. How far the taps are going to be from the vacuum pump or how long will the mainlines be? The longer the mainlines the greater the vacuum line loss you will experience. Just the estimate of how many taps and an average of how far the taps will be from the pump allows us the make the first draft calculation of how many lines we may need and how big those lines will need to be. Key to this calculation is access to a good line loss chart.



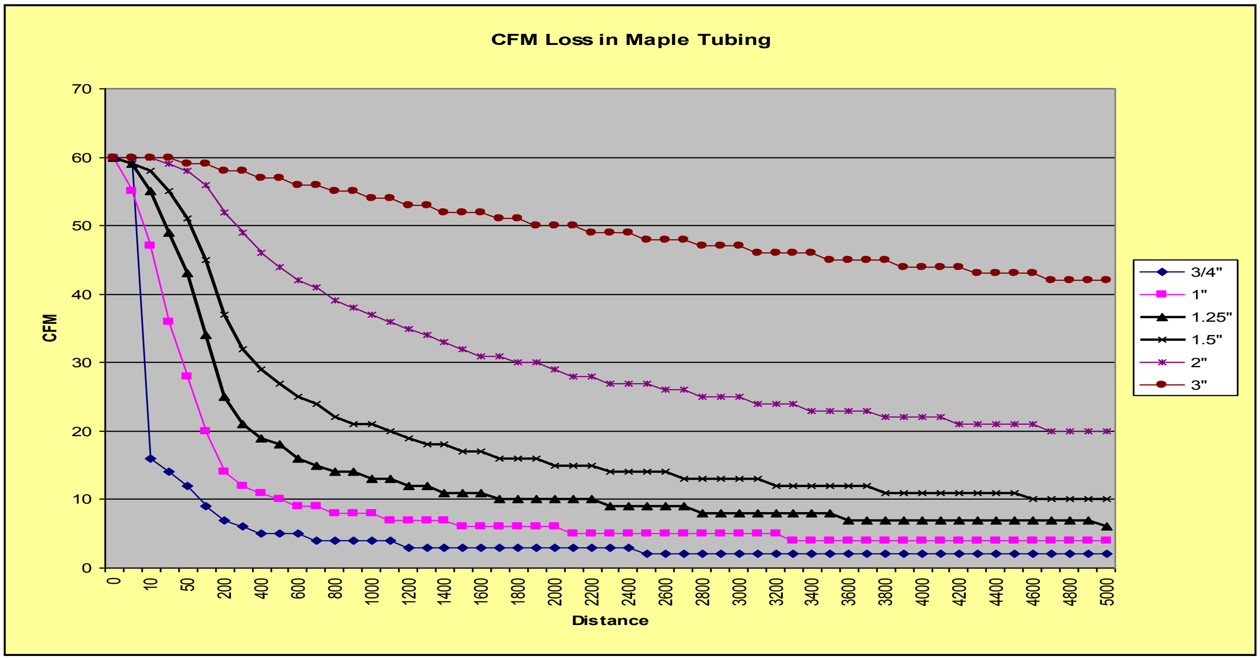
Trying to obtain a vacuum line loss chart was much more difficult than had been imagined. There was a line loss chart circulating among some of the maple producers but it did not identify it’s source. Then on searching various text books on vacuum and searching the web I nearly concluded that for some reason such a chart didn't even exist. Finally I came across the Uniform Building Code for Medical Facilities in New York, which charted out line loss for pipes of various diameters at 12” of vacuum on a 60 cfm pump. This chart did not give a lot of data points especially at the shorter lengths but it was very helpful to be able to make some system capacity comparisons. This chart also only extended to 1000’ in length so establishing the loss rates out to 3000’ was accomplished mathematically. In 2005 the Cornell Maple Program was able to obtain our own rotameters and to run tests of our own on 1”, 1¼”, 1½” and 2” tubing at a wide variety of vacuum levels ranging between 10” to 24” of vacuum. From this data we were able to create our own line loss charts. We were able to confirm that our chart, the mystery chart and the Building Code chart were nearly identical. The chart above was created from the Uniform Building Code for Medical Facilities in New York. The chart to the right was one created from the data collection by the Cornell Maple Program





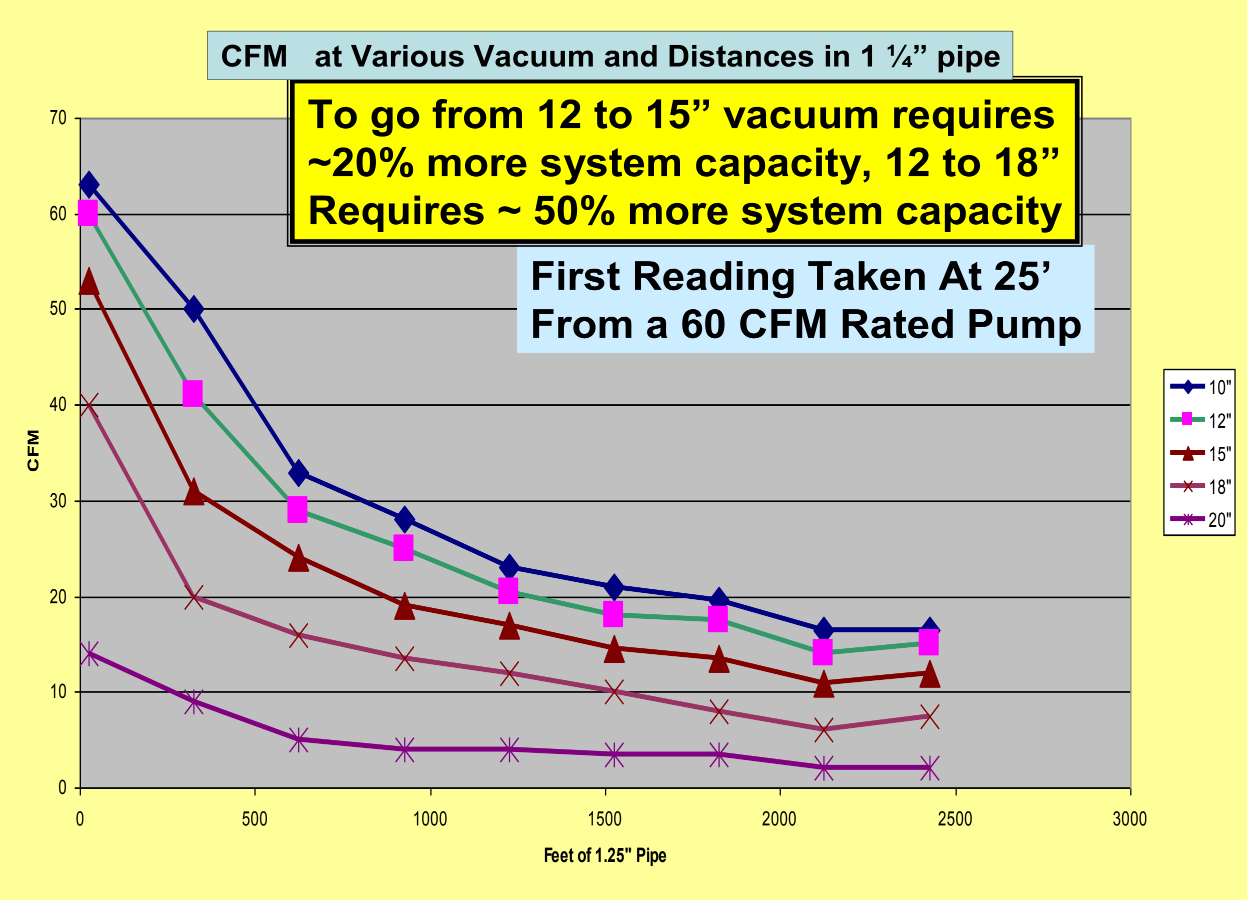
Finally we were able to obtain a very complete chart from researches in Quebec as seen in the chart above. We found all these sources were in reasonable agreement and these various charts will be used in the details and calculations we make as we work through sizing main lines in this section. Through the research of testing vacuum pumps and tubing under a variety of vacuum levels we have come to the conclusion that the line loss changes with change in vacuum level are small enough so we feel comfortable using the same line loss charts whether we are designing the system at 10″ of vacuum or 20″ of vacuum. Since line loss is determined primarily by pipe diameter and length along with the air flow volume and not by the vacuum level, it will not be considered in sizing mainlines. Though it must be understood that higher vacuum pulls some additional air through the same sized hole or leak.

Using the chart above, a few sample tubing system planning calculations will be estimated. For example if it is determined that a woods has the potential for 1000 taps that will average 1000 feet from the vacuum pump, what are the options at this tap number for mainline size? With the estimate that the natural leak rate at the lateral lines will be about 1 cfm per 100 taps, this system will need at least 10 cfm to operate where the main and lateral lines connect. To evaluate one inch main line look on the chart above and find where the 1″ line reaches 10 cfm. This appears to be about 500′ on the length of pipe axis. This instantly indicates that one 1″ line will not do the job. With 10 cfm at 1000′ needed, the chart shows even a 60 cfm pump on one 1″ line could only service that number of taps at 500′ of length. At 1000′ the chart shows only 8 cfm available, only enough for 800 taps even though it is hooked to a pump that should be able to service 6000 taps if no line loss was involved.



What would 2 one inch mainlines do in this situation? 10 cfm is needed and two 1" lines are available so each line would need to have capacity for 5 cfm. On the chart a one inch line has 5 cfm at 2100 feet. Look back 1000' so you look at 1100' where the cfm available is 7 cfm each. That would show that if the 1" line was provided with vacuum pump capacity of 7 cfm it would have the capacity at 1000' feet from the pump of 5 cfm or enough for meeting the vacuum needs of 500 taps. Two 1000' 1" lines attached to a 14 cfm vacuum pump will have the capacity to handle 1000 taps. But note that the volume of sap running through those lines, obstructing part of the capacity, has not been accounted for.

A review of past research would indicate that a maximum flow rate for taps is about .2 gallons per hour per tap or a little less than a quart. A number of calculations in older mainline sizing research were based on 1/2 gallon of sap per hour but a review of past research has not found any actual flow rates that high. So the figure of .2 gallons of sap per hour per tap has been selected as a typical high sap flow situation in maple tubing. Many sap flows will not reach this estimated peak. For 1000 taps running at .2 gallon of sap per hour at high flow would account for 200 gallons of sap coming through the main lines each hour at the same time that the vacuum leakage is being pulled through the same lines. A 1" line at 6% slope can carry 630 gallons of sap per hour (these flow rates are from the **chart in section 13.5**). In this example, two lines carrying half the flow or 100 gallons per hour each would take up about 16% of the main lines capacity. 5 cfm times 84% would leave 4.2 cfm available to the taps rather than the needed 5 cfm. There are now three options. First, add a third one inch line. Second, choose to go to a bigger line and re-calculate. Third, increase the vacuum capacity assigned to the lines from a pump to overcome the line loss and capacity being used by the sap. If vacuum capacity assignment is increased by the amount the sap is taking away that would mean each line would need to have about 8.2 cfm or a total available cfm capacity from the pump of 16.4 cfm for these 1000 taps. Each solution adds its own level of expense and maintenance.



The chart above demonstrates what happens with the flow of leakage air through the same 1¼" mainline attached to a single 60 cfm vacuum pump. Note the rapid loss of air flow capacity as the vacuum level is raised from 10" to 20". At about 500 feet from the pump there is the capacity to service 4000 taps at 10" of vacuum. The system could only service 500 taps at 20" of vacuum. If more than 500 taps were added to this line and pump it could simply not keep up with the air flow and would drop below the 20" of vacuum.

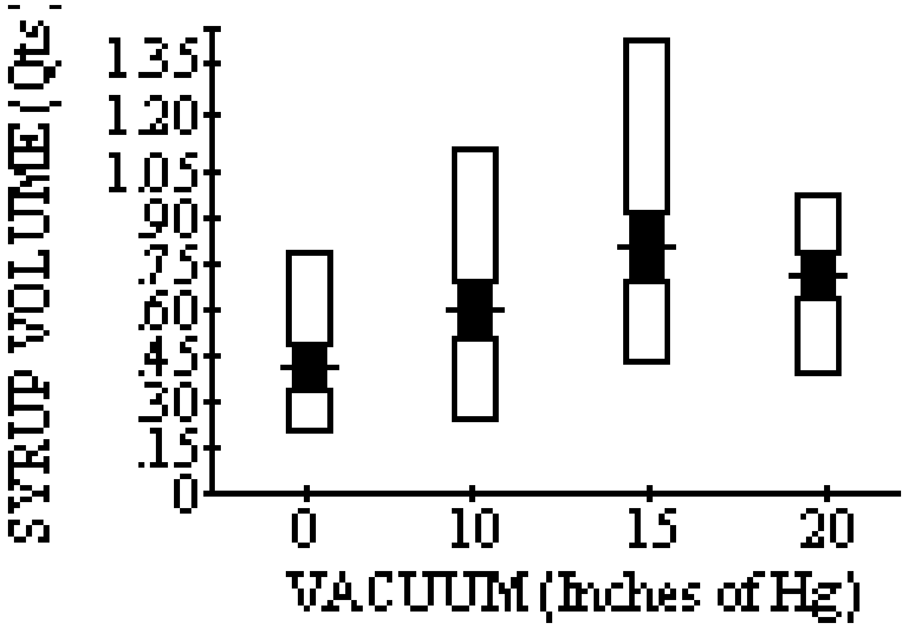
Note how the lines on these flow rate curves are pretty much identical once you get past the first 300 to 400 feet from the pump. Note the losses in the first 300 to 400 feet are the steepest for the highest vacuum levels. This reflects the fact that at the higher vacuum level the capacity of the vacuum pump to pull air is significantly diminished because of the greater distance or gap between the air molecules. To increase the vacuum level one of two things must happen. You must reduce the leak rate or the flow of air from leaks, or you must increase the capacity at the pump meaning purchasing more or bigger pumps. The main point to be learned from this chart is that the differences between the airflow at the different vacuum levels is primarily due to the gradual decreasing of the pump capacity with increased vacuum. The resistance loss in the tubing is caused primarily by volume of air flowing through, not by the level of vacuum at which it flows through. Vacuum pump capacity at different vacuum levels is very critical and was covered in the last chapter. In the sizing of mainlines, vacuum level will not be considered as a key factor.

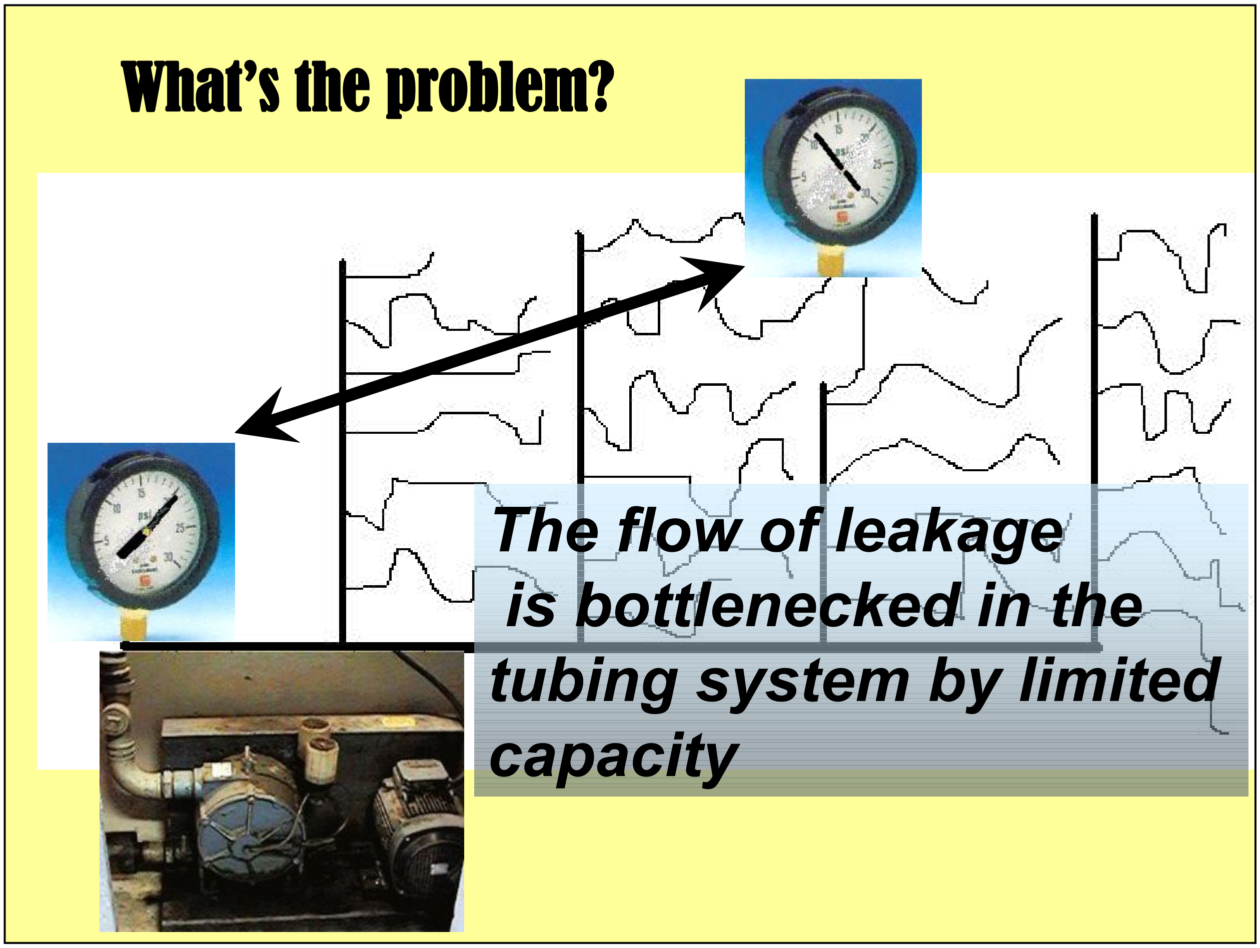
What vacuum do I want at the tap

- Research shows a consistent sap yield increase up to 15” of vacuum at the tree.
- Above 15” shows increases but more variable and scientifically not significant
- Some more recent research in Vermont shows a more direct correlation between higher vacuum and higher yield

Research conducted by Cornell Maple Specialist Lew Staats in the late 80’s showed that as vacuum is increased sap and syrup yield per tap also increased steadily up to 15″ of vacuum at the tree. Vacuum levels above 15″ gave him inconsistent results. See the results table below. This research is available in the appendix of this notebook.

Research conducted at the Proctor Maple Research Center in Vermont showed nearly a straight line improvement in sap yield as vacuum level was increased at the tap. So in this study the higher the vacuum the higher the yield. The question then becomes where is the economic balance between the investment and system maintenance it takes to keep a given vacuum level versus the value of the sap gained from the higher cost higher vacuum system. The Vermont research is available at http://www.uvm.edu/~pmrc/vacsap.pdf





What's the problem?

The flow of leakage is bottlenecked in the tubing system by limited capacity

Here are some things to look for in an existing system to determine if it is functioning correctly. In the example above there is a vacuum level of 20" of vacuum showing on the gauge at the vacuum pump but the gauge at the end of a lateral line, deep in the woods is only showing 11" of vacuum. This would be a typical example of either excessively long lateral lines, undersized mainlines or sap blockages in the system due to sudden slope changes or just too full of sap. Air is leaking into the tubing system faster than it can be delivered to the pump for removal. Undersized mainlines will allow the vacuum pressure to drop the further out the line you go due to friction or line loss or sap blockage. Increasing the vacuum level at the pump in this case will only make a very small difference deep in the woods with a significant increase in investment and energy required to maintain the higher vacuum level. A solution in an existing system would be to add a dry line. A mainline designed primarily to draw air from the system by adding a second mainline above the existing mainline and connecting them together at key points. A second solution would be to add additional lines from the pump to the woods so that existing lines can have some of their taps transferred to new additional lines. Third, dry lines could be added over the areas where slope changes occur and sap is blocking the movement of the vacuum air or leakage air. And fourth the system could be replaced with a larger capacity tubing system.

	60 cfm at 15 inch hg						30 cfm at 15 inch hg						15 cfm at 15 inch hg					
Distance (feet)	3/4 in	1 in	1 1/4 in	1 1/2 in	2 in	3 in	3/4 in	1 in	1 1/4 in	1 1/2 in	2 in	3 in	3/4 in	1 in	1 1/4 in	1 1/2 in	2 in	3 in
0	60	60	60	60	60	60	30	30	30	30	30	30	15	15	15	15	15	15
3	38	55	59	59	60	60	24	29	30	30	30	30	15	15	15	15	15	15
5	16	47	55	58	60	60	15	28	29	30	30	30	14	15	15	15	15	15
25	14	36	49	55	59	60	14	26	29	29	30	30	13	14	15	15	15	15
50	12	28	43	51	58	60	12	23	27	29	30	30	11	14	14	15	15	15
100	9	20	34	45	56	59	9	19	25	28	29	30	9	13	14	15	15	15
200	7	14	25	37	52	59	7	14	21	26	29	30	7	11	13	14	15	15
300	6	12	21	32	49	58	6	12	19	24	28	30	6	10	13	14	15	15
400	5	11	19	29	46	58	5	11	18	23	28	30	5	10	12	14	15	15
500	5	10	18	27	44	57	5	10	16	22	27	30	5	9	12	14	15	15
600	5	9	16	25	42	57	5	9	15	21	27	30	5	8	11	13	15	15
700	4	9	15	24	41	56	4	8	14	20	27	29	4	8	11	13	15	15
800	4	8	14	22	39	56	4	8	14	19	26	29	4	8	11	13	14	15
900	4	8	14	21	38	55	4	8	13	19	26	29	4	7	10	13	14	15
1000	4	8	13	21	37	55	4	8	13	18	25	29	4	7	10	13	14	15
1100	4	7	13	20	36	54	4	7	12	18	25	29	4	7	10	12	14	15
1200	3	7	12	19	35	54	3	7	12	17	25	29	3	7	10	12	14	15
1300	3	7	12	18	34	53	3	7	11	17	24	29	3	6	9	12	14	15
1400	3	7	11	18	33	53	3	7	11	16	24	29	3	6	9	12	14	15
1500	3	6	11	17	32	52	3	6	11	16	24	29	3	6	9	12	14	15
1600	3	6	11	17	31	52	3	6	10	15	23	29	3	6	9	12	14	15
1700	3	6	10	16	31	52	3	6	10	15	23	29	3	6	9	11	14	15
1800	3	6	10	16	30	51	3	6	10	15	23	29	3	6	9	11	14	15
1900	3	6	10	16	30	51	3	6	10	14	23	29	3	6	9	11	14	15
2000	3	6	10	15	29	50	3	6	10	14	22	29	3	5	8	11	14	15
2100	3	5	10	15	28	50	3	5	10	14	22	28	3	5	8	11	14	15
2200	3	5	9	15	28	50	3	5	9	14	22	28	3	5	8	11	14	15
2300	3	5	9	14	27	49	3	5	9	13	22	28	3	5	8	11	14	15
2400	3	5	9	14	27	49	3	5	9	13	21	28	3	5	8	11	13	15
2500	2	5	9	14	27	49	2	5	9	13	21	28	2	5	8	10	13	15
2600	2	5	9	14	26	48	2	5	9	13	21	28	2	5	8	10	13	15
2700	2	5	9	13	26	48	2	5	8	13	21	28	2	5	8	10	13	15
2800	2	5	8	13	25	48	2	5	8	12	21	28	2	5	8	10	13	15
2900	2	5	8	13	25	47	2	5	8	12	20	28	2	5	7	10	13	15
3000	2	5	8	13	25	47	2	5	8	12	20	28	2	5	7	10	13	15
3100	2	5	8	13	24	47	2	5	8	12	20	28	2	4	7	10	13	15

This is the most complete line loss chart. It represents six different sizes of mainline starting with 3/4″ up to 3″. It also represents the air flow in the pipe at various distances from the vacuum pump where the pump has a capacity of 60cfm, 30cfm or 15cfm. In every case it represents the situation where only one pipe is attached to the given sized pump. Each chart was too long to fit on one page and still be big enough to read so each as been split and placed on two pages. The length of mainline from the pump ranges from 0 feet to 6000 feet.

Reading and interpreting the line loss chart is fairly straight forward. Starting in the top left hand corner first notice that the first set of columns are rated when connected to a 60 cfm vacuum operating at 15″ of vacuum, the vacuum pressure at which the vacuum pump was rated. The first column on the far left is the length of the mainline from the vacuum pump. The second column in is titled 3/4 in indicating that the mainline being rated is 3/4 inches in diameter. At a length of 0 from the pump the cfm reading is 60. The same for all of the diameters of tubing. Drop down to the second row in the length column which is 3′from the pump, in the second column showing 3/4″ mainline the cfm being pulled into the far end of the tubing is just 38 cfm. In the first three feet of 3/4″ tubing the air flow has been reduced from 60 cfm to 38 cfm. 22 cfm of air flow has been lost to friction in the first 3′. Here we would say it suffered a line loss of 22 cfm. From a number of taps perspective, at the pump there was capacity for 6000 taps and after just 3′ in 3/4″ mainline capacity for only 3800 taps is available. Drop down the same column to where the length is 100′. At 100′ from the vacuum pump the 3/4″ mainline is pulling in only 9 cfm. At 100′ the line loss would be the original capacity at the pump of 60 cfm minus the 9 cfm of capacity available at 100′ for a line loss of 51 cfm. In taps that could be serviced, it goes from 6000 taps at the pump to just 900 taps 100′ in 3/4″ line from the pump. Now drop down to 1000′ of length in the first column and note that 4 cfm is all the vacuum capacity available in 3/4″ tubing. Here the line loss would be 56 cfm.

The method of calculating line loss is the same for each diameter of tubing. If you move to the fifth column from the left it gives the vacuum air flow capacities in 1½″ mainline when connected to a 60 cfm pump. If you check the capacity in this column at 100′ of length you see that 45 cfm of vacuum capacity is remaining. This would represent a line loss of 15 cfm over the first 100′ or the loss of capacity for 1500 taps at 15″ of vacuum. At 1000′ of length the 1½″ mainline would have the capacity of 21 cfm. In the first 1000′ from the 60 cfm vacuum pump in 1½″ mainline the line loss would be 39 cfm or the number of taps the vacuum system could service would have been reduced from 6000 taps to 2100 taps due to air flow reduction due to friction.

If you look at the upper right hand corner of the chart the various sized tubing is connected to a 15 cfm vacuum pump. The far column is data for 3″ diameter tubing. Here it is obvious as you look down the column that this size of line does not experience any line loss in the first 3000′. Every length on this page of the chart reads 15 cfm. This system could service 1500 taps at the pump and could service 1500 taps at 3000′ away in this 3″ tubing. If you look at the second half of the chart in the same column there is no line loss recorded until the length is 5500′ from the pump. This shows that the rate of air flow is very important to the rate line loss is experienced as the earlier example showed the importance that tubing diameter played in the line loss experienced in 3/4″ tubing.

In many cases, since there will be more than one mainline leading from the pump into the sugar bush it becomes important to correctly read line loss from a chart like this. If two mainlines are attached to the releaser to go to the woods, each would be expected to carry half of the leakage air as cfm to the pump based on their diameter size, length and assigned air flow rate. Where two lines were similar in number of taps, diameter and length the capacity could be simply divided in two.

	60 cfm at 15 inch hg						30 cfm at 15 inch hg						15 cfm at 15 inch hg					
Distance (feet)	3/4 in	1 in	1 1/4 in	1 1/2 in	2 in	3 in	3/4 in	1 in	1 1/4 in	1 1/2 in	2 in	3 in	3/4 in	1 in	1 1/4 in	1 1/2 in	2 in	3 in
0	60	60	60	60	60	60	30	30	30	30	30	30	15	15	15	15	15	15
3000	2	5	8	13	25	47	2	5	8	12	20	28	2	5	7	10	13	15
3100	2	5	8	13	24	47	2	5	8	12	20	28	2	4	7	10	13	15
3200	2	5	8	12	24	46	2	5	8	12	20	28	2	4	7	10	13	15
3300	2	4	8	12	24	46	2	4	8	12	20	28	2	4	7	10	13	15
3400	2	4	8	12	23	46	2	4	8	11	20	28	2	4	7	10	13	15
3500	2	4	8	12	23	46	2	4	7	11	19	28	2	4	7	10	13	15
3600	2	4	7	12	23	45	2	4	7	11	19	28	2	4	7	9	13	15
3700	2	4	7	12	23	45	2	4	7	11	19	27	2	4	7	9	13	15
3800	2	4	7	11	22	45	2	4	7	11	19	27	2	4	7	9	13	15
3900	2	4	7	11	22	45	2	4	7	11	19	27	2	4	7	9	13	15
4000	2	4	7	11	22	44	2	4	7	11	19	27	2	4	7	9	13	15
4100	2	4	7	11	22	44	2	4	7	11	19	27	2	4	6	9	13	15
4200	2	4	7	11	21	44	2	4	7	11	18	27	2	4	6	9	13	15
4300	2	4	7	11	21	44	2	4	7	11	18	27	2	4	6	9	13	15
4400	2	4	7	11	21	43	2	4	7	11	18	27	2	4	6	9	13	15
4500	2	4	7	11	21	43	2	4	7	10	18	27	2	4	6	9	12	15
4600	2	4	7	10	21	43	2	4	7	10	18	27	2	4	6	9	12	15
4700	2	4	7	10	20	43	2	4	7	10	18	27	2	4	6	9	12	15
4800	2	4	7	10	20	42	2	4	7	10	18	27	2	4	6	9	12	15
4900	2	4	6	10	20	42	2	4	6	10	17	27	2	4	6	9	12	15
5000	2	4	6	10	20	42	2	4	6	10	17	27	2	4	6	9	12	15
5100	2	4	6	10	20	42	2	4	6	10	17	27	2	4	6	8	12	15
5200	2	4	6	10	20	42	2	4	6	10	17	27	2	4	6	8	12	15
5300	2	4	6	10	19	41	2	4	6	9	17	27	2	4	6	8	12	15
5400	2	4	6	10	19	41	2	4	6	9	17	27	2	3	6	8	12	15
5500	2	4	6	10	19	41	2	3	6	9	17	26	2	3	6	8	12	14
5600	2	3	6	10	19	41	2	3	6	9	17	26	2	3	6	8	12	14
5700	2	3	6	9	19	41	2	3	6	9	17	26	2	3	6	8	12	14
5800	2	3	6	9	19	40	2	3	6	9	17	26	2	3	6	8	12	14
5900	2	3	6	9	19	40	2	3	6	9	16	26	2	3	6	8	12	14
6000	2	3	6	9	18	40	2	3	6	9	16	26	2	3	6	8	12	14

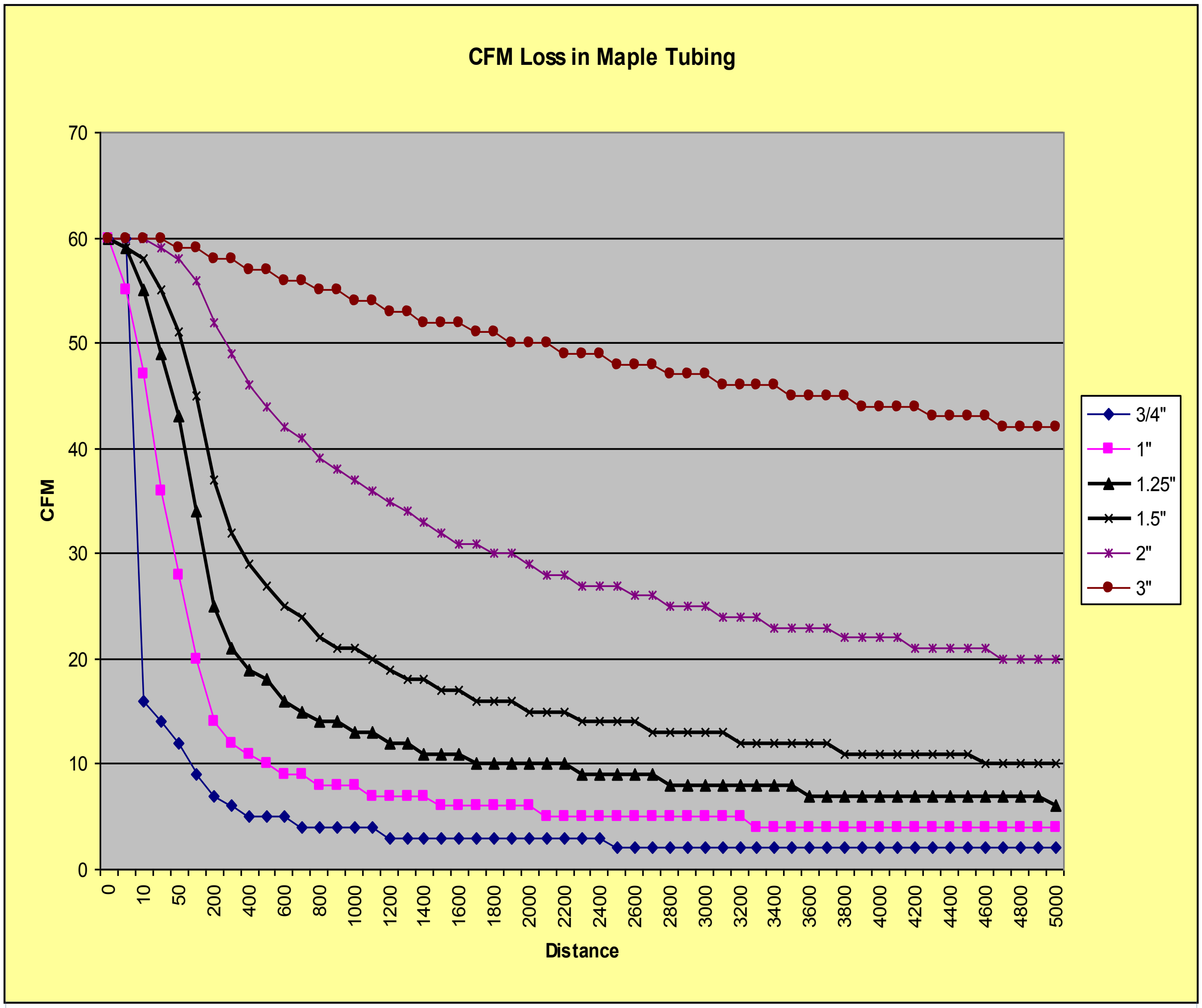
If two lines were attached to a 30 cfm pump then each line would be expected to carry about 15 cfm. To determine an estimated line loss either look at what a line would experience if attached to a 15 cfm vacuum pump or drop down on the chart from a larger cfm vacuum pump to where the chart showed 15 cfm for a line and go on down the chart the length of your mainline and see what cfm remained at that point on the chart. For example, two 1 inch lines are attached to the 30 cfm pump. Assume that each mainline will carry 15 cfm. On the 30 cfm shaded chart in the center it is closest to 15 cfm at about 200'. If the mainline will be about 1000 feet long, drop down to 1200' on the chart and see what of the 15 cfm remains available after the 1000'. The chart indicates that 5 cfm is all that remains available of the 15cfm after passing through 1000' feet of 1" mainline. The combined capacity of the two lines is 10cfm of the 30cfm that was available at the pump. 10 cfm is still available after 1000' to service the lateral lines or just enough capacity to service the needs of 1000 taps. This is before we take account of the capacity of the tubing that will be taken up by the flow of sap. Calculating the capacity of dry line is fairly simple from the chart. Accounting for the sap and air flow is significantly more challenging.

	100 cfm at 15 inch hg						80 cfm at 15 inch hg					
Distance (feet)	3/4 in	1 in	1 1/4 in	1 1/2 in	2 in	3 in	3/4 in	1 in	1 1/4 in	1 1/2 in	2 in	3 in
0	100	100	100	100	100	100	80	80	80	80	80	80
3	100	79	93	97	99	100	80	62	74	78	79	80
5	41	72	89	96	99	100	50	59	72	77	79	80
25	0	20	57	80	95	99	21	48	65	73	78	80
50	0	18	46	68	90	99	12	21	43	61	75	79
100	0	16	35	54	82	97	9	18	34	50	70	79
200	0	13	25	40	70	95	7	14	25	39	63	77
300	0	12	22	34	63	92	6	12	21	33	57	76
400	0	11	19	30	57	90	5	11	19	30	53	75
500	0	10	18	28	53	88	5	10	18	28	50	73
600	0	9	16	26	50	86	5	9	16	26	47	72
700	0	9	15	24	47	84	4	9	15	24	45	71
800	0	8	15	23	45	82	4	8	14	23	43	70
900	0	8	14	22	43	81	4	8	14	22	41	69
1000	0	7	13	21	41	79	4	8	13	21	40	68
1100	0	7	13	20	40	78	4	7	13	20	38	67
1200	0	7	12	19	38	77	3	7	12	19	37	66
1300	0	7	12	19	37	75	3	7	12	19	36	66
1400	0	6	11	18	36	74	3	7	11	18	35	65
1500	0	6	11	18	35	73	3	6	11	17	34	64
1600	0	6	11	17	34	72	3	6	11	17	33	63
1700	0	6	10	17	33	71	3	6	10	17	32	63
1800	0	6	10	16	32	70	3	6	10	16	32	62
1900	0	6	10	16	32	69	3	6	10	16	31	61
2000	0	6	10	15	31	68	3	6	10	15	30	61
2100	0	5	10	15	30	67	3	5	10	15	30	60
2200	0	5	9	15	30	66	3	5	9	15	29	59
2300	0	5	9	14	29	65	3	5	9	14	29	59
2400	0	5	9	14	29	64	3	5	9	14	28	58
2500	0	5	9	14	28	64	2	5	9	14	28	58
2600	0	5	9	14	28	63	2	5	9	14	27	57
2700	0	5	9	13	27	62	2	5	9	13	27	56
2800	0	5	8	13	27	62	2	5	8	13	26	56
2900	0	5	8	13	26	61	2	5	8	13	26	55
3000	0	5	8	13	26	60	2	5	8	13	26	55

If the two lines were not balanced with about the same number of taps then assign cfm to the lines based on the number of taps on each line. For example if one of two 1″ lines attached to a 30 cfm pump had 330 taps and the second line 660 taps assign one third of the cfm to the line with less taps and two thirds of the cfm to the line with two thirds of the taps. Line one in this case will be assigned 10 cfm of the thirty and the second line 20 cfm. If line one is 500 feet long then look on the chart to where 10 cfm is listed and that is at 500 feet. To determine line loss for this mainline we extend out to the 500 foot length of the pipe and note the reading at 1000′. It indicates there are 8 cfm left. If the second line is 1000 feet long, start where the reading on the chart is 20 cfm at about 100 feet, look down to where the chart is 1100′ and there are 7 cfm left. More than enough cfm are available on each line to service the taps, before the complementary sap flow is accounted for.

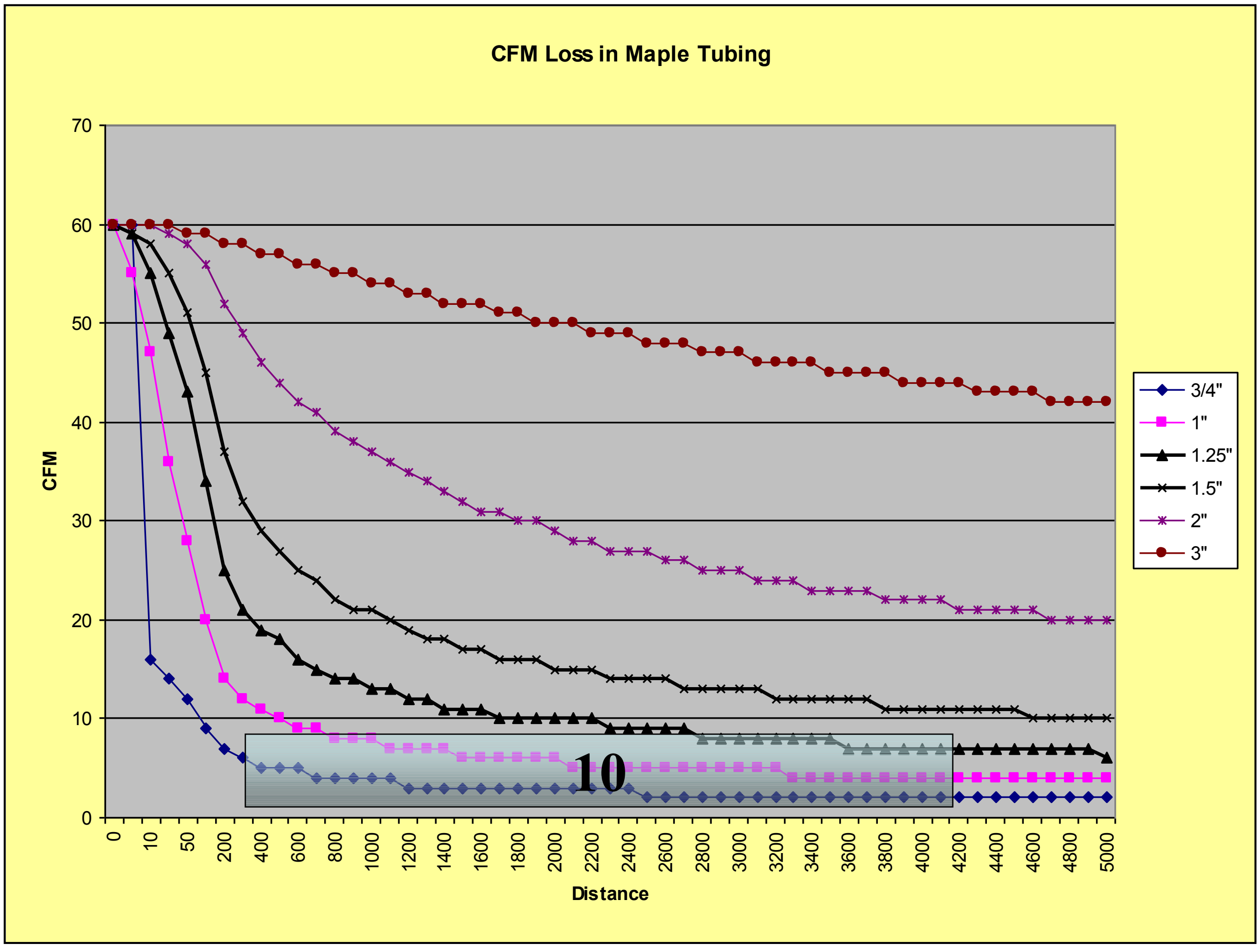
	100 cfm at 15 inch hg						80 cfm at 15 inch hg					
Distance (feet)	3/4 in	1 in	1 1/4 in	1 1/2 in	2 in	3 in	3/4 in	1 in	1 1/4 in	1 1/2 in	2 in	3 in
0	100	100	100	100	100	100	80	80	80	80	80	80
3000	0	5	8	13	26	60	2	5	8	13	26	55
3100	0	5	8	13	25	60	2	5	8	13	25	54
3200	0	4	8	12	25	59	2	5	8	12	25	54
3300	0	4	8	12	25	58	2	4	8	12	25	54
3400	0	4	8	12	24	58	2	4	8	12	24	53
3500	0	4	8	12	24	57	2	4	8	12	24	53
3600	0	4	7	12	24	57	2	4	7	12	24	52
3700	0	4	7	12	23	56	2	4	7	12	23	52
3800	0	4	7	11	23	56	2	4	7	11	23	51
3900	0	4	7	11	23	55	2	4	7	11	23	51
4000	0	4	7	11	23	55	2	4	7	11	23	51
4100	0	4	7	11	22	54	2	4	7	11	22	50
4200	0	4	7	11	22	54	2	4	7	11	22	50
4300	0	4	7	11	22	53	2	4	7	11	22	50
4400	0	4	7	11	22	53	2	4	7	11	22	49
4500	0	4	7	11	22	52	2	4	7	11	21	49
4600	0	4	7	10	21	52	2	4	7	10	21	49
4700	0	4	7	10	21	52	2	4	7	10	21	48
4800	0	4	7	10	21	51	2	4	7	10	21	48
4900	0	4	6	10	21	51	2	4	6	10	21	48
500	0	4	6	10	20	51	2	4	6	10	20	47
5100	0	4	6	10	20	50	2	4	6	10	20	47
5200	0	4	6	10	20	50	2	4	6	10	20	47
5300	0	4	6	10	20	49	2	4	6	10	20	46
5400	0	4	6	10	20	49	2	4	6	10	20	46
5500	0	3	6	10	20	49	2	3	6	10	19	46
5600	0	3	6	10	19	48	2	3	6	10	19	46
5700	0	3	6	9	19	48	2	3	6	9	19	45
5800	0	3	6	9	19	48	2	3	6	9	19	45
5900	0	3	6	9	19	47	2	3	6	9	19	45
6000	0	3	6	9	19	47	2	3	6	9	19	45

The procedure for calculating line loss is the same as more and more mainlines are added to the releaser and vacuum pump. It can become more complex if more lines of a variety of sizes and lengths are added as covered in the last chapter. This method of assigning part of the total cfm to individual mainlines is necessary to end up with a good estimate of the line loss the whole system will experience. One of the problems with using these tables is that sometimes there are large data gaps because the table only looks at specific data points of 25,50 and 100 foot intervals. Because of these gaps some find it simpler to do the calculations from a graph. The next page takes some of the same data and plots it in graph form for use in estimating line loss. The down side of the graph is the difficulty locating specific lengths of line. There are a few places where the graphs do not perfectly agree as in the case where a 3/4" line is connected to a 100 cfm pump vs. a 80 cfm pump. The chart goes to 0 with one but stays with 2 cfm on the others, here some common sense in choosing the better chart must be used.

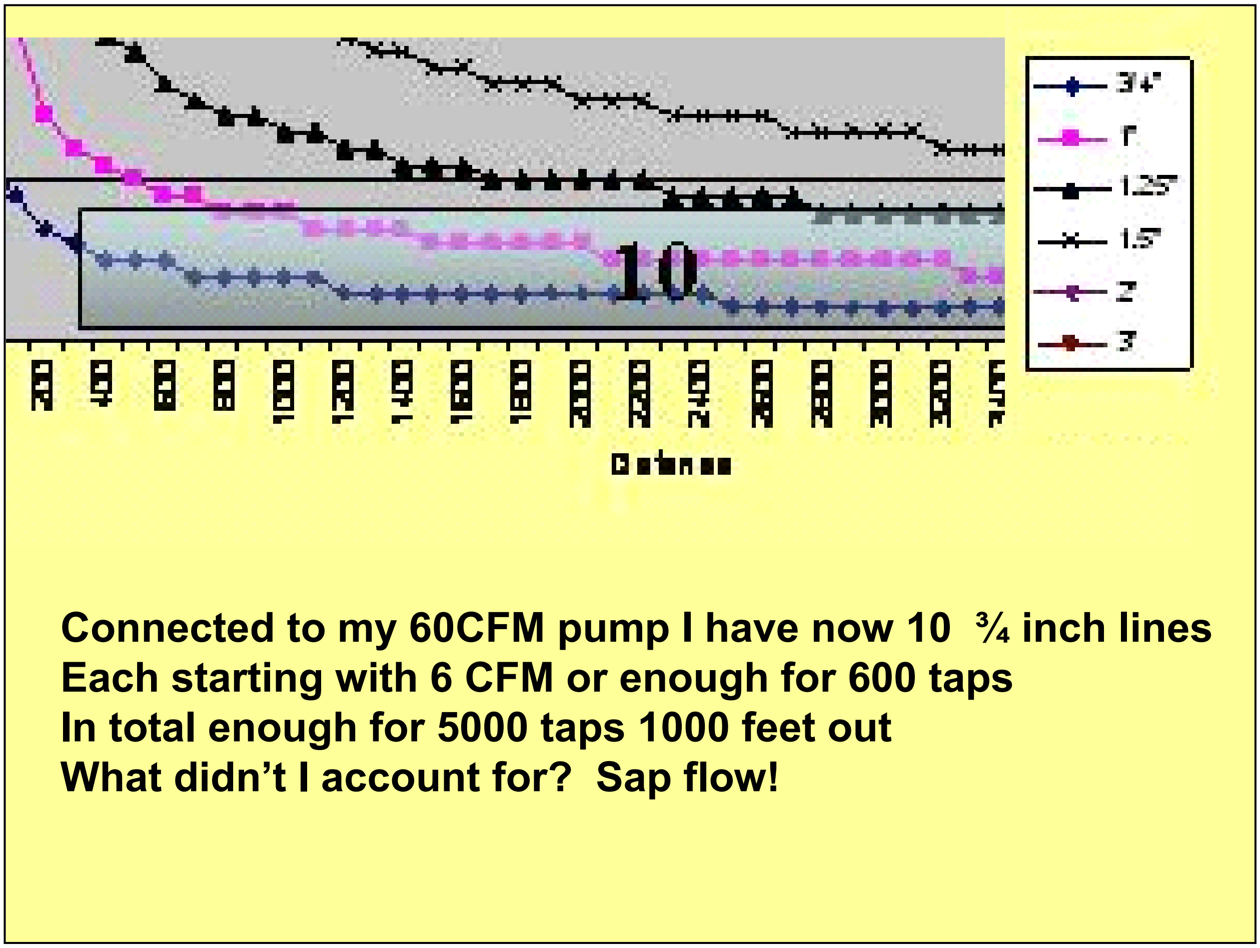


When the vacuum line loss chart is graphed it is easy to visualize the capacity differences between different sizes of main lines. This chart shows the air flow at different distances from the vacuum pump where just one mainline of the specified size is attached to a 60 cmf pump. It is easy to see that smaller main lines lose air flow capacity very quickly near the high air flow close to the pump. Where a 3/4 inch line is alone hooked to a 60 cfm pump it has just 16 cfm air flow 10 feet out the line. The capacity of the pump should be enough to provide vacuum for 6000 taps when the average tap leak rate is 1 cubic foot per minute for 100 taps. But just ten feet away in a 3/4 inch line only 1600 taps could be effectively supplied with vacuum. Even the 1, 1¼ and 1½ inch lines have difficulty providing the capacity for air flow at the 60 cmf level. The two and three inch lines are better matched to a pump of this capacity.

Near the pump, line loss due to high air flow is especially important when considering what size of line to install between the vacuum pump and the releaser. That is the worst place to use under sized main lines. That is where line loss is the most severe and it affects the capacity for the whole tubing system



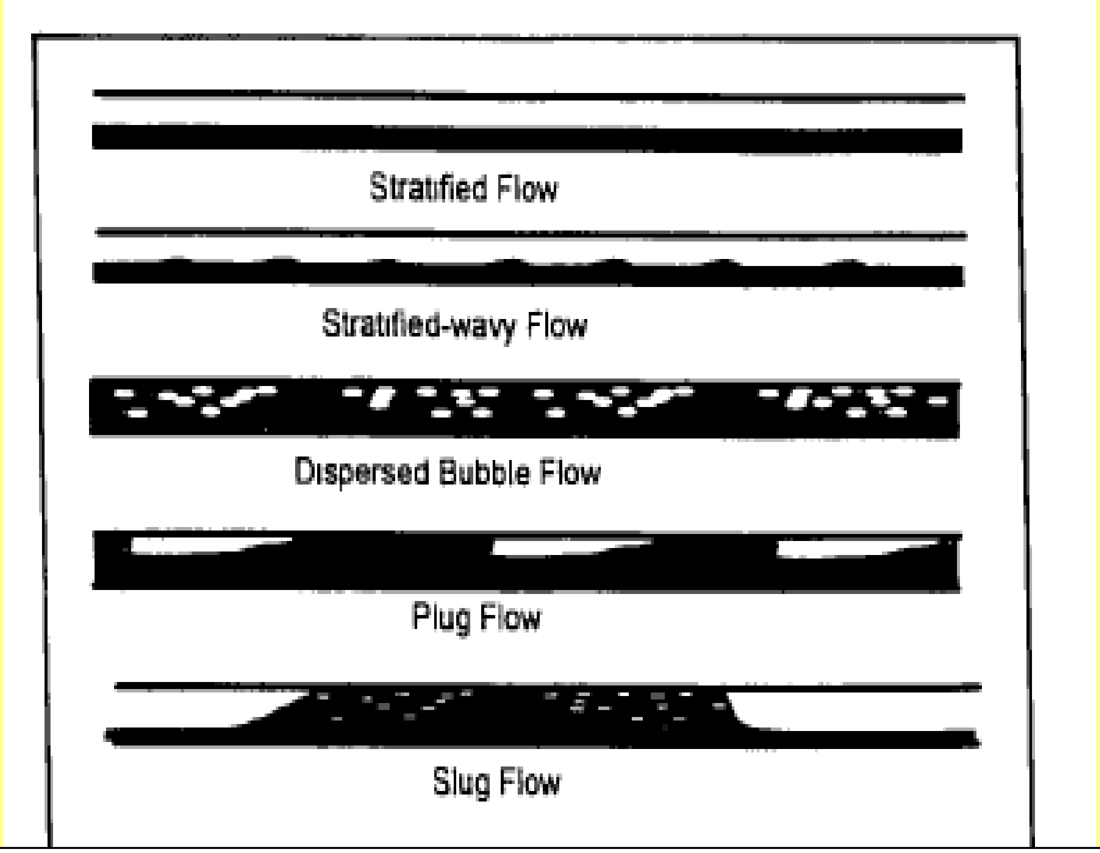
In the table above note the highlighted area on the graph. It is indicating the results if instead of having one three quarter inch line attached to the 60 cfm pump there were 10 3/4″ lines connected. One 3/4″ line would have given just 3 cfm 4000′ into the sugarbush or just enough for 300 taps from a pump that could have been able to supply capacity for 6000 taps with the right tubing system. With 10 three quarter inch lines just 6 cfm is assigned to each line and this time, 4000′ out in the woods, each line still has 3 cfm available, or a total of 30 cfm available, enough for 3000 taps. One three inch line at the same distance of 4000′ would still have 44 cfm available or enough for 4, 400 taps. Once again no account for the sap flow has been taken in the lines. Sap flow can significantly alter the tubing system capacity needs. All of the cubic feet per minute tables and graphs seen so far look only at what is happening with air flow in lines without sap.



Connected to my 60CFM pump I have now 10 ¾ inch lines
Each starting with 6 CFM or enough for 600 taps
In total enough for 5000 taps 1000 feet out
What didn't I account for? Sap flow!

These air flow calculations work great for a system that has no sap, or for calculations for dry lines. Accounting for the sap flow in the main lines is an important next step in the tubing system design or evaluation. The next important question becomes how much of the tubing system capacity does the sap take? What is the flow rate of a typical run. What is the flow rate of the very best run. Should the design be made for an average run or so that maximum vacuum can be maintained during the peak of an exceptional run? Since a primary way that vacuum improves yield is that it allows the sap to flow at a lower temperature, extending the time available to empty a tree of the available sap, keeping vacuum at the maximum possible level even during an exceptional flow period may not be the most important issue. Over sizing a system also has some negative consequences such as excessive costs and greater opportunity for sap to warm in the system causing it to loose quality. Identifying a flow rate for sap offers several complications. For instance, flow rate from fast growing trees is faster than from slow growing trees. Large trees may have a faster flow rate than smaller trees. Slope of lines also must come into play as steeper slopes will allow sap to drain away faster, using less of the tubing capacity than lines with less slope. Lines with uneven slope offer the greatest challenge of all as there may be locations in the line where sap backs up and obstructs air flow through the line. This may be a problem when the flow rate is just average, better than average or this may only occur when the flow rate is exceptional in a specific line.

Main Lines Must Be Sized for Sap and Air Flow



13.5 Including sap flow in the planning

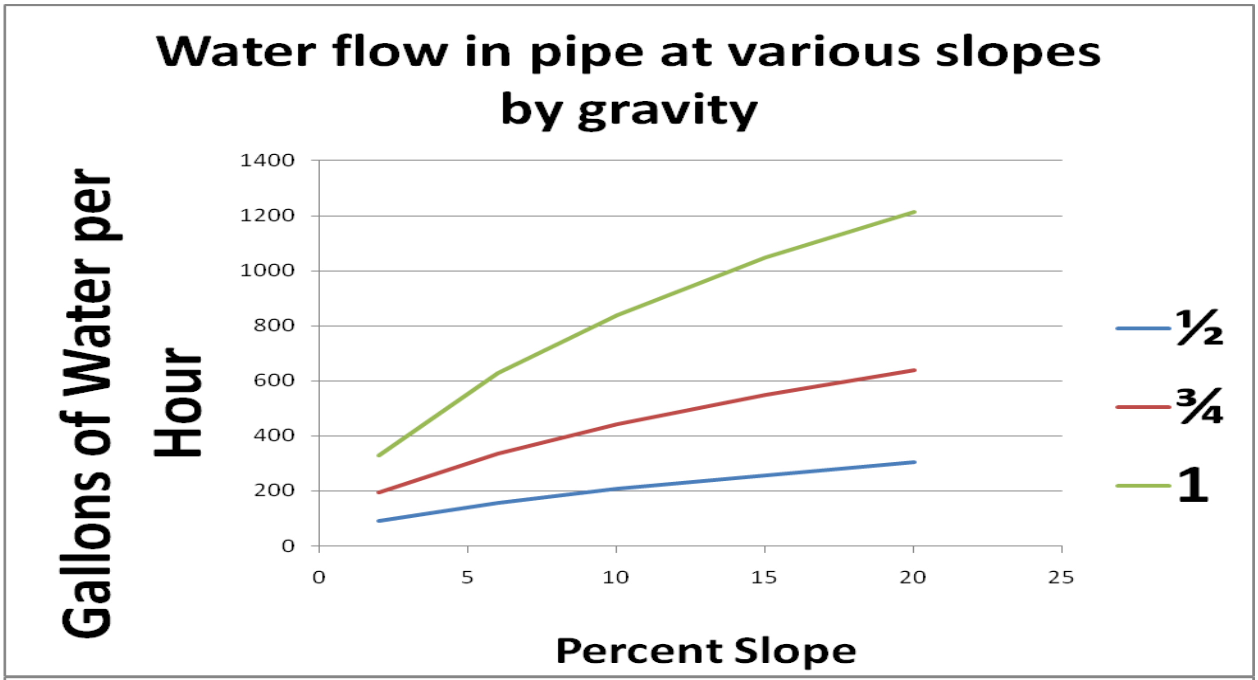
Ideally a tubing system would provide a clear uninterrupted path for both the flow of sap to the holding tank and the flow of leakage air to the vacuum pump. It is important to realize that both air and sap are moving in the same direction. If the tubing system is not designed with enough capacity, sap can take up too much of the space and block the movement of the leakage air reducing the effectiveness of the vacuum. This blockage is often represented in the slug or plug flow situation illustrated above. In severe cases the dispersed bubble flow may occur and very little vacuum is available at the tree. Ideal is to have the stratified or stratified wavy flow. In tubing systems where the steepness of the lines varies through the woods the tubing can be nicely stratified in part of the system but suffering slugs and plugs in other parts. These slugs and plugs are likely to be in areas where the lines have a steep downhill area followed by an area that is not as steep. Making sure these areas have extra tubing capacity or adding a dry line over these areas can help alleviate the blockage to free movement of vacuum or the leakage air. It can be very educational to install a section of clear tubing or nearly clear tubing where the maple producer questions what the sap is doing at that point in the line.

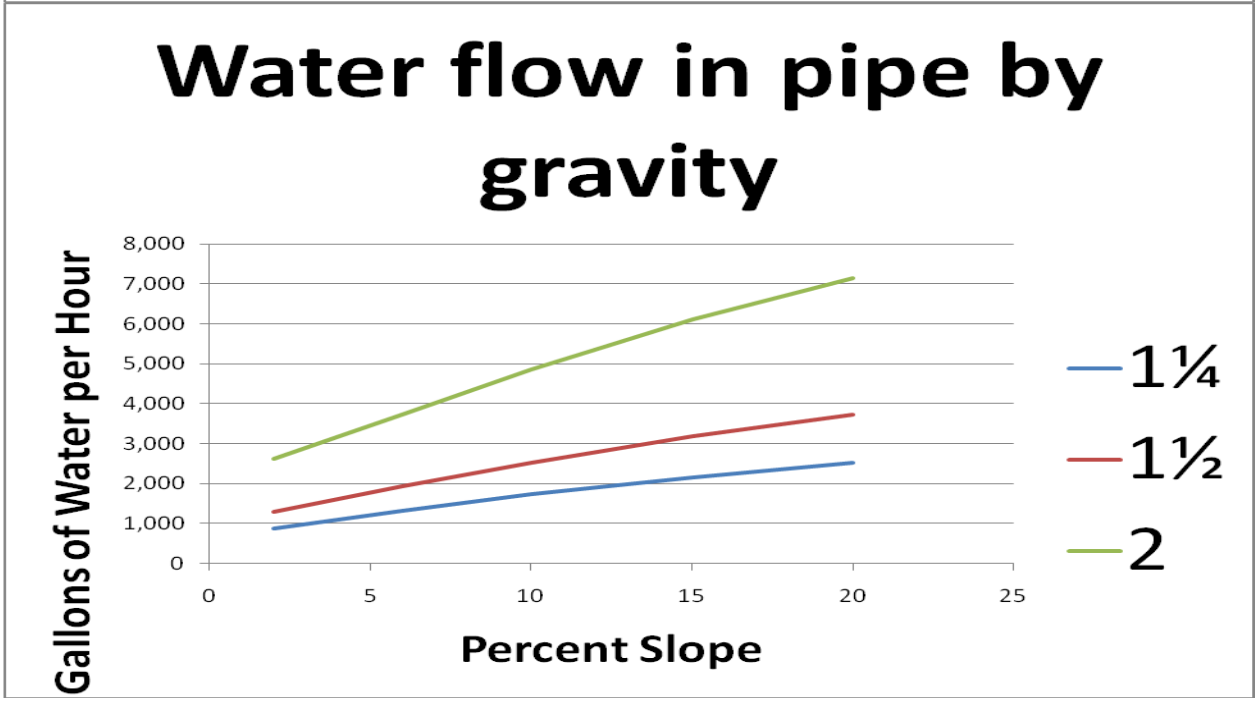
Water delivered per hour by gravity movement through plastic tubing of various diameters on a designated slope. [In gallons per hour]

Slope	Plastic tubing diameter, in inches					
Percent	½	¾	1	1¼	1½	2
40	444	933	1,752	3,600	5,400	10,450
30	378	795	1,500	3,120	4,620	8,940
25	342	720	1,350	2,820	4,200	8,040
20	303	640	1,215	2,520	3,720	7,140
15	258	549	1,050	2,160	3,180	6,120
10	207	444	840	1,740	2,526	4,860
6	156	336	630	1,320	1,920	3,720

Source: Republic Steel Corporation: Water delivery tables using Republic flexible plastic pipe. 12 pp., 1956.

The chart above is taken from the North America Maple Producers Manual. It is from an older source but seems to be the only one reflecting a flow rate through pipe of various sizes and slopes with no push from a pump and no head water influencing the flow. The negative aspect of the chart is that it only goes down to 6% slope where many maple systems are closer to 2% slope. Even though many sections of a maple woods are steeper than the 2% slope many have sections in mainlines where they temporarily flatten out to between 2 and 6% slope. If this happens in a line being evaluated or planned, the whole line should be considered to be at the more gradual slope. That lower slope section will influence the air flow for all the line above it. Adding a dry line over flatter areas can dramatically improve the whole line performance. So that a 2% option could be added to the chart, a graph was made of the chart above and the 2% flow rates estimated from the graph. Peak flow estimates are a maximum of .2 gallons of sap flow per hour per tap under peak flow conditions. Tubing must be only part full of sap so that there is capacity for air movement to facilitate vacuum through out the whole line. When the sap flow rate chart above and the line loss charts of previous pages are combined an ideal balance of sap and air flow can be estimated. The complication here is that the balance point in a mainline changes with each tap added or removed. Rather than have each maple producer or tubing system planner calculate the balance point for each line; it was decided to create a set of guidelines that recommend the number of taps a line of a given length, slope and vacuum capacity can handle under exceptional sap flow conditions. These estimates have been made for ¾", 1", 1¼", 1½" and 2" lines at 2%, 6%, 10% and 15% slopes. The result of these estimates are the "Guidelines for Taps on Mainlines". These guidelines suggest the number of taps that are recommended on mainlines. Worksheets have also been created to help use the information from the Guidelines while planning a new system or evaluating an existing tubing system.

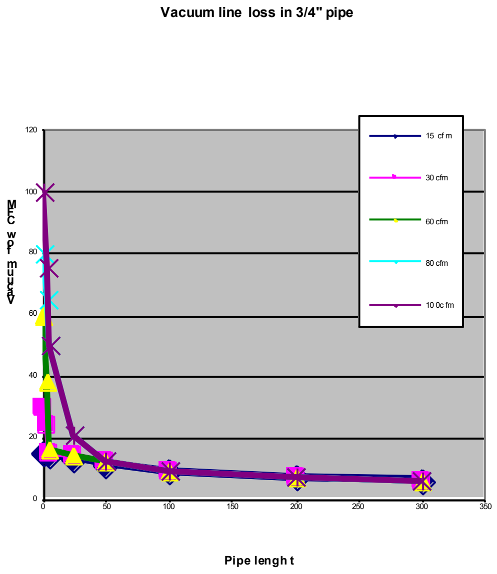




The graphs above reflect the flow of water in pipe from 2 % to 20% slope. This will allow the guidelines to reflect the more shallow slopes commonly found in maple tubing systems. Before going directly to the calculated guidelines there is one more concept of line loss that must be addressed. The guidelines do not reflect all of the various vacuum capacities in cfm that could be applied to a mainline but only those that are practical. It is not practical to apply so much vacuum capacity to a line that much of that capacity is simply lost to friction. The following charts are re-grouped in such a way that unnecessary line loss due to excess vacuum capacity becomes very obvious.

	3/4 in	3/4 in	3/4 in	3/4 in	3/4 in
Distance (feet)	15 cfm	30cfm	60cfm	80cfm	100cfm
0	15	30	60	80	100
3	15	24	38	65	75
5	14	15	16	50	50
25	13	14	14	21	21
50	11	12	12	12	12
100	9	9	9	9	9
200	7	7	7	7	7
300	6	6	6	6	6
400	5	5	5	5	5
500	5	5	5	5	5
600	5	5	5	5	5
700	4	4	4	4	4
800	4	4	4	4	4
900	4	4	4	4	4
1000	4	4	4	4	4
1100	4	4	4	4	4
1200	3	3	3	3	3
1300	3	3	3	3	3
1400	3	3	3	3	3
1500	3	3	3	3	3
1600	3	3	3	3	3
1700	3	3	3	3	3
1800	3	3	3	3	3
1900	3	3	3	3	3
2000	3	3	3	3	3
2100	3	3	3	3	3
2200	3	3	3	3	3
2300	3	3	3	3	3
2400	3	3	3	3	3
2500	2	2	2	2	2
2600	2	2	2	2	2
2700	2	2	2	2	2
2800	2	2	2	2	2
2900	2	2	2	2	2
3000	2	2	2	2	2
3100	2	2	2	2	2
3200	2	2	2	2	2
3300	2	2	2	2	2
3400	2	2	2	2	2
3500	2	2	2	2	2
3600	2	2	2	2	2
3700	2	2	2	2	2
3800	2	2	2	2	2
3900	2	2	2	2	2
4000	2	2	2	2	2
4100	2	2	2	2	2
4200	2	2	2	2	2
4300	2	2	2	2	2
4400	2	2	2	2	2
4500	2	2	2	2	2
4500	2	2	2	2	2
4600	2	2	2	2	2
4700	2	2	2	2	2
4800	2	2	2	2	2
4900	2	2	2	2	2
5000	2	2	2	2	2
5100	2	2	2	2	2
5200	2	2	2	2	2
5300	2	2	2	2	2
5400	2	2	2	2	2
5500	2	2	2	2	2
5600	2	2	2	2	2
5700	2	2	2	2	2
5800	2	2	2	2	2
5900	2	2	2	2	2
6000	2	2	2	2	2

To design a tubing system that would minimize capacity loss due to line loss it is useful to set up the line loss charts into a different format. To get a better picture of what is happening in a given size of line, the charts for line loss are re-arranged to see what the airflow is doing side by side with the various vacuum pump capacities applied to that line. This chart compares 3/4 inch line when connected to a 15, 30, 60, 80 and 100 cfm pump. Within the first 100 feet of 3/4 inch line, the chart shows that no matter how much vacuum capacity is connected to the line the flow capacity equalizes in this short distance. Air flow in 3/4 inch line is very limited and should only be expected to handle 3 or 4 cfm without significant loss to friction.



Guidelines Chart for 3/4" line at 2%, 6%, 10% and 15% slope, 15 cfm

			2% slope	6% slope	10% slope	15%slope
	3/4 in	3/4 in	3/4 in	3/4 in	3/4 in	3/4 in
	15cfm	15cfm	15cfm	15cfm	15cfm	15cfm
Distance (feet)	15cfm	Capacity for taps on dryline	Maximum # of taps	Maximum # of taps	Maximum # of taps	Maximum # of taps
0	15	1500	380	424	460	483
3	15	1500	380	424	460	483
5	14	1400	380	424	460	483
25	13	1300	380	424	460	483
50	11	1100	380	424	460	483
100	9	900	380	424	460	483
200	7	700	378	424	460	483
300	6	600	344	424	460	483
400	5.5	550	327	399	431	451
500	5	500	309	373	400	417
600	4.75	475	300	360	384	400
700	4.5	450	290	346	368	382
800	4.25	425	280	331	351	364
900	4	400	270	316	334	346
1000	3.75	375	259	301	317	327
1100	3.5	350	247	285	299	308
1200	3.4	340	242	278	292	300
1300	3.3	330	237	272	285	293
1400	3.3	330	237	272	285	293
1500	3.2	320	232	265	277	285
1600	3.2	320	232	265	277	285
1700	3.1	310	227	258	270	277
1800	3	300	222	251	262	269
1900	2.9	290	217	244	255	261
2000	2.8	280	211	237	247	253
2100	2.8	280	211	237	247	253
2200	2.7	270	206	230	239	245
2300	2.6	260	200	223	231	237
2400	2.5	250	194	216	223	228
2500	2.4	240	188	208	215	220
2600	2.4	240	188	208	215	220
2700	2.4	240	188	208	215	220
2800	2.3	230	182	201	207	212
2900	2.3	230	182	201	207	212

13.6 Mainline sizing guidelines and worksheets for 3/4” line

From the air flow line loss charts and water flow charts for 3/4” line, a table of guidelines based on a balance of air and sap flow in the line have been constructed. The first two columns show how long the tubing is and the cfm assigned to that line on the line loss chart . Understand that the shorter mainline lengths produce suggested tap numbers that are not possible. They become realistic at about 500′ simply due to tree density in the sugarbush or simple access to trees numbers with the short distances.

Guidelines Chart for 3/4" line at 2%, 6%, 10% and 15% slope, 15 cfm

			2% slope	6% slope	10% slope	15%slope
	3/4 in	3/4 in	3/4 in	3/4 in	3/4 in	3/4 in
	15cfm	15cfm	15cfm	15cfm	15cfm	15cfm
Distance (feet)	15cfm	Capacity for taps on dryline	Maximum # of taps	Maximum # of taps	Maximum # of taps	Maximum # of taps
3000	2.3	230	182	201	207	212
3100	2.3	230	182	201	207	212
3200	2.3	230	182	201	207	212
3300	2.2	220	176	193	199	203
3400	2.2	220	176	193	199	203
3500	2.2	220	176	193	199	203
3600	2.2	220	176	193	199	203
3700	2.1	210	170	185	191	195
3800	2.1	210	170	185	191	195
3900	2.1	210	170	185	191	195
4000	2.1	210	170	185	191	195
4100	2.1	210	170	185	191	195
4200	2	200	163	178	183	186
4300	2	200	163	178	183	186
4400	2	200	163	178	183	186
4500	2	200	163	178	183	186
4600	2	200	163	178	183	186
4700	1.9	190	157	170	174	177
4800	1.9	190	157	170	174	177
4900	1.9	190	157	170	174	177
5000	1.9	190	157	170	174	177
5100	1.9	190	157	170	174	177
5200	1.8	180	150	162	166	169
5300	1.8	180	150	162	166	169
5400	1.8	180	150	162	166	169
5500	1.8	180	150	162	166	169
5600	1.8	180	150	162	166	169
5700	1.7	170	143	154	157	160
5800	1.7	170	143	154	157	160
5900	1.7	170	143	154	157	160
6000	1.7	170	143	154	157	160

Column three shows how many taps can be serviced on a 3/4″ dry line of that length and associated line loss. Column four shows the number of taps suggested for one 3/4″ mainline at the listed length and cfm for near perfect balance between sap and air flow at the given slope. A worksheet will provide the outline for using the chart to identify the ideal combination for any given mainline in the sugarbush.

The key to understanding and reading the guideline chart to set your start point on the chart with the capacity of cfm you plan or currently provide to the main line. Not every system will be providing exactly 15 cfm to your 3/4″ mainline. In fact that would be foolish as the previous charts have shown that you suffer much less line loss if a much lower cfm is assigned to that line. For example if you have a 3/4″ line that you plan to provide with vacuum capacity of 4 cfm, look down the chart to where column 2 shows 4 cfm. The chart shows 4 cfm at 900 feet, that becomes the starting point to determine if 3/4″ line is the right choice, if the current main line has too many or could handle more taps, if it fits into your plan. If the line under consideration will be about 400 feet long, add 400′ to the starting point of 900′. That means you look at 1300 feet for the recommended tapping level. At 1300 the recommendation is for 237 taps at 2% slope. If the line was all at 15% slope, the line would support 293 taps. However, if a section of that 15% slope line flattened to about 6% slope you would need to take the recommendation for 6% slope as the guideline. That would be 272 taps. At the recommended number of taps when the sap was running at near maximum rate, there would be a near perfect balance between the space in the tubing to conduct sap as well as provide flow space for the leakage air that needs to escape the tubing system to be able to maintain the desired vacuum level to the lateral line.

Guidelines Chart for 3/4" line at 2%, 6%, 10% and 15% slope, 15 cfm

			2% slope	6% slope	10% slope	15%slope
	3/4 in	3/4 in	3/4 in	3/4 in	3/4 in	3/4 in
	15cfm	15cfm	15cfm	15cfm	15cfm	15cfm
Distance (feet)	15cfm	Capacity for taps on dryline	Maximum # of taps	Maximum # of taps	Maximum # of taps	Maximum # of taps
0	15	1500	380	424	460	483
3	15	1500	380	424	460	483
5	14	1400	380	424	460	483
25	13	1300	380	424	460	483
50	11	1100	380	424	460	483
100	9	900	380	424	460	483
200	7	700	378	424	460	483
300	6	600	344	424	460	483
400	5.5	550	327	399	431	451
500	5	500	309	373	400	417
600	4.75	475	300	360	384	400
700	4.5	450	290	346	368	382
800	4.25	425	280	331	351	364
4 cfm → 900	4	400	270	316	334	346
+400′ 1000	3.75	375	259	301	317	327
1100	3.5	350	247	285	299	308
1200	3.4	340	242	278	292	300
1300	Recommended taps	→	237	272	285	293
1400	3.3	330	237	272	285	293

Using the mainline sizing guidelines worksheet (single mainlines)

Evaluation for using a ¾" mainline:

Baseline information:

1. Target, how many taps on or anticipated on this line _______ taps
2. Length or estimated length of this line ________
3. Slope of the shallowest 50' of this line ___%
4. cfm of vacuum assigned to this line,

(see cfm assignment worksheet if necessary) ______

From the Guidelines for 3/4" line write the listed distance where for the first time the available CMF (in line 4 above) ____cfm shows up in the second column. _____ feet

Add the length of your line (from line 2 above) _____ feet

Total _____ feet

List the recommended number of taps from the guidelines at this distance and at your estimated slope from line 3 above _______ taps

If the suggested number of taps is less than our target number then the line is too small, more cfm need to be available or have less taps on the line. If the guideline number of taps is equal to or greater than our line count then this size of mainline is correct or possibly larger than necessary.

This worksheet is designed to help you follow a system of using the Guideline tables correctly. Once you are familiar with the process, answers can be very quickly figured directly from the tables without using a worksheet like this. If when working through the worksheet the suggested number of taps is less than the target number then the line is too small. You could then using the same worksheet run the calculation for the next bigger size of mainline along side of the last calculations. If on the other hand the maple producer has decided to have only one size of mainline in the woods the work sheet could be used to see how the lines could be divided. Worksheets further along in the section could be used to evaluate how adding a dry line in this situation could meet the desire to keep all the mainlines in the woods the same size and provide sufficient capacity for sap and vacuum in the system.

Using the mainline sizing guidelines worksheet (single mainlines)

Evaluation for using a ¾” mainline:

Baseline information:

1. Target, how many taps on or anticipated on this line 180 taps
2. Length or estimated length of this line 600
3. Slope of the shallowest 50' of this line 6%
4. cfm of vacuum assigned to this line,

(see cfm assignment worksheet if necessary) 3 cfm

From the Guidelines for 3/4" line write the listed distance where for the first time the available CMF (in line 4 above) 3 cfm shows up in the second column. 1800 feet

Add the length of your line (from line 2 above) 600 feet

Total 2400 feet

List the recommended number of taps from the guidelines at this distance and at your estimated slope from line 3 above 216 taps

If the suggested number of taps is less than our target number then the line is too small, more cfm need to be available or have less taps on the line. If the guideline number of taps is equal to or greater than our line count then this size of mainline is correct or possibly larger than necessary.

In this example, a 3/4″ line that has 180 taps is about 600 feet long with a consistent slope of about 6%. This could be either an existing line being evaluated or a proposed new mainline that is being planned for the best main line size option. Once the number of taps, the length and the slope have been identified, the next needed information is the vacuum pump capacity in cfm available to this one line. This may be a new concept for many maple producers and the answer can be fairly simple or may take some additional calculation. For example if a 6 cfm rated pump is connected to two 3/4″ lines then each line could be assigned 3 of the available cfm. That is provided the pump is operating at its rated vacuum level and rotation speed. These details were covered in the last section and there are worksheets there to assist when the calculations become more complex. In this example this mainline has 3 cfm available. Use the first two columns on the chart to find the length where 3 cfm first appears in the second column. This is what it is like at the beginning of the mainline being evaluated. It is 3/4″ in diameter and has 3 cfm of vacuum capacity available at it’s beginning and it is at 1800′ on the chart. Now move down the chart the length of the mainline being evaluated, in this case 600′. That will result in viewing the chart at 2400 feet. In the 6% slope column (5th column) the recommended number of taps is 216. Since this is more taps than our target of 180, the mainline is of sufficient size and capacity to service vacuum and sap flow for these taps.

Using the mainline sizing guidelines worksheet (single mainlines)
Evaluation for using a ¾" mainline:

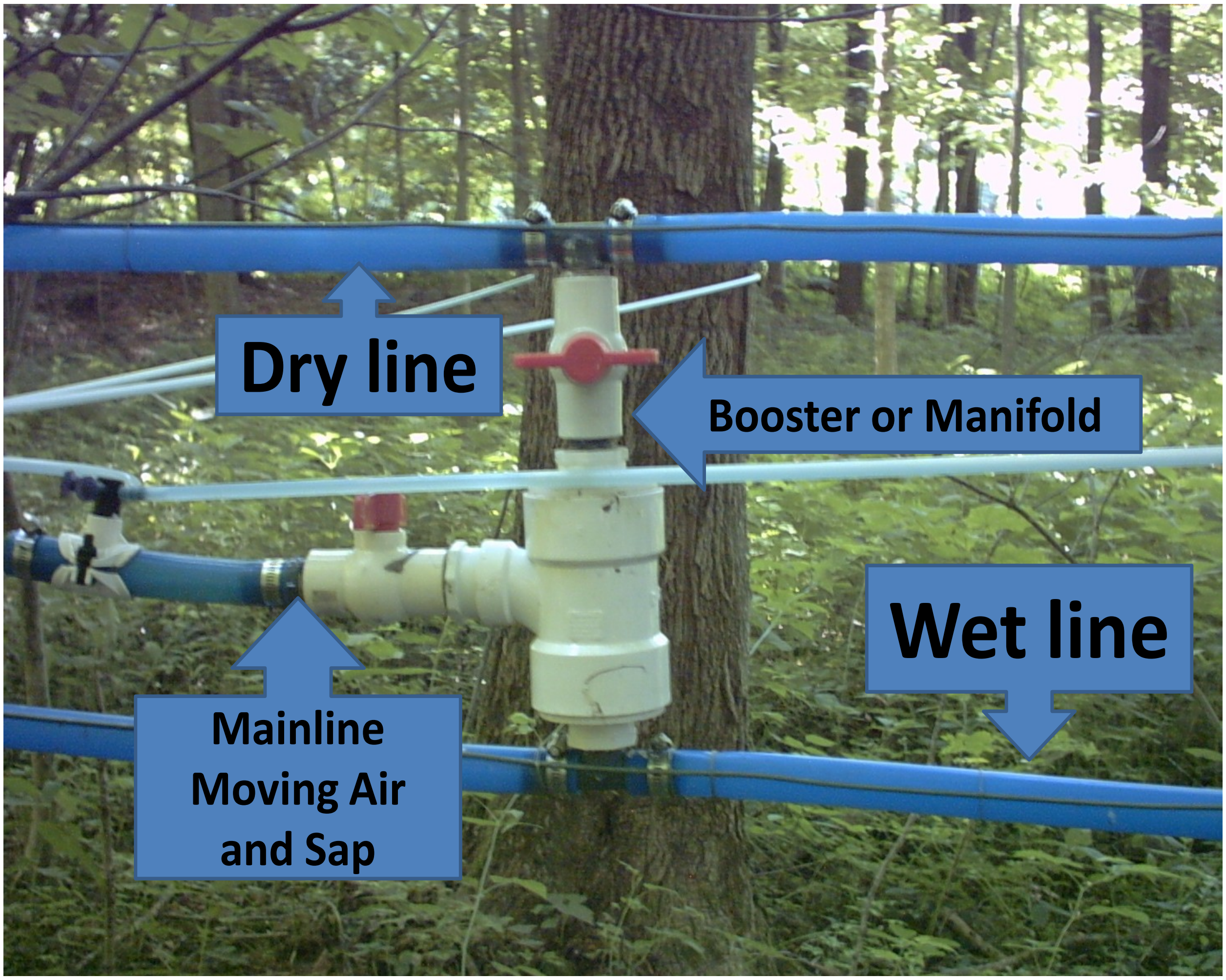
Baseline information:

Target, how many taps on or anticipated on this line 150 taps
Length or estimated length of this line 1500
Slope of the shallowest 50' of this line 2%
cfm of vacuum assigned to this line,
(see cfm assignment worksheet if necessary) 2 cfm
From the Guidelines for 3/4" line write the listed distance where
for the first time the available CMF (in line 4 above) 2 cfm
shows up in the second column. 4200 feet
Add the length of your line (from line 2 above) 1500 feet
Total 5700 feet

List the recommended number of taps from the guidelines at this distance and at your estimated slope from line 3 above 143 taps

If the suggested number of taps is less than our target number then the line is too small, more cfm need to be available or have less taps on the line. If the guideline number of taps is equal to or greater than our line count then this size of mainline is correct or possibly larger than necessary.

In this example, a 3/4" line that has 150 taps is about 1500 feet long with a consistent slope of about 2%. This could be either an existing line being evaluated or a proposed new mainline that is being planned for the best main line size option. Once the number of taps, the length and the slope have been identified, the next needed information is the vacuum pump capacity available to this one line. In this example this mainline has 2 cfm available. Using the first two columns on the chart find the length where the 2 cfm first appears in the second column. This is the vacuum capacity at the beginning of the mainline being evaluated. The line is 3/4" in diameter and has 2 cfm of vacuum capacity available at it's beginning and this first appears at 4200' on the chart. Now move down the chart the length of the mainline being evaluated, in this case 1500'. That will result in viewing the chart at 5700 feet. In the 2% slope column (4th column) the recommended number of taps is 143. Since this is less taps than our target of 180, the mainline is not of sufficient size and capacity to service vacuum and sap flow for these taps. Could this be solved by supplying more vacuum capacity to the beginning of the line. Retry using 4 cfm. 4 cfm first appears on the chart at 900' add 1500 feet of this line and the total is 2400' where the recommendation at 2% slope is 194 taps. This could serve as the solution to having this size of main line be workable.
There is a problem if you were to decide to look at switching to a 1" line. Anything below 3.4 cfm does not register on the 1" mainline charts leaving a gap in the information for smaller number of taps on 1" lines.



13.7 Wet/dry line systems

Calculations and Guidelines to this point have involved only single mainlines responsible for moving both sap and air. Many maple producers prefer to use the two line system or the dry line/wet line system. The illustration above demonstrates how this system is typically set up. Usually wet and dry lines are installed on their own support wires with the dry line 6″ to 18″ above the wet line. Each time a mainline moving both leakage air and sap comes to this mainline from the taps a booster or manifold is installed between the wet and dry line. The dry line is designed to provide only vacuum capacity, moving leakage air from the lateral lines to the vacuum pump. The wet line is designed to move primarily sap to the releaser. The booster or manifold is where the air flow and sap flow are divided. Lateral lines do not enter the wet and dry line directly. A single mainline collects the sap and air from the lateral lines and then joins the dry and wet lines at the manifold. The Guidelines provide information in the third column of air movement as cfm in an open or dry line. This adds to the complexity of sizing lines in a tubing system as the capacity of the dry and wet line need to be considered as well as the capacity of the single main lines that connect the lateral lines to the manifold of the dry line/wet line system. The worksheet for 3/4″ lines in a dry/wet line system is on the next page.

Using mainline sizing guidelines worksheet (wet and dry mainlines)
Evaluation for using a ¾” mainline:

Baseline information:

1. Target, how many taps on or anticipated on this line ________ taps
2. Length or estimated length of this line _________
3. Slope of the shallowest 50' of this line ___%
4. cfm of vacuum assigned to this line,

(see cfm assignment worksheet if necessary) _______

From the Guidelines for 3/4" line write the listed distance where for the first time the available CMF (in line 4 above) ____cfm shows up in the second column. ______ feet

Add the length of your line (from line 2 above) ______ feet

Total ______ feet

List the recommended number of taps from the guidelines at this distance in the column capacity for taps on dryline ________ taps

If the suggested number of taps is less than our target number then the line is too small, more cfm need to be available or have less taps on the line. If the guideline number of taps is equal to or greater than our line count then this size of mainline is correct or possibly larger than necessary.

Wet line. Multiply the number of taps by .2 gallons per hour, (line 1 above) _______ taps x .2 = _________gallons of sap per hour during exceptional flow. Now check the water flow chart at your given slope (line 3 above) to see the ¾” wet line can carry that load per hour. If yes then fine if not go to the next larger size of wet line.

Water (gallons) per hour through ¾” plastic tubing at the designated slope.

Slope	2%	6%	10%	15%	20%
Gallons/hour	195	336	444	549	640

The evaluation for the dry line part of the system is identical to following the worksheet for single main lines. Evaluating the wet line capacity is also fairly easy. Multiply the number of taps on the mainline by the .2 gallons of sap per hour per tap estimation for exceptional flow. Compare the gallons of anticipated sap flow to the pipe flow capacity estimations at the bottom of the worksheet. These estimations are based on unobstructed pipe which is not usually the case in a maple tubing system. Fittings, elbows, air pockets and slope variations all act as obstruction to sap flow. You would not want to have a wet line operating near its rated full capacity. Inflow of sap to the wet line would not likely be perfectly balanced over it’s whole length. However, no research could be found to determine an exact % of total capacity to be recommended. When the sap flow calculation for the wet line shows it nearly full, say over 75%, moving to a larger line would be suggested. In a wet line, unless it is specifically oversize to add air flow capacity, its air flow is not calculated or added.

Using mainline sizing guidelines worksheet (wet and dry mainlines)
Evaluation for using a ¾" mainline:

Baseline information:

1. Target, how many taps on or anticipated on this line 400 taps
2. Length or estimated length of this line 1000
3. Slope of the shallowest 50' of this line 2%
4. cfm of vacuum assigned to this line,
(see cfm assignment worksheet if necessary) 6

From the Guidelines for 3/4" line write the listed distance where for the first time the available CMF (in line 4 above) 6 cfm shows up in the second column. 300 feet

Add the length of your line (from line 2 above) 1000 feet

Total 1300 feet

List the recommended number of taps from the guidelines at this distance in the column capacity for taps on dryline 330 taps

If the suggested number of taps is less than our target number then the line is too small, more cfm need to be available or have less taps on the line. If the guideline number of taps is equal to or greater than our line count then this size of mainline is correct or possibly larger than necessary.

Wet line. Multiply the number of taps by .2 gallons per hour, (line 1 above) 400 taps x .2 = 80 gallons of sap per hour during exceptional flow. Now check the water flow chart at your given slope (line 3 above) to see the ¾" wet line can carry that load per hour. If yes then fine if not go to the next larger size of wet line.

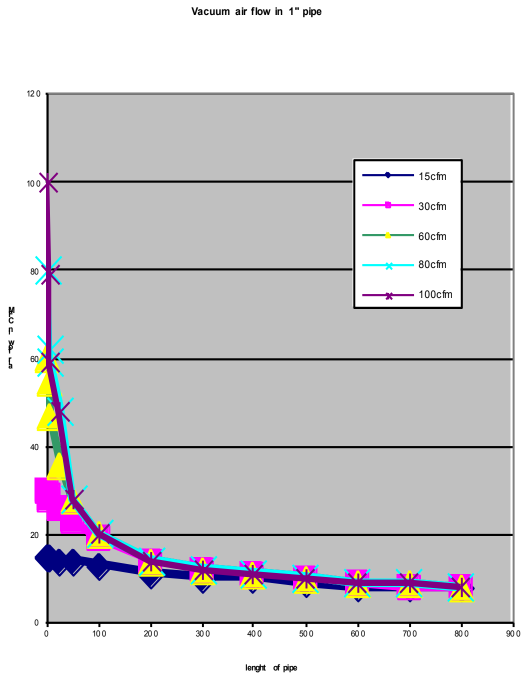
Water (gallons) per hour through ¾" plastic tubing at the designated slope.

Slope	2%	6%	10%	15%	20%
Gallons/hour	195	336	444	549	640

In this example the evaluation is of a 3/4" dry line and 3/4" wet line where the line is 1000' long with 400 taps at a 2% slope with vacuum pump capacity assigned to this line of 6 cfm. On the Guidelines Chart for 3/4" line, locate the distance where 6 cfm first appears in the second column. 6 cfm first appears at 300'. To that add the length of this mainline of 1000'. At 1300' on the chart check the third column "capacity for taps on dryline" for the recommended number of taps on a dry line. The guideline indicates 330 taps. 3/4" is too small for this number of taps under these conditions. To check the wet line capacity, multiply the 400 taps times .2 gallons of sap per hour during exceptional flow for a result of 80 gallons per hour. At the 2% slope the table at the bottom of the worksheet 3/4" line has the capacity for 195 gallons per hour the wet line of 3/4" would be fine for 400 taps. The 1" Guideline indicates that it would work fine for the dry line in this scenario.

13.8 Mainline sizing guidelines and worksheets for 1” line

	1 in	1 in	1 in	1 in	1 in
Distance (feet)	15cfm	30cfm	60cfm	80cfm	100cfm
0	15	30	60	80	100
3	15	29	55	62	79
5	15	28	47	59	59
25	14	26	36	48	48
50	14	23	28	28	28
100	13	19	20	20	20
200	11	14	14	14	14
300	10	12	12	12	12
400	10	11	11	11	11
500	9	10	10	10	10
600	8	9	9	9	9
700	8	8	9	9	9
800	8	8	8	8	8
900	7	8	8	8	8
1000	7	8	8	8	7
1100	7	7	7	7	7
1200	7	7	7	7	7
1300	6	7	7	7	7
1400	6	7	7	7	6
1500	6	6	6	6	6
1600	6	6	6	6	6
1700	6	6	6	6	6
1800	6	6	6	6	6
1900	6	6	6	6	6
2000	5	6	6	6	6
2100	5	5	5	5	5
2200	5	5	5	5	5
2300	5	5	5	5	5
2400	5	5	5	5	5
2500	5	5	5	5	5
2600	5	5	5	5	5
2700	5	5	5	5	5
2800	5	5	5	5	5
2900	5	5	5	5	5
3000	5	5	5	5	5
3100	4	5	5	5	5
3200	4	5	5	5	4
3300	4	4	4	4	4
3400	4	4	4	4	4
3500	4	4	4	4	4
3600	4	4	4	4	4
3700	4	4	4	4	4
3800	4	4	4	4	4
3900	4	4	4	4	4
4000	4	4	4	4	4
4100	4	4	4	4	4
4200	4	4	4	4	4
4300	4	4	4	4	4
4400	4	4	4	4	4
4500	4	4	4	4	4
4600	4	4	4	4	4
4700	4	4	4	4	4
4800	4	4	4	4	4
4900	4	4	4	4	4
5000	4	4	4	4	4
5100	4	4	4	4	4
5200	4	4	4	4	4
5300	4	4	4	4	4
5400	3	4	4	4	4
5500	3	3	4	3	3
5600	3	3	3	3	3
5700	3	3	3	3	3
5800	3	3	3	3	3
5900	3	3	3	3	3
6000	3	3	3	3	3



The table on this page pairs together the one inch line connected to a 15,30,60, 80, and 100 cfm pump. In just 800 feet all of these one inch lines are supporting exactly the same cubic feet per minute capacity. In the first 800 feet of line most of the significant line loss due to friction has occurred and no mater how big the vacuum pump connected to the line, the air flow in the line is essentially equal. From this information combined with sap flow calculations a set of guideline charts for various slopes are on the next pages.

Guidelines for 1" line at 2%, 6%, 10% and 15% slope, 15 cfm

			2% slope	6% slope	10% slope	15%slope
	1"	1"	1"	1"	1"	1"
	15cfm	15cfm	15cfm	15cfm	15cfm	15cfm
Distance (feet)	15cfm	Capacity for taps on dryline	Maximum number of taps	Maximum number of taps	Maximum number of taps	Maximum number of taps
0	**15**	**1500**	**693**	**834**	**877**	**913**
3	**15**	**1500**	**693**	**834**	**877**	**913**
5	**15**	**1500**	**693**	**834**	**877**	**913**
25	**14**	**1400**	**693**	**834**	**877**	**913**
50	**14**	**1400**	**693**	**834**	**877**	**913**
100	**13**	**1300**	**693**	**834**	**877**	**913**
200	**11**	**1100**	**693**	**834**	**877**	**913**
300	**10.2**	**1020**	**659**	**786**	**825**	**857**
400	**9.8**	**980**	**641**	**762**	**798**	**828**
500	**9**	**900**	**604**	**712**	**744**	**770**
600	**8.5**	**850**	**580**	**680**	**709**	**733**
700	**8.1**	**810**	**560**	**654**	**681**	**703**
800	**7.7**	**770**	**539**	**627**	**652**	**672**
900	**7.4**	**740**	**524**	**607**	**631**	**649**
1000	**7.2**	**720**	**513**	**593**	**616**	**634**
1100	**7**	**700**	**502**	**580**	**601**	**618**
1200	**6.8**	**680**	**491**	**566**	**586**	**603**
1300	**6.5**	**650**	**475**	**545**	**564**	**579**
1400	**6.3**	**630**	**464**	**530**	**549**	**563**
1500	**6.2**	**620**	**458**	**523**	**541**	**555**
1600	**6**	**600**	**447**	**509**	**526**	**539**
1700	**5.9**	**590**	**441**	**502**	**518**	**531**
1800	**5.7**	**570**	**429**	**487**	**502**	**514**
1900	**5.6**	**560**	**423**	**480**	**495**	**506**
2000	**5.5**	**550**	**418**	**472**	**487**	**498**
2100	**5.4**	**540**	**412**	**465**	**479**	**490**
2200	**5.3**	**530**	**406**	**457**	**471**	**482**
2300	**5.2**	**520**	**400**	**450**	**463**	**473**
2400	**5.1**	**510**	**394**	**442**	**455**	**465**
2500	**5**	**500**	**387**	**435**	**447**	**457**
2600	**4.9**	**490**	**381**	**427**	**439**	**448**
2700	**4.8**	**480**	**375**	**420**	**431**	**440**
2800	**4.7**	**470**	**369**	**412**	**423**	**432**
2900	**4.6**	**460**	**363**	**404**	**415**	**423**

From the air flow line loss charts and water flow charts for 1″ line, a table of guidelines based on a balance of air and sap flow in the line have been constructed. The first two columns show how long the tubing is and the cfm assigned to that line on the line loss chart .

Guidelines for 1" line at 2%, 6%, 10% and 15% slope, 15 cfm

			2% slope	6% slope	10% slope	15%slope
	1"	1"	1"	1"	1"	1"
	15cfm	15cfm	15cfm	15cfm	15cfm	15cfm
Distance (feet)	15cfm	Capacity for taps on dryline	Maximum number of taps	Maximum number of taps	Maximum number of taps	Maximum number of taps
3000	**4.6**	**460**	**363**	**404**	**415**	**423**
3100	**4.5**	**450**	**356**	**396**	**407**	**415**
3200	**4.4**	**440**	**350**	**389**	**398**	**406**
3300	**4.4**	**440**	**350**	**389**	**398**	**406**
3400	**4.3**	**430**	**343**	**381**	**390**	**398**
3500	**4.3**	**430**	**343**	**381**	**390**	**398**
3600	**4.2**	**420**	**337**	**373**	**382**	**389**
3700	**4.2**	**420**	**337**	**373**	**382**	**389**
3800	**4.1**	**410**	**330**	**365**	**374**	**380**
3900	**4.1**	**410**	**330**	**365**	**374**	**380**
4000	**4.1**	**410**	**330**	**365**	**374**	**380**
4100	**4**	**400**	**324**	**357**	**365**	**372**
4200	**4**	**400**	**324**	**357**	**365**	**372**
4300	**3.9**	**390**	**317**	**349**	**357**	**363**
4400	**3.9**	**390**	**317**	**349**	**357**	**363**
4500	**3.9**	**390**	**317**	**349**	**357**	**363**
4600	**3.8**	**380**	**310**	**341**	**349**	**354**
4700	**3.8**	**380**	**310**	**341**	**349**	**354**
4800	**3.7**	**370**	**304**	**333**	**340**	**346**
4900	**3.7**	**370**	**304**	**333**	**340**	**346**
5000	**3.7**	**370**	**304**	**333**	**340**	**346**
5100	**3.6**	**360**	**297**	**325**	**332**	**337**
5200	**3.6**	**360**	**297**	**325**	**332**	**337**
5300	**3.5**	**350**	**290**	**317**	**323**	**328**
5400	**3.5**	**350**	**290**	**317**	**323**	**328**
5500	**3.5**	**350**	**290**	**317**	**323**	**328**
5600	**3.5**	**350**	**290**	**317**	**323**	**328**
5700	**3.4**	**340**	**283**	**308**	**315**	**319**
5800	**3.4**	**340**	**283**	**308**	**315**	**319**
5900	**3.4**	**340**	**283**	**308**	**315**	**319**
6000	**3.4**	**340**	**283**	**308**	**315**	**319**

Column three shows how many taps can be on a 1″ dry line of that length and associated line loss. Column four shows the number of taps suggested for one 1″ mainline at the listed length and cfm for near perfect balance between sap and air flow at 2% slope. The worksheet will provide the outline for using the chart to identify the ideal combination for any given mainline in the sugarbush.

Using the mainline sizing guidelines worksheet (single mainlines)

Evaluation for using a 1" mainline:

Baseline information:

1. Target, how many taps on or anticipated on this line _______ taps
2. Length or estimated length of this line ________
3. Slope of the shallowest 50' of this line ___%
4. cfm of vacuum assigned to this line,

(see cfm assignment worksheet if necessary) ______

From the Guidelines for 1" line write the listed distance where for the first time the available CMF (in line 4 above) ____cfm shows up in the second column. _____ feet

Add the length of your line (from line 2 above) _____ feet

Total _____ feet

List the recommended number of taps from the guidelines at this distance and at your estimated slope from line 3 above _______ taps

If the suggested number of taps is less than our target number then the line is too small, more cfm need to be available or have less taps on the line. If the guideline number of taps is equal to or greater than our line count then this size of mainline is correct or possibly larger than necessary.

The tables and worksheet for 1" line are set up the same as the 3/4". Many maple producers have decided to only use one size of mainline in the sugarbush. This reduces the number of fittings and repair parts they need to have on hand as well as carry into the woods when line maintenance is being worked on. The extra volume in the 1" line also allows for less problems from sap obstructing the line when there are slope variations in the woods. However the bigger line does not allow for carelessness in installation or line maintenance. Sagging lines with variations of little more than the thickness of the line can create sap pooling that seriously restricts the movement of air through the lines. A good tight well graded system will assure better vacuum to the tap holes.

Using the mainline sizing guidelines worksheet (single mainlines)

Evaluation for using a 1" mainline:

Baseline information:

1. Target, how many taps on or anticipated on this line 600 taps
2. Length or estimated length of this line 1200
3. Slope of the shallowest 50' of this line 6 %
4. cfm of vacuum assigned to this line,
(see cfm assignment worksheet if necessary) 10 cfm

From the Guidelines for 1" line write the listed distance where for the first time the available CMF (in line 4 above) 10 cfm shows up in the second column. 300 feet

Add the length of your line (from line 2 above) 1200 feet

Total 1500 feet

List the recommended number of taps from the guidelines at this distance and at your estimated slope from line 3 above 523 taps

If the suggested number of taps is less than our target number then the line is too small, more cfm need to be available or have less taps on the line. If the guideline number of taps is equal to or greater than our line count then this size of mainline is correct or possibly larger than necessary.

In this example there are 600 taps on the mainline. It is 1200 feet long at a 6% slope and has 10cfm of vacuum pump capacity available to the line. On the 1″ Guidelines chart 10 cfm first show up at about 300 feet. From here we add the 1200 feet of this mainline to the total of 1500′ where the recommended number of the taps at 6% slope is 523 taps. This mainline is not of sufficient capacity to service this many taps. Sap during a good flow would obstruct the flow of leakage air from the tap to the vacuum pump and reduce the productivity of the vacuum system.

If 15 cfm of capacity were provided to this line the distance reading would start at 0. Move down the chart to 1200 feet and the recommended number of taps at 6% slope is 566. This is still below the guideline and indicates that this many taps should not be on this one line. Going to more than 15 cfm on the line would represent a significant loss of vacuum pump capacity to friction loss. 15 cfm at the beginning of the line and only 6.8 available after 1200 feet in a line not obstructed by sap shows over 50% of the pump capacity lost to friction. This does show that it could serve as a dry line. The Guidelines take into account both the space needed in the line for sap and the space needed to conduct the flow of leakage air.

Using the mainline sizing guidelines worksheet (single mainlines)

Evaluation for using a 1” mainline:

Baseline information:

1. Target, how many taps on or anticipated on this line 300 taps
2. Length or estimated length of this line 900
3. Slope of the shallowest 50' of this line 10 %
4. cfm of vacuum assigned to this line,
(see cfm assignment worksheet if necessary) 6 cfm

From the Guidelines for 1" line write the listed distance where for the first time the available CMF (in line 4 above) 6 cfm shows up in the second column. 1600 feet

Add the length of your line (from line 2 above) 900 feet

Total 2500 feet

List the recommended number of taps from the guidelines at this distance and at your estimated slope from line 3 above 447 taps

If the suggested number of taps is less than our target number then the line is too small, more cfm need to be available or have less taps on the line. If the guideline number of taps is equal to or greater than our line count then this size of mainline is correct or possibly larger than necessary.

For this example there are 300 taps on a 1″ mainline that is 900′ long with a consistent 10% slope. The line is connected to a vacuum pump capacity of 6 cfm. On the 1″ Guidelines chart 6 cfm first appears at about 1600′. To 1600′ add the length of this mainline (900′) for a total of 2500′. On the chart at 2500′ the recommended number of taps is 447 taps at a 10% slope. This number of taps is significantly more than the 300 taps available to the mainline. This would indicate that more taps could be added to this line if more are available. An evaluation could be done looking at using 3/4″ line. The capacity of the vacuum pump could be directed elsewhere in the system.
Note in the charts that more taps can be added when the slope of the mainline is greater. This simply reflects the fact that more sap can pass through a steeper line in the same amount of time. It is important to note that the steeper slope, in order to give this improved performance must be consistent for the whole length of the line. For example, if the slope of the line is 20% for 3/4s of its length then 10% for the remaining quarter, you should consider the capacity of the line to be at the shallower slope. In fact that slope variation may make the line function at even a lower level. Sap tends to back up and act as an obstruction to the movement of air when the pace of sap flow makes a change.

Using mainline sizing guidelines worksheet (wet and dry mainlines)
Evaluation for using a 1” mainline:

Baseline information:

1. Target, how many taps on or anticipated on this line ________ taps
2. Length or estimated length of this line _________
3. Slope of the shallowest 50' of this line ___%
4. cfm of vacuum assigned to this line,

(see cfm assignment worksheet if necessary) _______ cfm

From the Guidelines for 1" line write the listed distance where for the first time the available CMF (in line 4 above) _____cfm shows up in the second column. ______ feet

Add the length of your line (from line 2 above) ______ feet

Total ______ feet

List the recommended number of taps from the guidelines at this distance in the column capacity for taps on dryline ________ taps

If the suggested number of taps is less than our target number then the line is too small, more cfm need to be available or have less taps on the line. If the guideline number of taps is equal to or greater than our line count then this size of mainline is correct or possibly larger than necessary.

Wet line. Multiply the number of taps by .2 gallons per hour, (line 1 above) _______ taps x .2 = _________gallons of sap per hour during exceptional flow. Now check the water flow chart at your given slope (line 3 above) to see which wet line can carry that load per hour.

Water (gallons) per hour through plastic tubing at the designated slope.

Slope	2%	6%	10%	15%	20%
Gallons/hour ¾” line	195	336	444	549	640
Gallons/hour 1” line	330	630	840	1050	1215

This is the worksheet for a dry line/wet line system. The evaluation for the dry line part of the system is similar to following the worksheet for single main lines except the dry line column is used. To evaluate the wet line, multiply the number of taps by the .2 gallons of sap per hour per tap estimation for exceptional flow and compare the gallons of anticipated sap flow to the pipe flow capacity estimations at the bottom of the worksheet. These estimations are based on unobstructed pipe which is not usually the case in a maple tubing system. Fittings, elbows, air pockets and slope variations all act as obstructions to sap flow. You would not want to have a wet line operating near its rated full capacity. When the sap flow calculation for the wet line shows it nearly full, such as over 75%, moving to a larger line would be suggested. In a wet line, unless it is specifically oversize to add air flow capacity, its air flow is not calculated or added.

Using mainline sizing guidelines worksheet (wet and dry mainlines)

Evaluation for using a 1” mainline:

Baseline information:

1. Target, how many taps on or anticipated on this line 750 taps
2. Length or estimated length of this line 800
3. Slope of the shallowest 50' of this line 2 %
4. cfm of vacuum assigned to this line,

(see cfm assignment worksheet if necessary) 15 cfm

From the Guidelines for 1" line write the listed distance where for the first time the available CMF (in line 4 above) 15 cfm shows up in the second column. 0 feet

Add the length of your line (from line 2 above) 800 feet

Total 800 feet

List the recommended number of taps from the guidelines at this distance in the column capacity for taps on dryline 770 taps

If the suggested number of taps is less than our target number then the line is too small, more cfm need to be available or have less taps on the line. If the guideline number of taps is equal to or greater than our line count then this size of mainline is correct or possibly larger than necessary.

Wet line. Multiply the number of taps by .2 gallons per hour, (line 1 above) 750 taps x .2 = 150 gallons of sap per hour during exceptional flow. Now check the water flow chart at your given slope (line 3 above) to see which wet line can carry that load per hour.

Water (gallons) per hour through plastic tubing at the designated slope.

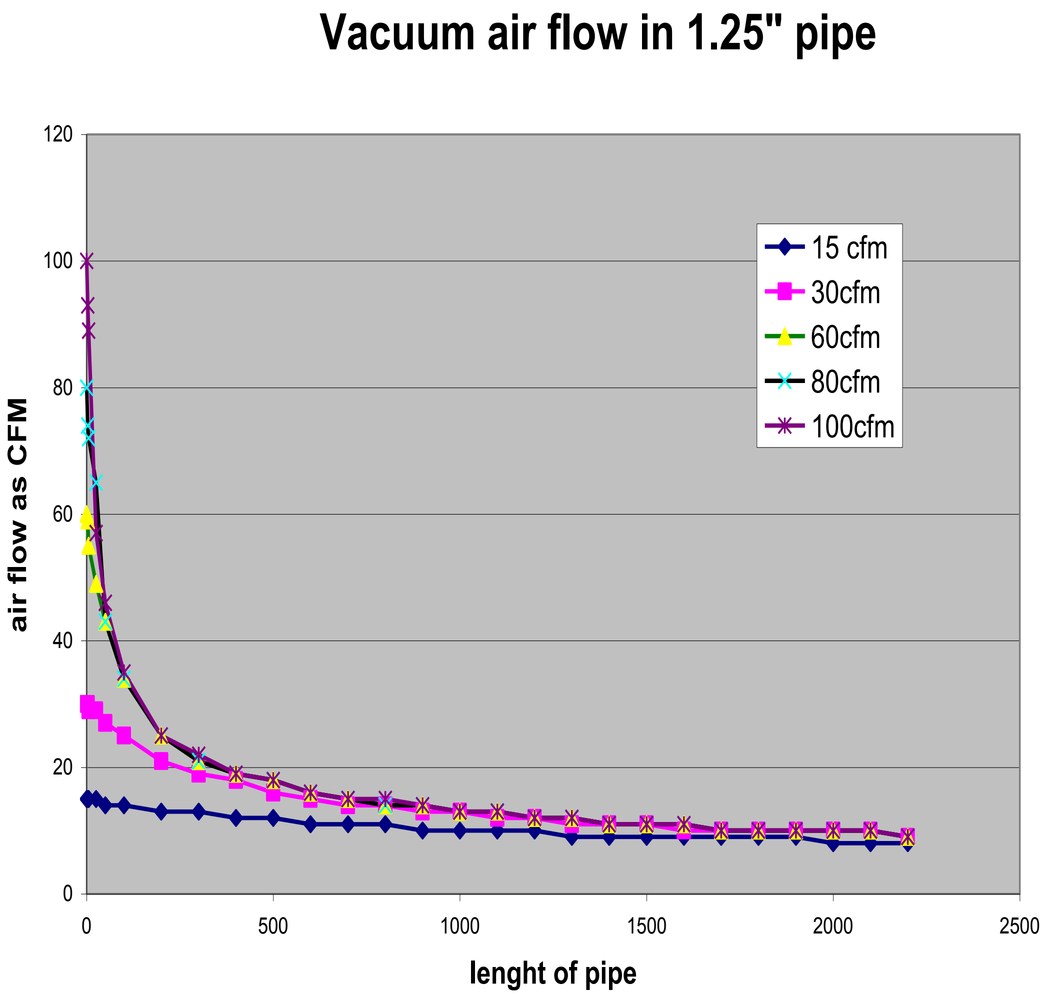
Slope	2%	6%	10%	15%	20%
Gallons/hour ¾” line	195	336	444	549	640
Gallons/hour 1” line	330	630	840	1050	1215

In this example there is 1″ dry line 800′ long with a 2% slope with 750 taps and a connection to 15 cfm of vacuum pump capacity. On the Guidelines chart for 1″ mainline the first place 15 cfm appears is at a distance of 0. Add the 800′ length of this mainline to the 0′ in the chart and read from the third column the capacity for taps on dry line at 770 taps. One inch dry line under these conditions has sufficient capacity. Then multiply the 750 taps times the .2 gallons of sap per hour estimate during excellent flow. Total sap flow is 150 gallons. From the chart at the bottom of the worksheet at 2% slope either the 3/4″ at 195 gallons per hour or the 1″ lines at 330 gallons per hour would be acceptable. During a good run the 3/4″ line could be over 75% full indicating that the 1″ line may be the better choice.

13.9 Mainline sizing guidelines and worksheets for 1¼" line

	1 1/4 in	1 1/4 in	1 1/4 in	1 1/4 in	1 1/4 in
Distance (feet)	15 cfm	30cfm	60cfm	80cfm	100cfm
0	15	30	60	80	100
3	15	30	59	74	93
5	15	29	55	72	89
25	15	29	49	65	57
50	14	27	43	43	46
100	14	25	34	34	35
200	13	21	25	25	25
300	13	19	21	21	22
400	12	18	19	19	19
500	12	16	18	18	18
600	11	15	16	16	16
700	11	14	15	15	15
800	11	14	14	14	15
900	10	13	14	14	14
1000	10	13	13	13	13
1100	10	12	13	13	13
1200	10	12	12	12	12
1300	9	11	12	12	12
1400	9	11	11	11	11
1500	9	11	11	11	11
1600	9	10	11	11	11
1700	9	10	10	10	10
1800	9	10	10	10	10
1900	9	10	10	10	10
2000	8	10	10	10	10
2100	8	10	10	10	10
2200	8	9	9	9	9
2300	8	9	9	9	9
2400	8	9	9	9	9
2500	8	9	9	9	9
2600	8	9	9	9	9
2700	8	8	9	9	9
2800	8	8	8	8	8
2900	7	8	8	8	8
3000	7	8	8	8	8
3100	7	8	8	8	8
3200	7	8	8	8	8
3300	7	8	8	8	8
3400	7	8	8	8	8
3500	7	7	8	8	8
3600	7	7	7	7	7
3700	7	7	7	7	7
3800	7	7	7	7	7
3900	7	7	7	7	7
3700	7	7	7	7	7
3800	7	7	7	7	7
3900	7	7	7	7	7
4000	7	7	7	7	7
4100	6	7	7	7	7
4200	6	7	7	7	7
4300	6	7	7	7	7
4400	6	7	7	7	7
4500	6	7	7	7	7
4600	6	7	7	7	7
4700	6	7	7	7	7
4800	6	7	7	7	7
4900	6	6	6	6	6
5000	6	6	6	6	6
5100	6	6	6	6	6
5200	6	6	6	6	6
5300	6	6	6	6	6
5400	6	6	6	6	6
5500	6	6	6	6	6
5600	6	6	6	6	6
5700	6	6	6	6	6
5800	6	6	6	6	6
5900	6	6	6	6	6
6000	6	6	6	6	6

This table shows the air flow capacity and line loss occurring when a one and one quarter inch line is connected to a vacuum pump with capacity of 15,30,60,80 and 100 cfm. Compared with the three quarter inch line and the one inch line it is easy to see that the larger the line the longer length is needed to totally equalize the air flow in the lines. It takes 2800 feet with inch and a quarter line before friction brings all the lines in the chart to the same flow level. As the lines in a tubing system get larger the vacuum pump capacity in cfm available to the line become more of a factor. As a result notice that more Guideline charts are involved, reflecting the greater variety of vacuum pump capacity.



This graph clearly shows the line loss occurring in a 1¼" mainline over distance when connected to at 15 cfm, 30 cfm, 60, cfm, 80 cfm and 100 cfm vacuum pump. It is easy to see that very little line loss occurs within this size of line when the applied vacuum capacity is 15 cfm while there is a huge line loss when higher pump capacities are applied. A chart like this makes it obvious that over sizing a vacuum pump without installing adequate mainline capacity to extend that capacity to the sugarbush is a waste of investment and operating costs to run the vacuum. Correct sizing is the best way to insure the most speedy financial return on a maple tubing system.

Guidelines for1¼" line at 2%, 6%, 10% and 15% slope, 15 cfm

			2% slope	6% slope	10% slope	15%slope
	1¼"	1¼"	1¼"	1¼"	1¼"	1¼"
	15cfm	15cfm	15cfm	15cfm	15cfm	15cfm
Distance (feet)	15cfm	Capacity for taps on dryline	Maximum number of taps	Maximum number of taps	Maximum number of taps	Maximum number of taps
0	**15**	**1500**	**1130**	**1228**	**1282**	**1282**
3	**15**	**1500**	**1130**	**1228**	**1282**	**1282**
5	**15**	**1500**	**1130**	**1228**	**1282**	**1282**
25	**14.9**	**1490**	**1125**	**1221**	**1275**	**1275**
50	**14.5**	**1450**	**1101**	**1194**	**1245**	**1245**
100	**14.2**	**1420**	**1083**	**1173**	**1223**	**1223**
200	**13.3**	**1330**	**1029**	**1111**	**1155**	**1155**
300	**12.8**	**1280**	**998**	**1075**	**1117**	**1117**
400	**12.3**	**1230**	**967**	**1040**	**1079**	**1079**
500	**11.8**	**1180**	**935**	**1003**	**1040**	**1040**
600	**11.5**	**1150**	**916**	**981**	**1017**	**1017**
700	**11.1**	**1110**	**890**	**952**	**985**	**985**
800	**10.8**	**1080**	**870**	**930**	**962**	**962**
900	**10.5**	**1050**	**850**	**907**	**938**	**938**
1000	**10.3**	**1030**	**837**	**892**	**922**	**922**
1100	**10**	**1000**	**817**	**870**	**898**	**898**
1200	**9.7**	**970**	**797**	**847**	**873**	**873**
1300	**9.5**	**950**	**783**	**832**	**857**	**857**
1400	**9.3**	**930**	**769**	**816**	**841**	**841**
1500	**9.1**	**910**	**755**	**801**	**824**	**824**
1600	**9**	**900**	**748**	**793**	**816**	**816**
1700	**8.9**	**890**	**741**	**785**	**808**	**808**
1800	**8.7**	**870**	**727**	**769**	**791**	**791**
1900	**8.6**	**860**	**720**	**762**	**783**	**783**
2000	**8.5**	**850**	**713**	**754**	**775**	**775**
2100	**8.3**	**830**	**699**	**738**	**758**	**758**
2200	**8.2**	**820**	**692**	**730**	**750**	**750**
2300	**8.1**	**810**	**685**	**722**	**741**	**741**
2400	**8**	**800**	**677**	**714**	**733**	**733**
2500	**7.9**	**790**	**670**	**706**	**724**	**724**
2600	**7.8**	**780**	**663**	**698**	**716**	**716**
2700	**7.7**	**770**	**656**	**690**	**708**	**708**
2800	**7.6**	**760**	**648**	**682**	**699**	**699**
2900	**7.5**	**750**	**641**	**674**	**691**	**691**

This is the guidelines chart for 1¼″ line when connected to a potential vacuum capacity of 15 cfm.

Guidelines for1¼" line at 2%, 6%, 10% and 15% slope, 15 cfm

			2% slope	6% slope	10% slope	15%slope
	1¼"	1¼"	1¼"	1¼"	1¼"	1¼"
	15cfm	15cfm	15cfm	15cfm	15cfm	15cfm
Distance (feet)	15cfm	Capacity for taps on dryline	Maximum number of taps	Maximum number of taps	Maximum number of taps	Maximum number of taps
3000	**7.4**	**740**	**634**	**666**	**682**	**682**
3100	**7.3**	**730**	**626**	**658**	**674**	**674**
3200	**7.2**	**720**	**619**	**650**	**665**	**665**
3300	**7.1**	**710**	**611**	**641**	**657**	**657**
3400	**7**	**700**	**604**	**633**	**648**	**648**
3500	**6.9**	**690**	**597**	**625**	**639**	**639**
3600	**6.8**	**680**	**589**	**617**	**631**	**631**
3700	**6.7**	**670**	**581**	**609**	**622**	**622**
3800	**6.7**	**670**	**581**	**609**	**622**	**622**
3900	**6.6**	**660**	**574**	**600**	**614**	**614**
4000	**6.6**	**660**	**574**	**600**	**614**	**614**
4100	**6.5**	**650**	**566**	**592**	**605**	**605**
4200	**6.5**	**650**	**566**	**592**	**605**	**605**
4300	**6.4**	**640**	**559**	**584**	**596**	**596**
4400	**6.4**	**640**	**559**	**584**	**596**	**596**
4500	**6.3**	**630**	**551**	**575**	**588**	**588**
4600	**6.3**	**630**	**551**	**575**	**588**	**588**
4700	**6.2**	**620**	**543**	**567**	**579**	**579**
4800	**6.2**	**620**	**543**	**567**	**579**	**579**
4900	**6.1**	**610**	**536**	**559**	**570**	**570**
5000	**6.1**	**610**	**536**	**559**	**570**	**570**
5100	**6**	**600**	**528**	**550**	**561**	**561**
5200	**6**	**600**	**528**	**550**	**561**	**561**
5300	**5.9**	**590**	**520**	**542**	**553**	**553**
5400	**5.9**	**590**	**520**	**542**	**553**	**553**
5500	**5.8**	**580**	**512**	**533**	**544**	**544**
5600	**5.8**	**580**	**512**	**533**	**544**	**544**
5700	**5.7**	**570**	**504**	**525**	**535**	**535**
5800	**5.7**	**570**	**504**	**525**	**535**	**535**
5900	**5.6**	**560**	**497**	**516**	**526**	**526**
6000	**5.6**	**560**	**497**	**516**	**526**	**526**

Guidelines for1¼" line at 2%, 6%, 10% and 15% slope, 30 cfm

			2% slope	6% slope	10% slope	15%slope
	1¼"	1¼"	1¼"	1¼"	1¼"	1¼"
	30cfm	30cfm	30cfm	30cfm	30cfm	30cfm
Distance (feet)	30cfm	Capacity for taps on dryline	Maximum number of taps	Maximum number of taps	Maximum number of taps	Maximum number of taps
0	30	**3000**	**1866**	**2115**	**2261**	**2366**
3	30	**3000**	**1866**	**2115**	**2261**	**2366**
5	29	**2900**	**1826**	**2063**	**2202**	**2302**
25	29	**2900**	**1826**	**2063**	**2202**	**2302**
50	27	**2700**	**1742**	**1955**	**2082**	**2173**
100	25	**2500**	**1652**	**1844**	**1958**	**2040**
200	21	**2100**	**1457**	**1611**	**1701**	**1763**
300	19	**1900**	**1353**	**1488**	**1566**	**1619**
400	18	**1800**	**1300**	**1425**	**1497**	**1546**
500	16	**1600**	**1188**	**1295**	**1355**	**1395**
600	15	**1500**	**1130**	**1228**	**1282**	**1319**
700	14.2	**1420**	**1083**	**1173**	**1223**	**1256**
800	13.9	**1390**	**1065**	**1152**	**1201**	**1233**
900	13.5	**1350**	**1041**	**1125**	**1171**	**1201**
1000	13	**1300**	**1010**	**1089**	**1133**	**1161**
1100	12.5	**1250**	**979**	**1054**	**1094**	**1121**
1200	12	**1200**	**948**	**1018**	**1056**	**1081**
1300	11.7	**1170**	**929**	**996**	**1032**	**1056**
1400	11.2	**1120**	**896**	**959**	**993**	**1015**
1500	10.8	**1080**	**870**	**930**	**962**	**982**
1600	10.5	**1050**	**850**	**907**	**938**	**957**
1700	10.3	**1030**	**837**	**892**	**922**	**941**
1800	10.1	**1010**	**824**	**877**	**906**	**924**
1900	9.9	**990**	**810**	**862**	**889**	**907**
2000	9.7	**970**	**797**	**847**	**873**	**890**
2100	9.6	**960**	**790**	**839**	**865**	**882**
2200	9.5	**950**	**783**	**832**	**857**	**873**
2300	9.3	**930**	**769**	**816**	**841**	**857**
2400	9.1	**910**	**755**	**801**	**824**	**840**
2500	8.9	**890**	**741**	**785**	**808**	**822**
2600	8.7	**870**	**727**	**769**	**791**	**805**
2700	8.5	**850**	**713**	**754**	**775**	**788**
2800	8.3	**830**	**699**	**738**	**758**	**771**
2900	8.2	**820**	**692**	**730**	**750**	**762**

This is the guidelines chart for 1¼" line when connected to a potential vacuum capacity of 30 cfm. Depending on the number of taps associated with the line, the system planner or maple producer may need to examine both guidelines to find the desired result.

Guidelines for1¼" line at 2%, 6%, 10% and 15% slope, 30 cfm

			2% slope	6% slope	10% slope	15%slope
	1¼"	1¼"	1¼"	1¼"	1¼"	1¼"
	30cfm	30cfm	30cfm	30cfm	30cfm	30cfm
Distance (feet)	30cfm	Capacity for taps on dryline	Maximum number of taps	Maximum number of taps	Maximum number of taps	Maximum number of taps
3000	8.1	**810**	**685**	**722**	**741**	**754**
3100	8	**800**	**677**	**714**	**733**	**745**
3200	7.9	**790**	**670**	**706**	**724**	**736**
3300	7.8	**780**	**663**	**698**	**716**	**728**
3400	7.6	**760**	**648**	**682**	**699**	**710**
3500	7.5	**750**	**641**	**674**	**691**	**701**
3600	7.5	**750**	**641**	**674**	**691**	**701**
3700	7.4	**740**	**634**	**666**	**682**	**693**
3800	7.4	**740**	**634**	**666**	**682**	**693**
3900	7.3	**730**	**626**	**658**	**674**	**684**
4000	7.3	**730**	**626**	**658**	**674**	**684**
4100	7.2	**720**	**619**	**650**	**665**	**675**
4200	7.2	**720**	**619**	**650**	**665**	**675**
4300	7.1	**710**	**611**	**641**	**657**	**666**
4400	7	**700**	**604**	**633**	**648**	**657**
4500	6.9	**690**	**597**	**625**	**639**	**649**
4600	6.8	**680**	**589**	**617**	**631**	**640**
4700	6.7	**670**	**581**	**609**	**622**	**631**
4800	6.6	**660**	**574**	**600**	**614**	**622**
4900	6.5	**650**	**566**	**592**	**605**	**613**
5000	6.5	**650**	**566**	**592**	**605**	**613**
5100	6.4	**640**	**559**	**584**	**596**	**604**
5200	6.4	**640**	**559**	**584**	**596**	**604**
5300	6.3	**630**	**551**	**575**	**588**	**595**
5400	6.3	**630**	**551**	**575**	**588**	**595**
5500	6.2	**620**	**543**	**567**	**579**	**586**
5600	6.2	**620**	**543**	**567**	**579**	**586**
5700	6.1	**610**	**536**	**559**	**570**	**577**
5800	6.1	**610**	**536**	**559**	**570**	**577**
5900	6	**600**	**528**	**550**	**561**	**568**
6000	6	**600**	**528**	**550**	**561**	**568**

Using the mainline sizing guidelines worksheet (single mainlines)

Evaluation for using a 1¼” mainline:

Baseline information:

1. Target, how many taps on or anticipated on this line _______ taps
2. Length or estimated length of this line ________
3. Slope of the shallowest 50' of this line ___%
4. cfm of vacuum assigned to this line,

(see cfm assignment worksheet if necessary) ______ cfm

From the Guidelines for **1¼**" line write the listed distance where for the first time the available CMF (in line 4 above) ____cfm shows up in the second column. _____ feet

Add the length of your line (from line 2 above) _____ feet

Total _____ feet

List the recommended number of taps from the guidelines at this distance and at your estimated slope from line 3 above _______ taps

If the suggested number of taps is less than our target number then the line is too small, more cfm need to be available or have less taps on the line. If the guideline number of taps is equal to or greater than our line count then this size of mainline is correct or possibly larger than necessary.

The above worksheet is a blank for system planners or maple producers to use in interpreting the Guidelines for 1¼″ mainlines

Using the mainline sizing guidelines worksheet (single mainlines)

Evaluation for using a 1¼” mainline:

Baseline information:

1. Target, how many taps on or anticipated on this line 950 taps
2. Length or estimated length of this line 2800
3. Slope of the shallowest 50' of this line 2%
4. cfm of vacuum assigned to this line,
(see cfm assignment worksheet if necessary) 11 cfm

From the Guidelines for **1¼**" line write the listed distance where for the first time the available CMF (in line 4 above) 11 cfm shows up in the second column. 700 feet

Add the length of your line (from line 2 above) 2800 feet

Total 3500 feet

List the recommended number of taps from the guidelines at this distance and at your estimated slope from line 3 above 597 taps

If the suggested number of taps is less than our target number then the line is too small, more cfm need to be available or have less taps on the line. If the guideline number of taps is equal to or greater than our line count then this size of mainline is correct or possibly larger than necessary.

In this example the mainline has 950 taps over a distance of 2800 feet of mainline. The line has a slope of 2% and has 11 cfm capacity from the vacuum pump. Locate in column 2 of the guidelines for 1¼” lines connected to a 15 cfm vacuum pump, where 11 cfm first appears which is about 700′. To this add the 2800′ of this mainline which comes to 3500′. At 3500′ on the chart note the recommended number of taps at 2% slope which is 597. This is very short of the target 950 taps so the system would not be sufficient to service this number of taps under these conditions. If 20 cfm of capacity were available to the line it would require looking at the guidelines chart created from the line loss chart utilizing a 30 cfm vacuum pump. In this case 20 cfm first appears at about 200 feet. To this add the 2800 feet of the current mainline for a total of 3000′ where the recommended tap number at 2% slope is 685. Still far short of the target. If all 30 cfm of the vacuum pump were directed to this line the count would start at 0 of the 30cfm chart and reading taken at 2800′ where 699 taps are recommended, again not sufficient. For this many taps a larger or more lines are needed. Trying to accomplish this by adding much more vacuum pump capacity would be in-efficient use of that vacuum equipment.

Using the mainline sizing guidelines worksheet (single mainlines)

Evaluation for using a 1¼" mainline:

Baseline information:

1. Target, how many taps on or anticipated on this line 675 taps
2. Length or estimated length of this line 1400
3. Slope of the shallowest 50' of this line 6%
4. cfm of vacuum assigned to this line,
(see cfm assignment worksheet if necessary) 12 cfm

From the Guidelines for **1¼**" line write the listed distance where for the first time the available CMF (in line 4 above) 12 cfm shows up in the second column. 1200 feet

Add the length of your line (from line 2 above) 1400 feet

Total 2600 feet

List the recommended number of taps from the guidelines at this distance and at your estimated slope from line 3 above 769 taps

If the suggested number of taps is less than our target number then the line is too small, more cfm need to be available or have less taps on the line. If the guideline number of taps is equal to or greater than our line count then this size of mainline is correct or possibly larger than necessary.

This example has 675 taps on a 1400′ line at 6% slope with vacuum pump capacity of 12 cfm available. On the guidelines for 1¼″ line 12 cfm is first listed at 1200′ on the 30 cfm source chart. To this add the 1400 main line length for a total of 2600′. At 2600′ in the column for 6% slope the recommendation is 769 taps indicating that the system has sufficient capacity for the target number of taps. Just for the comparison switch to the Guidelines for 1¼″ line with the 15 cfm source. In this case 12 cfm first shows up about 400 feet. Add the 1400′ of his mainline for the total of 1800′ where the recommendation at 6% slope is 769. This time the numbers came out exactly the same. Often when switching between the charts the number will be close but not exactly the same. The actual cfm at a given location on the chart may be a tenth of a cfm or so different changing the calculation of recommended taps.

Using mainline sizing guidelines worksheet (wet and dry mainlines)
Evaluation for using a 1¼" mainline:

Baseline information:

1. Target, how many taps on or anticipated on this line _______ taps
2. Length or estimated length of this line ________
3. Slope of the shallowest 50' of this line ___%
4. cfm of vacuum assigned to this line,

(see cfm assignment worksheet if necessary) ______ cfm

From the Guidelines for 1¼" line write the listed distance where for the first time the available CMF (in line 4 above) ____cfm shows up in the second column. _____ feet

Add the length of your line (from line 2 above) _____ feet

Total _____ feet

List the recommended number of taps from the guidelines at this distance in the column capacity for taps on dry line _______ taps

If the suggested number of taps is less than our target number then the line is too small, more cfm need to be available or have less taps on the line. If the guideline number of taps is equal to or greater than our line count then this size of mainline is correct or possibly larger than necessary.

Wet line. Multiply the number of taps by .2 gallons per hour, (line 1 above) ______ taps x .2 = ________gallons of sap per hour during exceptional flow. Now check the water flow chart at your given slope (line 3 above) to see which wet line can carry that load per hour.

Water (gallons) per hour through plastic tubing at the designated slope.

Slope	2%	6%	10%	15%	20%
Gallons/hour ¾" line	195	336	444	549	640
Gallons/hour 1" line	330	630	840	1050	1215
Gallons/hour 1¼" line	870	1,320	1,740	2,160	2,520

This worksheet is intended to be used to evaluate using an 1¼" dry line.

Using mainline sizing guidelines worksheet (wet and dry mainlines)
Evaluation for using a 1¼" mainline:

Baseline information:

1. Target, how many taps on or anticipated on this line 1010 taps
2. Length or estimated length of this line 1600
3. Slope of the shallowest 50' of this line 6 %
4. cfm of vacuum assigned to this line,

(see cfm assignment worksheet if necessary) 25 cfm

From the Guidelines for 1¼" line write the listed distance where for the first time the available CMF (in line 4 above) 25 cfm shows up in the second column. 100 feet

Add the length of your line (from line 2 above) 1600 feet

Total 1700 feet

List the recommended number of taps from the guidelines at this distance in the column capacity for taps on dryline 1030 taps

If the suggested number of taps is less than our target number then the line is too small, more cfm need to be available or have less taps on the line. If the guideline number of taps is equal to or greater than our line count then this size of mainline is correct or possibly larger than necessary.

Wet line. Multiply the number of taps by .2 gallons per hour, (line 1 above) 1010 taps x .2 = 202 gallons of sap per hour during exceptional flow. Now check the water flow chart at your given slope (line 3 above) to see which wet line can carry that load per hour.

Water (gallons) per hour through plastic tubing at the designated slope.

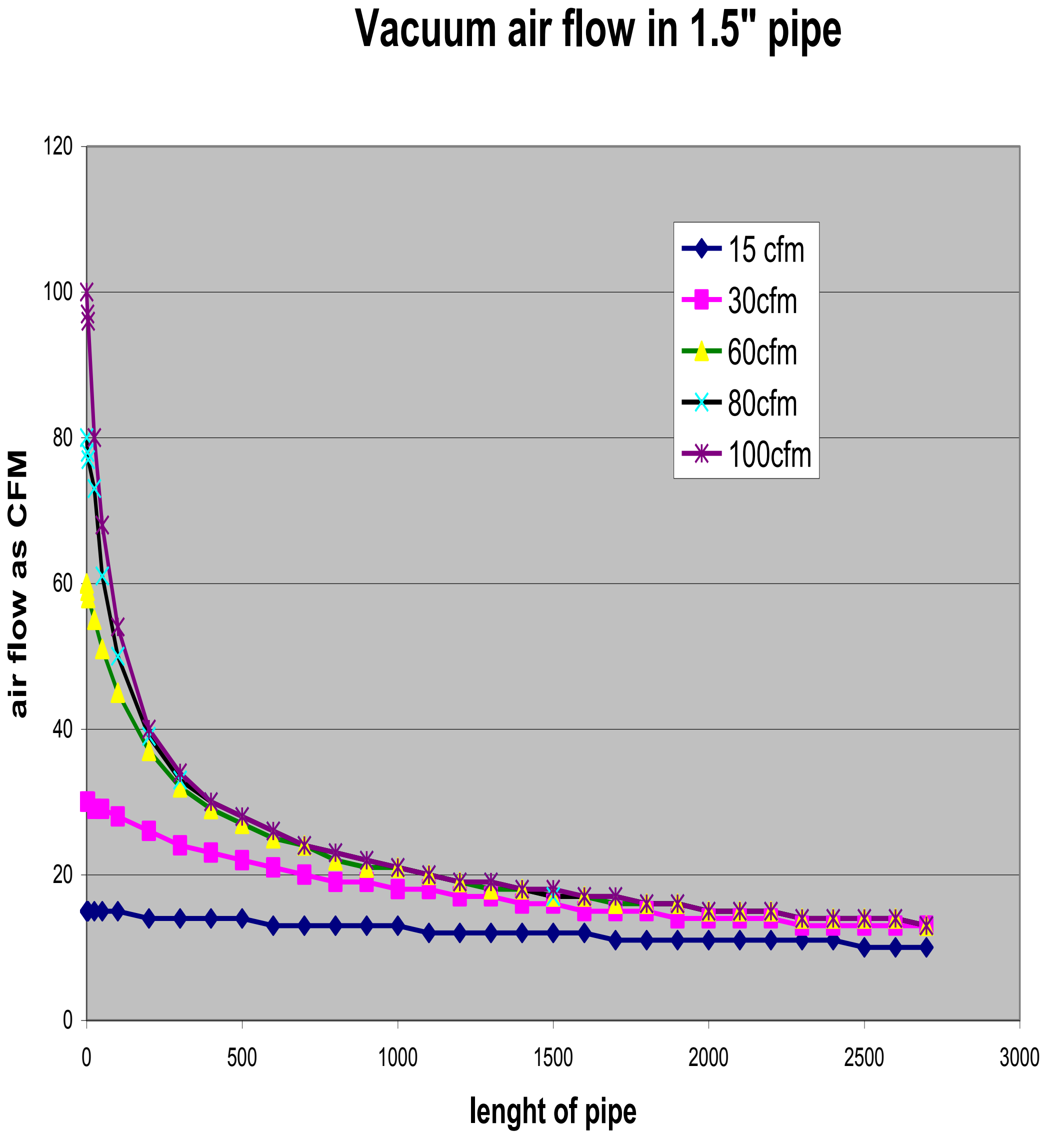
Slope	2%	6%	10%	15%	20%
Gallons/hour ¾" line	195	336	444	549	640
Gallons/hour 1" line	330	630	840	1050	1215
Gallons/hour 1¼" line	870	1,320	1,740	2,160	2,520

In this example there is a 1¼" dry line that is 1600' long with 1010 taps at 6% slope connected to a vacuum pump providing 25 cfm of capacity. For this use the guideline for 1¼" line developed from the 30 cfm line loss chart. Locate on that chart where 25 cfm first appears. 25 cfm first appears on the chart at 100'. To this add the 1600' length of this tubing, then at the 1700' distance read the third column, capacity for taps on dry line which is 1030 taps. This indicates that this size dry line has sufficient capacity to handle 1010 taps. Multiply 1010 taps times .2 gallons of sap per hour to get 202 gallons. At 6% slope 3/4" or larger would be acceptable. If the slope had been 2% the 3/4" line would be too small to handle the sap flow.

13.10 Mainline sizing guidelines and worksheets for 1½” line

	1 1/2 in	1 1/2 in	1 1/2 in	1 1/2 in	1 1/2 in
Distance (feet)	15 cfm	30cfm	60cfm	80cfm	100cfm
0	15	30	60	80	100
3	15	30	59	78	97
5	15	30	58	77	96
25	15	29	55	73	80
50	15	29	51	61	68
100	15	28	45	50	54
200	14	26	37	39	40
300	14	24	32	33	34
400	14	23	29	30	30
500	14	22	27	28	28
600	13	21	25	26	26
700	13	20	24	24	24
800	13	19	22	23	23
900	13	19	21	22	22
1000	13	18	21	21	21
1100	12	18	20	20	20
1200	12	17	19	19	19
1300	12	17	18	19	19
1400	12	16	18	18	18
1500	12	16	17	17	18
1600	12	15	17	17	17
1700	11	15	16	17	17
1800	11	15	16	16	16
1900	11	14	16	16	16
2000	11	14	15	15	15
2100	11	14	15	15	15
2200	11	14	15	15	15
2300	11	13	14	14	14
2400	11	13	14	14	14
2500	10	13	14	14	14
2600	10	13	14	14	14
2700	10	13	13	13	13
2800	10	12	13	13	13
2900	10	12	13	13	13
3000	10	12	13	13	13
3100	10	12	13	13	13
3200	10	12	12	12	12
3300	10	12	12	12	12
3400	10	11	12	12	12
3500	10	11	12	12	12
3600	9	11	12	12	12
3700	9	11	12	12	12
3800	9	11	11	11	11
3900	9	11	11	11	11
4000	9	11	11	11	11
4100	9	11	11	11	11
4200	9	11	11	11	11
4300	9	11	11	11	11
4400	9	11	11	11	11
4500	9	10	11	11	11
4600	9	10	10	10	10
4700	9	10	10	10	10
4800	9	10	10	10	10
4900	9	10	10	10	10
5000	9	10	10	10	10
5100	8	10	10	10	10
5200	8	10	10	10	10
5300	8	9	10	10	10
5400	8	9	10	10	10
5500	8	9	10	10	10
5600	8	9	10	10	10
5700	8	9	9	9	9
5800	8	9	9	9	9
5900	8	9	9	9	9
6000	8	9	9	9	9

With one and one half inch line, friction does not create perfectly matched air flow in a line connected to a 15,30,60,80 and 100 cfm pump even at a length of 6000 feet. However in the first 500’ of mainline very significant line loss occurs with the 60, 80 and 100 cfm vacuum pumps. This is particularly note worthy when this size of line is used to connect a vacuum pump to a releaser or distribution center. For example if you used inch and a half line to connect a 100 cfm pump to a releaser. You plumbed it up and over a walk way between the two pieces of equipment so the line was 25’ long. In just that 25’ length you would lose 20 cfm to friction. That is equal to the vacuum capacity for 2000 taps.



Inch and a half mainline is the smallest pipe where the flow capacity from the 100,80, 60, 30, and 15 cfm pumps does not completely equalize in the first 6000’ of mainline.

Guidelines for1½" line at 2%, 6%, 10% and 15% slope, 15 cfm

			2% slope	6% slope	10% slope	15%slope
	1½"	1½"	1½"	1½"	1½"	1½"
	15cfm	15cfm	15cfm	15cfm	15cfm	15cfm
Distance (feet)	15cfm	Capacity for taps on dryline	Maximum number of taps	Maximum number of taps	Maximum number of taps	Maximum number of taps
0	**15**	**1500**	**1225**	**1299**	**1342**	**1371**
3	**15**	**1500**	**1225**	**1299**	**1342**	**1371**
5	**15**	**1500**	**1225**	**1299**	**1342**	**1371**
25	**15**	**1500**	**1225**	**1299**	**1342**	**1371**
50	**14.8**	**1480**	**1211**	**1284**	**1326**	**1354**
100	**14.6**	**1460**	**1197**	**1269**	**1310**	**1338**
200	**14.4**	**1440**	**1184**	**1254**	**1293**	**1321**
300	**14.2**	**1420**	**1170**	**1239**	**1277**	**1304**
400	**14**	**1400**	**1156**	**1223**	**1261**	**1287**
500	**13.8**	**1380**	**1143**	**1208**	**1245**	**1270**
600	**13.5**	**1350**	**1122**	**1185**	**1220**	**1245**
700	**13.3**	**1330**	**1108**	**1169**	**1204**	**1228**
800	**13.1**	**1310**	**1094**	**1154**	**1187**	**1211**
900	**12.9**	**1290**	**1080**	**1138**	**1171**	**1193**
1000	**12.7**	**1270**	**1066**	**1123**	**1154**	**1176**
1100	**12.5**	**1250**	**1051**	**1107**	**1138**	**1159**
1200	**12.3**	**1230**	**1037**	**1091**	**1121**	**1142**
1300	**12.1**	**1210**	**1023**	**1076**	**1105**	**1125**
1400	**11.9**	**1190**	**1008**	**1060**	**1088**	**1107**
1500	**11.7**	**1170**	**994**	**1044**	**1071**	**1090**
1600	**11.6**	**1160**	**987**	**1036**	**1063**	**1081**
1700	**11.4**	**1140**	**972**	**1020**	**1046**	**1064**
1800	**11.3**	**1130**	**965**	**1012**	**1038**	**1055**
1900	**11.2**	**1120**	**957**	**1004**	**1029**	**1046**
2000	**11**	**1100**	**943**	**988**	**1012**	**1029**
2100	**10.8**	**1080**	**928**	**971**	**995**	**1011**
2200	**10.7**	**1070**	**920**	**963**	**987**	**1003**
2300	**10.6**	**1060**	**913**	**955**	**978**	**994**
2400	**10.5**	**1050**	**906**	**947**	**970**	**985**
2500	**10.4**	**1040**	**898**	**939**	**961**	**976**
2600	**10.3**	**1030**	**891**	**931**	**953**	**967**
2700	**10.2**	**1020**	**883**	**923**	**944**	**959**
2800	**10.1**	**1010**	**876**	**914**	**935**	**950**
2900	**10**	**1000**	**868**	**906**	**927**	**941**

The chart provides the guidelines for the number of taps on 1½″ mainlines connected to a vacuum pump with a 15 cfm capacity.

Guidelines for1½" line at 2%, 6%, 10% and 15% slope, 15 cfm

			2% slope	6% slope	10% slope	15%slope
	1½"	1½"	1½"	1½"	1½"	1½"
	15cfm	15cfm	15cfm	15cfm	15cfm	15cfm
Distance (feet)	15cfm	Capacity for taps on dryline	Maximum number of taps	Maximum number of taps	Maximum number of taps	Maximum number of taps
3000	**10**	**1000**	**868**	**906**	**927**	**941**
3100	**9.9**	**990**	**860**	**898**	**918**	**932**
3200	**9.8**	**980**	**853**	**890**	**910**	**923**
3300	**9.7**	**970**	**845**	**881**	**901**	**914**
3400	**9.6**	**960**	**838**	**873**	**892**	**905**
3500	**9.6**	**960**	**838**	**873**	**892**	**905**
3600	**9.5**	**950**	**830**	**865**	**884**	**897**
3700	**9.5**	**950**	**830**	**865**	**884**	**897**
3800	**9.4**	**940**	**822**	**857**	**875**	**888**
3900	**9.3**	**930**	**815**	**848**	**866**	**879**
4000	**9.3**	**930**	**815**	**848**	**866**	**879**
4100	**9.2**	**920**	**807**	**840**	**858**	**870**
4200	**9.1**	**910**	**799**	**832**	**849**	**861**
4300	**9.1**	**910**	**799**	**832**	**849**	**861**
4400	**9**	**900**	**791**	**823**	**840**	**852**
4500	**8.9**	**890**	**784**	**815**	**832**	**843**
4600	**8.8**	**880**	**776**	**806**	**823**	**834**
4700	**8.7**	**870**	**768**	**798**	**814**	**825**
4800	**8.6**	**860**	**760**	**790**	**805**	**816**
4900	**8.6**	**860**	**760**	**790**	**805**	**816**
5000	**8.5**	**850**	**752**	**781**	**797**	**807**
5100	**8.5**	**850**	**752**	**781**	**797**	**807**
5200	**8.4**	**840**	**745**	**773**	**788**	**798**
5300	**8.4**	**840**	**745**	**773**	**788**	**798**
5400	**8.3**	**830**	**737**	**764**	**779**	**789**
5500	**8.3**	**830**	**737**	**764**	**779**	**789**
5600	**8.2**	**820**	**729**	**756**	**770**	**780**
5700	**8.2**	**820**	**729**	**756**	**770**	**780**
5800	**8.1**	**810**	**721**	**747**	**761**	**771**
5900	**8.1**	**810**	**721**	**747**	**761**	**771**
6000	**8**	**800**	**713**	**739**	**752**	**762**

Guidelines for1½" line at 2%, 6%, 10% and 15% slope, 30 cfm

			2% slope	6% slope	10% slope	15%slope
	1½"	1½"	1½"	1½"	1½"	1½"
	30cfm	30cfm	30cfm	30cfm	30cfm	30cfm
Distance (feet)	30cfm	Capacity for taps on dryline	Maximum number of taps	Maximum number of taps	Maximum number of taps	Maximum number of taps
0	**30**	**3000**	**2107**	**2310**	**2437**	**2531**
3	**30**	**3000**	**2107**	**2310**	**2437**	**2531**
5	**30**	**3000**	**2107**	**2310**	**2437**	**2531**
25	**29**	**2900**	**2055**	**2249**	**2369**	**2459**
50	**29**	**2900**	**2055**	**2249**	**2369**	**2459**
100	**28**	**2800**	**2002**	**2187**	**2302**	**2386**
200	**26**	**2600**	**1893**	**2061**	**2164**	**2239**
300	**24**	**2400**	**1781**	**1931**	**2022**	**2088**
400	**23**	**2300**	**1723**	**1865**	**1950**	**2012**
500	**22**	**2200**	**1665**	**1798**	**1878**	**1935**
600	**21**	**2100**	**1605**	**1730**	**1804**	**1857**
700	**20**	**2000**	**1545**	**1661**	**1729**	**1778**
800	**19.5**	**1950**	**1514**	**1626**	**1692**	**1738**
900	**19**	**1900**	**1483**	**1591**	**1654**	**1698**
1000	**18.5**	**1850**	**1452**	**1556**	**1616**	**1658**
1100	**18**	**1800**	**1420**	**1520**	**1577**	**1618**
1200	**17.5**	**1750**	**1389**	**1484**	**1539**	**1577**
1300	**17**	**1700**	**1356**	**1448**	**1500**	**1537**
1400	**16.5**	**1650**	**1324**	**1411**	**1461**	**1496**
1500	**16**	**1600**	**1291**	**1374**	**1421**	**1454**
1600	**15.5**	**1550**	**1258**	**1337**	**1382**	**1413**
1700	**15.1**	**1510**	**1231**	**1307**	**1350**	**1380**
1800	**14.8**	**1480**	**1211**	**1284**	**1326**	**1354**
1900	**14.5**	**1450**	**1191**	**1262**	**1302**	**1329**
2000	**14.3**	**1430**	**1177**	**1246**	**1285**	**1312**
2100	**14**	**1400**	**1156**	**1223**	**1261**	**1287**
2200	**13.7**	**1370**	**1136**	**1200**	**1237**	**1262**
2300	**13.5**	**1350**	**1122**	**1185**	**1220**	**1245**
2400	**13.3**	**1330**	**1108**	**1169**	**1204**	**1228**
2500	**13.1**	**1310**	**1094**	**1154**	**1187**	**1211**
2600	**12.9**	**1290**	**1080**	**1138**	**1171**	**1193**
2700	**12.7**	**1270**	**1066**	**1123**	**1154**	**1176**
2800	**12.5**	**1250**	**1051**	**1107**	**1138**	**1159**
2900	**12.3**	**1230**	**1037**	**1091**	**1121**	**1142**

The chart provides the guidelines for the number of taps on 1½″ mainlines connected to a vacuum pump with a 30 cfm capacity.

Guidelines for1½" line at 2%, 6%, 10% and 15% slope, 30 cfm

			2% slope	6% slope	10% slope	15%slope
	1½"	1½"	1½"	1½"	1½"	1½"
	30cfm	30cfm	30cfm	30cfm	30cfm	30cfm
Distance (feet)	30cfm	Capacity for taps on dryline	Maximum number of taps	Maximum number of taps	Maximum number of taps	Maximum number of taps
3000	**12.1**	**1210**	**1023**	**1076**	**1105**	**1125**
3100	**12**	**1200**	**1016**	**1068**	**1096**	**1116**
3200	**11.8**	**1180**	**1001**	**1052**	**1080**	**1099**
3300	**11.7**	**1170**	**994**	**1044**	**1071**	**1090**
3400	**11.5**	**1150**	**979**	**1028**	**1054**	**1073**
3500	**11.4**	**1140**	**972**	**1020**	**1046**	**1064**
3600	**11.3**	**1130**	**965**	**1012**	**1038**	**1055**
3700	**11.2**	**1120**	**957**	**1004**	**1029**	**1046**
3800	**11.1**	**1110**	**950**	**996**	**1021**	**1038**
3900	**11**	**1100**	**943**	**988**	**1012**	**1029**
4000	**11**	**1100**	**943**	**988**	**1012**	**1029**
4100	**10.9**	**1090**	**935**	**979**	**1004**	**1020**
4200	**10.8**	**1080**	**928**	**971**	**995**	**1011**
4300	**10.7**	**1070**	**920**	**963**	**987**	**1003**
4400	**10.6**	**1060**	**913**	**955**	**978**	**994**
4500	**10.5**	**1050**	**906**	**947**	**970**	**985**
4600	**10.4**	**1040**	**898**	**939**	**961**	**976**
4700	**10.3**	**1030**	**891**	**931**	**953**	**967**
4800	**10.2**	**1020**	**883**	**923**	**944**	**959**
4900	**10**	**1000**	**868**	**906**	**927**	**941**
5000	**9.9**	**990**	**860**	**898**	**918**	**932**
5100	**9.7**	**970**	**845**	**881**	**901**	**914**
5200	**9.6**	**960**	**838**	**873**	**892**	**905**
5300	**9.5**	**950**	**830**	**865**	**884**	**897**
5400	**9.4**	**940**	**822**	**857**	**875**	**888**
5500	**9.3**	**930**	**815**	**848**	**866**	**879**
5600	**9.2**	**920**	**807**	**840**	**858**	**870**
5700	**9.1**	**910**	**799**	**832**	**849**	**861**
5800	**9**	**900**	**791**	**823**	**840**	**852**
5900	**8.9**	**890**	**784**	**815**	**832**	**843**
6000	**8.8**	**880**	**776**	**806**	**823**	**834**

Using the mainline sizing guidelines worksheet (single mainlines)

Evaluation for using a 1½" mainline:

Baseline information:

1. Target, how many taps on or anticipated on this line _______ taps
2. Length or estimated length of this line ________
3. Slope of the shallowest 50' of this line ___%
4. cfm of vacuum assigned to this line,

(see cfm assignment worksheet if necessary) ______ cfm

From the Guidelines for **1½**" line write the listed distance where for the first time the available CMF (in line 4 above) ____cfm shows up in the second column. _____ feet

Add the length of your line (from line 2 above) _____ feet

Total _____ feet

List the recommended number of taps from the guidelines at this distance and at your estimated slope from line 3 above _______ taps

If the suggested number of taps is less than our target number then the line is too small, more cfm need to be available or have less taps on the line. If the guideline number of taps is equal to or greater than our line count then this size of mainline is correct or possibly larger than necessary.

The worksheet for 1½" lines.

Using mainline sizing guidelines worksheet (wet and dry mainlines)
Evaluation for using a 1½" mainline:

Baseline information:

1. Target, how many taps on or anticipated on this line _______ taps
2. Length or estimated length of this line ________
3. Slope of the shallowest 50' of this line ___%
4. cfm of vacuum assigned to this line,

(see cfm assignment worksheet if necessary) ______ cfm

From the Guidelines for 1½" line write the listed distance where for the first time the available CMF (in line 4 above) ____cfm shows up in the second column. _____ feet

Add the length of your line (from line 2 above) _____ feet

Total _____ feet

List the recommended number of taps from the guidelines at this distance in the column capacity for taps on dryline _______ taps

If the suggested number of taps is less than our target number then the line is too small, more cfm need to be available or have less taps on the line. If the guideline number of taps is equal to or greater than our line count then this size of mainline is correct or possibly larger than necessary.

Wet line. Multiply the number of taps by .2 gallons per hour, (line 1 above) ______ taps x .2 = ________gallons of sap per hour during exceptional flow. Now check the water flow chart at your given slope (line 3 above) to see which wet line can carry that load per hour.

Water (gallons) per hour through plastic tubing at the designated slope.

Slope	2%	6%	10%	15%	20%
Gallons/hour ¾" line	195	336	444	549	640
Gallons/hour 1" line	330	630	840	1050	1215
Gallons/hour 1¼" line	870	1,320	1,740	2,160	2,520
Gallons/hour 1½"line	1,300	1,920	2,526	3,180	3,720

Using mainline sizing guidelines worksheet (wet and dry mainlines)
Evaluation for using a 1½” mainline:

Baseline information:

1. Target, how many taps on or anticipated on this line 1400 taps
2. Length or estimated length of this line 2200
3. Slope of the shallowest 50' of this line 2 %
4. cfm of vacuum assigned to this line,

(see cfm assignment worksheet if necessary) 28 cfm

From the Guidelines for 1½" line write the listed distance where for the first time the available CMF (in line 4 above) 28 cfm shows up in the second column. 100 feet

Add the length of your line (from line 2 above) 2200 feet

Total 2300 feet

List the recommended number of taps from the guidelines at this distance in the column capacity for taps on dryline 1350 taps

If the suggested number of taps is less than our target number then the line is too small, more cfm need to be available or have less taps on the line. If the guideline number of taps is equal to or greater than our line count then this size of mainline is correct or possibly larger than necessary.

Wet line. Multiply the number of taps by .2 gallons per hour, (line 1 above) 1400 taps x .2 = 280 gallons of sap per hour during exceptional flow. Now check the water flow chart at your given slope (line 3 above) to see which wet line can carry that load per hour.

Water (gallons) per hour through plastic tubing at the designated slope.

Slope	2%	6%	10%	15%	20%
Gallons/hour ¾” line	195	336	444	549	640
Gallons/hour 1” line	330	630	840	1050	1215
Gallons/hour 1¼” line	870	1,320	1,740	2,160	2,520
Gallons/hour 1½”line	1,300	1,920	2,526	3,180	3,720

In this example the dry line has 1400 taps at 2% slope with a length of 2200′ and connected to vacuum pump capacity of 28 cfm. For this use the guidelines chart created from the 30 cfm line loss chart. It first shows 28 cfm at 100′. To this add the 2200′ length of the dry line and read the dry line capacity column at 2300′. The Guidelines recommends only 1350 taps indicating that this is not sufficient dry line for this situation. Then check for size of wet line 1400 taps times .2 gallons of sap per hour = 280 gallons. At 2% slope 3/4″ line is too small and 1″ line would be about 85% full suggesting that going to the next larger line would be advisable.

Using mainline sizing guidelines worksheet (wet and dry mainlines)
Evaluation for using a 1½" mainline:

Baseline information:

1. Target, how many taps on or anticipated on this line <u>800</u> taps
2. Length or estimated length of this line <u>3200</u>
3. Slope of the shallowest 50' of this line <u>6</u> %
4. cfm of vacuum assigned to this line,

(see cfm assignment worksheet if necessary) 12 cfm

From the Guidelines for 1½" line write the listed distance where for the first time the available CMF (in line 4 above) <u>28 cfm</u> shows up in the second column. <u>1300</u> feet

Add the length of your line (from line 2 above) <u>3200</u> feet

Total <u>4500</u> feet

List the recommended number of taps from the guidelines at this distance in the column capacity for taps on dryline <u>890</u> taps

If the suggested number of taps is less than our target number then the line is too small, more cfm need to be available or have less taps on the line. If the guideline number of taps is equal to or greater than our line count then this size of mainline is correct or possibly larger than necessary.

Wet line. Multiply the number of taps by .2 gallons per hour, (line 1 above) <u>800</u> taps x .2 = <u>160</u> gallons of sap per hour during exceptional flow. Now check the water flow chart at your given slope (line 3 above) to see which wet line can carry that load per hour.

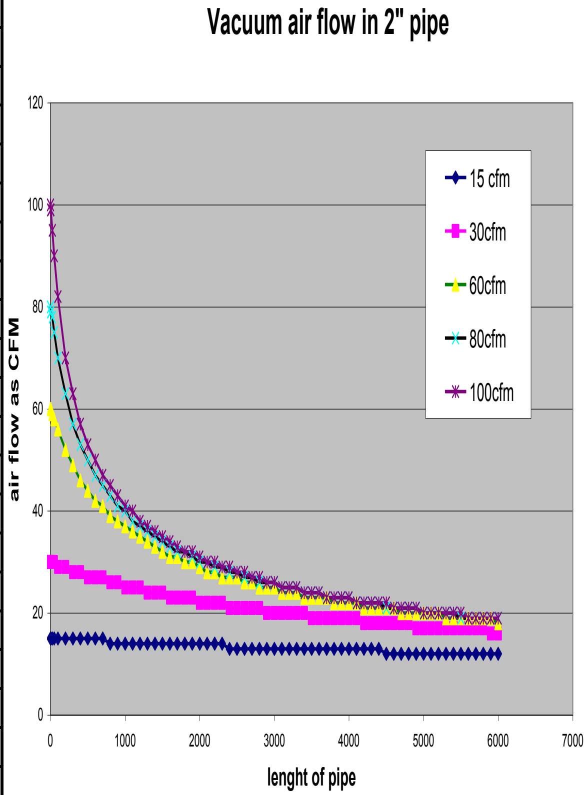
Water (gallons) per hour through plastic tubing at the designated slope.

Slope	2%	6%	10%	15%	20%
Gallons/hour ¾" line	195	336	444	549	640
Gallons/hour 1" line	330	630	840	1050	1215
Gallons/hour 1¼" line	870	1,320	1,740	2,160	2,520
Gallons/hour 1½"line	1,300	1,920	2,526	3,180	3,720

This example evaluates a 1½" dry line that is 3200′ long at 6% slope with 800 taps with 12 available cfm of vacuum pump capacity. If you check the guidelines chart created from the 30 cfm line loss chart, 12 cfm first appears at 3100′. Since this dry line is 3200′ that combination takes you off the chart. Using the guidelines chart that starts with 15 cfm, 12 cfm first appears at 1300′. Add this to the dry line length of 3200′ for a total of 4500′. At this distance note the number of taps recommended for a dry line in column 3. It recommends 890 taps. This indicates this size of dry line is sufficient and could even have more taps added. Multiply the 800 taps times .2 gallons of sap per hour estimated during a good flow for a total of 160 gallons. At 6% slope 3/4" or larger wet line would be sufficient. Note also the difference in vacuum pump efficiency with the previous example. In this case 12 cfm is servicing 800 taps or line loss is just 4 cfm or one third of the supplied capacity. In the previous example 28 cfm was used to service 1400 taps so line loss was 14 cfm or 50% or the provided capacity.

13.11 Mainline sizing guidelines and worksheets for 2” line

	2 in	2 in	2 in	2 in	2 in
Distance (feet)	15 cfm	30cfm	60cfm	80cfm	100cfm
0	15	30	60	80	100
3	15	30	60	79	99
5	15	30	60	79	99
25	15	30	59	78	95
50	15	30	58	75	90
100	15	29	56	70	82
200	15	29	52	63	70
300	15	28	49	57	63
400	15	28	46	53	57
500	15	27	44	50	53
600	15	27	42	47	50
700	15	27	41	45	47
800	14	26	39	43	45
900	14	26	38	41	43
1000	14	25	37	40	41
1100	14	25	36	38	40
1200	14	25	35	37	38
1300	14	24	34	36	37
1400	14	24	33	35	36
1500	14	24	32	34	35
1600	14	23	31	33	34
1700	14	23	31	32	33
1800	14	23	30	32	32
1900	14	23	30	31	32
2000	14	22	29	30	31
2100	14	22	28	30	30
2200	14	22	28	29	30
2300	14	22	27	29	29
2400	13	21	27	28	29
2500	13	21	27	28	28
2600	13	21	26	27	28
2700	13	21	26	27	27
2800	13	21	25	26	27
2900	13	20	25	26	26
3000	13	20	25	26	26
3100	13	20	24	25	25
3200	13	20	24	25	25
3300	13	20	24	25	25
3400	13	20	23	24	24
3500	13	19	23	24	24
3600	13	19	23	24	24
3600	13	19	23	24	24
3700	13	19	23	23	23
3800	13	19	22	23	23
3900	13	19	22	23	23
4000	13	19	22	23	23
4100	13	19	22	22	22
4200	13	18	21	22	22
4300	13	18	21	22	22
4400	13	18	21	22	22
4500	12	18	21	21	22
4600	12	18	21	21	21
4700	12	18	20	21	21
4800	12	18	20	21	21
4900	12	17	20	21	21
5000	12	17	20	20	20
5100	12	17	20	20	20
5200	12	17	20	20	20
5300	12	17	19	20	20
5400	12	17	19	20	20
5500	12	17	19	19	20
5600	12	17	19	19	19
5700	12	17	19	19	19
5800	12	17	19	19	19
5900	12	16	19	19	19
6000	12	16	18	19	19



Guidelines for2" line at 2%, 6%, 10% and 15% slope, 15 cfm

			2% slope	6% slope	10% slope	15%slope
	2"	2"	2"	2"	2"	2"
	15cfm	15cfm	15cfm	15cfm	15cfm	15cfm
Distance (feet)	15cfm	Capacity for taps on dryline	Maximum number of taps	Maximum number of taps	Maximum number of taps	Maximum number of taps
0	**15**	**1500**	**1347**	**1388**	**1413**	**1430**
3	**15**	**1500**	**1347**	**1388**	**1413**	**1430**
5	**15**	**1500**	**1347**	**1388**	**1413**	**1430**
25	**15**	**1500**	**1347**	**1388**	**1413**	**1430**
50	**15**	**1500**	**1347**	**1388**	**1413**	**1430**
100	**15**	**1500**	**1347**	**1388**	**1413**	**1430**
200	**15**	**1500**	**1347**	**1388**	**1413**	**1430**
300	**15**	**1500**	**1347**	**1388**	**1413**	**1430**
400	**14.9**	**1490**	**1339**	**1380**	**1404**	**1421**
500	**14.8**	**1480**	**1331**	**1371**	**1395**	**1412**
600	**14.7**	**1470**	**1322**	**1363**	**1386**	**1403**
700	**14.6**	**1460**	**1314**	**1354**	**1377**	**1394**
800	**14.5**	**1450**	**1306**	**1345**	**1368**	**1384**
900	**14.4**	**1440**	**1298**	**1337**	**1360**	**1375**
1000	**14.4**	**1440**	**1298**	**1337**	**1360**	**1375**
1100	**14.3**	**1430**	**1290**	**1328**	**1351**	**1366**
1200	**14.3**	**1430**	**1290**	**1328**	**1351**	**1366**
1300	**14.2**	**1420**	**1282**	**1320**	**1342**	**1357**
1400	**14.1**	**1410**	**1274**	**1311**	**1333**	**1348**
1500	**14.1**	**1410**	**1274**	**1311**	**1333**	**1348**
1600	**14**	**1400**	**1265**	**1302**	**1324**	**1339**
1700	**14**	**1400**	**1265**	**1302**	**1324**	**1339**
1800	**13.9**	**1390**	**1257**	**1294**	**1315**	**1330**
1900	**13.8**	**1380**	**1249**	**1285**	**1306**	**1321**
2000	**13.7**	**1370**	**1241**	**1276**	**1297**	**1311**
2100	**13.7**	**1370**	**1241**	**1276**	**1297**	**1311**
2200	**13.6**	**1360**	**1233**	**1268**	**1288**	**1302**
2300	**13.5**	**1350**	**1224**	**1259**	**1279**	**1293**
2400	**13.5**	**1350**	**1224**	**1259**	**1279**	**1293**
2500	**13.4**	**1340**	**1216**	**1250**	**1270**	**1284**
2600	**13.4**	**1340**	**1216**	**1250**	**1270**	**1284**
2700	**13.3**	**1330**	**1208**	**1241**	**1261**	**1275**
2800	**13.3**	**1330**	**1208**	**1241**	**1261**	**1275**
2900	**13.2**	**1320**	**1200**	**1233**	**1252**	**1265**

The chart provides the guidelines for the number of taps on 2″ mainlines connected to a vacuum pump with a 15 cfm capacity.

Guidelines for2" line at 2%, 6%, 10% and 15% slope, 15 cfm

			2% slope	6% slope	10% slope	15%slope
	2"	2"	2"	2"	2"	2"
	15cfm	15cfm	15cfm	15cfm	15cfm	15cfm
Distance (feet)	15cfm	Capacity for taps on dryline	Maximum number of taps	Maximum number of taps	Maximum number of taps	Maximum number of taps
3000	**13.2**	**1320**	**1200**	**1233**	**1252**	**1265**
3100	**13.1**	**1310**	**1191**	**1224**	**1243**	**1256**
3200	**13.1**	**1310**	**1191**	**1224**	**1243**	**1256**
3300	**13**	**1300**	**1183**	**1215**	**1234**	**1247**
3400	**13**	**1300**	**1183**	**1215**	**1234**	**1247**
3500	**12.9**	**1290**	**1175**	**1207**	**1225**	**1238**
3600	**12.9**	**1290**	**1175**	**1207**	**1225**	**1238**
3700	**12.8**	**1280**	**1166**	**1198**	**1216**	**1229**
3800	**12.8**	**1280**	**1166**	**1198**	**1216**	**1229**
3900	**12.7**	**1270**	**1158**	**1189**	**1207**	**1219**
4000	**12.7**	**1270**	**1158**	**1189**	**1207**	**1219**
4100	**12.6**	**1260**	**1150**	**1180**	**1198**	**1210**
4200	**12.6**	**1260**	**1150**	**1180**	**1198**	**1210**
4300	**12.5**	**1250**	**1141**	**1171**	**1189**	**1201**
4400	**12.5**	**1250**	**1141**	**1171**	**1189**	**1201**
4500	**12.4**	**1240**	**1133**	**1163**	**1180**	**1192**
4600	**12.4**	**1240**	**1133**	**1163**	**1180**	**1192**
4700	**12.4**	**1240**	**1133**	**1163**	**1180**	**1192**
4800	**12.3**	**1230**	**1125**	**1154**	**1171**	**1183**
4900	**12.3**	**1230**	**1125**	**1154**	**1171**	**1183**
5000	**12.2**	**1220**	**1116**	**1145**	**1162**	**1173**
5100	**12.2**	**1220**	**1116**	**1145**	**1162**	**1173**
5200	**12.1**	**1210**	**1108**	**1136**	**1153**	**1164**
5300	**12.1**	**1210**	**1108**	**1136**	**1153**	**1164**
5400	**12**	**1200**	**1100**	**1127**	**1144**	**1155**
5500	**12**	**1200**	**1100**	**1127**	**1144**	**1155**
5600	**11.9**	**1190**	**1091**	**1119**	**1135**	**1145**
5700	**11.9**	**1190**	**1091**	**1119**	**1135**	**1145**
5800	**11.8**	**1180**	**1083**	**1110**	**1125**	**1136**
5900	**11.8**	**1180**	**1083**	**1110**	**1125**	**1136**
6000	**11.8**	**1180**	**1083**	**1110**	**1125**	**1136**

Guidelines for 2" line at 2%, 6%, 10% and 15% slope, 30 cfm

			2% slope	6% slope	10% slope	15%slope
	2"	2"	2"	2"	2"	2"
	30cfm	30cfm	30cfm	30cfm	30cfm	30cfm
Distance (feet)	30cfm	Capacity for taps on dryline	Maximum number of taps	Maximum number of taps	Maximum number of taps	Maximum number of taps
0	30	3000	2310	2588	2673	2733
3	30	3000	2310	2588	2673	2733
5	30	3000	2310	2588	2673	2733
25	30	3000	2310	2588	2673	2733
50	29.8	2980	2298	2573	2657	2717
100	29.5	2950	2279	2550	2633	2692
200	29	2900	2249	2513	2593	2650
300	28.5	2850	2218	2475	2553	2608
400	28	2800	2187	2437	2512	2566
500	27.5	2750	2156	2399	2472	2524
600	27	2700	2124	2361	2431	2482
700	26.8	2680	2112	2345	2415	2465
800	26.2	2620	2073	2299	2366	2414
900	25.6	2560	2035	2253	2317	2363
1000	25.3	2530	2016	2229	2293	2337
1100	25	2500	1996	2206	2268	2312
1200	24.7	2470	1977	2183	2243	2286
1300	24.4	2440	1957	2159	2218	2260
1400	24	2400	1931	2128	2185	2226
1500	23.8	2380	1918	2112	2169	2209
1600	23.5	2350	1898	2088	2144	2183
1700	23.1	2310	1872	2057	2110	2148
1800	22.8	2280	1852	2033	2085	2122
1900	22.6	2260	1838	2017	2068	2105
2000	22.4	2240	1825	2001	2052	2088
2100	22.3	2230	1818	1993	2043	2079
2200	22	2200	1798	1969	2018	2053
2300	21.7	2170	1778	1945	1993	2027
2400	21.5	2150	1764	1929	1976	2009
2500	21.3	2130	1751	1912	1959	1992
2600	21.1	2110	1737	1896	1942	1974
2700	20.9	2090	1723	1880	1925	1957
2800	20.7	2070	1710	1864	1908	1939
2900	20.5	2050	1696	1848	1891	1922

The chart provides the guidelines for the number of taps on 2″ mainlines connected to a vacuum pump with a 30 cfm capacity.

Guidelines for 2" line at 2%, 6%, 10% and 15% slope, 30 cfm

			2% slope	6% slope	10% slope	15%slope
	2"	2"	2"	2"	2"	2"
	30cfm	30cfm	30cfm	30cfm	30cfm	30cfm
Distance (feet)	30cfm	Capacity for taps on dryline	Maximum number of taps	Maximum number of taps	Maximum number of taps	Maximum number of taps
3000	**20.3**	**2030**	**1682**	**1831**	**1874**	**1904**
3100	**20.1**	**2010**	**1668**	**1815**	**1857**	**1886**
3200	**20**	**2000**	**1661**	**1807**	**1848**	**1878**
3300	**19.8**	**1980**	**1647**	**1790**	**1831**	**1860**
3400	**19.6**	**1960**	**1633**	**1774**	**1814**	**1842**
3500	**19.5**	**1950**	**1626**	**1766**	**1806**	**1833**
3600	**19.4**	**1940**	**1619**	**1758**	**1797**	**1825**
3700	**19.3**	**1930**	**1612**	**1749**	**1788**	**1816**
3800	**19.1**	**1910**	**1598**	**1733**	**1771**	**1798**
3900	**18.9**	**1890**	**1584**	**1716**	**1754**	**1780**
4000	**18.7**	**1870**	**1570**	**1700**	**1737**	**1762**
4100	**18.5**	**1850**	**1556**	**1683**	**1719**	**1745**
4200	**18.3**	**1830**	**1541**	**1667**	**1702**	**1727**
4300	**18.1**	**1810**	**1527**	**1650**	**1685**	**1709**
4400	**18**	**1800**	**1520**	**1642**	**1676**	**1700**
4500	**17.9**	**1790**	**1513**	**1634**	**1667**	**1691**
4600	**17.7**	**1770**	**1498**	**1617**	**1650**	**1673**
4700	**17.6**	**1760**	**1491**	**1608**	**1641**	**1664**
4800	**17.5**	**1750**	**1484**	**1600**	**1633**	**1655**
4900	**17.4**	**1740**	**1477**	**1592**	**1624**	**1647**
5000	**17.3**	**1730**	**1469**	**1583**	**1615**	**1638**
5100	**17.2**	**1720**	**1462**	**1575**	**1607**	**1629**
5200	**17.1**	**1710**	**1455**	**1567**	**1598**	**1620**
5300	**17**	**1700**	**1448**	**1558**	**1589**	**1611**
5400	**16.9**	**1690**	**1440**	**1550**	**1580**	**1602**
5500	**16.8**	**1680**	**1433**	**1541**	**1572**	**1593**
5600	**16.7**	**1670**	**1426**	**1533**	**1563**	**1584**
5700	**16.6**	**1660**	**1418**	**1524**	**1554**	**1575**
5800	**16.5**	**1650**	**1411**	**1516**	**1545**	**1566**
5900	**16.4**	**1640**	**1404**	**1508**	**1537**	**1557**
6000	**16.3**	**1630**	**1396**	**1499**	**1528**	**1548**

Guidelines for2" line at 2%, 6%, 10% and 15% slope, 60 cfm

			2% slope	6% slope	10% slope	15%slope
	2"	2"	2"	2"	2"	2"
	60cfm	60cfm	60cfm	60cfm	60cfm	60cfm
Distance (feet)	60cfm	Capacity for taps on dryline	Maximum number of taps	Maximum number of taps	Maximum number of taps	Maximum number of taps
0	60	6000	4221	4588	4839	5032
3	60	6000	4221	4588	4839	5032
5	60	6000	4221	4588	4839	5032
25	59	5900	4169	4528	4773	4961
50	58	5800	4117	4467	4707	4889
100	56	5600	4010	4345	4573	4746
200	52	5200	3792	4096	4300	4454
300	49	4900	3624	3904	4091	4231
400	46	4600	3452	3709	3878	4005
500	44	4400	3335	3576	3734	3852
600	42	4200	3215	3442	3589	3697
700	41	4100	3155	3373	3515	3619
800	39	3900	3033	3236	3366	3462
900	38	3800	2971	3166	3291	3383
1000	37	3700	2908	3096	3216	3303
1100	36	3600	2845	3025	3140	3223
1200	35	3500	2781	2954	3063	3143
1300	34	3400	2716	2882	2986	3062
1400	33	3300	2651	2809	2909	2980
1500	32	3200	2586	2736	2830	2899
1600	31.5	3150	2552	2699	2791	2857
1700	31.1	3110	2526	2670	2760	2824
1800	30.8	3080	2506	2647	2736	2800
1900	30.4	3040	2479	2618	2704	2767
2000	29	2900	2384	2513	2593	2650
2100	28.5	2850	2350	2475	2553	2608
2200	28	2800	2315	2437	2512	2566
2300	27.5	2750	2281	2399	2472	2524
2400	27	2700	2246	2361	2431	2482
2500	26.6	2660	2218	2330	2399	2448
2600	26	2600	2176	2284	2350	2397
2700	25.7	2570	2155	2261	2325	2372
2800	25.5	2550	2141	2245	2309	2354
2900	25.3	2530	2126	2229	2293	2337

The chart provides the guidelines for the number of taps on 2″ mainlines connected to a vacuum pump with a 60 cfm capacity.

Guidelines for2" line at 2%, 6%, 10% and 15% slope, 60 cfm

			2% slope	6% slope	10% slope	15%slope
	2"	2"	2"	2"	2"	2"
	60cfm	60cfm	60cfm	60cfm	60cfm	60cfm
Distance (feet)	60cfm	Capacity for taps on dryline	Maximum number of taps	Maximum number of taps	Maximum number of taps	Maximum number of taps
3000	**25**	**2500**	**2105**	**2206**	**2268**	**2312**
3100	**24.5**	**2450**	**2069**	**2167**	**2227**	**2269**
3200	**24**	**2400**	**2033**	**2128**	**2185**	**2226**
3300	**23.5**	**2350**	**1997**	**2088**	**2144**	**2183**
3400	**23.2**	**2320**	**1975**	**2064**	**2119**	**2157**
3500	**23.1**	**2310**	**1968**	**2057**	**2110**	**2148**
3600	**23**	**2300**	**1961**	**2049**	**2102**	**2140**
3700	**22.8**	**2280**	**1946**	**2033**	**2085**	**2122**
3800	**22.6**	**2260**	**1931**	**2017**	**2068**	**2105**
3900	**22.3**	**2230**	**1909**	**1993**	**2043**	**2079**
4000	**22**	**2200**	**1887**	**1969**	**2018**	**2053**
4100	**21.7**	**2170**	**1865**	**1945**	**1993**	**2027**
4200	**21.5**	**2150**	**1850**	**1929**	**1976**	**2009**
4300	**21.3**	**2130**	**1835**	**1912**	**1959**	**1992**
4400	**21**	**2100**	**1813**	**1888**	**1934**	**1965**
4500	**20.9**	**2090**	**1805**	**1880**	**1925**	**1957**
4600	**20.7**	**2070**	**1790**	**1864**	**1908**	**1939**
4700	**20.5**	**2050**	**1775**	**1848**	**1891**	**1922**
4800	**20.4**	**2040**	**1768**	**1839**	**1883**	**1913**
4900	**20.3**	**2030**	**1760**	**1831**	**1874**	**1904**
5000	**20.1**	**2010**	**1745**	**1815**	**1857**	**1886**
5100	**19.9**	**1990**	**1730**	**1799**	**1840**	**1869**
5200	**19.7**	**1970**	**1715**	**1782**	**1823**	**1851**
5300	**19.5**	**1950**	**1700**	**1766**	**1806**	**1833**
5400	**19.3**	**1930**	**1684**	**1749**	**1788**	**1816**
5500	**19.2**	**1920**	**1677**	**1741**	**1780**	**1807**
5600	**19.1**	**1910**	**1669**	**1733**	**1771**	**1798**
5700	**19**	**1900**	**1661**	**1725**	**1763**	**1789**
5800	**18.8**	**1880**	**1646**	**1708**	**1745**	**1771**
5900	**18.6**	**1860**	**1631**	**1692**	**1728**	**1754**
6000	**18.4**	**1840**	**1615**	**1675**	**1711**	**1736**

Using the mainline sizing guidelines worksheet (single mainlines)

Evaluation for using a 2” mainline:

Baseline information:

1. Target, how many taps on or anticipated on this line _______ taps
2. Length or estimated length of this line ________
3. Slope of the shallowest 50' of this line ___%
4. cfm of vacuum assigned to this line,
(see cfm assignment worksheet if necessary) ______ cfm

From the Guidelines for **2**" line write the listed distance where for the first time the available CMF (in line 4 above) ____cfm shows up in the second column. _____ feet

Add the length of your line (from line 2 above) _____ feet

Total _____ feet

List the recommended number of taps from the guidelines at this distance and at your estimated slope from line 3 above _______ taps

If the suggested number of taps is less than our target number then the line is too small, more cfm need to be available or have less taps on the line. If the guideline number of taps is equal to or greater than our line count then this size of mainline is correct or possibly larger than necessary.

For 2” line, note that three separate guideline charts were created. One each from the 15 cfm, 30 cfm and 60 cfm line loss charts. This is to provide a broad source of information for the various ways this size of line may be used for larger sugar bush systems, for distance transfer of vacuum or for short distance transfer of relatively high vacuum. You will likely need to search between charts to find which provides you with the complete data to do a particular evaluation

Using mainline sizing guidelines worksheet (wet and dry mainlines)

Evaluation for using a 2” mainline:

Baseline information:

1. Target, how many taps on or anticipated on this line _______ taps
2. Length or estimated length of this line ________
3. Slope of the shallowest 50' of this line ___%
4. cfm of vacuum assigned to this line,

(see cfm assignment worksheet if necessary) ______ cfm

From the Guidelines for 2" line write the listed distance where for the first time the available CMF (in line 4 above) ____cfm shows up in the second column. _____ feet

Add the length of your line (from line 2 above) _____ feet

Total _____ feet

List the recommended number of taps from the guidelines at this distance in the column capacity for taps on dryline _______ taps

If the suggested number of taps is less than our target number then the line is too small, more cfm need to be available or have less taps on the line. If the guideline number of taps is equal to or greater than our line count then this size of mainline is correct or possibly larger than necessary.

Wet line. Multiply the number of taps by .2 gallons per hour, (line 1 above) ______ taps x .2 = ________gallons of sap per hour during exceptional flow. Now check the water flow chart at your given slope (line 3 above) to see which wet line can carry that load per hour

Water (gallons) per hour through plastic tubing at the designated slope.

Slope	2%	6%	10%	15%	20%
Gallons/hour ¾” line	195	336	444	549	640
Gallons/hour 1” line	330	630	840	1050	1215
Gallons/hour 1¼” line	870	1,320	1,740	2,160	2,520
Gallons/hour 1½”line	1,300	1,920	2,526	3,180	3,720
Gallons/hour 2” line	2,618	3,720	4,860	6,120	7,140

Using mainline sizing guidelines worksheet (wet and dry mainlines)
Evaluation for using a 2” mainline:

Baseline information:

1. Target, how many taps on or anticipated on this line 2500 taps
2. Length or estimated length of this line 3500
3. Slope of the shallowest 50' of this line 2 %
4. cfm of vacuum assigned to this line,

(see cfm assignment worksheet if necessary) 40 cfm

From the Guidelines for 2" line write the listed distance where for the first time the available CMF (in line 4 above) 40 cfm shows up in the second column. 700 feet

Add the length of your line (from line 2 above) 3500 feet

Total 4200 feet

List the recommended number of taps from the guidelines at this distance in the column capacity for taps on dryline 2150 taps

If the suggested number of taps is less than our target number then the line is too small, more cfm need to be available or have less taps on the line. If the guideline number of taps is equal to or greater than our line count then this size of mainline is correct or possibly larger than necessary.

Wet line. Multiply the number of taps by .2 gallons per hour, (line 1 above) 2500 taps x .2 = 500 gallons of sap per hour during exceptional flow. Now check the water flow chart at your given slope (line 3 above) to see which wet line can carry that load per hour.

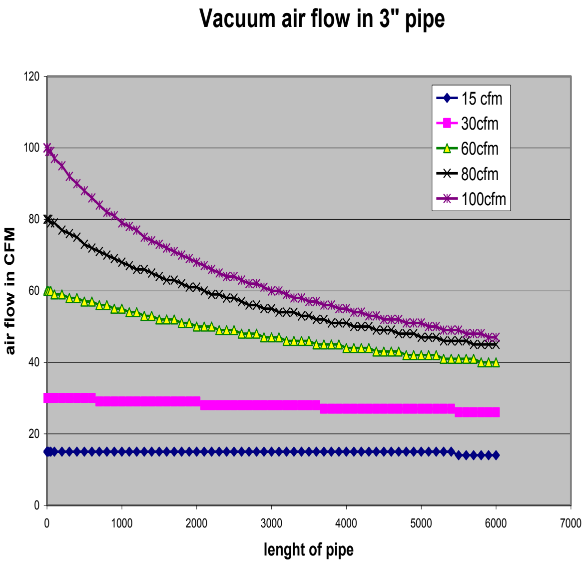
Water (gallons) per hour through plastic tubing at the designated slope.

Slope	2%	6%	10%	15%	20%
Gallons/hour ¾” line	195	336	444	549	640
Gallons/hour 1” line	330	630	840	1050	1215
Gallons/hour 1¼” line	870	1,320	1,740	2,160	2,520
Gallons/hour 1½”line	1,300	1,920	2,526	3,180	3,720
Gallons/hour 2” line	2,618	3,720	4,860	6,120	7,140

For this example the dry line is 3500′ long with 2500 taps at 2% slope with vacuum pump capacity of 40 cfm. Look at the guidelines created from the 60 cfm line loss chart. 40 cfm first appears at about 700′, add the 3500′ to that for a total of 4200′. At 4200′ read the dry line column which shows capacity for 2150 taps. This line is not sufficient for this number of taps. Even if all 60 cfm were provided this line it would still be too small. As far as sap flow, the 500 gallons of sap per hour would indicate that the wet line would need to be at least 1¼″ to handle the flow for 2500 taps.

13.12 Mainline sizing guidelines and worksheets for 3” line

	3 in	3 in	3 in	3 in	3 in
Distance (feet)	15 cfm	30cfm	60cfm	80cfm	100cfm
0	15	30	60	80	100
3	15	30	60	80	100
5	15	30	60	80	100
25	15	30	60	80	99
50	15	30	60	79	99
100	15	30	59	79	97
200	15	30	59	77	95
300	15	30	58	76	92
400	15	30	58	75	90
500	15	30	57	73	88
600	15	30	57	72	86
700	15	29	56	71	84
800	15	29	56	70	82
900	15	29	55	69	81
1000	15	29	55	68	79
1100	15	29	54	67	78
1200	15	29	54	66	77
1300	15	29	53	66	75
1400	15	29	53	65	74
1500	15	29	52	64	73
1600	15	29	52	63	72
1700	15	29	52	63	71
1800	15	29	51	62	70
1900	15	29	51	61	69
2000	15	29	50	61	68
2100	15	28	50	60	67
2200	15	28	50	59	66
2300	15	28	49	59	65
2400	15	28	49	58	64
2500	15	28	49	58	64
2600	15	28	48	57	63
2700	15	28	48	56	62
2800	15	28	48	56	62
2900	15	28	47	55	61
3000	15	28	47	55	60
3100	15	28	47	54	60
3200	15	28	46	54	59
3300	15	28	46	54	58
3400	15	28	46	53	58
3500	15	28	46	53	57
3600	15	28	45	52	57
3600	15	28	45	52	57
3700	15	27	45	52	56
3800	15	27	45	51	56
3900	15	27	45	51	55
4000	15	27	44	51	55
4100	15	27	44	50	54
4200	15	27	44	50	54
4300	15	27	44	50	53
4400	15	27	43	49	53
4500	15	27	43	49	52
4600	15	27	43	49	52
4700	15	27	43	48	52
4800	15	27	42	48	51
4900	15	27	42	48	51
5000	15	27	42	47	51
5100	15	27	42	47	50
5200	15	27	42	47	50
5300	15	27	41	46	49
5400	15	27	41	46	49
5500	14	26	41	46	49
5600	14	26	41	46	48
5700	14	26	41	45	48
5800	14	26	40	45	48
5900	14	26	40	45	47
6000	14	26	40	45	47



Since no liquid flow data in a 3” pipe is available no guidelines have been created for this size of mainline. However by multiplying the cfm by 100 taps per cfm the line loss chart can be used to evaluate it’s performance as a dry line.

Three inch or larger lines are not common in maple production in New York though they are used by some larger maple producers. To reduce the line loss due to running a smaller than adequate line between the vacuum pump and the releaser many midsized maple producers would conserve vacuum capacity by using a bigger sized line for this important application.

Evaluating and Assigning Vacuum Pump Capacity to the Sap Collection System

Vacuum pump basic information:

1. Make of pump ___________________________
2. Electric or gas? ________ Horse power _______
3. Cubic feet per minute rating at 15” of vacuum ___________cfm
4. Inches of vacuum as which you intend to operate this pump ________inches of vacuum
5. From the vacuum pump capacity loss as vacuum level increases chart, what is the estimated cfm output of your vacuum pump at your intended operation vacuum level? ________cfm
6. Pipe size between the vacuum pump and the releaser. _____
7. Length of pipe between the vacuum pump and the releaser. _______
8. From the line loss chart for this size of pipe, how many cfm are lost between the pump and the releaser? _________
9. Subtract line 8 from line 5. This is the true cfm available to the collection system at the releaser _______cfm
10. At the releaser list the pipe sizes or tap numbers of each pipe in one of the tables below.
11. Do not count or add in wet lines only dry lines and dual purpose lines.

Assigning cfm to mainlines based on the number of taps

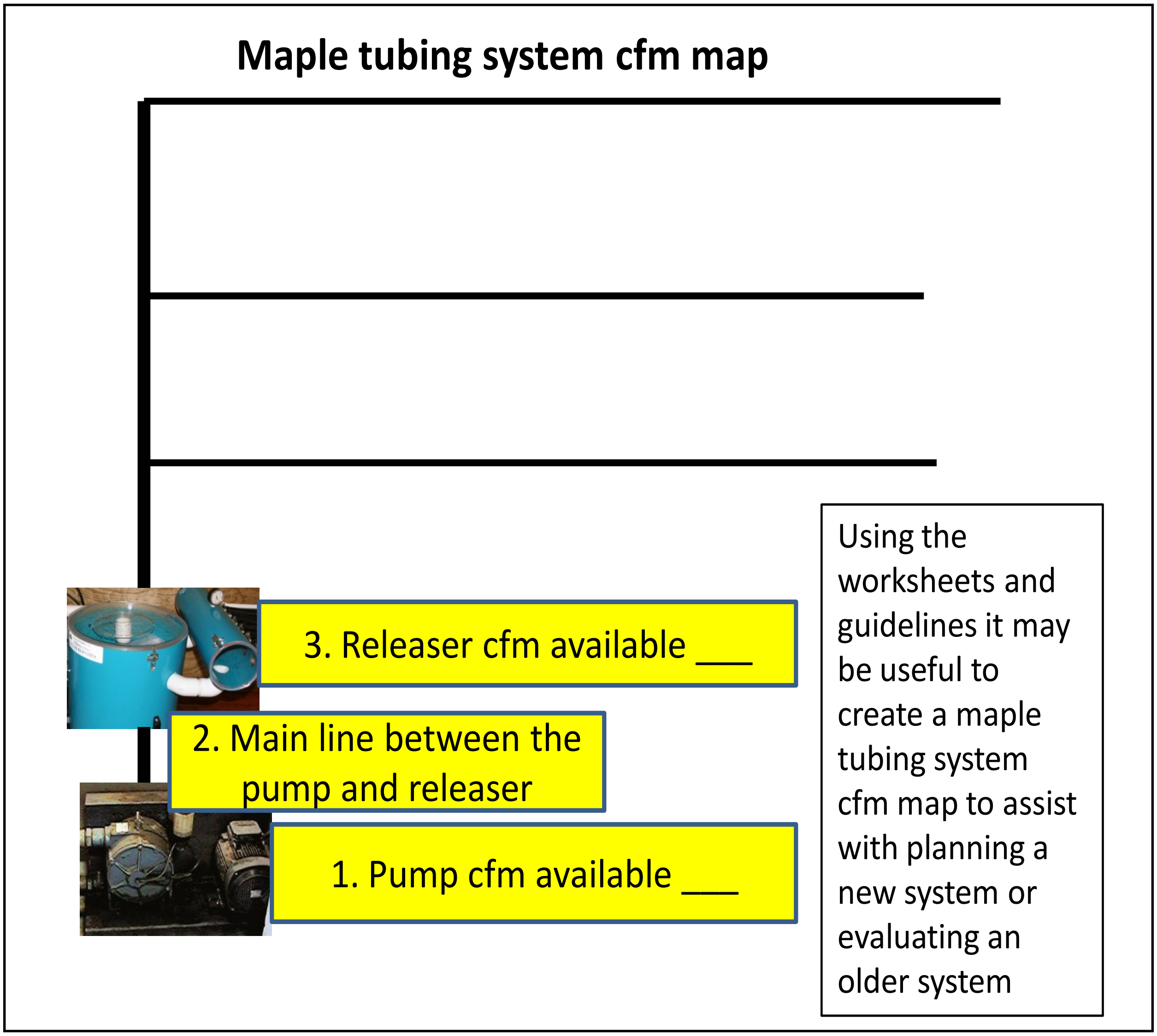
Line number	**# of taps on this line**	**Total system taps**	**% of the total system (# of taps on this line/total taps)**	**cfm assigned to this mainline (% of system x total cfm at the releaser)**
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

Assigning cfm to mainlines based on size of lines

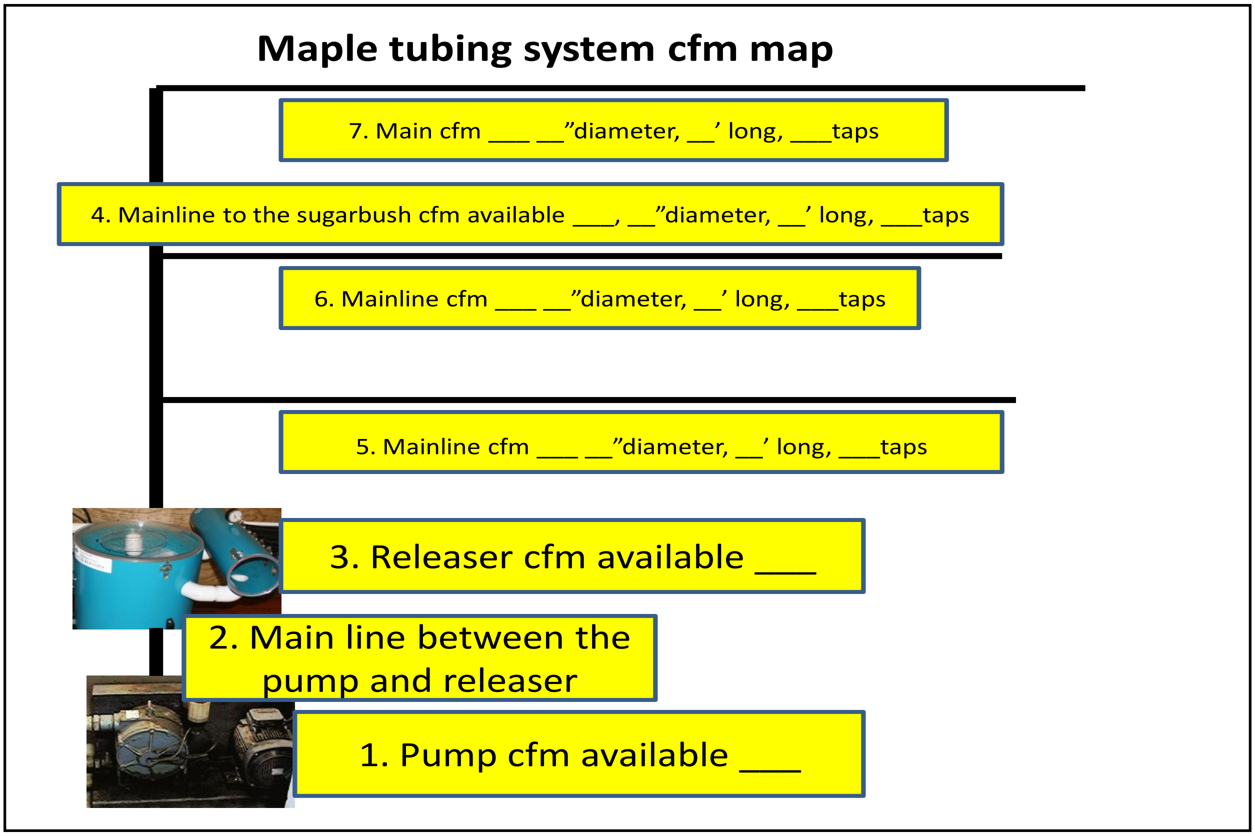
Size of lines method	**Number of lines**	**Area of single lines**	**Total area of this size of lines (# of lines x area)**	**% of total area (Total area of this sized of line/Total area of all lines)**	**% for each line (% total area/number of this sized line)**	**cfm assigned to this mainline (% for each line x total cfm at the realeaser**
3/4" lines		0.44				
1" lines		0.78				
1¼" lines		1.23				
1½" lines		1.77				
2" lines		3.14				
3" lines		7.07				
		Total area of all lines				

13.13 Mapping the cfm capacity in a maple tubing system.

Up to this point the examples have looked at fairly simple tubing system layouts. For larger systems it may be useful to approach the planning or evaluation by working through a tubing system map. Many producers have maps of their tubing system, others will need to create such a map. Some have used GPS to create maps that would work very well for this purpose. The map allows you to start at the vacuum pump and calculate capacity loss to the releaser and out through the mainline system. At each branch estimating the available vacuum capacity in cfm and suggested tap numbers to eventually include the whole system using the charts and worksheets presented this far in this notebook. At each change in the system a determination is made for the next level of vacuum capacity distribution. This is recorded on the map in terms of available cfm, suggested number of taps and if applicable the current number of taps. Recording the tubing diameters and length can also help complete the maps usefulness. The illustration below is a very simple start on such a map.



Using the worksheets and guidelines it may be useful to create a maple tubing system cfm map to assist with planning a new system or evaluating an older system

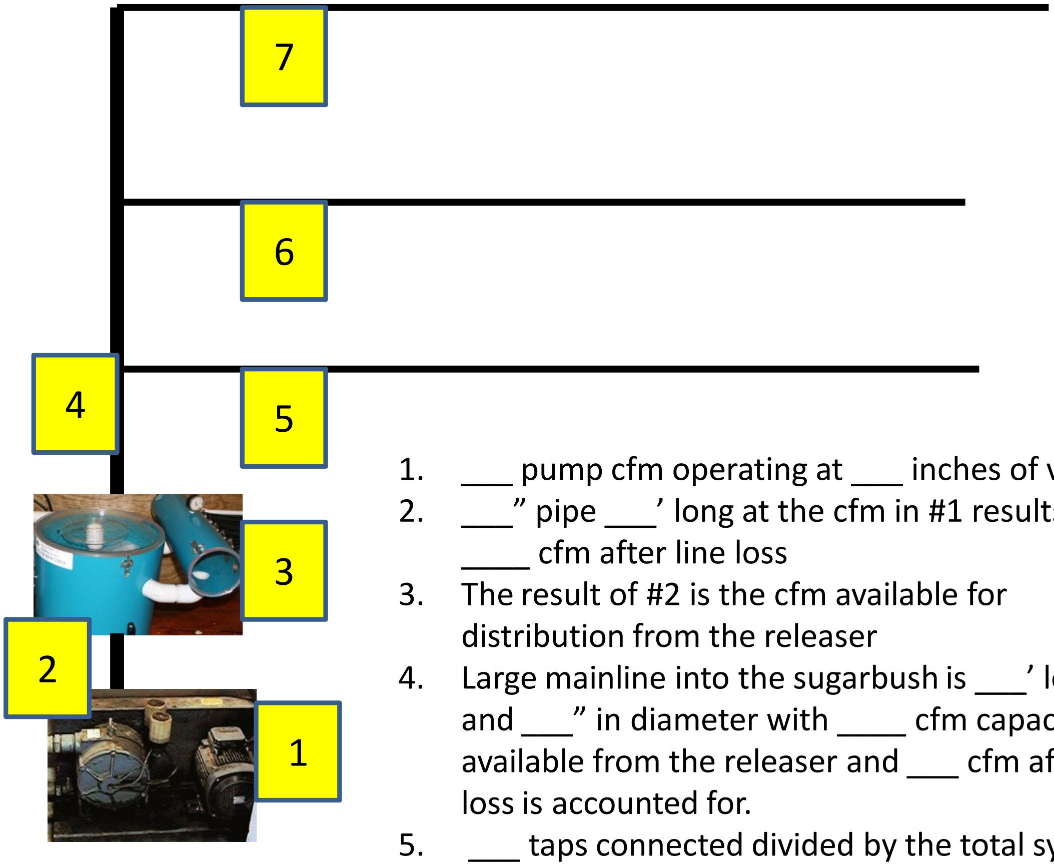


Sample map with more detail added.

Maps can be set up in a variety of ways. The main intent is for the map to be easy to use and at the greatest convenience to the planner or producer. Actually writing all the detail on the map is likely to lead to one that is confusing or unreadable. To avoid this, using a numbering system on the map itself and then keeping notes on an open section of the map or on associated pages may be preferred. These ideas are illustrated on the next several pages of this section.

In the example above: 1. The pump is rated at 30 cfm at 15” but the plan is to operate at 20” of vacuum. From the vacuum worksheet in the last chapter, I would lose 10% for each 1” of vacuum increased so this pump would now have 15 cfm available. 2. The mainline from the pump to the releaser is 1” diameter and 50’ long so from the line loss chart for 1” mainline shows 1 cfm loss. 3. Releaser cfm available 14 cfm. 4. Mainline to the sugarbush is 600’ long and is a wet/dry line system. The wet line is 3/4” and the dry is 1”. From the worksheet for 1” line in this chapter it has 8 cfm available after 600’. Line five has 89 taps, line 6 has 113 taps and line 7 has 161 taps for a total of 363 taps. 89/363=25%, 113/363=31%, 161/363=44% so 8 cfmX.25=2cfm, 8 cfmx.31=2.5 cfm, and 8cfmx.44=3.5 cfm. From the 3/4” Guidelines, line 5 is 200’ with 2% slope long = 162 suggested taps, line 6 is 350’ long with 6% slope = 205 suggested taps, line 7 is 700’ long at 10% slope = 262 taps suggested meaning the system is of sufficient size. The line 4 wet line must conduct up to 73 gallons per hour. The 3/4” wet line worksheet indicates a 3/4” wet line is less than 50% filled and a correct size. More taps could be added to this system before it would reach capacity limits.

Maple tubing system cfm map



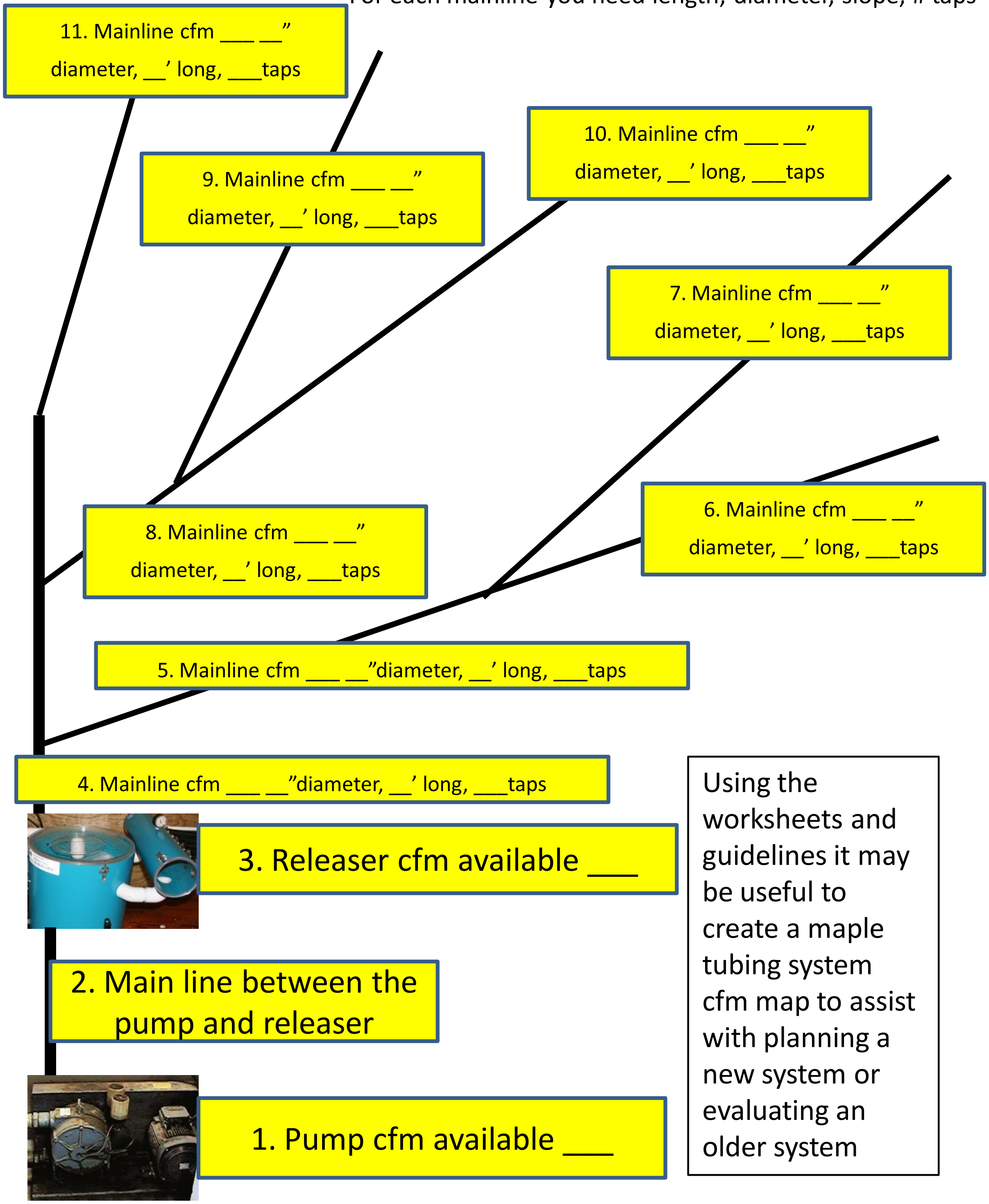
1. ___ pump cfm operating at ___ inches of vacuum
2. ___” pipe ___’ long at the cfm in #1 results in ____ cfm after line loss
3. The result of #2 is the cfm available for distribution from the releaser
4. Large mainline into the sugarbush is ___’ long and ___” in diameter with ____ cfm capacity available from the releaser and ___ cfm after line loss is accounted for.
5. ___ taps connected divided by the total system taps will = the % of cfm available from #4 above _____ cfm. Find that # of cfm on the guidelines for ___” pipe and move down the length ___’ of the mainline to find the suggested tap # ___
6. ___ taps connected divided by the total system taps will = the % of cfm available from #4 above _____ cfm. Find that # of cfm on the guidelines for ___” pipe and move down the length ___’ of the mainline to find the suggested tap # ___
7. ___ taps connected divided by the total system taps will = the % of cfm available from #4 above _____ cfm. Find that # of cfm on the guidelines for ___” pipe and move down the length ___’ of the mainline to find the suggested tap # ___

Using the worksheets and guidelines it may be useful to create a maple tubing system cfm map to assist with planning a new system or evaluating an older system

Using a numbering system and keeping details off the map may be useful.

Maple tubing system cfm map

For each mainline you need length, diameter, slope, # taps



11. Mainline cfm ___ __” diameter, __’ long, ___taps

10. Mainline cfm ___ __” diameter, __’ long, ___taps

9. Mainline cfm ___ __” diameter, __’ long, ___taps

7. Mainline cfm ___ __” diameter, __’ long, ___taps

6. Mainline cfm ___ __” diameter, __’ long, ___taps

8. Mainline cfm ___ __” diameter, __’ long, ___taps

5. Mainline cfm ___ __”diameter, __’ long, ___taps

4. Mainline cfm ___ __”diameter, __’ long, ___taps

3. Releaser cfm available ___

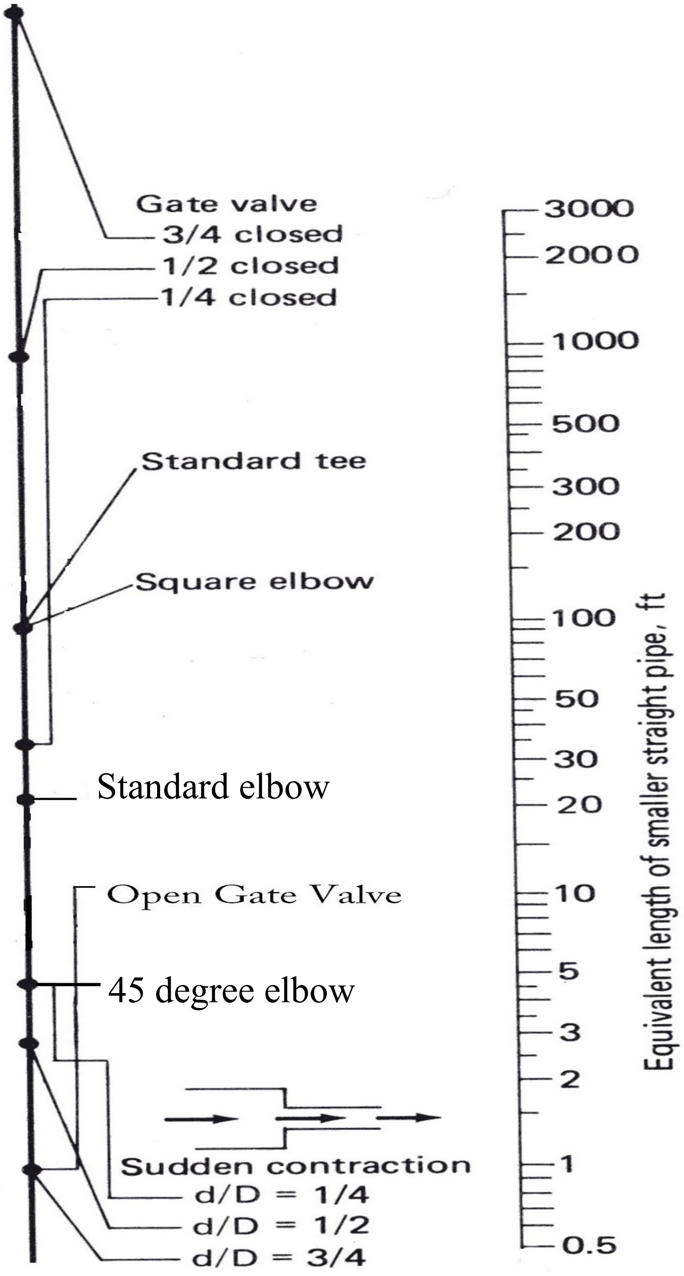
2. Main line between the pump and releaser

1. Pump cfm available ___

Using the worksheets and guidelines it may be useful to create a maple tubing system cfm map to assist with planning a new system or evaluating an older system

A system with multiple Ys makes for additional calculations

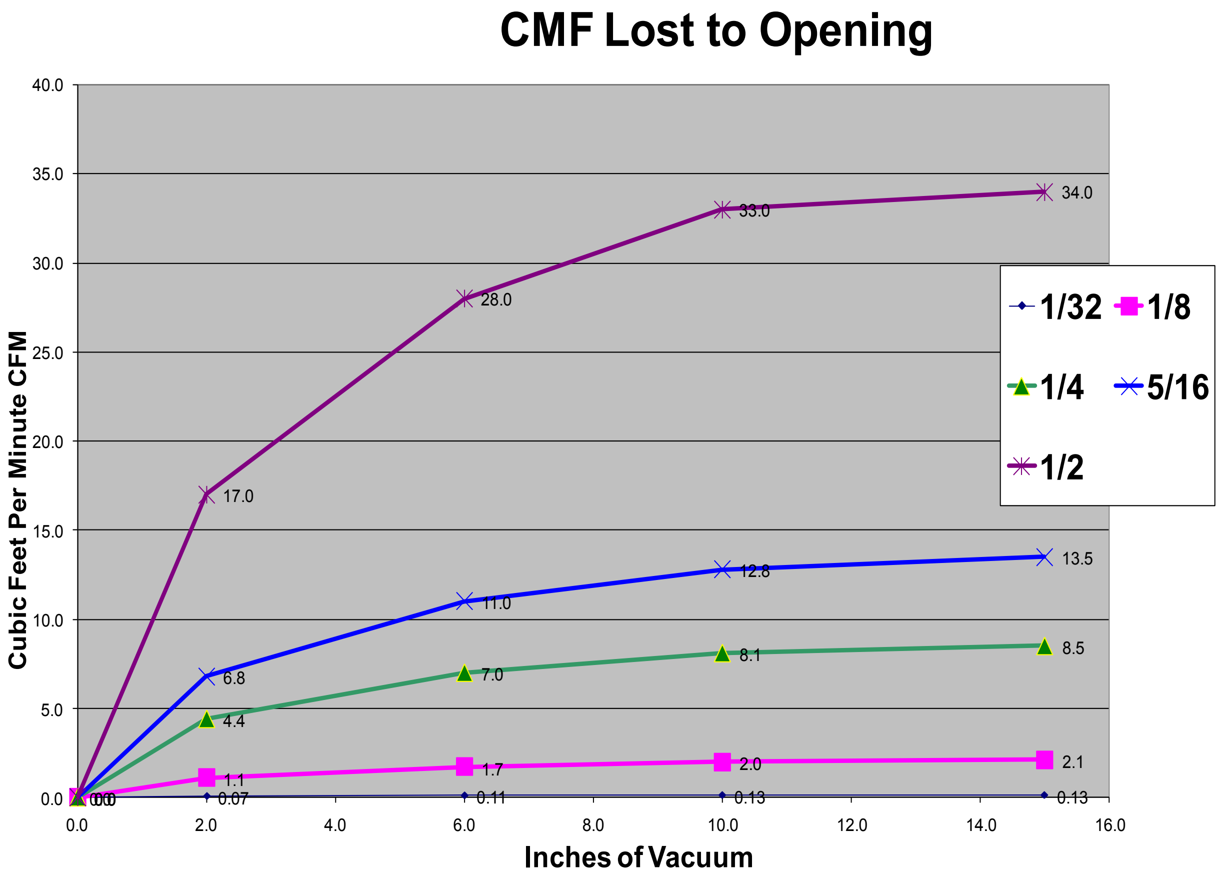
Factors To Consider In Addition To Length Of Pipe



Equivalent lengths for friction losses

13.14 Other effects on air flow

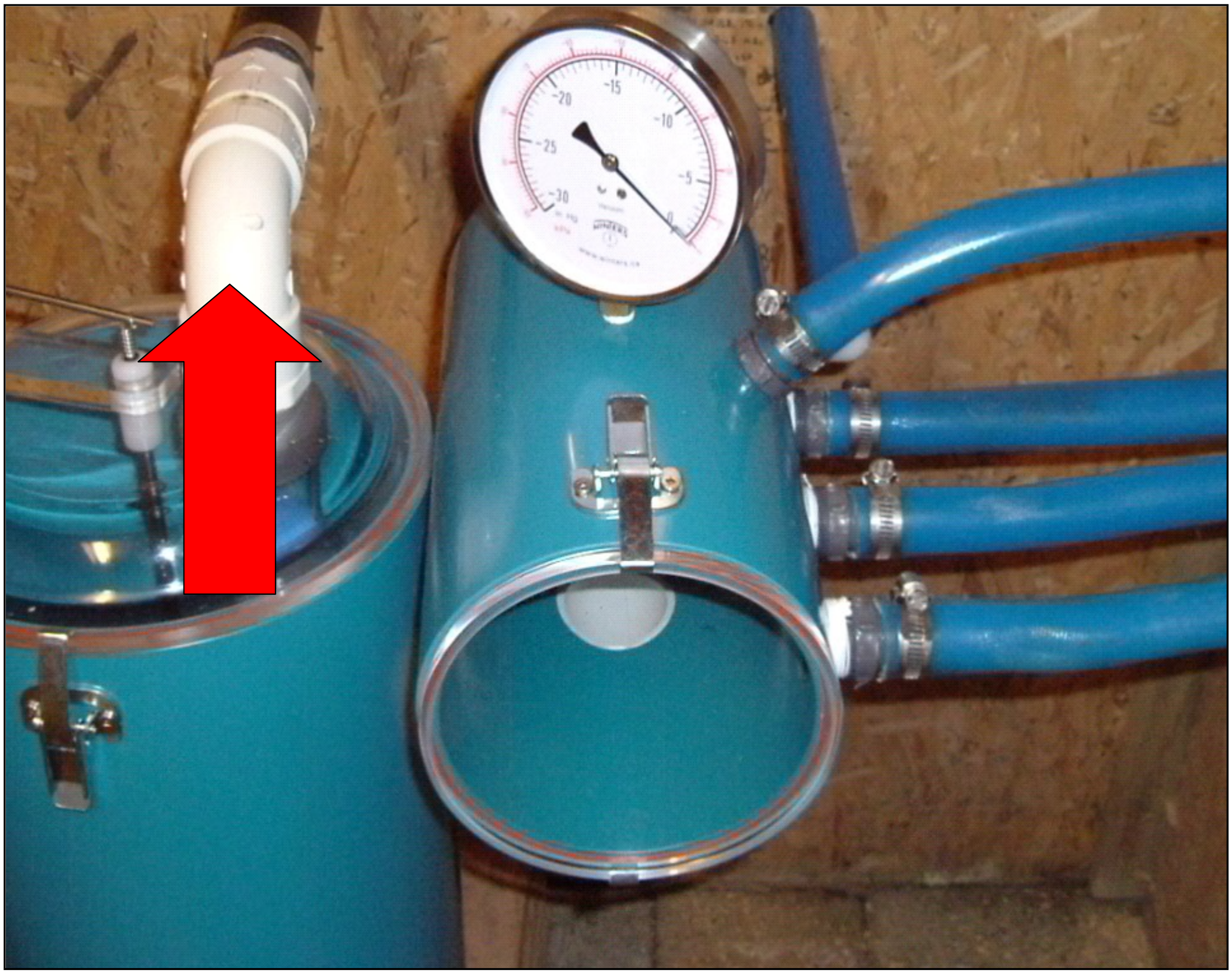
Another factor that can add confusion to air flow considerations is what various fittings can do to air flow in a mainline. Above is a simple chart of some common fittings in a mainline and how to adjust line loss for their presence. Find the mainline fitting on the list in the center of the chart then look straight across to the right for an estimate of the length of mainline you need to add to the actual mainline length to get a more accurate line loss reading from the line loss chart. For example one square elbow in the mainline is equivalent to adding 100′ of length to the mainline. A 45° elbow is equivalent to adding just 4 feet of tubing. A half closed gate valve is like adding 800 feet of tubing.



The chart above shows just how much vacuum capacity can be lost through various sized holes in tubing. Holes can be created by wildlife damage, falling limbs or system fatigue. For example, from the graph a 5/16th hole which would be what occurs where a lateral line pulls apart (the line identified with an x) can pull 13.5 cubic feet of air per minute into the tubing system at 15 inches of vacuum. A 1/8th inch hole, about the size of a rodent bite, can cost the system 2.1 cubic feet per minute at 15 inches of vacuum. These figures show clearly the value of keeping lines inspected and well maintained. It takes few openings to exhaust a substantial portion of the vacuum system air flow capacity. It is interesting that unless these leaks are fairly close to the vacuum pump the principles of line loss come into play and will moderate the effect of a leak on the whole tubing and vacuum system. Using the 1/2" hole represented in the graph above at 15" of vacuum it would leak at a rate of 34 cfm. If this hole was in a 3/4" line that volume of air would be difficult to vacuum through that size of line. The friction due to line loss would drop the vacuum pressure near the leak down to near 0" of mercury and the air being pulled into the pipe cut to 25% or less of what is was at 15" of mercury. By the line friction the effect of a 1/2" leak is mostly moderated. The vacuum level of taps in the region near the leak is severely reduced but the further taps are from the leak the less influence it will have on their vacuum level. If the leak were in a larger mainline that has less line loss the moderation effect would be reduced. This is no excuse for relaxing on tubing system maintenance but it does explain why a leak will have less effect than the graph above would make you think.

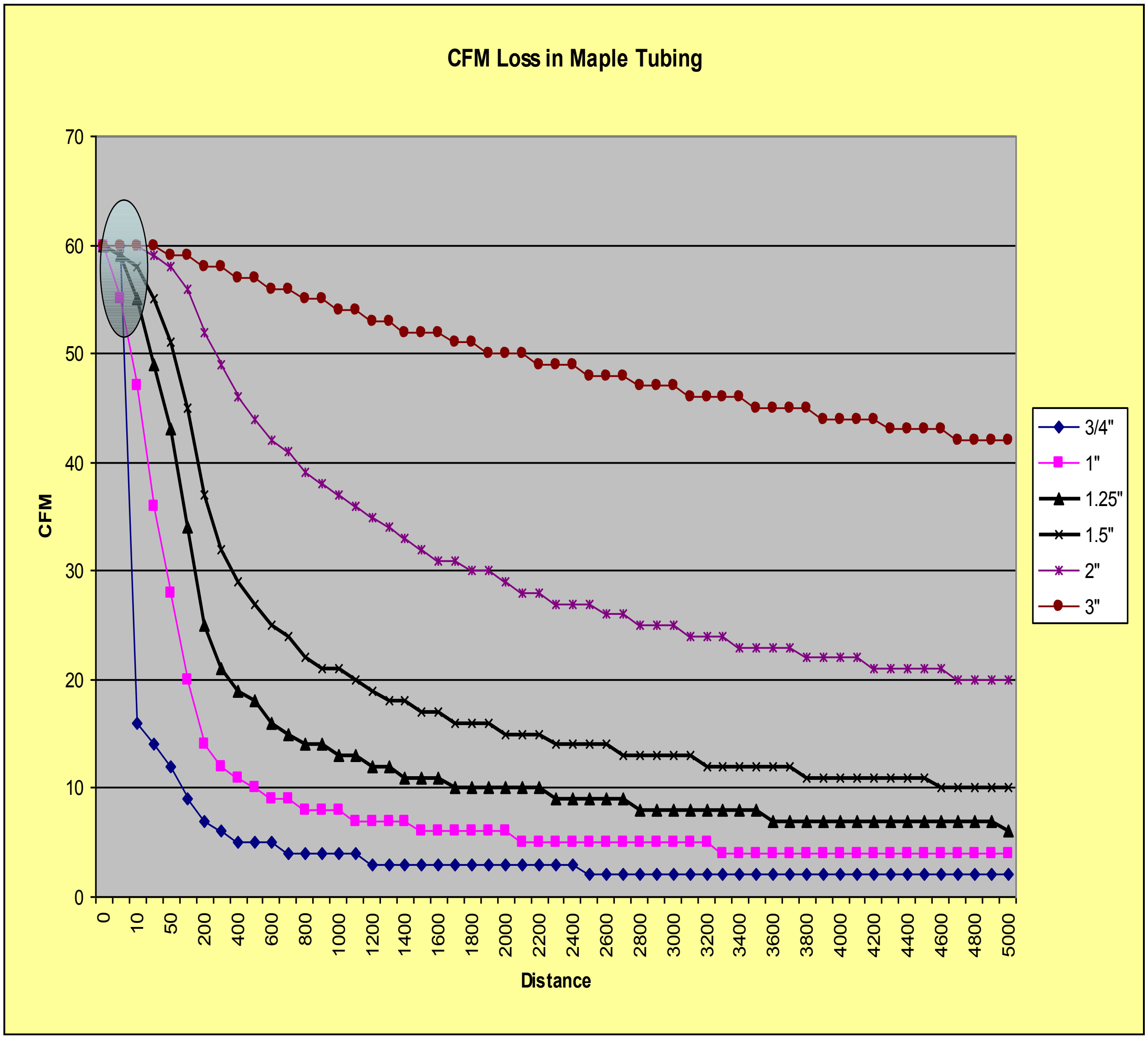
Section 14 Bottle neck evaluation

Summary:
Locating and correcting the weakest point in a tubing system can be the key to improved production in many maple sap collection systems. A bottle neck can be any number of things; an under sized pipe in an important location, too many elbows in a line, an under sized releaser, excessively long lateral lines or a mainline slope change just before entering the sugarhouse. Searching out bottle necks in a tubing system or system plan is an important part of tubing system management. This section takes a look at some of the most obvious and common bottle necks.

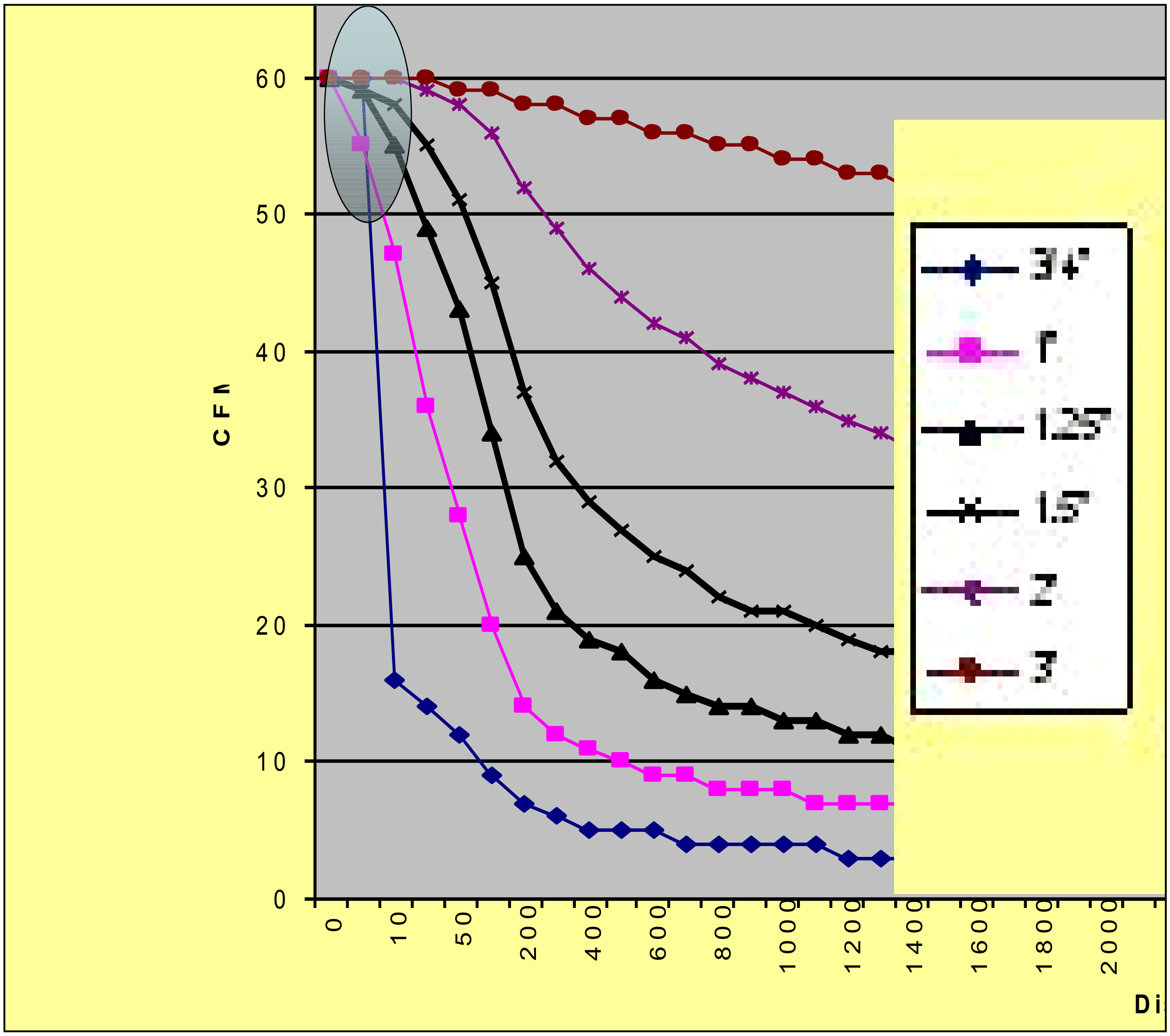


14.1 Avoiding a bottleneck between the vacuum and the releaser

The most important line in your vacuum system for line loss is the line that connects the vacuum pump to the releaser. Often the vacuum pump will have a fairly small opening as the suction port and a maple producer can be tempted to think that the lines connecting to that port can or should be the same size. This connection to the pump will likely be experiencing the greatest rush of air anywhere in the system and needs a pipe sized to handle the rush. Often I see the situation in sugar houses were the pump and the releaser are not right next to each other. Due to space considerations or where electric is available or were the mainlines enter the building or the need to walk around the vacuum pump or releaser, this line ends up 10′ to 40′ long and is nearly always a single line. This combination of factors can lead to under sizing this key line and the system suffers a significant line loss in the first, fairly short distance. The chart in the last section indicates that having a standard elbow in this line is the same as adding 20 feet of straight line. If there were four elbows to go up and over a walkway and connect to the vacuum pump and releaser that would be the same as adding 80 feet of line. In this high air flow part of the tubing system the loss to friction could be a significant bottleneck to providing the rest of the tubing system with the vacuum capacity that was available from the pump and expected in the system by the producer.

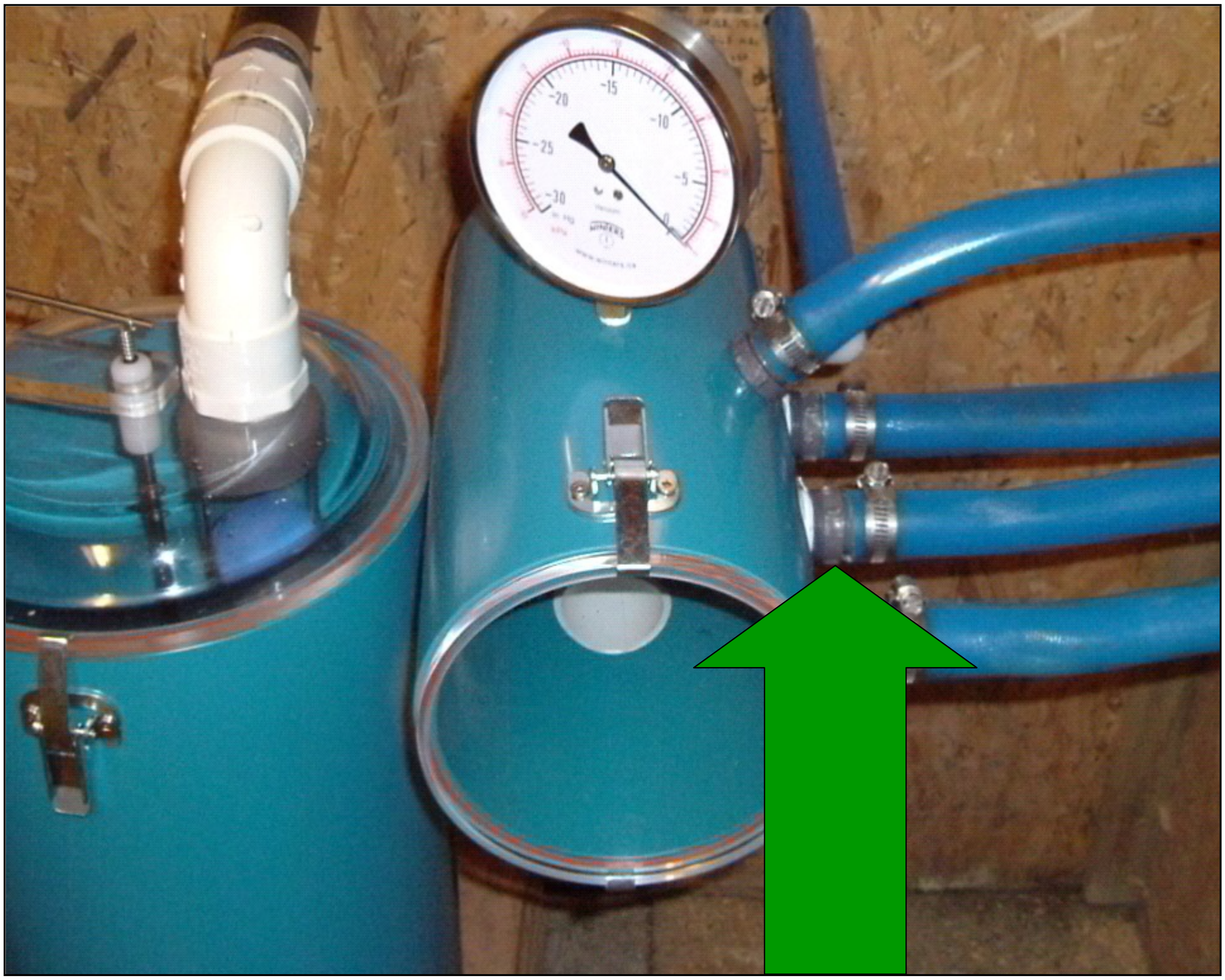


The line loss chart shows what the friction loss will be with various sized lines. For better visibility the key part of the chart that applies to the line between the vacuum pump and the releaser is circled in the chart above and enlarged for better viewing on the next page.



This chart shows the result of different sized lines attached to a 60 cfm pump. One 1″ line running 25′, a likely distance if the line simply loops up and over a walk way, from the vacuum pump to the reducer would start with 60 cfm from the pump and due to line loss deliver only 36 cfm to the releaser. With this the system would drop from a capacity for 6000 taps to just 3600 taps in this first 25′. One 1″ line is just too small to pull that much air through. If the same line was 1½″ the line loss in this same 25′ would deliver 55 cfm to the releaser, so you still would be losing the capacity for 500 taps. The 2″ line loses just 1 cfm while the 3″ line finally moves the air with no line loss.

If a smaller vacuum pump was in use with a 30 cfm capacity here is how the losses would compare. The 1″ line would lose 4 cfm, the 1½″ line would lose just 1 cfm, and the 2″ line would suffer no line loss in that first 25 feet.



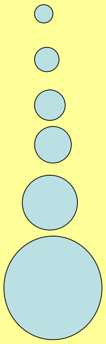
14.2 Avoiding a bottleneck at the releaser

Calculating the vacuum capacity available from the pump and vacuum line in cfm to the releaser and then from the releaser out to the maple woods is done using the line loss chart. In this example we have one 1½″ line entering the releaser from a 30 cfm pump that is 10 feet away. The chart would indicate that in this case there is no cfm loss between the pump and releaser. The selected tubing is large enough for the job. If we had just 2 1″ lines exiting the releaser going out to the woods each would have the capacity to be moving 15 cfm. According to the line loss charts these lines would lose 1 cfm each to friction in the first 25′ and an additional cfm each in the next 75′ reducing potential tapping capacity from 3000 taps to 2600 taps. In this case we have 5 1″ lines leaving the releaser. Here we need to divide the 30 cfm capacity available from the pump and vacuum line by 5 leaving each 1″ line with just 6 cfm load potential. Again we check on the chart starting where the 1″ line has 6 cfm and see that these lines will not lose anything to line loss until they reach 700′ in length and wouldn't lose a second cfm capacity each until another 1100 feet. If the lines were all 1800 feet long the system could carry 2500 taps.   Recognizing that just using the line loss charts does not take into account the sap flow in the lines and the reduction in capacity that results from the sap

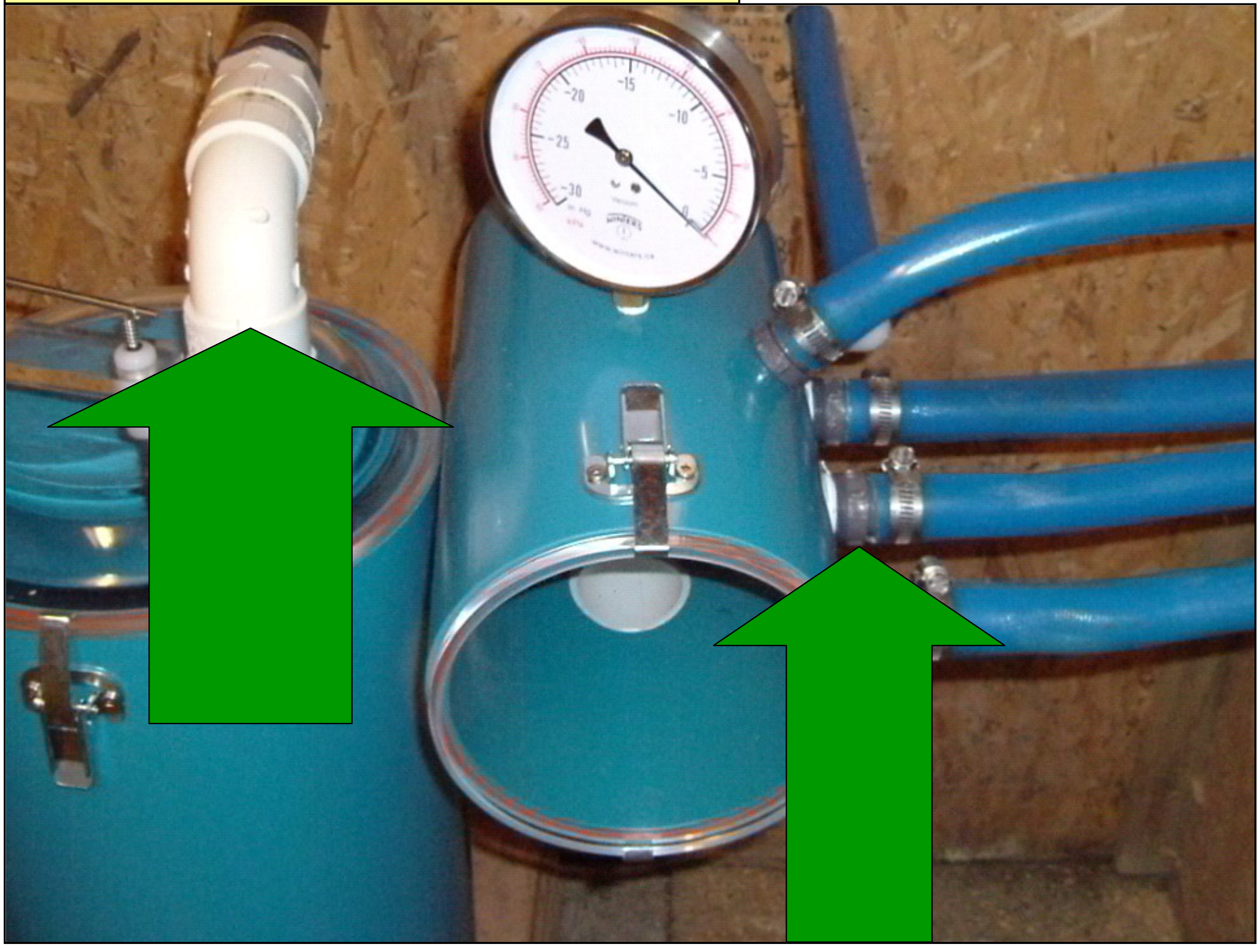
Dumper Choke!

- Area of a Pipe

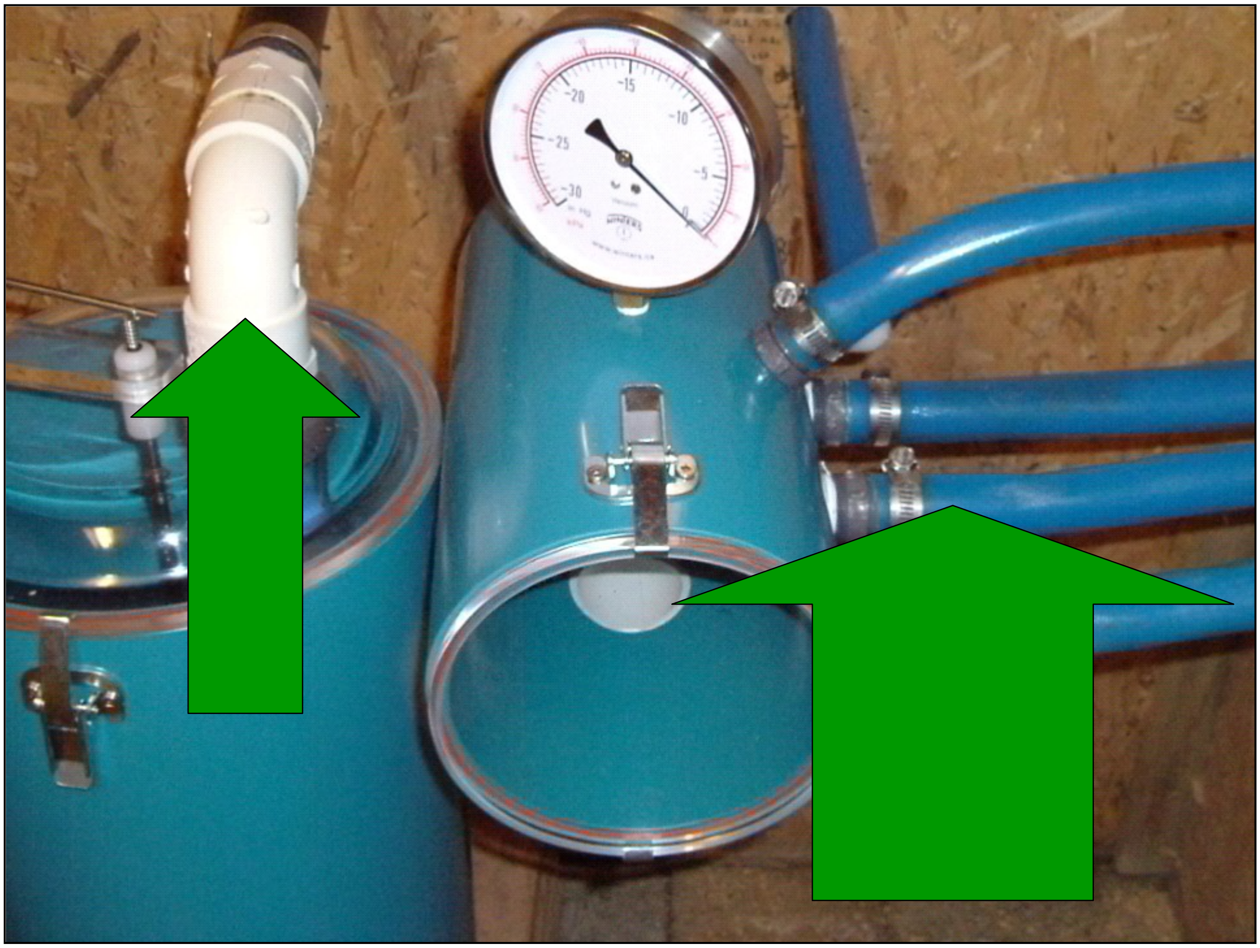
¾”	.44 sq. inches
1’	.78 sq. inches
1¼”	1.23 sq. inches
1½”	1.77 sq. inches
2”	3.14 sq. inches
3”	7.07 sq. inches



Where these calculations become more complex is when a variety of mainline tubing sizes connect the releaser to the woods. The calculation here would be the same as discussed earlier when looking at main line losses earlier.



Vacuum capacity can easily be lost in a vacuum releaser if the vacuum source piping is of greater capacity than the capacity of the main lines exiting the unit to the maple trees. This difference can leave part of your vacuum capacity trapped in the releaser, so vacuum cfm capacity to the trees is simply lost and the number of taps the system can support reduced.



The solution is to have excess tubing capacity leaving the releaser to ensure that vacuum capacity is not lost in the releaser.

14.3 Fixing the lateral lines are too long bottleneck

There are many tubing systems that were installed with 10 to 20 or even more taps per lateral line. Many times producers find that they cannot seem to get acceptable vacuum readings at the tap with these systems. Where the system was laid out on the contour it can be a reasonable investment to add a new mainline between two of the existing mainlines and cutting the number of taps per lateral in half. Making this change can both reduce line loss in the mainlines and reduce the vacuum loss in the laterals. Where the tree style of layout is in use the addition of branches can offer the same benefits but at a lower installation efficiency. Making these kinds of improvements are an alternative to replacing the whole system. If the vacuum system and the size of tubing is evaluated and found to also be a significant part of the problem making only these improvements may not result in the desired change. The whole system should be taken into consideration before changes are made.

14.4 Avoiding the slope change bottleneck

A common bottle neck in maple tubing systems occurs where there are steep hills in the sugarbush but the sugar house is on the valley floor or in an area where the steeper slopes are more than 30′ away. As in the photo of the Arnot Forest sugar house below, the last 30 to 100′ of mainlines are at a much more gradual slope than most of the rest of their length. In this situation, the flow rate of the sap was much higher when in the steeper parts of the line. When the sap arrives at the flatter section of the line the flow rate is slowed and the sap builds up and blocks or limits the flow of air that is being pulled to the vacuum pump. This blocking of air flow often limits the vacuum levels that can be sustained above the blockage. In our case at the Arnot Forest, that includes the vacuum available too much of the rest of the tubing system. If clear tubing was available to place in these locations maple producers would make corrections in these locations much more quickly because the problem would be so much more obvious. Sap entering the releaser in slugs instead of as a steady flow can be a symptom of this problem.

A solution is to place a dry line or second mainline from below the slope change to above the slope change. Just how far to go above and below depends on several factors including how close to full capacity the mainlines are during a good sap flow and the degree of slope change. To error on the side of going further on each side than necessary would be preferred to attaching the dry line into the congestion. The dry line does not need to go all the way back to the releaser, though that would be fine. It just needs to come off the mainline prior to the sap congestion. This is also suggested anywhere in the sugar bush where sudden slope changes occur. An alternative to using a dry line would be to use larger tubing between the sugar house and the steeper slope area or anywhere slope changes are in the system.

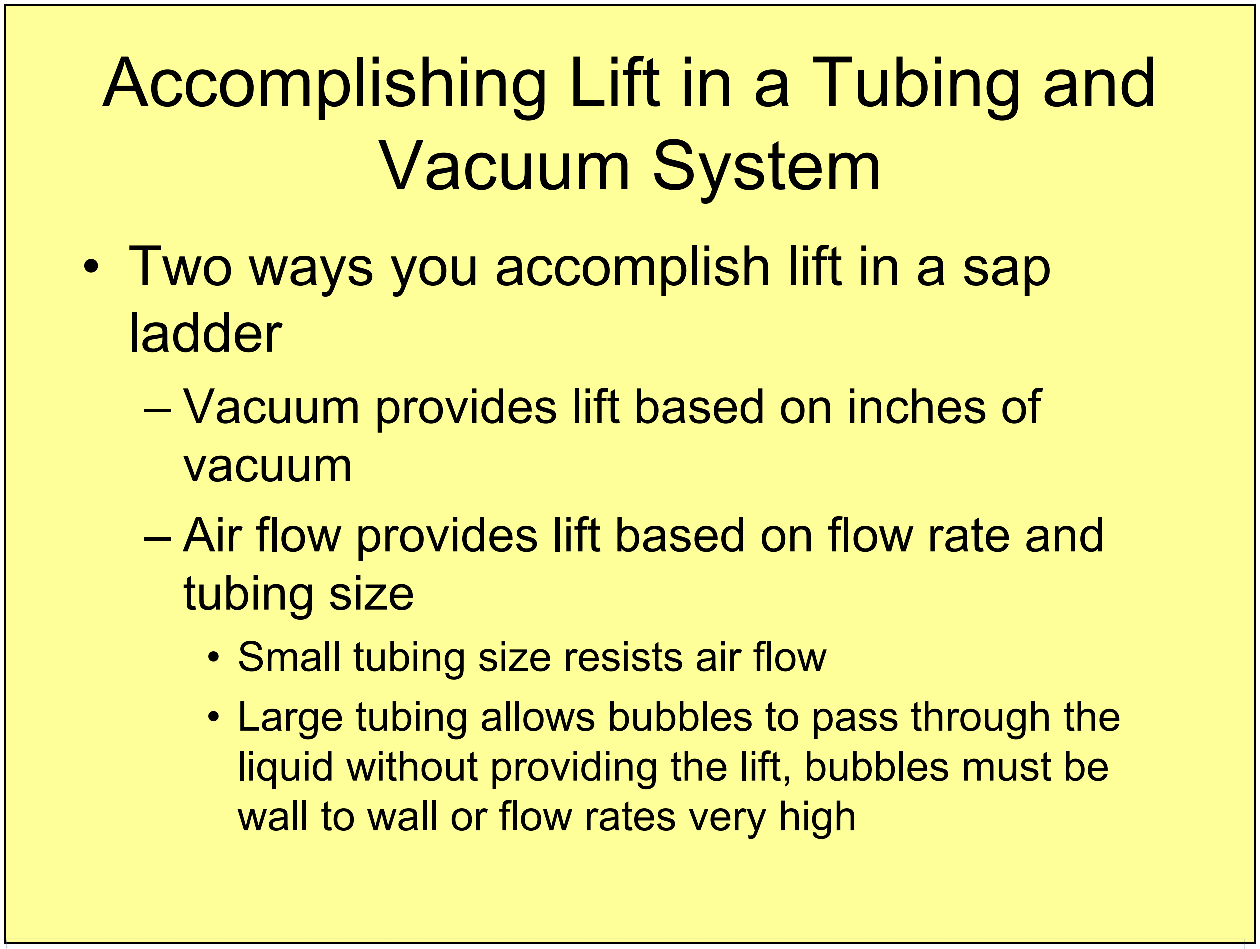
Testing the vacuum levels at distant points in your tubing system when there is no sap flow and then comparing that to a test of the vacuum level at the same point during a heavy sap flow is another way to see how significant this sap blockage may be for reducing vacuum and yield. Research has shown that you gain about 5% in sap yield for each additional inch of vacuum you have on the system but it only really matters what the vacuum level is at the tree. To test the vacuum on a system during heavy sap flow you cannot simply pull a spout and let it suck air while you get connected to your vacuum gauge. That will distort where sap is flowing and how quickly. Squeeze off the lateral line with a pair of vice grips, then pull the spout or plug, connect to the vacuum gauge and release the vice grips to get a true reading.

Our goal is to make sure our investment in vacuum and tubing reach all the way to the tree!

Section 15 Lifting sap with ladders

Summary:
Vacuum and air flow can generate the ability to lift sap in a maple tubing system. How the sap ladder is constructed as well as the vacuum pressure and air flow all combine to determine the ability of the ladder to move a volume of sap and provide enough transfer of vacuum capacity to provide the desired vacuum level to the taps on the far side of the ladder. Ladders can be a useful way to move sap over a ridge or out of a depression or even provide a way to leave an open driveway.

15.1 Creating sap lift in a sap ladder
15.2 Creating sap flow in a sap ladder



Accomplishing Lift in a Tubing and Vacuum System

- Two ways you accomplish lift in a sap ladder
  - Vacuum provides lift based on inches of vacuum
  - Air flow provides lift based on flow rate and tubing size
    - Small tubing size resists air flow
    - Large tubing allows bubbles to pass through the liquid without providing the lift, bubbles must be wall to wall or flow rates very high

15.1 Creating sap lift in a sap ladder

There are two ways that lift can be created in a maple tubing system to move sap vertically. Pulling sap up a sloping line with vacuum is not particularly efficient and depends on many factors. Lifting sap vertically or straight up has been found to be a fairly effective way to overcome problems of topography in a maple tubing system. Sap ladders can move sap from low spots, or over mounds in a system eliminating the need for multiple sap holding tanks or sap pick up sites. Ladders have also been used to bridge over roadways or other obstacles. Sap can be lifted using two mechanisms, vacuum lift and air flow push. Often these are used in combination. Vacuum lift does not require a specific size of tubing. The power of vacuum lift is functional with any solid column of water. Where air is being pulled through the tubing with the sap, vacuum lift in larger tubing can become in-effective because the air simply passes through the sap leaving the sap behind until it once again develops a solid column except where very large volumes of air are used. This can use up a significant part of the vacuum pumps capacity. In the smaller tubing, such as the standard 5/16″ tubing the bubbles or air will effectively push the sap in these smaller columns. See the previous page to see a sap ladder made with the standard 5/16″ tubing.

MM Mercury	PSI Negative	Feet Water	Inches Mercury Gauge	% Vacuum
0	0	0	0	0
20	0.000193	0.44109	0.42	1.3
40	0.0145	2.68047	2.32	7.9
60	0.01934	7.1253	6.32	21
80	0.147	11.5362	10.22	34
100	0.14912	15.9471	14.22	47
200	0.193	16.965	14.92	⬅ 50
300	0.39	20.6973	18.12	61
380	0.58	25.1082	22.07	⬅ 74
400	0.77	29.5191	25.98	87
500	1	30.36735	26.77	89.5
600	1.35	31.24953	27.56	92.1
700	1.93	32.16564	28.35	94.8
750	7.3	33.04782	29.14	97.4
760	15.5	33.93	29.92	100

The higher the vacuum the higher sap can be lifted. The chart above shows just how far sap can be lifted by vacuum of various pressures. For instance at about 15″ of mercury sap or water can be lifted about 17 feet. At 22″ of mercury sap can be lifted about 25 feet. At perfect vacuum of about 30″ of mercury the water can be pulled up about 34 feet. Even a 10″ vacuum can lift sap about 11 feet. When looking at flow-through capacity it takes 6 lines of 5/16″ tubing to equal one 3/4″ line and 10 lines of 5/16″ tubing to equal one inch line. These are direct volume comparisons and does not take into account the added friction loss associated with the smaller tubes. As of yet no source of line loss in 5/16″ tubing has been located or researched. In light of the likely friction loss in the 5/16″ line, if a ladder was placed in a 3/4″ mainline and the capacity of the air and sap in the line was to be maintained the ladder would need a minimum of 6 5/16″ lines and more likely 8 to 12 to avoid being a bottle neck. With the likely friction loss in the 5/16″ line, a 1″ mainline where the capacity of the air and sap in the line was to be maintained, the ladder would need a minimum of 10 5/16″ lines and more likely 12 to 20 to avoid being a capacity bottle neck

Static Lift Point

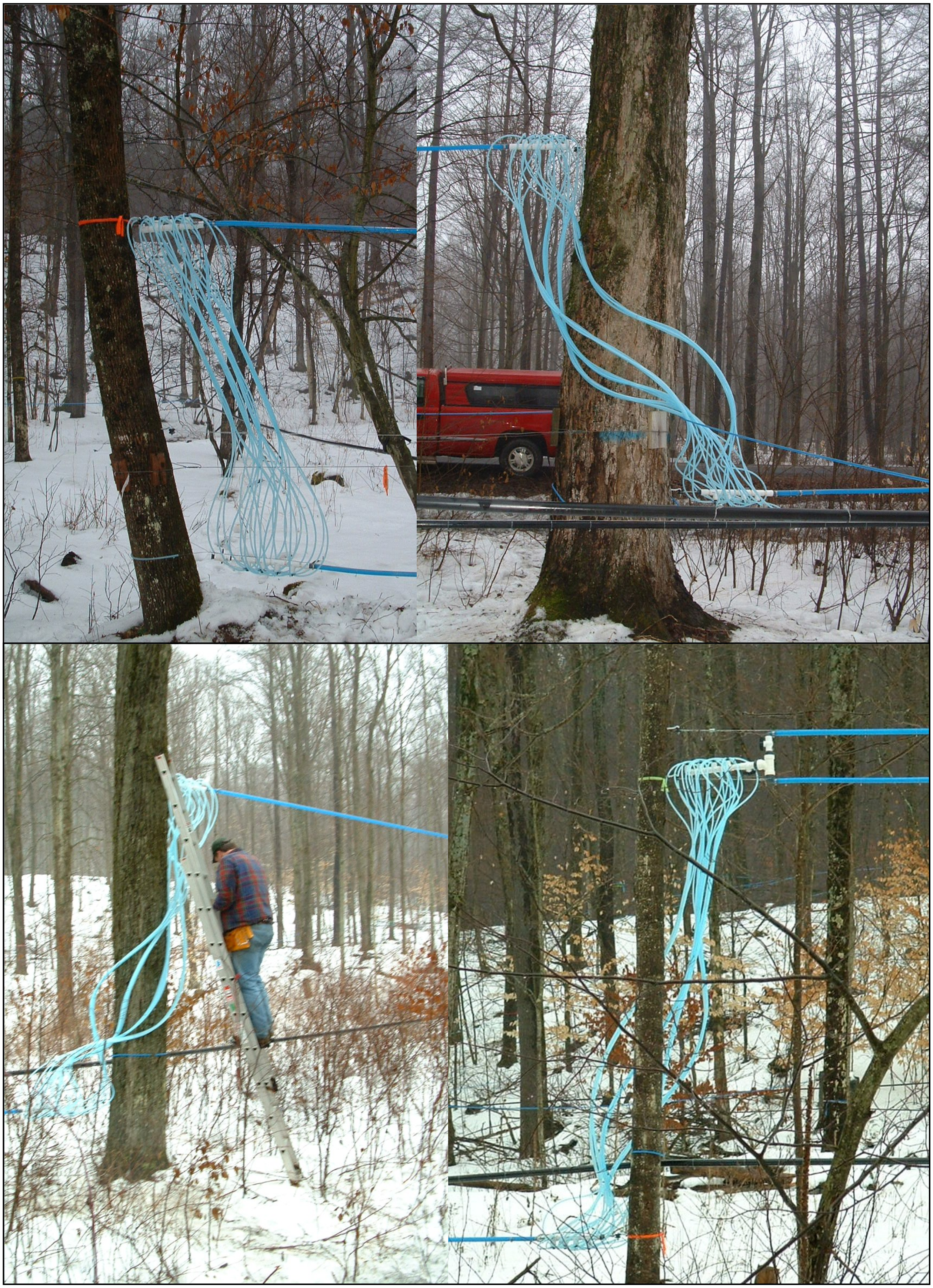
Feet Water	Inches Mercury Gauge	% Vacuum
0	0	0
0.44109	0.42	1.3
2.68047	2.32	7.9
7.1253	6.32	21
11.5362	10.22	34
15.9471	14.22	47
16.965	14.92	50
20.6973	18.12	61
25.1082	22.07 ⬅	74
29.5191	25.98	87
30.36735	26.77	89.5
31.24953	27.56	92.1
32.16564	28.35	94.8
33.04782	29.14	97.4
33.93	29.92	100

At 22 inches of vacuum you construct a ladder that is 25.1 feet tall, what is your flow rate in the ladder?

0

15.2 Creating sap flow in a sap ladder

Even though the vacuum has the power to lift the sap to a given height in vertical tubing according to the chart above , it does not have any flow capacity at that height. The sap would just sit there with no flow at all. To create flow a difference between the potential lift of the vacuum and the desired lift of the vacuum must be created. The greater this difference the greater the resulting flow. For example if the ladder needs to be 12 feet high and about 15″ of vacuum were applied, the potential lift of the vacuum would be about 17 feet. The difference would be 5′ or about 29%. 29% of the vacuum would be devoted to flow while 71% is devoted to lift. If the vacuum were raised to 22″ with the 12 foot ladder the potential lift at 22″ is 25 feet. The difference would be 13 feet or 52%. 52% of the vacuum would be devoted to flow while 48% devoted to lift. The bigger the difference the greater the flow rate through the ladder. An additional way to add flow to a ladder is to introduce a small air leak on the side of the ladder away from the vacuum pump. The air flow along with the vacuum pull often increases the volume of sap flowing through the ladder. Currently no reliable resource is known that allows a calculation of the number of taps that can flow through a ladder of specific construction at a given vacuum level. Hopefully this information will become available in future research projects



Section 15 Other materials

Listing:

Comparison of the small spout with the traditional 7/16″ spout.

Natural Vacuum and the Flow of Maple Sap

High-Vacuum Pumping Effects on Maple Sap Sugar Yield

COMPARISON OF THE "SMALL" SPOUT WITH THE TRADITIONAL 7/16" SPOUT

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The "small" spout, 19/64" or 5/16" in diameter, has been widely available to maple producers since the mid to late 1990's as a "healthy" alternative to the traditional 7/16" spout. While now in general use by producers in some regions, particularly those collecting sap by vacuum, the utility of these smaller spouts is still questioned by many sugarmakers, particularly those collecting sap by gravity. This article will review several studies conducted at the University of Vermont Proctor Maple Research Center comparing 7/16" spouts with small spouts (for the purposes of this article, 5/16", and 19/64" will be considered equally as "small" spouts). These studies were designed to examine sap yields, end-of-season drying, taphole closure and wounding (wood staining). While it is understood that even smaller diameter spouts are in use by some producers, as well as spout adaptors, and spouts made from non-plastic materials such as stainless steel, this research focused on common plastic spouts of the types offered by maple equipment dealers across the region.

When the small spouts were introduced, the principal benefit of switching from a 7/16" to a 5/16" or smaller hole was thought to be a reduction in damage to the tree. The difference in cross sectional area of the two holes is considerable: a 7/16" hole is 0.152 sq. inches in area, while a 5/16" hole is 0.077 sq in. or approximately 50% less. Taphole closure, understandably, is more rapid with a smaller hole, and the use of a smaller drill bit allowed many producers to switch to battery operated drills for tapping with small spouts (these of course can also be used for larger tapholes, albeit less efficiently). Because there was less visible damage, some producers assumed that tapping guidelines should be adjusted to allow for tapping smaller trees. An assessment of internal damage, which requires destruction of the test trees, was necessary to answer questions about just how much less impact the small spouts have on the maples. This subject will be covered below.

For most producers, the determining factor in whether or not to switch to smaller spouts is sap yield. Because the hole is smaller, it seems intuitive that less sap will flow from the hole. We tested this hypothesis in a number of studies over a period of several years, using both gravity (bucket) collection and vacuum collection methods.

SAP COLLECTION UNDER GRAVITY

Gravity collections were made using large and small spouts each spring between 1998 and 2002. In all trials we used plastic spouts connected to a short length of tubing, which entered a covered 5 gallon bucket hung on the tree.

Spouts were generally new, however if they had been previously used they were well washed in the lab. When used spouts were tested, both large and small spout were of equal age. Spouts from various manufacturers were tested; we found no significant differences in the performance of different brands of large or small plastic spouts under gravity collection.

Results for gravity collection are shown in Table 1. Values are gallons of sap/tap per season, or the ratio of sap production of small spouts to large spouts.

Table 1. Comparison of gravity sap yield for large and small spouts from 1998-2002.

Year	**1998**	**1999**	**2000**	**2001**	**2002**
Tree Size	Small	Small	Large	Large	Large
5/16” Spouts	8.2	9.1	21.4	10.4	13.6
7/16” Spouts	10.5	9.1	17.5	12.5	17.1
Ratio Sm/Lg	0.79	1.01	1.23	0.83	0.80

For the five year period, the yields averaged 12.54 gallons/taphole for small spouts and 13.29 gallons/taphole for large spouts, or 94% as much sap using small spouts compared to large spouts. In 1998 and 1999 we collected sap primarily from small trees (<8” dbh) while later collections were from larger trees (> 10” dbh). This explains why yields from 2000 from either size spout were greater than those of the previous years; other differences among years were primarily due to weather conditions. Small trees were used in the study because these trees were slated to be cut down to study internal wounds.

In 1998 we also studied yields from holes of different depths with each size spout. Holes that were 1 ½" deep yielded 98% as much sap as holes 2 ½" deep for either sized spout, while holes ¾" deep yielded approximately 86% as much sap as holes 1 ½" deep.

In addition to recording seasonal sap yield from large and small spouts, we collected weekly data during the years 2000-2002 from both sized spouts, using buckets, in order to explore possible differences in end-of-season taphole drying. In two of these three years, both sized tapholes dried at about the same time; while in the third year (2000), the tapholes fitted with small spouts ran about two weeks longer than the 7/16" tapholes.

Using specially constructed chambers (Fig.1) that isolated the sap from each taphole, sap yields under vacuum from large and small spouts were compared in 1999 and 2000. Vacuum in these tests was approximately 15" mercury at the

SAP COLLECTION UNDER VACUUM

Figure 1.
A chamber used to collect and measure sap volume under vacuum.

taphole. In 1999 the sap yield using small spouts was 95% of the yield from large spouts, while in 2000 sap yield using small spouts was 107% of the yield from large spouts (Fig. 2). These minor differences can be easily explained by tree to tree variation; thus we concluded that at this vacuum level there were no real differences in sap yield using either sized spouts.

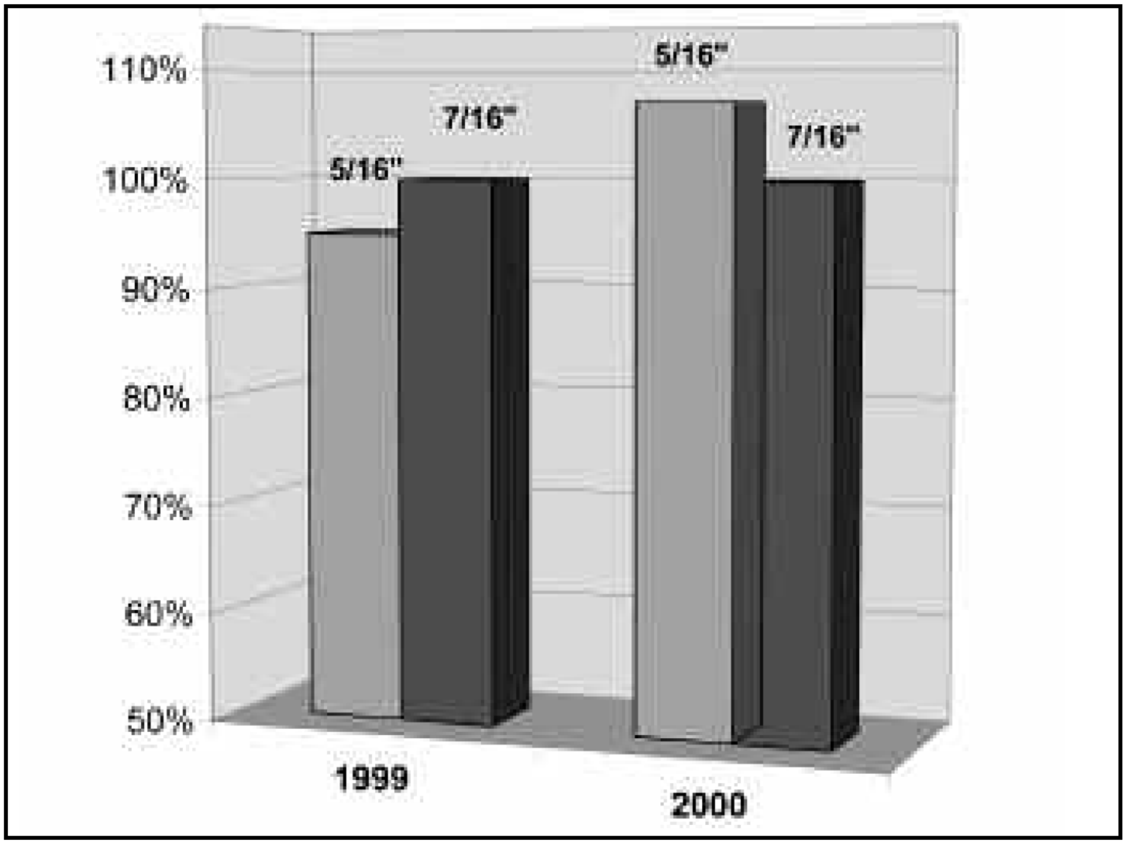

Figure 2. ***Sap Yield under vacuum for 5/16" and 7/16" spouts. Yield for 7/16" spouts was adjusted to 100%. There was no significant difference between yields for either size spouts in both years.***

INTERNAL DAMAGE

Staining of the wood surrounding a wound, such as a taphole, has long been recognized as an indication of the portion of the tree that has become non-functional for sap transfer. While it is now recognized that the non-functional area surrounding a wound is somewhat larger than the area that is stained, comparing the area that is stained between trees with similar wounds is a good way to assess the relative damage inflicted by those wounds. These stains, believed to be caused primarily by fungi, can be measured only after the tree is cut down and dissected. Several groups of trees were sacrificed as part of our comparative studies of large and small spouts.

Although sap yields using small spouts with gravity averaged 94% of yields from large spouts, staining from gravity collection with small spouts was much less: only about 59% the volume of stains from large spouts. A few of the trees had extensive stained areas when a taphole depth of 2 ½" was used. In these small trees, the staining had merged with a non-functional area in the tree's center (the heartwood), creating a larger than expected wound response. This is a good argument for not tapping small trees, as the non-functional area that may be created can represent a significant fraction of the total sap transport system.

In order to compare wounding under vacuum in an unbiased way, we chose to cut down several large (> 14" dbh) trees. These trees were connected to a vacuum system, and tapped with one large and one small spout on each tree. The spouts were staggered vertically to avoid any interaction of one wound with another. In these trees, the stained area resulting from small spouts ranged from 62% of the area of the large spout stain in the same tree, to 100% of the large spout stain. On average, the volume of stained wood resulting from the 5/16" holes was 80% of the stained wood resulting from 7/16" holes.

CONCLUSION AND SUMMARY

Small (5/16" or 19/64") spouts have a number of advantages over 7/16" spouts. Among these are:

1. The 5/16" holes are 50% smaller in cross sectional area than the 7/16" holes and usually close sooner than larger diameter holes.
2. The internal staining resulting from the wound, which is a measure of tree damage, is less with smaller diameter tapholes.
3. Because the bit is smaller, more holes can be drilled on a single charge using a battery operated drill.

Sap yield using small diameter spouts averaged slightly less than the yield from large spouts when collecting sap by gravity. With buckets, there was considerable variability from one year to the next in terms of which size spout had better yields. Sap yields using vacuum were the same for both 5/16” and 7/16” spouts. We did not test yields or other parameters resulting from the use of still smaller spouts, or adaptors, or spouts made from materials other than plastic.

Finally, there remains the question of whether or not the use of small spouts should allow for the use of more spouts per tree, or the tapping of smaller trees. Tapping guidelines, which recommend limiting the number of spouts based on tree diameter, serve two purposes: 1) protecting the heath of the tree, particularly of the tapping band, and 2) promoting efficient use of sap collecting resources. In consideration of the latter, we have found that adding a second tap on a large (24”+ dbh) tree will yield on average only about 50% more sap than a single tap when collecting with vacuum, while adding additional expense and additional materials to maintain year round. If a second tap was added to a smaller tree, 15”diameter for example, the added yield would undoubtedly be a lot less than 50%. In terms of tree health, while the internal damage resulting from a 5/16” hole was less than from a 7/16” hole, the differences that we found were not so dramatic as to suggest that the tree could sustain additional yearly wounds. Because sap yields with 5/16” spouts were similar to yields from 7/16” spouts using vacuum, and almost as large as 7/16” yields using gravity, we see no reason to change the current number of spouts per tree. As to the question of tapping small trees, (<10” dbh), producers can make their own decisions about the cost vs. benefits of putting buckets or tubing on small trees, but should consider our findings regarding wounds in small trees described above, and also understand that the yield from small trees is usually small.

ACKNOWLEDGMENTS

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High-Vacuum Pumping Effects on Maple Sap Sugar Yield

Research

Cornell University

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Abstract

Some maple producers are reluctant to take advantage of highvacuum pumping to increase yields of sugar maple sap in their closed-tubing sap collection systems. They believe that only sap of significantly lower sugar content will be obtained. During 1985 and 1986, at Lake Placid, NY, sap collected from sugar maple trees subjected to three levels of vacuum pumping (10-, 15-, and 20-in. Hg) was compared to sap obtained by gravity flow. In most instances the higher levels of vacuum resulted in significantly higher sap volumes with no significant decrease in sap sugar content. Application of 15-in. Hg pumped vacuum at the taphole in a well-maintained tubing system should result in a significant increase in syrup production.

Introduction

Since the advent of the dosed-tubing method of collecting sap from sugar maple, many producers have adopted the use of vacuum pumps to induce sap flows and to increase the volume of sap collected per tap. It has been well-documented that vacuum pumping can increase sap yield from a maple sugarbush (Blum and Koelling 1968, Morrow and Gibbs 1969, Laing and Arnold 1971). It has also been demonstrated that, in general, higher levels of vacuum result in collection of higher volumes of sap (Smith and Gibbs 1970, Laing et al. 1971, Walters and Smith 1975).

Smith and Gibbs (1970) examined the effects of low-vacuum pumping (5- and 10-in. Hg) and gravity sap flows from paired sugar maple trees. Sugar concentrations from the pumped sap were not significantly different from the gravity sap. High vacuum pumping levels were not examined.

Laing et al. (1971) examined the effects of high-vacuum pumping (defined as ". . . more than 15-in. Hg as measured at the pump"), on volume and composition of maple sap. Their results demonstrated a 73% increase in sap volume with vacuum pumping and no significant difference in either sugar or other solutes in the sap. Precise vacuum levels were not measured at the tapholes nor were performance data obtained from individual trees or specific vacuum levels.

In recent years, with improved technology and equipment, it has become more common for producers to employ high-vacuum pumping (15-in. Hg or more) in maple sap collecting. However, a position continues to be held by some maple producers that while high-vacuum pumping may produce more sap, its resulting sugar content would be noticeably lower than that of sap collected with low levels of vacuum or by gravity. And, due to the high energy costs of processing maple sap to syrup, the economic gains to be realized in processing higher volumes of sap with lower sugar content are questioned. The purpose of this study was to attempt to resolve this issue by comparing the volume and sugar content of sap collected under carefully controlled conditions from individual trees at 0-, 10-, 15 -, and 20-in. Hg of pumped vacuum.

The Study Area

The study was conducted at the Cornell University, Uihlein Sugar Maple Research- Extension Field Station in Lake Placid, NY. The specific study site was located in the Field Station's 197-ac sugarbush, which has an easterly aspect with 3%, slope and an elevation of about 2000 ft. The soils are strongly acid (pH 4.7), deep, welldrained sandy loams of glacial till origin. This is a relatively cold, high-elevation sugarbush, consisting of rather slow-growing trees. The sugarbush was developed from forest-grown trees, the oldest of which are now about 100 years old. Trees selected for the study are about 70 years old. The sugarbush was essentially unmanaged until about 15 years ago when a thinning program and other management activities were initiated. Since that time syrup production has averaged about 0.29 gallons per tap (Morrow 1982).

Methods

Following a period of preliminary experimentation during the 1984 sap season, 32 sugar maple trees were selected for study during the 1985 and 1986 sap seasons. The selected trees were healthy, vigorous, and free from obvious defect. They averaged 12.6 in. dbh (10.6-16.7 in.) and had an average crown diameter of 18 ft. Previous to this experiment the trees had not been tapped.

For each year of the experiment, the 32 selected trees were randomly assigned to one of four treatments (eight trees per treatment): no vacuum (the control group), a low-vacuum of 10 in. Hg, and two levels of high-vacuum, 15 in. Hg, and 20 in. Hg. Each tree received one tap at about 40 in. from the ground. All taps were placed on the same side of the trees, generally south (1985) and southeasterly (1986). Tapholes were sanitized before spile insertion with a 517, chlorine solution (5.25% sodium hypochlorite). Paraformaldehyde pellets were not used.

Sap was collected in vessels 30 in. long by 4 in. in diameter constructed from PVC drain pipe (fig. 1). The bottoms of the vessels were permanently sealed, and the tops were fitted with threaded plugs temporarily sealed with latex sealing compound. These 6 qt. capacity vessels served as containers for collection and measuring sap and as vacuum chambers. As designed, they were capable of withstanding at least 25 in. Hg vacuum without collapsing or leaking. Vacuum lines were fitted with a shutoff valve close to the collection vessels to permit opening an individual pressurized vessel without disrupting the vacuum to the remaining vessels within a particular treatment group. Collection vessels were held in place at each tree by a rubber strap. Droplines Of 5/16 in. tubing connected the tree taps to the collecting vessels. Other than the absence of a vacuum line attachment, the collection system for the control trees was identical to that of the trees receiving pumped vacuum.

Figure 1. A typical installed sap collection vessel.

Vacuum was supplied by three, 2.3 cfm, compressor- type, dry pumps driven by a single, 7 hp, gasoline engine. Vacuum was transferred to the collection vessels via 5/16, in. plastic maple tubing lines. Vacuum gauges were installed at the beginning and the end of each vacuum treatment line. Vacuum levels were monitored on an hourly basis whenever the experiment was running and were adjusted, as necessary, to maintain them at the desired levels of 10, 15, and 20 in. Hg at the tapholes. The system was reasonably trouble-free, and it was possible to maintain the desired levels of vacuum, in most instances to within 0.5 in. Hg throughout the experiment.

Sap was collected from all the trees during 11 collection periods in each year of the study. The total operation of the sap collection system was 72 hours in 1985 and 58 hours in 1986, for an average collection period of 6.5 hours and 5.2 hours, respectively. This sampling program represented 42% in 1985 and 55% in 1986 of the actual sap flow seasons based on 26 flow days in 1985 and 20 in 1986. A sap flow day was defined as a 24 hr period during which 0.5 qt or more of sap was collected per tap.

At the end of each collection period, vacuum pumps were turned off, and droplines to all containers were immediately disconnected. Sap volumes per tree were measured to the nearest 0.1 qt, and sap sugar content, expressed as total solids, was measured with a calibrated refractometer to the nearest 0.1%. After measurement, collected sap was discarded, and the empty containers were resealed. At the beginning of each collection period, droplines were reconnected in conjunction with reactivation of the vacuum pumps.

Results And Discussion

During the 2 years of the study, 704 measurements each of sap volume and sugar content were obtained from the 32 trees for 22 collection periods. In that yearly variation was not a primary focus of this study, data for the 2 years were combined. Mean sap volume values per tap for each treatment were computed. Mean sap sugar content values, weighted by volume, were likewise computed. Potential syrup production mean values per tap were then calculated from the volume and sugar content values. Analysis of variance, single classification, was used to detect significant differences between treatments (Snedecor and Cochran 1980). A summary of statistical comparisons between vacuum levels is given in Table 1. As expected, total sap volumes were higher for all vacuum treatments than for the controls (Fig. 2). The lack of significant sap volume increase between 15 in. Hg and 20 in. Hg of vacuum suggests that vacuum levels may be approaching the upper limit of practical effectiveness for this collection system. Larger sample sizes at the higher vacuum levels will be required to verify this result.

Table 1. Summary of vacuum level ANOV comparisons for average per tap sap volume, sap sugar content and syrup.

Vacuum level	Sap volume F-value	Sap sugar F-value	Syrup F-value
0 vs. 10	11.50**	1.11ns	11.33**
0 vs. 15	75.29**	0.40ns	37.50**
0 vs. 20	78.15**	2.11ns	50.00**
10 vs. 15	16.78**	0.51ns	7.00*
10 vs. 20	21.83**	0.14ns	4.50*
15 vs. 20	0.004ns	4.09ns	0.67ns

ns = no significant difference
* = significant difference at P =< 0.05
** = highly significant difference at P =< 0.01

Figure 2. Average sap volume, sap sugar content, and syrup volume per tap for each vacuum level. Length of boxes indicates total range of individual taphole averages. Shaded areas indicate +/-2 standard errors of the mean.

The lack of significant difference in sap sugar content between the control trees and those receiving the three levels of vacuum (Fig. 2) supports the previously reported work of others (Smith and Gibbs 1975, Laing et al. 1971) and the observed operational experience with vacuum pumping at the Uihlein Field Station (Staats and Kelley pers. obs.).

The results of the comparisons between the amounts of total syrup produced (Fig. 2 and Table 1) are predictable from the highly significant differences observed in sap volumes and the lack of significant differences in sap sugar content at increased vacuum levels. Ultimately the amount of syrup produced per tap is the primary concern, and from this study the use of high vacuum pumping appears to be justified.

Management Implications

This experiment strongly supports the position that high pumped vacuum does not result in the collection of sap of significantly lowered sugar content. This work also reinforces previous investigations that attribute substantial increases in collected sap volumes to high-vacuum pumping.

The results of this study further indicate that the optimum level of vacuum, applied at the tap, in terms of both sap volume and sugar content is about 15 in. Hg. The added expense and practical difficulty of attempting to maintain vacuum levels at the tap of greater than 15 in. Hg are not warranted. The importance of good collection system maintenance cannot be overemphasized. Very small leaks in the tubing and at fittings can easily prevent the delivery of vacuum at the taphole. Installation of vacuum gages in the sugarbush is the only accurate way to monitor the level of vacuum actually being delivered to the trees. Producers should exercise care that they use vacuum pumps of appropriate capacity that match the sizes and lengths of well-graded sap lines according to the number of taps in the system and other characteristics of the sugarbush.

The advantages of vacuum pumping are clearly demonstrated during sap seasons characterized by less than optimal or "weeping flow," conditions. Under such conditions a sugarbush under pumped vacuum at the level recommended herein will often produce a good syrup crop when nearby gravity flow sugar bushes yield a very poor crop. For example, syrup production at the Uihlein Field Station during the industry wide, generally disastrous seasons of 1986 and 1987 was 85% to 90% of an average crop. This is in contrast to the experience of many producers in the same locale, not using high vacuum pumping, who produced only 30% to 50% of an average crop of syrup (Staats, pers. obs. and unpub. Records Uihlein Field Stn.).

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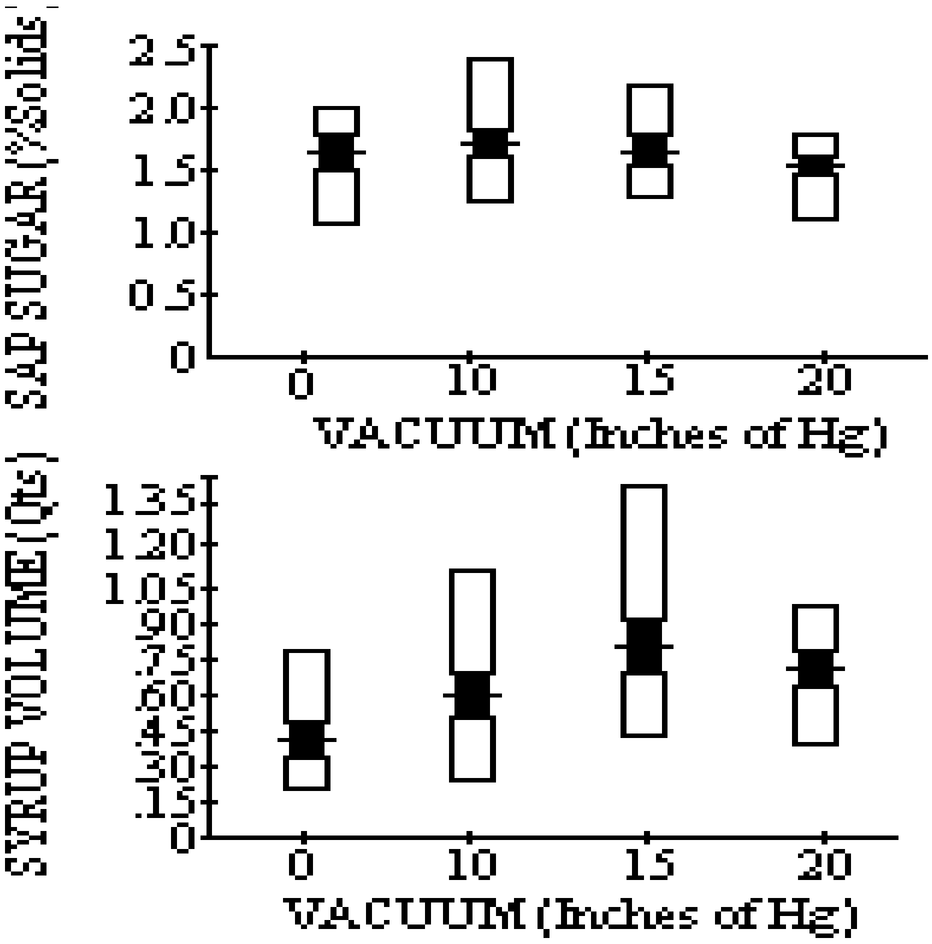
SAP SUGAR (% Solids)
2.5
2.0
1.5
1.0
0.5
0
0
10
15
20
VACUUM (Inches of Hg)
SYRUP VOLUME (Qts)
1.35
1.20
1.05
.90
.75
.60
.45
.30
.15
0
0
10
15
20
VACUUM (Inches of Hg)

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PLANT SCIENCES

NATURAL RESOURCES • NUMBER 1

CORNELL UNIVERSITY AGRICULTURAL EXPERIMENT STATION, NEW YORK STATE COLLEGE OF AGRICULTURE AND LIFE SCIENCES, A STATUTORY COLLEGE OF THE STATE UNIVERSITY, CORNELL UNIVERSITY, ITHACA, NEW YORK

Natural vacuum and the flow of maple sap

Robert R. Morrow*

In 1967, Blum (1) reported that 43 percent more sap was obtained from closed tubing installations on slopes than from open or vented tubing. He associated this increase with the natural vacuum created in the closed tubing. Gains in sap yield from natural vacuum[1] are especially important, since the collection of sap is the most costly and least profitable phase of making maple syrup. Moreover, sap costs for a tubing network are mostly fixed costs; increased sap flow from natural vacuum represents added profit with little or no added cost. Recently, Laing *et al.* (6) showed that sap produced with high vacuum differed little in chemical composition from sap produced without vacuum; both yielded syrup of comparable high quality.

While Blum's research results were exciting, they prompted numerous questions, answers to which were needed before successful field application of natural vacuum and tubing techniques could be assured.

The key questions were:

How does number of tapholes per tube line affect natural vacuum?
How does slope affect natural vacuum?
How do results vary by season and locality?
Where should vacuum be measured?

Is natural vacuum more effective at slow or fast flow rates?
What limits the production of natural vacuum?
What are optimum conditions for natural vacuum?
How does production with natural vacuum compare with pumped vacuum?

Our research commenced in 1968 with an attempt to answer the first two questions. In succeeding years it was extended to three localities and broadened in scope to gain information on the other questions. Altogether, about 4500 experimental tapholes were used, including 2000 in 1971. Moreover, in 1970 and 1971, tests were made of water flow through tubing to acquire theoretical knowledge concerning vacuum and flow rates, so that results of field tests could be properly interpreted.

Procedures

All experiments compared sap flow with natural vacuum in closed tubing with sap flow without vacuum in vented tubing or with sap flow with pumped vacuum in closed tubing. Naturalflow[2] tubing, with an inside diameter approximating 0.3 inch, and fittings were used. All tubing was suspended in the air; it was supported by wooden props where distance between trees exceeded 25-30 feet. Tubing was run from tree to tree without tee lines, except in 1971 when 20 percent of the tapholes were on tee lines in the upper half of some installations. Tapping dates were consistent with commercial operations; all experiments lasted throughout the season.

Localities

Experiments were made at our Heaven Hill sugar bush near Lake Placid, New York, in all years. It features steep slopes and a high elevation; most sap flow is delayed until April and the season often is short. Other experiments were made near Chazy, New York, at the Miner Institute sugar bush during 1970 and 1971. It is higher and colder than most neighboring bushes and sap production has been low to moderate. Supplemental experiments were made at the Arnot Forest sugar bush, located southwest of Ithaca, New York. It is the warmest bush and commonly has early flows and good production. In all bushes the trees are mostly 1-bucket size (10-16 inches), nearly the same age (about 70-100 years), and usually slow in growth. The three bushes will be referred to as Heaven Hill, Chazy, and Arnot.

Experimental Design

The principal method used was that of *paired tapholes* (fig. la). It is similar to the one used and described by Blum (1). Each tree was tapped twice, about 6-8 inches apart, and two tubing lines connected trees in installations that were identical in number of taps, taphole exposure, slope, tube length and sag, and other factors. All tapholes were treated equally–sound wood, equal tapping depth (usually 2 inches), and one paraformaldehyde pellet. All equipment was the same and was cleaned before being installed. The only difference was in the treatment – such as closed vs. vented tubing or natural vs. pumped vacuum. Since paired tapholes make use of the same trees for each treatment, much variation in sap flow is eliminated. Therefore little replication is needed to show differences between treatments.

Research conducted by the U. S. Forest Service (3) showed that sap is not ordinarily drawn laterally from the vicinity of one taphole to another 6 inches away when vacuum is applied. Nevertheless our experiments with paired tapholes have produced enough more sap under vacuum to suggest that the experiments may be biased. Paired tapholes clearly show which of two treatments is better, but we suspect that they may not show how much better. Therefore, in 1971 both paired tapholes and *paired trees* were used. In the latter, two adjacent lines or groups of trees were selected on the basis of similarity in bole size, crown size, vigor, and exposure. The two treatments were then applied to the two tree lines, on a random basis, with precautions to achieve equality in tapholes, tube installation, and topography. To reduce bias from tree differences, the treatments were reversed from one to the other line of trees at midseason.[3] Our use of paired trees in lines may have been insufficient to show significant results in some cases. However, the results concur generally with those obtained from paired tapholes; they strengthen our overall conclusions.

Figure la. *Paired tapholes; vented and closed.*

The experiments, whether using paired tapholes or paired trees, were laid out in successive lines of trees so that the effect of numbers of tapholes and slope on vacuum and sap flow could be evaluated. The groups of trees were usually close together, and trees of similar quality were used. Insofar as possible, lines testing the same slope were adjacent, but with differing numbers of tapholes. At Chazy, however, there were fewer steep slopes and trees from which to choose; therefore a few treatments were located in an adjacent forest about a mile distant. Such separation of experimental trees sometimes produced different flow rates because of different local microclimates. Such flow differences might influence the interaction of slope or numbers of taps and vacuum on sap flow, although no such influence is readily apparent. On the other hand, there would be no influence on sap flow comparisons between primary treatments.

[3] In 1971, the treatments were also reversed from one tap to the other in the paired taphole experiments at midseason.

Precautionary Techniques

To further assure both proper and equal installations, the following field procedures were used: Care was taken to drill straight with slow-speed tappers (700-1200 RPM). Drop lines were equal; looping below tube line was avoided (fig. la and lb). Tapholes and drop lines were checked for soundness and leaks, both at time of installation and removal, by trying to suck air from the installed drop line. All vents contained a piece of bent tubing to reduce microorganism entry (fig. la). Tapholes were inspected at season's end for gross differences in amount of microorganisms; no apparent differences were found between tapholes assigned to different treatments. Most trees had a single pair of tapholes. A few of the larger trees (about 10 percent of total of all trees) had two pairs of tapholes. Comparable tube installations used similar amounts of tubing; most averaged 18-20 feet per taphole.

Figure 1b. *Vacuum was measured in closed-tap installations after attaching gauge and opening petcock. (Arrow indicates petcock.)*

Average, maximum, and minimum slope of tube lines. Slope is defined as the vertical distance (between the highest and lowest tapholes) divided by the tubing length or distance (corrected to show horizontal rather than slope distance), expressed as a percent. Maximum and minimum slopes are defined as the slopes of the tube lines for 5 successive tapholes at the steepest and smallest gradients; they show the variation in slope. The accuracy of average slope figures is within 1 percent; for example, a 20 percent slope may be between 19 and 21 percent.

Amount of sap flow. Converted to quarts per taphole for each major sap run.

Vacuum in inches of mercury. Measured at top of tube lines. Experience has shown that, for natural vacuum, readings are highest where tubes are empty at upper elevations. Vacuum may drop sharply at the lower tapholes if tubes are filled with sap. Thus natural vacuum readings tend to be maximum rather than average readings. On the other hand, there is less difference between upper and lower pumped vacuum readings. Vacuum loss from tube lines during measurement was avoided by use of a petcock at measurement points (fig. Ib).

Sugar percentage differences between treatments, measured by refractometer.

Sap flow rate in quarts per minute, measured simultaneously with vacuum on natural vacuum lines.

Midseason sag in tube lines. At Heaven Hill, average sag was nearly 1 foot. At Chazy in 1970, special efforts were made to pull tubing tight; as a result, the sag averaged less than 6 inches (fig. Ic and Id).

Early Results

1968

An experiment was installed at Heaven Hill to test the effect of slope on sap flow in closed and vented tubing. On each of a dozen different slopes, installations with 20 paired tapholes were made. However, 1968 was the infamous peak year for rodent damage to tubing. Squirrels were especially abundant and harmful. They specialized in biting the black caps used to close the vent spiles.[4] As a result, most tube lines were partially vented, little vacuum was formed, and there was no significant difference in flows from paired tapholes. The experiment was useful in pointing out the limitations of natural vacuum; it is affected by air leaks caused by rodent damage, poor fittings, or careless installation.

Figure 1c. *Very little sag was allowed in tube lines at Chazy in 1970.*

Among the vented lines, there was a general correlation between sap flow and slope. The sap flow on a 25 percent slope was twice that on a 1 percent slope; intermediate flows occurred on 5 to 15 percent slopes. This relationship seems appropriate since there is more tube friction on shallow slopes; also there is more sap loss from vent leaks. On the other hand, steep slopes appear to eliminate problems of sap flow through vented tubing. This is an important factor in interpreting sap flow experiments that seek relationships between slope and vacuum influences.

In addition to the above experiment, an installation with 50 paired taps was made on a 5 percent slope. After early season rodent damage was repaired, it was noted that the closed tubing had markedly more sap flow than the vented tubing. During early April the closed tubing often had 5 to 7 inches of vacuum; it yielded 50 percent more sap than the vented tubing. In fact it out yielded all but one of the other installations.

Finding a substantial increase in sap flow in a 50-tap line was of special significance. First it showed that the tubing used in maple sap networks had more capacity than previously thought. Even more important, it showed for the first time that the number of tapholes on a line might significantly influence the amount of vacuum and sap flow. Our experimental designs in succeeding years were fundamentally changed to test the influence of number of tap-holes per line.

1969

An experiment to test the effects of both slope and numbers of taps on sap flow in closed and vented tubing was made at Heaven Hill. Paired taphole installations included 15, 30, and 50 tapholes each at slopes of 5, 11, and 17 percent. Table 1 shows the sap flow in quarts per tap-hole by sap run for the 1969 season. Table 2 depicts some of the effects of slope and numbers of tapholes on seasonal sap flow in closed and vented tubing. The steeper slopes yielded more additional sap in the closed tubing than the 5 percent slope. On land with shallow slopes of 5 percent or less, it is difficult to install tubing quickly without an occasional error in tap location that may force sap in the tubing to run uphill. This may cause leakage through vents or dissipation of vacuum. Although shallow slopes may cause difficulty in sap flow through either closed or vented tubing, we found that the closed

Figure 1d. *More typical installation at Heaven Hill.*

Table 1. *Sap flow in closed and vented tubing, by slope and numbers of taps. Heaven Hill – 1969*

Slope percent	5						11						17					
Slope variation	2–8		2–6		2–6		8–18		8–13		8–13		10–20		10–20		11–23	
No. of tapholes	15		30		50		15		30		50		15		30		50	
Date	*																	
March 23–24	4.0	3.7	3.8	3.2	3.6	3.3	5.9	4.3	4.7	4.0	3.6	2.6	5.4	5.9	4.8	4.5	4.2	3.9
March 28–29	.8	.8	2.0	1.4	.9	1.1	2.5	1.6	1.9	1.2	1.1	.8	1.3	1.6	1.7	1.3	1.9	1.1
April 4–5	2.4	1.9	3.2	2.5	3.0	3.2	4.1	3.6	3.8	2.6	3.8	2.0	5.2	5.1	3.6	3.3	4.1	3.1
April 6–9	6.4	5.5	5.3	2.5	5.9	5.4	7.6	5.9	7.3	4.5	7.9	4.0	8.8	6.7	7.2	5.9	8.1	4.8
April 11–13	5.9	4.0	5.7	3.6	5.8	4.9	6.7	3.7	5.3	4.4	7.6	4.4	8.3	6.4	6.1	4.7	6.9	3.9
April 20–22	8.3	6.7	7.7	5.0	6.3	5.4	6.9	6.1	6.4	4.7	7.0	4.2	11.7	9.3	6.4	5.5	9.1	4.9
Season total	27.8	22.6	27.7	18.2	25.5	23.3	33.7	25.2	29.4	21.4	31.0	18.0	40.7	35.0	29.8	25.2	34.3	21.7

**Data are quarts per taphole. Closed tube data on left, vented tube data on right, of each column.*

tubing was superior. Nevertheless we prefer pumps wherever possible to create vacuum and more sap flow on slopes of less than 5 percent.

It is of interest that for the closed tubing the 11 percent slopes produced larger gains than the 17 percent slopes. Perhaps this is partly because sap flow in vented tubing is at its best on the steepest slopes; consequently the gains for closed tubing on very steep slopes are relatively less than on medium slopes.

Except for the 50-tap line on the 5 percent slope (which showed a 50 percent superiority for sap flow in the closed tubing in April 1968), increases in the number of taps were associated with further superiority of sap flow in the closed tubing. Unfortunately we were able to obtain only a few vacuum readings during the year. They were generally low (average of 3 inches, maximum of 11 inches mercury

Table 2. *Increase in sap flow in closed tubing, by slope and numbers of taps. Heaven Hill —1969*

Treatment		*Yield per taphole*			*Percent increase*
		Closed	*Vented*	*Difference*	
			— quarts —		
5%	15 taps	27.8	22.6	5.2	23
	30 taps	27.7	18.2	9.5	52
	50 taps	25.5	23.3	2.2	9
11%	15 taps	33.7	25.2	8.5	34
	30 taps	29.4	21.4	8.0	37
	50 taps	31.0	18.0	13.0	72
17%	15 taps	40.7	35.0	5.7	16
	30 taps	29.8	25.2	4.6	18
	50 taps	34.3	21.7	12.6	58
5%	combined	27.0	21.4	5.6	26
11%	combined	31.4	21.5	9.9	46
17%	combined	34.9	27.3	7.6	28
15 taps combined		34.1	27.6	6.5	24
30 taps combined		29.0	21.6	7.4	34
50 taps combined		30.3	21.0	9.3	44
Overall mean		31.1	23.4	7.7	33

in comparison with those obtained in succeeding years and showed little relation to sap flow.

Altogether the closed tubing, even with low vacuum, was significantly better, by a third, than the vented tubing. Nevertheless it became more clear that the relationships between natural vacuum and sap flow were complicated. Of special concern was the inability to explain the superiority of large numbers of tapholes. Theoretical knowledge of sap flow and vacuum under controlled conditions was necessary to understand the field experiments.

Vacuum and Flow Rate – Theoretical Considerations[5]

Standing Sap Columns

Atmospheric pressure equals approximately 14.7 pounds per square inch. This will support a column of water of about 33 feet or a column of mercury of approximately 29 inches.[0] If water enters through the top of an open piece of tubing and the top is then sealed, up to 33 vertical feet of water will be supported (even if the bottom of the tubing is open). The weight of this water creates a vacuum in proportion to its height. For example, 11 feet of water will cause one-third of the maximum vacuum or a little less than 10 inches of mercury. Thus the first prerequisite for vacuum in a tube line is a lot of sap, preferably enough to fill the tube to at least a height of 30 feet.

Vertical columns of sap form rather easily in the lower portions of tube lines. The tube itself is small, with resultant high friction and some capillarity; thus tubes do not empty easily. Any dip or sag in the tube line can cause a column to start; there is usually some sag between trees. At the beginning of a sap flow, the amount of sap from the tapholes may exceed that flowing out of the tube line and the sap column is built up. Eventually a pressure equilibrium is reached wherein the sap inflow from the taps equals the outflow at the lower end of the tubing. It is probable that changes in equilibrium and sap columns occur throughout the sap run. As the sap flow dwindles near the end of a run, the sap column can be expected to lower. The effect of mixtures of sap and gas in a column is not clear; we suspect that slow runs with high proportions of gas may create little vacuum. However, excellent runs have been observed to create a nearly gas-free column of sap with a vertical height of 75 feet.[7] Much smaller columns are more typical; also sap columns may remain in tight tubing installations between runs.

Pressure and Flow Rate

While the vacuum associated with a standing column of sap is easily predicted, the vacuum (negative pressure) associated with moving sap or combinations of sap and gas is less well understood. Hydraulic engineers have long known that flowing water creates head loss and more pressure (less vacuum); as flow rates increase, pressure may change from negative to positive. In view of this, the *decreased* pressure (greater vacuum) associated with more tapholes and faster flow rates was especially puzzling. Therefore a series of tests was made, using Natural flow maple tubing, to find relationships between pressure and flow rate. These tests were conducted in a 6-story laboratory that permitted a total vertical drop of 60 feet and injecting water into the tubing at 5 points that were 12 feet apart in elevation. By winding maple tubing around posts at each floor level, different tube lengths and slopes could be simulated. Water flow to the tubing at different elevations could be regulated to simulate different sap flow rates.

A deficiency of the experiments was an inability to control the room temperature (70°F. or higher) and the water

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[5] *This portion of the research was principally accomplished with the guidance and cooperation of Prof. Terry, using the engineering facilities of Cornell's Riley Robb Hall.*

[0] *14.7 pounds per square inch (PSI) of air, 33 feet of water, and 29 inches of mercury (vacuum) are approximately equivalent. Thus 1 PSI is nearly equivalent to 2 inches of vacuum, and 1 inch of vacuum is roughly equivalent to 1 foot of supported water.*

temperature (40-60°F.). These warm temperatures led to a substantial amount of tube collapse (at 10 or more inches of vacuum) which increased friction and slowdown of the lower flow rates. Tubes collapse far less in the field because temperatures are much colder; also, most collapse is in the upper part of the installation, coinciding with maximum vacuums and minimum amounts of sap (sap from fewer tapholes enters the upper tubing). In general we followed a procedure of cooling the tubing by running cold water through it between tests. Nevertheless, duplication of absolute values of pressure-flow rate relations should not be expected in the field. Similar relative values and trends, however, may be expected in both the laboratory and the field.

Figure 2 shows typical curves, familiar to hydraulic engineers, that resulted from continuous flow when water was admitted only at the upper end of the tubing. As expected, low flow rates caused less head loss and more negative pressure (vacuum). Longer lines have more head and more vacuum for the same flow rate; they also have faster flow rates. Finally, steeper slopes[8] cause reduced friction and head loss; both flow rate and vacuum are increased. Thus, low flow rates, long lines, and steep slopes all tend to increase vacuum.

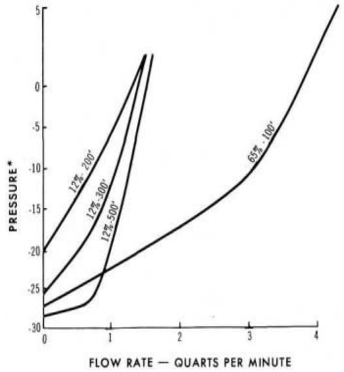
The curves of figure 2 do not simulate sap flow conditions, since the only source of water was at the upper end. Under field conditions, sap may enter the tubing at any level, depending on location of trees. This condition can be closely simulated by allowing near-equal amounts of water to enter the tubing from 5 sources of successively equal lower levels - at 60, 48, 36, 24, and 12 feet. Figure 3 shows a comparison of pressure-flow rate curves for this situation and the one depicted earlier in figure 2. High temperatures and variable amounts of air in the tube line caused variation in results at the lower flow rates; this is shown by the dashed portion of the curves.

It is clear that, where water enters tubing from several sources as in maple sap situations, an entirely different type of pressure-flow rate curve occurs. First of all, there is less water in the upper tubing. Consequently there is less friction loss and both more flow and relatively more vacuum at the faster flow rates than when water enters at the top only. Secondly, at low flow rates (about a quart per minute or less) vacuum *decreased* as flow rates decreased. This most important finding substantiates our field results – that is, more vacuum with faster flows occurs with large numbers of tapholes. Also, sap flow rates from sugar maple seldom exceed 1 quart per taphole per hour for very long (all 1971 flows at Heaven Hill and Chazy were at less than this rate). Therefore a tube line with 60 taps will have a flow rate that seldom exceeds 60 quarts per hour or 1 quart per minute. For most field installations then, more vacuum can normally be expected with the better flow rates.

Loss of Vacuum At moderately fast flow rates, it appears that the flow is continuous and pressure-flow rate relations are normal.

Fig. 2. *Typical pressure-flow rate curves for varying slopes and lengths of maple tubing for water source at top only.*

- *Negative pressure in inches of mercury; positive pressure in pounds per square inch.*



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[7] This occurred in a 50-tap line on a 10 percent slope. The tube was filled for three-fourths of its length, vacuum was 23 inches, much of the upper tubing was collapsed, and sap flow through the tubing was continuous and rapid.

[8] *The effect of tube size is predictable. The larger of two tube sizes would have reduced friction and head loss. It would have an effect much like that of a steeper slope.*

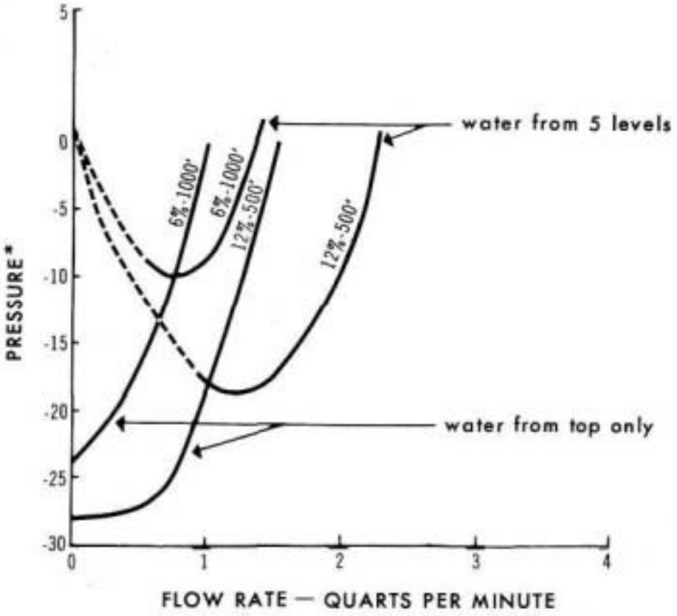


Figure 3. *Comparison of pressure-flow rate curves between 1and 5 sources of water.*

Negative pressure in inches of mercury; positive pressure in pounds per square inch. A

At lower rates, the flow becomes discontinuous and this may be a principal cause of vacuum loss. Because there is less water in the upper than in the lower tubing, flow rates fluctuate unevenly. Water may accumulate in a portion of the upper tubing for a time; then it is released in a slug flow. Discontinuous or slug flow is more apparent at the slowest flow rates; this coincides with maximum vacuum loss.

A comparison was made between flows in tubing without sag and flows in tubing with vertical loops which forced uphill flow. At slow flow rates these loops caused a marked reduction in vacuum. Presumably vacuum was dissipated in the process of siphoning water uphill. The effect on vacuum of gas emitted from tapholes is unknown. Fast flow rates may remove gas from the tube line quickly, while slow rates permit it to remain and possibly reduce vacuum. We conclude that, in slow and discontinuous flows, vacuum loss is associated with the nature of the flow, sags or loops in tubing, and possibly gas from the tapholes.

Uneven Slopes

Starting with a 12 percent slope (500 feet of tubing with a 60-foot elevation drop), the even slope was interrupted by adding 100 feet of coiled tubing at different floor levels. This simulated a level stretch of 100 feet at various points in an otherwise downhill slope. It is well known that the friction loss of sap flow through tubing is increased with decreasing slopes. The amount of increased friction and its effect on sap flow, however, is often not appreciated. When the 100 feet of tubing was added at the first floor (12 feet), where all the water had to pass through it, increased friction markedly reduced both the flow rate and vacuum. The vacuum was generally less than half that previously experienced for the same flow rates.

Placing the added 100 feet of tubing at the 60-foot level, where only 20 percent of the water had to flow through it, had less severe effects. A strong vacuum was maintained on the lower side (greatly reduced vacuum on the upper side) of the added coil of tubing. When the 100-foot coil was added at the 30-foot level, intermediate effects were found but the level of vacuum was markedly reduced. Thus, level stretches of tubing cause much vacuum loss when located at the base or lower portions of a hill and little loss when located at the top of a hill.

Summary

Numerous tests of pressure-flow rates were made with maple tubing in the laboratory. Typical curves are presented in figures 2 and 3. Exact duplication of results under field conditions is not expected because of variations in such factors as height of sap column, temperature, and gas. For example, an 80-tap line on a steep slope at Heaven Hill had 20 inches of vacuum with a flow of only .37 quart per minute or double that indicated by laboratory results. However, in the field, both the elevation and the sap column were higher than the 60-foot limit in the laboratory. Nevertheless, the laboratory data indicate the conditions favorable to production of natural vacuum. These conditions are: A high column of sap to permit a good head – obtained by steep slopes and/or long lines; also sufficient numbers of tapholes per line.

A fast flow rate – obtained by numerous tapholes per line; also vigorous trees, good sap flow weather, etc.

Reduction of sag in tube lines as far as practical.

Avoidance of shallow slopes, especially in the lower and middle portions of tubing installations.

Field Results –1970

The 1970 experiments were considerably enlarged over those of the previous year. Sap flows in closed and vented tubing were compared on 3 slopes, for a range of 5 to 50 tapholes per line, and in 2 climatic localities. Also in a few vented installations, the Naturalflow tubing connecting trees and drop lines was replaced by half-inch plastic water pipe (fig. la).

Ten or Fewer Taps

Table 3 shows that there was little difference in sap flow between closed and vented tube lines with few tapholes. The steeper slopes appeared to be slightly better. Vacuum was either nonexistent or low. Of 50 measurements during sap flows, only 18 indicated any vacuum, and the maximum reading was less than 3 inches.

Our laboratory tests suggest that these results are normal and predictable. Very little vacuum can be expected because there was too little elevation difference in the tube lines to permit a high sap column or head and, even more important, the few tapholes provided too little sap for either a high column or more than a minimum flow rate. Thus the physical conditions for creating a good vacuum in the closed tubing were lacking; therefore there was little difference in sap flow.

Table 3. *Sap flow in closed and vented tube lines with 10 or less tapholes — 1970*

Treatment			*Yield per taphole*		
Slope	*No. taps*	*Locality*	*Closed*	*Vented*	*Difference*
				— quarts —	
	5	Heaven Hill	29.4	29.2	.2
6%	10	Heaven Hill	27.3	24.0	3.3
	10	Chazy	19.4	22.5	−3.1
	5	Heaven Hill	23.2	22.6	.6
11%	10	Heaven Hill	29.5	28.4	1.1
	10	Chazy	23.5	20.7	2.8
	5	Heaven Hill	26.6	22.6	4.0
16%	10	Heaven Hill	37.4	34.2	3.2
	10	Chazy	26.7	22.6	4.1
6% combined			25.4	25.2	.1
11% combined			25.4	23.9	1.5
16% combined			30.2	26.5	3.8
5 taps combined			26.4	24.8	1.6
10 taps combined			27.3	25.4	1.9
Overall mean			27.0	25.2	1.8

Twenty-five to Fifty Taps

Tables 4 and 5 give the 1970 data for the many-tap installations by major flow periods. The closed tubing was superior in most installations and most sap runs, but there were exceptions. Apparently particular sap flow conditions, such as flow rate or temperature, can influence the relative value of closed tubing. For example, a small flow

Table 4. *Sap flow in closed and vented tubing, by slope and numbers of taps. Heaven Hill—1970*

Slope percent	5				10				15			
Slope variation	2–6		2–6		8–13		8–13		10–20		11–23	
No. of tapholes	30		50		30		50		30		50	
Date	*											
March 22–28	7.2	8.2	9.8	6.9	9.2	8.5	10.4	6.2	9.1	7.3	12.3	6.7
April 1–2	1.8	2.0	2.4	1.7	2.2	2.0	2.6	1.6	2.3	1.8	3.1	1.7
April 6–9	3.2	3.6	4.3	2.6	4.6	3.5	3.8	3.0	2.9	2.7	4.9	2.2
April 12–16	7.9	6.6	10.6	6.7	14.1	5.7	8.5	6.6	6.7	6.4	9.6	5.2
April 19–20	5.0	3.7	6.1	3.4	7.5	3.3	7.3	3.7	3.2	3.5	3.8	3.0
April 23	1.8	2.6	2.9	1.7	3.7	3.3	6.6	2.0	2.4	1.6	2.7	1.9
Season total	26.9	26.7	36.1	23.0	41.3	26.3	39.2	23.1	26.6	23.3	36.4	20.7
Mean vacuum†	3		6		3		16		0+		10	

**Data are quarts per taphole. Closed tube data on left, vented tube data on right, of each column. -fData are inches of mercury; mean of 5 measurements made during sap flows*

Table 5. *Sap flow in closed and vented tubing, by slope and numbers of taps. Chazy — 1970*

Slope percent	5						10						15					
Slope variation	3–7						8–12						13–17					
No. of tapholes	25		25*		50		25		25*		50		25		25*		50	
Date	†																	
March 18–20	.7	1.0	.9	1.1	1.3	1.0	1.6	.3	1.4	1.0	1.0	1.7	1.3	1.3	1.6	1.2	3.0	1.1
March 25–28	4.2	4.8	9.2	5.3	9.7	3.5	12.2	3.1	14.3	5.3	11.2	6.4	7.3	4.2	9.2	3.5	9.6	3.4
April 1–6	4.9	3.2	4.7	4.4	6.5	2.5	7.6	2.0	9.6	5.5	8.4	2.6	8.8	5.5	10.8	6.9	11.2	4.9
April 11–12	1.7	1.7	4.3	1.8	2.9	1.1	2.6	.5	5.5	1.1	7.6	.8	2.6	1.2	2.0	1.3	4.5	.8
April 16–20	2.1	2.7	7.3	2.9	3.6	2.0	6.3	3.4	7.8	2.2	12.1	.9	1.7	1.6	2.0	1.3	2.1	.8
Season total	13.6	13.4	26.4	15.5	24.0	10.1	30.3	9.3	38.6	15.1	40.3	12.4	21.7	13.8	25.6	14.2	30.4	11.0
Mean vacuum‡	0+		6		10		4		10		19		3		5		10	

**Half-inch water pipe between trees and drop lines.*

†Data are quarts per taphole. Closed tube data on left, vented tube data on right, of each column.

‡Data are inches of mercury; mean of 7 measurements made during sap flows.

may create no vacuum, while the vented tubes would empty more easily. There was a tendency for closed tubing to be relatively better near the end of the season in some, but not all, installations; for example, the 10 percent, 50-tap line at Chazy.

Season-end checks revealed 3 tube lines with leaks, as follows:

Heaven Hill: 15%, 30-tap, closed line. Leak at uppermost tee; taphole in hollow wood in one of the upper trees; relatively more sap on April 23 after leaks were removed. Leak was predicted because of negligible vacuum throughout the season.

Chazy: 5%, 25-tap, closed line. Numerous leaks caused by oversize tubing which did not properly fit tees and spiles. Leaks were predicted because of negligible vacuum throughout the season.

Chazy: 10%, 25-tap, vented line. Leak near base of tube line. Vented line had relatively better flow after leak was corrected on April 15. The seasonal total of 9.3 quarts per taphole is low and not suitable for comparison with flow in the closed tubing.

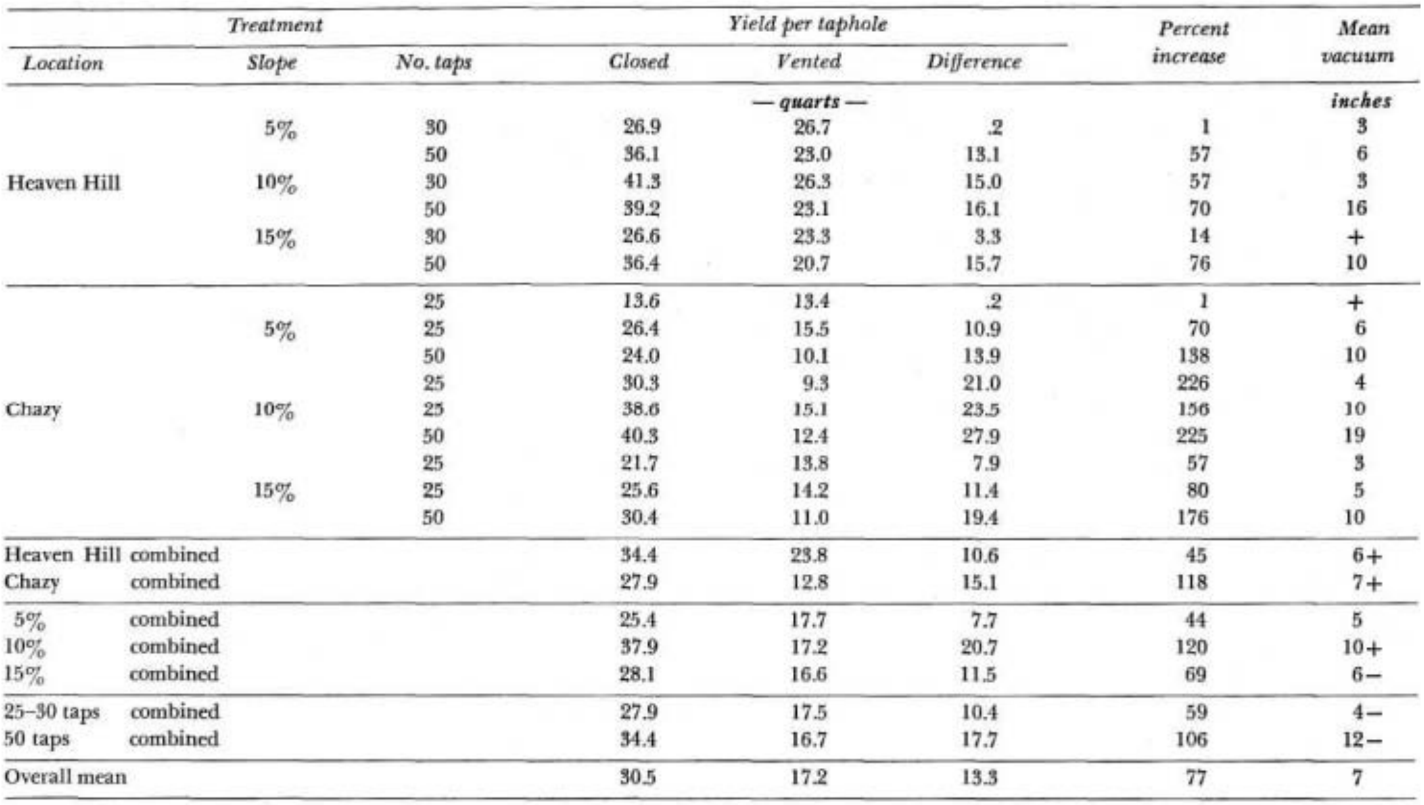
Since a leaky installation is a normal hazard of either closed or vented tubing, the results of these three tube lines are retained in the data in table 6. However, data from the two leaky closed lines are omitted from the vacuum comparison in table 7. Also data from the leaky vent line and the companion closed line are omitted in figure 4. Table 6 shows the marked increase in seasonal sap flow from closed tubing, the general relationship between sap gain and vacuum, and interactions of slope, numbers of taps, and locality. Of particular interest is the difference between localities. Closed tube installations at Heaven Hill produced 45 percent more sap than vented tubing. This is comparable with the 43 percent reported by Blum

(1)and the 33 percent increase found at Heaven Hill in 1969. But at Chazy there was a gain of 118 percent, more than ever previously measured. Perhaps this gain was due partly to the extremely careful installation at Chazy (an abney level was used between each tree to maintain tube slope within 2 percent of the mean; most sag was eliminated by pulling the tubing tight after installation) compared with the more normal and easily applied installation at Heaven Hill. Also the high percentage gain was due in part to abnormally low production in the vented lines at Chazy. This suggests that gains are more meaningful when expressed in seasonal totals; the total gain at Chazy was not unduly greater than at Heaven Hill (15.1 vs. 10.6 quarts per tap). Finally, the low production in the vented lines at Chazy is puzzling. We might suspect that vacuum drew some sap from one to the other of the paired tapholes. This possibility influenced us to use paired trees in addition to paired tap holes in the 1971 experiments.

As expected, sap gains in closed tubing were better for 50-tap installations than for the 25- or 30-tap lines. Without exception, 50-tap lines were superior in both vacuum and sap gain for each slope at both Chazy and Heaven Hill. For the season they produced an average of 8 more inches of vacuum and over 7 quarts of sap per taphole. Clearly, the large amount of sap from numerous taps is most important in making high sap columns, increased flow rates, and resultant high vacuums. The high vacuums in turn are correlated with large increases in sap flow.

The sap gains and vacuum in closed tubing were much better for the 10 percent than for either the 5 or 15 percent slopes. This substantiated the 1969 results. Ten percent slopes are clearly better than 5 percent slopes where tubing must be very carefully installed to prevent vacuum losses. For closed tubing, 10 percent slopes may be superior to steeper slopes for two reasons. First, there is less friction on steeper slopes which are optimal for vented tubing. Second, figure 3 shows that flow rate must increase with rise in slope for best results; if there are too few taps, both flow rate and sap column height may be limited. This should result in lower vacuums on very steep slopes and appears to do so, since the mean vacuum on the 10 percent slopes considerably exceeded that on the 15 percent slopes (10 + vs. 6 –). Conversely, more tapholes – perhaps a hundred – are needed for optimal vacuum on 15 percent slopes.

Table 6. *Increase in sap flow in closed tubing, by slope and numbers of taps —1970*

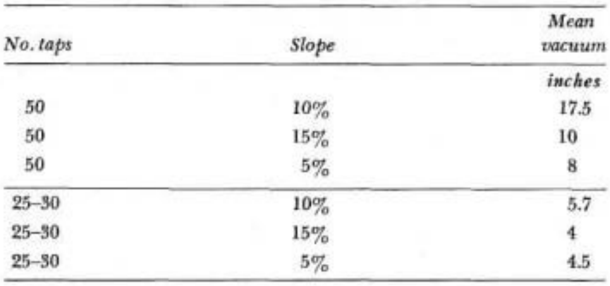


Treatment			*Yield per taphole*			*Percent increase*	*Mean vacuum*
Location	*Slope*	*No. taps*	*Closed*	*Vented*	*Difference*		
				— quarts —			*inches*
Heaven Hill	5%	30	26.9	26.7	.2	1	3
		50	36.1	23.0	13.1	57	6
	10%	30	41.3	26.3	15.0	57	3
		50	39.2	23.1	16.1	70	16
	15%	30	26.6	23.3	3.3	14	+
		50	36.4	20.7	15.7	76	10
Chazy	5%	25	13.6	13.4	.2	1	+
		25	26.4	15.5	10.9	70	6
		50	24.0	10.1	13.9	138	10
	10%	25	30.3	9.3	21.0	226	4
		25	38.6	15.1	23.5	156	10
		50	40.3	12.4	27.9	225	19
	15%	25	21.7	13.8	7.9	57	3
		25	25.6	14.2	11.4	80	5
		50	30.4	11.0	19.4	176	10
Heaven Hill combined			34.4	23.8	10.6	45	6+
Chazy combined			27.9	12.8	15.1	118	7+
5% combined			25.4	17.7	7.7	44	5
10% combined			37.9	17.2	20.7	120	10+
15% combined			28.1	16.6	11.5	69	6–
25–30 taps combined			27.9	17.5	10.4	59	4–
50 taps combined			34.4	16.7	17.7	106	12–
Overall mean			30.5	17.2	13.3	77	7

Relation of Sap Gain to Vacuum

From 5 to 7 vacuum measurements were made in each installation during flows throughout the season. This is insufficient to suggest accurately a true mean vacuum for

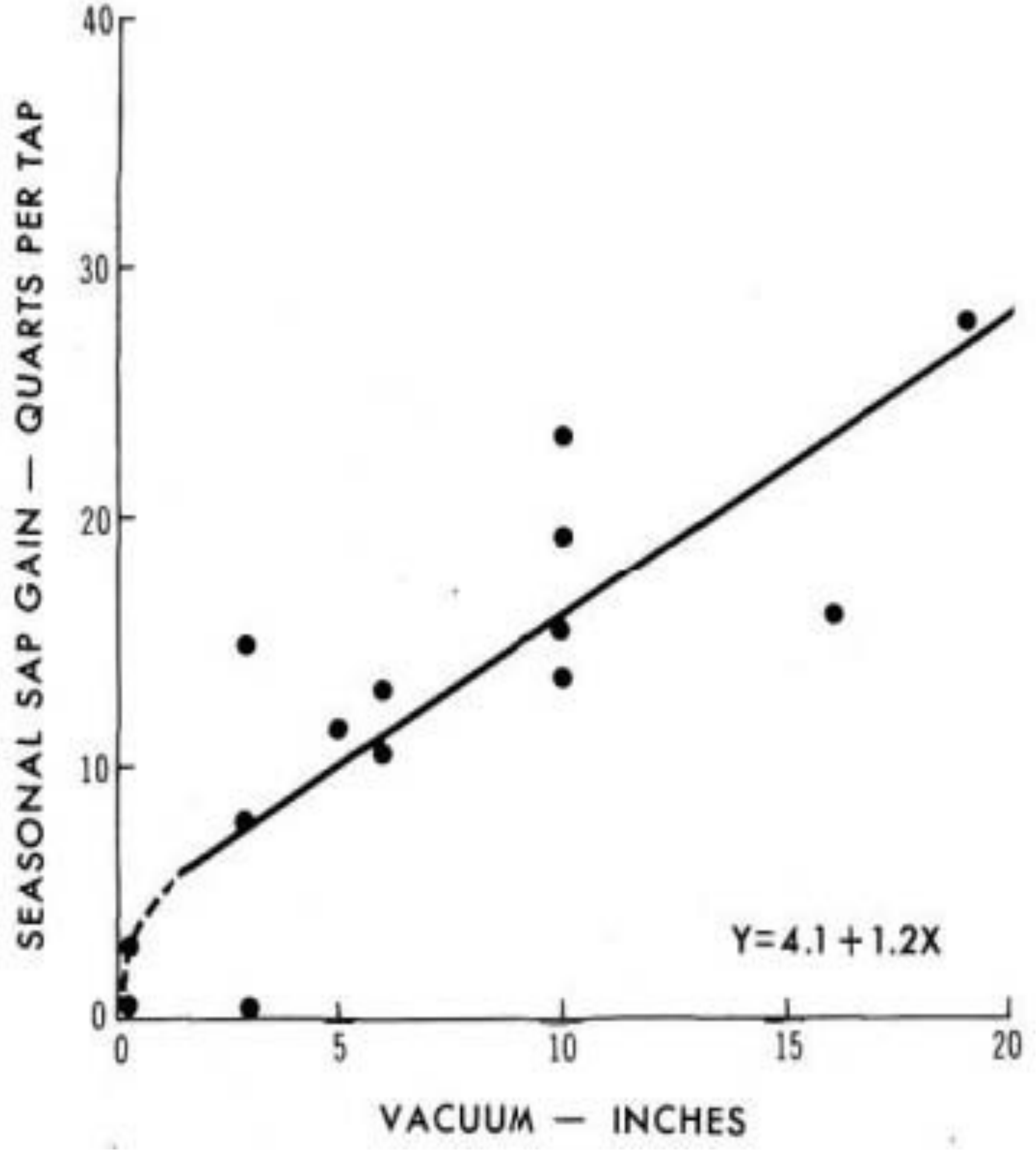
Table 7. *Relationship of vacuum to numbers of taps and slope. Heaven Hill and Chazy –1970*



No. taps	*Slope*	*Mean vacuum*
		inches
50	10%	17.5
50	15%	10
50	5%	8
25–30	10%	5.7
25–30	15%	4
25–30	5%	4.5

the season. Nevertheless there was a close relationship between the mean of the vacuum measurements made and the increased seasonal sap yields in the closed tube installations. Figure 4 shows this relationship. The linear re-gression Y (sap gain in quarts per taphole) = 4.1 + 1.2X (mean vacuum) was computed. The correlation coefficient is .84 and is significant at the 0.01 level. The regression accounted for 70 percent of the variation in sap gain.

Figure 4. *Relation of seasonal yield increase and natural vacuum –1970.*



Since vacuum is so important to increased sap flow, it is necessary to understand the physical conditions that contribute to it. Large numbers of taps and 10 percent slopes were associated with high vacuums. Therefore in table 7, the factors of numbers of taps and slopes are ranked in decreasing order of their importance to producing vacuum. Again the significance of many tapholes is most important in producing high natural vacuums. Next in importance for our installations was a slope of about 10 percent.

Closed Tubing vs. Other Methods

Three of the vented installations at Chazy had half-inch plastic pipe to carry sap downhill. Thus sap flow was not restricted. Since the use of half-inch pipe did not cause results that differed significantly from comparable installations with small tubing, we conclude that gains from the use of closed tubing are real – that they cannot be attributed to deficiencies in the vented tubing. Also closed tubing would have similar gains over buckets.

Field Results –1971

Natural Vacuum The 1971 experiments principally compared two treatment methods – paired tapholes and paired trees. In the latter adjacent lines of similar trees, each tapped once, were used to compare sap flow in closed and vented tubing. In midseason the treatments were reversed by closing or capping all vented lines and venting each taphole in the closed lines. Most test lines were installed at 12 percent slopes with 40 tapholes; two 80-tap comparisons and one of 20 taps were made. Results are shown in table 8.

For reasons unknown, one of the 80-tap vented lines out flowed the closed line, even though some vacuum was formed in the latter. The other 80-tap lines performed as expected; the sap flow from the closed line was twice that from the vented line. Also the closed 20-tap line was superior to the vented line, but the sap gain was less than in the 40-tap lines.

Results of all test lines, excepting the aberrant 80-tap line, were combined to compare the two methods (table 9). It is apparent that much less sap per taphole was obtained in the paired taphole experiments where the trees were double-tapped. I have shown (8) that multiple taps on otherwise similar trees reduce the sap flow from each taphole. In addition, the paired tree tests used somewhat younger and more vigorous trees; this would tend to enhance sap flow. It is also likely that the higher flow rates in the paired trees contributed to the higher vacuums recorded for this method.

When comparing the two methods on a percentage basis, there was more sap gain with less vacuum by the paired taphole method.[9] This suggests a bias that may cause the method to overestimate the value of closed tubing. Paired tapholes have an opposing bias, however, since added taps tend to reduce the amount of sap per tap and possibly the differences between treatments. This is suggested by the small difference in total sap gain (14.9 vs. 13.1 quarts per tap) between the paired taphole and paired tree methods. Such large gains by both methods confirm that consistent and substantial gains may be obtained from the use of closed tubing and natural vacuum.

8If data from the aberrant 80-tap test line were included, the 92 percent increase for closed tubing by the paired taphole technique would be reduced to 50 percent.

Table 8. *Comparison of sap flow in closed and vented tubing, from paired taps and paired trees —1971*

Treatment	Paired tapholes								Paired trees					
Location	Heaven Hill								Heaven Hill				Chazy	
No. of tapholes	40		80		40		80		40		20		40	
*Date**	†													
April 1–7	4.3	2.3	4.1	3.8	6.8	4.3	7.9	3.3	11.4	6.8	10.7	9.3	11.7	9.3
April 9–12	5.4	1.6	2.8	3.6	4.1	3.1	4.5	1.7	7.7	4.6	7.7	6.2	9.2	5.9
April 17–20	12.5	2.5	5.7	9.4	12.2	6.8	11.9	5.3	18.4	11.8	18.7	13.6	16.4	12.6
April 22–28	6.7	5.0	5.8	9.2	8.4	6.5	8.5	6.2	12.8	12.5	9.1	7.2	7.8	2.5
Season total	28.9	11.4	18.4	26.0	31.5	20.7	32.8	16.5	50.3	35.7	46.2	36.3	45.1	30.3
Mean vacuum‡	13		5		8		12		16		14		15	

**Flow dates are for Heaven Hill; Chazy flow dates approximately the same.*
Closed and vented tubing reversed on April 21 at Heaven Hill and April 14 at Chazy.

†Data are quarts per taphole. Closed tube data on left, vented tube data on right, of each column.

‡Data are inches of mercury; mean of 7 measurements made during sap flows.

Table 9. *Increase in sap flow in closed tubing, by two treatment methods — 1971*

Method	*Yield per taphole*			*Percent increase*	*Mean vacuum*
	Closed	*Vented*	*Difference*		
		— quarts —			***inches***
Paired tapholes	31.1	16.2	14.9	92	11
Paired trees	47.2	34.1	13.1	38	15

Flow Rate and Vacuum

The laboratory studies showed that increased flow rates led to more vacuum for normal sap flow rates (figure 3). Numerous measurements were made on the closed-tube lines – flow rate at the base was measured simultaneously with vacuum. The 1971 season was generally poor; the fastest flow rate measured was only .62 quart per minute. Nevertheless, weak correlations between vacuum and flow rate were obtained at both Heaven Hill and Chazy for individual sap flows. Figure 5 shows a good correlation for the means of 5 sets of measurements obtained on 9 closed-tube lines at Heaven Hill between April 3 and 18. A comparison with figure 3 shows that natural vacuum obtained in the field generally exceeded that in the laboratory. This is attributed to the limitation of elevation and head available in the laboratory.

Pumped versus Natural Vacuum Vacuum in maple tubing can be created directly by pumping, and sap flow may be more than doubled in some instances (2, 5, 10, 11). However accurate comparison of pumped and natural vacuum for sap flow is difficult for the following reasons:

Pumped vacuum tends to be consistent throughout the tube line; natural vacuum reaches a maximum at the upper trees. Thus natural vacuum readings tend to be maximal rather than average.

Pumped vacuum exists while the pumps are turned on. Pumped vacuum may occasionally extract sap from trees which otherwise would not yield. Thus the operator's judgment concerning pumping time may affect the amount of sap gain from pumped vacuum. On the other hand, the duration and amount of natural vacuum and its effect on sap gain depends on sap flow rates and other physical characteristics.

Despite these limitations, we compared pumped and natural vacuum at two localities, using both the paired taphole and paired tree methods (table 10). Most slopes were 10 percent. Pumps were run some 100 hours during the season; this was about 70 percent of the pumping time on our commercial operation. Most of the pumping hours were during normal flow periods, but for approximately 15 hours the pumps produced sap while the non-pumped taps failed to produce. Nevertheless most of the gains in sap due to pumping came during normal flow periods.

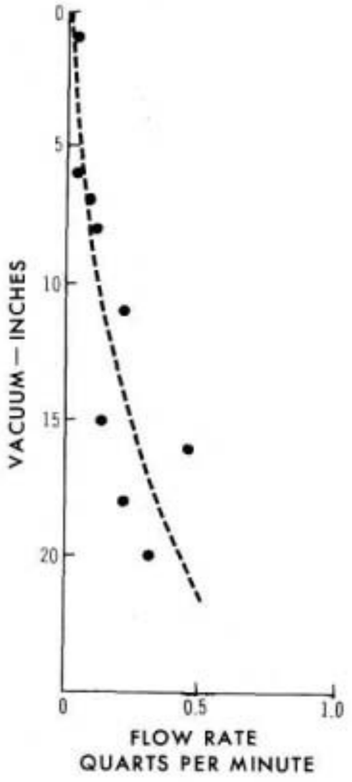


Figure 5.
Relation of vacuum to flow rate. Heaven Hill — 1971.

Table 10 shows the superiority of pumped vacuum over natural vacuum (note that one natural vacuum line had very little sag and averaged 21 inches of vacuum). The natural vacuum on lines with 40-50 taps exceeded that on lines with 20-25 taps. Therefore pumped vacuum showed more gain on the lines with few tapholes. This result is consistent with prior results concerning the effect of numbers of taps on natural vacuum and sap flow. As with the natural vacuum study, there were greater yields per tap-hole, smaller percent gains, but equal total sap gains for the paired-tree method.

Sap yield and vacuum in tube lines were related for individual and total season flows at both Heaven Hill and Chazy. Figure 6 shows the relation between total season yield and mean vacuum, based on 10 measurements during sap flows, at Chazy. Half of the tube lines had natural vacuum; half had pumped vacuum. Note the higher level of yields from the paired-tree lines. Even though there are limitations in the comparison of pumped and natural vacuum, it is clear that added vacuum creates more sap flow. Even though excellent results can be obtained from natural vacuum under proper conditions, pumped vacuum can be even better.

Table 10. *Comparison of sap flow under pumped and natural vacuum — 1971*

Treatment			*Yield per taphole*				*Mean vacuum*	
Method	*Location*	*No. taps*	*Pumped vacuum*	*Natural vacuum*	*Difference*	*Percent increase*	*Pumped*	*Natural*
			— *quarts* —				— *inches* —	
Paired tapholes	Heaven Hill	25	28.2	13.5	14.7	109	12	4
			34.0	15.5	18.5	119	14	4
		50	35.1	22.2	12.9	58	10	6
			35.4	21.5	13.9	65	15	7
Paired tapholes	Chazy	20	31.5	15.3	16.2	106	15	5
			27.5	11.8	15.7	133	20	6
		40	30.2	13.8	16.4	119	16	9
			27.7	20.0	7.7	39	18	10
Paired trees	Chazy	20	44.1	25.0	19.1	76	22	9
		40	49.2	39.4	9.8	25	21	21
Paired taps combined		20–25	30.3	14.0	16.3	116	15+	5−
Paired taps combined		40–50	32.1	19.4	12.7	65	15−	8
Paired taps combined			31.2	16.7	14.5	87	15	6+
Paired trees combined			46.7	32.2	14.5	45	21+	15

VACUUM-INCHES

Figure 6. *Relation of seasonal yield to vacuum. Chazy —1971.*

Sap production in southern New York normally exceeds that from the Adirondack area. For nearly a decade vacuum pumping has been used on a majority of the trees at Arnot Forest; sap production has exceeded that from many similar sugar bushes (9). To test the effect of vacuum on a larger scale, a 300-tap commercial area was selected in 1971. Tube lines with 70 taps were on nearly level ground; little natural vacuum was expected. The remaining 230 taps were on tube lines with slopes mostly between 3 and 10 percent. The paired taphole method was used so that comparisons could be made between 300 pumped, 70 non-pumped, and 230 non-pumped taps. Treatment of the paired taps was reversed on March 24 and again on April 10 to reduce taphole bias. Time of vacuum pumping exceeded 200 hours and coincided with commercial practice. Vacuum was measured 17 times in a dozen locations. Table 11 shows a comparison of sap yield with vacuum, as well as mean flow for the entire commercial enterprise. Although some vacuum was found on the non-pumped 70-tap line on nearly level ground, back pressure also occurred at times and sap yield was less than half that obtained by pumping. Moderate natural vacuums occurred on the hillside, and sap flow was intermediate between that from the non-pumped flat land and the pumped taps. It is important to note that, while percent increases in sap yield from pumping on hillsides were similar at Arnot, Heaven Hill, and Chazy, the actual amount of increase was much greater at Arnot (21 vs. 14.5 quarts per tap). This suggests that the use of vacuum to increase sap flow can be even more effective for the normally longer seasons and higher yields of southern New York than for Adirondack conditions.

Sugar Percentage

Sugar percentage was measured at numerous times at all three localities in both 1970 and 1971 in an attempt to discern differences between the various treatments. Although there was a tendency for sap that flowed under vacuum to have less sugar, seasonal mean differences in sugar content were .05 percent or less and not significant.

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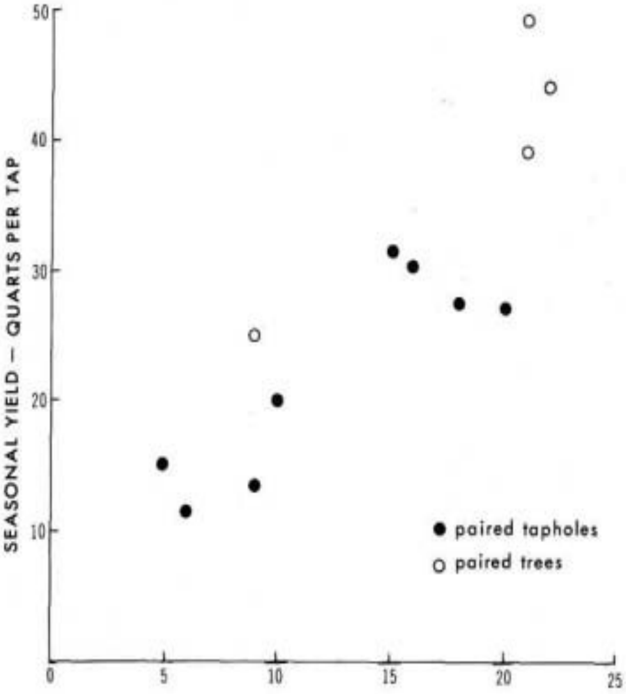

Table 11. *Comparison of sap flow and vacuum under commercial conditions Arnot — 1971*

Treatment	*300 taps pumped*		*230 taps nonpumped*		*70 taps nonpumped*		*Arnot mean*
	*yield**	*vacuum†*	*yield*	*vacuum*	*yield*	*vacuum*	*yield*
March 11–14	8.2		8.2		4.0		8
March 18–22	14.5		8.2		8.3		9
March 26–April 2	20.5	12 (60)	14.7	5 (40)	11.2	2 (20)	19
April 3–9	19.3	11 (30)	18.8	6 (20)	8.3	3 (10)	19
April 11–12	11.2	11 (12)	3.3	1 (8)	3.2	1 (4)	5
Season total	74	11+	53	5−	35	2	60

**Yield in quarts per taphole.*

†Vacuum in inches of mercury. No. of measurements given in parentheses.

Relation of Vacuum to Sap Production

Sap flow is the result of pressure gradients within the tree which cause sap to flow outward and drip from an open wound or taphole. Pressures may rise some 30 pounds per square inch above atmospheric pressure. At night, pressure may decrease to less than atmospheric and sap may be reabsorbed (7). Negative pressure or vacuum adds to the already existing pressure gradients (2" vacuum equivalent to 1 PSI). Laing and Arnold (5) found that vacuum was transmitted longitudinally within tree tissues for at least a foot. With high vacuums exceeding 25 inches, they increased low flow rates of single tapholes by as much as 0.8 quart per hour. Vacuum may also be present between flows because of either sap columns in tubing or pumping. In addition to enhancing normal sap flows, vacuum can also create earlier flows and delay flow stoppage.

The potential for increasing sap production with vacuum varies from zero in years of extreme tube damage by rodents, such as 1968, to the high increases found with vacuum application to single trees. The combined results of our experimental data may suggest practical sap gains that can be achieved in many commercial operations. In table 12 summary data from previous tables are presented with production figures rounded to the nearest quart per taphole. Where the comparison is between pumped and natural vacuum, the vacuum difference is used.

Great care must be exercised in interpreting table 12. Vacuum means for different years and localities are not necessarily comparable because they are affected by time of measurement in respect to flow conditions. Nevertheless some conclusions are suggested. As expected there was little relationship between sap gain expressed in total amount and in percent. Percent increases are unreliable because of lower base productions in the paired taphole method and in the Adirondack region. On the other hand, except for the low vacuum year of 1969, seasonal sap gain in quarts per taphole was remarkably constant (13-15 quarts) for the Adirondack area for both methods. The highest gain was for highly productive Arnot.

Although both our data and that of others suggest linearity between sap gain and vacuum, we are uncertain of the exact relationship. Our 1970 data (figure 4) were treated as if essentially linear. Blum (1) presents a similar graph which, although based on only one set of vacuum measurements, yields a linear regression nearly like ours when the scales are made equal. If linearity is assumed, our 1970 regression Y = 4.1 + 1.2X shows a seasonal sap gain of 1.2 quarts per taphole for each inch of natural vacuum. Laing and Arnold (5) obtained gains sometimes exceeding 2 quarts per tap for each inch of vacuum with high-vacuum pumping on 200- to 400-tap areas. The higher level gains with vacuum pumping are expected since natural vacuums, as measured, tend to be maximal rather than average. Inspection of table 12 suggests seasonal gains of 1 to 2 quarts per tap per inch of vacuum for a combination of natural and pumped vacuum situations.

Table 12. *Seasonal sap gain from vacuum, 3 years, 3 localities*

Treatment			*Sap gain per taphole*	*Percent increase*	*Mean vacuum*
Method	*Location*	*Year*			
			quarts		***inches***
Paired tapholes	Adirondacks	1969	8	33	3
		1970	13	77	7
		1971	15	92	11
		1971	15	87	9*
	Arnot	1971	21	40	6.5*
Paired trees	Adirondacks	1971	13	38	15
		1971	15	45	6.5*

**Mean difference in vacuum between pumped and natural vacuum installations. Other data are comparisons between closed and vented tubing.*

Measurements on our commercial production areas tend to confirm the experimental results. In 1970 and 1971 at Heaven Hill, pumped vacuum produced seasonal gains of 1 quart per tap per inch of vacuum (9-10 quarts for 8-11 inches vacuum) in two large areas. At Arnot in 1971 seasonal gains exceeded 2 quarts per tap per inch of pumped vacuum and reflect the excellent production year.

Most of our results were obtained in poor sap years, in cold localities, and with low-production trees. We conclude that sap gains from vacuum may commonly range from 1 to more than 2 quarts per taphole per inch of vacuum. The lower gains may be expected with natural vacuum, poor seasons, and low production localities and bushes. The better gains may be expected with pumped vacuum, good seasons, and high-production trees.

Conclusions

Field research, using 4500 tapholes, was conducted for 4 years at 3 geographical locations. This was supplemented by laboratory tests to determine the relationships of pressure to flow rate in maple tubing. Good natural vacuum in closed maple tubing requires the following conditions: A good, leak-free installation and freedom from rodent damage.

A high column of sap to make a good head. An elevation difference of 50 feet or more is best; this can be obtained by steep slopes and/or long lines, as well as sufficient numbers of tapholes per tube line.

A fast flow rate, obtained by numerous tapholes per line, vigorous trees, good climatic and weather conditions for sap flow, etc. Within the range tested, vacuum increased with larger numbers of taps; 10 taps per line were too few, while best vacuums were obtained with 50 or more taps.

Minimum sag in tube lines. We agree with Koelling *et al.* (4) that changes in elevation which restrict continuous downhill flow of sap will reduce vacuum in either aerial or ground tube lines.

Suitable slopes and matching numbers of tapholes. Five percent slopes had good vacuums with 50 taps per line; additional taps would likely overload the line. Ten percent slopes had the best vacuums; 50 to 80 taps were best. Fifteen percent slopes were not as good as 10 percent slopes probably because there were too few taps; we believe that 100 or more taps per tube line are necessary for best results with 15 percent or steeper slopes. On such steep land, tubing can be installed at less acute slopes simply by angling it away from the direction of steepest topography. On the other hand, good installations are difficult on slopes of less than 5 percent; we recommend the use of pumped vacuum where feasible. It is also important to avoid shallow slopes in the lower and middle portions of tubing installations. Gains in sap production tended to be proportional to increased vacuum, whether natural or pumped. Both experimental and commercial results suggest seasonal sap gains of 1 to 2 quarts per taphole for each inch of vacuum (33 to nearly 100 percent). The lower gains are associated with natural vacuum, poor seasons, and low-production localities and bushes. The better gains may be achieved with pumped vacuum, good seasons, and high-production trees.

Both the requirements for and potential sap gains from natural vacuum indicate the need for evaluation and proper use of slope for maple tube installations. Steep slopes, poorly regarded in the past, may now be considered assets.

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