How much water is "in the snow?"

Bernadette and Blanche are avid softball players who live in Fort Fairfield, Maine. At the start of last softball season, they were embarrassed when they had to practice in the parking lot and they were mad when could not play their first game, which was supposed to be a home game, at home. The softball field was so soggy in the spring that the AD had to keep players off the field. Over the winter and early spring a lot of snow had piled up in the woods around the athletic fields. When the snow finally melted, there was so much water in the snow that the runoff soaked the softball field.

Bernadette and Blanche are seniors this year and they don't want a repeat of last season. At least, they don't want to be surprised again. They contacted Glenn Hodgkins, a scientist at the US Geological Survey, a really nice guy, and asked him what they could do. He suggested that they take snow cores every week and keep track of the **snow water equivalent** in the woods around the athletic fields. Then they would know what to expect for springtime flooding. He told them to imagine the snow water equivalent this way: "If you melted all of the snow in the woods, how deep would the resulting meltwater be? It's an easy way to estimate **how much water is in the snow**," he said.

But, Bernadette and Blanche disagreed on what Glenn meant.

Bernadette: I think when Glenn says *how much water is in the snow* he means that if the snow in the core is really dense and sticky, you know, good for snowballs, then there is a lot of water stored in the snow in the woods, and when it comes out in the spring we are likely to get a flooded softball field.

Blanche: I think that's not what he means by "snow water equivalent." I think even if the snow in the woods was light and fluffy it could still be a lot of water if the snow is deep enough. We could get a flooded softball field when the snow melts even if the snow is fluffy and no good for snowballs.

Which softball player do you agree with more? (circle one) **Bernadette** **Blanche**

Think about why you agree with her and explain your reasoning please.

Teacher background

People have a hard time distinguishing between *snow water equivalent* (SWE) and *snow density*. The language we use does not help. We often say that SWE is “how much water is in the snow.” To a hydrologist, this means one thing, but to a naïve person it often means another thing. The hydrologist envisions a cylindrical sample of snow (taken with a coring tool that has a known diameter; only the depth of the snow core extracted with the coring tool changes). The snow in the sample may be fluffy or dense; more likely there will be denser parts, fluffier parts, and some of the snow in the sample may even have become more like ice than snow. The hydrologist only wants to know: if all the snow were melted how deep would the water be in the coring tool? This “amount” of water, the SWE, is reported as a ***depth****.* In the back of her mind, the hydrologist always has an ***area*** of land associated with this depth because what she is really after is a volume that could, say, run off into a river from the river’s watershed. The hydrologist can also think of the SWE as a mass because water has a known density, 1 milliliter = 1 gram.

Adults become accustomed to reporting “amounts” of rain as depths: “We got an inch of rain last night.” But due to lack of experience, many students don't know how to answer this question: *If a coffee cup and a bucket were left in the backyard last night and we got an inch of rain, how deep would the water be in the cup and in the bucket?* (Assume straight sides on the bucket and cup.) In fact it is weird to report an amount of rain as a depth because this alone tells you nothing about the volume (or mass) of rain that landed on your back yard overnight. With enough life experience, though, a person knows that “an inch” of rain fell everywhere in the back yard, so that if the whole back yard were a flat pan, there would be an inch-deep layer of water in the whole pan. But because snow can be anything from fluff to hard ice, it has to be melted, either literally or mathematically, before we can know how much water the snow is made out of, i.e.: *How much water the snow equals*.

When some students hear “*how much snow is in the water*” they might be thinking of the snow and the water as separate entities. In this student mental model, the snow can be a familiar, pleasing fluffy matrix and the “water in the snow” can be liquid water, whose occurrence needn't be explained, trapped within the matrix. According to this errant model of snow water equivalent, the more *water there is in the snow*, the more of this alien liquid there is trapped in the matrix. If students hold this errant model of SWE, it is easy to confuse SWE with snow density: The higher the SWE, the better the snow is for making snow balls, until there is too much alien water in the snow, then it's slush. Students can too easily move back and forth between this errant model of the “amount of water in the snow” to an experiential ranking of the snow's density. The thinking could proceed as:

The snow with more water in it is denser snow.

So…

The snow with a higher snow water equivalent is denser snow.

Making this snarl of language and experiential definitions worse is the famous difficulty with the concept of density itself due to the fact that density is a dread ***ratio****!* Another problem is the incomplete belief in the molecular nature of matter – that water is made of discreet units each with an unchanging mass that's not easily destroyed.

What does it mean for instruction?

So, to be all set with SWE and snow density, 9th graders may have to:

A. See some imagery of water molecules locking into ice crystals on the molecular scale as snowflakes begin to form

B. See/read about how snowflakes deform in the snowpack

C. Accept that the “amount” of water that a sample of snow is made of can be known as a depth if the container has straight sides, or as a volume. To get a depth or a volume, you have to melt the snow. The “amount” of water can also be known as a mass. It can be a stretch, however, for 9th graders to accept that if the mass does not change then the “amount” does not change. They have this difficulty because their molecular model of matter is not strong. It would be useful for students to predict how the mass of samples of snow (ideally, some fluffy and some dense) will change upon melting, then check those predictions with a graph of all the percentage mass change data. A dot plot turned into a box & whisker works.

D. Try the following work. Count out a *certain number* (so there is a molecular analog) of corn starch packing peanuts and measure the volume and mass of the sample. It would be better for arguing if each group used the same number of peanuts. For volume, perhaps use 2 liter soda bottles with the top cut off so you've got an approximate cylinder, marked with 0.5L increments. The marks could be made by pouring 0.5, 1.0, 1.5, etc. liters of water into the cylinder. Or the marks could be in units of mL (500, 1000...)

Questions could be:

1. What is the density of freshly fallen packing peanuts?

2. What range of densities is possible in a packing peanut snowpack without adding or removing snow? (Snow being peanuts)

3. With no new snow, how does changing the density affect the amount of water in the snow? (“amount of water” being mass of all the peanuts)

4. And later, for argumentation: How <u>can</u> you change the snow water equivalent?

For the second question, students will have to figure out that the way to address the question without adding or removing snow is to mash the peanuts to varying degrees. We teachers should explicitly question them about what will happen to the mass as the snow is variously mashed because enough of 9th graders think the mass will change.

For the first two questions, students should produce distributions to be graphed as side-by-side box and whisker plots (or as a dot plot with different symbols for fresh snow density and snowpack density). So the classes will need to compile their data into a big table with a row for each group.

Density of freshly fallen snow				Range of densities in the snowpack				
# of freshly fallen peanuts	mass of freshly fallen peanuts (g)	volume of freshly fallen peanuts (mL)	density of freshly fallen peanuts (g/mL)	# of peanuts in snowpack	mass of snowpack (g)	volume of snowpack (mL)	density of snowpack (g/mL)	**Δ** mass of snowpack (g)

Answering the third question will require that students accept the representation of snow with packing peanuts. If packing peanuts are a good way to represent snowfall and snowpack, it is here that some will have to confront their naïve acceptance of the unexplained appearance of alien water in the matrix of snow. It is also in answering this question that students will need to equate “amount” of water with “mass” of water. To help with this question, students should produce a **Δ** mass distribution graphed on a scale from zero to whatever the largest mass of packing peanuts is, because if they accept the non-conservation of mass as an OK thing in a mass-conserving universe, then the whole range of mass change is up for grabs.

Finally, I would have them **use the graphs** to write an argument:

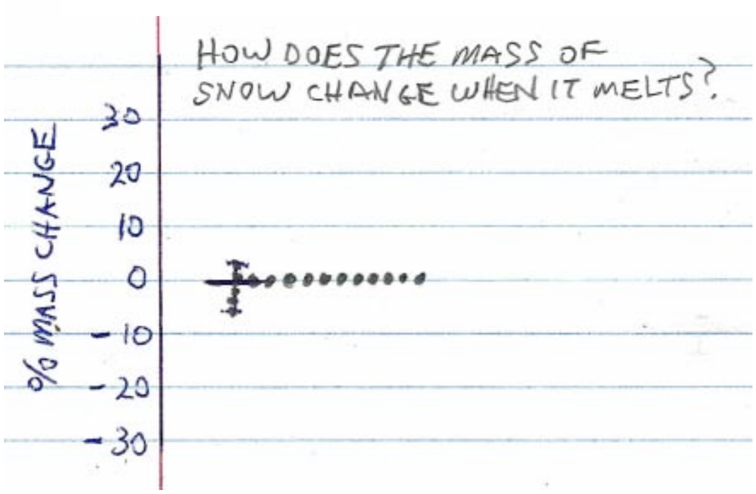
Dear students,

These data support a claim that the only way to change the snow water equivalent is to add or subtract snow from the snowpack. These data also support a claim that snow density alone can not predict the snow water equivalent.

Write this argument using the three graphs as evidence.
As you refer to each graph, provide a brief description of how the data were produced.
Since your audience will be confused about the difference between snow density and snow water equivalent, make sure you clear this up for them.
Good luck using these graphs to write an argument that the only way to change the snow water equivalent of the snowpack is to add new water (in the form of snow, sleet, etc.) or to lose water (through melting or evaporation).

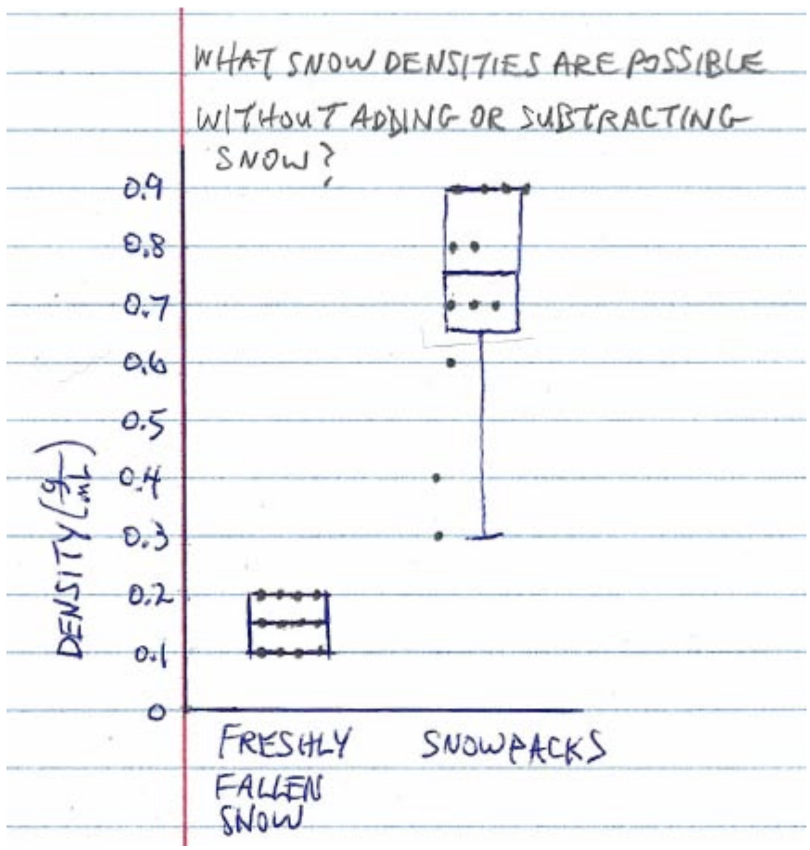
Here are some graphs I thought the data might produce. Real data are on a page below.

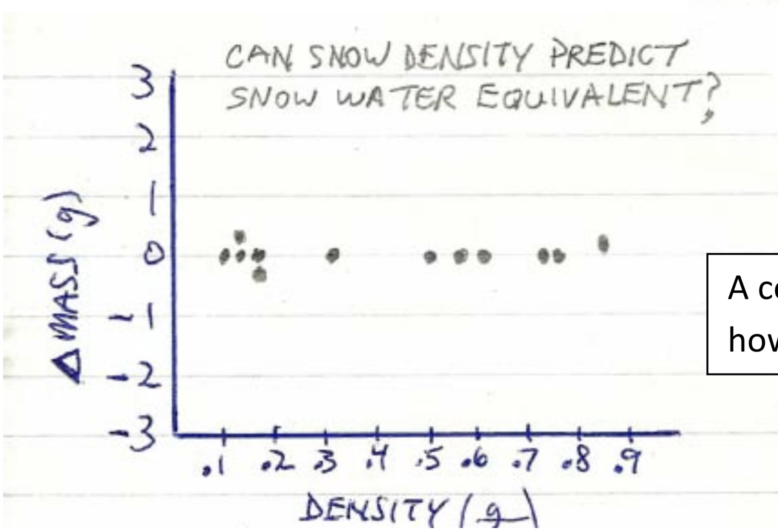
Graphs



A single distribution. One box & whisker. How spread out are the measurements?

Comparing categories. Two box & whiskers side by side. Is there a meaningful difference?



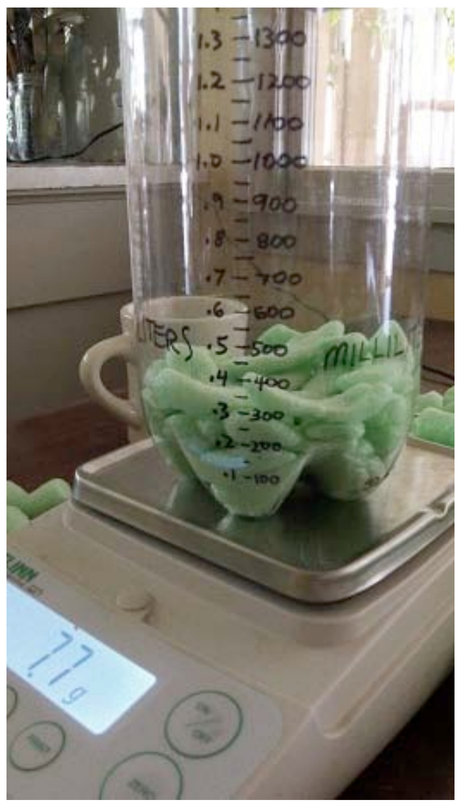


A correlation. As the density changes, how does the mass change?

Here are real data from corn starch packing peanuts.

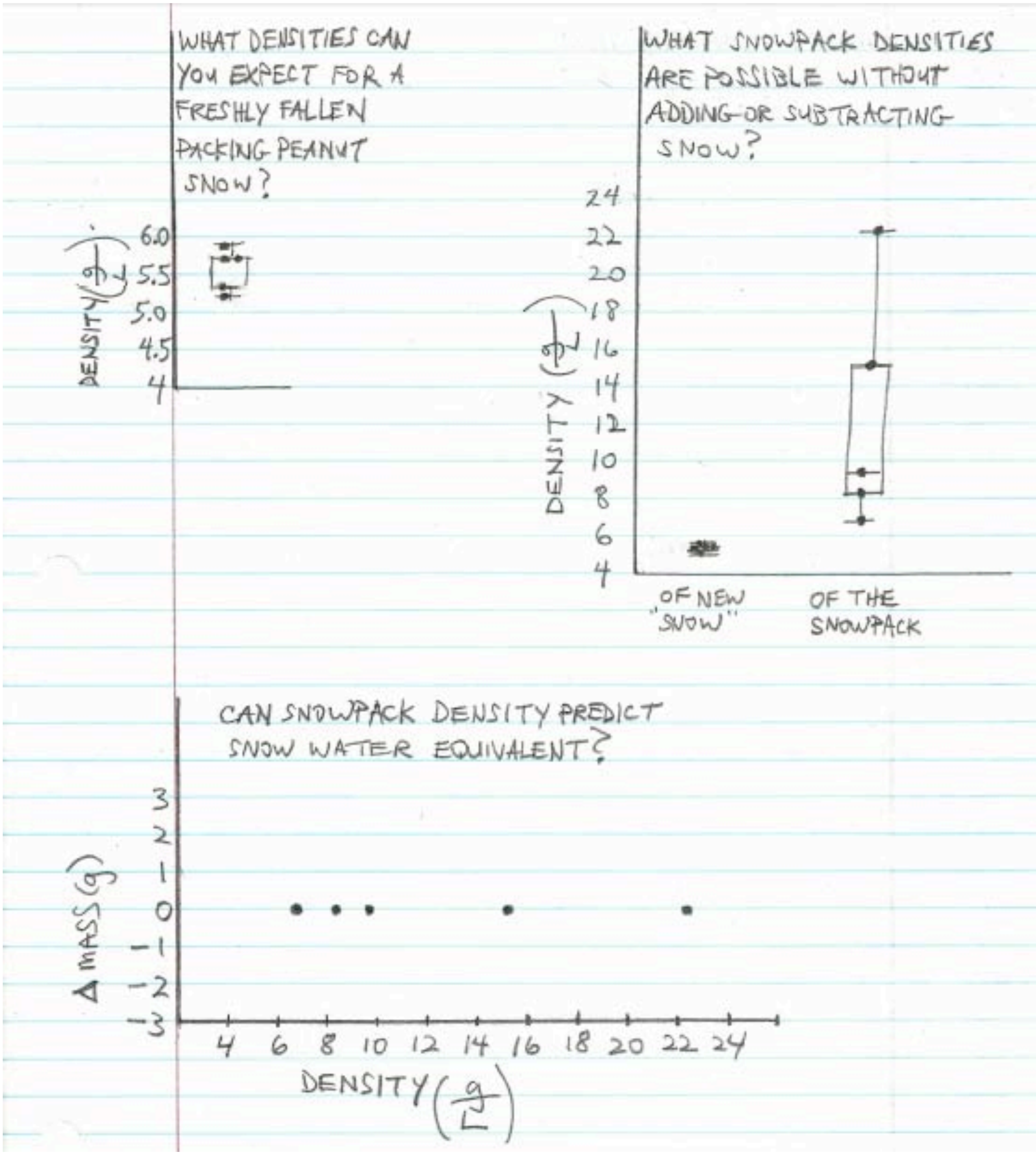
	# freshly fallen p-nuts	MASS OF freshly fallen p-nuts (g)	Volume of ff p-nuts (L)	Density of ff p-nuts (g/L)	# p-nuts in snowpack	MASS OF SNOWPACK (g)	VOLUME OF SNOWPACK (mL)	DENSITY OF SNOWPACK (g/mL)	Δ MASS (g)
1	50	7.8	1.35	5.8	50	7.7	1.10	7.0	0
2	50	8.0	1.40	5.7	50	7.7	0.95	8.1	0
3	50	7.7	1.45	5.3	50	7.7	0.80	9.6	0
4	50	7.7	1.40	5.5	50	7.7	0.60	12.8	0
5	50	7.7	1.35	5.7	50	7.7	0.50	15.2	0
6	50	7.6	1.40	5.4	50	7.7	0.35	22.2	0
	DENSITY OF FRESHLY FALLEN SNOW				RANGE OF DENSITIES IN THE SNOWPACK				

Newly fallen snow



A denser snowpack. SWE is the same, though. If you melted both samples of snow, you would end up with the same depth of water in the jug.

Here are graphs made with the five lines of the above data, to make box & whiskering easier.



Here is an example argument.

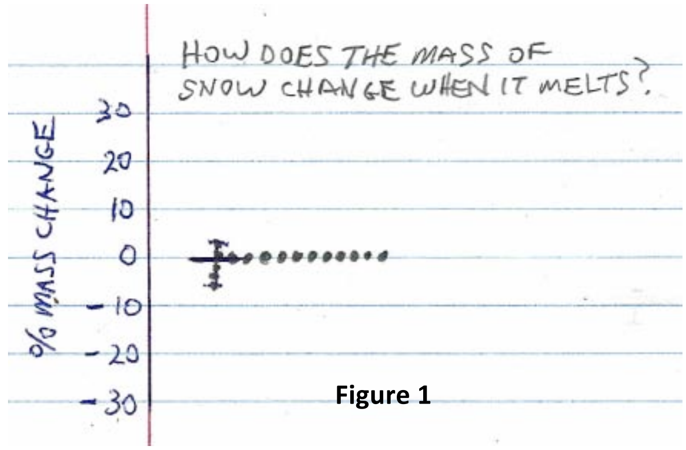


Figure 1

People confuse snowpack density and snow water equivalent (SWE). It is easy to see why. A cup full of dense snow weighs more than the same cup full of fluffy snow. Snow is just water molecules, so the more water molecules in the cup, the heavier the cup of snow is. If you melted the snow in the two cups, the resulting water would be deeper in the heavier cup. We did an experiment where we melted many samples of real snow to see if the mass would change. The data give good evidence that the mass does not change. As you can see in Figure 1, twelve out of sixteen groups got no mass change at all. A few groups got a tiny mass loss of less than 5% that could have been caused by water leaking from the bag. One group got a tiny mass increase of 4% that they can't explain. These data are important because they show that the snow ***is*** the water and water ***is*** the snow.

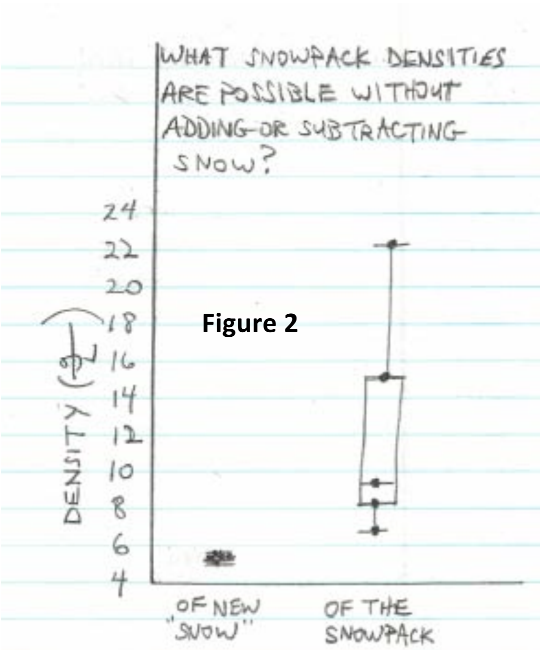


Figure 2

We did another experiment to simulate different snowpack densities starting from the same amount of snow. Corn starch packing peanuts represented "snowflakes." Each group used the same number of snowflakes to get a density for newly fallen snow. The masses of each snow sample were similar, ranging only from 7.6 to 8.0 grams. The falling peanuts arranged themselves the same way so the densities of newly fallen snow were practically the same for all groups, right around 5.5 g/L, with hardly any variability, as shown in Figure 2. But depending on how much you compress the snow, you can get a huge range of snowpack densities. Figure 2 shows that the groups got snowpack densities that ranged between 7 and 22 g/L.

The important thing, though, is that no matter what the density of the snowpack was, the amount of water did not change at all, as you can see in Figure 3.

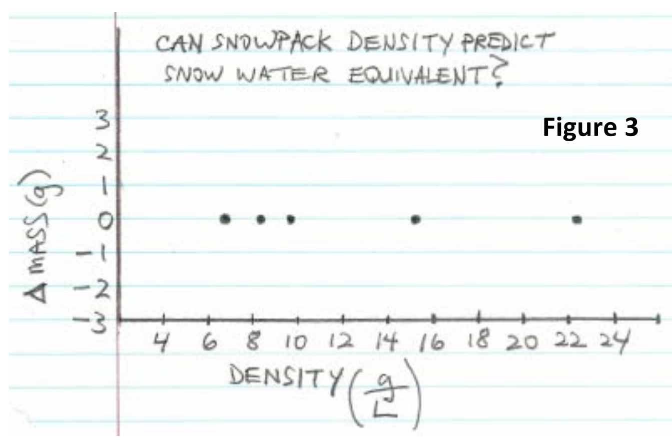
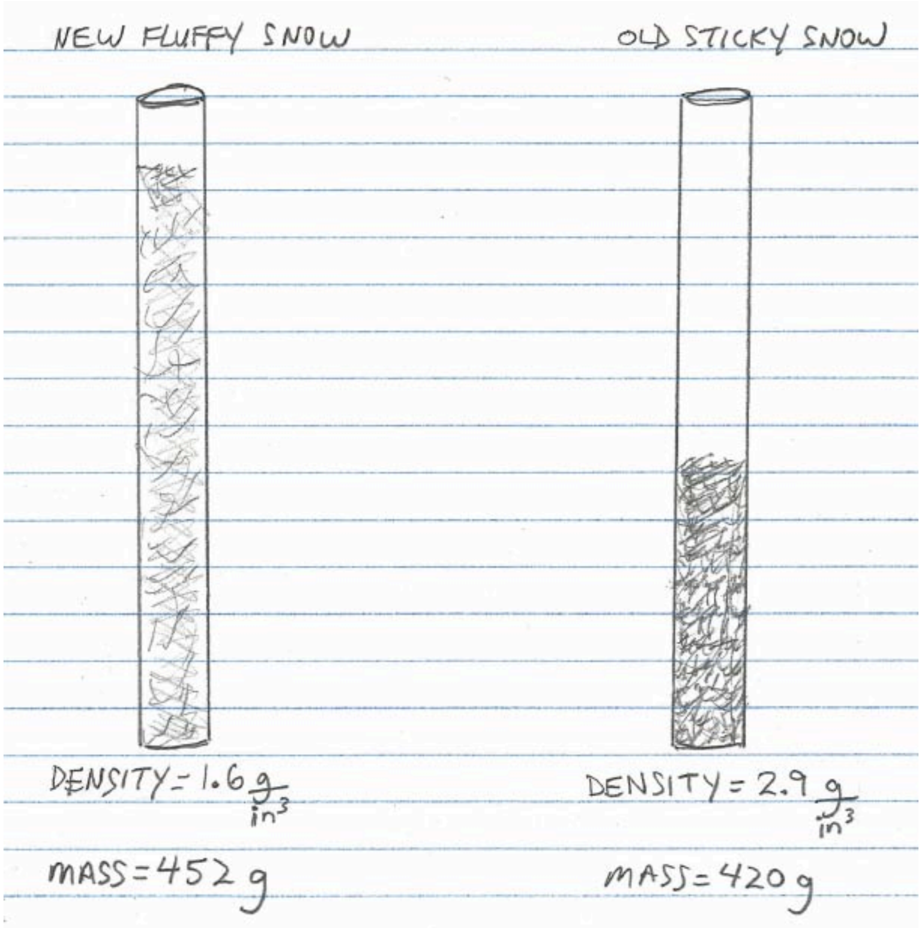


Figure 3

This all goes to support the argument that only way to change the SWE of the snow in a snow core is to add new snow or take snow away by melting or evaporation. This is the only way to change the mass and the only way to get a different depth of water if you were to melt the snow in the SWE corer.

The thing to keep in mind is that hydrologists always have an area of land in mind, for example, a football field covered with snow. If they want to know how much water the snow is equal to, they imagine melting the water on the field, all of it, then measuring how deep the water would be. That depth is the SWE. So as long as they know that and how much land you're talking about, they can tell you how much water you have to deal with when the snow melts.

A follow-up assessment might not be too difficult.



Is there enough information to tell which snow sample has a larger **snow water equivalent**?

YES **NO** (circle one)

If you said yes, which one has a larger snow water equivalent, and ***why***?

If you said no, why isn't there enough information to tell which sample has a larger snow water equivalent?