Dry January means more drought across West

After a rainy December, many states now have lower-than-normal snowpacks.

Kate Schimel Feb. 6, 2015

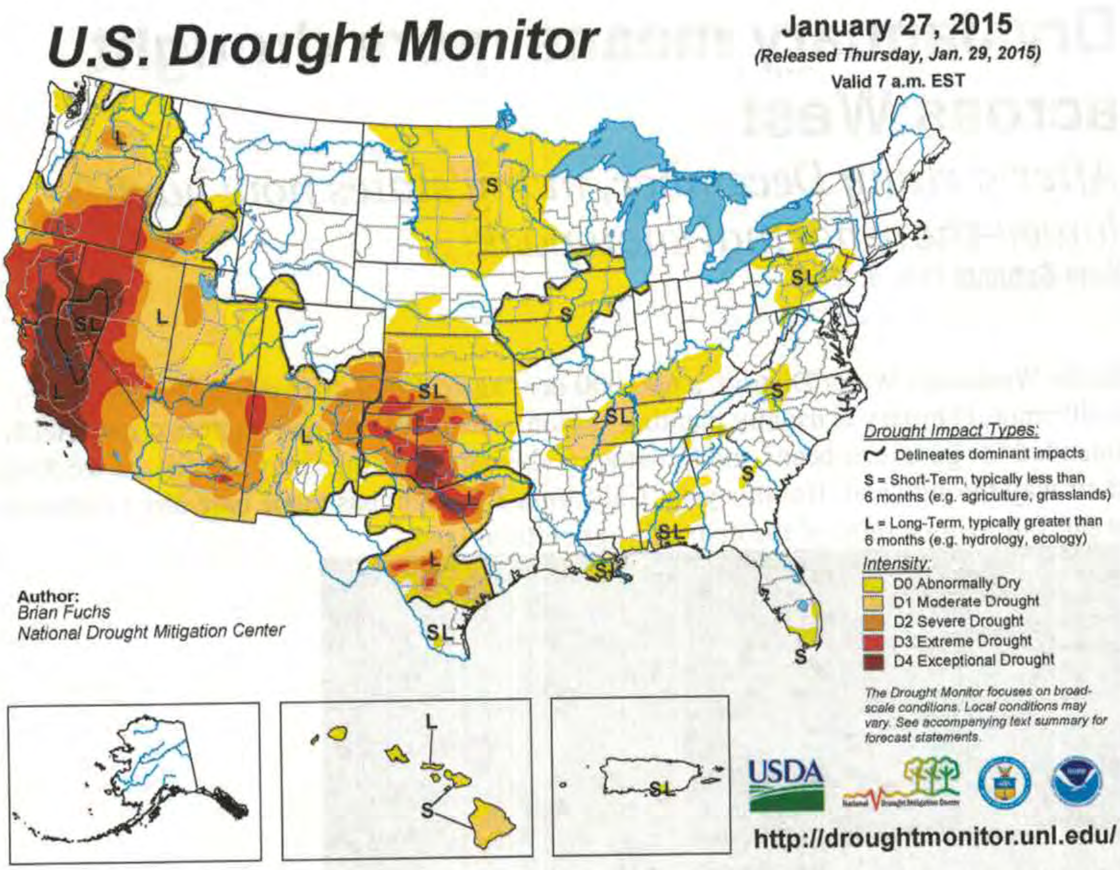
In the Westlands Water District, a 600,000-acre agricultural district near Fresno, California, February is usually planting season, when workers and tractors crowd fields intended for garbanzo beans and tomatoes and where seedlings may already be working their way through soil. But this year, California's drought has made bare dirt a common sight, fallowing a third of the district's agricultural land.

Snow survey site, California. Photo courtesy of Natural Resources Conservation Service.

That's not likely to improve anytime soon. Last week, the California Department of Water Resources took the second manual snowpack measurement of the season and found just a quarter of what has normally accumulated by this time. In some spots, the snowpack was as low as a tenth of normal.

California's not alone in facing a lack of water. The same day as the dismal snowpack measurement, the National Drought Mitigation Center released a map of conditions throughout the country. Much of the West was in some sort of desiccation, ranging from "abnormally dry" to "exceptional drought." But the effects of that drought aren't evenly distributed, even within California, thanks to the vagaries of local water systems.

At the start of this "water year," which begins in October and runs through April, things didn't seem so dire. Much of the West saw December rains. Heavy storms caused flooding in northern California, the source of much of Westlands' water, and drenched the southern half of the state.



But January was dry. December's weather prevented a total dry-out, but large swaths of California, Nevada, Oregon and the mountain West saw less than half their usual precipitation. When water did fall from the sky, warm temperatures meant that it often came as rain, rather than snow.

The dry spell in January, the midpoint of the water year, means bad news for water supply all year long. Even if things do look up, the West Coast, at least, doesn't have much time left to make up the deficit.

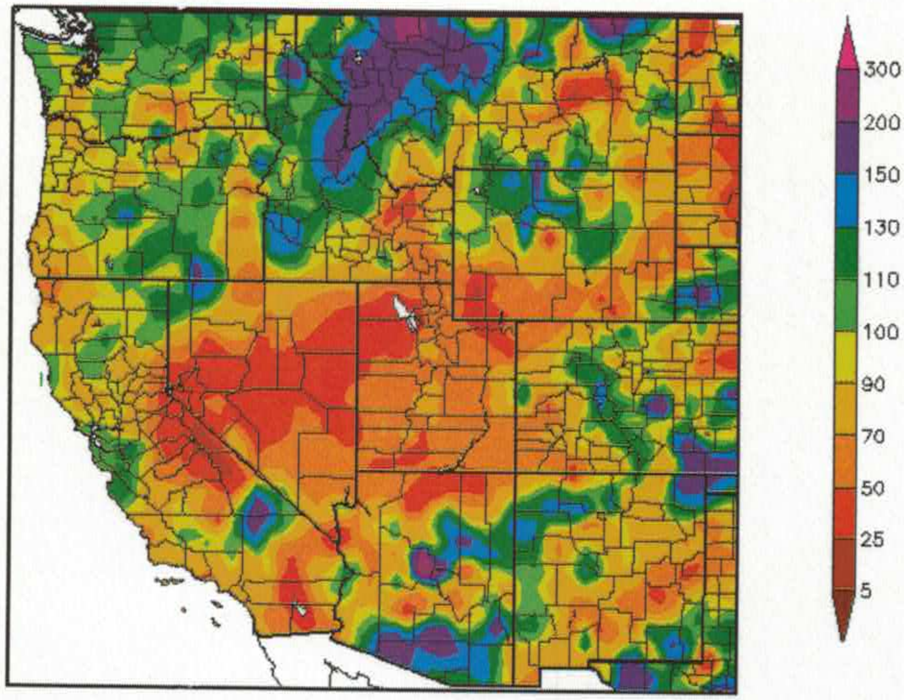
"If you don't get it by the end of April, you probably won't get it at all," said Kelly Redmond, the deputy director of the Western Regional Climate Center. "Stuff that falls in the summer just turns right around and evaporates again."

Further inland, cooler summer temperatures mean early summer rains can make a dent. Water managers are already eyeing conditions and beginning to plan how much water they'll give to farmers and to cities.

Lake Powell, in the Colorado River Basin, is projected to receive just 73 percent of its normal seasonal water supply. In New Mexico, the Rio Grande water system, which includes Albuquerque, is likely facing a fourth year of drought. The two New Mexico-based Rio Grande reservoirs—Elephant Butte and Caballo—currently have just 15 percent of their capacity.

In the Pacific Northwest, the trouble is less about the quantity of water that fell and more about how it fell.

Percent of Normal Precipitation (%)
10/1/2014 - 2/2/2015



Generated 2/3/2015 at HPRCC using provisional data. Regional Climate Centers

"We're not like California with massive reservoir capacity," said Cliff Mass, a professor of atmospheric science at the University of Washington. "We use snowpack like a reservoir."

Those reservoirs are looking pretty depleted. Most parts of the Cascade Mountains have less than half their usual snowpack.

Surprisingly, California reservoir levels are up from last year, thanks to the rain that ought to have been snow. The State Water Project, the state-run system for watering Central Valley farms and cities all along the coast, upped their promised water supply from 10 to 15 percent of what users asked for. But that may have no impact on the Westlands. Its supplier, the federally managed Central Valley Project, didn't allocate any water for agriculture last year. Gayle Holman, a spokeswoman for Westlands, says they are anticipating the same this year.

There's still a chance conditions could improve. Atmospheric rivers, narrow air flows that carry large amounts of moisture, can bring even severe droughts to an end. The December rains came from an atmospheric river hitting the coast last fall. Another will likely hit the West Coast this weekend. But for those hoping for the drought to end completely, Redmond has a word of caution.

"You probably don't want to get out of the drought completely," said Redmond. "That would mean a flood."

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Trends in snow water equivalent in the Pacific Northwest and their climatic causes

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[1] Observations of snow water equivalent (SWE) in the Pacific Northwest are examined and compared with variability and trends in temperature and precipitation at nearby climate stations. At most locations, especially below about 1800 m, substantial declines in SWE coincide with significant increases in temperature, and occur in spite of increases in precipitation. *INDEX TERMS:* 1655 Global Change: Water cycles (1836); 1863 Hydrology: Snow and ice (1827); 1630 Global Change: Impact phenomena. **Citation:** Mote, P. W., Trends in snow water equivalent in the Pacific Northwest and their climatic causes, *Geophys. Res. Lett.*, *30*(12), 1601, doi:10.1029/2003GL017258, 2003.

1. Introduction

[2] Several studies have noted recent declines in snow in various parts of the world. Satellite measurements indicate a decline in snow cover extent since 1966 [*Robinson*, 1999]. Surface observations of snow cover data for the northern hemisphere (1915–1992) indicate an increase in snow extent in winter and a decrease in spring [*Brown*, 2000], especially for the period since the 1950s. These changes have usually occurred in concert with gradual increases in temperature.

[3] This work examines variability and trends in snow course data in the Pacific Northwest (defined here as the states of Idaho, Oregon, and Washington in their entirety, southern British Columbia, and Montana west of the continental divide) and compares the snow data with variability and trends in temperature and precipitation at nearby climate stations. The Pacific Northwest relies heavily on melting snow to provide water for many uses during the summer, when relatively little precipitation falls. Persistent regional warming, therefore, would threaten an important resource, and resource managers need to know whether there is already evidence of a decline in snowpack and, if so, whether it is a harbinger of anthropogenic climate change or a natural cycle that will likely reverse.

2. Data and Methods

2.1. Snow Course Data

[4] Measurements of snow water equivalent (SWE) for the Northwest were described by *Clark et al.* [2001] and were used by *McCabe and Dettinger* [2002] to demonstrate an improved capability for seasonal streamflow forecasting. Data through 2002 were downloaded from the NRCS Water and Climate Center web site (www.wcc.nrcs.usda.gov/snow/snowhist.html) for the U.S. and, for British Columbia, from the Ministry of Sustainable Resource Management web site (srmwww.gov.bc.ca/aib/wat/rfc/archive/historic.html).

[5] The earliest measurements date back to 1915 at a location in south central Washington, but very few sites were observed routinely before 1935. Nearly all of the early observations were taken only yearly on April 1, near the peak of the snow accumulation season, but in subsequent years other routine observation dates were added.

[6] For inclusion in this study, a record must extend at least from 1950 to 2000, chosen to maximize total data (number of years × number of stations). Records missing more than 25% of the values were excluded, leaving 230 records. A subset of this data set was used to construct Figure 5.

[7] Most locations of snow course data are at high altitudes (1200–2300 m); the lowest used here (576 m) lies in the Washington Cascades, and the highest (2703 m) in south central Idaho.

2.2. Climate Data

[8] The climate records used here were described and analyzed by *Mote* [2003a, 2003b] and include data from the USA and Canada. Canadian data come from the Historical Canadian Climate Database (HCCD [*Vincent and Gullett*, 1999]), which has 32 stations in the study area with temperature records and 81 stations with precipitation records. For the USA I use the Historical Climate Network (USHCN [*Karl et al.*, 1990]), which has 122 stations in our study area with temperature records and 84 stations with precipitation records. In both data sets a majority of stations have periods of record beginning by 1920, and nearly all by 1940.

[9] For each snow record, comparisons with temperature and precipitation were performed as follows. First, I located the nearest five climate stations with complete records for 1950–2000, typically 20–100 km away and at lower elevation than the snow course. The climate anomalies for these stations were averaged for November–March (NDJFM). In this season (but not in summer) precipitation and temperature are themselves nearly uncorrelated at most locations. Correlations of April 1 SWE with NDJFM temperature ranged from −0.71 to +0.09 with a mean of −0.29, and correlations with NDJFM precipitation ranged from −0.18 to 0.89 with a mean of 0.55. Correlations between SWE and temperature are strong (<−0.5) in milder climates, notably in the Cascades below 1800m in Oregon and below 1500m in Washington, and correlations are weak (>−0.3) in colder climates, viz., most of BC, Idaho, and Montana. Correlations with precipitation are usually stronger than with temperature, and are especially strong in the Rockies (where temperature plays little role) and especially

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weak in the Wallowa Mountains of northeastern Oregon, where *McCabe and Dettinger* [2002] found that SWE varied fairly independently of the rest of the region. The correlations are insensitive to the number of climate stations used in the analysis; in fact, using a regionally averaged reference time series yields similar results. Such regional coherence of snow and climate, and their response to El Niño-Southern Oscillation and the Pacific Decadal Oscillation, hold promise for improving predictions of seasonal streamflow [*McCabe and Dettinger*, 2002].

2.3. Trend Analysis and Comparison

[10] To elucidate the roles of NDJFM temperature and precipitation in producing variations and trends in April 1 SWE, multiple linear regression is performed on the snow data $S(t)$ using reference time series for temperature $T(t)$ and precipitation $p(t)$, yielding coefficients of regression a_T and a_P. The component of any trend $\langle S \rangle$ in the snow data that can be attributed to the temperature trend $\langle T \rangle$ is given by

$$\langle S \rangle_T = a_T \langle T \rangle; \quad (1)$$

likewise for precipitation. Weighting the climate trend by its interannual regression assumes that if the connection between S and T is strong on the interannual timescale, it is strong also on longer timescales.

3. Results

[11] At nearly all snow course sites, linear trends over the period of record are negative, some substantially so (Figure 1). Decreases are generally largest in the Cascades, many in excess of 40%; this is true also for other periods of record.

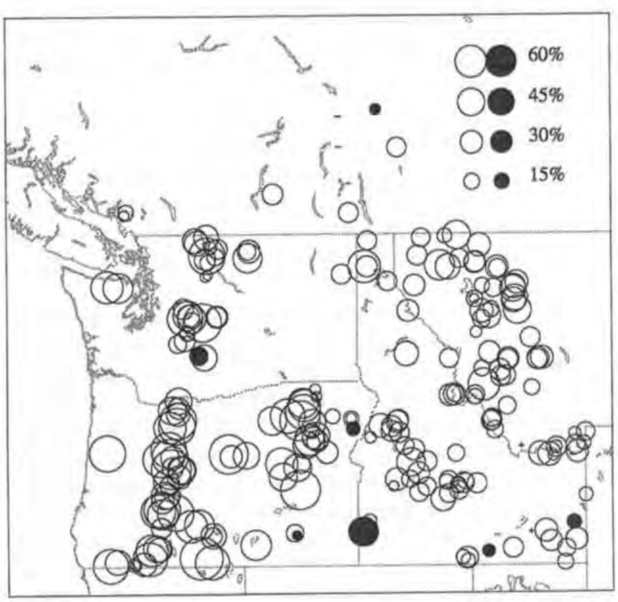

Figure 1. Linear trends, relative to starting value, in snow water equivalent (SWE) on April 1 over the period of record 1950–2000. Negative trends are shown as open circles, positive trends as solid circles; the magnitude of the trend is indicated by the area of the circle according to the legend. Trends less than 5% in absolute value are indicated by a + or − symbol.

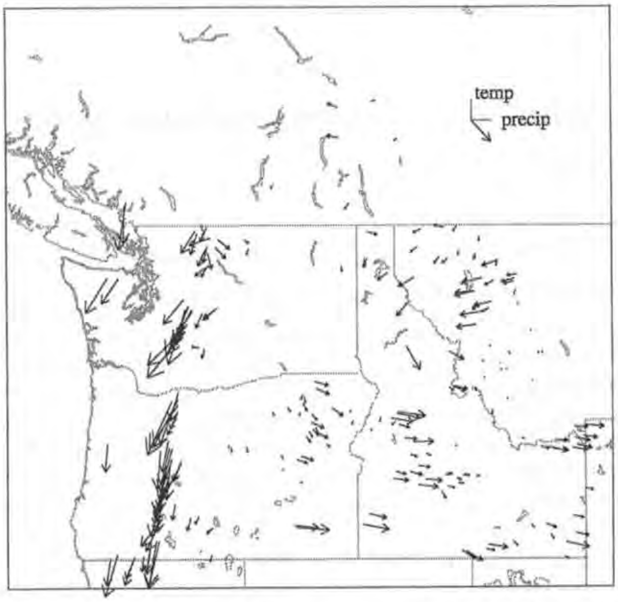

Figure 2. For each location, the arrow shows the trend in April 1 SWE attributed by multiple linear regression to precipitation $\langle S \rangle_P$ (x-direction) and temperature $\langle S \rangle_T$ (y-direction). The reference arrow in the legend has a length of 10 cm of SWE.

[12] Several important questions are raised by the data presented in Figure 1. Can we relate these changes in SWE to changes in temperature and precipitation? How do these changes vary with season and for different periods of record? How well do linear trends capture the important longer-term variations?

[13] To address the first question, Figure 2 shows $\langle S \rangle_P$ and $\langle S \rangle_T$ (see section 2.3). Several regional patterns emerge. In the Cascades and coast ranges, where declines in SWE have been largest, and at some locations in the northern Rockies, both temperature and precipitation have acted to decrease SWE as indicated by arrow directions ranging from south to southwest. In much of eastern Oregon and southern Idaho, and it is surprising how many sites show this pattern, the decreases in SWE have occurred in spite of an increase in precipitation (arrow directions ranging from south to east). For locations with large absolute trends, the sum $\langle S \rangle_P + \langle S \rangle_T$ is typically 40–80% of the observed trend, but in many locations with small trends the fit is poor, as for example in the Wallowa Mountains of northeastern Oregon (see Section 2.2).

[14] Another, more qualitative way to compare the roles of temperature and precipitation is to plot the snow trends as a scatterplot in a space spanned by precipitation trends and temperature trends (Figure 3). Nearly all the snow course data with near-zero or negative precipitation changes (upper left part of the diagram) have experienced decreases, regardless of temperature trend, but in addition nearly all of the points with positive precipitation changes have nonetheless also experienced decreases in SWE.

[15] Another approach to separating the temperature and precipitation influences is to examine the trends as a function of elevation. Relative changes in SWE should be nearly uniform with altitude for changes in precipitation, but

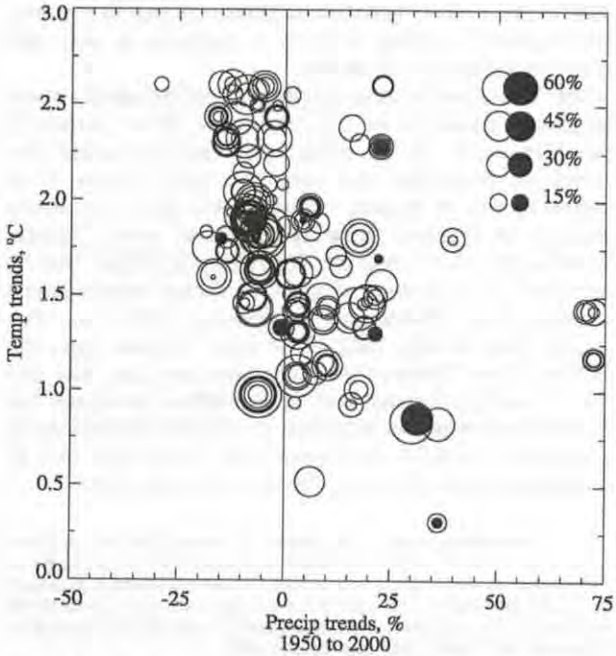

Figure 3. The same data as in Figure 1 are plotted against trends in NDJFM precipitation and temperature at nearby climate stations.

much greater at lower elevations for changes in temperature, since at elevations nearer the mean freezing level a moderate change in temperature can dramatically change the fraction of precipitation that falls as snow. To test this hypothesis, we plot in Figure 4 the trend in SWE as a function of snow course elevation. As expected, the data show a decrease in magnitude of trend with elevation, up to about 1800 m; the correlation of trend with elevation is 0.51. This result is even more pronounced when considering only the snow course records in the Cascades and Olympics (not shown), where freezing levels tend to be higher owing to the marine influence. Thus the elevational dependence of the trends confirms the dominant role of temperature increases in driving the trends.

[16] In order to examine changes in SWE by month and year, we combine the SWE data for those sites with long records. For this part of the analysis we use data from 1925 to 2002 and for each month we include all records that are 75% complete for this interval. Following the approach of *Clark et al.* [2001], the data at different locations are combined by first converting each time series of SWE to a time series of z-scores by subtracting the mean and normalizing by the standard deviation. The individual time series are then averaged and converted back to SWE using the mean and standard deviation averaged over all the time series. With this approach, the time series for each month is less sensitive to the particular combination of snow course records reporting in a given year, but it is inadequate to show the seasonal cycle since a different set of snow course records is used for each month. In fact, there is such a strong reporting bias in May and June toward sites with high SWE that it skews the mean seasonal cycle. For comparison, the mean value of the time series for May has been set to be 79% of the mean April value, using the basin average May/April ratio derived from SNOTEL data [*Clark et al.*, 2001].

[17] The temporal behavior of regional mean SWE thus derived (Figure 5) shows interdecadal variability with generally low values from 1925 to 1945 and after 1975, and high values in the 1950s and 1970s. In this analysis, the mean SWE in the 1990s was the lowest of any 10-year period in the record, but the difference is not significant because so few observations were made in the 1920s. However, regionally averaged USHCN climate data show that for no 10-year period in the 1920s and 1930s was NDJFM precipitation or temperature as high as in the 1990s.

4. Discussion and Conclusions

[18] The declines in Northwest spring snowpack presented here provide further evidence of regional increases in temperature and are qualitatively consistent with observed trends in temperature and precipitation at nearby stations. Both the dependence on elevation and the regression analysis confirm the role of temperature in reducing snowpack since the mid-20th century. Relative declines are most pronounced in the Cascades, where warming, moderate elevation, and declines in precipitation have all contributed to declines in SWE. In the upper Columbia River basin, moderate increases in precipitation in mid-century offset the warming to produce slight increases in SWE since 1940, though these change sign when considering only the period since 1950.

[19] These changes in recent decades are broadly consistent with those derived from lower-elevation weather stations [*Groisman et al.*, 1994; *Brown*, 2000], with little change in winter but with decreases in spring. Positive snow-albedo feedback likely contributes to the springtime

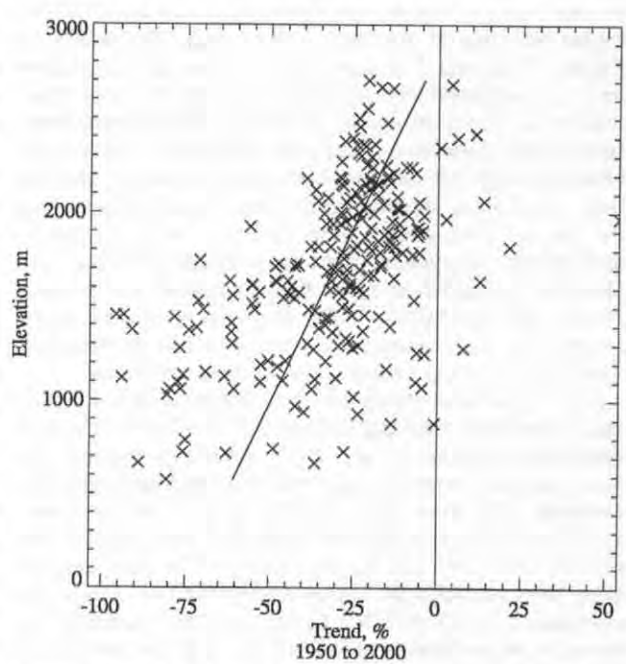

Figure 4. Relative trend in April 1 SWE plotted against snow course elevation (crosses) along with a linear fit.

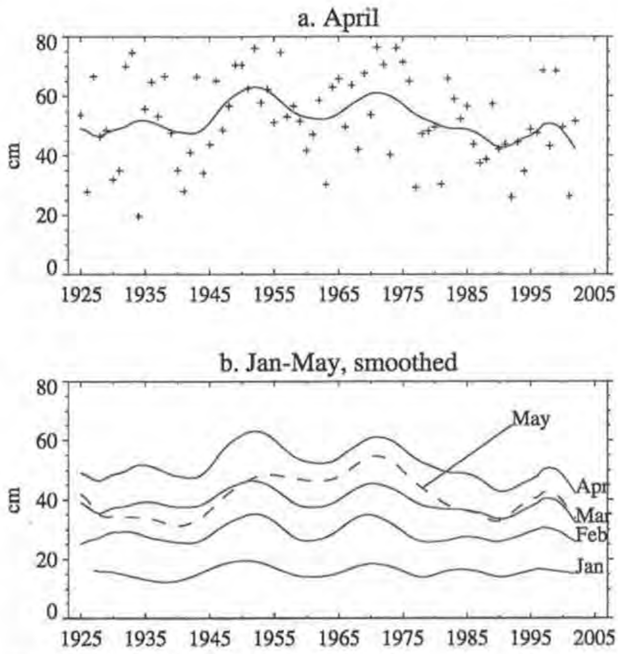

Figure 5. Regionally averaged SWE (a) for April 1 of each year, with a smooth curve overlaid, and (b) the smoothed annual values for each month January–May. The May curve has been adjusted for observational bias (see text). Smoothing is performed using locally weighted regression [*Cleveland*, 1993] with parameters chosen to emphasize timescales greater than about10 years.

trends in temperature and snow cover both at low elevations and in the mountains, especially in the forested zone.

[20] An issue of some concern in relating trends in snow course data to trends in climate data is whether trends at the lowland climate stations are representative of trends at the higher altitudes of the snow course data. The results in Figures 2 through 5 suggest that increases in temperature have overwhelmed changes in precipitation in recent decades, but a variety of factors complicate this interpretation. Interannual correlations between SWE and climate are relatively high but may mask long-term changes, whether they reflect a real climatic trend or are a result of changes in the nearby land cover, wind speed or wind direction, instrumental changes, or even air pollution affecting low-elevation precipitation more than mountain precipitation [*Givati and Rosenfeld*, 2003]. Regional averaging might reveal some such changes and remove others. Hydrological modeling may help answer some of these questions.

[21] Could these changes be a reflection of global warming, or are they a natural fluctuation? The Pacific Decadal Oscillation [*Mantua et al.*, 1997] influences regional climate, and the correlation between PDO and the regionally averaged SWE time series (Figure 5a) is −0.49. However, PDO alone cannot explain the changes in SWE between the period before 1945 and the period since 1976: Temperatures have been substantially higher during the later period for comparable values of PDO. Clearly, regional warming has played a role in the decline in SWE, but regional warming at the spatial scale of the Northwest cannot be attributed statistically to increases in greenhouse gases [*Stott and Tett*, 1998]. However, as greenhouse gases continue to accumulate, regional warming is likely to continue as well, and questions of cause will recede.

[22] These results have significant implications for water resources managers in the Northwest. Since snowmelt provides much of the water used during summer for irrigation, municipal and industrial water supply, flow targets for fish protection, recreation, and other uses, future changes in regional snow cover are of great concern. Simulations of the region's hydrology highlight loss of snowpack as a primary impact of future anthropogenic warming [e.g., *Hamlet and Lettenmaier*, 1999], but such studies have usually focused on time horizons (e.g., the 2050s) beyond those of most planning exercises. The fact that a warming-induced loss of springtime snowpack has already been observed heightens the urgency of developing adaptation strategies for coping with the gradual loss of snowpack, which is clearly already well under way.

[23] **Acknowledgments.** I am grateful to Martyn Clark for a first look at the data, to Mike Wallace for helpful comments on the manuscript, to Katya Partan for copy editing, and to Alan Hamlet and Dennis Lettenmaier for helpful discussions. This publication is funded by the Joint Institute for the Study of the Atmosphere and Ocean (JISAO) under NOAA Cooperative Agreement NA178RG11232, contribution #975.

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Guiding Questions for *Mote 2003*

Article Citation: Mote, P.W., 2003. Trends in snow water equivalent in the Pacific Northwest and their climatic causes, Geophysical Research Letters, 30(12):1601.

Read "Trends in snow water equivalent in the Pacific Northwest and their climatic causes" by Philip Mote and take the following notes to prepare for class discussion.

1. Highlight the words and concepts throughout the article that you don't understand.

2. The article states, "The Pacific Northwest relies heavily on melting snow to provide water for many uses during the summer, when relatively little precipitation falls." **Please list some uses.**

3. What do you think snow water equivalent is? How do water resource managers use it?

4. Read through the Results section. (It may be a little confusing, which is okay!) Jot down what you think are the main results from this research.

5. What impacts could declining mountain snowpack have on our community?

6. What does the author suggest as the main reason for declining springtime snowpack?

7. Do you remember if we had above average, average, or below average levels of snowpack last year? How did this impact our community and surrounding ecosystem?

Winter watersheds

Activity Education Standards: *Note alignment with Oregon Academic Content Standards beginning on p. 483.*

Objectives

The student will (1) collect snow samples, (2) determine the snow water content of the snow samples, (3) test the pH values of the snow samples, (4) calculate the snow water content of a model watershed, and (5) answer questions about snow water content.

Method

Students collect snow samples, calculate the snow water content of each sample, test the pH of each sample and apply that information to a model watershed.

For younger students

1. Consult extension activities at the end of each chapter to address the needs of younger students.
2. Read activity background information aloud to younger students or modify for your students' reading level.
3. Younger students can practice their addition and subtraction by figuring daily, weekly, or monthly precipitation totals obtained from local SNOTEL sites. Check the Internet for this data at http://crystal.or.nrcs.usda.gov/snowsurveys/.
4. Construct a large vertical scale on a bulletin board or against a wall for both precipitation and snow water equivalent (both in inches). Place the "0" mark at floor level so it is clear that it means zero accumulation. Make sure the two scales are side by side for easy comparisons. Using the Internet as a source of data from a SNOTEL site near your area, ask students to mark the total accumulations for each (precipitation and snow water equivalent) on a daily or weekly basis during the standard seasonal snowfall period—October 1 through April 1. Use a colorful, moveable pointer to mark the locations on the scale and post the date for the reading in a prominent location. Students may want to compare two SNOTEL sites in this manner or compare their school site with a SNOTEL site. As the snowmelt season begins and progresses, students can see the snow water decrease while the accumulated precipitation may remain the same or increase. Large decreases in snow water are usually related to warm weather and/or rainfall.
5. Use the discussion about SNOTEL sites and how professionals get information from snow courses as a lead-in to the topic of winter safety. What to do if you are lost, frost bite, and hypothermia are all appropriate topics. Ask the school nurse to assist with this safety presentation.

Parts of this activity are adapted from *Snow Chemistry and Air Pollution*, Burris, Frank, Rena McFarlane and Peter Stortz, Alaska Cooperative Extension, Fairbanks, Alaska, 1996, and used with permission. Additional information obtained and adapted from *Snow Surveys and Water Supply Forecasting*, U.S. Department of Agriculture, Soil Conservation Service, Agriculture Information Bulletin 536, June 1988.

Vocabulary

acid rain
acid shock
fry
organic matter
pH
snow courses
snow water content
sublimation
telemetry

6. To help younger students understand the concept of acid rain, use the first exercise in the "Deadly Skies" activity from *Aquatic Project WILD*, pp. 142-145.

7. Once students understand the concept of acidity and alkalinity, use pH test paper to sample a number of familiar liquid products (coke, orange juice, milk, etc.). Move the discussion to include water bodies and how pollutants falling into a water body can influence its acidity. Conclude the discussion with a collection of snow samples that they can sample for the presence of pollutants, using pH values as indicators of impurities.

Materials

- snow tube (a polypropylene 1,000 milliliter graduated cylinder, with a one-quarter-inch hole drilled into the tube near its connection with the base); one per team
- 1,000 milliliter graduated cylinder *without* a hole drilled near its base; one per team
- 3 one-gallon ziptop plastic bags for each sample team; if a team is collecting at more than one sample site, a different set of three bags is needed for each location
- permanent marking pen
- flat, stiff piece of plastic, or a tile, to slide across the opening of the snow tube to keep snow from falling out when it is moved
- data sheets
- clipboard or hard writing surface
- pencil
- pack (or cooler) for carrying supplies to the sample sites; it must be large enough to accommodate the snow samples on the return trip to the classroom
- small shovel
- thermometer
- large measuring stick (yardstick or meter stick)
- wide range pH test paper, pH test kit, or water quality test kit

Notes to the teacher

The snow sampling procedures outlined in this activity are highly simplified but sufficient to develop the concepts. For example, the part of the activity on snow water content portrays a simple ratio. A certain level of snow yields a certain amount of water. For example, a volume of 500 milliliters of unmelted snow yields 50 milliliters of water. This ratio—10 ml of snow to 1 ml of water—produces a conversion factor (0.1) that can be applied to a larger amount of snow and generalized to an entire watershed. Other factors, like density differences and other variables, obviously come into play, but the basic translation will help students understand the concept that snowmelt contributes to streamflow.

Drilling the hole in the plastic graduated cylinder allows air to escape when the snow tube is pushed into the snow. If you live in an area where snow fall is only an occasional event and snow depths are rarely more than a few inches, a much smaller polypropylene graduated cylinder works just as well.

Students can also use data posted on SNOTEL sites on the Internet to compare snowpacks and potential water supplies for various basins throughout Oregon and the western states. The Natural Resources Conservation Service (NRCS) also has an Adopt-A-SNOTEL-Site program that may be suitable for your students. For more information contact your local or statewide office of the NRCS.

Pollutants can contribute to acidity in water, and they are easily detected in snow samples with simple pH testing equipment (litmus paper, wide range paper test strips, or a water quality test kit) or pH meters, which work well but are very expensive. Students will explore pH in depth in Chapter 8, "Water Quality."

You can approach the topic of acid snow simply as information related to watersheds, current events related to weather, or environmental news that could affect your local area (nonpoint pollution fallout from contaminated air). This method does not involve field work or equipment.

Background: Part 1

Do you know . . .

Millions of Americans enjoy snow-covered landscapes for their beauty or as a winter playground. But snow also plays a vital role. It is a primary source of the water supply in the western United States.

The West's high mountain ranges hold a vast snowpack that provides 50% to 80% of the water supply for the year. But, melting snow does not provide an uninterrupted, dependable source of water for all the downstream needs. Reservoirs and other water storage facilities help store water for the growing needs of agriculture, industry, and communities. Successful water management begins with knowledge of the primary source of water in the West—snow.

Specially trained people from federal, state, and private cooperative snow survey programs work with the Natural Resources Conservation Service (NRCS). They create accurate and timely information on the amount of mountain snowpack and its water content. SNOTEL is a computerized **telemetry** network and forecasting system for collecting data on snowpack. It can provide daily, or more frequent, information about streamflow potentials. The information is especially valuable during periods of flood or drought.

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- ground water contributions,
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These factors change from year to year and vary from one location to another.

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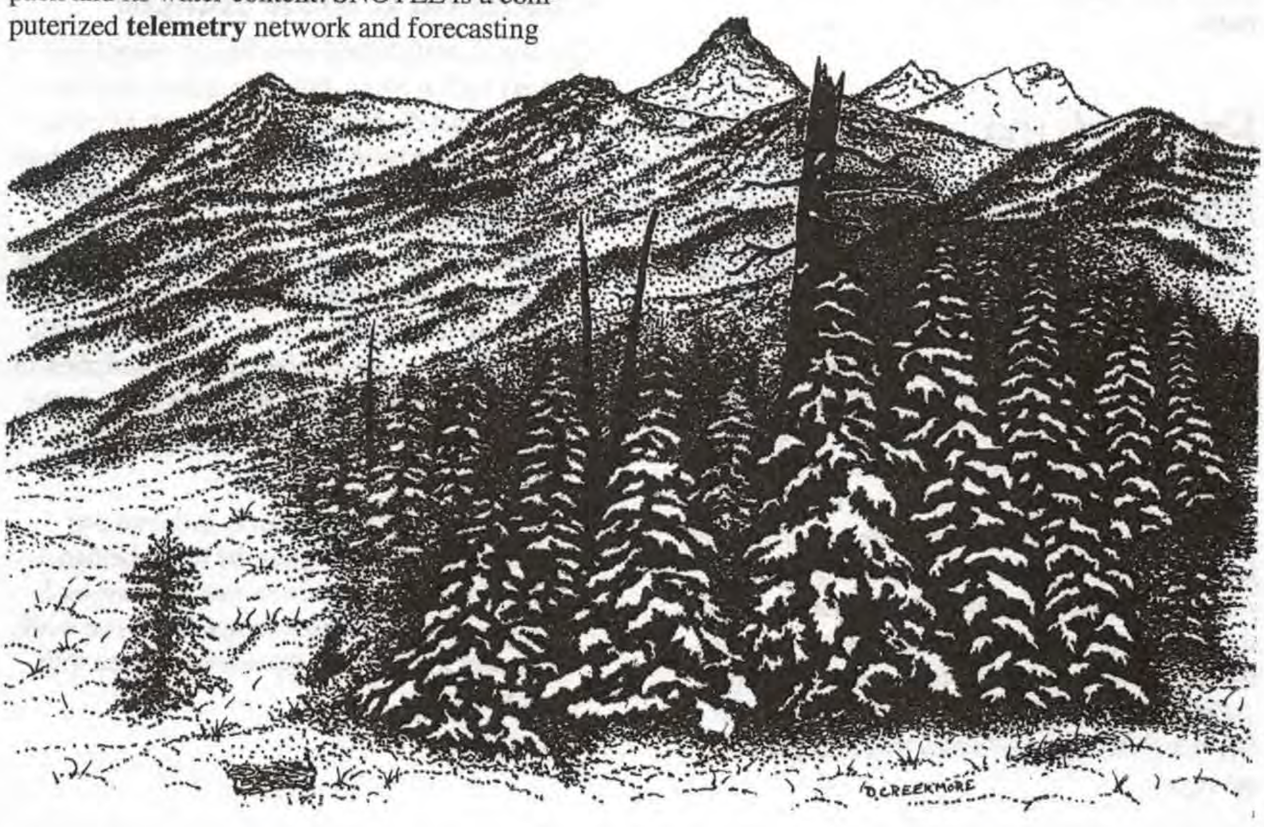

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Now it's your turn . . .

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Choose an undisturbed area free of animal (or human) tracks, twigs, fallen branches, leaves, cones, animal droppings, fur, feathers, or extra snow from overhead branches. Try to avoid areas of drifted snow or where the wind continually moves the snow.

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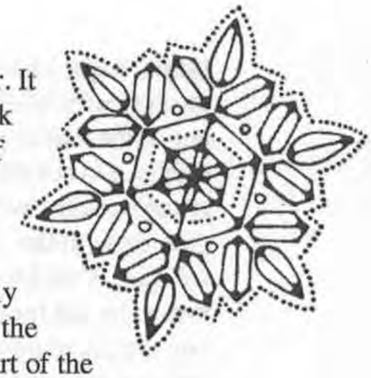
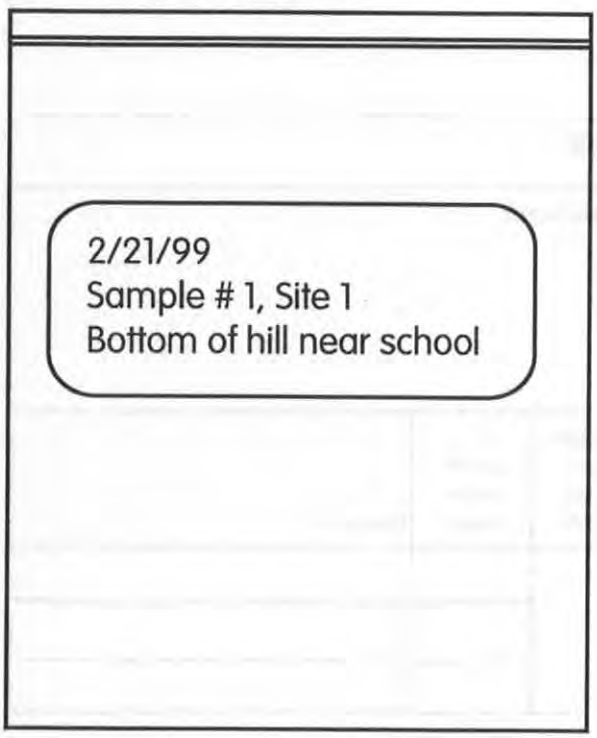
4. Pick a spot that looks representative of the sample area. Using a ruler or meter stick read the depth of the snow to the nearest half inch (or centimeter). You can make several measurements to find a representative depth, but record only one snow depth measurement per sample site on the data sheet.

5. Using the following procedure, collect at least three samples to get an average of the snowpack conditions at each individual sample site.

6. Shove the snow tube, open end down, vertically through the snow just beyond the edge of the pit. Do not push the snow tube into the soil or vegetation layer. It is important not to pack the snow in the tube. If the snow is deeper than the snow tube is long, stop before the snow tube is completely full. Carefully remove the tube and empty that part of the sample into your sample bag. Return the empty tube to where you stopped the sample and collect the rest of the column of snow.



Labeled Ziptop Bag



7. Move snow away from the wall of the cylinder on the pit side. From the side, carefully insert a flat, stiff object (tile, rigid plastic, or small flat aluminum shovel) under the bottom of the snow tube to prevent snow from falling out when the tube is moved. Make sure the cap is not too close to the ground where it could pick up soil and plant debris that could contaminate the sample. If any samples come in contact with **organic matter**, discard the sample and take another near the original sample location. This part of the process is important if you plan to continue with Part 2.

8. Holding the cap in place, tilt the snow tube and its cap into the pit. Be careful not to spill any of the snow core. Invert the snow tube so the snow core slides to the bottom. Using the scale on the graduated cylinder snow tube, note the height of the snow core and record that amount on the data sheet (p. 136). Repeat the process for the other two samples. Add the three amounts and divide by the number of samples taken (3). Record the average height of the snow core in the appropriate column on the data sheet.

   If the snow is hard or crusty or deeper than the length of your snow tube, remove the snow core in the same way, but in stages. Add the stage amounts to get the total height of the snow core.

9. Be careful not to spill snow from the tube and do not touch the snow with your hands. Empty the snow into the pre-labeled ziptop

plastic bags. Make sure the sample goes into the correctly labeled bag. Press as much air out of the bag as possible and close the bag tightly. Do not allow the snow to melt. Prolonged contact with the air can mix carbon dioxide with the snow water, forming a solution of carbonic acid. This acid will lower the **pH** levels of your snow sample, if you are planning to complete Part 2 of the activity. Impurities on your hands can also affect the pH of the snow sample.

10. Record air temperature, the temperature at the snow surface, and time taken on the data sheet. Return indoors to melt the snow core.

Handling snow samples in the classroom

Note: If you are going to do the pH activity in Part 2 it is very important to keep the snow samples frozen until ready to proceed with the melting process. Do not thaw samples overnight. Warming can stimulate biological organisms in the sample to become more active. Their respiration can add carbon dioxide to the sample and potentially change the acidity.

Agitate the samples as little as possible after thawing because this stirring process increases the contact with carbon dioxide in the atmosphere. (You can do this deliberately to determine the effect. First, take a pH reading following the exact directions in Part 2 below. Then expose the sample to air for an hour or more. Unless the snow is very acidic, the second reading should show a lower pH, or more acidic value.) To avoid contamination of the sample, reduce the handling time and do not touch the melted sample with your hands.

1. Transfer a snow sample from the ziptop bag to the 1,000 milliliter graduated cylinder (one without a hole near its base). Let snow samples melt at room temperature. This can take a while. Monitor the progress so water depth can be recorded soon after the disappearance of all ice.

Snow Survey Data Sheet

Sample site # ________

Date:	Watershed:	Team members:
Time:	Air temp:	
	Surface temp:	Nearest community:
Notes: (description of sample site, weather conditions, other observations)		

Sample No.	Average snow depth at site	Snow level in tube	Average snow tube level	Snow water content	Average snow water content	pH of snow water	Remarks
1							
2							
3							

2. Read the water level in the graduated cylinder as soon as possible after thawing. Record the amount to the nearest milliliter. Repeat for the other two samples. Add the three amounts and divide by the number of samples taken (3). Record the snowpack water content amount in the appropriate average column on the data sheet.
3. Calculate the snow water content conversion factor. To do this, first calculate a total volume for all three snow samples and the total volume of water they produced. Then simply divide the volume of water by the volume of snow. For example, if 500 milliliters of unmelted snow produced 50 milliliters of water, then divide 50 by 500. The answer, in this case 0.1, is the snow water content conversion factor for the area and time you sampled. Now you can convert any snow depth for that area to a water depth by multiplying the snow depth by the conversion factor.

Conversion factor: ______

4. To give your data a watershed perspective, complete the worksheet below. Show your work as you complete the calculations.

Note to the teacher: If you cannot collect your own snow samples, use information from the two Internet sites to develop a data sheet and worksheet for student calculations. Use the process to orient students to the kind of information available, how it is obtained, and how it is applied.

Student Worksheet

	Example
(a) Determine the area of a football field if it is 120 feet long and 60 feet wide. Area of a rectangle (ft^2) = length × width.	**7,200 ft^2**
(b) If using metric measurements for average snow depth, convert from centimeters to inches by multiplying the number of centimeters by 0.4. If measurements are in inches, conversion is not necessary.	**For example: If your snow depth at the site measured 75 centimeters, it converts to 30 inches.**
(c) Convert snow depth from inches to feet by dividing by 12.	**For example: 30 inches converts to 2.5 feet.**
(d) Find the total volume of snow (in cubic feet) on the football field by multiplying the answer from (a) by the answer from (c).	**7,200 ft^2 × 2.5 ft = 18,000 ft^3**
(e) If the entire football field "watershed" has the same snowpack depth (# from average snow depth column on your data sheet), what would be the total snow water content of the snowpack on the football field "watershed?" (Multiply the volume from (d) by the snow water content conversion factor).	**For example: if your snow water content conversion factor was 0.15, the answer would be:** **18,000 ft^3 × 0.15 = 2,700 ft^3**
(f) How many gallons is this? (To convert cubic feet to gallons, multiply by 7.48).	**2,700 ft^3 × 7.48 = 20,196 gals**

5. The following chart shows information from snow surveys for eight SNOTEL sites in the Rogue/Umpqua Basin on March 19, 1999. This information is from the Internet at http://www.wrcc.dri.edu/snotel.html. Check out the website for snowpack information in other Oregon watersheds or basins in other western states. Compare the average snow water equivalent and the percent of average data for those states. Consider how this information correlates to long-term weather patterns.

The snow water equivalent percent of average represents the snow water equivalent found at selected SNOTEL sites in or near the basin compared to the average value for those sites on this day. The reference period for average conditions is 1961-90.

SNOTEL Site	Elevation (feet)	Current snow water equivalent (inches)	Average snow water equivalent (inches)	Percent of average (%)
Bigelow	5,120	36.1	11.7	309
Billie Creek Divide	5,300	34.2	20.6	166
Diamond Lake	5,315	38.4	12.4	310
Fish Lake	4,665	16.8	9.1	185
Fourmile Lake	6,000	44.1	29.8	148
King Mountain	4,000	15.1	2.3	657
Sevenmile Marsh	6,200	46.1	31.5	146
Basin wide percent of average				184

The snow water equivalent information collected at SNOTEL sites or along snow courses is much more complicated than the simple procedures outlined in your snow sampling activity. However, the concept is the same in that the snowpack can contain varying amounts of water. Knowledge of that amount of water is valuable information for residents of a watershed.

Proceed to Part 2 if your teacher directs you to do so.

Questions: Part 1

1. From what direction do the prevailing winds come during the major precipitation months in your area? How does this correspond to areas of greatest snow concentrations in your area?
   Answers will vary.

2. Is the snow water content of your samples the same as those obtained by another group? Explain.
   Answers will vary depending on degree of compaction, snow water content at different sites, and accuracy of measurement.

3. Would the snow water content of compacted snow be the same as that of loosely packed snow? Explain.

   Generally, more compacted snow samples would contain a higher snow water content because compacted snow is more dense. Because of sublimation, the amount of snow water content can be less if samples are collected later in the snow. On the other hand, if it continues to snow, more water in the form of snow, continues to accumulate.

4. From the exercise in Step 4 above you can see that even a football field "watershed" covered with snow has the potential to contribute vast amounts of water to a stream system during thawing periods. The snow water equivalent table in Step 5 also provides information about water content. How could you apply the information learned in Steps 4 and 5 to your local watershed?
   Snow surveys provide an inventory of the total snow covering in a specific watershed and the resulting effects on local water supplies. This information is used to predict floods, regulate reservoir storage, determine hydropower potential at dams, forecast community water supplies, assess agricultural productivity, and other applications.

5. Why is it important to have a number of SNOTEL sites at different elevations in a watershed?
   Snow depths usually vary by elevation, as can snow water equivalents. Getting information from a variety of sites at different elevations provides a broad picture of the water potential in the watershed.

6. What does the percent of average figure tell you about the Rogue/Umpqua Basins in 1999 just prior to snowmelt?
   Year 1999 is an exceptionally high water year with snow water equivalents that are 184% of average when using the reference period 1961 through 1990 as a comparison. This could indicate a high potential for flooding during spring runoff.

Background: Part 2

Do you know . . .

... that the quality of water in our streams and lakes can depend on the quality of water in rain and snow? Like rain, snow may be contaminated with airborne pollutants. But unlike **acid rain**, pollutants carried with snow do not enter streams with each storm. Instead pollutants are stored in snow until the snowpack melts. When polluted snow melts, it can release large "pulses" of pollutants into local land and water environments. If the pollutants are acidic, this pulse of concentrated polluted water can create **acid shock**. Acid shock can harm fish, wildlife, and other organisms in the affected areas. Some fish and aquatic insects are killed outright by the rapid and extreme change in acidity. Although some adult fish can survive these pulses, eggs and **fry** cannot. A local fish population's entire annual reproduction can be wiped out. And, the loss of sensitive aquatic insects can disrupt the food chain fish depend on.

Often the effects of acid shock can be relatively brief and localized. As water from melting snow mixes with water already in streams and rivers, it is diluted, making it less harmful.

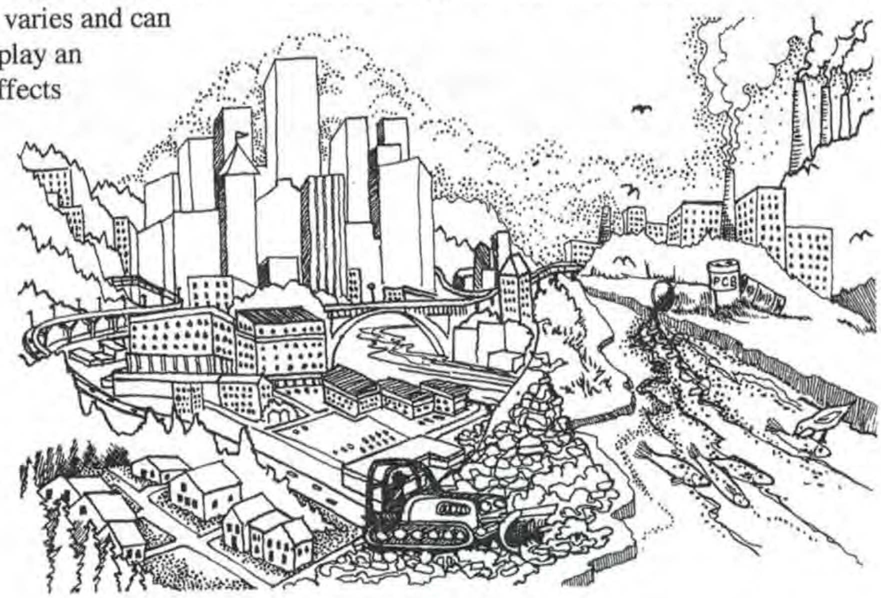
Other things, primarily calcium, in soils or water can buffer acidity by neutralizing the pollutants that reduce the pH of water in streams. The amount of buffering agents varies and can eventually be used up, but they play an important role in reducing the effects of pollutants in streams. Researchers are exploring how this affects the survival of terrestrial plants, aquatic invertebrates, and some fish species.

Where do snow pollutants come from? Pollutants can get into snow in several ways. The heaviest particles simply fall out of the atmosphere and land on the earth's surface or on the surface of the snow. High winds may carry these particles for a short distance, but they are usually deposited close to their source.

Gaseous forms of pollutants, very fine particles, and salt mists can happen in high concentrations in the atmosphere. Most of these pollutants first dissolve into airborne moisture and fall out of the atmosphere as rain or snow. How much and how fast this occurs depends on how often it rains or snows when pollutant concentrations are high.

Pollutants from human sources—hydrocarbons from the combustion of fossil fuels, heavy metals from industrial processes, and dust—are the most common forms of pollutants found in snow. When sulfur or nitrogen compounds from these sources combine with oxygen in the atmosphere, a mild solution of sulfuric or nitric acid forms. When it rains or snows these acids are washed out of the atmosphere and collect in local water bodies or in the snowpack on the ground.

Local pollution sources are often a problem in winter. More fuel is burned to provide heat, putting more pollutants to the air over a community. As a result, snow quality changes from one location to another depending on the size of the community, their source of heat or electricity, how close they are to urban areas or the ocean, prevailing weather patterns, and the frequency of temperature inversions in winter that trap pollutants in the layer of air next to the snow. Local



sources of pollutants include power plants, airports, coal, oil, and wood-burning stoves, and local transportation. Regional sources might include ocean mists, volcanic debris, and dust generated by large scale surface mining.

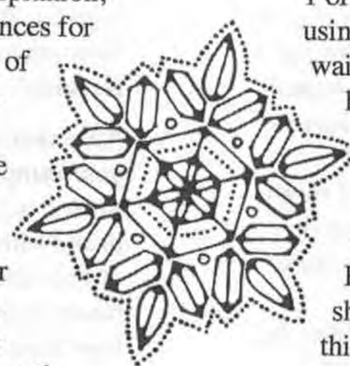
Contaminated snow can be a serious hazard to both land and water habitats. Some snow evaporates directly into the air through the process of **sublimation**, leaving pollutants behind in even greater concentrations. When temperatures are below freezing for long periods the pollutants in snow may be stored until the spring thaw.

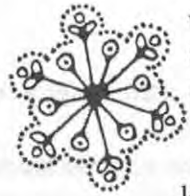
Procedure

Now it's your turn . . .

Does Oregon have a problem with acid rain? Is there the potential for acid shock in Oregon streams fed by melting snow? You can help find out. Snow sampling and testing may help answer this question.

Much of Oregon's annual precipitation, including snow, falls when the chances for polluted air is high in certain areas of the state. Although industries have tight air quality regulations, other sources of pollution may contribute to air quality alerts, especially in basins surrounded by mountains like the Klamath Basin or the upper Rogue River Valley near Medford. Since much of the snowpack in the higher mountains rarely thaws during the winter, pollutants accumulate throughout the snow season, making them easier to detect. Because access to high mountain areas is difficult, however, little testing is completed to determine these pollution levels.





1. Brainstorm possible sources of pollutants in your community or part of the state. Make a list of these sources and describe the kind of airborne pollutant that may result.
2. Consider the role of snowfall in Oregon's watersheds. How do Oregon's mountain ranges affect distribution of precipitation throughout the state? Do specific mountain ranges affect the weather patterns in your area? If so, how?
3. Pollutants are usually more concentrated in samples collected later in the winter. Samples collected in or near a community may show the effects of local pollution. Samples gathered farther from the community may provide information about pollution carried by winds from regional sources.

4. Use the water samples collected during Part 1 of this activity or collect new samples using the same procedures. If possible, avoid waiting more than one hour after the snow has melted to sample for pH. For each sample, dip one strip of wide-range pH test paper into the snow water. Match the resulting color on the test strip with the color scale on the package. Record the pH of each sample on the data sheet. (You can also use a pH test kit for this process.)

Questions: Part 2

1. Compare the pH values of your samples with samples from other groups. Are there any differences? What may have caused the differences?

   Answers will vary depending on snow sample locations and other variables. Samples taken from an area downwind of an industrial area or near a community whose residents primarily use coal or wood-burning for winter heating may detect changes in pH.

2. How do you think the pH levels of your snow samples would compare if you had data from both early winter and late winter? Explain?

   In areas of long-term snow coverage, the pH levels are likely lower (more acidic) as more pollutants have accumulated over time. Sublimation, snow compaction, and extended temperatures below freezing usually concentrate the levels of pollutants causing an increase in acidity.

Going further

1. Conductivity investigations with a conductivity meter are not included in this exercise, but are a good way to extend the activity further. Conductivity, or the ability of a liquid to conduct an electrical charge, is also used to test for impurities in snow samples. Since many pollutants are negatively charged (anions) or positively charged (cations), as their concentrations increase, there is a corresponding increase in the conductivity of the melted snow sample. Although both pH and conductivity provide evidence of impurities in snow samples, neither method identifies or measures the concentrations of specific impurities causing the low pH (high acidity) or high conductivity. Many impurities in snowmelt will not cause high acidity but they can cause high conductivity.

   Conductivity meters may be available for loan through water quality management offices or can be bought.

2. What role does snow density play in the calculation of snow water equivalents and potential runoff?

3. Try the "Deadly Skies" activity from *Aquatic Project WILD*, pp. 142-145.

4. Sample snow near all known and probable local pollution sites in and around the community. Record pH (and conductivity) measurements and source of impurity. On a map mark the values at the site where you collected the sample. Draw a line connecting all near identical values to see if there are high or low acidity "spots" in the area. (This is the same idea as connecting identical topographic elevations.) Can you tell when a local source gradually loses its effect with distance?

5. After determining the pH of the snowmelt in your samples, create water samples with similar pH levels. Keep salmon eggs or fry in them (with help from the Oregon Department of Fish and Wildlife's Salmon-Trout Enhancement Program; see Chapter 11) to see how these "pollutants" affect their growth rate, development, or survival.

6. Chart depth and water content of snow throughout the snow season for a SNOTEL site near your area. If snow level decreases and water content remains the same, what factor is responsible? (**Compaction.**) If water content decreases as snow level decreases, what factor is responsible? (**Sublimation.**)

Winter watersheds

Part 1

Do you know . . .

Millions of Americans enjoy snow-covered landscapes for their beauty or as a winter playground. But snow also plays a vital role. It is a primary source of the water supply in the western United States.

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Parts of this activity are adapted from *Snow Chemistry and Air Pollution*, Burris, Frank, Rena McFarlane and Peter Stortz, Alaska Cooperative Extension, Fairbanks, Alaska, 1996, and used with permission. Additional information obtained and adapted from *Snow Surveys and Water Supply Forecasting*, U.S. Department of Agriculture, Soil Conservation Service, Agriculture Information Bulletin 536, June 1988.

Vocabulary

acid rain
acid shock
fry
organic matter
pH
snow courses
snow water content
sublimation
telemetry

These factors change from year to year and vary from one location to another.

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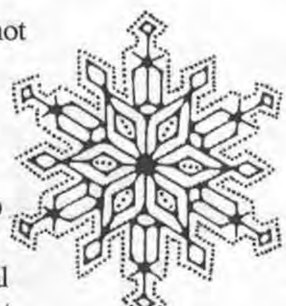

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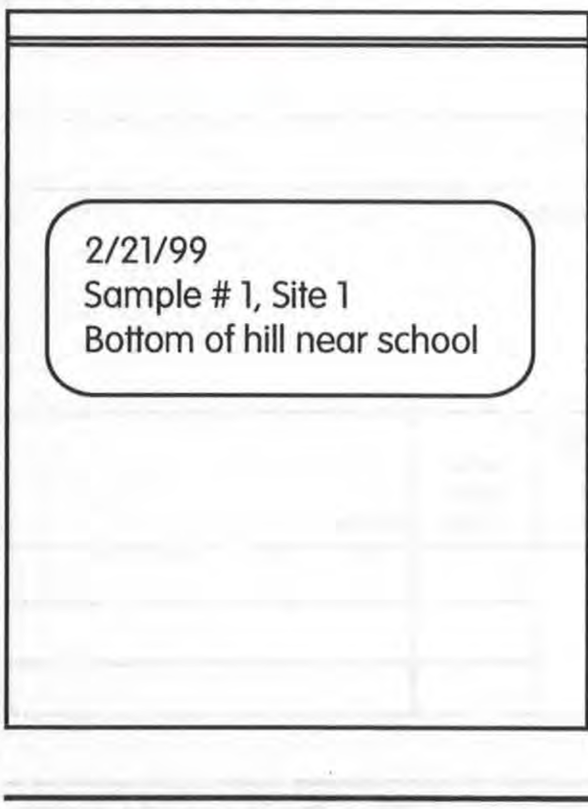
Labeled Ziptop Bag



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6. Shove the snow tube, open end down, vertically through the snow just beyond the edge of the pit. Do not push the snow tube into the soil or vegetation layer. It is important not to pack the snow in the tube. If the snow is deeper than the snow tube is long, stop before the snow tube is completely full. Carefully remove the tube and empty that part of the sample into your sample bag. Return the empty tube to where you stopped the sample and collect the rest of the column of snow.

7. Move snow away from the wall of the cylinder on the pit side. From the side, carefully insert a flat, stiff object (tile, rigid plastic, or small flat aluminum shovel) under the bottom of the snow tube to prevent snow from falling out when the tube is moved. Make sure the cap is not too close to the ground where it could pick up soil and plant debris that could contaminate the sample. If any samples come in contact with **organic matter**, discard the sample and take another near the original sample location. This part of the process is important if you plan to continue with Part 2.

8. Holding the cap in place, tilt the snow tube and its cap into the pit. Be careful not to spill any of the snow core. Invert the snow tube so the snow core slides to the bottom. Using the scale on the graduated cylinder snow tube, note the height of the snow core and record

Student sheet

that amount on the data sheet (p. 146). Repeat the process for the other two samples. Add the three amounts and divide by the number of samples taken (3). Record the average height of the snow core in the appropriate column on the data sheet.

If the snow is hard or crusty or deeper than the length of your snow tube, remove the snow core in the same way, but in stages. Add the stage amounts to get the total height of the snow core.

9. Be careful not to spill snow from the tube and do not touch the snow with your hands. Empty the snow into the pre-labeled ziptop plastic bags. Make sure the sample goes into the correctly labeled bag. Press as much air out of the bag as possible and close the bag tightly. Do not allow the snow to melt. Prolonged contact with the air can mix carbon dioxide with the snow water, forming a solution of carbonic acid. This acid will lower the **pH** levels of your snow sample, if you are planning to complete Part 2 of the activity. Impurities on your hands can also affect the pH of the snow sample.

10. Record air temperature, the temperature at the snow surface, and time taken on the data sheet. Return indoors to melt the snow core.

Handling snow samples in the classroom

Note: If you are going to do the pH activity in Part 2 it is very important to keep the snow samples frozen until ready to proceed with the melting process. Do not thaw samples overnight. Warming can stimulate biological organisms in the sample to become more active. Their respiration can add carbon dioxide to the sample and potentially change the acidity.

Agitate the samples as little as possible after thawing because this stirring process increases the contact with carbon dioxide in the atmosphere. (You can do this deliberately to determine the effect. First, take a pH reading following the exact directions in Part 2 below.

Snow Survey Data Sheet

Sample site # ________

Date:	Watershed:	Team members:
Time:	Air temp:	
	Surface temp:	Nearest community:
Notes: (description of sample site, weather conditions, other observations)		

Sample No.	Average snow depth at site	Snow level in tube	Average snow tube level	Snow water content	Average snow water content	pH of snow water	Remarks
1							
2							
3							

Student sheet

Then expose the sample to air for an hour or more. Unless the snow is very acidic, the second reading should show a lower pH, or more acidic value.) To avoid contamination of the sample, reduce the handling time and do not touch the melted sample with your hands.

1. Transfer a snow sample from the ziptop bag to the 1,000 milliliter graduated cylinder (one without a hole near its base). Let snow samples melt at room temperature. This can take a while. Monitor the progress so water depth can be recorded soon after the disappearance of all ice.

2. Read the water level in the graduated cylinder as soon as possible after thawing. Record the amount to the nearest milliliter. Repeat for the other two samples. Add the three amounts and divide by the number of samples taken (3). Record the snowpack water content amount in the appropriate average column on the data sheet.

3. Calculate the snow water content conversion factor. To do this, first calculate a total volume for all three snow samples and the total volume of water they produced. Then simply divide the volume of water by the volume of snow. For example, if 500 milliliters of unmelted snow produced 50 milliliters of water, then divide 50 by 500. The answer, in this case 0.1, is the snow water content conversion factor for the area and time you sampled. Now you can convert any snow depth for that area to a water depth by multiplying the snow depth by the conversion factor.

Conversion factor: ____

Student Worksheet

(a) Determine the area of a football field if it is 120 feet long and 60 feet wide. Area of a rectangle (ft^2) = length × width.	
(b) If using metric measurements for average snow depth, convert from centimeters to inches by multiplying the number of centimeters by 0.4. If measurements are in inches, conversion is not necessary.	
(c) Convert snow depth from inches to feet by dividing by 12.	
(d) Find the total volume of snow (in cubic feet) on the football field by multiplying the answer from (a) by the answer from (c).	
(e) If the entire football field "watershed" has the same snowpack depth (# from average snow depth column on your data sheet), what would be the total snow water content of the snowpack on the football field "watershed?" (Multiply the volume from (d) by the snow water content conversion factor).	
(f) How many gallons is this? (To convert cubic feet to gallons, multiply by 7.48).	

4. To give your data a watershed perspective, complete the worksheet below. Show your work as you complete the calculations.
5. The following chart shows information from snow surveys for eight SNOTEL sites in the Rogue/Umpqua Basin on March 19, 1999. This information is from the Internet at http://www.wrcc.dri.edu/snotel.html. Check out the website for snowpack information in other Oregon watersheds or basins in other western states. Compare the average snow water equivalent and the percent of average data for those states. Consider how this information correlates to long-term weather patterns.

The snow water equivalent percent of average represents the snow water equivalent found at selected SNOTEL sites in or near the basin compared to the average value for those sites on this day. The reference period for average conditions is 1961-90.

The snow water equivalent information collected at SNOTEL sites or along snow courses is much more complicated than the simple procedures outlined in your snow sampling activity. However, the concept is the same in that the snowpack can contain varying amounts of water. Knowledge of that amount of water is valuable information for residents of a watershed.

Proceed to Part 2 if your teacher directs you to do so.

SNOTEL Site	Elevation (feet)	Current snow water equivalent (inches)	Average snow water equivalent (inches)	Percent of average (%)
Bigelow	5,120	36.1	11.7	309
Billie Creek Divide	5,300	34.2	20.6	166
Diamond Lake	5,315	38.4	12.4	310
Fish Lake	4,665	16.8	9.1	185
Fourmile Lake	6,000	44.1	29.8	148
King Mountain	4,000	15.1	2.3	657
Sevenmile Marsh	6,200	46.1	31.5	146
Basin wide percent of average				**184**

Student sheet

Questions: Part 1

1. From what direction do the prevailing winds come during the major precipitation months in your area? How does this correspond to areas of greatest snow concentrations in your area?

2. Is the snow water content of your samples the same as those obtained by another group? Explain.

3. Would the snow water content of compacted snow be the same as that of loosely packed snow? Explain.

4. From the exercise in Step 4 above you can see that even a football field "watershed" covered with snow has the potential to contribute vast amounts of water to a stream system during thawing periods. The snow water equivalent table in Step 5 also provides information about water content. How could you apply the information learned in Steps 4 and 5 to your local watershed?

5. Why is it important to have a number of SNOTEL sites at different elevations in a watershed?

6. What does the percent of average figure tell you about the Rogue/Umpqua Basins in 1999 just prior to snowmelt?

Part 2

Do you know . . .

... that the quality of water in our streams and lakes can depend on the quality of water in rain and snow? Like rain, snow may be contaminated with airborne pollutants. But unlike **acid rain**, pollutants carried with snow do not enter streams with each storm. Instead pollutants are stored in snow until the snowpack melts. When polluted snow melts, it can release large "pulses" of pollutants into local land and water environments. If the pollutants are acidic, this pulse of concentrated polluted water can create **acid shock**. Acid shock can harm fish, wildlife, and other organisms in the affected areas. Some fish and aquatic insects are killed outright by the rapid and extreme change in acidity. Although some adult fish can survive these pulses, eggs and **fry** cannot. A local fish population's entire annual reproduction can be wiped out. And, the loss of sensitive aquatic insects can disrupt the food chain fish depend on.

Often the effects of acid shock can be relatively brief and localized. As water from melting snow mixes with water already in streams and rivers, it is diluted, making it less harmful.

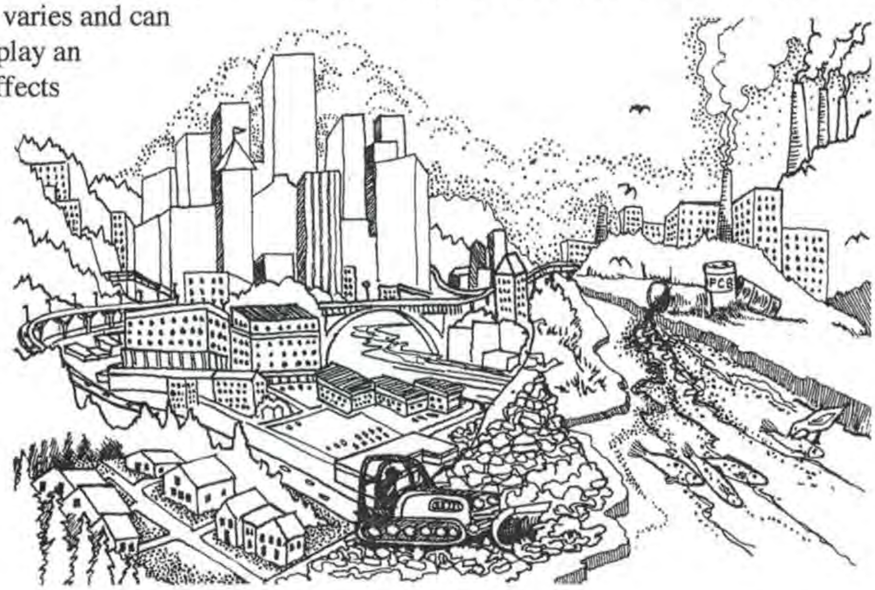
Other things, primarily calcium, in soils or water can buffer acidity by neutralizing the pollutants that reduce the pH of water in streams. The amount of buffering agents varies and can eventually be used up, but they play an important role in reducing the effects of pollutants in streams. Researchers are exploring how this affects the survival of terrestrial plants, aquatic invertebrates, and some fish species.

Where do snow pollutants come from? Pollutants can get into snow in several ways. The heaviest particles simply fall out of the atmosphere and land on the earth's surface or on the surface of the snow. High winds may carry these particles for a short distance, but they are usually deposited close to their source.

Gaseous forms of pollutants, very fine particles, and salt mists can happen in high concentrations in the atmosphere. Most of these pollutants first dissolve into airborne moisture and fall out of the atmosphere as rain or snow. How much and how fast this occurs depends on how often it rains or snows when pollutant concentrations are high.

Pollutants from human sources—hydrocarbons from the combustion of fossil fuels, heavy metals from industrial processes, and dust—are the most common forms of pollutants found in snow. When sulfur or nitrogen compounds from these sources combine with oxygen in the atmosphere, a mild solution of sulfuric or nitric acid forms. When it rains or snows these acids are washed out of the atmosphere and collect in local water bodies or in the snowpack on the ground.

Local pollution sources are often a problem in winter. More fuel is burned to provide heat, putting more pollutants to the air over a community. As a result, snow quality changes from one location to another depending on the size of the community, their source of heat or electricity, how close they are to urban areas or the ocean, prevailing weather patterns, and the frequency of temperature inversions in winter that trap pollutants in the layer of air next to the snow. Local



sources of pollutants include power plants, airports, coal, oil, and wood-burning stoves, and local transportation. Regional sources might include ocean mists, volcanic debris, and dust generated by large scale surface mining.

Contaminated snow can be a serious hazard to both land and water habitats. Some snow evaporates directly into the air through the process of **sublimation**, leaving pollutants behind in even greater concentrations. When temperatures are below freezing for long periods the pollutants in snow may be stored until the spring thaw.

Now it's your turn . . .

Does Oregon have a problem with acid rain? Is there the potential for acid shock in Oregon streams fed by melting snow? You can help find out. Snow sampling and testing may help answer this question.

Much of Oregon's annual precipitation, including snow, falls when the chances for polluted air is high in certain areas of the state. Although industries have tight air quality regulations, other sources of pollution may contribute to air quality alerts, especially in basins surrounded by mountains like the Klamath Basin or the upper Rogue River Valley near Medford. Since much of the snowpack in the higher mountains rarely thaws during the winter, pollutants accumulate throughout the snow season, making them easier to detect. Because access to high mountain areas is difficult, however, little testing is completed to determine these pollution levels.

1. Brainstorm possible sources of pollutants in your community or part of the state. Make a list of these sources and describe the kind of airborne pollutant that may result.

2. Consider the role of snowfall in Oregon's watersheds. How do Oregon's mountain ranges affect distribution of precipitation throughout the state? Do specific mountain ranges affect the weather patterns in your area? If so, how?

3. Pollutants are usually more concentrated in samples collected later in the winter. Samples collected in or near a community may show the effects of local pollution. Samples gathered farther from the community may provide information about pollution carried by winds from regional sources.

4. Use the water samples collected during Part 1 of this activity or collect new samples using the same procedures. If possible, avoid waiting more than one hour after the snow has melted to sample for pH. For each sample, dip one strip of wide-range pH test paper into the snow water. Match the resulting color on the test strip with the color scale on the package. Record the pH of each sample on the data sheet. (You can also use a pH test kit for this process.)

Questions: Part 2

1. Compare the pH values of your samples with samples from other groups. Are there any differences? What may have caused the differences?

2. How do you think the pH levels of your snow samples would compare if you had data from both early winter and late winter? Explain?

Student sheet

Snow way!

Activity Education Standards: Note alignment with Oregon Academic Content Standards beginning on p. 483.

Objectives

Students will (1) graph the annual rainfall for a basin, (2) graph annual snowpack for the same basin, (3) graph streamflow during the same period, and (4) analyze and describe the response of the stream to various types of precipitation.

Method

Students will graph rainfall, snowpack, and streamflow data for Silver Creek near Silver Lake in Lake County, Oregon. Students will then draw conclusions about the response of a watershed to various types of precipitation.

For younger students

1. This activity can also be done as a group.
2. Younger students may need graphing practice prior to this activity.

Materials

- copies of student sheets (pp. 101-104)

Notes to the teacher

Ask the students to describe the direct correlations shown on the graph. For example, peak snowpack is in February and March. At this time, streamflows are at their lowest. Then, as snowmelt occurs, streamflows increase as shown when lines cross and go in opposite directions. When streamflows are highest, precipitation is lowest. Notice that the streamflow peaks in September but continues to provide good flows throughout the warmest months of the year because of baseflow (groundwater recharge).

Background

Do you know . . .

. . . in many places snow is an important part of the total precipitation of a watershed? It is the main source of water for streams in the mountainous West. Melting snow may affect streamflow long after it falls as precipitation. Snow may melt slowly, creating streamflow throughout the otherwise dry summer. Or it may melt rapidly, creating floods.

During the spring and fall, temperature fluctuations can cause recent snowfall to melt. When this happens it creates runoff and streamflow affects similar to rainstorms. During the winter, snow may stay on the ground for long periods. This stores the water in snow until later in the year. Streams fed by melting snow often flow for much longer periods than streams fed only by rain.

Mountain snowpacks are measured to predict how much water will be available when it melts later in the year. To evaluate how much water is in snow it is important to measure not only its depth, but its **water equivalent**. This is the amount of water that would be released if all of the snow melted.

Snow disappears in other ways besides melting. In a process known as **sublimation** snow can pass directly from frozen form to vapor. Wind blowing directly across snow evaporates it. Blowing snow is especially prone to sublimation.

Vocabulary

water equivalent
sublimation
streamflow hydrograph

Procedure

Now it's your turn . . .

The information in the following table shows annual precipitation and snowpack amounts and streamflow for a basin in southeastern Oregon. The data for precipitation includes snowfall. Even though it falls as precipitation, snow may not affect streamflow until later in the year. When temperatures are below freezing, snow is stored in the watershed rather than being captured in, or stored by, soils. The data given for snowpack shows the accumulated amounts over a season.

Snowpack was measured near the top of the Silver Creek watershed. Precipitation and streamflow were measured near the mouth of Silver Creek.

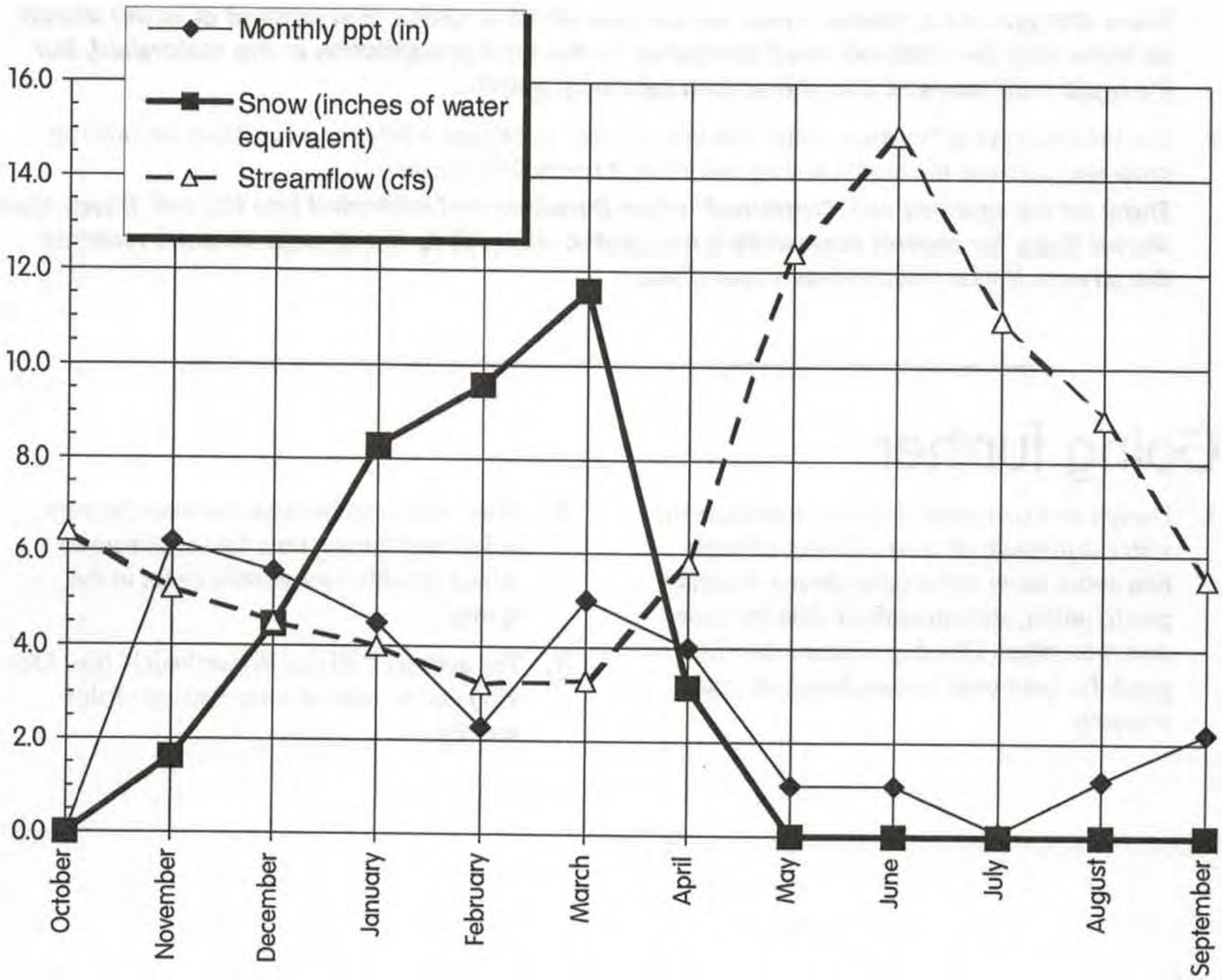
On the graph provided, create a line graph by plotting the annual precipitation and snowpack of the Silver Creek basin near Silver Lake in Lake County. Repeat the process for the streamflow data. This graph is called a **streamflow hydrograph**.

Use a different color for each line. Be sure to mark a legend with the color representing each line.

Silver Creek is a tributary of Silver Lake, in Lake County, Oregon. The drainage area of Silver Creek is 180 square miles.

1989	Monthly ppt (in)	Snow (inches of water equivalent)	Streamflow (cfs)
October	0.0	0.00	6.4
November	6.2	1.63	5.2
December	5.6	4.47	4.5
January	4.5	8.31	4.0
February	2.3	9.60	3.2
March	5.0	11.59	3.3
April	4.0	3.15	5.8
May	1.1	0.00	12.4
June	1.1	0.00	14.9
July	0.1	0.00	11.0
August	1.2	0.00	8.9
September	2.2	0.00	5.5

Silver Creek Streamflow Hydrograph



Questions

1. Which month had the greatest precipitation? The most water stored as snow? The highest streamflow?

   Precipitation was highest in November. The peak snowpack was in March. June was the month with the highest streamflow.

2. How long was it from the precipitation peak to the streamflow peak.

   The period between the precipitation peak and streamflow peak is November to June, or about 7 months.

3. How long was it from the peak storage of snow to the streamflow peak.

   The period between the snow storage peak and streamflow peak is March to June, or about 3 months

4. Which has a greater influence on the peak streamflow of Silver Creek, total precipitation or snow storage? Why?

   Snow storage has a greater effect on the flow of Silver Creek. The amount of water stored as snow may be relatively small compared to the total precipitation in the watershed, but it's rapid melt moves it into the stream relatively quickly.

5. Use the concepts of "capture, store, and safe release" to explain where the water from the melting snow was between the time it melted and when it reached to stream?

   Snow on the uplands was "captured" when it melted and infiltrated into the soil. It was then stored there for several days while it percolated downhill to the stream. When it reached the stream it was released as streamflow.

Going further

1. Design an experiment that will determine the water equivalent of snow. Collect information about snow water equivalence, monthly precipitation, and streamflow data for your own watershed. Develop a streamflow hydrograph for your own stream, based on your research.
2. What relationship exists between "stream order" and the lag time for the stream to reflect a sudden snow-melt event in the spring?
3. The activity "Winter Watersheds!" (pp. 131-152) can be used as an extension of this activity.

Name

Snow way!

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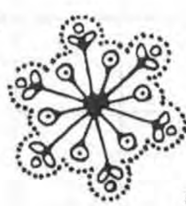

Vocabulary

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sublimation
streamflow hydrograph

Student sheet

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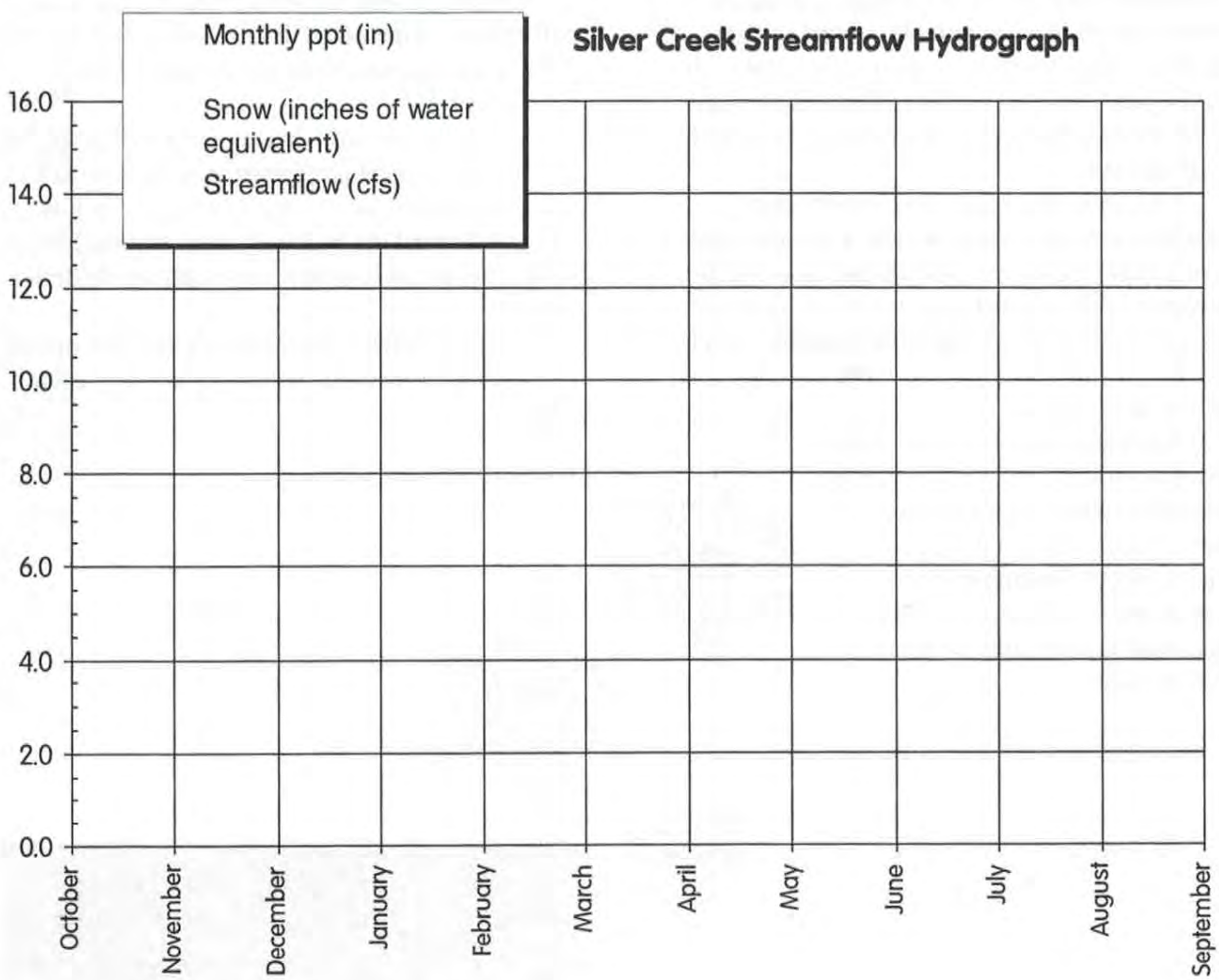

Student sheet

Questions

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