The Program for Hydroclimatological Measurement at the H.J. Andrews Experimental Forest

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18 Aug 1995

Introduction

**Mack Creek gaging station with heated orifice raingage and windshield on roof.
(Al Levno 1989)**

Hydrology, climatology, and biology interact over a wide range of spatial and temporal scales. Continuous interaction among climate, soils, landuse, and vegetation shape the hydrology and ecology of a landscape. Long-term measurements of such variables at various time and space scales provide a foundation for understanding ecosystem processes, and document changes in the local, regional, and global environments.

Research modeling and data collection are not independent processes and each drives and directs the other. Coordinated field measurements are necessary in a multidisciplinary program to efficiently obtain a detailed understanding of the patterns and processes at scales beyond that of the field plot. This emphasizes the value and importance of a quality observational and experimental data collection program.

The purpose of this document is to describe the current climatological and hydrological measurements program at the H. J. Andrews Experimental Forest. The proposed design is a 3-tier, coordinated program based on current data needs, topographic, and environmental gradients, and available financial resources.

Historical Perspective

The H. J. Andrews Experimental Forest of the Willamette National Forest was established in 1948 and originally designated for intensive study of the effects of forest management practices on hydrology and water quality. It has become an international center for ecological studies of forest and stream ecosystems. The Andrews Forest includes the entire 6400 hectare Lookout Creek drainage and represents diverse forest communities and stream systems characteristic of the central western Cascades of Oregon. The site was selected as an intensive study site for the Coniferous Forest Biome Project (1970-1978) of the National Science Foundation (NSF)-funded International Biological Program (IBP). In 1976, it was designated a Biosphere Reserve in the UNESCO Man and the Biosphere program, and in 1977, it was designated an Experimental Ecological Reserve. In 1980, it became a Long Term Ecological Research (LTER) site supported by NSF, and was also designated a Biosphere Reserve in the UNESCO Man and the Biosphere program.

The earliest hydrology measurements of streamflow in the Blue River drainage were made on Blue River by the U.S. Geological Survey (USGS) near the town of Blue River beginning in 1936. The USGS established gaging stations on Lookout Creek within the Andrews Forest in 1949, and on upper Blue River in 1964. The Willamette Basin Snow Laboratory (WBSL) of the U.S. Army Corps of Engineers recorded extensive climatic and snow hydrology data on Lookout Creek and the adjacent upper Blue River Basin from 1947 to 1955, which included a precipitation gage in the Andrews Forest at Carpenter Mountain (WBSL, 1956).

Much of the early hydroclimatological measurements on the Andrews Forest were associated with the investigation of the initial small watersheds experiment (Watersheds 1, 2, 3) which focused on the effects of roadbuilding and two methods of logging on both water quality and quantity (Rothacher et al., 1967). Streamflow gaging stations on Watersheds 1, 2, and 3 were established in 1952. Streamflow has been measured continuously since establishment. Precipitation measurements were started in 1951, and a network of precipitation storage gages on Watersheds 1, 2, and 3 was established in 1957 and maintained until 1970. The Climatic Station on WS 2 was installed in 1956 for precipitation, a hygrothermograph was added in 1958 and is still in operation. Extensive water sampling for suspended sediment was conducted during storm events from 1955 through 1988 on all three watersheds, and sediment basins have been surveyed annually for bedload since 1956. Stream temperatures were also monitored from 1960 to 1979. Data as collected from these watersheds in their natural, undisturbed condition for several years provide the basis for determining changes that occurred as the result of logging, road construction, and vegetation recovery. Watersheds 1 and 3 were both logged in the early 1960's.

Small, experimental watershed studies continued to drive hydroclimatological measurements through the 1960's, with the establishment of gaging stations on Watersheds 6, 7, and 8 in 1963, and on Watersheds 9 and 10 in 1968. These two sets of watersheds were used to examine the effects of different silvicultural treatments on runoff, sediment yield, and nutrient cycling (Martin and Harr, 1989). Streamflow has been measured continuously on all watersheds. Proportional water samplers were installed to determine output of nutrients from the watersheds, bedload was measured for WS 9 and 10, and stream temperatures were monitored. Precipitation collectors for both studies were also established to determine nutrient input. Precipitation gages were installed at the top and near the base of these watersheds. The late 60's and 70's placed greater emphasis on changes in nutrient cycling from clearcutting, and Watershed 10 was the subject of intensive study in IBP (Grier et al., 1974; Sollins et al., 1981; Swanson et al., 1982; Triska et al., 1984).

With the advent of IBP, greater emphasis on phenology, plant moisture stress, and leaf nutrient content led to more air and soil temperature measurement. A plant community classification system (Dyrness et al., 1971) was used as a primary means of stratification, and a set of permanent vegetation plots (Reference Stands) was installed to represent forest communities with distinct vegetation and hypothesized different environments (Dyrness et al., 1974). Along with extensive data on vegetation standing crop, tree growth and mortality, and plant succession, a thermograph network was installed within the reference stands in the early 1970's (Zobel et al., 1974). The majority of these sites were established to monitor micro-meteorological data under the canopy. The purpose of this network was to provide air and soil temperature data for modeling photosynthesis, respiration, phenology, and decomposition, and to measure environmental gradients. Driven by an emphasis on phenology, plant moisture stress, and plant physiology, hourly data were summarized into diurnal and nocturnal segments. In 1977, at the request of the aquatic research community, the thermograph network was expanded to include monitoring stream temperature at Mack Creek, McRae Creek, and upper Lookout sites.

A more general set of modeling needs led to the installation of the Primary Meteorological Station in 1972 to characterize the meso-scale environment. Originally, solar radiation, air temperature, dew point temperature, and windspeed were collected. Along with precipitation from the climatic station on WS 2, these were the primary climatic variables needed for the models predicting the rates at which materials accumulate or move through ecosystems (Waring et al., 1978). Significant improvements to the station were made in 1975, 1979, and 1988, as the station evolved from chart recorders to state-of-the-art digital data loggers (Bierlmaier and McKee, 1989).

The late 1970's and the 1980's brought expanded monitoring efforts, and the need to characterize the environment on broader scales. The Andrews Forest National Advisory Committee recommended the monitoring of streamflow at a mid- to high-elevation, third order watershed, and the Mack Creek Gaging Station was built in 1978. Stream, air temperature, and precipitation have also been measured at the Mack Creek station. A precipitation network for the Lookout basin was designed by the Andrews Forest Advisory Committee and installed in 1979 to characterize precipitation over the watershed. In 1981, proportional water nutrient sampling was initiated on Mack Creek and WS 2.

A National Atmospheric Deposition Program (NADP) sampler was installed at the Primary Met Station in 1980 to monitor precipitation chemistry in the central Cascades. Another NADP-like gage was installed in the Hi-15 in 1988 to compare precipitation chemistry at low- and mid- elevations within the Andrews Forest (Martin and Harr, 1988).

The Vanilla Leaf Met Station was installed in 1987. The primary intent was to provide micro-meteorological data for a study of seedling survival following clearcut and shelterwood logging at high elevation. Ultimately, the shelterwood site was discontinued and the clearcut site has evolved as a primary high elevation meteorological station.

During the early 1980's, most hydrology work focused on rain-on-snow hydrology, including plot studies (Harr and Berris, 1983; Harr, 1986) and and some related assessment of long-term records from the small experimental watersheds (Harr et al., 1982) and large basins (Christener and Harr, 1982). Monitoring existing hydrometeorological stations was still given a generally high priority, but there was little or no expansion of these efforts. The U.S. Forest Service interests in hydrology ebbed as streamflow monitoring efforts at the South Umpqua National Forest and Bull Run Watersheds were discontinued, and control of the hydroclimatological measurements program was shifted from researchers to field technicians and professionals.

However, the late 1980's and early 1990's brought greater interest and scrutiny to this historical data (Greenland, 1993, 1995; Jones and Grant, submitted 1995), and hydrologic modeling efforts were renewed. Outside interest in the Andrews Forest long-term datasets has also increased dramatically. Since 1991, the Forest Science Data Bank (FSDB), which houses all of this hydroclimatological data, has received 35-40 documented requests for information per year including those of local researchers. Consequently, all of the datasets have been standardized into common formats to help reduce time and effort in fulfilling these requests. Also, much of the historical chart-collected information has been digitized into high-resolution datasets.

Table 1 lists all of the current (as of 1995) meteorological monitoring sites with descriptions for sites within the Andrews Forest and near vicinity, and Figure 1 provides a map of the current monitoring sites. Table 2 lists all of the stream monitoring sites. For each meteorological variable currently being measured, tables show period of record, temporal resolution, and general methods and comments (Table 3, Table 4, Table 5, Table 6).

Limitations of Existing System in 1993

By late 1993, it had become apparent that the existing meteorological network was insufficient for capturing spatial and temporal patterns necessary for current modeling efforts. The existing system evolved as an accumulation of measurement programs with various designs, and objectives in response to individual projects and scientist interests. New objectives for the hydroclimatological measurements program have superseded many of the original objectives and require a more comprehensive network design and new instrumentation.

The hydroclimatological measurements program of 1993 is limited in terms of representativeness, completeness, and consistency of temporal resolutions, type of sensors and their heights, and periods of record. These limitations have made it difficult to establish functional relationships between meteorologic variables, such as precipitation and temperature, with elevation, slope, and aspect.

Much of the Andrews Forest occupies rugged terrain with steep mountain slopes and extensive conifer stands. The elevation range of 420 to 1630 m makes most of the forest accessible only by snowcat during most winters. This has traditionally limited the ability to find suitable, accessible sites for meteorological measurement, and especially precipitation measurement. Most of the precipitation gages are non-recording standard or storage gages and are correlated with other recording gages to obtain daily precipitation. Problems of access to these gages, especially in remote, higher elevation locations, where snow frequently bridges over the orifice of the gage, have led to unknown but occasionally severe undercatch in winter and have ultimately reduced the overall effectiveness of this network. The use of prorated daily values of precipitation from storage gages have further limited the development of useful spatial relationships. The Vanilla Leaf Meteorological Station is located on an exposed, south-facing, high elevation clearcut and has also had significant problems with undercatching precipitation due to exposed winter conditions.

The Primary Met Station is located at the Headquarters Site of the Andrews Forest and sits on an alluvial terrace subject to cold air drainage. The site location reduces the meso-scale representativeness of meteorological measurements, especially minimum air temperatures, wind direction, and soil moisture. There is also concern that increased building and human presence in the Andrews Headquarters facilities near the Primary Met Station could ultimately effect meteorological measurements. The proximity to the Headquarters offers real advantages in terms of access, however.

The thermograph network does not have open exposure sites. Most of the stations are under the canopy of mature and old-growth forest, or include regrowing clearcut sites with the intent of examining temperature change over the successional cycle rather than representing macro climate. Eight of the network sites have been outfitted with digital data loggers, but many sites are still recording on analog charts. Processing costs could be reduced and accuracy improved through the use of more data loggers.

Current Needs

1. Temporal and Spatial Scales of Data

With the advancement of remote sensing and Geographical Information Systems (GIS), spatial studies in hydrology and ecology have renewed impetus. Developing and applying spatially distributed models for ecosystem studies requires short time-step, spatially-distributed measurements of important input, output, and state variables to understand processes and test hypotheses at different scales. The choice of what, where, and when to measure greatly influences the type of questions being investigated at local or regional scales. Certain process- oriented field investigations and the development of process models require short temporal resolution data at plot to landscape spatial scales. Long-term data sets are required for detection of any changes or trends. Comprehensive data layers at a range of temporal scales are needed now and in the future.

2. Data Compatibility for Regional Studies

Most of the meteorological data in the past have been collected with site-specific questions in mind. Although the questions at these scales still remain important, there is a need to investigate environmental and management driven effects that have important consequences at larger scales. The meteorological network should produce data useful for analysis of Andrews Forest-scale phenomena and compatible with regional data, for nesting our landscape studies within regional scale studies.

Extending the point data to regional areas using remote sensing and other information sources, such as new meteorological observational technologies, is a future goal of the hydroclimatological program. Large-scale field experiments, combined with satellite and in-situ measurements at selected sites, have potential to verify and extend spatially extensive observations. Spatial estimation of leaf area index, land cover, soil moisture, or snowpack coverage may be possible by combining field observations with remotely sensed data.

3. Data consistency

Consistency in terms of methodology of measurement of variables, temporal resolution, sensor height, and QA/QC of data is needed. This is important when meteorological data are used for developing spatial relationships and comparability analysis.

4. Coordinated Measurement Program

Forest ecosystem models of hydrology, biodiversity, carbon allocation, long-term site productivity, energy and gas flux, and riparian-stream interaction will all benefit from a sound framework of hydroclimatological data. These growing scientific needs call for the design and execution of a coordinated program of measurements. Coordinated, multidisciplinary experiments can often achieve more than the sum of separate disciplinary goals if observations are coordinated to achieve a common overall objective.

Current Plans (1994-1998)

The proposed plan will capitalize on the historic and existing hydroclimatological network. Some current sites will be modified or removed, and other sites added within a coordinated approach. The network is designed to develop datasets that scientists feel are needed in their on- going and future studies (5-years). Consideration has been given to which variables should be measured, locations, temporal resolutions, duration, and accuracies of the measurements.

Objectives

1. To update the existing hydroclimatological measurement program to best meet present and future scientific needs (over next 5 years) at various scales.

2. To develop a network compatible for linking and/or expanding studies of Andrews Forest to province and regional scales.

3. To collect quality high-resolution data for investigating key bioclimatological processes, and for developing and validating spatially-distributed ecosystem models.

4. To develop a consistent, long-term dataset for general predictive studies with high resolution data for understanding processes from plots to landscape to regional scales.

A three-level hydroclimatological network for data monitoring is proposed. The networks at each level will be nested to form a coordinated program of data acquisition and measurement. A future vision of linking the benchmark meteorological stations with regional weather stations to expand the future scope of studies was also considered in designing this network. Figure 2 shows the layout of this design with three levels of networks.

First-level stations

The first-level in this top-down approach consists of Benchmark Meteorological Stations (BMS) and Benchmark Stream Stations (BSS).

The BMS are designed to represent the environment across the Andrews. These stations are intended to provide complete, long-term, high temporal resolution, meso-scale hydroclimatological data. The location of the BMS is based on factors such as elevation, aspect, vegetation gradients, and accessibility.

Four BMS are proposed for the Andrews. The Primary Met and Vanilla leaf Meteorological Stations will be retained and modified. Two new BMS will be installed. One new, high elevation (4200 ft, ENE aspect) BMS will be installed on clearcut L708 in the SE Andrews (Upper Lookout Met). The other new BMS will be a centrally located site on clearcut L351 (3300 ft, WSW aspect) in the east-central Andrews (Central Met)(Figure 3). A GIS analysis of elevation and aspect indicated the average elevation (3170 ft., 966 m) and average aspect (267 degrees) of the Andrews Forest, and the Central Met Station was located to represent these general averages.

Modifications will be made to the Primary and Vanilla Leaf Stations to standardize measured variables, temporal resolution, methods, and instrumention across all BMS. See Table 7 for the proposed list of measured variables and temporal resolution. Sites will be cleared and required openings maintained following standards of the National Weather Service, the LTER network, and where appropriate, the NADP network. Telemetering of all BMS will be completed by 1996.

The existing stream gaging stations will comprise the set of first-level BSS. Continuous streamflow records are available from this set of 10 semi-nested experimental watersheds over a 40-year period (Table 3). Location of these current sites is shown in Figure 1. No additional first level stream gaging stations are proposed. Additions in terms of increased temporal resolution, increased number of stream temperature sites, and telemetering stream data are proposed.

Second-level stations

The second-level stations (SLS) will be located along various toposequences, and primarily designed to represent spatial variability of precipitation, air, soil, and stream temperature in rugged mountain topography. As precipitation is one of the most sensitive input variables in hydrological and ecological models, is highly variable in space and time, and cannot be modeled as well as some other key variables, it needs to be obtained at higher spatial resolutions. The consistent precipitation data from these SLS and BMS should provide a better picture of precipitation over the mountain landscape. Similarly, temperature data from these stations should allow for the development of improved observation of temperature gradients.

Existing stations at the Hi-15, Mack Creek, and WS 2 Climatic Station will be considered as SLS and will continue to be maintained for measurement of precipitation, temperature, and other data to maintain continuity of historical records. These sites will be improved and established procedural standards will be followed.

Tentatively, an additional six SLS are proposed for precipitation collection, including modifying and/or relocating some existing precipitation sites and installing new gages. The locations at or near the older sites of Mirkwood, Mackwest, Trails End, Roads End, and Midway would be utilized by replacing storage gages with recording precipitation gages. A new SLS at an elevation ranging around 2500 ft in the west central portion of the Andrews (near clearcuts L201 and 203) is proposed to represent precipitation from lower elevations. The locations of these SLS are shown in Figure 3. All the other remaining precipitation sites are recommended for removal unless specific research studies require their continued maintenance. A snow course will be a part of this level of measurement but may be limited to two to four representative sites because it is a labor intensive and expensive process. Installation of snow boards, pillows or lysimeters at these sites will depend upon available resources for installation and maintenance.

The current thermograph sites need to be re-evaluated in terms of how they can serve the objectives of the overall strategy, and some sites will be discontinued. The air and soil thermograph network will be reduced after analysis of the historical long-term data from these sites. Remaining sites will be equipped with digital data loggers and will be considered SLS for air and soil temperature. Temporal resolution will be improved to hourly for these stations. For the present, 14 sites will be maintained.

The stream thermograph network will consist of 6 sites. Three new stream temperature sites, one near the McRae bridge, one at the Lookout Creek stream gage, and one near the confluence of Mack Creek and Upper Lookout Creek are proposed. Existing sites on McRae, Upper Lookout, and the Mack Creek Gaging Station will be improved and maintained (see Figure 3).

Third-level stations

The third-level of network would consist of stations at selected sites for collecting data for specific objective oriented, micro-level investigations. These will act as satellite or transient sites, operated on a temporary or short-term basis for understanding processes and for pattern analysis. Examples may include field measurements for stand-level, canopy, gap, and plot studies, hillslope hydrological investigations, or intensive field measurements in a sub- watershed. Measurements at sites might also include temperature, snow course, leaf area, or soil moisture.

Attempts should be made to pair third tier-sites with a nearby permanent BMS in order to compare data and extend records. Revolving sites could therefore be nested within the entire network. For example, spatially distributed soil moisture sampling in a sub-watershed to examine soil moisture variability could be extended to the rest of the Andrews with other measurements over a larger area. Historical examples include soil moisture measured on WS 3 to examine moisture changes during successional changes; measurements of solar radiation and temperature within forest gaps to examine meteorological variability within the gaps; air temperature data collected at log decomposition sites; and air temperature data pertaining to soil respiration and energy and gas exchange collected at various plots.

Thermograph sites that have been discontinued or only run for short spans of time will be considered third level stations. Potential use might include examining temperature variations between closed canopy sites and open canopy BMS sites.

A snow course designed around a more dispersed sampling scheme rather than a point intensive one is planned. Primary objectives would be noting the presence/absence of snow and snow depth. Snow depths on stakes which can be read from the road will allow more frequent observations. Truthing of points with snow core sampling will be done when possible.

Standardization of Measurements

The first- and second-level stations will be standardized such that the same variables are measured at each station with consistent temporal resolution, sensor types, sensor heights, and data collection and processing methods. These observations will be consistent with the LTER standards for meteorological observation (Greenland, 1986).

Variables to be measured and resolutions

All the first- and second-level meteorological stations will collect data with consistent methods and consistent resolutions. Benchmark Met Stations (BMS) will collect complete sets of measurements with a few exceptions. The variables to be measured, and temporal resolution for each BMS, BSS, and second level stations are given in Table 7. Standardization of third level stations is not proposed at this stage, but specific studies planned at this level should be coordinated with the overall design.

New measurement variables proposed include pan evaporation, photosynthetically active radiation (PAR), and UVB. These measurements will only be made at the Primary Met Station. Solar and air temperature outputs will be changed from hourly to 15- minute. Streamflow data will be output every 15 minutes. Precipitation, snow pillow, and snow lysimeter data will be collected at 5-minute resolution at the BMS for recording storm events with high temporal resolution. Soil temperature, stream temperature, wind speed, wind direction, and relative humidity will be collected on an hourly basis. Vapor pressure deficit and dew point temperature will be calculated from temperature and humidity every 15 seconds and output hourly. Pan evaporation, soil moisture, and wind rose vector totals will be collected on a daily basis.

Instrument heights and depths

Air temperature sensors at BMS will be standardized and maintained at four heights (1.5, 2.5, 3.5, 4.5 m). This will allow development of a temperature profile, and will allow for correction of data when lower sensors get buried in snow. Meteorological sensors will be mounted on towers with radiation shields. Relative humidity will be maintained at 1.5 m, except at higher elevation sites where a 4.5 m sensor will be maintained in the winter. Wind speed and direction will be maintained at 10 m. Similarly, soil temperature and soil moisture will be maintained at four depths (10, 20, 50, 100 cm). Solar and precipitation measurement heights will depend upon individual site configurations.

Thermograph network sensor heights vary from less than 1 meter to 5 meters. Snow conditions have largely dictated the heights of these sensors. Modification of the installation heights will probably cause more problems in terms of monitoring long-term temperature trends, and sensor heights will be left unchanged.

Precipitation measurement

Proper measurement of solid precipitation at high elevation stations has always been a serious concern. Heavy snows in the Andrews can be wet and sticky and can cause snow to bridge over the orifice. The remoteness of high elevation sites, along with windy conditions and snow bridging have led to unknown undercatch and have compromised precipitation records. General agreement exists that orifice sizes will be at least 12 inches, gages will have sharp-edged lips, weighing type gages with pressure transducer or magneto-strictive tank gages along with cryogenic solutions or anti-freeze will be used. Some level of heating the gage or orifice will be necessary. The relatively large orifice size is reported to reduce chances of snow bridging. Standard NWS raingages will also be maintained at all BMS.

Discussions on precipitation collection have led to two separate approaches, and both will be implemented at the new met station on Upper Lookout. The house-top gage takes advantage of the met station cabin, and the collection orifice sits atop the shelter with a conventional wind shield. This design provides a warm, dry environment for instrumentation, and heating of the gage is accomplished using building heat. A backup chart record is possible. The stand-alone design automatically controls the heating of the orifice to melt snow, and a 20 inch orifice is planned. A Valdais wind shield or snow fence will be constructed around gages on the exposed, higher elevation sites. This wind shield will try to minimize the effect of strong and turbulent winds around the collection chamber to improve efficiency of precipitation catch.

Snow lysimeters and snow pillows will be added to each BMS. Data from the snow pillows will be used in conjunction with precipitation gages and snow course data to make estimates of snow coverage. Snow boards were considered but rejected due to intensive maintenance requirements. The possibility of establishing a SNOTEL station in high altitude ranges of Andrews, such as Lookout Mountain/Carpenter Mountain, may be negotiated with the SCS of USDA to augment high elevation precipitation data in and around the Andrews.

Other considerations

In order that observations at different BMS be comparable, a proper exposure is to be maintained. A minimum required clear opening would be maintained at these stations according to national standards of the NWS. Vegetation will be maintained and controlled near measurement sensors at these sites. The NWS (1970, p.18) states that for forest conditions "as a general rule...(the) height of objects above the gage should not exceed twice their distance from the gage." The NWS (1989) document which supercedes the 1970 document does not address this point quantitatively. A regular maintenance program is recommended to check the consistency of the data being collected. Calibration equipment and protocols will be developed.

Information Acquisition, Management and Processing

Data Acquisition and Transmission

Digital data loggers will record and store all measurement data from all Benchmark Stations and certain SLS. Generally, data will be telemetered or collected on a three week basis. Winter collection will frequently require snow cat use for access to the higher elevation sites. Data storage modules will be swapped for download at the Headquarters or data will be downloaded to field computers directly in the field. Standard field calibration and maintenance checks will be done routinely, and all site visits will be documented with check sheet information.

Telemetering of first tier Benchmark Meteorological Stations (Central Met, Upper Lookout, and Vanilla Leaf), and a Second Level Station (Mack Creek) will be initiated in the 1996 water year with Primary Met serving as the base station. A telemetered network will directly transmit data from data loggers to a centrally located base station at the Headquarters. The base system will be able to interrogate measurement stations daily. Attended or unattended data retrieval, communication error checking, and data processing will be possible at the base station. Large data storage requirements could potentially be reduced. The Andrews telemetry communication system will use radio telemetry, and a radio frequency license has been acquired. Stream gaging sites and other SLS may later be included in the telemetered network.

The base station at the Headquarters is now linked (August, 1995) with the local computer network of the Forest Science Laboratory for accessing and downloading of collected data and information.

Data Processing and Management

Initial processing of all hydroclimatological data will be done at the Andrews. Data logger data sets will be converted into a database management system. Quality control checking rules will be applied as well as graphical checks. Immediate application of quality control checking programs will provide timely feedback to field personnel.

There is a well organized data and information management group within the Andrews LTER program. The Forest Science Data Bank (FSDB) has been actively involved with managing hydrological, meteorological, and other related data for over twenty years. Meteorological data processing will follow standard FSDB quality assurance and archiving procedures. Common data formats for storing and displaying stream and weather raw data and summaries have been developed. Access to daily, monthly, and annual summaries will be supported by this group.

All documentation regarding the hydroclimatological measurement system will also be stored and maintained by the FSDB. Records of all changes in field instrumentation, sensors, locations, sensor heights, and temporal resolutions will be maintained for every measurement variable. Consistent data management procedures will be developed.

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Table 1. Current Monitoring Sites: Meteorological Stations, 1995

Site Name	Tier	Elev (m)	Aspect (deg)	Slope (deg)	Exposure	Site Description
Central Met Station	1	1020			O	Clearcut (station under construction)
Primary Met Station	1	435	-	0	O	Maintained clearing
Upper Lookout Met Statn	1				O	Clearcut
Vanilla Leaf Met Station	1	1265	180		O	Clearcut 1985
Hi-15 Met Station	2	925	240	150	O	2nd growth opening
WS#2 Climatic Station	2	465	355	5	O	Old growth opening, tight canopy
Mack Creek Gaging Station	2	760	5	5	O	Clearcut 1965
Reference Stand #1	3	490	200	41	C	Midslope, near Blue R resevoir
Reference Stand #2	3	490	285	22	C	Near valley bottom
Reference Stand #3	3	945	315	5	C	Midslope
Reference Stand #4	3	1310	270	27	C	Midslope
Reference Stand #5	3	880	10	12	C	Midslope, Lookout Ridge
Reference Stand #7	3	460	1	19	C	On slope, near valley bottom Lookout Cr
Reference Stand #10	3	610	170	6	C	Midslope on bench
Reference Stand #12	3	1010	282	11	C	On slope, near bottom Upper Lookout Cr
Reference Stand #13	3	1355	270	20	C	Midslope, Wildcat Mtn RNA
Reference Stand #13 Open	3	1355	270	20	O	Midslope, Wildcat Mtn RNA
Reference Stand #14	3	1430	1	32	C	Midslope, Wildcat Mtn RNA
Reference Stand #15	3	760	350	33	C	Midslope moist site WS 2
Reference Stand #16	3	640	202	29	C	Midslope dry site WS 2
Reference Stand #17	3	490	315	14	C	Near valley bottom
Reference Stand #20	3	685	180		C	Midslope
Reference Stand #24	3	650	30	28	C	Midslope, 100 yr forest, Hagan Block RNA
Reference Stand #26	3	1040	180	20	C	Midslope WS#8,100yr forest,replaces RS11
Thermograph Site #38	3	978	170		O	Midslope WS#6, overgrown young stand
Reference Stand #86	3	630	215	28	O	Midslope WS#10,overgrown young stand,RS6
Reference Stand #89	3	450	315	37	O	WS#10, overgrown young stand, was RS9

Mack Creek upstream	2	756	310		C	Old-growth overstory
Mack Creek PVC Gage	3	760	75	10	O	Clearcut
Roads End	3	1325	300	45	O	Clearcut
Trails End	3	1030	285	17	O	Edge of clearcut
Wildcat Mountain	3	1340	220	15	O	Meadow
WS#10 bottom	3	445	130	40	O	Near Gaging Station

Exposure: O=Open Canopy, C=Closed canopy

Table 2. Current Monitoring Sites: Stream Stations, 1995

Site Name	Tier	Elev (m)	Aspect (deg)	Slope (deg)	Exposure	Drainage (acres)	Site Description
Lookout Cr Gaging Station	1	430				15,400	
Mack Creek Gaging Station	1	760	5	5	O	1436	Clearcut 1965?
WS#1 Gaging Station	1	455				237	Clearcut 1967
WS#2 Gaging Station	1	550				149	Old-growth forest
WS#3 Gaging Station	1	420				250	Old-growth forest
WS#6 Gaging Station	1	895				32	Edge of clearcut
WS#7 Gaging Station	1	940				38	
WS#8 Gaging Station	1	995				53	Old-growth
WS#9 Gaging Station	1	430	340	40		21	Edge of forest
WS#10 Gaging Station	1	475	130	40		25	Edge of clearcut
McRae Creek	2	830	220		C		Old-growth overstory, partly open
Upper Lookout Creek	2	975	330		C		Old-growth overstory
Mack-Lookout	2	655					At confluence (planned)
McRae-Lookout	2	550					At confluence (planned)

Exposure: O=Open Canopy, C=Closed canopy

Table 3. Current Streamflow Gaging Stations, 1995

STREAMFLOW

Site Name	Tier	Begin Daily (mm/yy)	Finest Resolution (mm/yy)	Drainage (acres)	Method	Comments
Lookout Cr Gaging Station	1	10/49	Peaks	15,400	USGS	Maintained by USGS
Mack Creek Gaging Station	1	10/79	15 Minute	1,436	CR10	Chart backup
WS#1 Gaging Station	1	10/52	15 Minute	237	Chart	
WS#2 Gaging Station	1	10/52	15 Minute	149	CR10	Chart backup
WS#3 Gaging Station	1	10/52	15 Minute	250	Chart	
WS#6 Gaging Station	1	10/63	15 Minute	32	Chart	
WS#7 Gaging Station	1	10/63	15 Minute	38	Chart	Discontinued 1987-1994
WS#8 Gaging Station	1	10/63	15 Minute	53	Chart	
WS#9 Gaging Station	1	10/68	15 Minute	21	Chart	
WS#10 Gaging Station	1	10/68	15 Minute	25	Chart	

Table 4. Current Temperature Stations, 1995

AIR TEMPERATURE

Site Name	Tier	Begin Daily (mm/yy)	Begin Fine Res (mm/yy)	Finest Resolution	Method	Comments
Central Met Station	1	NA	NA	NA	CR10	Planned installation for summer, 1995
Primary Met Station	1	5/72	5/72	15 minute	CR21X	Hourly data until 1994, 250,350,450 cm added
Upper Lookout Met Statn	1	10/94	10/94	15 minute	CR10	Data at 4 heights:150,250,350,450 cm
Vanilla Leaf Met Station	1	6/87	10/90	15 minute	CR21X	Data at 5 heights:50,150,250,350,450 cm
Hi-15 Met Station	2	3/92	3/92	Hourly	CR10	Sensors at 150, 450
WS#2 Climatic Station	2	2/58		Daily	Chart	Max-min only, longest HJA record
Mack Creek Gaging Station	2	8/87	12/94	Hourly	CR10	Sensor relocated over stream in 1993
Reference Stand #1	3	4/70		Day/night	Chart	Scheduled for termination
Reference Stand #2	3	5/70		Day/night	CR10	CR10 installed summer,1987
Reference Stand #3	3	4/70		Day/night	Chart	Scheduled for termination
Reference Stand #4	3	6/70		Day/night	CR10	CR10 installed summer,1987
Reference Stand #5	3	5/71		Day/night	Chart	CR10 planned
Reference Stand #7	3	5/70		Day/night	Chart	Scheduled for termination
Reference Stand #10	3	4/71		Day/night	Chart	CR10 planned
Reference Stand #12	3	7/71		Day/night	CR10	CR10 installed summer,1987
Reference Stand #13	3	8/71		Day/night	CR10	CR10 installed summer,1987
Reference Stand #13 Open	3	8/87		Day/night	CR10	Adjacent meadow to RS13
Reference Stand #14	3	8/71		Day/night	CR10	CR10 installed summer,1987
Reference Stand #15	3	7/72		Day/night	Chart	Scheduled for termination
Reference Stand #16	3	7/72		Day/night	Chart	Scheduled for termination
Reference Stand #17	3	6/72		Day/night	Chart	Scheduled for termination
Reference Stand #20	3	1/79		Day/night	CR10	CR10 installed summer,1987
Reference Stand #24	3	6/77		Day/night	CR10	CR10 installed summer,1988
Reference Stand #26	3	1/78		Day/night	CR10	CR10 installed summer,1987

Thermograph Site #38	3	6/75		Day/night	Chart	CR10 planned
Reference Stand #86	3	9/75		Day/night	Chart	CR10 planned
Reference Stand #89	3	9/75		Day/night	Chart	CR10 planned
Mack Creek upstream	3	8/76		Day/night	Chart	Scheduled for termination
McRae Creek	2	8/76		Day/night	Chart	CR10 planned
Upper Lookout Creek	2	1/77		Day/night	Chart	CR10 planned
Lookout Cr Gaging Station	2	3/95	3/95	Hourly	CR10	Daily by USGS 1964-1981
Mack-Lookout	2	NA	NA	NA	CR10	Planned installation for summer, 1995
McRae-Lookout	2	NA	NA	NA	CR10	Planned installation for summer, 1995

DEW POINT TEMPERATURE

Site Name	Tier	Begin Daily (mm/yy)	Begin Fine Res (mm/yy)	Finest Resolution	Method	Comments
Central Met Station	1	NA	NA	NA	CR10	Planned installation for summer, 1995
Primary Met Station	1	5/72	5/72	Hourly	CR21X	Calculated after 1987, every 15 sec
Upper Lookout Met Statn	1	10/94	10/94	Hourly	CR10	Calculated from temperature, RH
Vanilla Leaf Met Station	1	8/93	8/93	Hourly	CR21X	Calculated from temperature, RH
Hi-15 Met Station	2	3/92	3/92	Hourly	CR10	Calculated from temperature, RH

SOIL TEMPERATURE

Site Name	Tier	Begin Daily (mm/yy)	Begin Fine Res (mm/yy)	Finest Resolution	Method	Comments
Central Met Station	1	NA	NA	NA	CR10	Planned installation for summer, 1995
Primary Met Station	1	7/88	7/88	Hourly	CR21X	20 cm depth, 10,50,100 added 11/94
Upper Lookout Met Station	1	10/94	10/94	Hourly	CR10	Data at 10,20,50,100 cm depths
Vanilla Leaf Met Station	1	6/87	10/90	Hourly	CR21X	10,20,30 cm depth, 10,20,50,100 after 10/94
Reference Stand #1	3	4/70		Day/night	Chart	Scheduled for termination, 20 cm depth
Reference Stand #2	3	5/70		Day/night	CR10	CR10 installed summer,1987; 10,20,30 cm
Reference Stand #3	3	4/70		Day/night	Chart	Scheduled for termination, 20 cm depth
Reference Stand #4	3	6/70		Day/night	CR10	CR10 installed summer,1987; 10,20,30 cm
Reference Stand #5	3	5/71		Day/night	Chart	CR10 planned, 20 cm depth
Reference Stand #7	3	5/70		Day/night	Chart	Scheduled for termination, 20 cm depth
Reference Stand #10	3	4/71		Day/night	Chart	CR10 planned, 20 cm depth
Reference Stand #12	3	7/71		Day/night	CR10	CR10 installed summer,1987; 10,20,30 cm
Reference Stand #13	3	8/71		Day/night	CR10	CR10 installed summer,1987; 10,20,30 cm
Reference Stand #13 Open	3	8/87		Day/night	CR10	Adjacent meadow to RS13
Reference Stand #14	3	8/71		Day/night	CR10	CR10 installed summer,1987; 10,20,30 cm
Reference Stand #15	3	7/72		Day/night	Chart	Scheduled for termination, 20 cm depth
Reference Stand #16	3	7/72		Day/night	Chart	Scheduled for termination, 20 cm depth
Reference Stand #17	3	6/72		Day/night	Chart	Scheduled for termination, 20 cm depth
Reference Stand #20	3	1/79		Day/night	CR10	CR10 installed summer,1987; 10,20,30 cm
Reference Stand #24	3	6/77		Day/night	CR10	CR10 installed summer,1988; 10,20,30 cm
Reference Stand #26	3	1/78		Day/night	CR10	CR10 installed summer,1987; 10,20,30 cm
Thermograph Site #38	3	6/75		Day/night	Chart	CR10 planned, 20 cm depth
Reference Stand #86	3	9/75		Day/night	Chart	CR10 planned, 20 cm depth
Reference Stand #89	3	9/75		Day/night	Chart	CR10 planned, 20 cm depth

STREAM TEMPERATURE

Site Name	Tier	Begin Daily (mm/yy)	Begin Fine Res (mm/yy)	Finest Resolution	Method	Comments
Mack Creek Gaging Station	1	8/87	12/94	Hourly	CR10	
McRae Creek	2	8/76	3/95	Hourly	CR10	CR10 installed 3/95
Upper Lookout Creek	2	1/77	3/95	Hourly	CR10	CR10 installed 3/95
Lookout Cr Gaging Station	2	3/95	3/95	Hourly	CR10	Daily by USGS 1964-1981
Mack-Lookout	2	NA	NA	NA	CR10	Planned installation for summer, 1995
McRae-Lookout	2	NA	NA	NA	CR10	Planned installation for summer, 1995

Table 5. Current Precipitation Stations, 1995

PRECIPITATION

Site Name	Tier	Begin Daily (mm/yy)	Begin Fine Res (mm/yy)	Finest Resolution	Method	Comments
Central Met Station	1	NA	NA	NA	CR10	Planned installation for summer, 1995
Primary Met Station	1	1/79	3/79	5 Minute	CR21X	Hourly until 10/94
Upper Lookout Met Statn	1	10/94	10/94	5 Minute	CR10	
Vanilla Leaf Met Station	1	6/87	10/90	5 Minute	CR21X	Hourly until 10/94
Hi-15 Met Station	2	10/63	10/84	5 minute	CR10	CR10 installed 3/92
Mack Creek Gaging Station	2	10/78	10/84	5 minute	Chart	CR10 planned
WS#2 Climatic Station	2	10/57	10/57	5 minute	Chart	Digitized record
Mack Creek PVC Gage	3	5/79		Daily	Prorate	Collected monthly
Roads End Storage Gage	3	12/78		Daily	Prorate	Collected monthly
Trails End PVC Gage	3	12/78		Daily	Prorate	Collected monthly
NADP Universal	3	5/80		Daily	Chart	NADP study gage, PRIMET backup
WS#10 bottom	3	10/70		Daily	Prorate	Collected monthly
Wildcat Mountain	3	7/80		Daily	Prorate	Collected monthly

SNOW LYSIMETER

Site Name	Tier	Begin Daily (mm/yy)	Begin Fine Res (mm/yy)	Finest Resolution	Method	Comments
Central Met Station	1	NA	NA	NA	CR10	Planned installation for summer, 1995
Upper Lookout Met Statn	1	10/94	10/94	5 Minute	CR10	
Vanilla Leaf Met Station	1	NA	NA	NA	CR21X	Planned installation for summer, 1996
Hi-15 Met Station	1	10/90	3/92	5 Minute	CR10	

SNOW MOISTURE

Site Name	Tier	Begin Daily (mm/yy)	Begin Fine Res (mm/yy)	Finest Resolution	Method	Comments
Central Met Station	1	NA	NA	NA	CR10	Planned installation for summer, 1995
Primary Met Station	1	NA	NA	NA	CR10	Possible installation for summer, 1996
Upper Lookout Met Statn	1	10/94	10/94	5 Minute	CR10	
Vanilla Leaf Met Station	1	6/87	10/90	5 Minute	CR21X	Hourly until 10/94
Road Snow Course	3		11/94	Weekly	Spot	Depths noted from road
Reference Stand #4	3		1/78	Monthly	Spot	Snow Course Midslope, forest
Reference Stand #4 Open	3		1/78	Monthly	Spot	Snow Course Road
Reference Stand #13	3		2/78	Monthly	Spot	Snow Course Midslope, Wildcat Mtn RNA
Reference Stand #13 Open	3		2/78	Monthly	Spot	Snow Course Midslope, Wildcat Mtn RNA Meadow
Reference Stand #14	3		1/78	Monthly	Spot	Snow Course Midslope, Wildcat Mtn RNA
Reference Stand #14 Open	3		12/84	Monthly	Spot	Snow Course Midslope, Wildcat Mtn RNA Open

Table 6. Other Meteorological Variables Currently Measured, 1995

RELATIVE HUMIDITY

Site Name	Tier	Begin Daily (mm/yy)	Begin Fine Res (mm/yy)	Finest Resolution	Method	Comments
Central Met Station	1	NA	NA	NA	CR10	Planned installation for summer, 1995
Primary Met Station	1	7/88	7/88	Hourly	CR21X	Sensor at 150 cm
Upper Lookout Met Statn	1	10/94	10/94	Hourly	CR10	Sensor at 450 cm, 150 cm planned
Vanilla Leaf Met Station	1	6/87	10/90	Hourly	CR21X	Sensor at 450 cm, 150 cm planned
Hi-15 Met Station	2	3/92	3/92	Hourly	CR10	Sensors at 150, 450 cm
WS#2 Climatic Station	2	2/58		Daily	Chart	Max-min only, sensor at 130 cm

VAPOR PRESSURE DEFICIT

Site Name	Tier	Begin Daily (mm/yy)	Begin Fine Res (mm/yy)	Finest Resolution	Method	Comments
Central Met Station	1	NA	NA	NA	CR10	Planned installation for summer, 1995
Primary Met Station	1	7/88	7/88	Hourly	CR21X	Calculated every 15 sec from temp, rh
Upper Lookout Met Statn	1	10/94	10/94	Hourly	CR10	Calculated every 15 sec from temp, rh
Vanilla Leaf Met Station	1	10/94	10/94	Hourly	CR21X	Calculated every 15 sec from temp, rh

SOIL MOISTURE

Site Name	Tier	Begin Daily (mm/yy)	Begin Fine Res (mm/yy)	Finest Resolution	Method	Comments
Central Met Station	1	NA	NA	NA	CR10	Planned installation for summer, 1995
Primary Met Station	1	11/94		Daily	CR21X	1987-90 data, restarted at 10,20,50,100 cm depth
Upper Lookout Met Statn	1	10/94		Daily	CR10	Depths: 10,20,50,100 cm
Vanilla Leaf Met Station	1	6/87		Daily	CR21X	Hourly data 1990-94, depths:10,20,50,100 cm

SOLAR RADIATION

Site Name	Tier	Begin Daily (mm/yy)	Begin Fine Res (mm/yy)	Finest Resolution	Method	Comments
Central Met Station	1	NA	NA	NA	CR10	Planned installation for summer, 1995
Primary Met Station	1	5/72	5/72	Hourly	CR21X	Much estimation of data in 1970's
Upper Lookout Met Statn	1	10/94	10/94	15 minute	CR10	
Vanilla Leaf Met Station	1	6/87	10/90	15 minute	CR21X	Hourly until 10/94

WIND DIRECTION

Site Name	Tier	Begin Daily (mm/yy)	Begin Fine Res (mm/yy)	Finest Resolution	Method	Comments
Central Met Station	1	NA	NA	NA	CR10	Planned installation for summer, 1995
Primary Met Station	1	7/88	11/94	Hourly	CR21X	Resultant vector, daily wind rose, std dev
Upper Lookout Met Statn	1	10/94	10/94	Hourly	CR10	Resultant vector, daily wind rose, std dev
Vanilla Leaf Met Station	1	6/87	10/94	Hourly	CR21X	Resultant vector, daily wind rose, std dev
Hi-15 Met Station	2	3/92	3/92	Hourly	CR10	Resultant vector, daily wind rose, std dev

WIND SPEED

Site Name	Tier	Begin Daily (mm/yy)	Begin Fine Res	Finest Resolution (mm/yy)	Method	Comments
Central Met Station	1	NA	NA	NA	CR10	Planned installation for summer, 1995
Primary Met Station	1	5/73	5/73	Hourly	CR21X	After 7/88 max wind, resultant magnitude
Upper Lookout Met Statn	1	10/94	10/94	Hourly	CR10	Wind speed, max wind, resultant magnitude
Vanilla Leaf Met Station	1	6/87	10/90	Hourly	CR21X	Wind speed, max wind, resultant magnitude
Hi-15 Met Station	2	3/92	3/92	Hourly	CR10	Wind speed, max wind, resultant magnitude

Table 7. Proposed variables for measurement and their temporal resolution at the benchmark and second level stations.

Variables	Temporal Resolution	Remarks
Air temperature	15 min & Hourly**	Heights of 1.5, 2.5, 3.5, and 4.5 meters
Precipitation	5 min	Two approaches have been implemented at BMS sites
Solar radiation	15 min	Incoming shortwave
Photosynthetically Active radiation (PAR) *	15 min	Primary Met only
Relative humidity	Hourly	Move to 4.5 meters during winter at high elevation
Dew point temperature	Hourly	Continuously calculated
Vapor pressure deficit	Hourly	Continuously calculated
Wind speed	Hourly	
Wind direction	Hourly	Wind rose vectors summed
	Daily wind rose	Daily
Snow pillow	5 minute	Instantaneous snow moisture
Snow melt lysimeter	5 minute	Not at Primary Met
Soil temperature	Hourly	Depths of 10, 20, 50, and 100 cm
Soil moisture	Daily	Depths of 10, 20, 50, and 100 cm
Streamflow	15 min	Finest resolution of 5 min in selected storms
Stream temperature	Hourly	Mack Gaging Station, and second level sites
Pan evaporation *	Daily	Primary Met only
Sunshine duration *	Daily	Primary Met only, might calculate

* Proposed new variable
** Second level stations only