WA State Fruit Frost Forecast Service History

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The fruit frost forecast service has been in place for over 100 years in Washington State. This program came to Washington in 1922 in order to help mitigate damage to tree fruits when they are particularly vulnerable while budding and blossoming during the spring transition season. By having meteorologists dedicated to forecasting overnight low temperatures and weather patterns from the middle of March through the end of May, growers are able to better determine whether they will, or will not, have to take measures to protect their prospective crops from cold weather damage. The goal ultimately being to help growers conserve financial resources by knowing whether they will need to utilize cold temperature mitigation methods or not. A single significant cold event can cause substantial bud and blossom losses that can quickly total into the six figure dollar amount and provide a meager harvest in the autumn. Utilizing mitigation methods when not needed is also detrimental to a grower's bottom line. A brief history of the program will be outlined along with a few images depicting portions of the annual frost reports compiled at the end of the season as well as other interesting clips.

Above: Original Weather Bureau temperature shelter that originally housed a manually read minimum temperature thermometer. Many were also outfitted with an ink-on-chart 7 day thermograph so a continuous temperature record could be obtained. Most were eventually refitted with digital instrumentation, beginning around the year 2000 by Clearwest. This shelter has been refitted by AgWeatherNet with an automated temperature and relative humidity sensor

that records data every 5 minutes and relays it every 15 minutes. This is the Selah-Speyers station. The East Kennewick and East Tieton shelters have been retrofitted in the same way.

U.S. Weather Bureau/National Weather Service Years (1922-1995)

Agricultural interests have certainly had concern for frost and cold weather events and their potential damaging impacts to crops for many, many years prior to the advent of the frost service. In fact, an excerpt from the National Weather Services *'History of the National Weather Service'* webpage states that in 1901:

> *"At the Weather Bureau Conference in Milwaukee, Wis., Chief Willis Moore observed the Post Office Department was delivering slips of paper with daily forecasts, frost and cold-wave warnings, to everyone's door with the mail. The one disadvantage to the system was the mail carriers started their routes about 7:00 a.m. and that day's forecast was not issued until 10:00 a.m., so the previous night's forecasts were used."*

This seems to indicate that frost specific forecasts were already being produced and disseminated as an official product at the turn of the 20th century, at least on a local and/or regional level. This perhaps initiated the U.S. Weather Bureau (which eventually became the National Weather Service in 1970) to begin to consider the dissemination of frost specific forecasts for agriculture. And at the time, the Weather Bureau was indeed a part of the Department of Agriculture beginning in 1890. As an aside, the bureau was formed in 1870, it was considered a part of the U.S. Army Signal Services Division of Telegrams and Reports for the Benefit of Commerce, with the goal focused "to provide for taking meteorological observations at the military stations in the interior of the continent, and at other points in the States and Territories...and for giving notice on the northern lakes and on the seacoast, by magnetic telegraph and marine signals, of the approach and force of storms."

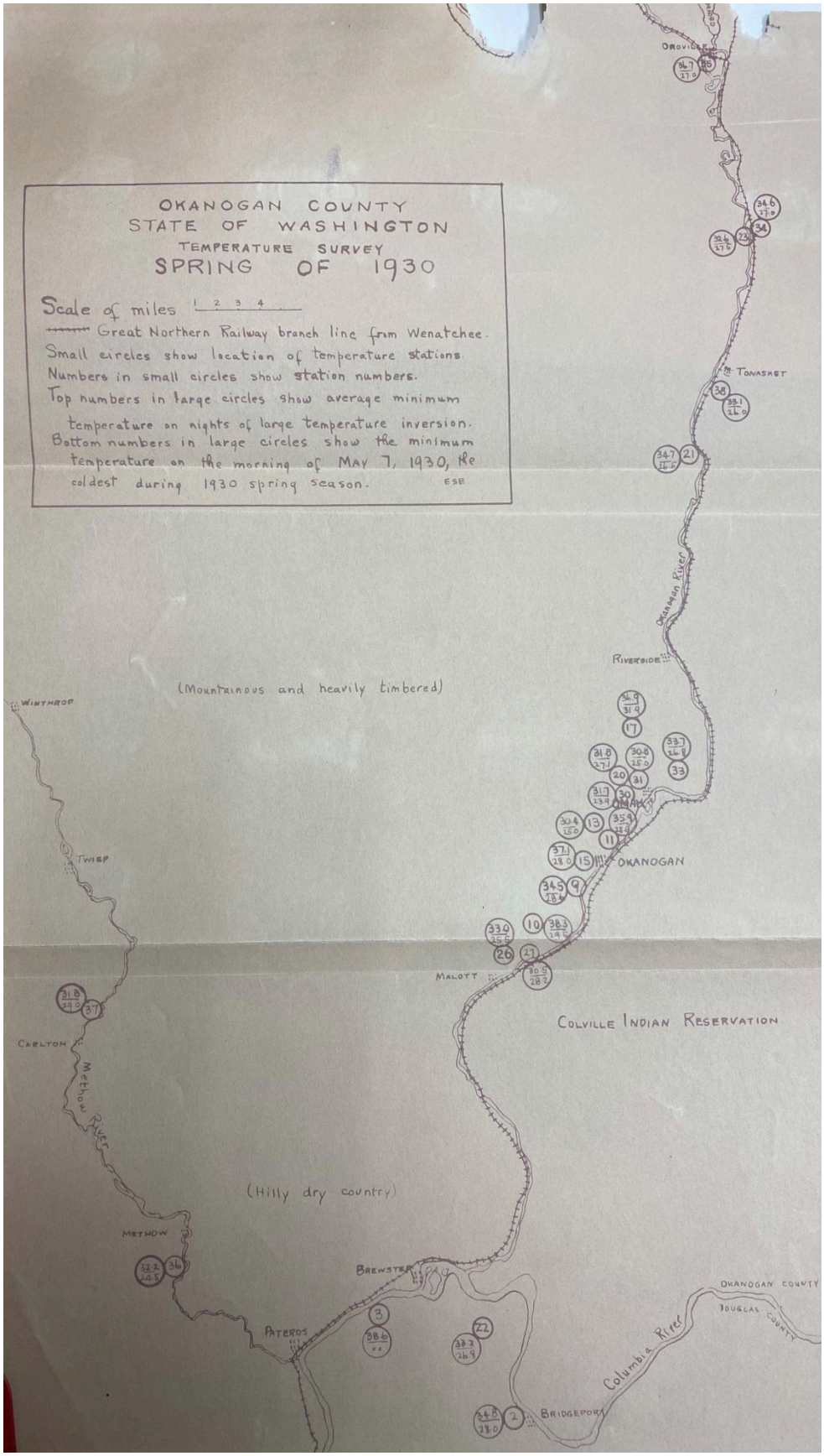
Fast forward a few years and the fruit frost forecast service that is tied directly to us here in Washington state, was initially started in 1918 due to demands from southern California citrus and vegetable growers who were being hurt by damaging frost events which were not predicted. The growers requested help from the Federal Government and they in turn asked the Weather Bureau to create a special forecast unit to handle this problem. Floyd Young was chosen to head this unit and he employed several accomplished meteorologists to assist him, one of which was Eckley Ellison, who was the person that established the Yakima (1922) and Wenatchee Frost Districts (1923). Interestingly, both Bud Graves and Jim Holcomb, coauthors of this paper and formerly of the National Weather Service and Clearwest Agricultural Forecast Service (of which we'll learn more about later), both have a tie with Ellison as he was the Meteorologist in Charge at the Portland, Oregon office when both started working there in the late 1950s and early 1960s.

Setting up a Frost District required first placing temperature observation stations around the district to determine where the cold areas were, then selecting several of them to be 'Key Stations' where specific temperature forecasts were to be made. Collaborators would read the manual mercury or alcohol minimum temperature thermometers every morning and phone the measurement into the Weather Bureau/Weather Service office.

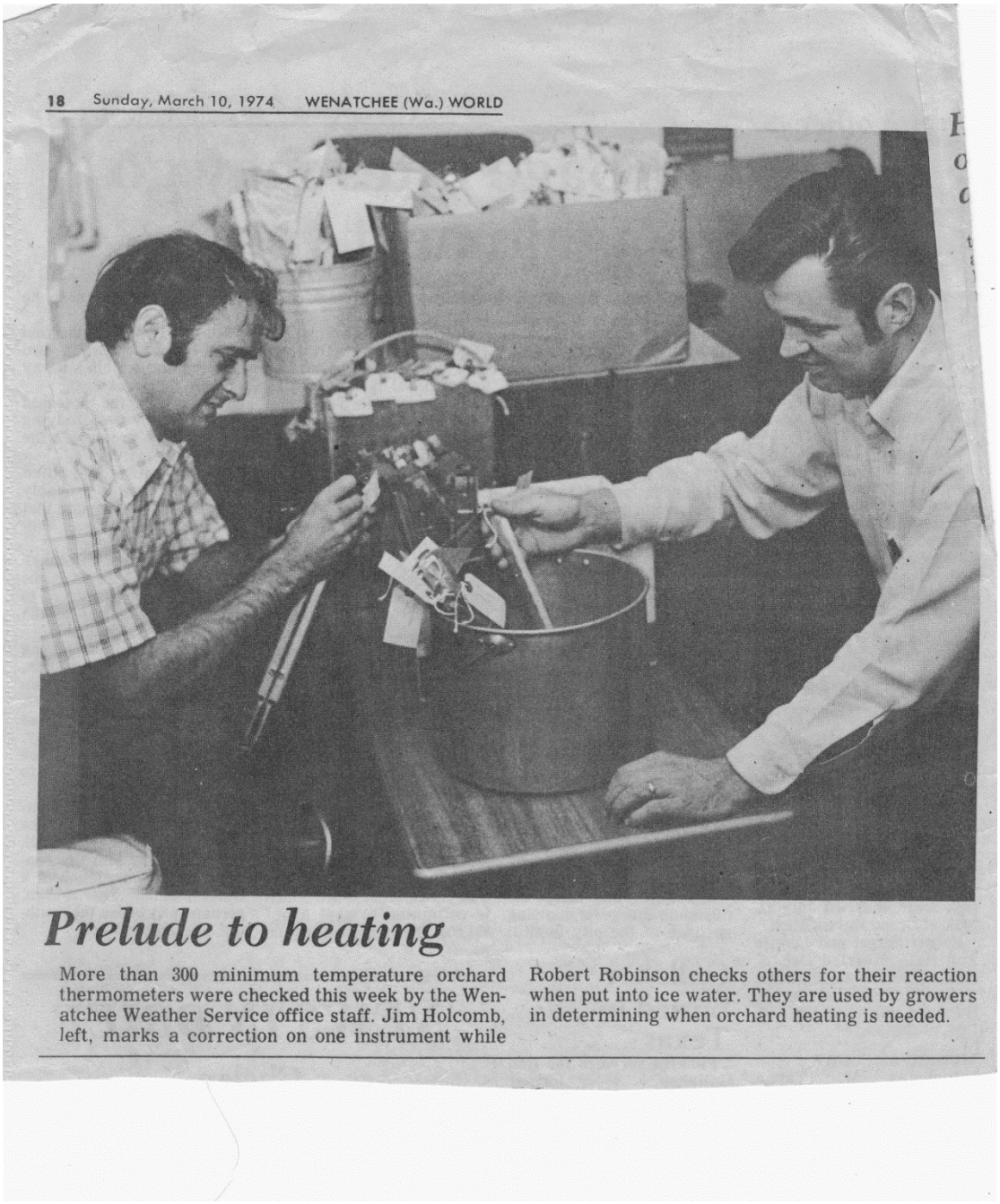
The frost forecast service was headquartered in southern California and forecasters were assigned to various districts for the duration of their frost seasons, which was over the winter period in the southern citrus groves, and spring in the northern fruit areas. These forecasters often worked the summer season as fire weather forecasters so it was a nomadic life for them working at several different locations through the year.

Initially they came to Washington for the frost season, but in 1928 the Weather Bureau opened a permanent office in Yakima and a forecaster remained there year-round. The first forecaster at Yakima was Ed Jones, followed by Harry Swift in 1945, Bob Borders in 1956, Bob Cardinal in 1972, and Bud Graves in 1977 until 1996 when the Yakima Office was closed. Several other meteorologists were assigned to help with the work in Yakima as well; including Darrell Lewis whose tenure began in the late 1960's and ran through 1991.

Various forecasters were assigned to the Wenatchee and Okanogan Districts over the years from the beginning of the forecasts in the 1920s until a permanent office was opened in Wenatchee in 1957. The Wenatchee Office was established by grower demand after a severe November freeze in 1955 which killed many of the orchards and was not well predicted. Alan Jones took over the Wenatchee office in 1958 after the initial forecaster passed away, and remained the main forecaster for the Wenatchee District until he retired in 1980. Jim Holcomb and Ron Surface came to Wenatchee in 1964 as fire weather forecasters but were integrated into frost forecasting the next year and Jim Holcomb continued doing frost forecasting until he retired in 1989. Bob Robinson, also active in the fruit frost service for the Wenatchee district, came to the Wenatchee office in 1972 and remained until he transferred offices for another position in 1985, and eventually retired from the Weather Service in 1995. A separate frost forecaster was assigned to the Okanogan District, where a separate small field office existed, until 1980, when Wenatchee took over forecasting for that district also. Other small field offices also existed in Hood River, OR and Walla Walla, WA for some time, but were eventually closed as well, as the National Weather Service gradually moved away from the practice of utilizing multiple small field offices and consolidated these into the regional offices located in Spokane, Portland, and Pendleton.


OKANOGAN COUNTY
STATE OF WASHINGTON
TEMPERATURE SURVEY
SPRING OF 1930
Scale of miles 1 2 3 4
Great Northern Railway branch line from Wenatchee.
Small circles show location of temperature stations.
Numbers in small circles show station numbers.
Top numbers in large circles show average minimum temperature on nights of large temperature inversion.
Bottom numbers in large circles show the minimum temperature on the morning of MAY 7, 1930, the coldest during 1930 spring season.
ESE
OROVILLE
TONASKET
RIVERSIDE
OKANOGAN
MALOTT
WINTHROP
TWISP
CARLTON
METHOW
BREWSTER
PATEROS
BRIDGEPORT
Okanogan River
Methow River
Columbia River
(Mountainous and heavily timbered)
(Hilly dry country)
COLVILLE INDIAN RESERVATION
OKANOGAN COUNTY
DOUGLAS COUNTY

Above: Map of key frost station locations and end of season summary data for the Okanogan district from the 1930 season compiled by the U.S. Weather Bureau in Pomona, California by Eckley Ellison and others. The legend reads, "*Okanogan County, State of Washington, Temperature Survey Spring of 1930. Small circles show location of temperature stations. Numbers in small circles show station numbers. Top numbers in large circles show average minimum temperature on nights of large temperature inversion. Bottom numbers in large circles show the minimum temperature on the morning of May 7 1930, the coldest during the 1930 spring season."* Also indicated on the map are the locations of rivers, towns, some of the surrounding terrain features, and the route of the Great Northern Railway branch line.



18 Sunday, March 10, 1974 WENATCHEE (Wa.) WORLD

Prelude to heating

More than 300 minimum temperature orchard thermometers were checked this week by the Wenatchee Weather Service office staff. Jim Holcomb, left, marks a correction on one instrument while Robert Robinson checks others for their reaction when put into ice water. They are used by growers in determining when orchard heating is needed.

Above: Newspaper clipping from *Wenatchee World* Sunday, March 10, 1974. The Caption reads: "*More than 300 minimum temperature orchard thermometers were checked this week by the Wenatchee Weather Service office staff. Jim Holcomb, left, marks a correction on one instrument while Robert Robinson checks others for their reaction when put into ice water. They are used by growers in determining when orchard heating is needed.*"

TABLE 1

FORECAST DATA FOR WENATCHEE KEY STATION

All nights of the 1966 season. Data Show: Hygrometric formula from 4:40 p.m. (PST) observations; local forecast; actual minimum temperature; and the variation of local forecast from the actual minimum. "AF" signifies "Above Freezing." Forecasts verified to a base of 32°. The dates listed are those on which the minimums occurred.

Date	Form. Est.	Local Fcst.	Actual Min.	Variation
		APRIL		
8	37.2	AF	34.8	0
9	36.2	AF	48.4	0
10	34.8	AF	33.8	0
11	34.8	SAF	40.0	0
12	33.0	AF	28.9	3
13	23.2	21	23.9	-3
14	30.5	30	33.7	-2
15	34.5	AF	40.1	0
16	34.0	AF	37.6	0
17	31.5	26	37.9	-6
18	20.9	28	22.8	5
19	20.5	23	21.7	1
20	23.0	29	32.1	-3
21	31.0	31	31.9	-1
22	31.2	SAF	41.2	0
23	35.0	AF	50.9	0
24	33.0	AF	35.7	0
25	35.0	AF	35.3	0
26	29.5	27	31.0	-4
27	27.8	28	27.3	1
28	29.5	30	33.0	-2
29	33.5	SAF	32.9	0
30	33.5	AF	38.7	0

Date	Form. Est.	Local Fcst.	Actual Min.	Variation
		MAY		
1	33.8	32	35.8	0
2	34.0	AF	35.0	0
3	39.8	AF	35.6	0
4	40.8	AF	39.3	0
5	37.4	AF	43.0	0
6	50.0	AF	56.7	0
7	36.5	AF	37.0	0
8	39.5	AF	38.9	0
9	40.2	AF	43.8	0
10	38.5	AF	41.8	0
11	31.8	AF	51.1	0
12	37.8	AF	52.0	0
13	33.5	AF	44.0	0
14	27.5	32	41.3	0
15	29.0	AF	45.3	0
16	34.5	AF	38.7	0
17	22.5	22	23.8	-1
18	33.0	SAF	30.7	1
19	34.8	AF	41.9	0
20	33.2	AF	58.5	0
21	39.5	AF	49.0	0
22	23.0	SAF	30.4	2
23	30.5	30	46.0	-2
24	37.2	AF	39.0	0
25	39.0	AF	46.3	0
26	45.0	AF	50.2	0
27	41.2	AF	43.1	0
28	32.0	AF	47.1	0
29	41.0	AF	53.0	0

TABLE 2

SUMMARY OF TABLE 1 IN PERCENTAGE FORM

Summary of forecast verification for all nights for the main key station.
Total number of forecasts: 52

	Degrees local forecasts in error						
	0	1	2	3	4	5	6
Number of forecasts	37	5	4	3	1	1	1
Percentage	71	10	7	6	2	2	2
Accumulated percent	71	81	89	94	96	98	100

Above: Summary of forecast and verification data from the Wenatchee key station at the Washington State University Tree Fruit Research Extension Center from the 1966 season compiled by the U.S. Weather Bureau. Columns are grouped by month with April on the left and May to the right. From left to right the individual columns within each month grouping are date, the estimated overnight low temperature calculated using the hygrometric formula developed some years earlier by Weather Bureau Meteorologists based on weather observations taken at 0440pm, the actual low temperature forecast, the observed overnight low, and lastly the departure between the forecast and observed low. The table near the bottom indicates that out

of a total of 52 forecasts, 37, or 71%, were right on, 81% were within 1 degree, and 88% were within 2 degrees.

There was a period from 1933 to 1944 where there was no frost fruit service to the Yakima district, initiated by the troubles associated with the great depression. However, curiously enough, service to the Wenatchee district, and likely the Okanogan district, remained during this time. The exact reason for this is now unknown, but it is speculated that the cost of running the satellite office at Yakima was too prohibitive. Whereas only sending a seasonal forecaster to the Wenatchee district, where there was not a permanent office established at that time recall, was less cost prohibitive and the frost fruit service was able to continue.

The last of the four frost districts to discuss is the Basin district. This district was established at a much later date as fruit orchards that originated across the valley locations took time to begin creeping into the Columbia Basin as irrigation infrastructure continued to improve and expand. One of the biggest factors in establishing this district was the advent of AgWeatherNet (then known as PAWS, Public Agricultural Weather System) in 1988 with credit going to Thomas Ley, the growers, and many others involved with the project. The deployment of several automated stations across what is now the Basin district made it possible for the Weather Service to begin key station forecasts at these locations in the early 90's and frost service duties were handled by the Yakima office.

Clearwest Agricultural Forecast Service Years (1996-2020)

In 1996 the National Weather Service ceased the frost fruit service nationally, and it came to an end after 74 years of service in Washington State. Along with that, the remaining satellite offices in Yakima and Wenatchee were closed and consolidated into the larger offices in Pendleton and Spokane respectively. At this time, Jim Holcomb, who had already established Clearwest as a weather consulting firm upon his retirement in 1989, teamed up with newly retired long time weather service colleagues Bud Graves and Bob Robinson to continue to produce the same key station based frost specific forecasts as they had done for many years with the Weather Service. Forecasts along with the verification data continued to be produced and provided across the four districts. Tom Swift, another retired NWS forecaster, also helped with wine grape forecasts for a few seasons.

The goal of Clearwest was to allow the service to remain free and readily available to all growers as a public product. In order to achieve this, funding needed to be secured and was generously provided by various private and public entities. This was critical in being able to provide the forecast products, making them available via continued radio reports and eventually online as more growers migrated to the web. The first year, 1996, Clearwest was competing with another private company out of the Seattle area who also offered the frost forecast. Dow Elanco and the Washington Apple Commission jointly offered to sponsor the forecast but were not sure who to award the contract to, so they sponsored both companies in 1996. One would do the morning forecast and the other the evening forecast. For the 1997 season, Dow Elanco put all their sponsorship into the Seattle based forecast company, and the Washington Apple Commission along with Orchard-Rite wind machine company, and some additional contribution from the Yakima Pom club, decided to sponsor Clearwest. From 1999 to 2008 Clearwest was sponsored almost entirely by Orchard-Rite. And during this time forecasts were able to be expanded to

provide a winter arctic outbreak forecast, and for a few years, a fall forecast for the wine grape growers. Forecasts were even provided for the wine grape area in southern British Columbia.

After Orchard-Rite ended sponsorship in 2009, various fruit organizations across Washington picked up and continued sponsorship until 2020. Some of these include the Washington Horticultural Association, Washington Growers Clearing House, Wenatchee Traffic Association, Yakima Valley Growers/Shippers, North Central Washington Fieldman, and the Yakima Pom club. Several of these combined in 2015 to form the Washington Tree Fruit Association, and was the main sponsor from 2015 onward.

Additionally, sponsorship allowed for the maintenance of the key station sites themselves along with investment in automated temperature sensors for deployment at some sites. Several sites continued to have daily measurements provided by the same collaborators, who would read the manual minimum temperature thermometers and phone in the readings every morning.

Sadly for the team, Bob Robinson passed away rather suddenly in 2014 with the frost service continuing to be operated by Bud and Jim until their official second “retirement” at the end of the 2020 season. Of special note, beginning their forecasting careers in the late 50s/early 60s, and running until 2020, Bud and Jim have likely been doing operational forecasting longer than any meteorologist in the country. Some other former Weather Service fruit frost forecasters also went into the private sector in the same way after the Weather Service ended the program in 1996. But Bud and Jim are likely the last of this generation to still be involved in the service, continuing to lend expertise and provide bud/blossom stage reports to the meteorologists at AgWeatherNet.

FIRING NOTES

Morning of	Description
3/18	Scattered light to moderate protection in soft fruits Lower Valley. Isolated light protection in soft fruits Upper Valley, Tri-Cities areas.
3/19	Light to moderate protection in soft fruits Lower Valley. Isolated light protection in soft fruits Upper Valley and Tri-Cities areas.
3/27	Long, hard night early areas of Lower Valley, Tri-Cities area. Widespread light to moderate protection in soft fruits all areas. Began as early as 9:30 PM PST Lower Valley area.
3/28	Long, hard night early areas of Lower Valley, Tri-Cities area. General light to moderate protection all areas. Began as early as 10:30 PM PST Lower Valley area.
3/29	Isolated light protection Mid and Upper Valley areas.
3/30	Scattered light protection Lower Valley, Tri-Cities areas.
4/1	Isolated light protection Mid and Upper Valley.
4/2	Widespread light protection cold spots Lower Valley. Isolated light protection cold spots Upper Valley.
4/4	Scattered light protection cold spots entire Yakima Valley.
4/6	Widespread light protection cold spots Lower Valley, Tri-Cities area. Scattered light protection Upper Valley.
4/7	Widely scattered light protection entire Yakima Valley.
4/8	Moderate to heavy protection Lower Valley cold spots. Supplemental heat applied. Scattered light protection Upper Valley and Tri-Cities areas. Protection began by 11 PM PDT Lower Valley cold spots.
4/12	General moderate to heavy protection Lower Yakima Valley beginning as early as 10 PM PDT. Scattered light protection Tri-Cities area. Widespread light to moderate protection Upper Yakima Valley.
4/13	Isolated light protection Upper Valley. Scattered light protection Lower Valley. More widespread protection Tri-Cities area.

Above: Summary of protections needed for the first half of the 1998 season for the Yakima district as compiled by Clearwest Agricultural Forecast Service.

AgWeatherNet Years (2021-present)

In 2019 Jim Holcomb and Bud Graves of Clearwest approached AgWeatherNet with the proposition of continuing the fruit frost service upon their retirement. During the 2020 season, AgWeatherNet meteorologists shadowed Clearwest meteorologists with almost daily meetings in order to learn the forecasting technique and the nuances of the individual key stations. The goal of the frost service remained the same, allow the service to be provided to all growers for free on an easily accessible platform. This is currently achieved through AgWeatherNets own financial resource as well as continued financial contribution provided by the Washington State Tree Fruit Association.

Due primarily to staffing and the withstanding workload associated with operating the mesonet, the morning forecast product unfortunately needed to be dropped with the focus turned to continuing the evening forecast in a similar fashion and layout as Clearwest. The current frost service provided by AgWeatherNet includes a daily forecast product that is released between 5:30pm and 6:30pm with the individual key station minimum temperature forecasts for the upcoming night, as well as a description detailing the weather conditions for the upcoming night and for the next day/night. A broader 3-5 day outlook is also provided daily along with a 6-10 day extended outlook twice per week. Observed low temperatures from the previous night for the key stations (where verification is available) are presented daily along with blossom degree and growing degree counts that are updated daily. Charts illustrating different bud stages for apples and cherries are also presented.

In house development also continues on a high resolution weather model that is currently in a beta test stage and utilizes machine learning techniques in conjunction with the nightly observed low temperatures from the key stations. Additional instrumentation is planned to be deployed at some of the remaining key station sites, perhaps reutilizing more of the existent manual shelters where possible, in order to aid in both the forecast process and model development. Frost service products can be found by navigating to the AgWeatherNet webpage, *https://weather.wsu.edu*, and finding '*Spring Frost Program'* within the menu at the left on the page.

The Changing Frost Season

The frost season has changed drastically in the last 100 years, presenting new challenges to both forecasters and growers. Using a continuous record of 75 years of weather observations from the Yakima Airport (KYKM) beginning in 1947, 100 year estimates of the changing climate were made. The frost season in the Yakima Valley has shifted approximately 10 days earlier on average. The average last frost date (air temperature $\leq 32°F$) is now around May 7th, while the average last frost date in 1922 is estimated to have been around May 17th.

The fruit trees also begin budding and blossoming earlier in present day. The buds first become susceptible to frost after around 400 Blossom Degree Days (BDD), which is a seasonal accumulation of the daily high temperature above 43°F. The 400 BDD threshold is estimated to occur around 11 days earlier than it did in 1922, now March 2nd on average compared to March 13th 100 years ago. Therefore, the length of the frost season is about the same as it was 100 years ago, just shifted about 10 days earlier.

A more relevant frost metric for tree fruit is the last average "moderate" frost date (air temperature ≤ 28°F) as temperatures in this range cause more damage to buds and blossoms. This date is now only around 4 days earlier on average, April 21st compared to April 25th in 1922. However, on this last average "moderate" frost date the BDD is approximately 10% higher than it was 100 years ago. This indicates a greater frost threat to growers as blossoms are more developed making them more susceptible to "moderate" frosts. Fortunately, frost mitigation techniques have advanced considerably in the last 100 years to help growers deal with the increased vulnerability of buds and blossoms from a changing frost season.

Closing

A cost benefit analysis released in 1977 by Oregon State University determined that the average cost benefit of the frost forecasting service was about $337.50 per acre, per season. This was determined from data compiled from 15 seasons between 8 different pear orchardists at the time. This is a significant value that can have meaningful implications, especially when multiplied over several acres for a small hobbyist, to thousands of acres of orchard as a whole. This tremendously aids both small and large operations and makes it clear how critically important the service has been, and will continue to be, to the Washington State fruit industry.

Over 100 years of the fruit frost forecasting service in Washington State is a significant and historical achievement. There have been many great meteorologists who have been able to work closely with the great fruit growers of Washington to achieve a common goal. This service has, and always will be, a close collaboration between these two groups. It comes with great reverence to be able to commemorate those who through the many years have made strides in furthering the goals of the service, and also facilitate its continuation. Many thanks are owed to many people, including growers, meteorologists, and financial contributors who have been critical for the success of the service for so long.

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