Guidelines
for the Collection of
Hydrologic and Meteorologic Data

Volume 1: Field Applications

Revised Edition

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Preface

The State of Florida has mandated the management of the State's water resources to five regional water management districts: The Northwest Florida Water Management District, the Suwannee River Water Management District, The Southwest Florida Water Management District, the St. John's River Water Management District, and the South Florida Water Management District. These agencies have the basic responsibility for the appraisal, conservation, regulation, and efficient utilization of the State's water resources. As part of their overall mission, the water management districts are responsible for a large part of the collection and compilation of water data for rivers, lakes, canals, and groundwater that are used by planners, engineers, scientists, developers, water-quality managers, and pollution control agencies. A high degree of reliability and standardization of these data is essential.

This document is a product of an Inter-District Data Collection Focus Group, comprised of individuals from the South Florida, St. Johns River, Suwannee River, and the Southwest Florida Water Management Districts. These individuals are experienced in the collection and management of hydrologic and meteorologic data.

The purpose of this document is to condense into one volume information valuable as a reference for those engaged in, or actively planning, water management monitoring programs. The implications of monitoring activities are clearly great and this manual should serve as a useful tool as Florida's water management districts strengthen their programs.

Generally, this document includes fundamentals and provides information to assist the user by setting forth guidelines for standardizing hydrologic data collection. This standardization will enhance the acquisition and analysis of data from data collection network design through product quality assurance.

This document suggests that, during network design, the scientist should address some major data acquisition questions, including:

- Which of the field parameters should be monitored in order to achieve desired network results?

- What are the general, random, and systematic errors of uncertainty associated with these data?

General uncertainties are quantified by evaluating accuracy through implication of collection or analysis procedures. The random uncertainties which are due to chance, such as accidents and bad judgement, can be reduced through training and implementing quality control procedures. Systematic uncertainties, which relate to instrument specifications, technician idiosyncrasies, and instrument calibration also require consideration.

The basic field observations suggested for water budgeting are surface water discharges, groundwater levels, and selected meteorological parameters. Surface water measurements should include overland flow, channel discharges, and, where possible, a relational measurement between stage and surface water discharge. Groundwater measurements are primarily water levels from a network of properly constructed observation wells. Meteorological observations should include precipitation (depth and rate), surface wind (speed and direction), surface temperature (ambient and dewpoint), solar radiation (total and net), and atmospheric pressure.

High variability make precipitation the most influential parameter when deciding the optimum density of a data collection network. Detailed studies of gauge density versus areal precipitation show that densities of 282 square miles per gauge allowed errors of up to 62 percent, and one square mile per gauge allowed up to four percent, in hourly rainfall depth measurements. Errors decrease considerably when longer time periods are used.

This document details the critical importance of site selection which allows for the proper exposure of instruments measuring parameters such as precipitation, wind, temperature, and solar radiation. Precipitation and wind are severely affected by obstructions which block the instrument or cause eddy currents that degrade the instruments ability to capture the dynamics of the monitored parameter. Temperature and radiation are adversely influenced by any obstruction that will capture and re-radiate or generate energy, such as a paved parking area, a jet-blasted runway, or a large mirrored building.

Basic theory is included for the meteorological parameters of precipitation, atmospheric pressure, surface wind, atmospheric temperature and moisture, and solar radiation. Also included are very basic theories of surface and groundwater measurements.

This document describes a multitude of specific instruments used by the water management districts in measuring various hydrometeorologic parameters. Each specific instrument description includes its principle of operation, manufacturer's specifications, installation procedures, calibration procedures, and general maintenance requirements. It should be noted that many diverse instruments are listed for measuring the same parameter. Each has its own advantages and limitations, and thus should be carefully matched to the application of measuring a particular variable within a specific site configuration.

Acknowledgments

This report was prepared by the Inter-District Data Collection Focus Group, which was formed in 1992 following the first annual Water Management District/Department of Environmental Protection Technical Research Conference. The purpose of the group is to increase communications, standardize methods, and share data collection technologies among the water management districts of the State of Florida. The following staff have made significant contributions of their expertise to the compilation of this document:

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In the preparation of this document, abundant use was made of technical and instructional materials supplied by the various equipment manufacturers. Their assistance is appreciated.

This document does not imply endorsement of any commercial products discussed herein, nor deny endorsement of those products not included. The instruments discussed are all currently used by at least one of the five water management districts in the State of Florida. Each user must carefully consider instrumentation solely on its own merit to assure its appropriateness for the use intended.

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Introduction

The Collection of Hydrologic Data

Water is one of the world's most valuable resources. For a resource that is so widely used and so important to the health and economy of Florida, the hydrologic cycle is poorly understood and is subject to many misconceptions. One often-heard belief is that Florida's groundwater supplies are concentrated in underground rivers, the origins of which are Georgia, North Carolina, Pennsylvania, and New York. This misconception along with many others have hindered the proper development and conservation of water, and have adversely affected the protection of its quality.

In order for Florida to receive the most benefit from its water, it is important that everyone become more concerned about this vital resource, from the homeowner to the industrial and municipal water supply managers to the heads of water regulatory agencies. We all must become more knowledgeable about the occurrence, development, and protection of water. This manual has been prepared to help meet some of the needs of technicians, hydrologists, and others engaged in the planning of studies, development, and management of water resources. The information contained herein is intended to provide some guidelines toward standardization of hydrologic and meteorologic data collection.

Historically, hydrometeorological data collection networks were a product of evolution, and not design. There were as many different methods of measuring these hydrometeorological parameters as there were technicians performing the measurements. The technician often knew little of the hydrologic cycle, especially the extreme dynamics associated with surface water and meteorology. As a result, reams of unreliable data presently reside in archives throughout the world.

Each section of this document consists of a brief text or parameter discussion followed by instruction as to instrument principles of operation, manufacturers specifications, installation, calibration, and maintenance.

The first chapter, General Data Collection Guidelines, includes a reminder of the importance of proper site selection in the collection of quality data. This section discusses network design and the importance of addressing the data acquisition uncertainties of general, random, and systematic errors. Also discussed are field discharge, ground water levels, and pertinent meteorological observations. Attention is given to optimum network density with a short history of the many studies used to establish the errors of rain catch versus time. A listing of site selection criteria is discussed in detail for parameters of wind precipitation, atmospheric pressure, solar radiation, air temperature, and humidity.

The second chapter, Meteorological Monitoring, contains information about the measurements of precipitation, atmospheric pressure, wind speed and direction, solar radiation, air and water temperature, and atmospheric moisture. Basic theoretical comments are included within each parameter introduction along with detailed statements about instrument siting and exposure. Individual instruments are listed under their own

subsection including operational principles and specifications followed by specific procedures for installation, calibration, and maintenance.
The third chapter, Water Level Monitoring, contains information about the different methods and instruments used in measuring water levels. Basic theoretical comments and statements of instrument siting and exposure are followed by important discussions of manual measurements and recording instrumentation. This section also includes subsections about:

- Surface followers such as graphical and punch paper tape recorders, potentiometers, and encoders most of which are float-counterweight technology instruments.

- Pressure transducers, which measure the weight to the column of water above them, or use the side pressure of the water to vary the resistance of an underwater sensor.

- Ultrasonic sensors, which use sound waves to measure the actual linear position of a float riding upon the water surface.

The fourth chapter, Velocity/Discharge Monitoring, contains some general information about open channel and closed pipe velocity measurements. Details of the two- and three-point methods of estimating mean velocity along a vertical are discussed along with the criteria for selecting a cross section for these measurements. Specific discussions are contained about measurement standards and measurement types such as boat, bridge and wading measurements. The Acoustic Doppler Current Profiler, Price and Pygmy current meters, Electromagnetic current meters, acoustic velocity meters, and closed pipe flowmeters are discussed. Other important discharge measurement methods discussed in this section are rod floats, portable weir plates, volumetric measurement, and tracer dilution.

The fifth chapter, Flow Control Structure Monitoring, contains general information about water control structures and general instrument siting and exposure requirements followed by more specific discussions of the parameter concerned with the actual operation of the structure. This includes information on pump operation, gate position, lock operation, fuel reserves and stop log measurements. Instruments within this section include detailed procedure for their installation, calibration, and maintenance and a discussion of its principle of operation.

The sixth and final chapter, Data Acquisition, details many of the methods used by the Water Management Districts to acquire hydrologic data.

General Data Collection Guidelines

1.0 Network Design, Site Selection, and Installation

1.1 Monitoring Information System Design

Procedures for design of monitoring system networks are complex, and cannot be quantified by a set of hard-and-fast rules. After giving due consideration to the importance of network design, and after quantitative analyses have determined from where, how often, and for what variables to sample, the designer must incorporate these quantitative techniques into the information system. This must be accomplished in an orderly manner or these techniques will be ineffective.

The following steps are subjective aspects to network design and do not include specific details. In this summary, monitoring system design is described as a five step process. Network design (step three) is but one step of this process.

1. Evaluate Information Expectations

All data are expensive. Quality information is even more expensive. Persons responsible for fund allocation, and those who use the information in making management decisions, should work together to establish monitoring goals. To identify the expectations of the monitoring system, the designer should:

A. Coordinate the purposes of monitoring with the information users and the persons funding the operation.

B. Generate a prioritized, written statement of monitoring objectives, including data utilization.

C. Review these objectives and purposes with the information users to obtain a consensus opinion.

Prioritizing the goals and objectives is important to the designer because some objectives often conflict with others. For instance, trend determinations may compete with detection of regulatory violations. Trend determinations require independent sampling (non-uniformly scheduled) while regulatory monitoring often needs uniformly scheduled sampling.

2. Establish Statistical Design Criteria

Basically, monitoring is statistical sampling. Therefore, the hypotheses for testing should be identified. The statistical procedures needed for testing the hypotheses must be selected.

The hypotheses are determined from the goals and objectives identified in step one. As an example, if a goal is to determine water quality trends, should the trend be measured by:

- testing for a linear trend in the data for some measured variable;
- testing for a linear trend in the annual mean of the measured variable;
- testing for linear trends after the seasonal variations and serial correlations have been removed;
- testing for comparative annualized means of each parameter with flow effects removed;
- testing if the past three years of data for each variable are from the same population as the previous three years?

Each of the above is a different hypothesis for testing to determine trends. The network designer, with assistance from the information users, must determine which hypothesis best fits the management decision requirements.

Upon completion of steps 1 and 2, most of the trade-offs between budgeting and information requirements should be resolved. Detailed network design is ready to commence.

3. Design the Monitoring Network

After the monitoring goals and objectives are determined, the objectives expressed as hypotheses, and the essential statistical techniques defined, the designer is ready to deal with the geographic, hydrologic, and geologic considerations that influence the monitoring operation. These considerations must be carefully documented and integrated into the network design. Integrating these considerations is no small task, especially if the designer is not familiar with the geography of the monitoring area.

The designer is now ready to consider what variables to measure, where to measure them, and how often to measure them.

A. Variables to Measure

Variables measured are dependent upon the budgetary constraints of the network, monitoring objectives, and hydrogeological characteristics of the basin.

A regulatory monitoring network may determine the variables from those stated in the regulation standards. If more than one variable is considered, then attention must be given to the different statistical behavior of the different variables.

B. Measuring/Sampling Site Locations

Measurement site selection is extremely critical. In water quality monitoring it is probably the most important factor in network design. Cost and time compromises often reduce the quality of information allowing short cut measurement techniques. Stage should not be used to estimate stream discharge rather than an actual measurement. Bridge grab samples should not be used instead of paddling the boat to the center of the stream where the sample would be more representative. Manual water level measurements at a gauging station are sometimes not representative of the recorders calibration record because of excessive time between the manual measurements and the value logged by the recorder.

Site locations for a permanent network can be classified in two categories. Macrolocation and microlocation. Macrolocation is a function of monitoring objectives and microlocation is a function of measurement representativeness. A macrolocation is usually determined by political boundaries, population areas, major pollution loads, or flood probability areas. Microlocations are determined by the areal coverage specified by the monitoring agency.

Once the macrolocations (the reach of the monitoring system) are established, the microlocations (the points within the reach) are then determined.

C. Measurement Frequency

When the measurement sites are situated such that the measurements are representative in space, the measurement frequency should be established so the measurements are representative in time.

Parameter dynamics often prescribe the measuring frequency. Rain should be measured as an event function whereas wind speed should be integrated over a specified period or recorded as wind run. The stochastic nature of hydrologic variables in the environment affords numerous statistically meaningful procedures for determining sampling frequencies.

Measuring too often generates redundant information, not often enough may skip an important event or cause an extended period of observation.

4. Develop Operating Plans and Procedures

At this point the system is far from operational. These procedural requirements need to be specified before the monitoring system becomes operational:

- Plan site visitation routes and inspection procedures
- Gather inspection forms and sample logs
- Define sample preservation and transport procedures
- Establish quality control and quality assurance procedures
- Design data storage and retrieval system with data analysis software

Other factors to consider include:.

- Personnel -- Determine the number of staff required and the amount of training needed for them to perform their activities properly. The overloading of staff because of budget constraints is often false economy because the resulting data may be of less than desired accuracy. Hiring poorly trained personnel often results in a complete disregard for accurate measurements.
- Facilities and equipment -- The caliber of facilities and equipment must equal the network design if desired quality information is to be obtained. Equipment failures will cause lost record, crowded facilities may cause equipment failures, contaminated measuring equipment or containers will cause incorrect laboratory analysis.

Just as network design needs careful documentation, so do operating plans and procedures.

5. Develop Information Reporting Procedures

If the data or information are not properly available or accurately presented to the information user, the monitoring program has failed. Lack of reporting procedures is common in many networks. Devoted communication between the collecting agency and the users ensures that network results meet the objectives for which the system was established.

1.1.1 Factors Affecting Accuracy

Numerous factors can affect the accuracy of the values obtained from a field site. Extreme care and attention to measurement and maintenance procedures must be given to minimize these occurrences. Among these are:

- **The accuracy of the measuring point elevation used as established by the vertical survey**. If the initial measuring point was incorrectly determined or determined using poor quality benchmarks, all data gathered from the site will carry this inaccuracy.

- **The accuracy of the positional survey and transcription of the latitude and longitude.** If the initial survey does not adequately define the absolute position of the measuring point, or if transcription errors occur, areal interpretations of data may be skewed, resulting in significant potential liability to the Districts.

- **The accuracy of the instrument used to measure the environmental parameter**. Accuracies of readings gathered by different methods and instruments vary widely. The accuracy of each specific instrument is discussed within the body of this report. The user of the instrument must be intimately familiar with the uses and abuses of the various instrumentation, and exercise good judgement and attention to detail to ensure the results match the results expected from the instrument. Inadequate care will result in sub-standard equipment performance and accuracy.

- **The frequency of maintenance and equipment calibration of the site.** Measuring point elevations may change with time due to accidental causes (gauges or well casing being knocked over vandalized) or by natural causes (such as subsidence). Instrument drift is inherent in many sensors, requiring close monitoring of the data to determine recalibration intervals. Ambient atmospheric voltages due to lightning may adversely affect electronic sensors that are not properly grounded.

- **Site- and parameter-specific environmental considerations**. The range of water level fluctuation, depth to water, rate of change in water levels, and sampling frequency, will all affect the measured accuracy of ground water readings. Wells in which the range in fluctuation and/or depth to water is great are much more difficult to ensure absolute measurement accuracy. When levels change rapidly, as in some wellfield monitoring wells, by the time the measurement of water level is completed and necessary adjustments are made to the recording instrumentation, it is most likely that the adjusted levels are already off. A daily average of 1-hour or 15-minute measurements of water levels is more accurate estimation of the water level than a weekly or monthly water level measurement.

Each parameter at each site can be expected to have a unique combination and degree of severity of the problems identified in the preceding paragraphs. It is suggested that the Water Management Districts jointly develop a method to gauge and to weight these site specific problems. From this, a subjective "data quality" code can be developed for integration with the data collected from these sites in the hydrologic data bases used by the Water Management Districts.

1.2 Site Selection Guidelines

Every aspect of the hydrologic cycle, particularly the surface water and meteorologic environments, are extremely dynamic in nature. In order to collect accurate data and information about ground water, meteorology, and surface water requires considerable finances, meticulous planning, and careful organizing as well as ingenuity and imagination. These data must be of acceptable quality to all users including courts of law.

Site selection is of critical importance in preventing the collection of a vast hodgepodge of unreliable data.

1.2.1 Network Design

Most data are collected in response to an existing need, in compliance with a political or legal obligation to collect and document, or in anticipation of a future need.

Most existing data acquisition programs have evolved with time and are not a product of any grand scheme or design. The dynamic nature of the hydrometeorological environment does not lend itself to concise design due to the unforeseen changes in data needs.

Data acquisition networks will always benefit through the standardization of collection and analysis methods.

Uncertainty in data acquisition methods

Network design must consider three major data acquisition questions.

- **General measurement uncertainty**: All measurements of hydrometeorological parameters are inaccurate to some degree. This poses problems when it becomes necessary to quantify the errors of the observation. When data quality is not precisely known, it is necessary to evaluate the data accuracy. Evaluate subjectively, through implication due to the acquisition and/or analysis procedure, and quantitatively through statistical and/or mathematical estimations. This of course cannot prevent the inclusion or misrepresentation of data collected by inadequate or questionable methods.

- **Random error of uncertainty**: Random errors are a product of repeated measurements. Considered due to chance or accidental, the random error is usually an error in judgement (variation in reading); or fluctuation in condition (water turbulence, wind eddy); or an inadequate instruction to procedures.

- **Systematic error of uncertainty**: Errors associated with repeated measurements which are constant or in the same amount are systematic errors. These relate to errors in calibration of instruments, exceeding manufactures specifications, personal idiosyncrasies, and/or imperfect data collection techniques.

Field measurements.

Network design must consider the various field parameters from which data are needed to achieve the desired results from the data acquisition program.

The following parameters are suggested when designing a network for water budgeting.

1. Surface water

Overland flow. Water flowing on the surface without definable and continuous channel boundaries. Most commonly this is the flow occurring when rainfall rates exceed infiltration rates. Another type of overland flow (channel-source) exists in the southwestern United States where ephemeral streams discharge onto flattened alluvial cones.

Important measurements for overland flow are hydraulic roughness (terrain contour), rainfall rate and depth, land surface infiltration, and ephemeral stream stage.

Open channel flow. Water flowing within definable and continuous channel boundaries. Most commonly this is the flow of water bodies such as streams, rivers, or canals having beds, banks or sides, and an open water surface.

Important measurements for open channel flow are stage, cross sectional area of the channel, and cross sectional velocity of the water within the channel.

2. Ground water levels

Water levels are fundamental measurements of ground water studies. The data are used to define the directions of ground water flow, to evaluate the effect of anthropogenic and natural stresses on the ground water system, to define the hydraulic character of the aquifer, and to indicate areas of recharge and discharge.

A properly constructed observation well will greatly enhance the pertinence of measured ground water levels. Required information for observation wells:

- The aquifer must be tapped, and identified
- Lithologic and geophysical logs
- Well depth, size and type of casing, location and type of perforations
- Land surface and measuring point elevations
- Date drilled, capacity test, and proposed use
- Location by narrative description, index map, section-township and range, and latitude and longitude
- Features near the well that could influence the water level

3. Hydrometeorological observations.

There exist a number of meteorological and solar process parameters that are of vital interest to the hydrologist. Examples are, precipitation, air temperature, relative humidity, atmospheric pressure, wind, and solar radiation. These parameters require careful quality control practices and sound measurement techniques to maintain the standards and integrity desired of the data.

Precipitation. Precipitation depths and rates are especially useful to the studies of surface water discharge and ground water recharge. Maintaining proper siting and exposure is crucial to the collection of quality data. Obstructions in the area can influence the precipitation catch to the extent that these data become unusable.

Surface wind, temperature, pressure, and solar radiation. These parameters are very important in the calculations of evapotranspiration used in the management of water budgets and in the studies of ground water recharge. Proper site selection is critical to quality data collection of these parameters. Surrounding objects can generate eddy currents which will adversely affect wind measurements. These same objects can render temperature and radiation measurements useless, with their thermal-mass radiation.

1.2.2 Optimum Network Density

Precipitation is probably the most influential parameter in the study of water balances and the calculations of water budgets. Therefore, precipitation should be the dominate consideration when determining the site density of a given monitoring network.

Considering the many problems associated with accurate rainfall, it is easy to understand that even greater problems exist when determining areal distribution of rainfall from a given rainfall site. The three most common methods of determining rainfall distributions via point data are arithmetic mean, Thiessen method, and isohyetal method (Winter, 1981). Linsley, et al. (1958), showed areal distributions interpreted by arithmetic mean were 18 percent greater, and by Thiessen method were 9 percent greater than those distributions interpreted by isohyetal methods. Nwa (1977), however, compared the isohyetal method with the Thiessen method for a few storms of varying size and showed the Thiessen method to be only five percent greater.

Considering the high variability of precipitation, especially in Florida, one of the objectives in studying rainfall patterns is optimizing gauge density.

Sampling errors tend to increase with increasing areal distribution interpretations and to decrease with increasing network density, size of area, and duration of precipitation. Linsley and Kohler(1951) studied a 55-gauge network over a 220 square mile area in Ohio. Using the 55-gauge average as the standard for comparison, they showed that one inch storms had average errors of 18 percent if only one gauge was used, 12 percent errors if 12 gauges were used, and three percent if 18 gauges were used.

Detailed studies of precipitation verses gauge density were conducted in Illinois for many years (Huff and Neill, 1957; Huff, 1967; Huff and Shipp, 1969; Huff, 1970; Huff and Schickedanz, 1972). These studies showed that densities of 282 square miles per gauge allowed errors of about 62 percent in measuring areal daily rainfall on any particular day. With densities of 8.2 miles per gauge the error decreased to 11 percent, and at one mile per gauge the error was about four percent. These errors decreased significantly as longer time periods were considered. When annual precipitation was considered with 100 square mile gauge density, errors of less than five percent were common.

Precipitation study information is vast and far-reaching. Estimates of measurement errors are confusing if a general number is desired. As a result of research by the Huff contingent, some general conclusions seem valid.

- Instrument errors can range from one to five percent.
- Errors caused by gauge exposure range from 5 percent to 15 percent for long term measurements and up to 75 percent for storm event measurements. Wind shields can reduce storm event errors by as much as 20 percent.
- Errors associated with areal averaging of point data are often greater than 60 percent for storm events depending on storm type, duration, and gauge density.
- Gauge densities of 250 square miles per gauge (National Weather Service) cause daily mean rainfall errors as high as 60 percent. As the averaging period increases the error decreases. Monthly average errors equal about 15 percent and annual averages equal five percent or less.
- Areal average daily mean errors versus gauge density are about: 60 percent for 280 square miles/gauge, 10 percent for 8 square miles/gauge, and four percent for one square mile/gauge.
- Different methods of estimating areal distributions using identical numbers can differ by as much as 18 percent.

1.2.3 Site Selection Criteria

Precipitation. Gauges should be distributed uniformly and be consistent with the practical needs for data. Install gauges on level ground, as close to ground level as is practical, and at a distance from obstructions of at least two, and preferably four, times the height of the object above the top of the gauge. At all times the receiver of the gauge must be exposed in a level horizontal plane.

Objects that individually, or in groups, reduce the prevailing wind speed, turbulence, and eddy currents around the gauge may allow a more accurate catch. In no case should the distance between the obstruction and the gauge be less than twice the height of the obstruction above the gauge.

Temperature and Humidity. The ground surface beneath the sensor housing should have the same vegetation and be representative of the surrounding area. The area should be level and clear to allow instrument ventilation by an unobstructed flow of air. The instruments should be no closer to any obstruction than four times the height of the obstruction. The shelter should be mounted such that the instrument is approximately two meters above ground level with the service door facing north and at a distance of no less than 100 feet from any area having extensive concrete or paved surfaces. The instrument shelter should be located no closer than 300 feet of an obstruction that would unduly influence the instrument's measurement capability (a jet blast or a tall reflective building). Mount the instrument rigidly to reduce vibration.

Atmospheric Pressure. Install the barometer at a location that is readily accessible to the observer, safe from tampering, and free from vibration. The location should be clean, relatively dry, maintain as constant a temperature as is practicable, and **free** of direct sunlight. Install the sensor well away from any obstruction that would cause any wind-influenced change in static pressure, or reflect solar energy to the sensor.

Wind. Surface wind sensing equipment should be installed 20 feet above the ground over terrain that is relatively level and free from obstructions to wind flow. Obstructions such as hills or buildings should be no closer to the wind sensors than a distance of 10 times their height above the sensors. Avoid sites where topography or any other influence is known to create updrafts, downdrafts, eddy currents, or jet blasts.

When a compromise of sensor exposure is necessary, the sensors should be exposed at least 12 feet above any obstruction within 100 feet and at least as high as any obstruction lying within 100 and 200 feet. Supporting towers should not be of shape or density as to create significant obstruction to windflow.

Solar Radiation. These instruments should be installed at a site that is as free of obstructions as possible. Care should be taken to avoid obstructions lying in a plane from east-northeast to west-northwest in the northern hemisphere. No obstruction should extend more than five degrees above the sensor field of view. Ensure that no obstructions will reflect or capture and re-radiate any solar energy into the sensor.

1.2.4 Survey Requirements

Accurate survey information is required for integration of hydrologic data with digital orthophotography in the Districts' Geographic Information Systems (GIS). To properly display the location of a data collection site, and to relate the specific information gathered at that location to data from other sites, extreme precision must be used in determining horizontal position using global positioning system (GPS) hardware. Optimally, to achieve the precision required for integration with Digital Orthophotographic Quad maps (DOQ), the survey should be accurate to within one meter.

Accuracy is also of extreme importance in establishment of vertical benchmark measurements at locations where elevation of surface or ground water will be measured. Gauge heights are used with a stage-discharge relation in computing records of stream discharge. The discharge record is therefore dependent on the accuracy of the gauge-height record as well as on the accuracy of the stage-discharge relation. Accurate stage records are a requirement for hydrologic studies and design.

Reliable water-level (stage or gauge-height) records of wells and surface water bodies require establishment and maintenance of measuring point elevation or gauge datum by surveying levels from a stable benchmark.

When a station is established, it should be assumed that a permanent datum will be maintained at the site. To maintain a permanent datum, each gauging station requires at least two and preferably three reference marks as permanent points of known elevation that are independent of the gauge structure. The datum at each station should be periodically checked by running levels from the reference marks to the gauges (or measuring points) at the station. Periodic verification of the gauge stability by levels to reference marks established at each gauge site is needed to assure datum integrity.   New levels to reliable benchmarks may be required when evidence indicates lack of relative stability of the site gauge and reference marks.

Levels should be run from a reliable benchmark to establish gauge datum or measuring point elevation. Station levels should then be run to reference the gauge to reference marks. Station levels should be run again within about six months or if settling or disturbance is suspected. Once vertical stability is established, station levels should be run every three or four years.

Survey of most data sites should be made at a second-order precision. When station levels are run, staff gauges should generally be within 0.015 (fifteen thousandths) ft of the established datum. Float tapes or recording gauges should generally be within 0.005 (five thousandths) ft of datum. Gauges not within these tolerances, or the tolerances established for the site, should be reset during the leveling process. Reference marks found to be unstable should be destroyed or abandoned and new ones established and described.

A level summary should be maintained for each station. The summary should include the date, leveling party; elevations of reference mark, reference point, measuring point; and individual gauge datum or corrections as found and as left or reset. A reference should also be noted as to the description of the original benchmark origin and elevation. Descriptions of each gauge or reference point and reference marks should be maintained in the site description with copy for field use.

1.2.4.1 Determining Horizontal Coordinates Using GPS

The Global Positioning System (GPS) is used to accurately determine the latitude and longitude of a monitoring site. GPS is a satellite-based, radio navigation system operated by the U.S. Department of Defense (DoD). GPS accuracy is a function of the equipment and data processing methods. Also, the DoD has the ability to degrade GPS accuracy at any time with Selective Availability (SA). SA degrades the code used by civilian navigation receivers so that they miscalculate their position by hundreds of meters. SA error is almost completely removed through differential correction.

The following describes the use of a Trimble Navigation GPS Pathfinder Basic Plus receiver. Refer to the Operating Manual and Software User's Guide for specific instructions.

Recommended Settings

Four screens contain the settings. Critical settings directly affect the way positions are computed or data is recorded in the receiver. If these are set incorrectly, the receiver might not compute positions or the positions it records might not be differentially correctable. Non-critical settings affect the way data is displayed on the screen. They can be set to any desired value. The receiver does not automatically return to default settings when it is shut off. Always check all settings to make sure they are acceptable every time the receiver is turned on. Standard settings are listed below (settings in bold are critical).

Mask Screen

PDOP Mask	**Max PDOP: 06**
PDOP Switch	**2D Switch: 08**
Elevation Mask	**Elev Mask: 10** (or 15)
Filter Coefficient	**F: 0.20**

Set Up Screen

Dynamics Code	**LAND** (or SEA, or AIR)
Position Fix Mode	**3D**
Altitude Reference	HAE
North Reference	TR
Units of Measure	ENGLISH
Coordinate System	DMS
Waypoints Available	99
Datum	WGS-84
Clock/Time Zone	LOC=UTC-5 (UTC-4 during DST)

Datalogging Screen

Logging Mode	**Rovr**

Position Logging Interval	**005 Sec**
Velocity Recording	NO VEL

Communications (COMM) Screen

Communications Protocol	**XMODM**
Baud Rate, Parity, Data Bits	**9600,N,8,1**
Differential Mode	**Non-diff GPS**
Stale RTCM Value	**060 Sec**

Data Collection

GPS accuracy is increased by collecting data for 2-3 minutes at a point, differentially correcting the data, and averaging the positions after they have been differentially corrected. 3D positions are more accurate than 2D positions. Make sure that the receiver is in Manual 3D position fix mode (see Set Up Screen).

Go to an area with a clear view of the sky. The receiver requires line-of-sight visibility to the satellites. Hold the unit level, with its internal antenna facing toward the sky.

Turn the receiver on. Turn the rotary knob to **POS**. Wait approximately 3 minutes to view the current position. The word **OLD** is displayed in the lower right corner of the screen until the receiver computes its first position. In the few minutes it takes to begin computing positions, check the critical settings.

Check the satellite tracking status. Turn the rotary knob to **STS**. The receiver must be tracking at least four satellites in order to compute a position. **N/A** indicates there are not enough satellites available for a position fix. **BAD** indicates the satellite geometry is not good enough to yield an accurate position. **OK** indicates the geometry is good.

Store the current position. Start logging data to a rover file. Move the cursor to the **START** field with the **L/R** switch and activate using the +/- key. Collect readings for approximately 2-3 minutes. When finished, end the datalogging by moving the cursor to the **STOP** field with the *L/R* switch and pressing the *+/-* key.

Turn the receiver off. Turn the rotary knob to **OFF**. After 15 seconds the receiver will shut off.

Post-Processing

In post-processed differential correction, the base station receiver records the error for each satellite in a computer file. The rover receiver records its own positions in a computer file. The two files are processed in PFINDER and the output is the differentially corrected rover file.

Transfer the rover file to the PC using PFINDER.

Differentially correct the file using PFINDER.

1.2.5 Site Maintenance

Site maintenance is usually a collection or summation of maintenance requirements of each sensor and or instrument that is installed at the site.

Each site visit should start with a preliminary visual inspection as service personnel are approaching the site. Look for things such as:

- Observe and clear any ingress/egress obstructions.

- Birds perching atop the ionizers or on the antenna and solar panel.

- Any animals that may adversely affect the site's integrity. Such as cattle that graze through the barbed wire fencing.

- Any fast growing trees or shrubs that may soon become obstructions to the precipitation, wind, or radiation instruments. Any signs of increased vehicle traffic that may effect the measurements at the site. Any signs of high water levels that may cause or have caused flooding problems.

- Be especially observant for evidence of construction, dredging, and/or drilling whose residuals or debris may have an adverse effect on the measurements of water level or flows.

Upon arrival at the site, perform a detailed visual inspection to ensure that:

- The solar panel faces south.
- The antenna is horizontal to the ground and pointing toward the proper receiving station. The antenna mounting pole should be vertically plumb and secure in the ground.

- The ionizer points up. The fine wires atop the ionizer should all be in place, and have no damage from perching birds.

- All exposed wires and cables are secure and not able to move in the breeze. Cables should not be deteriorated from exposure.   Gently tug the Earth grounding wires to verify secure connections to the grounding rods.

- The fence is undamaged, with the wire tight and the post secure.

- There is no evidence of vandalism. If damage is detected, document the evidence with drawings, pictures, and/or notes to determine the extent of damages, and contact your supervisor.

After completing a thorough visual inspection of the site, document all adverse findings before attempting any as found measurements. All as found measurements should be performed before **any** calibration, routine service or repair maintenance is started.

The following list includes suggested service items that require attention at each site visit unless otherwise specified.

1. Verify that the well or stilling well is vertically plumb. This is to ensure that the float and/or counterweight do not scrape the well casing or stilling sides as the water level moves up and down.

2. Verify the overall integrity of the instrument shelter. Check the shelter floor for level and signs of deterioration. Check locks, hasps, and hinges and lubricate, replace, or repair as required. Check shelter venting and weather stripping to ensure resistance to insect entry.

3. Verify equipment inventory at the site. Compare site equipment identification numbers with the equipment inventory database to ensure current inventory control. Correct the equipment inventory database as required. Perform this service at 6 month intervals.

4. Verify the measurement point (MP) elevations for all liquid level parameters at the site. Check the MP by running levels from the reference marks at the site. Verify the site MP elevations six months after the establishment of the site and then at three year intervals thereafter.

5. Check the instrument shelters and sensor enclosures for insect debris and signs of corrosion. Check the integrity of the pest strips and desiccant packs. Evidence of insects may indicate damaged vent screens or weather stripping. Renew pest strips and desiccant as required but not to exceed intervals of 120 days.

6. Clean the instruments and shelters. Remove any soiling and debris.

   A. Clean the rain gauge screens, funnels, tipping buckets, and drain holes. Remove any corrosion from the tip switch terminals. Verify that the tip magnet is secure. Verify that the gauge is mounted level.

   B. Clean the solar panel with a soft and damp cloth.

C. Remove any corrosion from the battery, solar charger, and Earth grounding terminals. Clean and clear the battery box drain. After removing any corrosion, treat these terminals with a corrosion resistant material.

D. Groom the ground inside the site perimeter. Mow the grass as required. Renew the rain gauge weed mat as required. Remove insect infestations. Clear all vines or other vegetation from the fence to allow for free air circulation.

Perform the scheduled routine maintenance and calibration procedures as discussed previously in appropriate chapters within this manual. Carefully document the results of these procedures. Manual water level, dewpoint, relative humidity, and temperature measurements, along with rain gauge tip test, and wind direction and wind speed estimations are extremely important functions used in establishing data integrity. Without these tests and manual measurements, accurate data verification is impossible.

Upon completion of the previous suggested service items and before leaving the site, perform the following site departure actions.

1. Ensure that all active devices are enabled.

2. Verify proper completion of any site service documentation and/or Q. A. Logs.

3. Disconnect all instruments used for this field service visit. Replace all serial port covers.

4. Ensure that all instrument shelters and sensor enclosures are secure. Doors closed, locks locked, etc.

5. Verify that station equipment inventory is up to date and correct.

6. Inspect and confirm that any instrument or shelter ventilating fans are operating.

7. Perform a last general site inspection. Collect debris, and tools, parts, or materials that could be left behind.

8. Ensure fence gate is locked and that the site is generally cosmetically adequate.

1.3 Site Installation Guidelines

The type of installation and equipment needed at a site is usually dictated by the physical setting, the intended use of the documented record, accessibility of the station, and related operational and maintenance expenses.

Selected instruments will have their own siting and exposure criteria depending upon the intended use of the acquired data.

Stage is often not the primary reason for measuring water levels. The main purpose is usually to establish a relationship between the stage, stage-slope, and discharge. This requires that the stage sensor be strategically located (referenced to the control point) such that the data will be substantially consistent and representative of the discharge at the site.

The monitoring elevations for wind, temperature, and atmospheric moisture are determined by the scientific, engineering, or modeling purposes. Examples as follows:

- Evaporation requires wind at one foot above the evaporation pan with ambient temperature and relative humidity or dewpoint at two meters.

- Evapotranspiration (ET) requires wind, temperature, dewpoint, and solar radiation at an elevation of two meters. Depending upon the method of ET measurement, these parameters, except for solar radiation, may require monitoring at higher elevations such as 10, 50, and 100 meters above grade.

- Environmental impact background studies usually require the same sensor elevations as ET with and additional level of 200 meters.

1.3.1 Instrument Enclosures and Data Collection Shelters

The primary purpose of the instrument enclosure or data collection shelter is to provide protection and security for the sensors, instruments, and other related equipment at the station. The design should be such to facilitate ease of maintenance, inspection, and repair, provide security for the field equipment and be aesthetically acceptable in and to the surrounding environment.
These shelters and enclosures should be hardy enough to withstand the environmental elements yet gentle enough to be serviced by one person. They must be clean, well ventilated, free of rodents and insects, and well maintained. They should be protected from the elements with paint and/or water sealing such that will greatly increase their useful life.

These shelters and enclosures should have a high resistance to thermal effect. The sun can cause temperatures inside these shelters to exceed 150°F. This can certainly effect sensor accuracy. Thermal effects can be reduced drastically by painting the shelters exterior with a highly reflective **white** paint. Facing the data logging instruments toward the north and shielding from the sun will also help reduce the thermal effects.

1.3.2 Materials Standards

Tangible materials used for fasteners should be made of brass, stainless steel, or galvanized steel. Aluminum fasteners may be used where the weaker tensile strength of aluminum is adequate. Underwater installations should always use bronze or 316/318 series stainless steel.

Exposed wood must be pressure treated to a value of not less than 25 lbs. and be factory labeled for exterior use.

The best material for instrument shelters and sensor enclosures is aluminum painted with white reflective paint. This material is highly conductive, both electrically and thermally, and provides an effective Faraday shield lending resistance against damage caused by nearby electrical surges.

Electrical conductors should be made of very low resistance materials such as copper and coated with silver or an alloy of tin/lead. Small wires must always be made with stranded conductors.

Exterior coverings of any wires or cables which extend outside the instrument shelter or sensor enclosure must be of sunlight and oil resistant material. These coverings should have nomenclatures such as THN or THHN or equivalent.

1.3.2.1 Cabling

Cabling is one of the more critical elements of a station installation.

Conductor sizes must be carefully selected to properly accommodate the amount of current required in the circuit without incurring any appreciable voltage drop. The longer the wire, the higher the resistance, therefore a larger conductor is required to accommodate a specified current.
Signal cables that extend outside the instrument shelter must be of twisted wire construction and enclosed in a metal shield. This is to aid in resisting any inductive coupling of nearby electrical power surges.

In most cases, cable shields should be terminated at the surge suppressor. This allows for a shorter and quicker path to ground for and inducted power surges.

Terminate all cables and wires with careful consideration of corrosion. In Florida, corrosion is a major cause of intermittent electrical connections. Conductors must be cleaned of all insulation and foreign materials before any solder, screw, or crimp connections are performed.

1.3.3 Power Requirements

Each site will have its own energy requirement. This requirement must be established before any power source can be determined. Most remote stations are powered by batteries. If the power requirement for the station is 3 amp days (.125 amps per hour) and the desired service interval is 25 days, the a 85 amp hour battery is sufficient (85/3 = 28 days. If a solar charger is used to replenish the battery then longer service intervals of up to 60 days can be accommodated. A planned power capacity of 85 amp hours plus a solar charger is probably adequate since the longest totally cloud covered days in Florida is during a hurricane and they don't usually last for 28 days.

1.3.3.1 Batteries

Establishing the battery size required by a station is discussed in the preceding Power Requirements section. A variety of batteries have proven to perform in an adequate fashion. A well made deep cycle battery with a paste electrolyte will perform exceptionally well for a long period of time (years).

1.3.3.2 Photovoltaic Arrays

The solar panel is made up of small photovoltaic cells that convert solar radiation (sunlight) into direct current (DC) electricity through a process of photoelectric effect. Photoelectric effect is the emission of electrons by substances when light falls on their surfaces.

A photovoltaic cell is a specially constructed diode, usually constructed of silicon crystal. When light strikes the exposed active surface, it dislodges electrons from their sites in the crystal. Some of the electrons have enough energy to cross the diode junction, and having done so, cannot return to positions on the other side without passing through an external circuit. Upon completion of this external a direct electrical current will flow from one side of the silicon crystal to the other side of the crystal.

Since the current generated from these devices is very small and the voltage is very low, several must be connected in series/parallel arrays if useful amounts of solar energy are to be converted to DC current. Each cell produces an output power proportional to solar intensity. These cells are connected in series and terminated into external positive and negative posts.

Devices of this kind are only about 10 to 15 percent efficient and their output current and voltage will vary greatly with the amount of incident radiation received.

Array Size Selection

Before selecting a photovoltaic array the station power requirements must first be established. See section 1.3.3. After establishing the amount of power needed by the station, the electrical size of the array can be selected. If the power requirement for the station is 3 amp days at 12 volts, the array should output between .75 and 1.5 amperes at 14 to 18 volts. This will allow the array and charge controller to maintain the battery at full charge yet not overcharged to the point of excess electrolyte evaporation.

Array Installation

The array should be installed such that allows full exposure to the sun and at a location near the connected battery. The array should be securely fixed at an elevation sufficient as to prevent access by local animals. The panel should be mounted at an elevation of 15-30 degrees and facing South.

Array Maintenance

The solar panel has no moving parts therefore requires only minimal maintenance. of the panel becomes dirty use a non-abrasive cloth or sponge to clean the clear surface. A mild non-abrasive detergent can be used on persistent soiling.

Conduct a visual inspection of all modules for signs of delamination, discoloration, cracked or broken cells, dirt, and insect or bird residue.

Inspect for excessive vegetation growth around the array that may shade or otherwise effect the panel.
Ensure that the modules are securely mounted.

Inspect the array frame and attachment hardware for signs of corrosion. Remove any corrosion as required.

Ensure that all wires and cables are securely attached.

Inspect the junction box for cracks and moisture and ensure that it is properly sealed.

Ensure that the electrical connections are securely attached. If there is any visible corrosion on the connections, disconnect the wires or cables, remove the corrosion, and securely reattach.

If it is suspected that the solar panel is not operating correctly first check the cable for proper connections. If connections are found loose, tighten in place and see if the problem has been corrected. Examine the panel for physical damage that could effect the operation, such as signs of a lightning strike or a broken moisture seal.

Test the panel with a current meter. First disconnect the positive lead of the solar panel from the battery. Set a volt ohm meter to the 10 ampere scale. Connect the positive lead of the VOM (volt ohm meter) to the positive lead of the solar panel. Connect the negative lead of the VOM to the positive connection of the battery. The VOM will now indicate the current going from the solar panel to the battery. This test should be performed on a bright sunny day to produce maximum current flow. If the battery is moderately discharged and the test is performed between noon and 2:00 p.m., the VOM current reading should indicate approximately 90 percent of the solar panel output rating.

Note: The solar panel has a blocking diode installed at the factory to prevent damage caused by reversed lead connection. If the VOM is connected backward for the above test, it will indicate a negative value but will cause no damage.

1.3.4 Instrument Grounding and Lighting Protection

It is estimated that at any given moment there are over 1,800 active electrical storms throughout the world, producing 100 lightning flashes per second. Per day, this is in excess of 8 million flashes, 20 percent of which are cloud-to-ground. Millions of dollars in damage are caused by lightning each year.

Communications systems, computers, telephones, and electronic data collection equipment and devices, require the best lightning protection in order to remain reliable. Attaining such a level of protection requires the proper use of sound engineering practices and design.

The traditional lightning rod (air terminal) has been around for over 150 years. So has lightning damage from lightning's secondary effects, and ground surges. Lightning rods were effective in controlling the physical damage of a strike, but did little to prevent damages caused by the other effects of lightning.

Static dissipation is the reduction of ground charge associated with an electrical storm at a rate that is sufficient to maintain the level of that charge below the level at which a lightning strike can occur. Natural dissipation, or the ionization produced by trees, grass, towers, fences, or other structures can dissipate 95 percent of the total energy generated by a storm, without the formation of lightning. This natural phenomenon know to scientists for centuries as the point discharge principle, is known to the layman as "Saint Elmo's Fire". The energy dissipation concept of the point discharge principle contends that a sharp point in a strong electrostatic field will leak off electrons by ionizing the adjacent air molecules, if the point's potential is raised above 10,000 volts.

A multi-point electrostatic dissipating air terminal will provide the best method to control both effects. It will act like a traditional air terminal (lightning rod), and will also work to dissipate the electrical charge between the clouds and the ground, thus reducing the probability of a lightning strike. This static dissipation greatly reduces the probability of damages resulting from secondary, electromagnetic, and/or ground surge effects.

The air terminal provides an umbrella-shaped protection cone of 45°, and should be installed at an elevation high enough such that the protection angle of 45° from the tip of the terminal to the ground encompasses as many of the sensors and equipment as possible.

Equipment and sensor grounding is critical to instrument longevity. The air terminal or static dissipator should be isolated from the signal ground until these conductors are below ground level. This will eliminate the secondary effect and greatly reduce the electromagnetic effect of electrostatic charges.

There is no sure method of preventing a lightning strike. The proper use of sound engineering practices will greatly reduce the probability of lightning damage and will ensure minimum damage is such a strike occurs.

See Figure 1.1 for typical grounding and lightning protection.

Figure 1.1 Typical Site Grounding Diagram

Meteorological Monitoring

2.0 Precipitation Measurement

2.1 Introduction

2.1.1 Theory

Precipitation is defined as any form of water particle, liquid or solid, that falls from the atmosphere and **reaches** the ground. It is not fog, dew, rime, or frost because it must fall. It is not cloud or fog because it must reach the ground.

Precipitation includes the following forms:

Rain - Precipitation of liquid water as particles larger than 0.5 mm in diameter or as smaller, widely separated drops.

Drizzle - Fairly uniform fine droplets which are close together. Drizzle is fine enough to float on the air currents, although, unlike fog, it will fall to the ground. Drizzle means that the drops are too small and fall too slow to disturb a stillwater pool.

Freezing Rain or Drizzle - Rain or Drizzle that freezes upon impact with objects in flight or on the ground.

Hail - Precipitation in the form of lumps or balls of ice. Hail is always produced by convective clouds and is usually associated with thunderstorms where surface temperatures are above freezing.

Snow - Precipitation composed of white ice crystals of hexagon form and/or amassed into snowflakes.

The intensity of precipitation is described as a rate of rainfall. The following terms define the intensity:

Very Light - Scattered drops or flakes that do not completely wet the surface.

Light - Trace to 2.54 mm/hour; max 0.25 mm in 6 min.

Moderate - 2.8 to 7.6 mm/hour; max 0.76 mm in 6 min.

Heavy - More than 7.6 mm/hour; max 0.76 mm in 6 min.

The amount of precipitation is expressed as the vertical depth of water that would accumulate on the earth's surface if all precipitation including snow and ice were in the form of water. The purpose of this measurement is to obtain a sample that is representative of the precipitation over the observed area.

2.1.2 Instrument Siting and Exposure

In general, precipitation gauges should be distributed uniformly and should be consistent with the practical needs of data, and the locations of observers and other data collection sites.

In a situation of ideal gauge exposure, the rain catch would represent the precipitation falling at that point as well as the surrounding area. This ideal exposure is very difficult to attain because of the effect of the wind. Therefore use considerable care in selecting each rainfall site. Locate precipitation gauges on level ground at a distance from any obstruction (including instrument shelters) of at least two, and preferably four, times the height of that obstruction **above the top of the gauge.** The receiver (outer funnel) of all gauges must be exposed horizontal (level).

Objects that individually, or in groups, reduce the wind speed, turbulence, and eddy currents in the vicinity of the gauge may provide for a more accurate catch. The best exposures are often found in groves of trees such as orchards or pine forest where the clearing for the gauge meets the preferable height/distance requirement.

2.1.3 Measurement Standards

The measurement accuracy of precipitation is dependent upon the specific purpose of the measurement. The various commissions of the World Meteorological Organization have established measurement accuracy requirements for selected meteorological parameters. For hydrometeorological use, accuracy standards are for measurement of total rainfall between two observations to within ± 1 mm, and at intensities of ± 1 mm/hour. The Water Management Districts of the State of Florida use instruments that measure rainfall totals to the nearest one-hundredth of an inch and the nearest one millimeter. Sampling frequency is project-dependent, and may range from 5-minute to one-day totals. Daily rainfall accumulation is the normal measurement used by the WMD's.

To achieve proper measurement accuracy, instruments should be calibrated periodically against National standards. The instrument should be calibrated at the time it is installed at the station and should be calibrated at succeeding six-month intervals.

2.2 Instrumentation--Tipping Bucket Rain Gauges

2.2.1 Principle of Operation

The tipping-bucket type rainfall gauge is used by the Districts exclusively for real and/or near time rainfall measurements.

This type of gauge consists of a light-weight container or bucket divided into two equal compartments (buckets) and balanced atop a horizontal axis. Two stops, one under each end of the container, limit the containers movement. The rainfall which is caught by the receiver runs through the outer funnel into one of the two compartments until the bucket becomes unbalanced and tips to its other position. This places the second compartment in position to receive rain from the funnel and at the same time drains the collected water from the first compartment.

This tipping of the bucket actuates a contact closure (switch) and produces a recordable event. The time between tips represents the rate of rainfall depending upon the capacity of each compartment.

2.2.2 Maintenance

Perform routine maintenance on rain gauges at an interval of at most every two months. Clean the outer funnel, insect screens, and drains, wiping them free of all debris and obstructions. Wipe the tipping bucket and inner funnel clean and clear all insect materials. Be especially observant for spider webbing on the side of the tipping bucket.

Move the bucket from side to side to ensure that the pivot pin has enough play for it not to bind, yet not fall out.

Perform the following field calibration check at least annually: First pour water through the outer funnel until the tipping-bucket has tipped two times. Perform this calibration check only while the gauge is wet. Using the Qualimetrics, Inc., Model 10603 gauge calibrator, pour the specified calibration amount of water into the rain gauge funnel (see bottom of calibration form, Figure 2.1). Be sure the stream from the calibrator does not flow directly through the funnel hole and into the tipping bucket. The calibration amount of water should generate 24 tips of the bucket within 12 minutes, although 23.5 and 24.5 tips are acceptable. Perform this test three times and enter the results in the calibration form (Figure 2.1). If the three tests are consistently in error by more than 0.5 tip, then a calibration adjustment is required (see calibration procedures section under individual instrument.

Calibration volume is determined by the following equation:

$$V = ACT + W$$

where:

V = calibration volume, in milliliters

A = area of the collecting orifice, in square inches

C = conversion factor, 0.1639 milliliters/0.01 cubic inches

T = number of tips (24)

W = volume lost to wicking and wetting (2 ml)

TIPPING BUCKET RAIN GAUGE CALIBRATION FORM

Site Name:_________________ Station Name:___________________
Date/Time:_______/________ Technician:_____________________

Gauge Manufacturer:____________ Model:______ SN:_______Property #:_______

Gauge Catch Opening Size:_________ Calibration Volume:___________

	As Found	As Left
Run 1		
	Time Start_____________	Time Start_______________
	Time Stop _____________	Time Stop _______________
	Tip Count _____________	Tip Count _______________
Run 2		
	Time Start_____________	Time Start_______________
	Time Stop _____________	Time Stop _______________
	Tip Count _____________	Tip Count _______________
Run 3		
	Time Start_____________	Time Start_______________
	Time Stop _____________	Time Stop _______________
	Tip Count _____________	Tip Count _______________

Comments:____

____

Remember:
Rainwise 8.688 inch opening: 0.01 inch = 230 ml = 24 tips
Standard 8 inch opening: 0.01 inch = 200 ml = 24 tips

Figure 2.1 Raingauge Calibration Form

2.2.3 Sensors Used

2.2.3.1 Sierra-Misco Model 2500 Tipping Bucket Rain Gauge

The Sierra-Misco Model 2500 Rain Gauge is a tipping-bucket type gauge with an 8-inch orifice. The gauge consists of an outer funnel with bug screens, an inner funnel, a two-compartment tipping bucket with a magnet, and a magnetic proximity switch, in a metal enclosure.

The precipitation enters the collecting orifice, through the bug screens, through the outer and inner funnels, and into one of the compartments of the calibrated tipping bucket assembly. When the calibrated amount of rain enters one bucket compartment, the bucket tips. As the bucket tips, its attached magnet passes the proximity switch causing the switch to momentarily close creating a recordable signal.

2.2.3.1.1 Manufacturer's Specifications

Orifice Diameter:	8 inch Standard
Mounting:	Four Mounting Pads, 0.25 inch diameter bolt holes on 8.5 inch diameter bolt circle.
Calibration:	0.01 inch Standard
Accuracy:	±3% (rates of 1 to 6 inches per hour)
Switch Closure:	0.01 second magnetically operated reed switch

2.2.3.1.2 Installation Procedures

The Model 2500 is shipped complete and no additional assembly is required. The gauge must be mounted level on a platform. Four mounting brackets are provided for mounting. The holes in the mounting brackets are sized for 1/4 inch mounting hardware. For accurate measurements of precipitation, the orifice of the gauge must be in a horizontal plane. Check this by laying a carpenter's level across the open top of the gauge in two directions at 90 degrees apart. If the top is not level in both directions the condition must be corrected. When the gauge is properly mounted remove the outer enclosure. The tipping bucket assembly has been fixed at the factory for shipping. This fix could be in the form of taping, a rubber band, or foam under each bucket. This must be removed before attempting any performance testing or setting the unit into service.

Check the tipping-bucket assembly adjustment by moving the bucket from side to side to ensure that the pivot pin has enough play for it not to bind, yet not fall out.

Check the proximity switch by applying an ohm meter across the two electrical terminals and tip the bucket. With the bucket at rest on one of the calibration screws the meter should read infinite resistance. Slowly move the bucket, simulating a tipping motion until contact closure is indicated by the meter. Note the angle of the bucket at this point. Also check that the resistance of the closed switch is less than 1 ohm. Continue the bucket tip while observing the meter. When the meter shows switch opening, note the angle of the bucket again. The angle of switch closing and opening should be approximately equal on each side of the switch.

2.2.3.1.3 Calibration Procedures

For gauges with 0.01" resolution with 8" orifice:

Two-hundred (200) milliliters of calibration water represents 24 tips of the bucket when calibrating this instrument. If the calibration check is outside the range of 23.5 to 24.5 tips, then calibration adjustment is required. Use the following procedures for field calibration adjustment:

Verify calibration volume by equation $V = ACT + W$

where:

V = calibration volume, in milliliters

A = area of the collecting orifice, in square inches

C = conversion factor, 0.1639 milliliters/0.01 cubic inches

T = number of tips (24)

W = volume lost to wicking and wetting (2 ml)

Release the lock nuts on the calibration screws. The tipping-bucket rests on these screws. If the number of tips during the calibration check was less than 23.5, the calibration screws need to be adjusted upward so it will take less water to tip the bucket. If the number of tips during the calibration check is more than 24.5, the screws need adjusting downward so it will take more water to tip the bucket. Perform the field calibration check after each screw adjustment. Do not wipe water from the tipping buckets between tests. Once the correct heights of the calibration screws have been determined, carefully tighten the lock nuts without changing the position of the calibration screws. After securing the lock nuts, recheck the gauge calibration by performing the following **field calibration check**.

First, pour water through the outer funnel until the tipping-bucket has tipped two times. Perform this calibration check only while the gauge is wet. Using the Qualimetrics Inc. Model 10603 gauge calibrator, pour 200 milliliters of water into the rain gauge funnel. Be sure the stream from the calibrator does not flow directly through the funnel hole and into the tipping bucket. Two-hundred (200) milliliters should generate 24 tips of the bucket within 12 minutes although 23.5 to 24.5 tips is acceptable. Perform this test three times and enter the results in the calibration form. If the three tests are consistently in error by more than 0.5 tips then the calibration adjustment in 2.2.3.1.3 is required.

2.2.3.1.4 Maintenance Procedures

Perform routine maintenance on rain gauges every two months:

1. Clean the outer funnel, insect screens, and drains wiping them free of all of all debris and obstruction. Wipe the tipping bucket and inner funnel clean and clear all insect materials. Be especially observant of spider webbing on the side of the tipping bucket.

2. Move the bucket from side to side to ensure that the pivot pin has enough play for it not to bind yet not fall out.

Perform the field calibration check annually.

2.2.3.2 Sierra-Misco Model 2501 Tipping Bucket Rain Gauge

The Sierra-Misco Model 2501 Rain Gauge is a tipping-bucket type gauge with an 8-inch orifice. The gauge consists of an outer funnel with bug screens, a two-compartment tipping bucket with a magnet, and a magnetic proximity switch, in a metal enclosure.

The precipitation enters the collecting orifice, through the bug screens, through the outer funnel, and into one of the compartments of the calibrated tipping bucket assembly. When the calibrated amount of rain enters one bucket compartment, the bucket tips. As the bucket tips, its attached magnet passes the proximity switch causing the switch to momentarily close creating a recordable signal.

2.2.3.2.1 Manufacturer's Specifications

Orifice Diameter:	8-inch Standard
Mounting:	Three Mounting Brackets, 0.25-inch diameter bolt holes on 8.5-inch diameter bolt circle.
Calibration:	0.01 inch Standard
Accuracy:	±5% (rates of 1 to 6 inches per hour)

Switch Closure: 0.01 second magnetically operated reed switch

2.2.3.2.2 Installation Procedures

The Model 2501 is shipped complete and no additional assembly is required. The gauge must be mounted level on a platform. Three mounting brackets are provided on the gauge. The holes in the mounting bracket are sized for 1/4 inch mounting hardware. For accurate measurements of precipitation, the orifice of the gauge must be in a horizontal plane. Check this by laying a carpenter's level across the open top of the gauge in two directions at 90 degrees apart. If the top is not level in both directions the condition must be corrected. When the gauge is properly mounted remove the outer enclosure. The tipping bucket assembly has been fixed for shipping at the factory. This fixing could be in the form of taping, a rubber band, or foam under or around each bucket. This must be removed before attempting any performance testing.

Check the tipping-bucket assembly adjustment by moving the bucket from side to side to ensure that the pivot pin has enough play for it not to bind, yet not to fall out.

Check the proximity switch by applying an ohm meter across the two electrical terminals and tip the bucket. With the bucket at rest on one of the calibration screws the meter should read infinite resistance. Slowly move the bucket simulating a tipping motion until contact closure is indicated by the meter. Note the angle of the bucket at this point. Also check that the resistance of the closed switch is less than 1 ohm. Continue the bucket tip while observing the meter. When the meter shows switch opening, note the angle of the bucket again. The angle of switch closing and opening should be equal on each side of the switch.

2.2.3.2.3 Calibration Procedures

For units with 0.01" standard resolution, two hundred (200) milliliters of calibration water represents 24 tips of the bucket when calibrating this instrument. If the calibration check is outside the range of 23.5 to 24.5 tips, then calibration adjustment is required. Use the following procedure for field calibration adjustments:

Verify calibration volume by equation $V = ACT + W$

where:

V = calibration volume, in milliliters

A = area of the collecting orifice, in square inches

C = conversion factor, 0.1639 milliliters/0.01 cubic inches

T = number of tips (24)

W = volume lost to wicking and wetting (2 ml)

Release the lock nuts on the calibration screws. The tipping-bucket rests on these screws. If the number of tips during the calibration check was less than 23.5, the calibration screws need to be adjusted upward so it will take less water to tip the bucket. If the number of tips during the calibration check is more than 24.5, the screws need adjusting downward so it will take more water to tip the bucket. Perform the field calibration check after each screw adjustment. Do not wipe water from the tipping buckets between tests. Once the correct heights of the calibration screws have been determined, carefully tighten the lock nuts without changing the position of the calibration screws. after securing the lock nuts, recheck the gauge calibration by performing the field calibration check again to assure proper calibration is maintained.

1. First, pour water through the outer funnel until the tipping-bucket has tipped two times. This wets the funnel and the tipping bucket. Perform this calibration check only while the gauge is wet. Using the Qualimetrics Inc. Model 10603 gauge calibrator pour 200 milliliters of water into the rain gauge funnel. Be sure the stream from the calibrator does not flow directly through the funnel hole and into the tipping bucket. 200 milliliters should generate 24 tips of the bucket within 12 minutes, although 23.5 to 24.5 tips is acceptable.

2. Perform this test three times and enter the results on the calibration form. If the three tests are consistently in error by more than 0.5 tips then the calibration adjustment in 2.2.3.2.3 is required.

2.2.3.2.4 Maintenance Procedures

Perform routine maintenance on rain gauges every two months.

1. Clean the outer funnel, insects screens, and drains by wiping them free of all debris and obstruction. Wipe the tipping bucket and inner funnel clean and clear of all foreign materials. Be especially observant of spider webbing on the side of the tipping bucket.

2. Move the bucket from side to side to ensure that the pivot pin has enough play for it not to bind yet not fall out.

Perform the field calibration check annually as described above.

2.2.3.3 Weathermeasure Model P-501 Tipping Bucket Rain Gauge

The Weathermeasure Model P-501 Rain Gauge is a tipping-bucket type gauge with an 8-inch orifice. The gauge consists of an outer funnel with bug screens, an inner funnel, a two-compartment tipping bucket with a mercury switch attached, in a metal enclosure.

The precipitation enters the collecting orifice, through the bug screens, through the outer and inner funnels, and into one of the compartments of the calibrated tipping bucket assembly. When the calibrated amount of rain enters each bucket compartment, the bucket tips. As the bucket tips, its attached mercury switch momentarily closes creating a recordable signal.

2.2.3.3.1 Manufacturer's Specifications

Orifice Diameter:	8-inch Standard
Mounting:	Three Mounting Pads, 0.25 inch diameter bolt holes
Calibration:	0.01 inch Standard
Accuracy:	± 0.5% at a rate of 0.5 inch per hour
Switch Closure	0.01 second gravity operated mercury switch

2.2.3.3.2 Installation Procedures

The Model P-501 is shipped complete and no additional assembly is required. The gauge must be mounted level on a platform. Three mounting brackets are provided on the gauge. The holes in the mounting bracket are sized for 1/4 inch mounting hardware. For accurate measurements of precipitation, the orifice of the gauge must be in a horizontal plane. Check this by laying a carpenter's level across the open top of the gauge in two directions at 90 degrees apart. If the top is not level in both directions the condition must be corrected. When the gauge is properly mounted remove the cover. The tipping bucket assembly has been fixed for shipping at the factory. This fixing could be in the form of taping, a rubber band, or foam under and/or around each bucket. This must be removed before attempting any performance testing or setting the unit into service.

Check the tipping-bucket assembly adjustment by moving the bucket from side to side to ensure that the pivot pin has enough play for it not to bind, yet not to fall out.

Check the mercury switch by applying an ohm meter across the two electrical terminals and tip the bucket. With the bucket at rest on one of the calibration screws the meter should read infinite resistance. Slowly move the bucket simulating a tipping motion until contact closure is indicated by the meter. Note the angle of the bucket at this point. Also check that the resistance of the closed switch is less than 1 ohm. Continue the bucket tip while observing the meter. When the meter shows switch opening, note the angle of the bucket again. The angle of switch closing and opening should be equal on each side of the switch.

2.2.3.3.3 Calibration Procedures

For gauges with 0.01" standard resolution, two hundred (200) milliliters of calibration water represents 24 tips of the bucket when calibrating this instrument. If the calibration check is outside the range of 23.5 to 24.5 tips, then calibration adjustment is required. Use the following procedure for field calibration adjustments:

Verify calibration volume by equation $V = ACT + W$

where:

V = calibration volume, in milliliters

A = area of the collecting orifice, in square inches

C = conversion factor, 0.1639 milliliters/0.01 cubic inches

T = number of tips (24)

W = volume lost to wicking and wetting (2 ml)

Release the lock nuts on the calibration screws. The tipping-bucket rests on these screws. If the number of tips during the calibration check was less than 23.5, the calibration screws need to be adjusted upward so it will take less water to tip the bucket. If the number of tips during the calibration check is more than 24.5, the screws need adjusting downward so it will take more water to tip the bucket. Perform the field calibration check after each screw adjustment. Do not wipe water from the tipping buckets between test. Once the correct heights of the calibration screws have been determined, carefully tighten the lock nuts without changing the position of the calibration screws. After securing the lock nuts, recheck the gauge calibration by performing the field calibration check again to assure that calibration is maintained.

First, pour water through the outer funnel until the tipping-bucket has tipped two times. Perform this calibration check only while the gauge is wet. Using the Qualimetrics Inc. Model 10603 gauge calibrator, pour 200 milliliters of water into the rain gauge funnel. Be sure the stream from the calibrator does not flow directly through the funnel hole and into the tipping bucket. Two-hundred (200) milliliters should generate 24 tips of the bucket within 12 minutes although 23.5 to 24.5 tips is acceptable. Verify calibration volume in Section 2.2.2.

Perform this test three times and enter the results in the calibration form. If the three tests are consistently in error by more than 0.5 tips then the calibration adjustment in Section 2.2.3.3.3 is required.

2.2.3.3.4 Maintenance Procedures

Perform routine maintenance on rain gauges every two months:

> Clean the outer funnel, insects screens, and drains wiping them free of all debris and obstruction. Wipe the tipping bucket and inner funnel clean and clear all foreign materials. Be especially observant of spider webbing on the side of the tipping bucket.
>
> Move the bucket from side to side to ensure that the pivot pin has enough play for it not to bind, yet not fall out.

Perform the field calibration check annually.

2.2.3.4 Handar Model 444A Tipping Bucket Rain Gauge

The Handar Model 444A tipping bucket rain gauge is composed of a funnel and tipping mechanism. Rain is collected through the funnel, then directed to a tipping mechanism adjusted to tip and dump when a calibrated amount of water is collected. With each tip of the bucket, a magnet passes over a magnetic reed switch which causes a momentary contact closure. The contact closure is counted by the circuitry in a data collection platform. The tip also causes a second bucket to come into position below the funnel, ready to be filled and repeat the cycle.

2.2.3.4.1 Manufacturer's Specifications

Funnel Diameter:	8-inch Standard
Mounting:	Three brackets with 0.44-inch diameter holes
Event resolution:	0.01 inch Standard
Accuracy:	± 2%, when rainfall rate is less than 1 inch per hour ± 3%, when rainfall rate is more than 1 inch per hour
Contact Closure:	Mercury-wetted reed, activated by magnet arm
Output:	1 pulse per 0.01 inch of rain

2.2.3.4.2 Installation Procedures

The Model 444A is shipped complete and no additional assembly is required. The gauge must be mounted level on a platform. Three mounting brackets are provided on the gauge assembly. For accurate measurements of precipitation, the orifice of the gauge must be level in a horizontal plane. To assist in installation, a bull's eye level is mounted on the base of the rain gauge assembly.

The tipping bucket rain gauge has been fixed for shipping at the factory. This fixing in the form of tapping, rubber bands, or foam should be removed before attempting any performance testing.

Check the tipping bucket assembly adjustment by moving the bucket from side to side to ensure that the pivot pin has enough play for it not to bind, yet not fall out.

Check the proximity switch by applying an ohm meter across the two electrical terminals and tipping the bucket. With the bucket at rest on one of the calibration screws, the meter should read infinite resistance. Slowly move the bucket simulating a tipping motion until contact closure is indicated by the ohm meter. Note the angle of the bucket at this position. Also check that the resistance of the closed switch is less than 1 ohm. Continue moving the bucket while observing the meter. When the meter shows switch opening, note the angle of the bucket again. The angles when switch closing and opening should be equal on each side of the switch.

2.2.3.4.3 Calibration Procedures

Please refer to Sections 2.2.3.1.3 and 2.2.3.3.3 for calibration procedures. Verify calibration volume in Section 2.2.2.

2.2.3.4.4 Maintenance Procedures

Perform routine maintenance on rain gauges dependent upon local experiences (weekly, monthly, or at least every two months). Clean the outer funnel, obstruction screen, and drains by clearing them free of all debris. Wipe the tipping bucket and inner funnel clean and clear all insect materials. Be especially observant for the spider webbing inside the tipping bucket.

Move the bucket from side to side to ensure that the pivot pin has enough play for it not to bind, yet not fall out.

Perform the field calibration check annually.

2.3 Instrumentation--Weighing Bucket Rain Gauges

2.3.1 Principle of Operation

The Universal-type weighing bucket rain gauges are designed to record the rate of rainfall as well as total accumulation. The gauge consists of a receiving annulus eight inches in diameter through which rainfall is funneled into a collecting bucket mounted onto a weighing mechanism. The weight of the water that falls into the bucket is recorded on a clock driven chart, and is calibrated to inches of precipitation. The clock cylinders are furnished with gears that rotate the cylinder and the attached chart at a constant rate, which may range from one revolution every six hours up to one revolution per eight days. These gauges can measure rainfall accumulations of up to 12 inches.

2.3.2 Maintenance

The Universal-type weighing bucket rain gauge requires occasional calibration to maintain accuracy of operation. Clock failure is the single-most common reason for failure. Care should be given that the clock is not overwound. In addition, the weighing mechanism should be tested and adjusted at least every six-months

2.3.3 Sensors Used

2.3.3.1 Belfort Model 5-780 Weighing Bucket Rain Gauge

The Catalog Number 5-780 Universal Recording Rain Gauges are weighing-type gauges and are designed to record the rate of fall as well as the depth of precipitation. The weighing mechanism converts the weight of the rainfall caught by an 8-inch circular opening at the top of the gauge into the curvilinear movement of a recording pen which makes an inked trace on a rectangular paper chart. The chart, graduated in inches or millimeters of rainfall, is wrapped around a vertical cylinder which is rotated either by an 8-day spring-powered, or a long-term battery-powered, chart drive. In some gauges of this series, the record capacity of the gauge is reached in a single traverse of the pen (6 inches of rainfall) across the chart; in others, it is reached after a double traverse of the pen (12 inches of rainfall).

The rainfall falling through the 8-inch diameter collector is caught in a bucket resting on a platform mounted to the vertical linkage of the pen arm. Clock cylinders may be furnished with gears that rotate the cylinder from one revolution every 24 hours to one revolution every 30 days. Most clocks operate on a 4-day or 8-day rotation.

The Universal-type weighing gauge requires occasional calibration and other adjustments to maintain accuracy of operation. Such checks and adjustments will be made by inspectors with suitable equipment. Clock failure, or any trouble that cannot be corrected as outlined in the following paragraphs, should be reported immediately to the supervising official.

Zero Adjustments

All gauges are equipped with both coarse and fine zero adjustments with which the pen may be set on the zero-line of the chart. this setting must always be made with an empty catch bucket, or bucket-equivalent calibration weight, on the weighing mechanism. In making continued zero adjustments, care should be taken to make use of both adjustments so as to keep the bar of the fine adjustment reasonably parallel to the top of the mechanism frame.

2.3.3.1.1 Manufacturer's Specifications

Accuracy:	1/3 of 1% F.S. for single-traverse gauges, (-40 to +125 F.)
	½ of 1% F.S. for dual-traverse gauges, (-40 to +120 F.)
Sensitivity:	0.01 inch of precipitation.
Collector Diameter:	8 inch
Chart Record:	6 inches wide x 11.5 inches long
Chart Periods:	6, 12, 24, 48, 96, 168, and 192 hours per revolution for 8-day, spring-powered chart drives; any of the preceding periods and 861 hours/rev. for 3-volt battery-powered chart drives.
Chart Timing Accuracy:	within 14 minutes/week
Finish:	aluminum lacquer
Gauge Weight:	25 lbs., empty
Federal Specifications:	The Cat. No. 5-780 Series Universal Recording Rain Gauges are built to National Weather Service Specifications #450.2201 and 450.2203.
Ranges:	0-6 inch ST 4.8 inch DT 12 inch DT 300mm DT 20"DT 500mm DT Cat. No. No Dash 5-780 -6 04.8 No. -300MM -20 -500MM

2.3.3.1.2 Installation Procedures

Unpacking. Unpack the gauge carefully. The chart cylinder has been removed from the chart drive and stowed in the catch bucket along with the recording ink and damping fluid. Rotate the collector sufficiently to disengage the bayonet lock, and lift the collector up and of the gauge housing, exposing the collector bucket. The exposure of a rain gauge is of primary importance to the accuracy of precipitation measurements.

A sturdy wooden, or concrete foundation should be prepared for mounting the gauge at the required height above ground level. It is essential that the edge of the collector opening be horizontal as determined by a carpenter's level. The gauge design is such that this condition will be satisfied if provision is made to ensure that the surface to which the gauge is mounted is horizontal, whether it be the foundation or the accessory support base. The support base can be bolted to either type of foundation or embedded in the concrete foundation.

1. Remove the collector (Figure 2.2, #1) by rotating it sufficiently clockwise to disengage the bayonet lock and pulling it up and off of the gauge housing. Use extreme care not to distort the area of the collector opening.

2. Remove the catch bucket. The chart cylinder, recording ink, and damping fluid have been packed and shipped in the bucket.

3. Remove the screw, washer, and bucket platform (Figure 2.3, items 19, 18, and 17).

4. Remove five screws and washers, and remove gauge housing from the base (Figure 2.2, items 3, 2, and 9). Note the location of the sliding access door relative to the chart drive and pen arm.

5. Three 3/8-inch diameter holes, 120° apart on a 10.75 inch diameter circle, are provided in the mechanism base for mounting it to the support base or foundation. Exercise extreme care in mounting the mechanism base: the machined gauge housing shoulder must be horizontal, and the bolting-up must not distort the base. Hardware for mounting the mechanism base is not supplied with the gauge, however, hardware is supplied with the support base for mounting it to the mechanism base. Additionally, hardware is supplied with the support base for mounting it to the foundation, or to assist in embedding it in the concrete foundation.

6. Remove the shipping tie holding the pen arm to the pen shifter (Figure 2.4, item 13).

Figure 2.2   Universal Recording Raingauge

Figure 2.3 Universal Recording Raingauge Mechanism, Front View

Figure 2.4 Universal Recording Raingauge Mechanism, Single Spring

7. Loosen the mechanism locking screw (Figure 2.3, item 21) and nut, and back out the screw until the top lever is stopped by limit screw (14).

Retract the locking screw a turn or two farther; lock in position with its nut. Remove the stop sleeve (Figure 2.2, item 8) from about the movement bracket limit screw (7). Do not discard the sleeve; it will be needed for reshipment of the gauge. Do not disturb the setting of the limit screws; their positions are a part of the gauge's calibration.

8. Remove the wrapping from the chart drive mechanism, and unscrew the mechanism from the base.

9. The dashpot (Figure 2.5, item 3) is mounted to the mechanism base with two identical thumbscrews (1 and 2). Remove thumbscrew (2), loosen thumbscrew (1), push up the dashpot cover (4), and pull the dashpot out from between the mechanism frame, as shown in Figure.

10. From the bottle of damping fluid shipped in the catch bucket, fill the dashpot cylinder to within an 1/8 inch of its rim, and replace the dashpot between the mechanism frame. Empty the catch bucket, setting aside the recording ink and discarding all packing materials, and set the bucket on its platform. If the gauge is equipped with an overflow attachment, the overflow tube is placed in the round hole in the platform centering the tube over the overflow funnel mounted in the mechanism base.

11. Replace the chart drive mechanism. The mounting stud of the chart drive mechanism has been adjusted so that the winding key of the spring-powered chart drive and the movement viewing part of the battery-powered chart drive are accessible from the sliding access door of the gauge housing. Make certain that the stud flange is firmly seated against it mounting surface, but do not overtighten the mechanism and disturb the stud setting.

12. Remove thumbnut from chart drive mechanism spindle. Mount chart cylinder (with chart clip), supplied in the catch bucket, on the spindle, making certain that the mechanism pinion and the cylinder gear are meshed, and replace the thumbnut.

13. Replace the gauge housing, positioning it on the mechanism base so that the chart drive and pen arm are accessible from the sliding access door. If the gauge is equipped with overflow protection, make certain that the overflow-clearance hole in the dust shield, which rests on an interior bead of the gauge housing, is centered over the overflow funnel in the base. Fasten the housing in place with five screws and washers (Figure 2.2, item 3).

14. Replace the bucket platform (Figure 2.3, item 17) on the movement bracket (16) and fasten it in place with the washer (18) and screw(19). If the gauge is equipped with an overflow attachment, make certain the

round hole in the bucket platform is over the over-flow funnel (Figure 2.6, item 6) mounted in the mechanism base.

15. Replace the collector on the gauge housing, reversing the procedure used to remove it, detailed above. The collector can be padlocked to the gauge housing through the staples provided on each.

16. The gauge housing and its sliding access door are equipped with a sliding-bolt and staple so that the door can be padlocked shut.

17. Using the large zero and fine adjustment screws (Figure 2.3, items 20 and 15), re-zero the pen.

The gauge is now ready to be put into operation.

2.3.3.1.3 Calibration Procedures

Calibration of the gauges described herein is based on the assumption that 822.7 grams is the weight of a volume of water 1 inch high with an area equal to the area of the 8 inch diameter collector opening of the gauge. It also assumes that the weight of the bucket used in the 12 inch (300mm) gauge is one kilogram and 2.1 kg for the 20 inch (500mm) gauges, and that the gauge zero-adjustment range is sufficient to accommodate normal variations in bucket weight.

Calibration of the gauges requires a calibration weight set and a small machinist's level (approximately 2 inch long). Each set consists of an equivalent-bucket weight, a number of calibration weights, and a linearity setting tool (Figure 2.7, item 4). Inch weights are finished in aluminum lacquer, and millimeter weights are gold-colored.

The pen arm adjustment is not a calibration tool; its sole, intended purpose is to re-zero the pen, if necessary, when changing charts and chart drives.

Figure 2.5 Universal Recording Raingauge, Removal of Dashpot

Pre-Calibration

Calibration of all gauge mechanisms requires the mechanism base to be level and the following preliminary adjustments to be made:

1. Loosen the Limit Screws (Figure 2.2, item 7; Figure 2.3, items 14 and 21) sufficiently enough so that endplay is not restricted on the Back Shaft and the Movement Bracket (16), the Top Lever (23), the Extension Levers (11), the Lower Casting (not shown), and the Pen Arm Shaft (33), within the range of the calibration.

2. Center the screws and nuts (12) in the slot lengths of the Lever Extension (11).

Single Traverse Calibration

1. Center the equivalent-bucket weight in the bucket platform, and place a number of calibration weights equal to one-half of the gauge capacity on the bucket weight.

2. Place the machinist's level across the two pads in front finger of the Top Lever (23), and rotate the linkage with the zero-adjustment thumbscrews (15 and 20) so as to make the pads level. In making continued zero-adjustments, care should be taken to make use of both the Fine and Large Adjustment Screws so as to keep the Fine-Adjustment setting bar reasonably parallel to the top of the mechanism frame.

3. Loosen the Set Screw (6) fastening the Lever (6) to the Pen Arm Shaft (33), and rotate the Pen Arm Shaft to put the recording pen in the center of the chart; tighten the set screw.

4. Remove the calibration weights from the bucket weight. Set the pen to the zero-line of the chart; rotate the thumbscrews (15 and 20) clockwise to lower the pen and counter-clockwise to raise it.

5. Place all calibration weights on the bucket weight, one at a time. Check the pen position after the addition of each weight to determine if the pen position is within the accuracy tolerance.

Figure 2.6   Universal Recording Raingauge Mechanism, Dual Spring

Figure 2.7 Universal Recording Raingauge Linearity Setting, Dual Traverse Gauges

6. If the pen movement is linear but the pen positions are not sufficiently accurate, it will be necessary to change the Lever Extension (11) length. Moving the link pivot (10) away from the top lever will raise the pen position. Remove the calibration weights, loosen the nuts (12) fastening the extension sufficiently to move the extension with the screw (13), and make the adjustment with the screw - one turn of the screw will move the pen about one chart division; tighten the nuts. If an outward adjustment is required, back out the screw sufficiently to allow an over-adjustment of the extension, and return to the required adjustment by use of the screw. Re-zero the pen, and repeat this procedure until the pen positions are within tolerance.

7. If the pen movement is nonlinear as well as inaccurate, it will also be necessary to rotate the pen shaft (33) relative to the Lever (5). Viewed from the pen arm side of the gauge, rotation of the pen arm shaft in a counter-clockwise sense relative to the lever will increase the pen movement per calibration weight in the upper-half of the chart; clockwise rotation will decrease it. The magnitude of the adjustment will be in the order of three chart divisions. Loosen the setscrew (6) fastening the lever to the pen arm shaft, and rotate the pen arm shaft to reposition the pen on the chart. Tighten the setscrew. Remove the calibration weights, re-zero the pen, and repeat the procedure.

8. Repeat the procedures of the three previous paragraphs until the calibration of the gauge meets the accuracy requirements.

9. Calibration of the gauge is now complete. It remains only to reset the Limit Screws (Figure 2.2, item 7; Figure 2.3, item 14) as required.

Dual Traverse Calibration

1. Using the Red Fine Adjustment Screw (20), level the Zero Set Assembly Plate (35), and tighten the four side screws.

2. Place the bucket weight onto the Bucket Platform (17), and put half the gauge's capacity of weights onto the bucket weight.

3. Line up the Pen Arm Bracket (32) so that the screws line up straight across with the First and Second Traverse levers.

4. While holding the Pen Arm Bracket steadily in place, insert the Linearity Setting Tool onto the First Traverse Link. Line the link up straight, and tighten the screw (2). The link must be perpendicular to the base before the screw is tightened.

5. The same process is repeated on the Second Traverse link. Continue to

hold the Pen Arm Bracket steady while inserting the Linearity Setting Tool (4) onto the Second Traverse Link. Line the link up perpendicular to the base, and tighten the screw (2).

6. Continue to hold the Pen Arm Bracket straight and steady. Place the complete Pen Arm (Figure 2.3, items 25, 27, and 28) onto the bracket. Line the pen up to the three inch or center line of the chart and tighten the screw (32). The Lever Screw (6) on each traverse should be straight across.

7. Release the Pen Arm Bracket (32). The Pen Arm should rise above the center line. Using the Large Zero Adjustment Knob (15), adjust the pen down to the center line. The Screw should be turned clockwise to adjust the pen down into place.

8. Place the linearity setting tool back onto the First Traverse Link. Make sure the tool fits easily, without bending the link. Loosen the screw. While holding the First Traverse Link and tool steady, move the pen down four division, and tighten the screw. If a linearity setting tool is not available, make all adjustments while keeping the First Traverse Link perfectly straight (perpendicular to the base).

9. Place the linearity setting tool into the Second Traverse Link. The tool should once again fit easily into the slot without bending the link. Loosen the Screw. While holding all parts steady, move the pen up four division on the chart, and tighten the screw (2).

10. Remove all the weights from the bucket weight.

11. Use the Large Zero Adjustment Knob (15) to position the pen at zero. Tap the base of the gauge to make sure the pen is not sticking and that it returns to zero.

12. Place the first weight onto the bucket weight and tap the base to check for sticking. DO NOT ADJUST IF THE PEN IS OFF THE DESIRED MARK.

13. One by one, place the remaining weights onto the bucket weight, tapping the gauge each time to ensure non-sticking of the pen. Again, do not adjust if the pen is not exactly correct.

    A. If the pen reads fast, i.e. higher than the expected increment, use the following steps to correct the problem:

1 Using the First Traverse Lever Link (8), loosen the two nuts at the top of the link (12).

2. Turn the Adjusting Screw (13) clockwise until the pen adjusts to the proper reading (½ turn is approximately one division).

3. Once adjusted to the proper reading, tighten the nuts (12).

4. Remove all the weights.

5. Using the Large Zero Adjust Knob (15), adjust the pen (28) to zero if necessary.

6. One at a time, place the weights back into the bucket, taking note of the readings.

7. Continue to repeat this entire process, steps 1 through 6 until the pen reads correctly.

NOTE: If weights 1 through 4 read correctly, it can expected that both weights 5 and 6 will read slightly higher than the correct mark. This is attributed to the springs and should not be adjusted out.

B. If the pen is reading slow, i.e. lower than the expected increments, adjust the gauge as follows:

1. Using the First Traverse Lever Link (8), loosen the two nuts (12) on the top of the link.

2. Turn the Adjusting Screw (13) counter-clockwise until the pen adjusts to the proper reading.

3. Once adjusted to the proper reading, tighten the nuts (12).

4. Remove all the weights.

5. Using the Large Zero Adjustment Knob (15), adjust the pen (28) to zero, if necessary.

6. One at a time, place the weights back onto the bucket weight, noting the reading for each weight.

7. Continue to repeat the entire process, steps 1 through 6, until the pen reads correctly.

NOTE: If weights 1 through 4 read correctly, it can be expected that both weights 5 and 6 will read slightly higher than expected. This can be attributed to the springs and should **not** be adjusted for.

C. When the pen (28) reads correctly with all the weights on the bucket weight, this signifies that the First Traverse is zeroed. (Zero to six inches for a 12 inch DT Gauge.)

14. Next, proceed to the Second Traverse Lever Link. Turn the screw (34) down until the pen (28) is exactly at the top of the chart and will go no higher than the top measurement line, 6 inches.

15. Place the second set of weights onto the bucket weight, noting the readings as the pen descends down the chart.

16. If the pen is reading fast or slow, follow the same procedures are used on the Second Traverse as on the First, as detailed in 13 A or B.

17. Once the pen is zeroed, place some extra weight (anything) onto the bucket weight. Using the Back Screw (not shown) directly behind the Movement Bracket (16), turn it clockwise to bring the pen up, stopping immediately before the pen reaches the bottom of the flange (30). Tighten the nut on the back screw once this has been done.

18. Remove all weights and the bucket weight from the gauge.

19. Turn the Front Screw (21) clockwise bringing the pen to rest slightly above the flange (30). Tighten the nut on the screw.

20. Replace the bucket weight on the gauge.

21. Using either Zero Adjustment Knob (15 or 20), adjust the pen to zero.

2.3.3.1.4 Maintenance Procedures

Chart Changing.

The chart drive and pen arm are accessible from the sliding access door in the gauge housing. The following procedure should be followed when changing charts:

1. Open the sliding access door, and make a short vertical mark (time-check) on the chart by lightly touching the bucket platform. If the chart drive has stopped, turn the chart cylinder slightly in both directions to mark the existing pen position. If the pen is not making a trace, indicate the pen position by a dot enclosed in a circle.

2. Lift the pen off of the chart by moving the pen shifter (Figure 2.4, item 13) outward.

3. Remove the collector, and empty the catch bucket.

4. Remove the chart cylinder thumbnut, and remove the cylinder by lifting it up and off of its spindle. Take care not to smear the pen trace. Release the chart clip holding the chart, and remove the chart. Do not store the chart until the pen trace has dried.

5. Wind the chart drive if it is spring-powered. The battery-powered chart drive will need no preparation for a new recording period unless the time has arrived for a battery change. Refer to the chart drive instructions for details of the chart operation.

6. Clean the pen if necessary: refer to instruction book #12049, included with these instructions, for proper care of the recording pen.

7. Mount new chart to the cylinder as follows:

   A. If chart is the double-tab type, fold right-hand tab under back of chart, and wrap chart snugly around cylinder so that a) time is read from left to right, b) corresponding rainfall graduations meet, c) the bottom edge of the chart is against the cylinder flange, d) the folded end of the chart overlaps the opposite end, and e) the crease in the fold is at the right-hand edge of the cylinder and the slot in the cylinder flange.

   B. Clamp the chart to the cylinder by placing the clip inside the fold at the overlapping end of the chart, placing the straight end of the clip in the slot in the cylinder, and seating the formed end of the clip in the notch in the upper edge of the cylinder.

   C. If the chart is the single-edge type, wrap it snugly around the cylinder so that a) time is read left to right, b) corresponding rainfall graduations meet, c) the bottom edge of the chart is against the cylinder flange, d) the untabbed end is at the right-hand edge of both the notch in the upper edge of the cylinder and the slot in the cylinder flange.

D. Clamp the chart to the cylinder by placing the clip over the untabbed end of the chart, inserting the straight end of the clip into the slot in the cylinder flange, and seating the formed end of the clip in the notch in the upper edge of the cylinder.

8. Replace the chart cylinder and thumbnut on the chart drive mechanism spindle making certain that the mechanism pinion and cylinder gear mesh.

9. Refill the pen, and push in pen shifter to return the pen almost to the chart surface. If the catch bucket is empty, and the pen does not indicate **zero** within the gauge tolerance, set the pen to the zero line with the coarse (Fig 2.3, item 15) and fine (20) adjustment screws. Set chart to time by first turning the cylinder clockwise past the correct time and then returning it counterclockwise to the correct time. Be sure the time is correctly set with respect to a.m. or p.m.

10. Push the pen shifter all the way in to put the pen on the chart. Lightly touch the bucket platform to make a time check on the chart. The gauge is now ready for a new recording period. Close and padlock the access door.

Chart Sets

Charts available for use with the 5-780 Series Rain Gauges are listed in Table 2.1. Chart sets of the 6 through 192-hour period charts contain 100 charts; sets of the 861-hour charts contain 25 charts.

The frequency with which the gauge is serviced will depend on the environment of the gauge: as frequent as once every three months in dusty climates and as infrequent as once a year in mild climates. The appearance of the gauge at

regular operational visits will make apparent the need for servicing. The following procedures and recommendations should be made part of the gauge service schedule:

1. Clean all moving parts with a soft brush moistened with varsol. Solvents that attach paint must never be used for this purpose.

   Except as required in the chart drive mechanism, never oil any part of the gauge: corrosion-resistant materials have been used throughout the gauge's construction, and oil will, in time, become gummy and cause sluggishness in the gauge's operation.

2. Examine the weighing mechanism linkage for evidence of excessive

friction. If corrections for this fault require significant disassembly or part replacement, recalibrate as described in the fourth section.

3. Clean the bucket thoroughly. Sufficient foreign matter accumulating in or on the bucket, adding to its weight, can cause depletion of available zero-adjustment.

4. Inspect the dashpot: add silicone fluid, if necessary, to cover the piston when it is in its uppermost position (gauge zero).

5. Clean the pen: see instruction book #12049.

6. Inspect the chart drive, and if necessary, service it. See instruction book #12049 for details of chart drive maintenance.

CHART NUMBER	RANGE	CHART PERIOD HRS/REV	GRID SIZE		LEAST DIVISION	
			WIDTH	LENGTH	RANGE	TIME
5-4003-B	0 to 6", ST	24	6"	11.52"	.05	20 min
5-4006-MM	0 to 150mm, ST	192	6"	11.30"	1mm	2 hrs
5-4041-B	0 to 12", DT	6	6"	11.52"	.05"	5 min
5-4042-B	0 to 12", DT	12	6"	11.52"	.05"	10 min
5-4044-B	0 to 12", DT	48	6"	11.52"	.05"	15 min
5-4045-B	0 to 12", DT	96	6"	11.52"	.05"	1 hr
5-4046-B	0 to 12", DT	192	6"	11.52"	.05"	2 hrs
5-4046-MM	0 to 300mm, DT	192	6"	11.30"	1mm	2 hrs
5-4047-B	0 to 12", DT	24	6"	11.52"	.05"	15 min
5-4047-MM	0 to 300mm, DT	24	6"	11.30"	1mm	15 min
5-4048-B	0 to 4.8", DT	6	6"	11.52"	.02"	5 min
5-4049-B	0 to 4.8", DT	24	6"	11.52"	.02"	15 min
5-4050-B	0 to 4.8", DT	192	6"	11.52"	.02"	2 hrs
5-4068	0 to 20", DT	168	6"	11.52"	.10"	2 hrs
15620	0 to 300mm, DT	861 (1)	6"	11.52"	1mm	6 hrs
15668	0 to 12", DT	861 (1)	6"	11.52"	.05"	6 hrs
15669	0 to 20", DT	861 (1)	6"	11.52"	.10"	6 hrs

Table 2.1 Available Rain Gauge Charts

2.4 Instrumentation--Manually-Read Rain Gauges

2.4.1 Principle of Operation

The manually-read rain gauge is a graduated (incremented) wedge or cylinder with the open end pointing upward. The rain gauge should be read between 7:00 AM and 8:00 AM following each rain event and recorded to the nearest hundredth of an inch. This record should include time and date. The clear wedge rain gauge should be held level, provided it is not already mounted eye-level, and read from the front. The bottom of the meniscus (the curved upper surface of the water level) should be used as the level to be read. The funnel on top of the 8-inch non-recording rain gauge should be removed to measure rainfall totals. If the center tube is full it indicates at least two inches and should be discarded. Rain outside the center tube but still within the gauge should then be poured into the center tube. If the tube does not fill entirely, place the dip stick to the bottom of the tube and withdraw. Read the wet line measurement off the dip stick and add two inches for each full tube previously discarded.

2.4.2 Maintenance

The Tru-Chek wedge rain gauge is made of weather resistant plastic which can be periodically cleaned internally. The 8-inch non-recording rain gauge is made of aluminum that should also be inspected for detritus and bugs, and should be cleaned. The cleaning solution should be a mixture of 1/4 cup of water and 1/4 cup of liquid bleach. Rinse gauge after allowing solution to stand for 10-15 minutes.

2.4.3 Sensors Used

2.4.3.1 Tru-Chek Wedge Rain Gauge

The Tru-Chek raingauge is a smooth one-piece wedge-shaped molding of heavy weather resistant plastic. A graduated scale from 0.01 to six inches is imprinted on the gauge. Tests of this gauge by the American Geophysical Union show that it closely approximates readings obtained by the standard 8-inch gauge.

2.4.3.1.1 Manufacturer's Specifications

Orifice Diameter: 2.5 x 2.3 inches

Maximum Capacity: 6 inches

Calibration: 0.01 inch

Accuracy: < 1% error

2.4.3.1.2 Installation Procedures

For an accurate installation of the Tru-Chek wedge rain gauge, the wedge should be secured to a post in a true vertical position at eye level. The wedge rain gauge has a holder that should be screwed to the post and which the wedge slides into. The post should be located one to two times as far away from obstructions as the height of surrounding buildings or trees.

2.4.3.1.3 Calibration Procedures

Calibrations of the Tru-Chek wedge rain gauge is not necessary, although small amounts of rainfall can be read to a greater precision than larger amounts.

2.4.3.1.4 Maintenance Procedures

The Tru-Chek wedge rain gauge is clear plastic and therefore needs to be periodically cleaned for accurate readings. Detritus and bugs should be emptied out at all times. To clean a discolored bottom, a mixture of 1/4 cup of water and 1/4 cup of liquid bleach is placed in the wedge and allowed to soak for 10-15 minutes. Rinse the wedge with clean water to remove the solution. Sunlight may degrade the strength of the plastic. Therefore, gauge replacement is recommended approximately every two years.

2.4.3.2 Standard 8-Inch Non-Recording Rain Gauge

The non-recording or standard can gauge has a top collector exactly 8 inches in diameter with a funnel shaped bottom which directs precipitation into the cylindrical measuring container and has a capacity of two inches. The accumulated precipitation may be measured daily to give a total amount of rainfall over a 24-hour period, or measured immediately after cessation of the rain to get an immediate precipitation amount. Any amount greater than two inches will spill over into the overflow can.

2.4.3.2.1 Manufacturer's Specifications

Accuracy:	Measures precipitation to within .01 inch
Capacity:	2 inches in measuring tube; 20 inches in overflow can
Dimensions:	8 inch diameter x 27 inch high
Weight:	10 lbs.
Shipping Weight:	14 lbs.
Finish:	Aluminum Lacquer
Gauge:	All brass and copper construction

2.4.3.2.2 Installation Procedures

The standard can gauge is installed by first securing a gauge support, which consists of two cast iron rings and tubular legs, into the ground or a concrete pad. The pad used is concrete precast 24" x 24" x 3" slab with no. 3 rebar reinforcement. The overflow can is set inside the gauge support and checked to ensure it is level. The measuring container and collector are then set in place.

2.4.3.2.3 Calibration Procedures

Rainfall data is collected daily, as follows:

1. Remove the collector and measuring tube.

2. Insert the measuring stick vertically into the accumulated rainfall. The measuring stick has a scale which is magnified ten times, and the value in inches is read directly from the scale.

3. Record the value on a rainfall observation form. Pour out the accumulated water and replace the measuring tube in the can.

4. If the amount of rain has exceeded two inches, and there is water in the overflow can, pour this water into the measuring tube, insert the stick to get the value, and include this in the total rainfall.

2.4.3.2.4 Maintenance Procedures

Non-recording precipitation gauges require minimal maintenance which consists of removing debris from the collector, keeping trees or shrubbery from growing over the gauge, and checking periodically for rust and leaks.

2.5 Instrumentation--Calibrated Stilling Well Rain Gauge

2.5.1 Principle of Operation

The Dual Rainfall and Ground Water graphic recorder system is used in areas where the effect of rainfall on the shallow groundwater aquifer is needed. Information is provided which assists in determining the overall effect of rainfall on groundwater within a given network. A Leupold and Stevens, Model 2A35, dual graphic recorder is used to record both the groundwater level and the rainfall amount.

Floats and counterweights are used to sense the groundwater level and the rainfall volume. Two pipes are used for both sensors, a 3-inch aluminum pipe for the floats and a 2-inch aluminum pipe for the counterweights. The 3-inch groundwater pipe is open at the bottom and varies in length (depth) depending on the site. The 3-inch rainfall pipe is sealed at the bottom and is 12.5 feet long. Both 2-inch counterweight pipes are open at the bottom.

2.5.2 Maintenance

Please refer to Section 2.5.3.1.4 which covers the Leupold & Stevens Model 2A35 Dual Graphic Recorder.

2.5.3 Sensors Used

2.5.3.1 Leupold & Stevens Model 2A35 Dual Graphic Recorder

2.5.3.1.1 Manufacturer's Specifications

Float operated water-level recorder; rectangular strip chart 10 inches by 25 yards; float pulley standard for 1:6 English, with 0.01 foot sensitivity; cartridge type pen with spare cartridge; plastic cover with viewing port; cast aluminum base with three leveling screw legs. Geometrically wound, non-twisting beaded float line cable, 0.04 inch diameter is standard. Beads are crimped on at uniform intervals of 6 inches, and match recesses in float pulley for non-slip operation.

2.5.3.1.2 Installation Procedures

Initially, the selection of site is determined by the project manager. A reconnaissance trip is made and a test hole is drilled to find how far below the ground is the water level. Water must be detected before the first rock layer for the site to be used for groundwater monitoring.

The installation of a rainfall sensor entails the use of two pipes which consist of a 3-inch pipe that collects the rain and a 2-inch pipe to accommodate a counterweight, both of aluminum, 12.5 feet long, and welded together. The 3-inch pipe is sealed at the bottom approximately 1 inch from the end to retain the rainfall volume. The 2-inch counterweight pipe is open at the bottom.

Two pipes are also used to set up the groundwater level sensor which consists of a 3-inch aluminum pipe and a 2-inch aluminum counterweight pipe, both open at the bottom. The length of the groundwater pipe is determined in the field at time of installation.

The rainfall pipes are driven approximately 10 feet into the ground by use of a jet pump and sledge hammer. This usually means going through the first rock layer and helps establish the length of the groundwater pipe. Groundwater pipes are installed in the same manner with the depth varying at each site. The pipes extend above ground by approximately 2.5 feet. All pipes must be level at top and perfectly straight.

A platform is installed approximately 0.5 inch below the top of the pipes, and sits on four 4" x 4" wooden legs driven into the ground. The pipes extend above the platform in order to keep water from seeping onto the platform from underneath the shelter and running into the rainfall pipe. All openings around pipes and platform are sealed with sealastic.

The recorder (2A35) is then placed in position. The rainfall pulley on the recorder is fabricated at a machine shop and pre-calibrated so that a pen movement of 1 inch on the chart is equal to 0.50 inch of rainfall. The groundwater pulley is a standard 18-inch circumference pulley wheel used on all stage recorders. For groundwater, a pen movement of 1 inch on the chart is equal to one-half foot change in water level.

A rainfall catch basin is mounted on top of the aluminum shelter. This device is fashioned by taking the top collecting funnel from a U.S. Weather Bureau Standard Can Raingauge, attaching it to the top of the shelter, and securing it with three metal support arms.

A 0.25-inch diameter copper tubing carries the rainfall from the catch basin into the 3-inch rainfall pipe that collects and measures the rainfall by the float method. The rainfall catch basin is sealed to the shelter to prevent rainfall from running down the copper pipe into the well.

The following procedure should be followed in setting the rainfall pen on the recorder:

1. With the float out of the well, put approximately one foot of water in the rainfall well.

2. Measure the distance from the reference point to the water surface to get depth to water (DTW).

3. Replace the float and set the pen one inch above the bottom horizontal axis of the chart at the correct-time axis. The one-inch ordinate represents the zero-base of the chart, and allows for negative readings which would represent any evaporation that may occur prior to any rainfall.

4. Record the information on the chart.

Record all information needed from the field to write a complete and concise station description, and to be able to locate the station on a quad map.

2.5.3.1.3 Calibration Procedures

Water Level

Water Level calibration is provided by the manufacturer of the graphic recorder. The user selects the desired scale at time of purchase or by changing gears supplied by the manufacturer. For this application an 18-inch circumference tape pulley is used on the recorder to effect a 2-inch pen movement for each 1-foot change of water level. This scale may be changed by changing gears or the circumference of the tape pulley. Mechanical recorders of this type are calibrated by the manufacturer and under normal use and conditions require only maintenance as described in Section 2.5.3.1.4

Rain Gauge

The rain gauge is much more difficult to calibrate because of the number of variables; These include the diameter of the rain collector, the diameter of the rain receiver pipe and the diameter of the rain gauge float pulley. For the system described in this manual, an 8-inch, standard Weather Service collector is used, the receiver pipe is 3-inch inside diameter (pipe diameters can vary significantly from the listed diameter) and the pulley is machined to a calculated diameter so that 1-inch of rainfall will cause the chart pen to move 2 inches on the chart.

In order to establish a 2-inch pen movement for 1 inch of rainfall, the volumetric ratio between the rain collector and the rain receiver must equate to 2/3 the circumference of the required pulley.

The volumetric ratio of the dimensions listed above, an 8.00 inch diameter collector to a 3.00 inch diameter rain receiver =

$$(\pi(8.00/2)^2) / (\pi(3.00/2)^2) = 7.11111$$

Therefore,

$$7.11111 = 2/3 \text{ (required circumference)}$$

The circumference of the pulley required = 10.667 inch or 3.685 inch diameter. After the pulley size is calculated, fabricated and installed, the calibration should be verified under actual conditions. As stated above only periodic inspections and maintenance is required.

2.5.3.1.4 Maintenance Procedures

Maintenance of the dual groundwater and rainfall recorders involves performing specific steps to ensure the integrity of the data collection site. Most of the recorders are located on private property, and sites are usually accessed by helicopter. It is important, therefore, to perform full general maintenance on the site on an annual basis. Maintenance proceeds as follows:

1. Update the station description; check for new routes, fences, locks, etc.

2. Refer to Data Collection - Steps 1-8, before disturbing the recorder to perform maintenance. Indicate "off for maintenance" in the notes.

3. Remove the chart roll and perform the required maintenance.

4. Inspect all the mechanical parts of the recorder for wear and replace if necessary.

5. Inspect all accessory parts such as floats, float tape, counterweights, and replace if worn out.

6. Lubricate the slides, the pulley wheels, and all the other moving parts.

7. Remove the clock if it is driven by a negator and allow band to back off onto the supply spool. Rewind the band and wipe off any dirt and rust, visibly check for cracks or weak areas. Replace if necessary.

8. Check pens to ensure that ink is flowing freely. If the pen is of the capillary type, clean and replace if necessary; fill the ink reservoir to the two-thirds mark. If the pen is of the cartridge type, replace if the trace is faint.

9. Clean any spilled ink off the recorder as it is corrosive to some parts.

10. If the platform is damaged, remove the recorder and repair or replace, resetting top of wells 0.25 inch to 0.50 inch above the platform.

11. Check the rainfall funnel for clogging, damage to the screen, sealing all holes in the shelter with sealastic.

12. Take a distance-to-bottom measurement in the rainfall well and in the rainfall counterweight pipe, as well as in the groundwater well and counterweight pipe, as they may have become silted. Record this information on the trip report form. (See section on Jetting Out Wells).

13. Replace the chart roll on the recorder, clip it in place and advance it past the "off" information.

14. Take a new DTW for rainfall, and replace the float. Take a new DTW for groundwater, and replace the groundwater-well float.

15. Position the rainfall pen at the one inch mark on the chart. Make sure the rainfall pen is in the same reversal/non-reversal state it was found in upon arrival at the site.

16. Record the "on" information.

17. After completing the stamped information and notes, advance the chart one full 24-hour period to the correct time, index, and indicate the "on" mark.

18. Perform a final check by ensuring that:

    A. The tension knob is pushed in to lock the roller.

    B. The tape is in the pulley splines.

    C. The weight-driven clock is not wound so tightly that it might hang up on the platform, and that the pawl on the negator type is not left partially engaged.

    D. The adjusting nuts on pulley wheel are tight, as well as the lock nut in the center of the pulley.

    E. The pin on the sprocket chain is in the diamond.

    F. The feeder roll lock nut is tight.

    G. The tape and distance to water measurement match. Any discrepancy should be reported.

19. Close the shelter and lock.

20. Clear the recorder site of any weeds and small trees which would interfere with an accurate rainfall record.

21. If the recorder is fenced in, repair the fence and fill any holes at the site.

22. Fill out a trip report for annual maintenance records and note any problems remaining.

Jetting Wells

The groundwater well and counterweight pipes are open ended and may become silted, requiring the use of a jet pump to clear them to the maximum operational depth. In addition, the rainfall pipe, though closed in at the bottom, may become filled with debris and require jetting out. The following additional procedure is used at maintenance time if needed:

1. Check original installation depths.

2. Jet out wells if difference in depths is 1.00 foot or greater.

3. Jet the rainfall well until water runs clear.

4. Increase the lengths of tapes and lines as needed, and replace if kinked. Cut off all excess lines and tapes.

5. Wait until groundwater well has settled before taking the final DTW's.

6. Bail out the rainfall well, take a new DTW, and set the rainfall pen to the zero position on the chart.

3.0 Atmospheric Pressure Measurement

3.1 Introduction

3.1.1 Theory

Atmospheric or barometric pressure is the pressure exerted by the atmosphere as a result of gravitational pull upon a column of air directly above the measuring point.

Most barometric pressure sensors are calibrated with reference to the standard pressure at sea level. Since atmospheric pressure varies with altitude, the measured pressure at any given site is termed station pressure. The accuracy of this station pressure measurement is a direct function of the siting and exposure of the sensor (see Section 3.1.2).

Atmospheric pressure is usually measured in either millibars (mB), or inches of mercury (Hg). The following conversions apply if cross reference is needed.

0.02953[millibars (mB)] = inches of mercury (Hg)

33.864[inches of mercury (Hg)] = millibars (mB)

3.1.2 Instrument Siting and Exposure

A barometer site should be clean, relatively dry, vibration free, maintained at a constant a temperature as is practical, and without direct sunlight on the instrument. The location must be free of drafts or the potential of hot-air currents or other causes of rapid temperature changes. The instrument must be situated away from any obstacles such as windows and doors or the windward and leeward sides of buildings that could cause changes in the static pressure due to wind eddy currents. Additional siting and exposure information is discussed in the installation procedures section of the individual instruments.

3.1.3 Measurement Standards

The mercury barometer (Fortin, fixed-cistern, and siphon) is accepted by the World Meteorological Organization as a primary standard for measurements of atmospheric pressure.

The standard unit of measurement of atmospheric pressure is millibars.

The accepted tolerance between station and **primary standard** values is 0.68 mb (0.02 in Hg). When a station barometer deviates from a standard barometer by more than 0.68 mb, the station barometer requires calibration.

3.2 Instrumentation--Atmospheric Pressure

3.2.1 Principle of Operation

Numerous instruments exist which measure atmospheric pressure to acceptable standards. These many instruments often use different methods of measurement therefore many different principles of operation.

Some different types of barometric pressure instruments are:

Mercury - (Fortin, fixed-cistern, and siphon)

Aneroid - (vibrating-diaphragm and aneroid capsule)

Piezo - (piezoelectric and piezoresistive)

The principles of operation of these instrument types will be discussed in the individual sections following in this chapter.

3.2.2 Maintenance

Maintenance requirements vary with the individual instruments and are discussed in the maintenance procedures sections of the specific instruments.

3.2.3 Sensors Used

3.2.3.1 Princo Instruments Model 469 Mercury Barometer

This is a Fortin type mercurial barometer consisting of a long glass tube, closed at one end, evacuated, filled with mercury and inverted. The open end being submerged in a reservoir of adjustable level mercury called a cistern. The mercury is supported in the glass tube by the atmospheric pressure acting on the mercury in the cistern. The height of the mercury in the glass tube is a measure of that pressure. Air must never enter the glass tube. Air in the mercury column could cause separation thus the barometer will read too high, or the air could rise to the top, depressing the mercury and causing a low barometer reading.

3.2.3.1.1 Manufacturer's Specifications

The measurement resolution of the Model 469 Fortin Type Mercurial Barometer is 0.001 inch and/or 0.1 millimeter. The accuracy reflected by resolution is dependent upon the proper application of the correction factors for temperature, gravity, and sea level differential. If correction factors are applied correctly then measurement accuracy is equal to measurement resolution.

3.2.3.1.2 Installation Procedures

Mount the barometer board in a vertical position such that the barometer scale is at eye level. Use a level to ensure vertical mounting because any slant will cause a high reading. Carefully turn the barometer right side up (cistern side down). Place the cistern end in the centering ring of the board and the suspension ring or knob in the hanging bracket of the board. Slowly turn the cistern adjusting screw down 10 full turns. If the mercury column does not come down with these 10 turns then tap the top of the barometer tube with your fingers to snap it loose. After the mercury releases from the top of the glass, continue turning the thumb screw until the mercury is just touching the pointer inside the cistern.

3.2.3.1.3 Calibration Procedures

Pressure changes due to weather are small and must be measured accurately. During periods of fair weather, the barometer may not change for days. With the arrival of a cold front the barometer will drop markedly. The long scale of this barometer is necessary to allow for different pressure levels at different elevations. When the pressure increases, the cistern level will be depressed and mercury will rise in the glass tube. When the barometer is first installed, an accurate reading should not be expected until the mercury, glass, scales, etc, have equalized to the same temperature as the surrounding atmosphere. This may take as much as 24 hours.

The height of the mercury column can now be read against the scale, as follows:

1. Turn the thumb screw at the bottom of the cistern adjusting the mercury until it just touches the tip of the pointer protruding from the cistern roof. Notice the pointer makes a slight dimple in the mercury surface. Accuracy in the pointer setting is important as any error in this setting is reflected in the resulting reading. The smaller the dimple the more accurate the measurement.

2. Tap the cistern glass and the glass tube at the top of the mercury to bring the mercury meniscus to its average height.

3. Recheck cistern dimple as in step 1.

4. Raise the vernier above the top of the mercury meniscus, and then lower it slowly until the bottom edge is just touching the mercury level. The observers eye should be at the same level as the bottom of the vernier sleeve. When the vernier is properly adjusted a white reflection will be visible at both sides of the mercury meniscus but not at the top.

5. Read the barometer scale at the lower edge of the vernier. Estimate the last digit. Use the vernier to confirm the last digit. If the third line of the vernier lines up with a line on the main scale, then your estimated last digit should be three.

3.2.3.1.4 Maintenance Procedures

The standard temperature for measuring the density of mercury is 0 degrees centigrade. Mercury becomes less dense with increasing temperature. The barometer barrel is made of brass. The barometer scale has a thermal coefficient similar to brass. Mercury has a thermal coefficient about 10 times greater than brass. Since the barometer is not usually at 0 degrees C, a temperature correction factor must be applied to reduce your reading to mercury at standard temperature. Tables 3.1 and 3.2 are used to correct for temperature.

The barometer is also affected by gravity which varies with latitude. Standard gravity corrections are listed in Table 3.3.

Temperature and gravity corrected barometer readings give you the local station pressure at the surface of the mercury in the cistern. To determine the sea level pressure you must know the elevation of the barometer's cistern. Using this elevation, sea level pressure can be computed from Table 3.4.

3.2.3.2 Sierra-Misco Inc. Model 1522 Barometric Pressure Sensor

The Model 1522 Barometric Pressure Sensor is a piezoelectric device consisting of a strain gauge diaphragm, a signal conditioning PC board, a water resistant housing, and a signal cable.

The fluctuations in atmospheric pressure act upon the strain gauge diaphragm causing a piezoelectric generation of a small EMF or voltage. This EMF or voltage is amplified by the signal conditioning PC board to provide 0-5 VDC output which is proportional to the barometric pressure.

Table 3.1 Temperature Correction (English Units) to Reduce the Reading of the Barometer to Standard Temperature

Table 3.2 Temperature Correction (Metric Units) to Reduce the Reading of the Barometer to Standard Temperature

Table 3.2, continued

Table 3.3 Gravity Correction to Reduce the Reading of the Barometer to Standard Gravity

Table 3.4 Barometric Sea Level Differential for Standard Conditions Based on the ICAO Standard Atmosphere

3.2.3.2.1 Manufacturer's Specifications

Range:	85 mB
Zero Adjust:	600 mB to 900 mB

Output: 0-5 VDC

Power Requirements: 12 VDC at 50 mA

Accuracy: Sensor ± 0.1%

Overall ± 1 mB

Linearity ± 0.5 mB

Hysteresis =_ 0.05 %

Turn on Time: 10ms to 99% full scale

Operating Temp: -40 to +60 degrees C

Temp Coefficient: 0.1 mB/degree C

3.2.3.2.2 Installation Procedures

The sensor housing has four 5/16 inch mounting holes on the back for mounting to any stable wall or other surface that is free of obstructions that would affect the static pressure. The location should be clean, dry, vibration free and render as constant a temperature as is practical.

3.2.3.2.3 Calibration Procedures

Calibration is required when the barometric pressure sensor is installed. It must be adjusted to compensate for the altitude at the sensor location. The sensor zero point must be adjusted so the output is relative to sea level barometric pressure. Refer to discussion later in this section for details on how to adjust the zero point output. If the instrument is located higher than sea level it may output zero and appear not to be working if it has not been correctly adjusted for that elevation since the conditioning circuit can only read positive. There are two methods of calibrating this sensor.

Method One

Obtain an accurate sea level pressure using a reliable barometer which is located close to the sensor under calibration. Then refer to the calibration curve enclosed with the sensor (see example in Figure 3.1) and adjust the output of the sensor to match the output indicated on the curve for sea level at that time.

Figure 3.1 Sierra-Misco Barometric Pressure Calibration Curve

Method Two

Make note of the altitude at the sensor location. Take a reading with a reliable barometer at the sensor site and adjust its output by the difference between the site reading and the reading shown on the Pressure Altitude Equivalent Table (Table 3.5) for that elevation. For example, if the barometric pressure at the site is 970 mB and the site elevation is 1340 feet (a difference of plus 5 mB from standard) then the barometric pressure at sea level at that time is 1018 mB (1013 plus 5). The output of the sensor at 1340 feet should then be adjusted to 1018 mB.

Millibar (mB)	Inches of Mercury (Hg)	Altitude (Feet)
813	24.0	5974
830	24.5	5425
847	25.0	4886
864	25.5	4356
880	26.0	3824
897	26.5	3320
914	27.0	2814
931	27.5	2315
948	28.0	1824
965	28.5	1340
982	29.0	863
999	29.5	392
1013	29.9	0
1016	30.0	-73
1033	30.5	-531

Table 3.5 Pressure Altitude Equivalents

The coarse and fine zero adjustment potentiometers (refer to Figure 3.2) are used to set the output to represent a known pressure.

The span adjustment is set at the factory and should not be altered without proper equipment. Unless otherwise specified the sensor will have been calibrated at sea level with a range of 85 mB and its zero set at 950 mB. At 950 mB the output will be 0 VDC and at 1035 mB the output will be 5 VDC.

3.2.3.2.4 Maintenance Procedures

Maintenance of this instrument requires the good practice of general cleanliness. Do not allow any foreign material to become lodged in the small pressure equalization hole at the bottom of the instrument enclosure. A properly sized desiccant (or other suitable drying agent) package must be maintained inside the instrument enclosure at all times. Rejuvenate or replace this drying agent every 2 months.

3.2.3.3 Weathertronics Model 7105-A Analog Output Barometer

This instrument is contained in a rugged aluminum enclosure. It is not direction sensitive and therefore can be mounted in any position. It should be installed in a weather shelter when used outdoors. A hose barb is provided for remote sensing of outside pressure if the instrument is installed in a tightly sealed building.

The sensor requires DC voltage excitation, and is well suited to applications in remote automatic weather stations. The operator may select continuous or periodic operation. In the periodic mode, designed for automatic weather station use, the data acquisition system will power up the sensor just prior to measurement thereby conserving system power.

The Model 7105-A barometer uses a piezoresistive sensor element to measure atmospheric pressure. A diaphragm with implanted resistors responds to the pressure, and built-in integrated circuits provide signal conditioning. This signal conditioning consists of amplification, temperature compensation, and voltage regulation. The sensor output is a linear voltage (2.9008 to 5.3167 VDC) proportional to pressure between 600 and 1100 mB. Accurate trimming of the sensor components provides close control of hysteresis, repeatability, and long term stability. The measuring range of this instrument is from 600 to 1100 mB. This range allows use from sea level to an elevation of approximately 14,000 feet.

Figure 3.2   Sierra-Misco Barometric Sensor Assembly Diagram

3.2.3.3.1 Manufacturer's Specifications

Sensor:	Piezoresistive Diaphragm
Range:	600 to 1100 mB
Output:	2.9008 to 5.3167 VDC
Sensitivity:	4.83 mV/mB
Accuracy:	± 0.88 mB
Resolution:	Infinite
Operating Elevation:	0' to 14000'
Operating Temperature:	-10 to 50 degrees C
Input Voltage:	10.5 to 24 VDC
Power Required:	0.18 VA
Physical Dimensions:	4.5"L X 3.1"W X 2.1"D
Weight:	0.5 lbs

3.2.3.3.2 Installation Procedures

Mount the instrument away from windows and doors such that the location is free of eddy currents and drafts which may effect the atmospheric pressure. The location should be free of rapid temperature fluctuations and excessive vibration.

The inlet port or hose barb must **always** be connected **through a desiccant filter** to the atmosphere.

This instrument should never be mounted in direct sun light. When in use outdoors, it must be installed in a well ventilated instrument shelter.

3.2.3.3.3 Calibration Procedures

Calibration of this instrument should be accomplished within standard laboratory conditions. If such conditions are unavailable, then the instrument should be returned to the manufacturer for calibration.

3.2.3.3.4 Maintenance Procedures

No maintenance of this instrument is required other than general cleaning and replacing the desiccant every two months.

3.2.3.4 Vaisala Model PTA-427 Analog Output Barometer

The PTA-427 is designed to be used in the same enclosure as the datalogger. The enclosure must be vented to the atmosphere and kept dry with desiccant. A two foot power switching cable is supplied to connect the sensor to the datalogger, however if used outside the datalogger a longer cable is required.

The PTA-427 requires 11 to 30 volts DC excitation, and outputs 0-5 volts DC. When used with the Campbell CR10 Datalogger, a 2 to 1 voltage divider is built into the switching cable and is supplied from Campbell Scientific, Inc. (CSI). The voltage divider converts the output from the sensor to 0-2.5 volts.

The PTA-427 uses a silicon capacitive pressure sensor patented by Vaisala. A linear output of 0-5 VDC (0-2.5 when used with the CR10) is proportional to 800 - 1060 millibars (other ranges available). The transmitter is temperature compensated over an operating range of -40° C to 60° C and requires a three-second warm-up time.

3.2.3.4.1 Manufacturer's Specifications

OPERATING RANGE:

PTA-427:	800 to 1060 mB
PTA-427A:	600 to 1060 mB
Temperature Range:	-40°C to 60°C
Humidity Range:	non-condensing

ACCURACY:

PTA-427

Linearity:*	±0.3 mB
Hysteresis:*	±0.03 mB
Repeatability:*	±0.03 mB
Accuracy:**	±0.3 mB
Calibration uncertainty:***	±0.2 mB

ACCURACY, continued:

Total accuracy:	±0.5 mB

PTA-427A	
Linearity:*	±0.6 mB
Hysteresis:*	±0.03 mB
Repeatability:*	±0.03 mB
Accuracy:**	±0.6 mB
Calibration uncertainty:***	±0.2 mB
Total accuracy:	±0.8 mB
Temperature dependence:	
at 1000 mB	±0.02 mB/°C
at 800 mB	±0.08 mB/°C
at 600 mB	±0.12 mB/°C
Systematic offset drift:	+03 mB/year
Effect of thermal and mechanical shock:	less than ±0.3 mB
Dimensions:	5.0 in x 2.7 in x 1.2 in
Weight:	160 g

* Defined as ± standard deviation limits of endpoint non-linearity, pressure hysteresis error and pressure repeatability error.

** Defined as the root sum of the squares of endpoint non-linearity, pressure hysteresis error and pressure repeatability error at room temperature.

*** Defined as ± standard deviation limits of inaccuracy of the primary and working standards in reference to international standards.

3.2.3.4.2 Installation Procedures

The Vaisala PTA-427 should be mounted in the environmental enclosure with the datalogger. As stated earlier the enclosure must be vented to the atmosphere and protected from moisture with an ample supply of active desiccant. The location of the enclosure should be free of rapid temperature changes and vibration. When deployed in the field it should not be mounted in direct sunlight.

The sensor connections are made through a 4 post terminal, designed for connecting stripped wire. The connections are marked; AGND (analog ground), GND (earth ground), VIN (input excitation voltage) and VOUT (output voltage). When this sensor is used with a CSI datalogger it requires a power switching cable with six (6) connecting wires. This cable and instructions will be included when the sensor is supplied by CSI.

3.2.3.4.3 Calibration Procedures

Calibration of this instrument should be accomplished within standard laboratory conditions. If such conditions are unavailable, the instrument should be returned to the manufacturer for calibration.

Output from the PTA-427 is 0-5VDC, which corresponds to 800-1060 millibars (other ranges available). The multiplier and offset used to convert the voltage measurement to millibars of pressure are:

Multiplier = Pressure range/output voltage range

= (1060 mB - 800 mB) / (5000 mV- 0 mV)

= 260 mB / 5000 mV = 0.052

The offset of the PTA-427 sensor is equal to the lower limit of the sensor range (i.e., the sensor range is 800 to 1060 mB, the offset is 800 mB).

The measurement result using a multiplier of 0.052 and an offset of 800 is true barometric pressure in millibars.

The following equation is used to determine the pressure correction factor, which is added to the 800 mB offset to have the output barometric pressure corrected to sea level. Because the barometric pressure is strongly affected by elevation, the elevation of the site should be as accurate as possible.

$$P = 1013.25[1-(1-E/44307.69321)^{5.25328}]$$

where E is the elevation in meters above sea level.

3.2.3.4.4 Maintenance Procedures

No maintenance of this instrument is required other than general cleaning and replacing the desiccant every two months or as required by visual inspection.

4.0 Wind Run, Wind Speed, and Wind Direction Measurement

4.1 Introduction--Wind

4.1.1 Theory

The Earth's rotation and differences in temperature create differences in pressure. These pressure differences drive a complex system of winds in a never ending attempt to reach equilibrium. In order to relate wind to pressure patterns and the movement of weather systems, we must first discuss a few elements of wind and how they relate to pressure. These elements are: convective pressure gradients, and the Coriolis force.

Convective pressure gradients:

These gradients are more commonly known as convective currents. They are created when two adjacent surfaces are heated unequally thus heating the overlaying air unevenly. The warmer air expands and becomes lighter or less dense than the cool air. The more dense or heavy cool air will move toward the warmer area displacing the warm air forcing it upward. An example of this is the daytime winds of coastal Florida. The land surface of Florida will warm faster than the surrounding sea therefore the air above the land will be warmer and less dense than the air above the sea. The cool heavy air over the sea will then move toward the warmer land surface forcing the lower level air above the land upward. This movement of cooler air toward land is called the "sea breeze". Another example of this convective flow is the global circulation of air. Because of the uneven heating of the Earth, surface pressure is low in warm equatorial regions and high in cold polar regions. A pressure gradient develops from the poles to the equator. If the Earth did not rotate, this would be the only force acting on the wind. Circulation would be two giant hemispheric convective currents. Cold air would sink at the poles, and wind would blow straight from the poles to the equator. The warm air at the equator would be forced upward, and high level winds would blow directly toward the poles.

The Coriolis force:

The Earth does rotate and because of this rotation the simple theory of convective circulation is greatly distorted.

A moving mass travels in a straight line until acted upon by some outside force. However, if a moving mass is viewed from a rotating platform, the path of the moving mass appears deflected or curved. To illustrate, start rotating the turntable of a record player. Then, using a piece of chalk, draw a straight line from the center to the outer edge of the turntable. To you, the chalk traveled in a straight line. Now stop the turntable. The line spirals outward from the center as if some "apparent" force acted to deflect the chalk.

A similar apparent force deflects moving particles on the Earth. Because the Earth is spherical, the deflective force is much more complex than the turntable example. Although the force is termed apparent, it is very real. The principle was first explained by a Frenchman, Coriolis and carries his name--the Coriolis force.

The Coriolis force affects the paths of aircraft, flying birds, ocean currents, and most important air currents. This force deflects the air to the right in the Northern Hemisphere and to the left in the Southern Hemisphere. Our discussion of this force will concentrate on the Northern Hemisphere.

The Coriolis force is at a right angle to the wind direction and is directly proportional to wind speed. If wind speed increases the Coriolis force increases. At a given latitude, if the wind speed doubles, the Coriolis force doubles. This force varies with latitude from zero at the equator to maximum at the poles. The force influences wind direction everywhere except at the equator, but the effects are much more pronounced at the higher latitudes.

Remember that the pressure gradient force drives the wind and is perpendicular to isobars. When the pressure gradient force is first established, wind begins to blow from higher to lower pressure directly across the isobars. However, the instant the air starts moving, the Coriolis force deflects it to the right. Soon the air is deflected a full 90° and is parallel to the isobars or contours. At this time, the Coriolis force exactly balances the pressure gradient force. With the forces in balance the wind direction will be parallel to the isobars or contours.

Although there exist a sizable number of elements relating to the makeup of surface wind the Water Management Districts are interested only in the element of wind velocity.

Wind Velocity is a three-dimensional vector quantity that has small random fluctuations superimposed on a larger more organized flow of air. These dimensions are vertical direction, horizontal direction, and rate of flow (speed). For the purpose of these data collection guidelines, the vertical component is disregarded. Therefore surface wind is considered as a two-dimensional vector quantity specified as horizontal wind speed and wind direction.

The rate of air flow or wind is defined in two methods. One is the speed of the wind as in miles per hour (mph). The other is wind run which is the duration in time it takes for a one mile long horizontal column of air to flow past a given point.

Wind direction is defined as the direction **from** which the wind is blowing. This is reported as true wind direction because it is referenced to true north and not to magnetic north.

4.1.2 Instrument Siting and Exposure

Surface wind sensing equipment should be placed 20 ft. above the ground on a well exposed tower over terrain that is level and free from obstructions to wind flow. Obstructions mean hills, trees, buildings or other structures whose height above ground at the exposed site are greater than one tenth their distance from the site.

Sites where topography and/or obstructions are known to create eddy currents or other adverse wind effects should be avoided. If instrument exposure must be compromised, the sensor should be installed at least 12 feet above any obstruction lying within 100 feet and at least as high as any obstruction between 100 and 200 feet of the instruments. Supporting towers should be small and not of such size as to create any appreciably detrimental effect to the pattern of wind flow.

4.1.3 Measurement Standards

The measurement standards of the World Meteorological Organization for wind speed is ± 1 knot with a distance constant of 2 to 5 meters, and for wind direction is ± 5 degrees with a damping ratio of 0.3 to 0.7. In the United States of America, the measurement standards are ± 10% for wind speed and ±5 degrees for wind direction.

4.2 Instrumentation--Wind Speed and Direction

4.2.1 Principle of Operation

Both the cup and propeller type wind speed sensors (anemometers) are used to determine wind speed. Each sensor consists of a rotor subassembly and a signal generating subassembly. In both types of anemometers, the rotation of the rotor is almost proportional to the wind speed. The propeller type sensor is slightly more accurate at lower wind speeds because the wind is parallel with the axial rotation of the rotor. However, considerable deviation from linear will occur at or near the starting threshold.

The ability of the sensor to respond to rapid changes in wind speed varies directly with the moment of inertia of the rotor assembly. In other words the larger the mass of the rotor/cup subassembly the slower the sensor will respond to rapid wind speed changes. This slow response can create a significant error when measuring wind speed directly. When measuring wind run this slower response of the rotor assembly will tend to offset the error because the assembly will respond as slowly to a reduction in speed as it will to an increase in speed.

The optical disc (photo chopper) and the magnetic pulse type signal generators are popular with most equipment users. These generators are simple, long lasting, and do not create any adverse effect upon the moment of inertia of the rotor.

Wind Direction Sensors (wind vanes)

Wind direction is the direction **from** which the wind is blowing. Instruments used for measuring the direction of wind are called wind vanes. These vanes have a relatively long air foil type tail and are mounted on a vertical axis. The lateral force of the wind upon the tail causes the vane to align itself toward the direction from which the wind is blowing. The vane mass relative to tail area will determine the sensitivity of the instrument. A small vane mass with a large tail area will allow the vane to respond to a light wind speed or a subtle change in wind direction.

The vertical shaft of the wind vane drives a linear single turn continuous potentiometer which generates an analog signal proportional to the wind direction.

4.2.2 Maintenance

Maintenance is discussed in the individual sections later in this chapter.

4.2.3 Sensors Used

4.2.3.1 R. M. Young Wind Monitor Model 05103

The Wind Monitor measures horizontal wind speed and direction. Originally developed for ocean data-buoy use, it is constructed of corrosion resistant materials with no slip rings or brushes thereby improving reliability at a lower cost. This instrument houses both the wind speed sensor and the wind direction sensor.

The wind speed sensor is a four-blade helicoid shaped plastic propeller, 18 cm diameter x 30 cm pitch. The propeller rotation produces an AC sign wave or an AC square wave voltage signal with frequency directly proportional to wind speed. The AC sign wave signal is induced in a coil by a six-pole magnet mounted on the propeller shaft. The square wave signal is generated by an optical disc/photo chopper assembly with the disc mounted directly to the propeller shaft. Three complete signal cycles are produced for each propeller revolution.

The wind direction sensor is a precision single-turn continuous potentiometer directly coupled to the vertical vane shaft. With a regulated 5 volt excitation applied to the potentiometer the output signal is an analog voltage directly proportional to the azimuth angle of the vane (Figure 4.1).

Construction is of ultraviolet light-stabilized thermoplastic with stainless steel precision ball bearings. The instrument mounts on a standard 1 inch pipe (1.34 inch OD). An orientation ring is supplied as standard equipment for maintaining direction orientation when the instrument is removed for maintenance.

4.2.3.1.1 Manufacturer's Specifications

Wind Speed:

Operating Range:	0 to 130 mph, gust survival 220 mph.
Sensor:	18 cm diameter 4-blade helicoid propeller molded of polypropylene.
Pitch:	29.4 cm air passage per revolution.
Distance Constant:	2.7 m for 63% recovery
Threshold Sensitivity:	2.2 mph
Transducer:	Centrally mounted stationary coil, 3K ohm nominal DC resistance.
Transducer Output:	AC sine wave signal induced by a rotating magnet on the propeller shaft. 125mV p-p at 100 rpm. 12.5 V p-p at 10,000 rpm.
Output Frequency:	3 cycles per propeller revolution (0.098 meters per Hz)

Wind Direction (Azimuth) Specification Summary:

Operating Range:	360° mechanical, 355° electrical (5° open)
Sensor:	Balanced Vane, 15 inch turning radius.
Damping Ratio:	0.25
Delay Distance:	4.3 feet for 50% recovery
Threshold Sensitivity:	2.2 mph at 10° displacement and 3.4 mph at 5° displacement
Damped Wavelength:	24.3 feet
Undamped Wavelength:	23.6 feet
Transducer:	Precision conductive plastic potentiometer, 10k ohm (±20%), 0.25% linearity, life expectancy 50 million revolutions, rated 1 watt at 40° C, 0 watts at 125° C.
Transducer Excitation:	Regulated DC voltage, 15V max
Transducer Output:	Analog DC voltage proportional to azimuth angle with regulated excitation voltage applied.

4.2.3.1.2 Installation Procedures

When the Wind Monitor is unpacked it should be inspected carefully for any signs of shipping damage. Remove the plastic nut on the propeller shaft and install the propeller onto the shaft with the letters on the propeller facing forward (into the wind). Check the instrument mechanically before installation. The vane and propeller should rotate 360° easily without friction. Check the vane balance by holding the instrument base and vane horizontal. The vane should be balanced, with little tendency to rotate. A slight imbalance will not significantly degrade the performance of the instrument.

Proper placement of the instrument is important. The turbulence created by obstructions can greatly influence surface wind measurements. To get meaningful data, locate the sensor well above or away from obstructions. As a general rule the instrument should be located a minimum of two but preferably four times the height of the obstruction away from the obstruction. Instrument siting should conform to instructions in 4.1.2.

Proper grounding of this instrument is very important. The Wind Monitor is often subjected to certain static charges which without proper grounding would discharge through the transducer. These discharges will often cause erroneous data and can even cause instrument failure. The transducer housing or bottom part of the instrument is made of anti-static material. This housing should be connected to an unpainted mounting post which is connected to a good earth ground. If this cannot be accomplished, then connect the **spare** terminal inside the junction box to a good earth ground. This **spare** terminal is connected to the anti-static mounting post.

Initial installation is most easily accomplished by using two people, one to adjust the instrument and the other to observe the data. After initial installation, the instrument may be removed and reinstalled without realigning the vane since the orientation ring maintains the wind direction reference.

Install the Wind Monitor according to the following directions:

1. Mount Wind Monitor:

   A. The mounting post should be extended such that the Wind Monitor will be

   B. Place the orientation ring on the mounting post with the alignment pin pointing up. Do not tighten the band clamp yet.

   C. Place Wind Monitor on the mounting post. Do not tighten the band clamp yet.

2. Connect Sensor Cable:

   A. Slide the instrument junction box cover up.

   B. Route cable through the strain relief opening at the bottom of the junction box. Secure the cable by tightening the packing nut.

   C. Connect the sensor cable to the terminal strip as per wiring diagram (Figure 4.2). Excitation voltage applied to the wind direction potentiometer **must not exceed 15 VDC.**

   D. Slide the junction box cover closed when connections are properly secured.

3. Align Vane:

   A. Connect the instrument to an indicator (monitor, logger, recorder, etc.).

Figure 4.1 Curve of Wind Speed vs Propeller RPM and Output Frequency, R. M. Young Wind Monitor

B. Choose a known wind direction reference on the horizon. For instance, while siting through the vertical sensor support, look through your compass at a prominent land mark and note the heading.

C. Sighting down the vane centerline, point the nose at the reference point on the horizon.

D. While holding the vane in position, slowly turn the base until the indicator shows the proper value representing the heading noted in (b) above.

Note: This vane alignment is referenced to magnetic north and not true north. The magnetic declination in Florida is approximately 1° and well inside instrument accuracy.

E. Tighten the mounting post band clamp.

F. Engage the orientation ring indexing pin in the notch on the instrument base.

G. Tighten the orientation ring band clamp.

4.2.3.1.3 Calibration Procedures

The Wind Monitor is fully calibrated at the factory and should require no adjustments after shipment. Periodic calibrations may be necessary where the instrument is used in programs where auditing of sensor performance is required. Consult manufacturer's instruction manual for additional information.

4.2.3.1.4 Maintenance Procedures

Given proper care the Wind Monitor should give years of service. Inspect the propeller and vane for freedom of movement at each routine maintenance visit. The only components needing replacement due to normal wear are the precision ball bearings and the wind direction potentiometer. Only qualified instrument technicians should perform these replacements. Refer to Figures 4.3 and 4.4 to become familiar with part names and locations.

NOTE: Maximum torque on all set screws 80 oz-in.

Figure 4.2Wind Monitor Wiring Diagram

Potentiometer Replacement:

The potentiometer has a life expectancy of fifty million revolutions. As it becomes worn, the wiper may begin to produce a noisy or non-linear signal. When this condition becomes unacceptable replace the potentiometer.

1. Remove main housing:

    A. Unscrew nose cone from main housing. Set o-ring aside for later use.

    B. Gently push main housing latch.

    C. While pushing latch, lift the main housing up and remove it from the vertical shaft bearing rotor.

2. Un-solder transducer wire:

    A. Slide junction box cover up exposing the circuit board.

    B. Remove screws holding circuit board.

    C. Un-solder three potentiometer wires (white, green, and black), two wind speed coil wires (red and black), and earth ground wire (gray) from the board.

3. Remove potentiometer:

    A. Loosen set screw on the potentiometer coupling and remove it from the potentiometer adjustment thumbwheel.

    B. Loosen the set screw on the potentiometer adjust thumbwheel and remove it from the potentiometer shaft extension.

    C. Loosen two set screws at base of transducer assembly and remove assembly from vertical shaft.

    D. Unscrew potentiometer housing from potentiometer mounting and coil assembly.

Figure 4.3 Wind Monitor Mechanical Cut-through Drawing

Figure 4.4 Wind Monitor Assembly Drawing

E. Push potentiometer out of mounting and coil assembly by applying firm but gentle pressure on potentiometer shaft extension. Set o-ring aside for later use.

F. Loosen set screw on the potentiometer shaft extension and remove it from the potentiometer shaft.

4. Install new potentiometer:

A. Place potentiometer shaft extension with o-ring on new potentiometer (gap 0.040") and tighten set screw to 80 oz-in.

B. Push new potentiometer into mounting and coil assembly.

C. Feed potentiometer and coil wires through hole in bottom of potentiometer housing.

D. Screw potentiometer housing into mounting and coil assembly.

E. Gently pull transducer wires through bottom of potentiometer housing to take up slack. Apply a small amount of silicone sealer around hole.

F. Install transducer assembly on vertical shaft allowing 0.020" clearance from vertical bearing. Tighten set screws at bottom of transducer assembly.

G. Place potentiometer adjust thumbwheel on potentiometer shaft extension and tighten set screw. (80 oz-in).

H. Place potentiometer coupling on potentiometer adjust thumbwheel. Do not tighten set screw.

5. Reconnect transducer wires:

A. Using needle-nose pliers or a hook bent paper clip to pull transducer wires through hole in junction box.

B. Solder the wires to the circuit in the junction box according to the wiring diagram. Observe color code.

C. Secure circuit board in junction using two screws removed in step 2B. Do not overtighten.

6. Replace main housing:

A. Place main housing over vertical shaft bearing rotor until potentiometer coupling is near top of main housing. Be careful to align indexing key and channel in these two assemblies.

B. Turn potentiometer adjust thumbwheel until potentiometer coupling is oriented to engage ridge in top of main housing. Set screw on potentiometer coupling should be facing the front opening.

C. With potentiometer coupling properly oriented, continue pushing main housing onto vertical shaft bearing rotor until main housing latch locks into position with a "click".

7. Align vane:

A. Connect excitation voltage and signal conditioning electronics to terminal strip according to wiring diagram.

B. With mounting post held in position so junction box is facing due South, orient vane to a known angular reference.

C. Through the main housing, turn the potentiometer adjust thumbwheel until the signal indicates the proper value.

D. Tighten the set screw on the potentiometer coupling.

8. Replace Nose Cone:

A. Screw the nose cone into the main housing until o-ring seal is seated. Be certain threads are properly engaged to avoid cross-threading.

Flange Bearing Replacement:

If the anemometer becomes noisy or if the wind speed threshold increases above acceptable levels, the bearings need replacing. A rough check of the bearing status can be performed by adding an ordinary paper clip to the propeller. While holding the propeller blade with the paper clip parallel to the ground and carefully releasing it, the propeller should rotate; failure to rotate indicates a need for bearing replacement. Repeat the test with the paper clip on different blades until the bearing has completed a full revolution.

1. Remove Old Bearings:

A. Unscrew nose cone. Do not lose o-ring seal.

B. Loosen set screw on magnet shaft collar and remove the magnet.

C. Slide the propeller shaft out of the nose cone assembly.

D. Remove the front bearing cap which covers the front bearing.

E. Remove both the front and rear bearings from the nose cone assembly. Insert the edge of a pocket knife under the flange and lift it out.

2. Install new bearing:

A. Insert new front and rear bearings into the nose cone.

B. Replace the front bearing cap.

C. Carefully slide the propeller shaft through the bearings.

D. Place the magnet on the propeller shaft allowing 0.020 inches clearance from the rear bearing.

E. Tighten the set screw on magnet shaft collar.

F. Screw nose cone into the main housing until o-ring seal is seated. Be careful that threads are properly engaged to avoid cross-threading.

Vertical Shaft Bearing Replacement:

The vertical shaft bearings are much larger than the speed bearings and will not require replacement as often. A rough test of these bearings is performed by holding the wind monitor and vane horizontal to the ground. Tape a U.S. penny to the outside edge of the tail. The vane should rotate. Change the vertical bearings if the tail does not rotate. Repeat the test at different positions to check full bearing rotation.

Consult the manufactures instruction manual for replacement directions.

Adjustment Procedures

This instrument is factory-adjusted, and therefore no adjustments are required other than those explained in the maintenance and calibration instructions.

4.2.3.2 R. M. Young Wind Sentry Model 03001

The Wind Sentry Anemometer and Vane measure horizontal wind speed and direction. The cup wheel and vane shaft uses stainless steel precision ball bearings. These bearings have light contacting seals to reject contamination and help retain lubricant for longer service life.

The anemometer cup wheel rotation produces an AC sine wave signal which is directly proportional to wind speed. This AC signal is induced in a stationary coil by a two pole magnet mounted on the cup wheel shaft. One complete sine wave cycle is produced for each cup wheel revolution.

Wind vane position is transmitted by a one-turn 10,000 ohm precision plastic potentiometer is directly coupled to the vane shaft. A precision 5 volts is applied across the electric ends of the potentiometer thus generating an analog output signal voltage directly proportional to azimuth angle.

These sensors are installed on an anodized aluminum crossarm which mounts on a vertical standard one inch pipe, with an outside diameter of 1.34 inches. The crossarm is secured to the pipe by a stainless steel band-clamp. These sensors are connected directly to the data logger.

4.2.3.2.1 Manufacturer's Specifications

Wind Speed Specification Summary

Operating Range:	0 to 112 mph, gust survival 134 mph
Sensor:	12 cm diameter cup wheel assembly, 40 mm diameter hemispherical cups
Turning factor:	2.46 feet
Distance Constant (63%):	7.5 feet
Transducer:	Stationary coil, 1350 ohm nominal resistance
Transducer Output:	AC sine wave signal induced by rotating magnet on cup wheel shaft 100 mV p-p at 60 rpm. 6 volt p-p at 3600 rpm.
Output Frequency:	1 cycle per cup wheel revolution. 0.75 meters per second per hertz.

Wind Direction Specification Summary

Range:	360° mechanical, 355° electrical (5° open)
Sensor:	Balanced vane, 16 cm turning radius
Damping Ratio:	0.2
Delay Distance (50%):	1.6 feet
Threshold:	2.9 mph at 10° displacement 4.2 mph at 5° displacement
Transducer:	Precision conductive plastic potentiometer, 10,000 ohm, ± 20% resistance 0.5% linearity, life expectancy 50 million revolutions. Rated 1 watt at 40° C, 0 watts at 120° C.

Transducer Excitation:	Regulated 5 volts. Maximum 15 VDC
Transducer Output:	Analog DC voltage proportional to wind direction angle with regulated excitation voltage applied across potentiometer

4.2.3.2.2 Installation Procedures

Proper placement of the instrument is important. The turbulence created by obstructions can greatly influence surface wind measurements. To get meaningful data, locate the sensor well above or away from obstructions. As a general rule the instrument should be located a minimum of two but preferably four times the height of the obstruction away from the obstruction. Instrument siting should conform to instructions in 4.1.2.

Proper grounding of this instrument is very important. The Wind Sentry is often subjected to certain static charges which without proper grounding would discharge through the transducer. These discharges will often cause erroneous data and can even cause instrument failure. The transducer housing or bottom part of the instrument is made of anti-static material. This housing should be connected to an unpainted mounting post which is connected to a good earth ground. If this cannot be accomplished, then connect the **spare** terminal inside the junction box to a good earth ground. This **spare** terminal is connected to the anti-static mounting post.

Initial installation is most easily accomplished by using two people, one to adjust the instrument and the other to observe the data.

Follow the instructions below for installation of the Wind Sentry (refer to Figure 4.5).

Figure 4.5   R. M. Young Wind Sentry Cable and Wiring Diagram

1. MOUNT WIND SENTRY

   A. Mount sensors onto crossarm.

   B. Place crossarm onto vertical mounting post. Do not tighten band clamp yet.

   C. Connect sensor cables.

2. ALIGN VANE

   A. Select a known azimuth reference point on the horizon while siting through the vertical sensor support.

   B. Sighting down the vane centerline, point the counterweight toward the reference point on the horizon.

   C. While holding the vane in position, slowly turn the base or crossarm until the display (or logger) indicates the proper value. The wind direction of the crossarm should then be pointing north.

   D. Tighten sensor in base (or post band clamp).

4.2.3.2.3 Calibration Procedures

The Wind Sentry is fully calibrated at the factory and should require no adjustments. Perform field calibration as follows:

With the crossarm pointing north-south and the sensor connected to the signal conditioning unit, point the counterweight south along the crossarm. This should result in the signal conditioner or data logger indicating a value of 180°. Rotate the vane clockwise in 45° increments and observe that the signal conditioner follows in the proper direction.

Adjustment Procedures:

No field adjustments are required for this instrument.

4.2.3.2.4 Maintenance Procedures

The Wind Sentry is made entirely of non-corrosive materials and requires little maintenance. The components most likely to need replacement are the ball bearings and potentiometer. Refer to Figures 4.6 and 4.7 to become familiar with part names and locations before attempting component replacement.

NOTE: Maximum torque on all set screws is 80 oz-in.

Potentiometer Replacement

If the potentiometer begins to produce noise or becomes non-linear then replacement is required. Replace as follows:

1. Remove Potentiometer:

    A. Remove three screws which secure the upper and lower sections of main housing.

    B. **Carefully** remove the upper housing exposing the wiring connections to the circuit board.

    C. Un-solder the potentiometer wires from the circuit board. Note color coding.

    D. Using a knife blade, loosen potentiometer assembly from the upper housing and slide out.

2. Install New Potentiometer

    A. Slide new potentiometer assembly into upper housing. Be sure to engage the assembly key into the housing notch.

    B. Solder the potentiometer wires to the circuit board being sure to observe color code.

    C. Join the two sections of the housing. Secure with the screws removed in step 1A.

Figure 4.6 Wind Sentry Cup Wheel Anemometer and Vane Section View

Figure 4.7 Wind Sentry Vane/Anemometer Replacement Parts

3. Align Vane
   A. Connect excitation voltage and signal conditioning unit to the sensor as per wiring diagram in 4.2.3.2.3

B. Loosen the set screw in the side of the vane hub.

C. Position the sensor such that the crossarm is oriented north-south with the vane on the north side. Orient the vane to a known reference.

D. While holding the vane in the reference position, slowly turn the vane skirt until the signal conditioning unit indicates the proper value.

E. Tighten the set screw in the side of the vane hub. **Do not over-torque**.

Anemometer Flange Bearing Replacement:

Bearing replacement is required when they become noisy or the wind speed threshold increases above an acceptable level. A rough test for speed threshold is to attach an ordinary paper clip to the **outside** edge of one of the cups. While holding the sensor housing horizontal the weight of the paper clip should cause the cups to rotate. If not, change the bearing.

1. Remove Bearings

   A. Loosen set screw on the side of the cup wheel hub. Remove the cup wheel.

   B. Remove three screws holding the two sections of main housing.

   C. Carefully separate upper and lower housing. Remove coil transducer assembly from upper housing. Do not disconnect from circuit board.

   D. Loosen screw and remove ring magnet on end of shaft inside upper housing.

   E. Slide shaft and skirt assembly out of both upper and lower bearings.

   F. Using knife edge under bearing flange, carefully remove upper bearing.

   G. Using a pencil, gently push out lower bearing from above.

2. Install New Bearing

A. Insert new upper bearing. Use care not to apply excessive pressure.

B. Slide cup wheel shaft through upper bearing.

C. Slide lower bearing on shaft inside upper housing.

D. Using ring magnet assembly, push lower bearing into its seat in upper housing.

E. Secure ring magnet to shaft using screw loosened in step 1D. Use a sealant on screw to keep it from loosening.

F. Join two housing sections. Secure using three screws loosened in step 1B.

G. Place cupwheel on shaft. Tighten set screw on side of hub. **Do not over-torque**.

Vane Flange Bearing Replacement

If bearings become noisy or if the wind direction threshold increases by an acceptable level, replace the bearings.

Bearing replacement in the vane is almost identical to that in the anemometer except for vane alignment. See calibration for vane alignment.

4.2.3.3 Qualimetrics Skyvane Model 2100

The Model 2100 Skyvane is a wind sensor that combines the features of a heavy-duty rugged instrument with response characteristics similar to those of a lightweight cup and vane. The aerodynamic shape of the sensor maintains alignment with wind direction. A four-bladed, low-threshold propeller is used to measure wind velocity.

The propeller of the skyvane sensor is connected to an HF tachometer with the output fed into the wind speed portion of the translator. Wind direction is sensed by a potentiometer located in the base of the Skyvane, providing a voltage output corresponding to sensor direction.

The Skyvane is a heavy-duty wind sensor suited for installation in severe environments. A flanged base provides a mounting surface for platforms and decks. A separate adaptor, Model 21101 can be purchased to mount the sensor with 1.25 inch I. D. pipe (1.5 inch O.D.). the sensor provides outputs compatible with electronic signal conditioning modules and data logging equipment.

4.2.3.3.1 Manufacturer's Specifications

Wind Speed Summary:

Range:	200 mph
Starting threshold:	2 mph
Complete tracking:	3 mph
Distance constant:	6.2 ft.
Accuracy:	± 1 mph < 30 mph;
	± 3% > 30 mph
Sensor output:	461.3 Hz
Propeller:	4-blade; 13.75" dia.

Wind Direction Summary:

Range:	0 to 360 degrees
Accuracy:	± 1% of full scale
Sensor output:	0 to 5000 ohms
Potentiometer:	Conductive plastic, single wiper, shorting contact

General:

Size:	29.75"L x 30"H
Weight/Shipping:	12 lbs/25 lbs

4.2.3.3.2 Installation Procedures

When the sensor is unpacked it should be inspected carefully and refer to the return authorization card included in the packing box if damage has occurred. When transporting, packing, and unpacking the sensor, always grasp the main support shaft with one hand and the tail assembly with the other hand. Supporting the tail is necessary to prevent it from swinging freely and becoming damaged. The propeller is very fragile. Do not drop or impact the propeller.

The sensor is shipped without the propeller attached. To attach the propeller, first remove the retaining screw from the sensor shaft. Second, slide the propeller onto the shaft and align the slot in the propeller hub to the key on the shaft. Finally, re-install the retaining screw tightly, but do not overtighten.

Attach the sensor cable from the sensor to the datalogger. Verify correct sensor operation prior to final installation. This instrument is thoroughly tested and carefully calibrated at the factory and is ready for installation. Refer to the appropriate instruction manuals for operating this sensor with electronic recorders or dataloggers. Section 4.2.3.3.3 of this manual contains calibration information for this sensor. The desired cable is a five-conductor, shielded, PVC-jacketed, size 20 AWG cable and is provided by Qualimetrics when ordered with the sensor.

The sensor can be attached to the top of a wooden pole or to a pipe support with a drilled top plate. Take care to make the sensor exactly vertical, otherwise a biased indication of direction will result. The mounting hole opposite the connector is oriented south with respect to the direction sensor contained in the unit. The unit is designed so that when the hole faces south and the connector faces north, the direction measured by the sensor is true relative to this north-south orientation. Select a distant object that is directly north or south of the site and align the sensor. A transit located directly north of the instrument can be used to sight the connector on the base or the scribe line on the upper sensor body. The scribe lines are located on the sensor housing on the support shaft where the two faces meet. When the scribe lines are aligned, the sensor points to north, and the lines will be on the north side of the sensor.

4.2.3.3.3 Calibration Procedures

Each sensor has been factory calibrated before shipment and is ready for installation. The following steps describe how to calibrate the Skyvane.

Wind speed calibration is accomplished by removing the propeller and driving the shaft at a known RPM by means of a synchronous motor calibrating unit. This calibration is accomplished in the laboratory prior to field installation.

The wind speed transducer output wires should be connected to a wind speed module such as Model 1275. Otherwise a +12 Volt DC regulated supply must be attached to the sensor and the output monitored with a frequency counter or an oscilloscope.

The wind direction transducer can be aligned using the following procedure. Remove the side cover of the sensor. Loosen the set screw that holds the coupling to the main shaft, not the transducer shaft. Align the tail assembly to north by lining up the two scribe lines on the sensor. Rotate the coupling and transducer shaft assembly until the gap is found in the potentiometer or the indicator aligns with north. Tighten the set screw at the top of the coupling. Replace the side cover. The potentiometer will read 4995 ohms or more before shorting to zero ohms. Try to hold the sensor as close to the shorting point as possible.

4.2.3.3.4 Maintenance Procedures

This instrument should operate for an extended period of time with a minimum of care and maintenance. The only periodic maintenance which may be required is the application of oil to the felt washer behind the propeller. Frequency of application is dependent upon the environmental conditions to which the instrument is subjected, but it should not be required more than once a year. If trouble should occur, refer to the drawings supplied with the instrument to isolate the problem. If parts or maintenance are required, contact the factory.

Disassembly and re-assembly of the Skyvane is sometimes required for inspection or repair and can be accomplished easily and quickly using the instructions in the following paragraphs.

1. Removal of Propeller

   To remove the propeller, first remove the propeller retainer screw. The propeller can now be slipped forward from the wind speed transducer shaft.

2. Removal of Wind Speed Transducer

   With the propeller and propeller retainer screws removed as described above, the transducer mounting screws will be exposed. Remove the transducer mounting screws, and the transducer may be pulled slowly from the upper housing. When the transducer is just clear of the housing, it is necessary to unsolder the wiring connections behind the transducer before it can be completely removed.

3. Removal of Wind Direction Transducer

   Remove 3 screws from the bottom cover, and remove the bottom cover from the lower housing. Remove the two front cover retaining screws and remove the front cover. Loosen the upper set screws from the coupling. Remove the 3 transducer mounting screws and slowly remove the transducer from the lower housing. Remove the 4 electrical connector mounting screws from around the bulkhead receptacle, and then remove this receptacle from the lower housing. Unsolder the wind direction transducer wires from this connector. The wind direction transducer may now be completely removed as the wires are withdrawn through the lower housing.

4. Removal of Slip Ring Brushes

   After the above procedure has been performed, the slip ring brushes may be removed by first removing the two mounting screws and then withdrawing the brush assembly. The wires from the assembly must be unsoldered before it can be completely removed. This can be done at the electrical connector or at the terminals on the brush assembly.

Items Requiring Factory Disassembly

Removal and replacement of the slip rings must be done at the factory, because rerouting of the wires from the slip rings to the wind speed transducer requires removal of the upper housing. Removal of the upper housing must be done at the factory because special bearing setting procedures are required.

Re-assembly can be accomplished by following the above procedures in reverse order.

4.2.3.4 Belfort Model 5-349C Totalizing Anemometer

This anemometer measures wind passage and is available in one of three calibrations - statute miles, knot, or kilometers, and with one of two styles of unit-switch actuation.

In essence, the totalizing anemometer is a pair of switches and a 5-digit odometer which are wind-operated. Passage of the wind past the anemometer causes rotation of the 3-cup rotor which is attached to a vertical spindle supported in the anemometer housing. The spindle in turn is connected to the pair of switches and the odometer through appropriate gearing. The switches and the odometer are contained in a mechanism which is removable as a complete assembly from the anemometer housing.

This series of anemometers is available to be coupled with two forms of recorders. A wheel for recorder application that actuates the unit-switch carries ten equally spaced pins. Where the anemometer is to be used with a triple or quadruple register or an Esterline-Angus Model A event-recorder, two adjacent pins of the ten are bridged to produce a relatively long switch closure so as to identify the passage of ten units of wind. However, where the anemometer is to be used with Belfort's Cat. No. 6081 Event Recorder, the bridge is omitted and the ten pins will all produce switch closures of equal length.

4.2.3.4.1 Manufacturer's Specifications

Operating Range:	not known
Sensor:	6.303" (16 cm) radius cup wheel assembly, 4.5" (11.4 cm) diameter hemispherical cups
Switch Closure:	each unit or 1/60 unit of wind passage
Contact Rating:	0.6 amp @ 24 Volt DC/AC

4.2.3.4.2 Installation Procedures

Proper placement of the instrument is important. The turbulence created by obstructions can greatly influence surface wind measurements. For general wind observations, select a location that provides unobstructed exposure to winds from all directions. Where the anemometer is part of an evaporation station, consult the updated technical publication for appropriate anemometer location.

For shipping purposes, the 3-cup rotor is removed from its spindle and is replaced with a phenolic spacer. When ready to mount the anemometer, remove the acorn nut from the anemometer spindle. Remove the phenolic spacer from the spindle and set it aside for future reuse. Place the rotor on the spindle and tighten the setscrew just enough to prevent the spindle from rotating as the acorn nut is tightened against the rotor hub. Then the anemometer is fastened to the ½" IPS pipe by hex-head capscrew.

4.2.3.4.3 Calibration Procedures

The anemometer is fully calibrated at the factory and should require no field adjustments.

4.2.3.4.4 Maintenance Procedures

The anemometer should be serviced at least twice a year. A routine servicing schedule should include the following procedures.

1. Cleaning

   A. Disassemble the anemometer sufficiently so as to be able to remove dirt and gummy oil from all critical surfaces. Use only Varsol or similar, approved petroleum-based solvent to clean the anemometer.

   B. Before reassembling the anemometer, check all critical parts for excessive wear and damage; replace or repair as necessary.

   C. Clean switch contacts by rubbing lightly with very fine sandpaper; wipe clean with a lint-free cloth.

2. Re-oiling:

   A. During reassembly, add a drop of instrument grade oil at the following locations: worm threads, worm wheel shaft bearings, upper spindle bearing, and spindle thrust bearing.
   B. Do not over-oil; keep oil away from the spindle switch contacts.

4.2.3.5 Weathermeasure Model 2510 Totalizing Anemometer

The Weathermeasure Model 2510 and 2511 totalizing anemometers are equipped with a cup assembly that consists of three hemispherical, beaded cups. Driven by the wind passage the cup assembly in turn drives a spindle that, through a worm gear, increments a counter. An electrical contact in the form of a reed switch is also provided.

The counter and switch assembly are located inside the instrument with the counter visible through a viewing window. The gearing is arranged to measure the wind passage in statute miles (Model 2510) or kilometers (Model 2511). The counter registers in units and tenths of a unit.

The electric contact in the form of a reed switch is activated by a magnet mounted on an idler gear. The contact is closed once per revolution of the gear. The counter is not resettable and therefore requires a reading at the beginning and ending of each observation period. Record the reading at the beginning of the period along with the starting time. Each time a reading is made, the reading time should also be recorded. The average wind speed for a given period can then be determined.

4.2.3.5.1 Manufacturer's Specifications

Maximum Speed:	100 mph (160 km/hr)
Starting Speed:	1 - 2 mph (1.6 - 3.2 km/hr)
Sensor:	3-cup, 4" diameter, brass, conical and beaded shape
Cup Constant:	869 Rev/mile (540 Rev/km)
Resolution:	0.1 mile (0.1 kilometer)
Electrical Contact:	Reed switch
Contact Rating:	0.4 amp @ 24 VDC

4.2.3.5.2 Installation Procedures

Select a location for the anemometer that provides the best available exposure to winds from all directions. Avoid locations shielded by nearby objects that will set up swirls or updrafts. Consult Section 4.1.2 for further instruction.

Mount the cup assembly on the spindle. After the nut and acorn nut are installed, spin the cup assembly by hand to determine if it turns freely.

Mount the anemometer on a suitable support. Typically the base is bolted to the wooden platform supporting the evaporation pan or to a wooden post. A mounting adapter can be used for applications requiring a pipe support.

If a Model 6422 electro-mechanical event counter or similar device is to be used for remote accumulation of wind run, the electrical contact cable can then be easily wired to the anemometer.

4.2.3.5.3 Calibration Procedures

Calibration of this instrument is not required, since it is factory calibrated and has a fixed gear train.

4.2.3.5.4 Maintenance Procedures

The anemometer should be inspected every six months unless experience shows that the exposure is so favorable that longer service periods are in order. On the other hand, some atmospheres are so highly corrosive that more frequent inspection is necessary. If the inspection shows that mechanism is corroded or extremely dirty, more than a routine service operation is required, the instrument should be dismantled and thoroughly cleaned. Refer to the Section 4.2.3.4.4 The instrument bearings should also be replaced if noisy or if the starting threshold is too high.

5.0 Atmospheric Temperature and Moisture Measurements

5.1 Introduction--Atmospheric Temperature and Moisture

5.1.1 Theory

Sensors for the measurement of atmospheric temperature and moisture are often housed in the same instrument enclosure. Therefore measurements of these parameters will be covered in this same chapter but the parameters will be introduced individually.

Surface Temperature

Heat and temperature are not the same, but they are related. Temperature is measured with a thermometer. The liquid (mercury or colored alcohol) sealed in a thermometer expands and contracts with the addition or removal of heat.

Heat is a form of energy. When a substance contains heat, it exhibits the property we measure as temperature (the degree of hotness or coldness). A specific amount of heat absorbed by or removed from a substance raises or lowers its temperature a definite amount. The amount of temperature change however, depends on the conductivity of the substance. Each substance has its unique temperature change for a specific change in heat. For example, if a land surface and a water surface have the same temperature and an equal amount of heat is added, the land surface becomes hotter than the water surface. Conversely, with equal heat loss, the land becomes colder that the water. This indicates that the land is a better temperature conductor than water.

The Earth receives energy from the sun in the form of radiation. The Earth's atmosphere reflects about 55 percent of this radiation; the remaining 45 percent is absorbed and converted to heat. The Earth, in turn, radiates energy. This radiated energy is known as "terrestrial radiation". The world-wide average heat gained from incoming solar radiation must equal the world-wide average heat loss through terrestrial radiation in order to keep the Earth from getting hotter or colder. However, regional and local imbalances occur which create temperature variations that must be considered.

Diurnal Variation

Diurnal variation is the change in temperature from day to night, and is brought about by the rotation of the Earth. The Earth gains heat during the day by absorbing solar radiation, but continually loses heat by terrestrial radiation. The amount of heating and cooling depends on the imbalance between solar and terrestrial radiation. During the day solar radiation exceeds terrestrial radiation, and the surface becomes warmer. At night, solar radiation ceases, but terrestrial radiation continues and cools the surface. Cooling continues after sunrise until solar radiation equals or exceeds terrestrial radiation. Minimum temperatures usually occur within the first hour after sunrise.

Seasonal Variation

In addition to its daily rotation, the Earth revolves in a complete orbit around the sun once each year. Since the axis of the Earth tilts in relation to the plane of orbit, the angle of incident solar radiation varies seasonally between the hemispheres. The Northern Hemisphere is warmer in June, July, and August because it receives more solar energy than the Southern Hemisphere. During December, January, and February, the Southern Hemisphere receives more solar radiation and is warmer than the Northern Hemisphere.

Latitude Variation

The shape of the Earth causes a geographical variation in the angle of incident solar radiation. Since the Earth is essentially spherical, the sun is more nearly overhead in equatorial regions that at higher latitudes. Equatorial regions, therefore, receive the most radiant energy and are warmest. The slanting rays of the sun at higher latitudes deliver less energy over a given area, with the least being received at the poles. Thus, temperature varies with latitude from the warm equator to the cold poles.

Topographic Variation

Water absorbs and re-radiates energy with less temperature change than does land. Large, deep bodies of water tend to minimize temperature changes, while land favors large changes. Wet soil such as that in swamps and marshes is almost as effective as water in suppressing temperature changes. Thick vegetation tends to control temperature changes since it contains some water and insulates against heat transfer between the ground and atmosphere. Arid, barren surfaces permit the greatest temperature changes.

To compare a land/water variation, consider Abilene, Texas and southern California near San Diego. In the interior of Texas, the July average temperature is about 85°F and the January average is about 40°F, a seasonal range of about 45°F. Near San Diego, due to the proximity of the Pacific Ocean, the July average is about 70°F and the January average about 50°F. The seasonal variation here is only about 20°F.

Atmospheric Moisture

Water evaporates into the air and becomes an ever-present but variable constituent of the atmosphere called **water vapor.** Water vapor is invisible, however it can be readily measured and expressed in different terms. Two commonly used terms are relative humidity and dew point temperature.

Relative Humidity

Relative humidity is routinely expressed in percent. As the term suggest, relative humidity is "relative". It relates the actual water vapor present to that which could be present if the air were saturated with water vapor.

Temperature is the constituent which largely determines the maximum amount of water vapor a given volume of air can hold. Warm air can hold more water vapor than cold air. Relative humidity expresses the degree of saturation. Air with 100 percent relativity humidity is saturated, while less than 100 percent is unsaturated.

Dew Point Temperature

Dew point temperature is the temperature to which the air must be cooled in order to become saturated by the water vapor already present in the air.

The Spread

The "Spread" is a popular term defined as the difference between the air temperature and the dew point temperature. As the spread decreases the relative humidity increases and is 100 percent when the air temperature and dew point temperature are equal. The spread is important in predicting precipitation but has little bearing on the amount. To support precipitation, air must be saturated through thick layers aloft.

Sometimes the spread at ground levels is quite large while at high altitudes the air is saturated and clouds form. These clouds may form water droplets large enough to fall toward the ground as precipitation. The larger droplets will reach the ground while the smaller ones will evaporate as they fall into drier air. Our never ending weather cycle depends upon this continual reversible change of water from one state (water) to another (water vapor).

Change of State

Evaporation, condensation, sublimation, freezing, and melting are all changes of state. Evaporation is the changing of liquid water to invisible water vapor. Condensation is the reverse process. Sublimation is the changing of ice directly to water vapor, or water vapor to ice, bypassing the liquid state in the process. Snow or ice crystals are examples of sublimation of water vapor directly to the solid state. The freezing and melting processes need no explanation.

Latent Heat

Any change in state involves a heat transaction with no change in temperature. Evaporation requires heat energy that comes from the nearest heat source. This heat energy is called the "latent heat of evaporation", and its removal cools the source it comes from. An example is the cooling of your body by the evaporation of perspiration.

What becomes of this heat energy used by evaporation? Energy can neither be created nor destroyed, so it is hidden or stored in the invisible water vapor. When the water vapor condenses to liquid water or sublimates directly to ice, the energy originally used in evaporation reappears as heat and is releases to the atmosphere. This heat is "latent heat" and is quite significant. Melting and freezing involve the exchange of "latent heat of fusion" in a similar manner.

Dew and Frost

During clear nights with little or no wind, vegetation often cools by radiation to a temperature at or below the dew point of the adjacent air. Moisture then collects on the leaves just as it does on a pitcher of ice water in a warm room. Heavy dew often collects on grass and plants but not on pavement or large solid objects. These more massive objects absorb more heat energy during the day and give up this energy more slowly during the night and cool to the dew point only on rare occasions.

Frost forms in much the same way as dew. The difference is that the dew point of the surrounding air must be 32°F or colder. Water vapor then sublimates directly to ice crystals or frost rather than condensing to dew. Sometimes dew forms and then later freezes; however, frozen dew is hard and transparent while frost is white and opaque.

5.1.2 Instrument Siting and Exposure

Surface air temperature refers to the free air at a height of 1.25 to 2 meters above ground level. A representative reading of the air temperature can be obtained only if the sensor is well protected from the sun, sky, earth, and any surrounding objects. At the same time, the sensor should be adequately ventilated. The landscaping beneath the sensor should be representative of the surrounding area.

These sensors should not be installed on a steep slope, in a sheltered hollow, or in an area that becomes shaded. Do not install closer to an obstruction than four times the height of the obstruction (trees, fence, building etc.). Install sensors no less than 100 feet away from any area having extensive concrete or paved surfaces.

These sensors must be installed inside a ventilated housing or shelter which is designed specifically for the purpose of shielding against radiated heat energy.

5.1.3 Measurement Standards

The World Meteorological Organization (WMO) recommends that the following manufacturing tolerance requirements for thermometers not be exceeded:

Item	**Temperature Range (Degrees, Celsius)**	**Maximum Tolerance**
Max. Thermometers	Above -18° C	±0.2
	Below -18° C	±0.3
Min. Thermometers	Above -18° C	±0.3
	-18° to -35° C	±0.6
	Below -35° C	±0.8
Ordinary Thermometers	Above 0° C	-0.2 to +0.1
(Mercury in glass, etc)	Below 0° C	-0.3 to +0.2
Change of error in an	Above 0° C	0.2
interval of 17° C	Below 0° C	0.3

The World Meteorological Organization (WMO) recommends that the following manufacturing tolerance requirements for humidity measuring instruments not be exceeded:

Instrument and Quantity	**Sensitivity**	**Accuracy**
Sling Psychrometer		
Wet-bulb temperature	0.1° C	0.5° C
Dry-bulb temperature	0.1° C	0.5° C
Aspirated Psychrometer		
Wet-bulb temperature	0.02° C	0.1° C
Dry-bulb temperature	0.02° C	0.1° C
Dew/frost-point Hygrometer	0.05° C	0.25° C
Mechanical Hygrometer		
Relative humidity	1%	5%
Dew cell (dew-point temp)	0.5° C	2.0° C
Electric Hygrometer		
Relative humidity	0.5%	2.0%

5.2 Instrumentation--Temperature Sensors

5.2.1 Principle of Operation

Principles of operation vary with the instrument type and are discussed within the individual instrument section.

5.2.2 Maintenance

Maintenance requirements vary with the instrument type and are discussed within the individual instrument section.

5.2.3 Sensors Used

5.2.3.1 Sierra-Misco Model 5050T Temperature Sensor

The 5050T Temperature Sensor consists of a 5050T-SC signal conditioning unit and a 5050T temperature probe and is designed to measure ambient air temperature. The probe is a semiconductor device with internal conductance changes which are directly proportional to temperature. The signal conditioning unit processes this signal to provide a 0-5 volt output which is directly proportional to temperature.

5.2.3.1.1 Manufacturer's Specifications

Accuracy:	±4°F
Linearity :	±1.5°F over full range
Resolution:	0.4% of full scale
Turn on Time:	Less than 1ms
Output signal:	0-5 VDC
Power Requirements:	12 VDC @ 1.033 mA

5.2.3.1.2 Installation Procedures

These sensors must be installed inside a ventilated housing or shelter which is designed specifically for the purpose of shielding against radiated heat energy. Installation must conform to the siting and exposure guidelines discussed in 5.1.2.

The electrical connections are made at the terminal block J1 adjacent to the zero and span adjustment potentiometers inside the signal conditioning module. Route the connecting cables through the strain reliefs on the signal conditioning module and attach the cable wires as follows:

Terminal J1-1	Input--Red or plus lead
Terminal J1-2	Input--Black or minus lead
Terminal J1-24	Output--High
Terminal J1-22	Output--Low
Terminal J1-19	+ 12 VDC
Terminal J1-21	2 V Ref (gnd)

5.2.3.1.3 Calibration Procedures

Check the temperature in close proximity (3-5 inches) to the probe with an accurate thermometer. Compare the thermometer temperature to the output of the 5050T sensor. If the difference is more than one degree perform the following calibration adjustment. If the calibration adjustment does not correct the error, perform the probe test in the maintenance section above.

If the instrument is out of calibration, the span and zero set points must be adjusted. Please refer to Figure 5.1. The span is adjusted first. An accurate temperature control chamber is required.

1. Span Adjustment

   Place the instrument in the temperature chamber with its output connected to a voltmeter and perform the following steps.

   A. Lower the temperature of the chamber until it reaches the temperature corresponding to the low end of the sensor temperature range. Measure the instrument output voltage and convert this to temperature.

   B. Raise the temperature of the chamber until it reaches the temperature corresponding to the high end of the sensor temperature range. Measure the instrument output voltage and convert this to temperature.

   C. Compare the measured output temperatures and subtract the lower temperature from the upper temperature. This difference in temperature is the span of the instrument. If this measured span of the instrument does not correspond to the factory specified span (high end of sensor temp range - low end of sensor temp range = specified span) then adjust the span potentiometer (R9). Turning R9 in a clockwise direction increases the span and in the counter clockwise decreases the span.

2. Zero Adjustment

   Once the span is adjusted correctly, compare a known temperature with the instrument output temperature. If this comparison differs by more than one degree F then adjust the zero potentiometer (R4) until the instrument output equals the known temperature within one degree F. Turning R4 clockwise raises the instrument indicated temperature and counterclockwise lowers the instrument indicated temperature.

   Repeat the high and low end temperature chamber test to ensure that the instrument remains within calibration.

Figure 5.1 Sierra-Misco Temperature Sensor, PCB Assembly Diagram

5.2.3.1.4 Maintenance Procedures

This instrument is designed for high longevity service. If the instrument does not register correctly, first check the 12 volt power source at J1-19(+) and J1-21(-). Check for corrosion and loose connections of terminal strip J1. If corrosion exists, remove the connecting terminals, clean thoroughly both the terminal and terminal strip and reconnect the terminals to their proper pins and tighten securely.

Check the probe by disconnecting it from the signal conditioning unit and connect it in a series circuit with a 12 Volt DC power source and an ammeter as follows.

Connect the negative side of the power source to the negative lead (black wire) of the probe.

Connect the positive side of the power source to the positive lead of the ammeter.

Connect the positive lead (red wire) of the probe to the negative lead of the ammeter.

Set the ammeter on 1 mA or 2 mA range setting and observe the current. The measured current should correspond to the ambient temperature (refer to Figure 5.2). The higher the temperature the higher the current reading. If the sensor does not respond as described then replace the sensor.

Figure 5.2 Sierra-Misco Temperature Sensor Current vs Temperature Calibration Curve

5.3 Instrumentation--Hygrothermographs

5.3.1 Principle of Operation

Principles of operation vary with the instrument type and are discussed within the individual instrument section.

5.3.2 Maintenance

Maintenance requirements vary with the instrument type and are discussed within the individual section.

5.3.3 Sensors Used

5.3.3.1 Sierra-Misco Model 2046 Relative Humidity/Temperature Sensor

The Sierra-Misco Model 2046 Temperature and Humidity Sensor is a solid state device which measures temperature with an integrated circuit and humidity with a cellulose crystal.

The Model 2046 humidity sensor is a composite hygromechanical crystal and a piezoresistive strain gauge. The sensing element responds to changes in humidity with proportional changes in resistance. With an excitation voltage of 1.22 volts DC, the signal conditioning unit will transform the 0-100 percent relative humidity into a proportional linear output of 0-5 volts DC.

The Model 2046 temperature sensor is a two terminal integrated circuit transducer which produces a current proportional to temperature. The signal conditioning unit transforms the sensors current output of a given temperature range into a proportional linear output of 0-5 volts DC.

5.3.3.1.1 Manufacturer's Specifications

Ambient Range:	-40 to +80 - °C
Power Requirements:	10 to 16 VDC @ 40mA
Turn on Time:	1 millisecond
RH Sensor Range:	0 to 100% RH
RH Sensing Element:	Inert Cellulose Crystallite
RH Output:	0 to 5VDC or 0 to 1mA
RH Accuracy:	± 2% 0 to 100% RH

RH Repeatability:	± 1%
RH Hysteresis:	± 2%
RH Thermal Coefficient:	0.057% per °C
RH Response Time:	3 min to 63% change
Temp Sensing Element:	AD590 KH transducer
Temp Measuring Range:	-70 to +85 °F
Temp Output:	0-5 VDC or 0 to 1mA
Accuracy:	± 4° F

5.3.3.1.2 Installation Procedures

These sensors must be installed inside a ventilated housing or shelter which is designed specifically for the purpose of shielding against radiated heat energy. Installation must conform to the siting and exposure guidelines discussed in 5.1.2.

The electrical connections are made at the terminal block between the adjustment potentiometers inside the signal conditioning module. Route the connecting cable through the strain relief on the signal conditioning module and attach the cable wires as follows (Refer to Figure 5.3):

Terminal 1	Supply voltage (+10 to +16 VDC)
Terminal 2	Ground
Terminal 3	Temperature signal
Terminal 4	Humidity signal

5.3.3.1.3 Calibration Procedures

Temperature Calibration

The signal conditioning is adjusted by simulating the sensor with an accurate current source. The zero (R12) and span (R16) potentiometers (Figure 5.4) are

Figure 5.3 Sierra-Misco Relative Humidity/Temperature Sensor Wiring Diagram

Figure 5.4 Sierra-Misco Relative Humidity/Temperature Sensor PCB Assembly Diagram adjusted for zero and full scale output at the lower and upper current values for the temperature range being calibrated (Figure 5.5). For example, - 70°F equals 216.5 microamperes and + 185°F equals 358.2 microamperes. The current which corresponds to a given temperature is found by: (X°F-32)/1.8 + 273.2.

Example:

Current for -70°F = (-70-32)/1.8 + 273.2 = 216 microamperes

In the field, adjustments of the zero potentiometer may be made at a known temperature. The zero potentiometer (R12) is adjusted such that the output of the signal conditioning unit agrees with the expected output for that temperature. This equation is: [X°F-(-70)]/255 x 5 = Volts. The output voltage for the known temperature of 70°F is given by: [70-(-70)]/255 x 5 = 2.745 Volts.

Relative Humidity Calibration

Complete sensor calibration requires a resistance source capable of producing numerous very accurate values and a **clean room** laboratory facility . Therefore it is strongly suggested that the sensor and its signal conditioning unit be returned to the factory for calibration and recertification.

In the field, adjustments of the zero and span potentiometers may be made at known humidities. These potentiometers (R4) and (R8) are adjusted such that the output voltage of the signal conditioning unit agrees with the expected output for that known humidity (Figure 5.6). Adjust the zero potentiometer (R4) when that known humidity is below 65 percent and the span potentiometer (R8) when the known humidity is above 65 percent.

> **Important Note: Do Not** attempt field calibration adjustments of the zero and span potentiometers if the noted calibration error of temperature or humidity are in excess of 5 percent of the sensor range.

5.3.3.1.4 Maintenance Procedures

Minor maintenance is required for continued satisfactory operation of these temperature and relative humidity sensors. They resist contamination and are easily cleaned and environmental exposure will determine the necessary cleaning frequency. Clean the elements by dipping in lukewarm water several times and then let dry before returning to operation.

Figure 5.5 Sierra Misco Sensor Calibration Curve for Temperature

Figure 5.6   Sierra Misco Sensor Calibration Curve for Relative Humidity

Warning: Do not attempt to clean these elements by mechanical means such as brushing or wiping. The sensors are very delicate and can be easily damaged beyond repair.

Verify the temperature and relative humidity calibration by comparing the sensor outputs to a calibrated psychrometer. If either the relative humidity or temperature sensors are out of specification, follow the appropriate calibration procedure.

5.3.3.2 General Eastern Model DEW-10 Dewpoint Hygrometer with Temperature Sensor

The General Eastern Dew-10 instrument is a high performance unit providing measurements of dew point and air temperature that are stable, accurate, and traceable to National Standards. Air flows convectively through a sensor chamber containing a dew point sensor and an air temperature sensor.

Dew point temperature is established via a platinum resistance thermometer (PRT) embedded in a metal mirror (Figure 5.7). The mirror temperature is cooled to a point at which the water vapor in the surrounding air just slightly begins to condense on the mirror's surface thus representing dew point temperature.

The temperature of the metal mirror is controlled by a **peltier effect device**. This is a device that heats when current is passed through it in a forward direction and cools when current flows in the opposite direction. The direction of current flow is determined by a light emitting diode pointed on an angle at the mirror surface. The reflected light from this light emitting diode activates a photo receiving diode which is pointed at this mirror at a 90° angle of incidence to the light emitting diode. When the receiving diode captures light, it switches a relay applying a current in the reverse direction across the peltier device. This cools the mirror until water vapor in the surrounding air condenses on the mirror surface. This condensation on the mirror prevents reflection of the emitted light thereby turning off the photo receiving diode. This causes current to flow through the peltier device in the forward direction which heats the mirror, evaporates the condensate, and again turns on the photo receiving diode. This heat/cool cycle continues until the mirror temperature is at a balance which allows only a slight amount of condensation. **The mirror temperature is then at the dew point temperature.** The output of the PRT embedded in the mirror is a direct measurement of dew point temperature.

Air temperature is measured via a PRT in the flow chamber but is located in front of the dew point sensor allowing it to measure ambient air unbiased by the peltier device.

Figure 5.7   Dewpoint Hygrometer Chilled Mirror Sensor Operation

5.3.3.2.1 Manufacturer's Specifications

Accuracy:	± 0.05°C (± 1.0°F)
Repeatability:	± 0.05° C (± 0.1°F)
Response time:	Two minutes max for one time constant
Environs. Limits:	0°C - 60°C and 0 - 5 psi
Power Requirements:	24 ± 6 VDC at 350 mA
Standard Output:	Linear 4 - 20 mA (1 - 5 VDC with 250 ohm load) for both dew point and air temperature.

5.3.3.2.2 Installation Procedures

These sensors must be installed inside a ventilated housing or shelter which is designed specifically for the purpose of shielding against radiated heat energy. Installation must conform to the siting and exposure guidelines discussed in 5.1.2.

Identify the installation method by first determining the mount style of the instrument. Remove the Velcro attached plastic cover and use the chassis mounting holes as a template for locating the mounting screws. Wall-mount varieties (Figure 5.8) are mounted with the chassis of the unit against the wall and the metal cap or optional air temperature probe directed toward the floor. Avoid any detectable drafts in the downward direction. The instrument should be mounted in a way that will allow easy access for periodic maintenance.

Referring to Figure 5.9, connect external wiring to this unit via connector P4 as follows.

Pin 5	Dew Point Temperature output
Pin 6	Air Temperature output
Pin 8	+24 VDC input
Pin 10	24 VDC Common (gnd or return)

Note: The output of this unit is 4 - 20 mA. For voltage output of one to five volts install a 250 ohm resistor between J4 pins 5 and 10 and between J4 pins 6 and 10.

After verifying external electrical connections, check unit operation by moving SW1 on PCB no 1 to the **Check** position (see Figure 5.10). The LED should

Figure 5.8   General Eastern DEW-10 Wall Mount Installation Drawing

Figure 5.9 General Eastern DEW-10 Sensor Wiring Diagram

Figure 5.10 PCB Assembly Drawing for General Eastern DEW-10 Sensor light within two minutes to confirm the unit can operate correctly. If the LED does not light see periodic maintenance procedures in 5.3.3.2.4. If the LED does light within two minutes then return SW1 to the **Operate** position. The LED will go out when dew collects on the sensor mirror.

Replace the unit's plastic cover and the unit is in full operation.

5.3.3.2.3 Calibration Procedures

Procedure for Fine Optical Reference Adjustment

This procedure adjusts the light receiving diode to match the light intensity of the reference or light emitting diode. The mirror should be clean and dry and ambient light must be prevented from entering the sensor cavity during this adjustment.

1. Move SW1 to BAL (balance) position. Clean mirror according to mirror cleaning procedure. Replace sensor cavity filter.

2. Turn the trimpot clockwise to light the LED and counterclockwise to turn the LED off. Turn the trimpot until the LED just lights. If the LED does not light with trimpot adjustment then perform the coarse optical reference adjustment.

3. Move SW1 to the operate position. LED should go out within 40 seconds as dew forms on the mirror. If LED does not go out then replace PCB #1 and repeat fine optical reference adjustment.

Procedure for Coarse Optical Reference Adjustment

This procedure adjusts the intensity of the light emitting diode to within the range of the light receiving diode. This field adjustment allows for reference bridge aging and different versions of PCB #1. The mirror must be clean and dry and ambient light must not be allowed to enter the sensor cavity during the adjustment.

1. Remove the sensor cavity filter

2. While blocking the light from entering the sensor cavity, adjust the coarse adjusting screw inside the sensor cavity. Be sure to note the number of turns as this screw is being adjusted. Adjust this screw in one direction or the other **(no more than five turns)** until the LED is lighted, then reverse the screw until the LED goes out. If the LED does not come on during the first direction return the screw to its starting position then adjust the screw in the opposite direction **(no more than five turns)** until the LED is lighted, then reverse the screw until the LED goes out. This screw is aluminum and requires a 1/16 Allen wrench for adjustment.

3. Reinstall the sensor cavity filter

4. Perform the fine optical adjustment.

5.3.3.2.4 Maintenance Procedures

The ability of this unit to control the temperature of the mirror at the dew point is dependent on the mirror surface condition and the optical balance of the light emitting and light receiving diodes. Contaminants trapped in dew on the mirror may alter the dew point as well as reduce its reflectance. The optical balance performed at the factory may become altered by a physical change in the mirror surface or by aging of the optical components. The mirror condition and optical balance must be checked regularly and serviced as required.

Service checks should be performed monthly although the period is specific to the installation environment. A service kit containing the following items is required to properly maintain this instrument: Cotton swabs, cleaning solution (isopropyl alcohol if factory solution is not available), fuses and O-rings, and a small screwdriver for adjusting the optical balance

A mirror surface condition check should be performed at each site visit; even non scheduled visits. A surface condition check and surface cleaning **must** be performed at each scheduled site visit.

Procedure for mirror surface condition check:

1. Move switch SW1 to **check** position and wait 120 seconds for adjacent LED to light.

2. If the LED lights and the site visit is not a scheduled visit then reset SW1 to the **operate** position and replace unit cover.

3. If the LED does not light then perform the mirror cleaning procedure below.

Procedure for mirror surface cleaning:

1. Move switch SW1 to the **check** position

2. Remove lower sensor cavity filter

3. Locate mirror surface in sensor cavity and wipe/clean with cotton swab saturated with mirror cleaning solution. Wipe dry with second dry swab.

4. Reinstall sensor cavity filter to its original position

Note: LED should be on. Return SW1 to the operate position. LED should go out as moisture condenses on the mirror.

If the LED does not light after mirror cleaning then perform fine optical balance adjustment procedure in 5.3.3.2.3.

5.3.3.3 Belfort Hygrothermograph Model 594

The Belfort Catalog Number 594 Hygrothermograph is a combination temperature and relative humidity recorder. Dual sensing-elements generate inked traces on a single, two-channel rectangular chart. The temperature pen is actuated by either a liquid-filled bourdon tube or a bi-metallic element depending on the instrument's usage. The humidity pen's movement is caused by the increase or decrease of humidity acting on a human hair element causing it to expand or contract.

Both the spring-wound and battery-powered drives are made of corrosion-resistant metal. The spring-powered chart drive is driven through an appropriate pair of time-scale gears by a dual-output mechanism capable of providing better tan 8 days of operation from a full wind. The optional battery-powered chart drive is similar to the above one. Timing of the mechanism is managed by a quartz crystal-controlled oscillator. The timing accuracy of both chart drives have + 5 sec/hr, but not in excess of 14 min/week over the temperature range of -40 F to + 125 F.

The hygrothermograph is housed in a portable metal case with a handle on the top. Openings on the front, back, and side of the case allow circulation of air to the sensors. A window provides a view of the chart record. V-point pens are used for recording.

5.3.3.3.1 Manufacturer's Specifications

Range:	+10° to +110° F, 0 to 100% RH
Sensitivity:	2° F, 1% RH
Accuracy:	±1°F between -20° to 110° F ±3% RH between 20% and 95%

5.3.3.3.2 Installation Procedures

Direct solar radiation on the instrument will cause large errors in the temperature and humidity measurements. For the best and most accurate results and to protect it from rain and dust, the hygrothermograph should be placed into an instrument shelter designed for outdoor use.

The instrument is fully calibrated and assembled at the factory and is ready for installation. For desired recording time period, select the appropriate chart drive and stripe chart. By winding the spring or inserting batteries, depending on the type of the chart drive, the drive is ready for use.

Remove the chart clip from the side of the clock drum. Place the right hand margin of the chart in line with the right side of the chart clip notch. Wrap the chart around the drum in a clockwise motion. The left-hand edge of the chart should overlap the right-hand edge. Place the chart clip over both layers of the chart and seat it in the notch. The lower edge of the chart should be in contact with the flange at the base of the clock drum. Fill in the station identification and the date the chart is started.

Place the clock over the gear post and secure it with the knurled nut. Install a cartridge pen onto the pen lift lever and remove the protective cap. Turn the clock assembly so that the pen is set to the correct time mark. Close and lock the instrument cover. Now the instrument is placed into operation.

5.3.3.3.3 Calibration Procedures

Calibration of Temperature

The temperature span is set at the factory. Normally, no span adjustment is required in the field. However, if the bimetallic strip is replaced or if for any reason the temperature span must be adjusted, proceed as follows.

1. Check the temperature span by alternately operating the hygrothermograph in cold and warm atmospheres with at least 50 F differential. Allow sufficient time for the temperature to stabilize, and check the temperature using good quality mercury thermometers for reference.

2. Adjust the linkage for the temperature span. Reset the length of the horizontal arm of the pen linkage; that is, shorten the arm to increase the span or length the arm to decrease the span. Make only slight adjustments in the arm length. An adjustment of 0.012 inches will change the span about 1 F.

3. After each adjustment, measure and record the arm length. (Note: A drastic loss of span could indicate failure of the bimetallic strip, in which case the element should be replaced.)

4. When the temperature span is properly adjusted, the temperature pen position must be set to correspond with the chart paper in use. This adjustment should be made with the hygrothermograph in operation on the location. Pen adjustment will not affect the temperature span setting.

5. Allow sufficient time for the temperature to stabilize. To fine tune the temperature recording, make adjustments at the temperature adjustment screw. Check the instrument after fifteen minutes and repeat the adjustment until the pen indicates within one degree or better of the thermometer reading.

Calibration of Humidity

The relative humidity portion of the hygrothermograph is fully calibrated at the factory. The first time it is used, it only requires trimming of the pen position. A wet-dry bulb psychrometer can be used for reference relative humidity. Once the relative humidity is determined, set the pen position by turning the humidity adjustment screw. When the hair bundle is cleaned or replaced, the relative humidity span should be checked as follows.

1. Place the operating hygrothermograph in a shallow pan and drape the instrument with wet towels, leaving the window portion uncovered. Then cover the instrument and wet towels with a clear plastic bag or sheet. Tuck the plastic into the pan so that it fits tightly. When the relative humidity recording trace stabilizes, note the value it indicates. This value is equivalent to 100 percent RH. Remove the plastic cover and towels. Remove the instrument from the pan, and wipe off any moisture.

2. Place the hygrothermograph in a dry environment (less than 50 percent RH) and let the relative humidity trace stabilize. Use a psychrometer to determine the ambient relative humidity. Note the RH value of the psychrometer as well as the reading of the hygrothermograph. Subtract this hygrothermograph value from the previous value recorded in the previous step (1). Subtract the actual ambient RH from 100 percent. Compare this actual span difference to that of the instrument. The instrument humidity span should be adjusted accordingly, if the differences do not agree. To adjust the span, shorten the humidity linkage

lever to increase the span, or lengthen the lever decrease the span. Make only slight changes and note the length of the lever before and after each adjustment.

3. Repeat the processes in steps (1) and (2) until the span is satisfactorily set. Once the span calibration is complete, reset the pen position to correspond with the chart paper. Note: Do not disturb the quadrant arms during the calibration procedure.

5.3.3.3.4 Maintenance Procedures

The hygrothermograph should be cleaned on a routine basis to prevent dust and dirt build-up. Whenever the chart paper is changed, simply brush off any dust or dirt from the instrument. Every 3 to 6 months clean all pivot points with a solvent, and with a small brush apply a light coat of instrument oil. This type of preventive maintenance will ensure long and reliable operation.

Replace the hair bundle every two years. Hair bundles should be kept clean. Periodically, use ether or distilled water to thoroughly clean the hair bundle. Washing will minimize creeping of the zero, especially when the element has been exposed to low humidities. Do not touch the hair bundle with any portion of the skin. The presence of oil or grease adversely effects the performance of the hair. If contaminated by oil or grease, carefully remove the hair bundle from the instrument and soak it in ether. Carry the bundle at the extreme ends (outside clamp points) and make certain that the hairs remain together and parallel to one another.

Ink that is exposed to air tends to absorb moisture and become diluted, especially in damp or rainy weather. If the ink trace becomes unsatisfactory, replace with a new pen.

5.3.3.4 Weathermeasure Hygrothermograph Model 5045-B

The Weathermeasure Model 5045 hygrothermograph provides a continuous chart record of relative humidity and air temperature. The humidity sensor is a human hair element which changes in length with changes in ambient humidity. A lever system links the hair element to the recording pen arm. Two cams are included in the system to convert the nonlinear response of the hair element into a linear response of recording.

The temperature sensor is a bimetallic strip which responds to changes in temperature with changes in shape. These changes are transferred to the recording pen arm by a lever system. The system is precisely arranged to magnify the small motions of the bimetallic strip into larger motions which can be recorded.

The hygrothermograph is housed in a portable metal case with a handle on the top. Openings on the front, back, and side of the case allow circulation of air to the sensors. A window provides a view of the chart record. V-point pens are used for recording.

5.3.3.4.1 Manufacturer's Specifications

Ranges:	10° to 110° F, 0 to 100% RH
Sensitivity:	2° F, and 1% RH
Accuracy:	+1° F between -20° and 110° F +3% RH between 20% and 95% RH
Pen Type:	V-point cartridge type

5.3.3.4.2 Installation Procedures

Refer to procedures in 5.3.3.3.2

5.3.3.4.3 Calibration Procedures

Refer to description in 5.3.3.3.3

5.3.3.4.4 Maintenance Procedures

Refer to description in 5.3.3.3.4

5.3.3.5 Campbell Scientific HMP35C Hygrothermograph

The Model HMP35C probe contains a Vaisala capacitive relative humidity sensor and a Fenwal Electronics UUT51J1 thermistor. The probe is designed to be housed in the 41002-2 12 Plate Gill Radiation Shield; a ten foot lead length is standard. Longer lead lengths are available up to 1000 feet. Voltage drop in the longer lead lengths will lower the RH reading by approximately 0.6 percent RH per 100 feet of cable. Do not extend lead lengths by adding wire to the pigtail (connection) end or measurement errors will result.

The overall probe accuracy is a combination of Fenwal's interchangeability specification, the precision of the bridge resistors, and the polynomial error. In the "worst case" all errors add to an accuracy of ± 0.4°C over the range of -33°C to +48°C. The error is typically less than the specification and, if desired, can be reduced with a single point calibration. The major error component is the ±0.2°C interchangeability specification of the thermistor from 0 to 60°C (±0.5°C at -40°C). The interchangeability error is predominantly offset and can be determined with a single-point calibration. Compensation can then be done with an offset entered in the datalogger measurement instruction. The bridge resistors are 0.1 percent tolerance with a 10 ppm temperature coefficient.

5.3.3.5.1 Manufacturer's Specifications

Measurement Range:	0 to 100% RH
Output Signal Range:	0.002 to 1 Volt DC
Accuracy (at 20° C, including non-linearity and hysteresis)	
against factory references:	± 1% RH
against field references:	± 2% RH, 0 to 90% ± 3% RH, 90 to 100%
Temperature dependence:	± 0.04% RH per 1° C
Typical long-term stability:	better than 1% RH per year
Response time @ 20° C, 90% response:	15 seconds with membrane filter
Settling time:	1 second
Supply voltage (via switching circuit):	12 Volts DC
Current consumption:	≤4 mA
Operating temperature:	-20 to +60° C

5.3.3.5.2 Installation Procedures

The HMP35C probe requires two single-ended analog measurements. The green (RH) and the orange (temperature) leads can be inserted in either HI or LO inputs of the datalogger.

The black thermistor excitation lead connects to any excitation channel. The yellow lead is used to control switching 12 volts to the relative humidity sensor, and is normally connected to an excitation channel, although a control port could be used with a different program in the data logger. The number of HMP35C probes per excitation channel is physically limited by the number of lead wires that can be inserted into a single excitation terminal (approximately ten). The white lead connects to Analog Ground. Analog Ground, labeled "AG" on the CR10, is the same as other CSI data loggers. The clear lead is the shield which connects to Ground (G) on the data logger.

5.3.3.5.3. Calibration Procedures

The HMP35C hygrothermograph should be returned to the manufacturer for recalibration.

5.3.3.5.4 Maintenance Procedures

The HMP35C requires minimal maintenance. Monthly, check to make sure the radiation shield is free from debris. The screen on the sensor should also be checked monthly. Annually, check the calibration of the probe.

5.4 Instrumentation--Leaf Wetness

5.4.1 Principle of Operation

Principle of Operation is discussed in individual instrument sections.

5.4.2 Maintenance

Sensor maintenance is discussed in individual instrument sections.

5.4.3 Sensors Used

5.4.3.1 Campbell Scientific, Inc. Model 237 Leaf Wetness Sensor

Leaf wetness sensors are classified into three types: surface contact types that measure the electrical resistance of a water film on the leaf surface, artificial leaf electrical resistance types, and mechanical types that detect a change in sensor length or weight. The 237 is an artificial leaf type for use with the Campbell Scientific, Inc. dataloggers.

The sensor consists of a circuit board with interlacing gold-plated copper fingers. Condensation on the sensor lowers the resistance between the fingers which is measured by the datalogger. Droplets small enough to not touch two fingers simultaneously do not change the sensor resistance. For this reason, the type of sensor is often coated with flat latex paint to spread the water droplets. The color and type of paint affect sensor performance. Campbell Scientific supplies only the raw sensor since individual modifications vary depending on the application. The following paper details the effect of paint color and sensor angle on the response of the leaf wetness sensor:

5.4.3.1.1 Manufacturer's Specifications

Outside Dimensions: 2 x 2.5 inches

Grid Dimensions: 2 x 2.25 inches

Grid Spacing: 0.05 inches
Grid Material: Gold plated copper

Dry Resistance: >3,000,000 ohms

Nominal Wet Resistance: 1,000 ohms

Standard cable length: 25 feet

5.4.3.1.2 Installation Procedures

The Model 237 Sensor is read on a single-ended analog input, the red lead connects to a single-ended analog input, the black lead connects to the excitation voltage, the purple lead connects to Analog Ground and the clear lead is the shield which connects to earth ground (Figure 5.11).

The sensor should be placed in the vegetation, whose wetness is to be monitored, and secured to ensure it will be exposed to moisture the same as the vegetation. The sensors resistance is artificially reduced by contaminants such as finger prints and smudges. Before painting and calibrating the sensor, wash it with alcohol to remove possible contaminants. Observe the vegetation until it reaches the desired wetness by natural means. When the vegetation is at the desired "wetness", note the measured resistance of the sensor. This resistance is the transition point. The sensor resistance varies from above 3,000,000 ohms when dry to around 1,000 ohms when wet.

A sharp change in resistance occurs in the wet-dry transition on the uncoated sensor. Coated sensors have a poorly defined transition. The resistance of the uncoated sensor at the wet/dry transition is normally between 50 and 200 K ohms. The coated sensor transition normally occurs from 20 K ohms to above 1,000 K ohms.

For best results, the leaf wetness sensor should be field calibrated. The transition point will vary for different areas and vegetation.

5.4.3.1.3 Calibration Procedures

The 237 sensor is read as an AC Half Bridge measurement. The reading is a ratio of the measured voltage to the excitation voltage (V_s/V_x), which is equal to a ratio of sensor resistances as shown below (refer also to Figure 5.11).

$$V_s/V_x = R_2/(R_2+R_1+R_s)$$

The output of the sensor is the fraction of time the sensor is wet or dry. This can only be done after the wet/dry transition point has been determined.

Calculating Sensor Resistance
An alternate expression of leaf wetness is sensor resistance (R_s) in thousands of ohms (K ohms). R_s is calculated as follows:

$$R_s = R_2/(V_s/V_x) - R_2 - R_1$$

where R_2 is 1 K ohm and R_1 is 100 K ohms, substituting these values yields:

$$R_2 = 1/(V_s/V_x) - 101.$$

The reading will be 99999 if the sensor is completely dry. A completely dry sensor is an open circuit, and therefore has infinite resistance.

Output - Recording Fraction of Time Wet or Dry

Out putting the fraction of time wet or dry cannot be done until the resistance at the wet/dry transition point is determined. See 5.4.3.1.2

The fraction of time the sensor is wet or dry can be obtained by plotting the sensor outputs as a histogram, with the lower limit of the sensor output at "0" and the upper limit at the calibrated wet/dry transition point. This will give the fraction of time the sensor is wet. Subtract this fraction from 1 to get the fraction of time the sensor is dry. Multiply both fractions by 100 to obtain the percent of time wet and the percent of time dry.

5.4.3.1.4 Maintenance Procedures

The sensor should be kept clean and free of any foreign material such as insect nests or eggs. The sensor's resistance is artificially reduced by contaminants such as fingerprints, smudges and the all foreign material as listed above. The sensor should be inspected periodically, depending on environmental and climate conditions.

Figure 5.11 Campbell Scientific Leaf Wetness Sensor Schematic

6.0 Evaporation Measurement

6.1 Introduction

6.1.1 Theory

Evaporation from the land surface comprises evaporation directly from the soil and vegetation surface, and **transpiration** through plant leaves, in which water is extracted by the plant's roots, transported upwards through its stem, and diffused into the atmosphere through tiny openings in the leaves called stomata. The processes of evaporation from the land surface and transpiration from vegetation are collectively termed **evapotranspiration**.

The two main factors influencing evaporation from an open water surface are the supply of energy to provide the latent heat of vaporization and the ability to transport the vapor away from the evaporative surface. Solar radiation is the main source of heat energy. The ability to transport vapor away from the evaporative surface depends upon the wind velocity over the surface and the specific humidity gradient in the air above it. Evapotranspiration is influenced by the two factors described previously for open water evaporation, and also by a third factor, the supply of moisture at the evaporative surface. The **potential evapotranspiration** is the evapotranspiration that would occur from a well-vegetated surface when moisture supply is not limiting, and this is calculated in a way similar to that for open water evaporation. Actual evapotranspiration drops below its potential level as the soil dries out.

6.1.2 Instrument Siting and Exposure

There are three types of exposures employed for pan installations - sunken, floating, and surface. Divergent views on the best exposure persist. The standard National Weather Service Class A pan is the most widely used. It is of unpainted galvanized iron or stainless steel 4 ft in diameter by 10 in deep and is exposed on a wood frame to let air circulate beneath the pan. It is filled to a depth of 8 in, and instructions require that it be refilled when the depth has fallen to 7 in. Water-surface level is measured daily with a hook gauge in a stilling well, and evaporation is computed as the difference between observed levels, adjusted for any precipitation measured in a standard rain gauge. Alternatively, water is added each day to bring the level up to a fixed point in the stilling well. This method assures proper water level at all times.

6.1.3 Measurement Standards

The direct measurement of evaporation under field conditions is not feasible, at least in the sense that one is able to measure river stage, rainfall, etc. As a consequence, a variety of techniques have been derived for determining or estimating vapor transport from water surfaces. There are water-budget, energy-budget, aerodynamic, and combination methods of estimating reservoir evaporation. These approaches are simple in theory, but application rarely produces reliable results since all errors in measuring inflow, outflow, and change in storage of media are reflected directly in the computed evaporation.

It is not possible to measure transpiration loss from an appreciable area under natural condition. Most measurements are made with a **phytometer**, a large vessel filled with soil in which one or more plants are rooted. The only escape of moisture is by transpiration (the soil surface is sealed to prevent evaporation), which can be determined by weighing the plant and container at desired intervals of time. Since it is virtually impossible to simulate natural conditions, the results of phytometer observations are mostly of academic interest.

The pan is undoubtedly the most widely used evaporation instrument. Although criticism of the pan may be justified on theoretical grounds, for some types of pans the ratio of annual lake-to-pan evaporation (**pan coefficient**) is quite consistent, year by year, and does not vary excessively from region to region.

6.2 Instrumentation--Evaporation

6.2.1 Principle of Operation

Principles of operation tend to vary with the instrument type and will be discussed within each individual instrument section.

6.2.2 Maintenance

Maintenance requirements vary with instrument types and will be discussed within each individual instrument section.

6.2.3 Sensors Used

6.2.3.1 Belfort Catalog Number 6066 Evaporation Station

The Belfort Evaporation Station is a collection of instruments which measure the amount of water evaporating from an open pan.

6.2.3.1.1 Manufacturer's Specifications

Class "A" Evaporation Pan	Low carbon stainless steel, passivated after welding, heliarc welded, 10-inches deep by 47.5-inches I. D.

Hook Gauge	3" span, 0.1" graduations
Stilling Well	Brass or monel cylinder, 8" x 3.5" O.D.

6.2.3.1.2 Installation Procedures

The ground should be filled sufficiently to level the support and keep the bottom of the pan above the level of surface water in rainy weather. The support should be constructed of 2 X 4 lumber certified for in-ground use. The pan will be centered on the platform.

Place the stilling well in the pan about one foot from the north edge. Level the top rim of the well using the three leveling screws in its base and a spirit level. The well should rest firmly on the bottom of the pan, which must be free from "buckling" in order to maintain a level adjustment of the well.

A three-legged spider and adjusting-nut assembly supports the hook and provides for adjustment of the height of the hook when the gauge is installed on the stilling well. The adjusting nut is threaded to screw on the stem of the hook. After assembly, the gauge is placed on the stilling well with the three legs of the spider resting on the top rim of the well and the hook centered in the well. The stem should then be vertical.

6.2.3.1.3 Calibration Procedures

Calibration is not required for these instruments.

6.2.3.1.4 Maintenance Procedures

Inspect the pan for leaks carefully at least once a month. Clean the pan as frequently as necessary to keep it free from sediment, scum, and oil films. The pan will be emptied by siphoning and/or by dipping the water out. Under no circumstance is the pan to be lifted and emptied with any significant amount of liquid remaining in the pan. The growth of algae in the evaporation pan can be discouraged by the addition of small amounts of copper sulphate to the water. However, algae already present must be removed by a thorough cleaning of the pan.

Clean the stilling well occasionally and remove any sediment.

Keep the hook gauge clean, and oil the threads on the stem lightly about twice a year with a single drop of light-viscosity machine oil. Before oiling, clean the gauge thoroughly with kerosene, Varsol, Stansol, or a similar petroleum-base solvent. When the gauge is assembled after cleaning, determine that the threads of the stem and adjusting nut are properly matched, by turning the adjusting nut counterclockwise until the top of the nut coincides with one of the graduations of the stem.

6.2.3.2 Balluff Linear Displacement Transducer

The Balluff Linear Displacement Transducer (BTL) is a rugged linear positioning device for use over stroke positioning lengths of 5.9 inches to 10.5 inches. A traveling magnetic ring is used as a positioning marker to determine the measuring point. The signal generating and processing electronics is contained in the handle of the unit.

Metal is a very good conductor of sound. Metal conducts sound without the influences of air pressure, humidity, and in this case, temperature. This characteristic is exploited by the BTL. It uses as a basis, the travel time of an ultrasonic pulse over a metal conductor to determine the path length. The accuracy of this process is established by detecting the leading edge of the ultrasonic pulse as it arrives at the receiver.

The ultrasonic pulse is generated directly in the conductor (or wave guide) following the principles of magnetostriction. The waveguide therefore must be constructed of magnetostrictive material such as nickel-iron alloy. The proper alloy has a crystalline structure deformed along the axis of the magnetic field. This deformation will induce a mechanical wave or torsional pulse in the wave guide with a frequency in the ultrasonic range. The measured position is marked on the wave guide by the magnetic field of the four magnets embedded in the float ring. The field runs axially in opposite directions. Another magnetic field is formed when the current pulse is sent through the wave guide. At the point of intersection of the two magnetic fields an ultrasonic pulse is formed by means of magnetostriction. The pulse is propagated in both directions of the waveguide at a speed determined by the alloy.

The pulse which reaches the end of the waveguide is absorbed by the damping zone. The pulse going the other direction is detected by the receiver and converted to an electrical signal.

The time between the origination of the current pulse and the reception of the leading edge of the torsion pulse is directly proportional to the measurement length.

6.2.3.2.1 Manufacturer's Specifications

Power Requirements:	24 VDC @ 150 mA
Noise:	5% max 20 mV
Output Signal:	BTL-A 0 to 10 V
	BTL-B 0 to 20 mA
	BTL-C 4 to 20 mA
Output Load Capacity:	Voltage out 20 mA max
	Current out 50 mA max

Operating Temperature:	0 to 60° C
Storage Temperature:	-25 to +80° C

6.2.3.2.2 Installation Procedures

If this instrument is operating in a hostile environment the handle (housing the electronics) must be installed in a water proof enclosure (factory option). Use a drying agent such as desiccant inside the enclosure to assist in moisture control.

It is recommended that the mounting surface for this instrument be made of non-ferrous materials such as aluminum, brass, copper, or stainless steel.

Mount the BTL away from pulse-loaded power supply lines. Do not run cables parallel with any noisy electrical lines. Use twisted, **braided** shielded wire. Use 22 or larger gauge twisted pair for all power and ground lines.

6.2.3.2.3 Calibration Procedures

Field calibration of this instrument is best accomplished by changing the base value in the data logger. If a span calibration is required, remove the instrument to a suitable electronics lab and consult the manufacture's service manual.

No field adjustments are permitted. Instrument zero and span adjustments require accurate measurement conditions in a clean service area.

6.2.3.2.4 Maintenance Procedures

Perform preventative maintenance in the form of general cleaning, drying agent rejuvenation, and installation inspection at approximately 60 day intervals. Ensure that all magnetic materials are more than 15 mm away from the positioning magnet and electronics head. Verify that instrument supply voltage is 24 volts DC ±10 percent and is not shared by other devices.

7.0 Solar Radiation Measurement

7.1 Introduction--Solar Radiation

7.1.1 Theory

The sun's radiation is the ultimate energy source. Solar radiation to and from the Earth's surface is one of the most important factors in the heat economy of the Earth and its atmosphere. Data from the quantitative measurements of this radiation are extremely important in the research of many scientific disciplines.

Biologists and hydrologists use these data to study and forecast plant growth, evaporation, and snowmelt. Meteorologists use these data to study the uneven heating of the earth-atmosphere system and as a result our weather. Many nations are using these data to research the possibility of using solar radiation as an alternate fuel.

In order to report solar radiation measurements in a method that all users can understand, a standard language for defining the elements of radiation must be established. The following definitions of radiation elements are recommendations of the World Meteorological Organization (WMO, 1971).

Solar Radiation	The radiation emitted by the sun and reaching the observer.
Terrestrial Radiation	The radiation emitted by the earth and the objects on the earth.
Atmospheric Radiation	The radiation emitted by the atmosphere.
Total Radiation	The combined total of solar, terrestrial, and atmospheric radiation.

Solar Radiation is further defined by:

Direct Solar Radiation -- Radiation coming direct from the sun at a solid angle to a horizontal surface perpendicular to the axis of this angle.

Sky Radiation -- Downward diffuse solar radiation as received on a horizontal surface.

Global Solar Radiation -- The downward direct and diffuse radiation as received on a horizontal surface.

Reflected Solar Radiation -- Upward solar radiation reflected by the earth's surface and diffused by the atmosphere between and the ground and the point of observation.

Net Radiation -- The difference between downward and upward solar radiation.
Photosynthetically Active Radiation -- Very short wavelength solar radiation conjunctive to plant sciences.

Radiation measuring instruments vary with the type of radiation element.

Pyrheliometer -- Measures the direct solar radiation at normal incidence to the sun. This is an expensive research tool generally measuring in a band of about 0.3 to 3 μm.

Pyranometer -- Very accurately measures global downward radiation received from the total hemisphere. Generally measures in a band of 0.3 to 3 μm which includes all short-wave solar radiation but none of the long-wave terrestrial radiation.

UV Radiometer (Photometer) -- Measures ultraviolet radiation received on a horizontal surface. Generally measures in a band of 0.295 to 0.385 μm.

Net Radiometer -- Measures the radiation balance. This instrument has two sensors. One positively polarized sensor directed upward and serially connected to a negatively polarized sensor directed downward. The negative sensor subtracts from the positive sensor resulting in an output representative to net radiation. Generally measures in a band of 0.3 to 60 μm which includes most of the ultraviolet, visible, and infrared radiation from both the sun and earth.

Pyrgeometer -- Measures infrared radiation in a band of 4 to 50 μm. Measures both incoming and outgoing radiation depending upon the direction of orientation.

Pyrradiometer -- Measures infrared, visible, and, ultraviolet radiation from a single hemisphere. Measures in selected bands from 0.3 to 100 μm.

PAR Photometer -- Measures photosynthetically active radiation in a band of 400 to 700 nm. Data from this radiation is useful in plant sciences research.

The preferred units of measurements for radiant energy flux per unit area are milliWatts per square centimeter (mW/cm^2)and for radiation per unit area, joules per square centimeter (J/cm^2) or milliWatt-hours per square centimeter (mWh/cm^2). In the United States, a calorie per square centimeter is designated a langley, and the corresponding unit of flux is langley per minute (ly/min). The conversion factors for a langley are:

$$
\begin{aligned}
\text{one langley} &= \text{one cal/cm}^2 \\
&= 4.1855 \text{ J/cm}^2 \\
&= 69.373 \text{ mWh/cm}^2 \\
&= 3.6855 \text{ BTU/ft}^2 \\
&= 697.2 \text{ W/m}^2
\end{aligned}
$$

The preferred units of measurement for photon flux is mole.

one mole	=	one einstein
	=	6.022×10^{23} photons
1 $\mu mol/s/m^2$	=	$1 \mu E/s/m^2 = 6.022 \times 10^{13}$ photons

7.1.2 Instrument Siting and Exposure

Siting and exposure of a solar radiation instrument is critical to the collection of accurate data. The site should be as free as possible of obstructions above the plane of the sensing element. Take particular care in the northern hemisphere to avoid obstructions from west-northwest to east-northeast as these obstructions tend to reflect and/or collect and re-radiate solar energy toward the sensor. The azimuth range for sunrise and sunset as seen by the sensor for the period of December 21 through June 21 shall have no obstructions exceeding an elevation angle of five degrees above the horizon.

Mount the instrument such that, except for aircraft and clouds, no shadow will ever be cast upon the sensor and the sensor is never exposed to any artificial radiation sources. The sensor should be mounted between 1.25 and 2 meters above ground level. If a bubble level is attached, install the sensor such that the level is pointed north as this was the orientation at the time of factory calibration.

> **Note:** Most radiation sensors are influenced by mechanical vibration and shock. This should be considered when site locations near roadways, railroads, or in industrial areas are necessary.

7.1.3 Measurement Standards

Accuracy standards for the measurement of solar radiation using pyranometers as stipulated by the World Meteorological Organization are listed in Table 7.1.

WMO Class	1st Class	2nd Class	3rd Class
Sensitivity (mV/Joule cm^2 min)	0.1	0.5	1.0
Stability (percent per year)	1	2	5
Temperature (percent per °C)	1	2	5

Selectivity (percent departure from ideal spectral response)	1	2	5
Linearity (percent)	1	2	3
Max time constant (seconds)	25	60	240
Cosine response (percent)	3	5-7	10
Azimuth response (percent)	3	5-7	10

Table 7.1 WMO Standard Accuracies for Pyranometers

7.2 Instrumentation--Solar Radiation

7.2.1 Principle of Operation

Principles of operation vary with instrument type, and will be discussed in each individual instrument section.

7.2.2 Maintenance

Maintenance requirements vary with individual instrument types, and are discussed within the individual instrument section.

7.2.3 Sensors Used

7.2.3.1 Eppely Precision Infrared Radiometer (PIR) Radiation Sensor (Pyrgeometer)

The Eppley Precision Infrared Radiometer is an accurate radiation instrument for measuring infrared solar radiation. The detector is a multifunction, non-wavelength selective, wire-wound and plated copper-constantan thermopile. The detector outputs a low level DC voltage proportional to the measured radiation. The detector is temperature compensated and renders a response essentially independent of ambient temperature.

This instrument isolates terrestrial long-wave radiation from the shorter wave solar radiation in the daytime. This is accomplished by incorporating a silicon hemisphere with a vacuum-deposited interference filter. This hemisphere has a composite transmission window of about 4-50 µm.

7.2.3.1.1 Manufacturer's Specifications

Sensitivity:	Approximately 5 microvolts per watt meter^2
Output Impedance:	700 ohms
Temperature dependence:	±1%, -20 to +40°C
Linearity:	±1%, 0 to 700 watts/m^2
Response time:	2 seconds
Cosine response:	5 % nominal
Orientation:	No effect on instrument performance but level on north side is factory calibration orientation.
Mechanical vibration:	Tested to 20 g's without damage. Shock easily exceeds 20 g's.
Calibration:	Blackbody reference

Size:	5 3/4 in. diameter, 3 ½ in high.
Weight:	7 pounds

7.2.3.1.2 Installation Procedures

This instrument should not be installed until the guidelines in Section 7.1.2 are thoroughly understood.

Due to the weight of this instrument, the supporting stand or mount should be sufficiently sturdy to hold it without vibration or shift in position during high winds, etc. Mount the instrument such that the bubble level is on the north side as this is the position of the instrument at the time of initial factory calibration.

> **Note:** Take precautions at all times to avoid exposing the instrument to mechanical shock because all thermopile detectors are sensitive to vibration and calibration could easily become void.

Mount the instrument securely to the mounting stand and ensure that the bubble level indicates level.

7.2.3.1.3 Calibration Procedures

Ideally, radiation instruments are calibrated annually. If not achievable and highly accurate measurements are not critically needed then every three years is a reasonable compromise.

The instrument is calibrated at the factory with a National Bureau of Standards traceable standard. If a traceable standard is not available for comparison, then the instrument must be returned to the factory for calibration.

7.2.3.1.4 Maintenance Procedures

Radiometers in continuous operation should be inspected daily. This, of course, is the ideal inspection schedule although it often not practical. Inspect the instrument as often as is possible with the knowledge that a soiled hemisphere will seriously degrade the instrument accuracy.

At each inspection, wipe the outer hemisphere clean and dry with a soft lint-free cloth. In desert or arid regions, clean the hemisphere **gently** in order not to scratch the surface. Such abrasion can appreciably alter the transmission properties of the hemisphere and degrade the instrument calibration. In cases of snow or ice on the hemisphere, use a warm cloth to remove the deposit.

If the internal surface of the hemisphere becomes coated with moisture, remove it and allow the moisture to evaporate, then reinstall it. **Do not** wipe the inside of the hemisphere unless it is badly soiled as this inside coating is very delicate.

At each inspection, observe the desiccator. If the drying agent (silica gel) is pink or white, replace it. The silica gel can be rejuvenated by drying in an oven at about 175°F for a few hours until the original dark blue color reappears.

Check that the instrument is level at each inspection.

7.2.3.2 Eppely Precision Spectral Photometer (PSP) Radiation Sensor

The Eppley PSP is an accurate radiation instrument for measuring global sun and sky radiation totally or in defined wavelength bands. The detector is a circular multifunction wire-wound copper constantan thermopile. The detector outputs a low level DC voltage which is proportional to radiation. The unit is temperature compensated and renders an output essentially independent of ambient temperature.

The PSP receiver is coated with Parson's black lacquer (non-wavelength-selective absorption) and is supplied with a pair of removable precision ground and polished concentric hemispheres of Schott optical glass (clear WG295), which is transparent over a wavelength range of 0.285 - 2800 nM.

7.2.3.2.1 Manufacturer's Specifications

Sensitivity:	9 microvolts per watt meter², approximately
Output Impedance:	650 ohms, approximately
Receiver:	Circular 1 cm², coated with Parsons' black optical lacquer.
Compensated Temperature Range:	± 1 per cent over range of -20°to +40°C.
Response Time:	1 minute from 0 to 2 langleys
Linearity:	Response is linear up to intensities of 4 cal cm²/min.
Calibration:	Integrating hemisphere (approx 1 cal cm²/min at 25°C)
Size:	5.75" dia., 0.75" high.
Weight:	7 pounds

7.2.3.2.2 Installation Procedures

This instrument should not be installed until the siting and exposure guidelines (Section 7.1.2) are thoroughly understood.

Due to the weight of this instrument, the supporting stand or mount should be sufficiently sturdy to hold it without vibration or shift in position during high winds, etc. Mount the instrument such that the bubble level is on the north side as this is the position of the instrument at the time of initial factory calibration.

> **Note**: Take precautions at all times to avoid exposing the instrument to mechanical shock because all thermopile detectors are sensitive to vibration, which could void calibration.

Mount the instrument securely to the mounting stand and ensure that the bubble level indicates level.

7.2.3.2.3 Calibration Procedures

Ideally, radiation instruments are calibrated annually. If not achievable and highly accurate measurements are not critically needed then every three years is a reasonable compromise.

The instrument is calibrated at the factory with a National Bureau of Standards traceable standard. If a traceable standard is not available for comparison, then the instrument must be returned to the factory for calibration.

7.2.3.2.4 Maintenance Procedures

Radiometers in continuous operation should be inspected daily. This, of course, is the ideal inspection schedule although it is often not practical. Inspect the instrument as often as is possible with the knowledge that a soiled hemisphere will seriously degrade the instrument accuracy.

At each inspection, wipe the outer hemisphere clean and dry with a soft lint-free cloth. In desert or arid regions, clean the hemisphere **gently** in order not to scratch the surface. Such abrasion can appreciably alter the transmission properties of the hemisphere and degrade the instrument calibration. In cases of snow or ice on the hemisphere, use a warm cloth to remove the deposit.

If the internal surface of the hemisphere becomes coated with moisture, remove it and allow the moisture to evaporate, then reinstall it. **Do not** wipe the inside of the hemisphere unless it is badly soiled as this inside coating is very delicate.

At each inspection, observe the desiccator. If the drying agent (silica gel) is pink or white, replace it. The silica gel can be rejuvenated by drying in an oven at about 175°F for a few hours until the original dark blue color reappears. Check that the instrument is level at each inspection.

7.2.3.3 LI-COR LI-190SA Photosynthetic Active Radiation (PAR) Radiation Sensor

Plants use the 400 - 700 nm wavelength of light spectrum for photosynthesis, therefore this range of wavelength is called Photosynthetically Active Radiation. An integral relationship exists between the number of molecules changed photochemically and the number of photons absorbed within the requisite waveband regardless of the photon energy. The preferred measurement for PAR is Photosynthetic Photon Flux Density (PPFD). This is the number of photons in the 400 - 700 nm waveband incident per unit time on a unit surface.

The LI-COR LI-190SA PAR sensor incorporates colored glass filters to tailor the spectral response of the silicon photodiode to the desired quantum response. An interference filter is used to provide a sharp cutoff at the 700 nm point. This sharp cutoff is needed when PAR measurements are taken under plant canopy where the ratio of infrared to visible light is high. A small response to the infrared region will cause an appreciable measurement error.

7.2.3.3.1 Manufacturer's Specifications

Calibration:	± 5% traceable to U.S. National Bureau of Standards.
Sensitivity:	Typically 8µA per 1000µmol/sm²
Linearity:	Max deviation of 1% up to 10,000µmol/sm²
Stability:	Less than ± 2% change over 1 year period.
Response time:	10µs
Temperature stability:	± 0.15% per °C Max
Cosine Correction:	Cosine corrected up to 80° angle of incidence.
Azimuth:	Less than ± 1% error over 360° at 45° elevation.
Operating Temperature:	-20° to 65°C
Humidity Range:	0 to 100%
Detector:	High stability silicon photovoltaic detector (blue enhanced).
Size:	2.38 cm Dia. x 2.54 cm High.
Weight:	one ounce.

7.2.3.3.2 Installation Procedures

This instrument should not be installed until the siting and exposure guidelines (Section 7.1.2) are thoroughly understood.
The supporting stand or mount should be sufficiently sturdy to hold it without vibration or shift in position during high winds, etc. Mount the instrument in its mounting flange. Mount the flange such that the bubble level is on the north side as this is the position of the instrument at the time of initial factory calibration.

Note: Take precautions at all times to avoid exposing the instrument to mechanical shock because the silicon diode detectors are sensitive to vibration which could void calibration.

Mount the instrument securely to the mounting stand and ensure that the bubble level indicates level.

7.2.3.3.3 Calibration Procedures

Ideally, radiation instruments are calibrated annually. If not achievable and highly accurate measurements are not critically needed then every three years is a reasonable compromise.

The instrument is calibrated at the factory with a National Bureau of Standards traceable standard. If a traceable standard is not available for comparison, then the instrument must be returned to the factory for calibration.

7.2.3.3.4 Maintenance Procedures

Radiometers in continuous operation should be inspected daily. This, of course, is the ideal inspection schedule although it is often not practical. Inspect the instrument as often as is possible with the knowledge that a soiled external filter will seriously degrade the instrument accuracy.

At each inspection, wipe the outer filter clean and dry with a soft lint-free cloth. In desert or arid regions, clean the outer filter **gently** in order not to scratch the surface. Such abrasion can appreciably alter the transmission properties of the filter and degrade the instrument calibration. In cases of snow or ice on the outer filter, use a warm cloth to remove the deposit.

7.2.3.4 LI-COR Model LI-500 Integrator

The LI-500 is used to integrate over time the current output of all LI-COR light sensors, such as LI-200S pyranometer discussed in the next section. The LI-500 is designed on a module basis. The instrument has three functions which are performed by three different modules. The input from light sensor is amplified by a specific module. The amplified signal is then fed to the voltage controlled oscillator (VCO) which has a sensitivity of 100,100 counts per volt-hr. The output of the VCO is in the form of pulses which are fed to the count divider and counter driver module. The count divider is set at 512 at the factory but may be changed by the user.

7.2.3.4.1 Manufacturer's Specifications

Count Rate:	3 counts
Max. Input:	130 amps
Error at 25°C:	1% @ 100 µA, 5% @ 0 .4 µA
Error 0-50°C:	< 2%
Input Impedance:	< 1
VCO Sensitivity:	100,100 counts per hr per volt.
Max. Count Rate:	5 counts per second.

7.2.3.4.2 Installation Procedures

Install the correct module in the integrator corresponding to the sensor used. Connect sensor to the integrator or use a 50-ft extension cable on the sensor. For permanent installation the mounting and leveling fixture may be used for the sensor.

The LI-500 Integrator may be mounted outside in the shade, but inside mounting is preferable.

To interpret the integrator reading two facts must be known. These are: (1) sensor output definition, and (2) integrator response to the sensor output. Each LI-COR light sensor is accompanied by a calibration certificate which defines the sensor output in terms of a light unit. Other instruments are similarly stated in their individual specifications. LI-COR provides a table to define the LI-500 Integrator counting rate with all modules and divider adjustments.

7.2.3.4.3 Calibration Procedures

To calibrate the integrator, the equipment required are: 1 percent accurate voltmeter, 1 percent accurate microammeter, frequency counter and timer, and 0-20 volt power supply (0.1 amp).

The VCO module has a zero offset potentiometer and a CAL potentiometer. The VCO zero-offset can be adjusted by connecting a DC voltmeter to the VCO amp output and the negative supply. With no module in place and the module output shorted to circuit ground, adjust the zero-offset potentiometer so that the output varies slowly from either 0.7 or 4.7 volts to about 2.7 volts. Then adjust the potentiometer for a minimum drift rate at the VCO amp output. To calibrate the VCO, connect a frequency counter timer to the VCO pulse output referenced to the negative supply. With no module in place, apply +1.000 volt to the module output referenced to circuit ground. Adjust the CAL potentiometer for a period of 0.03600 seconds between pulses. The VCO is now set to a sensitivity of 100,000 counts per hour per volt input.

7.2.3.4.4 Maintenance Procedures

Conditions which cause water vapor condensation within the instrument can result in unusable data. This can be avoided in many locations by placing silica gel in a cloth bag and closing it in the instrument case. The instrument will function properly again if it is dried soon after the condensate forms. If water enters the mechanical counter as freezing conditions occur, then the counter may jam.

Check batteries for corrosion at least at two-month intervals. Remove corrosion with a damp cloth. This is common with mercury batteries. Place a shorting wire across the input of voltage modules when the instrument is not in use. This prevents the battery from draining due to the fast count rate which may occur with open circuit input.

7.2.3.5 LI-COR Model LI-200S Pyranometer

A pyranometer is an instrument for measuring solar radiation received from a whole hemisphere. It is suitable for measuring global sun plus sky radiation.

Solar radiation varies significantly among regions. Season and time of day are major considerations but atmospheric conditions, surrounding terrain elevation, man-made obstructions, and surrounding trees can cause large variations among locations with a small area. The most often required measurement is the energy flux density of both direct beam and diffuse sky radiation passing through a horizontal plane of known unit area.

The silicon photodiode has made possible the construction of simple pyranometers of reasonable accuracy. The photodiode is stable. The response of the silicon photodiode sensor does not cause serious measurement errors provided the photodiode is used only for solar radiation and not under conditions of altered spectral distribution. For this reason, the LI-200S is not recommended for use under artificial lighting or within plant canopies. Reflected radiation is also erroneously measured.

7.2.3.5.1 Manufacturer's Specifications

Sensitivity:	50 µA/1000 watts m^{-2}
Linearity:	Maximum deviation of 1% up to 3000 watts m^{-2}
Stability:	Less than 2% change over a 1-year period
Response Time(10-90%):	10 microseconds
Temperature Dependence:	±15% /°C maximum
Cosine Correction:	Cosine corrected up to 80° angle of incidence
Azimuth Error:	Less than 1% over 360° at 45° elevation

7.2.3.5.2 Installation Procedures

The LI-200S may be hand-held or mounted at any required angle provided that reflected radiation is not a significant portion of the total. In its most frequent application the pyranometer sensor is set on a level surface free from any obstruction to either diffuse or direct radiation. The sensor may be most conveniently leveled through the use of the 2003S mounting and leveling fixture.

The LI-200S is designed to be compatible with LI-COR models LI-170 and LI-185A quantum/radiometer/photometer meters and the LI-COR integrator, as discussed in the previous section.

The LI-200S may be connected to millivolt recorders if the 2200S Millivolt Adapter is fastened to the cable connector near the recorder. Cable length of 1000 feet or more will not degrade the signal when high impedance (>1 meg-ohm) recorders such as potentiometric types are used. Recorder range adjustment should be approximately 0 - 10 mV full scale. The cable should be 2-wire shielded, #20 gauge or more. Sensor output in this configuration is given in mV/1000 watts m^{-2} (see calibration certificate). This figure is obtained by multiplying 0.1 times the microampere calibration constant.

7.2.3.5.3 Calibration Procedures

The LI-200S has been calibrated against an Eppley precision pyranometer of which the calibration is periodically confirmed. The calibration was performed in open daylight. The uncertainty of the calibration is ± 5 percent.

7.2.3.5.4 Maintenance Procedures

Keep the sensor clean and treat it as a scientific instrument in order to maintain accuracy of calibration. The vertical edge of the diffuser must be kept clean in order to maintain appropriate cosine correction.

8.0 Soil Temperature and Moisture Measurement

8.1 Introduction--Soil Temperature and Moisture

Text to be added at a later date

Water Level Monitoring

9.0 Water Level Measurement

9.1 Introduction--Water Levels

9.1.1 Theory

Surface levels of water bodies have been observed for various purposes over several centuries. Some data in China date back to the Ming Dynasty. Water levels in wells were probably observed in the centuries BCE. In order to be useful, the levels were measured to a common datum. This could be distance from a bailer spindle for a dug well, depth above a stationary rock in a stream, or distances above or below a permanent reference object.

Currently, water levels are measured as a distance above or below a measuring point (MP) such as the top of the well casing for a ground-water site or top of a recorder shelf for lakes and rivers. In order for water-level data from one site to be related to that from another site, both sites must have the same datum. Previously, levels in wells were referenced to the ground elevation at the site, or the land surface datum (LSD). Most sites currently use mean sea level (MSL), also known as the National Geodetic Vertical Datum (NGVD), as a datum.

Measurements of distance-to-water are usually made with a graduated instrument. This can be a manual observation with a ruler, a reading on a pressure gauge or an analog measurement with an encoding device.

Surface levels of water bodies are affected by several natural phenomena as well as anthropogenic influences.

Water levels in lakes and rivers are influenced by the size of the contributing drainage basin, amount of precipitation in the basin, inflow from ground water sources and other inflows. Water is also lost from a basin due to evapotranspiration, withdrawals, and ground water recharge. Ground water systems react similarly as surface water systems, only at a slower and less intense rate. Ground water levels generally are influenced by recharge to and discharge from an aquifer. Locally, levels can change rapidly to such inflows as drainage wells and outflows such as intense pumping.

9.1.2 Instrument Siting and Exposure

Instruments must be located near a water body so the sensors can be mounted above or below the water surface, or adjacent to the water. The sensors must be mounted in stable housing, such that the elevation of the MP does not change with time due to settling of the structure. Recording equipment must be protected from the elements.

9.1.3 Measurement Standards

Measurements should be accurate to 0.01 feet. However, this may be altered by variables such as the distance from the MP to the water surface, the accuracy of the analog recorder, the accuracy of an analog to digital interface or even the hydrodynamics of the water body. Ofttimes this standard may not be achieved but the data may be valid as long as the accuracy is defined.

9.2 Instrumentation--Manual Measurements

9.2.1 Principle of Operation

A graduated instrument, whose calibration does not change significantly with temperature, is used to measure the distance from a reference point (RP) or an MP to a water surface.

9.2.2 Maintenance

Instruments must be kept clean so that all graduations can be read accurately and be handled so that the calibration is not altered.

9.2.3 Sensors Used

9.2.3.1 Staff Gauges

9.2.3.1.1 Manufacturer's Specifications

Staff gauges consist of either porcelain-enameled iron sections 3.4 feet long (some plastics are 4.0 feet long), 4 inches wide and graduated every 0.02 foot. In addition to holes in the plate for mounting purposes, there should be two slots about ½" long at the mid-point of the panel. These slots are used to adjust the section before final securing to a backing plate.

9.2.3.1.2 Installation Procedures

Staff gauges should be attached to a backing plate and mounted to a stable structure in the water body. The site location should be one that does not allow the water level to exceed the range of the gauge, and allows an observer to read the gauge with the naked eye. The gauge is to be mounted vertical and plumb to the water surface. If more than one gauge section is used, they should be adjusted for accuracy between sections by measuring the distance from the middle of one section to that of an adjacent section.

9.2.3.1.3 Calibration Procedures

The datum of the gauge should be referenced to mean sea level or an arbitrary datum. The elevation of the datum should be checked 6 months after installation and thence every 3 years.

9.2.3.1.4 Maintenance Procedures

Gauges should be kept in a readable condition by periodic brushing.

9.2.3.2 Stainless Steel Tape Measure

Stainless steel measuring tapes are used by the Water Management Districts for determining depth to water in ground water wells and surface water stilling wells. The standard tape length is 100 feet (or 30 meters), but are available by special order in other lengths. Steel tapes should be long enough to measure deep water levels at ground water sites. Etched markings are graduated in hundredths of a foot or millimeters. Some tapes have both scales on opposite sides of the tape. Steel tapes are normally mounted to a reel for ease of rolling/unrolling, and have a hook at the bottom for attachment of a stainless steel or brass weight.

9.2.3.2.1 Manufacturer's Specifications

Tape length	100 feet (30 meters) 165 feet (50 meters)
Graduations	0.01 inch (1 millimeter)

9.2.3.2.2 Installation Procedures

Steel tapes are used by manually unrolling the tape down a well casing until the bottom section of the tape contacts the water, thereby wetting the tape surface. The length of tape down the well is read at a specific measuring point, often a notch in the casing. In order to identify the depth to water, the tape is typically rubbed with chalk as it descends the casing. As the tape is reeled up from the well casing, the technician looks for the line denoting dry chalk and the wet tape. The tape scale is red at this line, and is subtracted from the total length of tape previously recorded at the measuring point to determine depth to water. To convert this depth to water reading to a level relative to NGVD, a surveyed elevation value for the measuring point is added. To ensure water level is correctly measured, this procedure should be repeated at least two times, holding the tape at different scale level each time. The calculated depth to water should not vary by more than 0.03 foot. If variance between two readings is greater than 0.02 foot, the well should be re-measured until the readings fall within this tolerance. Water levels in wells near other pumping wells may react vary quickly, and present a challenge to this measuring procedure. Prior knowledge of the approximate depth to water at a particular well allows only enough tape to be unreeled as is necessary to recognize the wet line and therefore depth to water.

9.2.3.2.3 Calibration Procedures

The calibration markings on the stainless steel tape measure are permanent. No calibration is required.

9.2.3.2.4 Maintenance Procedures

Tapes should be kept clean and free of debris, and wiped off after use. It is important to keep the tapes tightly wound on the reel to prevent kinking. Serious kinking of the tape will adversely affect measurements of depth to water.

9.2.3.3 Ametek Cal-Pal Hand Held Digital Pressure Gauge

Pressure gauges can be used to determine water levels in artesian wells. A wide variety of pressure gauges for fluid media exist. In general, the gauge should have the capability of registering water levels in hundredths of a foot. Optimally, a field person should have a set of pressure transducers calibrated for 15 foot ranges. One gauge should have a range of 0 to 100 feet, to be used to identify the general elevation of the water level. The other gauges should have the following ranges: 0-15, 15-30, 30-45, and so forth until the complete range is attained. The dial should be designed to prevent parallax.

The Cal-Pal is a hand-held precision digital pressure gauge available in three pressure ranges (0-10 PSI, 0-30 PSI, and 0-200 PSI). Microprocessor control provides temperature compensation throughout the range.

9.2.3.3.1 Manufacturer's Specifications

Units Selection:	PSI, In. H_2O @ 20°C (ISA) In. H_2O @ 60°F (AGA) In. of Hg Bar., KPa, Kg/cm^2
Mode Selection:	Pressure, current (0-50 mA), current (% of 4-20 mA); alternate pressure and current with four second cycle; alternate pressure and percent with four second cycle
Indicator:	LED switch closure
Current Range:	0 to 50 mA
Accuracy:	± 0.05% of full scale + 1 least significant digit including linearity, repeatability, and hysteresis.
Resolution:	4-digits with floating decimal
Temperature Range:	30 to 130°F (0 to 55°C)
Temperature Effect:	Not greater than 0.05% of full scale throughout temperature range
Over Pressure:	"OV RANGE" appears on the display when pressure reaches 110% of rating. The gauge is protected by a pressure relief valve which will relieve pressure before physical damage will occur.
Over Current:	"OV RANGE" appears on the display when the current reaches 110% of rating. The gauge is protected by a fusible link which will break at 60 mA.
Power Requirements:	Two 9 VDC Alkaline batteries. "LOW BATT" appears on the display periodically when battery voltage is approaching operational limit. The battery life is approximately 40 hours.
Media Compatibility:	Air, nitrogen, water, natural gas, hydraulic oil, glycol.
Dimensions:	6-7/8" H x 3-3/4" W x 2-5/8" D
Weight:	Three pounds.

9.2.3.3.2 Installation Procedures

Pressure gauges are manually connected to a well by a technician using a valved, semi-rigid-walled tube that does not balloon under pressure. The gauge is held so that the dial is vertical and the water inlet is at the bottom. The gauge is positioned such that the center of the gauge is at the same elevation as the measuring point. The valve is opened slowly so as to prevent a water hammer and possible damage to the Bourdon tube.

The Cal-Pal pressure input connection is a 1/4-inch male NPT. The Cal-Pal gauge is supplied with a relief valve to protect the gauge from excessive overpressuring. These relief valves are preset at the factory. DO NOT READJUST THIS VALVE.

Pressing and releasing the ON/OFF switch applies power to the Cal-Pal. The unit goes through an initialization sequence, and then eight dashes will appear on the display followed by the engineering units to be used for pressure measurement. Pressing and holding the UNITS switch will cycle the display through the engineering units available. When the desired unit is displayed, release the switch. The gauge will continue using the selected unit until changed and will power up with the last unit selected. For the purposes of water level measurement, the UNITS should be set on I60, inches of water at 60°F. Pressing and holding the MODE switch will cycle through the available options. When the desired mode is reached release the switch. For the purposes of water level measurement, MODE should be set on PRESSURE. The unit always defaults to the PRESSURE mode upon power up. Allow approximately ten seconds before taking readings with the unit. For best accuracy, when moving the unit from one temperature to another, allow time for the unit to stabilize before taking readings. The ZERO switch is used to zero out any offset that may be present on the pressure. If a reading is too high to zero out, the display will read "TOO HIGH" and return to normal displays. To zero the gauge, press and hold the ZERO switch until the display shows eight dashes, then release the switch. To turn off the unit, press and hold the ON/OFF switch until the display reads OFF, then release the switch.

9.2.3.3.3 Calibration Procedures

Calibration of analog gauges can be checked by a dead-weight tester or by a column of water with known head above a reference point. At least 5 points within the range of the gauge should be checked. If the unit is found to be out of calibration, it must be returned to the factory for recalibration.

9.2.3.3.4 Maintenance Procedures

Gauges should be stored and transported in a case that reduces vibration and shock. Water should be drained from the gauge after use. Do not subject the gauges to freezing conditions. The Cal-Pal is powered by two replaceable 9 VDC Alkaline cell batteries, which normally supply approximately 40 hours of operation before the low battery (LOW BATT) indication is displayed. After the LOW BATT indication appears, the batteries should be replaced within two hours for reliable operation. When the battery reaches an unreliable level, LOW BATT will be continually displayed. Access to the batteries is from the back of the Cal-Pal unit.

9.3 Instrumentation--Surface Followers

9.3.1 Principles of Operation

This system usually consists of a float and counterweight that are suspended on a perforated steel tape or a beaded cable over a float pulley that is attached to a recorder. As the float rises or falls the float pulley turns a proportional amount, driving an encoding device on the recorder.

9.3.2 Maintenance

Although most surface follower instruments are designed for lengthy service without maintenance, general cleanliness is very important to ensure trouble-free operation. At each site visit, inspect the instrument and remove all foreign materials such as corrosion and insect debris. Be especially observant for spider webs on float lanyards and tapes.

Specific maintenance procedures are covered within the chapters concerning the specific instruments.

9.3.3 Sensors Used--Punched-Tape Recorders

9.3.3.1 Stevens Model 7001 Recorder

The Stevens Model 7001 Digital Punch Paper Tape Recorder is a highly accurate monitoring device used in recording liquid levels. The instrument converts rotational shaft position into coded digital information and periodically records this information as punched holes in paper tape. These position measurements are recorded in binary form. Four digits of information are recorded. Each digit is described by four hole positions. The Recorder punches data at particularly selected intervals of time which are controlled by a timer. The standard recorder is provided with a one-foot circumference float pulley and is geared for a measurement resolution of 0.01 feet.

9.3.3.1.1 Manufacturer's Specifications

Power Requirements:	7.5 to 15 volts 2.0 Amp max Surge 250 mA Nominal 10 watt-sec/cycle approx.
Range:	99.99 feet or 10,000 counts.
Accuracy:	± ½ count
Resolution:	0.01 feet/1 ft cir. pulley
Drive Torque:	Less than 1 ounce-inch
Operating Temp Range:	-40° to +122°F
Punch Interval:	5 minute intervals/5 minute min/60 minute max
Physical Dimensions:	13" X 13" X 8"
Weight:	14 lbs

Maximum rate of change: 1.2 Revolutions per minute

9.3.3.1.2 Installation Procedures

When installing the Stevens recorder, position the instrument above the stilling well such that the float and counterweight do not strike each other or rub the sides of the stilling well or any part of the mounting platform throughout the instrument operating range.

Mount the instrument using the three mounting holes in the base of the unit. **Be sure** that the float pulley is plumb (perpendicular to level horizontal). Spacer washers may be used at the rear mounting screw to adjust the float pulley for plumb. If the float pulley is not plumb the tape may have a tendency to climb the pulley edge thereby disengaging the pulley spines from the holes in the tape. This will render the instrument inoperative.

Determine Tape Length

To calculate the appropriate tape length, measure the current distance down to water (DTW) from the MP. Subtract DTW from the measuring point to determine the present water level referenced to National Geodetic Vertical Datum (NGVD). Subtract the period-of-record minimum water level relative to NGVD from the current water level NGVD. This value indicates the distance between the current level and the period-of-record low level. The tape length should be equal to the distance calculated above plus the measured distance to water plus an additional 20% of the DTW.

$$\text{Tape Length} = (\text{Current Level} - \text{POR Low}) + \text{DTW} + 0.2(\text{DTW})$$

In other words, if the period of record minimum water level is 30 feet NGVD, the current level is 34 feet NGVD, and DTW = 20 feet, then the tape length should be 28 feet.

Determine counterweight and float weights

The **counterweight** must weigh at least 2 times as much as the total weight of the tape plus 2 attachment clips. The **float** must weigh at least 1.5 times as much as the combined weight of the tape, 2 attachment clips and counterweight. The perforated tape weighs 0.1738 ounces per foot and the attachment clips weigh 0.4044 ounces each. In the example above the 28 feet of tape weighs 4.9 (28 X 0.1738 = 4.866) ounces and the 2 attachment clips weigh 0.81 ounces for a combined weight of 5.7 ounces. Therefore, the counterweight should weigh at least 11.4 ounces. The combined weight of 11.4 ounces of counterweight and 5.7 ounces of tape and clips equal a total of 17.1 ounces. Therefore the float should weigh at least 26.6 ounces.

It is important to note that improper weight ratios may allow the tape weight to overcome the counterweight or the combined weight of the counterweight and tape to overcome the float, either of which would render the unit inoperative resulting in lost data.

Upon fabricating the tape-float-counterweight system, complete the installation by lowering the float to the surface of the water inside the stilling well. Pass the float tape around the float pulley such that while facing the pulley the float hangs on your **left** hand side of the pulley and the counterweight hangs on your right hand side of the pulley. The tape holes must engage the spines in the pulley.

> **CAUTION - do not turn input shaft faster than ½ revolution per second.**

Loosen the two knurled thumb screws which clamp the float pulley to the input shaft. **One screw is a left hand thread the other is a right hand thread.** While holding the float pulley stationary rotate the input shaft until the encoded value agrees with the water level. The encoded value is indicated by the alignment of the pointer with the stamped numbers on the encoding drums located on the input shaft inside the instrument. Only even numbers are stamped on the drums. Odd numbers must be interpolated.

With thumb and forefinger, firmly tighten the two knurled thumb screws that clamp the float pulley to the input shaft.

Slowly and carefully rotate the float pulley clockwise one full revolution **raising** the float. Hold at this point and observe that the encoding drum indicates an increase in value of 1.00 feet. If the indication decreases, exchange the float and counterweight positions with relation to the pulley wheel.

> **Note: Do not attempt this test by raising the counterweight.** This creates slack in the tape on the float side of the pulley and may cause the attachment clip to hang in the float eye ring. If the clip hangs, then the

tape is shortened on the float side and will cause an error of up to 0.125 feet in water level measurements if the clip releases itself.

Loading or replacing the punch paper tape

Ensure that the chad tray is installed correctly before threading paper tape. A retainer clip is located on the bottom of the chad tray. Press this clip over the guide rod until it rests between the guide rod collars. Push the tray straight up until the ears snap into place in the openings on the stripper bracket.

Twist the locking knob or keeper of the supply roll stud 1/4 turn. Remove the tape roll retainer. Place a roll of recording tape on the spindle so that the paper will feed from the bottom of the roll when mounted on the recorder. Check that the sides of the roll are smooth and flat (telescoping rolls will cause excessive drag). Replace the retainer and turn the keeper knob 1/4 turn.

Unroll approximately 18 inches of tape. Write the Site name and number along with the date and time within the first 18 inches of tape. Pass the tape below and around the guide rod. Insert it through the slot in the punching head. Pull the tape up and over the Tape Advance Roller Assembly meshing the projecting pins in the center of the drum with the holes in the center of the tape. Insert the end of the tape in the slot of the Take-up Drum. Turn the Take-up Drum counterclockwise to take up the remaining 8 to 10 inches of slack tape thus securing the tape. Push and hold the test switch until the instrument has punched about six times. Check that the tape has smoothly engaged the spines of the tape advance roller and that the rows of punched holes are evenly spaced . This checks that the tape is correctly threaded and is feeding properly.

Timing the instrument

The Stevens Solid State Timer electronically initiates the punch cycle at time intervals selected by the operator. Intervals are selected in 5-minute increments from 5 to 60 minutes. The preset button is used to synchronize the timer.

Most instruments in service are synchronized with the time of day; for instance on the hour. The "preset" feature saves the operator a long wait while synchronizing. While the timer is establishing the synchronizing period the minutes knob can be set to the operating punch interval.

Begin the timer set up by applying power to the recorder. Determine the time when you wish the timer to start. Rotate the minutes knob to a number less than the waiting period. For example, if the starting time is 1:00 PM and it is now 18 minutes until 1:00, set the knob to 15. Wait until 15 minutes before 1:00 p.m. and press the preset button. The recorder will immediately begin its punch cycle, including a pause of up to 7 seconds while the electronics package resets.

When the punch cycle is completed, set the knob to the punch interval desired. Example; each hour on the hour set the knob to 60. Do not turn the knob until the recorder has completed its punch cycle as this will **spoil the preset time interval.** No further time adjustment is necessary. The timer will operate the recorder at 1:00 and every 60 minutes thereafter.

To remove the punched tape from the recorder

Empty and reinstall the chad tray. Pull enough slack tape from the supply roll to permit the tape to disengage from the spines of the tape advance roller assembly. Lift the tape free of that roller and pull enough through to permit all the punched tape to be wound onto the take-up drum. Cut the tape several inches after the last punch entry and roll the tape tightly onto the take-up drum. Gently pull the tape from the take-up drum (a finger access slot is provided in the drum to permit gripping the coil with the thumb and forefinger).

Check the supply roll to ensure enough tape remains for the next recording period and reload the tape as described previously.

A tape leader must be completed in **all respects** and attached to the end of each tape as it is removed from the recorder and carefully transported to District Headquarters for data reduction.

9.3.3.1.3 Calibration Procedures

Calibration of the instrument should be accomplished at each site visit. Manual DTW (distance to water) measurements must be repeated until two consecutive measurements compare within 0.01 feet. Subtract the DTW from the measuring point at the shelter floor to establish the water level referenced to MSL (mean sea level). The indicator cams inside the Stevens should show these same values within 0.02 feet. If the manual and Stevens MSL values differ more than 0.02 then loosen the two knurled thumb screws which clamp the float pulley to the input shaft. While holding the pulley stationary, turn the input shaft until the encoder value agrees with the MSL or water level. Tighten the knurled thumb screws evenly and firmly with thumb and forefinger. Slowly turn the float pulley one full revolution in the direction that raises the float. The encoder should indicate a water level of one foot higher than the manual measurement. Slowly return the pulley to the balanced position and the encoder should then indicate the same as the previous manual measurement.

Adjustment Procedures

Adjustments other than cleaning and clearing, should not be performed in the field. Most adjustments require proper and or special tools and should be performed in the more suitable environment of a repair laboratory.

9.3.3.1.4 Maintenance Procedures

Maintenance requirements of the Stevens Recorder are minimal as the instrument is completely adjusted at the factory and should operate for years without needing further adjustments. The routine maintenance consist of general dusting and cleaning. The punch head assembly should be brushed and or sprayed with tuner cleaner to remove any foreign material such as ink from marking pens, damp chad, etc. The instrument should be visually inspected for chafed wires, loose springs, soiled tape, and punched data matching manual measurements. Troubleshooting tips are shown in Table 9.1.

> **IMPORTANT NOTE**: **Do not use WD 40 or other types of lubricant on any of the bearings or moving parts of this instrument. The bearings in particular are made to run dry. The lubricant collects dust and grit causing the bearings to increase friction or seize.**

MALFUNCTION	POSSIBLE CAUSE	CORRECTIVE PROCEDURE
Punched data does not agree with true value of parameter measured. IF error is consistent. IF punched value decreases as true parameter value increases. IF one or more encoding drums jam at the "O" position of the drums.	Instrument is incorrectly calibrated. Input is reversed Trip gearing is sticking. Plastic idler gears may be misaligned and interfering with mating gear.	Check instrument setting as described in 9.3.3.1.3. Install mechanism as described in 9.3.3.1.2. (Float rises for increasing stage.) Clean gearing. Check for burrs or damage to gears. Check for axial misalignment of plastic gears. Replace damaged parts.
One or more punch positions are constantly unpunched, partly punched, or incorrectly punched.	Punch pins are damaged. The punch head and encoding drums are misaligned.	Replace punch and align punch head.
Tape is torn.	Pins are jammed in die.	Free pins, clean with tuner cleaner, and test.
Punched holes are ragged or fuzzy.	Paper is damp. Punching pins or pin guides are worn.	Replace with dry roll or use foil-backed tape. Replace Punch Assembly.
Excessively long series of identical punches.	Motor maintain switch contacts are stuck.	Replace switch.
Elongated holes, up to four holes, may be punched in any one digit	Faulty tape drive. Paper advance cam is loose or retaining collar is loose.	Repair or replace. Align and tighten cam set screw.
Holes punched too closely together.	Ratchet arm bent. Misalignment of punch head.	Carefully straighten. Align punch assembly.
Tape record does not agree with time of day.	Instrument was not correctly timed when tape was installed.	Synchronize instrument with timer described in

MALFUNCTION	POSSIBLE CAUSE	CORRECTIVE PROCEDURE
		9.3.3.1.2.
	Instrument has stopped or does not punch on command.	Check motor operation. Check batteries. Check motor maintain switch. Check motor maintain cam setting.
	Bad clock.	Check clock operation.
Punched holes do not center on time lines on tape.	Ratchet pawl finger bent.	Adjust.

Table 9.1 Troubleshooting Chart for Stevens Model 7001 Punched Tape Recorder

9.3.3.2 Belfort Model 35-1542 Punched-Tape Recorder

The Digital Recorder is composed of three basic sub-assemblies. They are the encoder assembly, the punch assembly, and the structural assembly.

The encoding assembly consists of an input shaft geared to an encoding drum assembly. The drum assembly consists of 4 interdependently rotating drums. Input shaft position is recorded in four digits of information, with each digit represented by the position of one drum.

The encoding shaft is geared to the encoding drum assembly at a ratio of 1:10. The first drum turns 10 times for each single rotation of the input shaft. Each drum is subdivided into ten equal rotational segments. Since the first drum is divided into ten segments and this same drum turns ten times to one turn of the input shaft, then each segment of the first drum represents 1/100 of 1 input rotation. Special trip gearing enables each succeeding drum to increment one segment for each full revolution of the drum preceding it. This enables the **drum assembly** to count 100 full revolutions of the input shaft and resolve 1/100 part of each revolution. Therefore the rotation of a one foot circumference pulley wheel can be measured to a resolution of 0.01 feet.

Lock-up of the encoding drums occurs during the punch cycle to ensure that the drums are not in an ambiguous position. Lock-up also prevents **any** rotation of the drums while a punch is in process.

Rotational input that occurs during the punch cycle, or while the drums are locked up, is stored in a torsional spring on the input shaft. After the punch cycle is complete the stored energy in this spring will drive the drums to their correct positions. The spring will store approximately 80 degrees of rotation. This storage during lock-up limits the maximum rate of input shaft rotation change that can be accommodated. The Belfort recorder can accommodate, during punch cycles, a maximum of 1.2 feet per minute rotational change (water level change) before serious data degradation occurs.

The Punch Head Assembly has a single lobe cam that moves the punching mechanism. The punching head is moved forward pressing the punch pins against the raised portions of the encoder drums. The forward cam rotation continues until the pins are forced through the paper tape. The cam then allows the spring-loaded punch head to return to its normal idle position and the punching pins are retracted from the tape by a stationary comb.

9.3.3.2.1 Manufacturer's Specifications

Electrical Requirements:	7.5 VDC battery
Readout Range:	0 to 99.99
Readout:	Binary code on 16-channel punched tape
Readout Accuracy:	0.01 foot with 6" float
Input Torque:	One inch-ounce
Recording Tape:	Paper
Standard Enclosure:	Drip-proof with window for direct reading
Unattended Operation:	60 days (5-minute cycle) to 6-months or more (15, 30, or 60-minute cycle)

9.3.3.2.2 Installation Procedures

The Punched Tape Recorder when encased in the standard enclosure is drip-proof and should be placed horizontally next to the well or stilling well opening. The instrument should be mounted so that the code disks are vertical and the punch tape operates horizontally. The instrument is furnished with a hub, pulley, washer, flange and thumb screws mounted on the input shaft. Place the pulley on the shaft butting up against the pulley. Thread the flange on the shaft and thread the two thumb screws through the flange; do not tighten the thumb screws at this time. Place the cable and float assembly over the pulley and note the exact depth to which the float is positioned in the well. Rotate the code disk shaft while holding the pulley in a fixed position, until the code disk indicates the depth of the float in the appropriate measurement units. Tighten the thumb screws; the Level Recorder is aligned with the measuring medium.
Timer Unit Connections

The Level Recorder is typically furnished with an external Solid-State Timer that operates directly from the 12 VDC battery source. The timer must be wired in accordance with the applicable wiring diagram.

Installation of Data Recording Tape

1. Make certain power is shut off. Certain models may have a power toggle switch located on the front panel.

2. Remove the plastic chad tray from the punch arm assembly by lifting and tilting the top edge outward.

3. Remove the outer tape supply spool disk by rotating counterclockwise.

4. Place a full tape roll on the tape supply spool, positioned so that the "printed time digits" are right side up facing the front of the instrument.

5. Replace the outer tape supply spool disk.

6. Pull the end of the tape off the supply roll, leading it under the base of the punch arm assembly, between the tape drive sprocket and paper retaining clamp and towards the front of the instrument (push down on the retaining clamp, allowing the tape to pass through the sprocket).

7. Withdraw about 24" of paper tape beyond the tape drive sprocket at the base of the punch arm assembly.

8. Feed the end of the paper tape between the punch holder and the punch die; Then take up the slack and seat the tape drive sprocket holes over the drive sprocket pins.

9. Pull the tape up behind the upper paper guide to the take-up spool.

10. Fold the end of the tape over and slip the end of the tape into the lateral slit in the periphery of this spool, inserting the tape down into the center portion of the spool. Make certain that the paper tape is square with the spool.

11. Take up the slack in the tape by rotating the take-up spool in a forward position. Wrap three turns of paper around the spool.

12. Take up any final slack by pulling gently on the spring drive belt making certain that the spring does not jump out of the groove on the cam shaft pulley.

Manual Punch Out

Provisions for a manually initiated punch out have been furnished by the inclusion of a push-button switch mounted on the front plate of the instrument. Actuation of the switch applies energizing power to the punch motor to initiate a punch out. Use of this switch should be limited to test and alignment purposes inasmuch as each off schedule manual punch out operation will desynchronize the pre-printed time increments of the data recording tape with actual time of day. After a test punch, the paper tape must be time synchronized with the time of day.

9.3.3.2.3 Calibration Procedures

Reference to illustrations in the equipment manual are helpful in this section.

High Order Code Disk

Adjust and tighten the collar mounted on the front hub of the high-order code disk, allowing .003" end play; the code disk must rotate freely.

Locking Lever

By means of the locking lever, lock the low-order code disk at zero. Adjust the locking lever stop to allow .005" minimum clearance between the locking lever stop and the locking lever tang; tighten. With the motor switch cam in the "off" position, the locking lever heel should be approximately 1/32" above the detent wheel.

Programming Cam Shaft

The molded witness marks (.030" wide x .015" high) on the nylon cams (code disk locking, punch actuating and paper tape advancement) must be in line with each other and offset 60^0 clockwise with the hex cam shaft pin (looking at the motor end). The drop-off point of the motor switch cam will be in line with the drop-off of the punch arm cam. Allow approximately 1/32" total end play between the stacked cam assembly and the bearing blocks. The programming cam shaft must rotate freely.

Paper Tape Advancement Lever

Initiate punch out several times to ascertain that the punched holes appear exactly on the horizontal time grid line of the data recording tape. If the punched holes are slightly below the horizontal line, the paper tape advancement lever must be shortened; conversely if the punched holes are slightly above the line, the advancement lever must be lengthened. Loosen the two screws that fasten the upper and lower sections of the lever together and adjust the length accordingly; tighten the screws.

As a guide, line up the horizontal time grid line in the punch die block holes. Loosen the two feed panel screws and place the lower feed panel so as to fully engage the sprocket tooth; then tighten the panel screws.

Motor Switch Cam

Rotate the cam shaft until the leaf switch falls into the cam valley; turn off the power. Depress the switch until it "clicks"; allow it to return until the switch "clicks" again. The distance between the switch and the cam should be approximately 1/32". Re-apply power.

Advance the cam shaft until the high position of the cam shuts off the motor. Re-energize the motor with the timer and note that the switch moves downward approximately 1/32". If these conditions are not met, adjust the switch.

Punch Stripper Plate

With the punch arm vertical (against the stop) and the punches completely withdrawn, slide the stripper plate down in front of the punch shoulders so that the stripper plate is resting against all punch pins. Pull the punch arm casting away from the code disks and tighten the stripper plate screws while holding in this position. This procedure will allow for approximately .005" clearance between the punches and stripper plate when in the punch position.

Punch Arm Cam Follower

Pull the punch arm assembly forward as far as possible (punches shall touch the rear of the stripper plate); hold in this position and slide the punch arm cam follower against the high lobe on the punch arm actuating cam; then back off 1/32" and tighten.

Punching Pressure

To properly set the punching pressure (i.e., spring tension), stop the instrument with the punch arm cam follower on the high spot of the punch arm cam. Place the hook of a graduated spring scale around the cam follower hold down screw (mounts to punch arm). Now pull the scale perpendicular to the punch arm casting and observe the force required to just lift the cam follower from the cam face. If the reading is between 9 and 11 pounds, punch pressure is adequate and no further adjustment is necessary. If the reading is not within the required pressure, lock the code disks at 7777 reading. Gradually adjust the spring pressure (by means of the screw on the front face and the locking nut on the rear of the punch arm), until the punch pierces cleanly through the paper tape; tighten 1-1/2 turns further.

9.3.3.2.4 Maintenance Procedures

The Punched Tape Recorder is relatively maintenance free. The instrument is aligned, calibrated, and locked in position at the factory; no adjustments are necessary. Do not attempt to make any adjustment to the code disks unless it is definite that the instrument is functioning improperly as may be evidenced by false output readings. Errors in coding may be a result of worn or broken code hills on the disk; replacement disks are available from the factory.

In the event that any part of the mechanical cams, gears or linkages become worn or broken, the instrument will have to be disassembled as far as necessary to replace the worn or broken parts. Disassembly is relatively simple and does not require special tools. Under no conditions should parts be replaced unless a thorough knowledge of the operating principles have first been acquired. Reference to the illustrations and this text as well as the exploded drawings in the Parts List Bulletin will prove helpful in locating adjustment points and in disassembly procedures. If parts are replaced it may be important to assure alignment as discussed previously.

Chad Tray

Clean out the chad tray whenever loading a new roll of paper tape or during inspection periods.

9.3.4 Sensors Used--Resistive Sensors

9.3.4.1 SFWMD Stage Potentiometer

The SFWMD stage potentiometer (Figure 9.1) is a resistive-type sensor used to convert the torsional position of a shaft into a resistance value. The sensor consists of a 10-turn precision potentiometer, mounting bracket, standard one-foot circumference tape pulley, float, counter weight and stainless steel tape. Used with the standard pulley the water level range is limited to 10 feet (10 turns of the potentiometer shaft), other sizes and types can be used for specific applications. The Stage Potentiometer is designed to be used with a data logger that can accurately measure the voltage drop across the potentiometer.

The potentiometer type used is a wire wound, servo mount with ball bearing.

9.3.4.1.1 Manufacturer's Specifications

Electrical

Standard resistance tolerance:	± 5%
Independent linearity:	± 0.15 %
Standard resistance:	5 - 10 K ohms
Power rating at 40 degree C:	5.0 watts

Mechanical

Number of turns:	10
Starting torque:	1.3 oz/in.
Shaft size:	¼ in.
Shaft length :	1.0 in.
Housing diameter:	1 13/16 in.
Mounting hole:	1.875 in. dia.
Total diameter:	2.0 in.
Life expectancy:	2,000,000 shaft revolutions

9.3.4.1.2 Installation Procedures

The Stage Potentiometer should be mounted over the stilling well so that the float and counterweight will be free to move up and down inside the well. The mounting bracket is fixed to the stilling well instrument shelter base with two screws through two elongated holes in the bottom of the mounting bracket. The potentiometer is supplied with a ¼ inch shaft that rotates on ball bearing mounts. With the low starting torque of the potentiometer and a properly balanced 6" float, this sensor should be sensitive enough to measure water level changes to ± .01 ft.

When the Stage Potentiometer is used with a standard 1-foot circumference tape pulley (Figure 9.2) with ½" dia. hole, a hub must be machined and pressed into the ½" hole. The hub should have a set screw to attach the pulley to the potentiometer shaft.

The Stage Potentiometer is also used with a special cable pulley (Figure 9.3). This pulley is designed to allow both the float and counter weight to operate inside the same small stilling well. The counter weight is suspended from a smaller dia. pulley and therefore has a much shorter range of movement. This configuration allows the counterweight to operate above the float, inside the well and never cross. The cable used with this type pulley is a very fine, stranded, stainless steel type with very low resistance to flexing. The cable/pulley will allow sensing in a smaller well, using a 2-inch or larger float. The degree to which the float size can be reduced depends on the distance to water, the vertical trueness of the well and the type of cable used.

9.3.4.1.3 Calibration Procedures

Calibration of the Stage Potentiometer depends on two factors: the diameter of the pulley, and the type of datalogger used to make and record the measurement. The measuring datalogger must have a regulated output voltage to excite the potentiometer, or one must be provided. The accuracy of the measurement depends on measuring the voltage drop across the resistance wire of the potentiometer, between the slider and ground. This measurement will give the exact location of the slider, therefore the location of the float pulley.

Example: When dropping 5 volts across the potentiometer and reading 2.5 volts on the datalogger means the slider is in the middle of the potentiometer. If a 1-foot circumference float pulley is used, the range of water level will be 10 ft. In this example the water level will be ±5 ft.

9.3.4.1.4 Maintenance Procedures

There is very little maintenance required for this device. Keep the stilling well clear for free float and counterweight movement. Make sure the pulley is secured to the potentiometer shaft, and the float and counterweight are secure to the tape or cable. When an installation requires the counterweight to move past the float, an idler pulley may be required to position the counterweight not to touch the float in passing. The wire-wound potentiometer will wear prematurely if the water level moves continuously in a very narrow range. Wear of this type can be minimized by routinely changing the slider position, thereby requiring an equal change in the datalogger offset.

Figure 9.1 Stage Potentiometer Detail Drawing Showing Bracket

Figure 9.2 Detail of Standard Pulley for Stage Potentiometer

Figure 9.3 Detail of Special Pulley for Stage Potentiometer

9.3.4.2 Metritape

Metritape brand sensors are simply a long resistor where resistance changes with water levels. The sensor consists of a metal bar wrapped with wire at even spacings. The bar and wire are enclosed in a water tight membrane. As the water level rises, the pressure of the water exerts a force on the membrane causing the wires to touch the metal bar. The deeper the water, the more wires make electrical contacts with the bar causing the resistance to change. The change in resistance is associated with a water level change.
The Metritape sensor uses a precisely formed helical resistor to locate the air/liquid interface for water level sensing. The Metritape sensing resistor is unique in that it is elongated and extends throughout the full range of water level range, and it is acted upon directly by the water being measured.

The sensor backbone is a high-strength stainless steel strip having a gold contact strip down the center of the front side, and film insulation wrapped around both the edges and the back. A nichrome resistance helix is wound precisely around this partially insulated core, generally with a 1/4" turns spacing, and the helix is gold-finished so that gold-on-gold contacting can occur between helix turns and the gold stripe on the base strip.

A sealed and compliant envelope, usually of Teflon fluorocarbon film, encloses the electrical core assembly. A light pressure exerted on the outer jacket collapses the jacket and forces helix turns to short against the gold stripe. When the surrounding jacket is not so collapsed, the helix turns stand away from the base strip and are not making contact. A bumper channel may be added to surround and protect the edges and/or back of the tape-like sensor; but the total structure remains sufficiently flexible to be coiled on a one meter diameter reel for storage and shipping.

Figure 9.4 shows schematically how the sensor reacts to water pressure. Made in continuous lengths from 3 to over 100 feet, the sensor is suspended usually vertically, in a stilling well. As water is introduced, its hydrostatic pressure collapses the sealed outer envelope and shorts the wound helix progressively against the base strip, from the helix bottom end (which is welded to the base strip) to a location close to the water surface. The wound helix above the water surface remains unshorted and its resistance, and thus its length, is precisely measurable across two lead wires brought out the top of the sensor, with the sensor base strip serving as the return path from the point of uppermost helix contact. The Metritape sensor essentially forms an active electro-ohmic resistor which extends from the top of the stilling well to the water surface and is directly analogous to the depth-to-water (DTW) so commonly used for water level measurement. The sensor has a nominal resistance gradient (RG) of 305 ohms/foot, the exact RG values are shown on the Sensor Log supplied with each Metritape sensor. As water level falls the resistance measured sensor resistance increases; and as water level rises, the sensor resistance drops to near zero at the high end of the water level range.

Actuation Depth

The resistance helix of the Metritape sensor is formed from full-hard nichrome to provide positive and stable spring action. The resultant spring rate of helix windings and compliant jacket requires a minimum head of water for helix-to-base strip contacting to occur. Thus, the uppermost helix contact occurs below the water surface by a distance call "Actuation Depth", or AD, which is uniform for any given sensor and nominally 0.33 ft. for 1.0 specific gravity water. This constant offset is specified for each sensor and balanced out at initial calibration. AD leads to the slight specific gravity sensitivity defined later, and to a region at stilling well bottom where the sensor will not measure unless a small sump is provided.

As shown in Figure 9.4, the sensor helical winding system is enclosed within a compliant outer jacket which is hydrostatically sealed at the bottom and pneumatically open at the top. The resultant enclosing boot contains a small gas volume (approx. 0.1 cubic inch per foot of sensor length), which is exhaled and inhaled as surrounding liquid level rises and falls. In addition, for the sensor to operate accurately in the presence of pressure or vacuum, the surrounding pressure condit

Jacket Materials

The sealed outer sheath of the Metritape sensor is of two types. The first is comprised of several layers of film, principally Mylar polyester, applied in succession and adhered to one another with an acrylic adhesive. A thin metallic film is usually included in the composite jacket as a vapor barrier, and the final wrap-around film clamps a heavy "keystrip" to the back of the sensor. This strip extends beyond the sensor edges to engage an extruded bumper channel that fends the sensor off the ID of a stilling well. Sensors of this construction are the LA and AGS, sealed at the bottom and potted in epoxy at the top.

Figure 9.4   Metritape Sensor Operation

Sensor Protection

Bumpers protect the sensor against chafing, make the sensor more rugged and less vulnerable to damage during installation. Bumpers are a 3-sided channel of semi-rigid extruded plastic, or a pair of tubular side pieces attached to the sensor edges and act as an intermediate between the precision jacketed element and the holding pipe or channel-way which is used to position the sensor inside the stilling well.

9.3.4.2.1 Manufacturer's Specifications--Type LA

Sensors (code "L") are liquid-level sensors, having the standard gold-finished helix winding (code "A") are the sensor designations used in water.

Overall Length:	3 to 100 ft.
Active Helix:	Starts 10 inch from top reference
Zero:	extends to approx. 1 inch from bottom
Operating Temperature:	-15° to 70° C
Helix Resolution:	± 1/8 in.
Actuation Depth (AD):	Norm 6 in. head of water
Specific Gravity Effect:	plus 1% in SG=1.5 mm in level
Resistance Gradient (RG):	305 ohms/ft.

9.3.4.2.2 Installation Procedures

As you approach the planning of a Metritape installation, the following miscellaneous pointers may help you get started in the right direction.

Metritape gauging is unique. The sensor is elongated, sensitive over its entire length, and coilable. New sensors have been evacuated, specially padded and coiled for shipment and storage. Check the procedures for uncoiling and installing, or recoiling for storage or shipment, so as not to cause sensor damage.

In use, the Metritape sensor is best housed within a straight, vertical, perforated still pipe for protection against turbulence, floating objects and mechanical contact. When installed in a large stilling well this small pipe will keep the sensor straight and in the desired position. Use standard orifice for stilling wells. It is also desirable to utilize still pipes of an integral footage (5.0', 12.0', 28.0'...) when measured from mounting flange to still pipe bottom. Metritape sensors are stocked in these sizes, therefore an advantage can be gained if stilling wells are of an integral length. The sensor still pipe must have unimpeded breather holes at the highest point under the recorder base or must be open at the top to prevent airlocking and to allow water to rise and fall within the pipe. The length of the still pipe should be carefully checked to make certain it is long enough to accommodate the full sensor length plus 1 to 2 inches to allow for expected expansion of the sensor's plastic protective channel in elevated temperatures. The head of a Metritape sensor should be mounted above the highest expected water level.

The Metritape sensor is corrosion resistant and coilable because it uses advanced polymers in its outer jacketing. These polymers can, however, be punctured, cut or torn by sharp metallic edges and burrs. **It is important** to de-burr sensor still pipes to remove any rough, sharp or cutting edges. Installation of a coiled Metritape sensor is best performed by two people. The storage reel should be rotated on a short axle, while the bottom end of the sensor is detached from the reel, separated from its protective packing, and guided into the prepared still pipe. Installing a Metritape sensor takes about five minutes.

A new Capillary Breather/Equalizer is supplied with each new sensor, and must be connected to allow the sensor to breathe, to keep sensor electric contacts clean and dry, and to continuously equalize atmospheric pressure. Never use an old breather with a new sensor. Some models of the Metritape sensor and Capillary Breather are joined with pneumatic snap-couplings that open only when positively engaged. When separated, these fittings seal shut to protect both sensor and breather. The Metritape sensor is thus inoperable until its breather is firmly coupled. The outboard end of the Capillary Breather tubing must not be covered or plugged, it must be open to atmosphere.

The well-installed Metritape level sensor should experience neither drift nor wear. Only the Capillary Breather/Equalizer requires annual inspection to assure that it maintains its original blue color.

Electrical Connections

At the Metritape sensor head, electrical connections may be made to field wiring, or to a compact 4-20 mA transmitter mounted in the Sensor Housing in the recorder shelter.

Sensor electrical connections are made with a hard splice or with a neoprene, usually 4-pin, connector that is keyed to ensure proper lead wire interconnect.

The pin-out, color-code and circuit assignments for the most common Metritape sensors is as follows:

Level Sensor Only

Pin 1 - black - signal, level sensor
Pin 2 - white - return, level sensor
Pin 3 - blank and plugged
Pin 4 - blank and plugged

Connectors for the sensor are identical and the sensors can thus be electrically interchanged.

A single separate multi-conductor cable should be used to connect between each sensor housing and the Metribarrier. This must be one continuous length of cable without junctions or splices. The cable should contain enough wires to make all connections in the sensor housing plus at least two spares. The wire should be stranded copper, number 18 - 22 AWG.

The insulation must be resistant to any materials to which it may be exposed. An outer sheath is recommended for mechanical protection and electrical shielding. An insulated sheath should be grounded at the barrier end only, to avoid large circulating currents. The cable should be placed in a metal conduit but only with intrinsically safe wires. The cable must not be placed in a conduit with power wiring or with other leads that are not intrinsically safe. The total loop resistance of the installed cable should not exceed 10 ohms. The total capacitance from any wire to any other conductor should not exceed 0.75 µf. The total inductance in the loop should not exceed 1.0 mH.

The total installation must be watertight and mechanically strong enough to withstand the rigors of the intended service and environment.

Capillary Breathers

The inactivated Metritape sensor, suspended above the water in a well has open contacts throughout its full length, except for the welded connection at the bottom end. The relaxed, uncompressed jacket has an internal gas volume of approximately 0.1 cubic inch per foot of sensor length. As liquid is brought into the chamber being gauged, the sensor jacket is progressively collapsed, helix contacts are progressively shorted, and the contained gas volume is exhaled out of the tube at the top of the sensor cap. Decreasing water level causes the opposite to occur: built in spring action of the wound metallic helix and the jacket system cause the jacket to reopen to its natural state, and requires that air be inhaled through the breather tube at the sensor top.

Contact Protection

For best long-term operation of Metritape sensor contacts, and to prevent condensation of vapors within the sensor envelope, it is desirable that only a clean, dry atmosphere be inhaled into the sensor. Thus, a Capillary Breather/Equalizer assembly is pneumatically coupled to the top of the sensor, and is comprised of the elements shown in Figure 9.5.

A pneumatic snap-coupling is provided at the top end of the sensor that communicates with the inner sensor chamber. A flexible small-bore tube couples a desiccant cartridge to the inner sensor. This contains several types of cleaning and drying chemicals which also have the capacity to absorb certain corrosive chemicals. The cartridge is, in turn, attached to a long coil of small-bore tubing the end of which is either vented to atmosphere within the sensor housing.

To reach the sensor inner chamber, moisture in the atmosphere must travel the length of the capillary breather coil, avoid absorption by chemicals in the desiccant cartridge, before commencing to enter the sensor itself. Since the sensor is pneumatically sealed and all elements of the capillary breather are tightly joined to one another, the pathway into the inner sensor is dead-ended and there is no net gas through-flow, only back-and-forth respiration. The capillary breather assembly generally contains a gas volume several times greater than that contained by the sensor itself, and the breather thus serves as the reservoir for a conditioned gas volume that is used and reused, and cleaned and dried with each usage.

Unconditioned vapors enter only the outboard end of the breather coil and travel very slowly (by Brownian movement) to join the large conditioned gas volume.

An indicator chemical is contained within the breather cartridge which changes color with change in dryness, or moisture absorption capacity, of the desiccant material. As the desiccant absorbs moisture, it changes from its original light blue color, first to purple, then to pink, and finally to white. White desiccant can no longer protect the inner sensor, and breathers should be replaced when they have reached a pink color.

Figure 9.5 Metritape Capillary Breather/Equalizer

Pressure Equalization

Despite its length and labyrinthine path, the pneumatic circuit of the Capillary Breather/Equalizer is, when connected to the sensor, open throughout its entire length. It is thus unable, under steady state conditions, to support to pressure differential across its length. The pressure at the outboard, or return, end of the breather, is thus repeated at the Metritape sensor head and maintains the inner sensor at atmospheric pressure, depending upon the return connection.

To keep moisture or corrosive vapors out of both the sensor and the capillary breather, either self-sealing pneumatic fittings or protective caps and plugs are used. This means that the Metritape sensor **cannot breathe** until a capillary breather is firmly attached. It also requires that the sensor be vacuum pumped **before it is coiled** for storage or shipment, as instructed later. This explains why a new sensor from the factory appears to have its outer jacket tightly compressed and indicates only minimum resistance value until it is connected to its breather and allowed to inhale and open fully.

Bottom Clearance

The Metritape sensor should be positioned well clear of the stilling well bottom to avoid scuffing. The sensor should also be fully skirted by the pipe and terminated within so as not to abrade on the pipe bottom internal edge. In addition, the sensor plastic bumper channel expands and contracts much more than steel with change in temperature, and such changes increase linearly with sensor length. A plastic still pipe will change dimension more nearly like the sensor channel.

Sensor Sizing

When possible, a ground water well or surface water stilling well, of integral footage level LP should be used and fitted with a Metritape sensor of like integral footage length LS (see Figure 9.6). Such standardization simplifies sensor supply, and allows interchangeability of sensors. When possible, historical maximum and minimum stage values will dictate the sensors overall range.

Figure 9.6   Sizing Metritape Sensor to Still Pipe in Integral Feet

9.3.4.2.3 Calibration Procedures

Gauging Accuracy

Several factors govern the total gauging accuracy of a sensor, its conditioning circuit, its output display and the interconnecting means of signal transmission. Also involved is the "standard" used for calibration and accuracy determination. Competitive accuracy claims tend to focus on static, short-term measurement capability; but the major concern in tracking water levels is long-term gauging stability in the presence of changes in the gauged product and in the operating environment. The Metritape sensor has a gauging resolution related to helix turns pitch (±1/8" resolution for a 1/4" turns spacing), plus the drift-free stability of a precision wire wound resistor, progressively shorted by a gold-on-gold contact system.

Calibration Procedures

A resistance-tape sensor can be precisely calibrated, using a calibration chamber or by lowering the sensor into the stilling well to exact depths. Each sensor will have to be calibrated, using one of the above methods, for offset or zero and span or gradient values. The span will match the sensor resistance gradient. Once it is set, it should not need calibration. When inserted into the stilling well, adjustment of Zero can be trimmed against precise water level measurements. For a vertically installed sensor, the change in resistance per unit change in water level is exactly the sensor resistance gradient (RG). For a standard type LA sensor, having a precision gold-on-gold helix winding, the resistance gradient is 305 ohms per foot, throughout the active sensor length.

Calibration Logs

A log for calibration activity is recommended and all calibration changes should be made with care and recorded. Sensor resistances are shown on the Metritape Sensor Log for "as made" sensor lengths and also appear on the Sensor Tag. These values should be used for precise circuit calibration.

9.3.4.2.4 Maintenance Procedures

Sense the only moving parts of the Metritape sensor is the flexing of the Teflon fluorocarbon film, there is very little to maintain. Visual inspections and a knowledge of how the water level record should look will indicate problems, should they occur.

Preventative maintenance consists of visual examination of the chemicals in the cartridge assembly. One of the chemicals is and indicating desiccant that is blue when dry. As the desiccant absorbs moisture it will change color; first purple, then pink and finally white. The cartridge assembly must be replaced when the desiccant has turned pink. If the desiccant turns white, it con no longer absorb moisture and the sensor will suffer irreversible damage. It is recommended that the breather assemblies be examined every 6 months.

Wiring can suffer from corrosion of conductors and degradation of insulation. Wiring should be dry and free of such defects to assure accurate water level measurements.

The sensor should be raised to inspect its physical condition; but if it continues to produce smooth and accurate readings, it is likely to be in good condition.

The sensor can be removed and cleaned, but care should be exercised as it is susceptible to damage when removed from the stilling well.

9.3.4.3 SJRWMD Stage Potentiometer

The St. Johns River Water Management District's Stage Potentiometer is an analog resistance device which uses float/counter technology in monitoring water levels. When connected into a circuit as a voltage divider it converts rotational shaft position to a voltage which is directly proportional to changes in water level.

9.3.4.3.1 Manufacturer's Specifications

Sensor:	Bourns Mod 3540S 10 turn wire wound potentiometer.
Shaft size:	1/4" dia. SS with rubber coupling
Pulley:	12" circumference with five equally-spaced spines
Size:	4 ½"H X 4 ½"W X 8"L

9.3.4.3.2 Installation Procedures

Install the stage potentiometer above the well such that the float and counterweight do not strike each other or rub against the sides of the well or any part of the platform. Ensure this condition throughout the operating range of the instrument. Use a carpenter's or bubble level to ensure the instrument is mounted with the float pulley plumb or perpendicular to the horizontal plane. If the pulley is not plumb the tape will have a tendency to climb the pulley edges thereby disengaging the pulley spines from the holes in the float tape.

Determine Tape Length
To calculate the appropriate tape length, measure the current distance down to water (DTW) from the surface. Subtract DTW from the measuring point to determine the present water level referenced to National Geodetic Vertical Datum (NGVD). Subtract the period-of-record minimum water level relative to NGVD

from the current water level NGVD. This value indicates the distance between the current level and the period-of-record low level. The tape length should be equal to the distance calculated above plus the measured distance to water plus an additional 20% of the DTW.

Tape Length = (Current Level - POR Low) + DTW + 0.2(DTW)

In other words, if the period of record minimum water level is 30 feet NGVD, the current level is 34 feet NGVD, and DTW = 20 feet, then the tape length should be 28 feet.

Determine counterweight and float weights

The counterweight must weigh at least 2 times the total weight of the tape plus 2 attachment clips. The float must weigh at least 1.5 times the combined weight of the tape, 2 attachment clips, and counterweight. The perforated tape weighs 0.1738 ounces per foot and the attachment clips weigh 0.4044 ounces each. In the example above the 28 feet of tape weighs 4.9 (28 X 0.1738 = 4.866) ounces and the 2 attachment clips weigh 0.81 ounces for a combined weight of 5.7 ounces. Therefore the counterweight should weigh at least 5.7 X 2 = 11.4 ounces. The combined weight of 11.4 ounces of counterweight and 5.7 ounces of tape and clips equal a total of 17.1 ounces. Therefore the float should weigh at least 17.1 X 1.5 = 26.6 ounces.

It is important to note that improper weight ratios may, at low water levels, allow the tape weight to overcome the counterweight. Conversely, at high water levels, the combined weight of the counterweight and tape may overcome the float, either of which would render the unit inoperative resulting in a total loss of data.

Upon fabricating the tape-float-counterweight system, complete the installation by lowering the float to the surface of the water inside the well. Pass the float tape around the pulley such that the tape on the float side of the pulley falls in the opening of the notch in the sensor mounting bracket. The notch opening of the sensor mounting bracket and the float should, **if possible,** face the front of the instrument shelter. The tape holes must engage the spines of the pulley.

Slowly and carefully rotate the float pulley one full revolution **raising** the float. Hold at this point and observe that the recording device indicates an increase in value of 1.00 feet. If the indication decreases, reverse the power and ground wire connections to the potentiometer.

> **Do not attempt this test by raising the counterweight.** This creates slack in the tape on the float side of the pulley and may cause the float/tape attachment clip to hang in the float eye ring. If the clip hangs, then the tape is shortened on the float side and will cause an error of up to

0.155 feet in water level measurements if and or when the clip releases itself.

9.3.4.3.3 Calibration Procedures

Calibration of this instrument is accomplished by applying a precision voltage to the potentiometer in an amount equal to the maximum acceptable input voltage of the recording device. In the cases of Sierra-Misco and Omnidata, the applied voltage is 5.00 volts. Attach a voltmeter across the signal and ground leads of the potentiometer and rotate the pulley until the output voltage equals 0.00 volts. Then rotate the pulley in the opposite direction and read the voltmeter as follows:

Full Revolutions	Voltmeter
1	0.50 volts
2	1.00 volts
3	1.50 volts
4	2.00 volts
6	3.00 volts
8	4.00 volts
10	5.00 volts

Since the sensor element is a 10-turn potentiometer, one full revolution should cause the voltmeter to indicate 1/10th of the voltage applied to the potentiometer. Each successive full revolution should cause the voltmeter to indicate an additional 0.50 volts.

9.3.4.3.4 Maintenance Procedures

Normal maintenance procedures are general cleanliness and inspecting the sensor for foreign materials. All insect debris and contact corrosion should be removed at each station inspection. Float tape condition and spine alignment should be carefully observed.

9.3.4.4 Environmental Sensing Device

This instrument is a magnetically actuated potentiometric linear position sensor designed to measure the physical location of a magnetic actuator. The instrument consists of a lineal length of resistive wire, a lineal length of conductive fingers (adjacent but very close to the resistive wire), and a block actuator magnet. The resistive wire and conductive fingers (100 fingers per foot) are housed inside a long sealed and pressurized stainless steel sheath. The block actuator magnet fits around this steel sheath. As the magnet moves along the sheath it pulls the conductive fingers (one at a time) into contact with the resistive wire. The lineal length of conductive fingers are connected as if they were the wiper of a potentiometer. As the conductive fingers contact the resistive wire, the instrument outputs an electrical signal proportional to the linear position of the block actuator. The block actuator floats such that the water level and magnetic actuator move in direct incidence.

9.3.4.4.1 Manufacturer's Specifications

Device Type:	Three wire potentiometric
Internal impedance:	200 ohms per foot standard
Size:	0.5 inch by 1.0 inch rectangular tube, length to customer order
Length:	Up to 250 inches standard
Material:	316 stainless steel
Connector:	Mil Spec 27471 Hermetically sealed 3-pin connector
Resolution :	0.08 inch steps
Temperature Range :	- 0.5°C to +50°C
Temperature effect:	accuracy is affected less than 0.007% per°C
Block actuator size:	2.25" X 3" rectangular
Block actuator construction:	structural foam
Block guides:	Teflon
Block active device:	encapsulated horseshoe magnet

9.3.4.4.2 Installation Procedures

First assemble the instrument.

Install the block actuator by removing the 9/16" hex nut and large washer from the bottom of the sensor. Slide the block actuator onto the stilling well such that the word "TOP" on the actuator faces the round flange and connector t the top of the sensor. The word "TOP" on the actuator **must** be on the same side of the sensor tube as the connector.

If the sensor is equipped with the optional longitudinal bracket, a type "B" block actuator must be used. If the sensor has no longitudinal bracket, use a type "A" block actuator. This is important because the type "A" actuator has a smaller opening than the type "B".

To calibrate the sensor to a known position after installation, first calculate the Unit Voltage.

> Unit Voltage = Active Length/(Full Scale V - Offset V)

Then with the sensor installed and the actuator at a known position (the calibrate position), read the voltage between the white and black wires. This voltage is the calibration point voltage.

The actuator position relative to the calibration position is then given by the following formula:

> Actuator Position = [Calibration Position + Unit Voltage] X [Voltage Reading -Calibration Point Voltage]

9.3.4.4.3 Calibration Procedures

The connecting cable supplied with the instrument has three color coded wires: red, white, and black. To calibrate the sensor connect a regulated voltage source (usually +5 volts DC from the recording device) to the red wire, and common or ground of that source to the black wire. For most accurate calibration, the regulated voltage source and total circuit wiring for the sensor calibration should be the same source and wiring that will be connected to the sensor during field operation.

Place the block actuator against the bottom stop (round washer). Read and record the voltage measured between the white and black wires (white is [+] and black is [-]). This voltage should be very low, but probably not zero. This is the offset voltage.

Move the block actuator along the sensor tube until it touches the round flange at the top of the sensor. At this position read and record the voltage between the same white and black wires. This voltage should be slightly less than the regulated supply voltage and is the full scale voltage.

The sensor is now calibrated. The position of the actuator at any point along the sensor can be calculated by reading the voltage between the white and black wires and applying the following formula:

AP = SL x [VR-OV]/[FSV-OV]

Where: AP = Actuator Position

SL = Active Sensor Length*

VR = Voltage Reading at Actuator Position

OV = Offset Voltage

FSV= Full Scale Voltage

* The active sensor length is the distance the actuator can travel on the sensor tube and is given in the sensor part number. For example, the LPS-120I sensor has a 120-inch active length.

9.3.4.4.4 Maintenance Procedures

Observe the block actuator for cracks in the foam, loose attachment screws, or badly worn Teflon guides. Check the mounting brackets and remove any visible corrosion.

9.3.5 Sensors Used--Encoders

9.3.5.1 Sierra-Misco Model 5050EL-FT Liquid Level Sensor

The 5050EL-FT is a liquid level sensor designed for monitoring and flood warning of liquid levels in water and waste water management applications. The 5050EL-FT provides high measurement resolution over a wide range of liquid levels. The unit generates a relative measure of the liquid level through incremental count and count direction signal outputs. The 5050EL-FT is intended for use in applications where the sensor can be fixed to a structure that is independent of the water level.

The 5050EL-FT consists of a Float/Pulley/counterweight arrangement, and a sensor unit. The float and pulley sense the liquid level and this measurement is transformed by the sensor electronics into count and direction signals and sent to the data logging equipment.

The 5050EL-FT can be fitted with two sizes of pulleys to provide different resolution. Both pulley sizes are available for use with either a beaded chain or stainless steel perforated tape. The unit can also be mechanically coupled to other measuring devices with sprocket or pulley mechanisms.

The 5050EL-FT converts a liquid level (mechanical position) into Up/Down count signals (electronic representation) that can be logged and processed. As the liquid level changes, the float moves up and down. The motion of the float rotates the pulley (via chain or tape) which in turn rotates a large gear on the pulley shaft. The rotation of the large gear rotates a small gear which is mounted to the same shaft as the magnet arm. As the magnet moves, it passes over reed switches which are activated by the magnet's magnetic field. The switch closures are processed by the electronics to provide output signals indicating count and direction.

The switches are arranged in three groups (A, B & C) as shown in Figure 9.7. All switches in a given group are connected in parallel. Only half of the switches are shown for simplicity.

When the magnet arm shaft rotates, the magnet passes over switches SW1 to SW6 causing the wave form in Figure 9.8 to be generated. The count direction is determined by the sequence that the pulses are produced in. Figure 9.8 shows the sequence A-B-C-A-B-C... showing a rotation of the magnet shaft in the clockwise direction. Figure 9.9 shows the sequence C-B-A-C-B-A... indicating a rotation in the counterclockwise direction.

Figure 9.7 Sierra-Misco Model 5050EL-FT Switch Groupings

Figure 9.8   Sierra-Misco Model 5050EL-FT Count Up Wave Forms

Figure 9.9 Sierra-Misco Model 5050EL-FT Count Down Wave Forms

The output signals are generated by the state machine and passed out to the output driver section which consists of relays and associated drive circuitry. This section of the circuit provides contact closure type output signals and good sensor/data logger isolation. The relays can be powered either from Vin(+) and Vin(-) or from Vsig(+) and Vsig(-). The latter is useful when the 5050EL-FT is used in conjunction with the C1040-6-3 Terminal Strip Board.

9.3.5.1.1 Manufacturer's Specifications

Mechanical Specifications:

Float:	4" diameter ball float standard; 5" or 10" diameter cylinder floats optional
Chain:	Beaded chain standard; Perforated stainless steel tape optional
Pulley:	375 mm circumference standard, 750 mm optional
Weight:	3.6 Kilograms (7.7 pounds).
Dimensions:	11.5 cm x 27 cm x 16.5 cm (4.5" x 10.6" x 6.5").
Operating Temperature Range:	-40°C to +60°C

Electrical Specifications

Supply Voltage:	4 to 15 VDC (open collector outputs), 11 to 20 VDC (dry contact outputs).
Output Signal:	Break before make dry contact (standard), open collector with pull-up resistor (user selectable), or open collector without pull-up resistor (user selectable).
Outputs Provided:	two complementary Form C outputs, one Up/Down count control line.
Maximum Output Resolution:	2.5 mm/count (375 mm pulley), 5 mm/count (750 mm pulley).
Protection:	Transient and lightning protection on supply lines, relay isolation on output lines.

9.3.5.1.2 Installation Procedures

This section covers the installation of the 5050EL-FT liquid level sensor. It is assumed that the configuration for the correct measurement resolution has been obtained. That is, the correct pulley size has been obtained and the S1100 board has the correct number of reed switches.

Mounting

The 5050EL-FT should be mounted on a rigid platform, above the liquid to be monitored. The unit must be level (use the bubble level inside the sensor to adjust this) and the pulley must rotate freely. Once leveled, the sensor must be securely fastened so that vibration cannot loosen it. The float/chain/pulley is installed by lowering the weight and float into the stilling well and placing the chain over the pulley. The beaded chain must move freely around the pulley and neither the weight or float may bind. If the unit is not level the chain can bind and possibly jump off the pulley.

Description of Controls

The only control on the 5050EL-FT is the Up Polarity Select switch (SW13). In the CW position, a clockwise pulley rotation (looking from the pulley side of the sensor) will produce a positive count direction. Conversely, in the CCW position, a counterclockwise rotation will produce a positive count direction. Figure 9.10 shows the location of the Up Polarity Select switch in the 5050EL-FT.

Stilling Wells

There should be one float per stilling well only. Staff gauges should be installed to allow zeroing of the sensor (setting the base value).

Electrical

The connections for the cabling are shown in Figure 9.11. The cable is run through a fitting in the 5050EL-FT. The wires are connected to screw type terminal blocks on the S1100 board inside the 5050EL-FT housing. There are two connectors on the 5050EL-FT. Connector J1 is the power connector and accepts 12V from the data logging equipment. Connector J2 is the output connector which provides count and direction output signals.

IMPORTANT: The wires must NOT be tinned with solder as this can cause corrosion and poor contact.

When a jumper is not installed (OUT), place the jumper block on one of the pins of the jumper header such that the other hole in the jumper block is not contacting a pin. This will keep the jumper blocks with the 5050EL-FT so that they are not lost.

Figure 9.10 Connector and Switch Locations of the Model 5050EL-FT

Figure 9.11   Model 5050EL-FT Interfaces to Sierra-Misco Data Logger Systems

9.3.5.1.3 Calibration Procedures

This section provides a basic procedure for troubleshooting the 5050EL-FT. Before proceeding, the previous sections of this manual should have been read and understood.

Ensure the unit has been installed correctly and the cables are properly connected.

Power up the equipment. Set the monitoring equipment to monitor the input that the 5050EL-FT is connected to. This equipment will vary from station to station. Refer to the station operating manuals for more information.

Rotate the pulley in the direction of rising liquid. If the float hangs off of the left of the pulley (facing the front of the pulley/sensor) the direction of rising liquid is clockwise. A rotation in this direction should cause up count increments to be generated, and should register as an upward count on the monitoring equipment.

If a count in the down direction is generated, switch the up polarity select switch (SW13) on the S1100 printed circuit board and again rotate the pulley in the direction of rising liquid.

If no count is registered, check the wiring of the sensor and data logging equipment. Refer to the data logging equipment manuals and check that it is configured properly. If the problem persists, contact Sierra-Misco.

9.3.5.1.4 Maintenance Procedures

Preventative maintenance begins with proper installation. The goal is to reduce the effects of atmospheric interference which can cause damage to the equipment and/or drift in the data. This is best achieved by using shielded cable, metal conduit where necessary and placing the sensor in a metal enclosure that is bonded into the site's grounding network.

Routine maintenance is a simple matter of assuring that all signal cable connections are clean of corrosion and making proper contact. Inspecting the pulley and shaft assembly to ensure that the combination is allowed to spin freely.

An inspection of the magnetic contacts can be done by slowly moving the magnet past the magnetic contacts while a continuity meter is set up to monitor magnetic contact closure which occurs as the magnet passes the contact. Listening closely should yield a slight clicking noise as each closure is made. The final test is executed after the sensor is put back together, and a reference reading is taken with a laptop computer. The pulley is then tagged for a reference point (this must be done carefully and with precision to guarantee good results) and slowly turned five complete revolutions. A reading is then taken with a laptop computer that should reflect a reading five feet higher or lower (depending on the direction in which the pulley was turned) than the reference reading taken before the wheel was turned. If the test reading varies more than .04 foot from the beginning reference reading, the test procedures are repeated. Check to make sure that all components that interface between the magnetic contacts and pulley are properly aligned. If two more attempts are unsuccessful, the unit should be replaced and returned to the manufacturer for repair. Completion of three consecutive successful tests should indicate the instrument is working correctly.

After a successful test, the tape which is connected to the float and weight is inspected for any signs of fatigue or kinks (bends) in the tape that may produce a problem.

9.3.5.2 Acro Optical Shaft Encoder

The Acro Model SA101 Optical Shaft Encoder is packaged in a small weather resistant enclosure for mounting in a stilling well. The pulley, float, counterweight, and tape are optional. The encoder provides 0.01' resolution using 100 or 150 counts per revolution. The output goes directly to the Acro Universal Data Logger, or any compatible RTU for data storage and retrieval. The encoder is powered by a regulated 5-volt DC power supply and draws a small 2 milliamperes of current. Its small size and low torque requirements makes it ideal for sites which have limited space.

9.3.5.2.1 Manufacturer's Specifications

Range:	Limited by stilling well
Accuracy:	± 1 increment
Sensitivity:	0.01' w/100 counts standard, (50, 100, 150, or 300 counts per revolution)
Power Required:	5V DC, 2 mA
Sensor Cable:	3 foot ribbon cable for DL86
Shaft mount diameter:	1/4" SS std, ½" hub on (SA101)
Shaft mounting hole:	7 mm std
Starting Torque:	0.65 inch-ounce
Signal Output:	Acro-Increment and decrement Lines; Other--Increment & Direction Lines
Wiring:	4 wire, +5V DC, Gnd, + Incr., - Incr. for Acro std.
Size:	4.3"H x 4.5"L x 1.8"D; 15 oz.

9.3.5.2.2 Installation Procedures

The ACRO shaft encoder may be attached to a flat surface using 1/4-inch bolts or screws through the four holes in the L-shaped cover plates of the Encoder housing. A common application is the measurement of stream or lake stage (water level) by means of a float and pulley as is discussed in more detail below. The Shaft Encoder may be used to indicate the position of any shaft which can be coupled or geared to the encoder shaft. Carefully matched high-quality mechanical components are required to match the shaft encoder resolution. A standard pulley is attached to the shaft, and a metal tape is hung over the pulley, with a float at one end and a counterweight at the other. The float is protected from the action of waves and currents by a stilling well, and the whole may be enclosed in a gauge house. The pulley is 1.00 ft. circumference, with each step of shaft rotation corresponding to a water level change of 0.01 ft.

Attach the pulley to the encoder shaft; there is no need for any type of pulley-to-shaft adjustments. Readings can be adjusted by using the controls on the ACRO data logger.

In planning your shaft encoder installation, keep in mind that if the float and the counterweight encounter each other as the water level changes, the counterweight will not clear the float, and the interference may cause bad readings. If the 8-inch float is used, the interference will be less than with the 10-inch float, but it will not be absent. The 4-inch float should eliminate the interference, but may not be heavy enough to keep the tape tight if a long tape is required due to great distance-to-water or range of fluctuation..

One way to avoid the problem with the larger floats is to set the encoder high enough above the water so that the entire range of water levels can be accommodated with the float remaining in the lower half of its travel (between the point where the counterweight reaches the pulley and the point where it hits the float). Another way to keep the counterweight clear of the float is to install an idler pulley (components may be bought in most hardware stores) which would guide the tape clear of the float. If such a pulley were included in the installation, it would be mounted to the right of the encoder on the supporting shelf . Thus the tape and counterweight can be pulled to the right to clear the float.

Cut the float tape to the required length with metal shears, and fasten a hook to each end. Clamp the hook assembly to the end of the tape by inserting the tape between the hook body and the clamp plate and tightening the two screws. Force one hook open with the hand or pliers and place it over the eye on the float at one end of the tape, and open the other hook and place it over the eye of the counterweight. Bend both hooks closed so that the float and counterweight cannot accidentally come off the tape. Place the tape over the encoder pulley (and idler pulley if used) so that the holes in the tape engage the pins in the surface of the encoder pulley. Note the direction (clockwise or counterclockwise) in which the encoder shaft rotates as the water rises; you will need this information for programming the data logger.

9.3.5.2.3 Calibration Procedures

Calibration can be checked by rotating the pulley exactly 1.00 foot up or down, while confirming the reading on the data logger (this must be done carefully and with precision to guarantee good results). If the reading varies more than .04 foot from the expected reading, the test procedures should be repeated. If two more attempts are unsuccessful, the unit in the field should be replaced and returned to the manufacturer for calibration or repair. Completion of three consecutive successful tests should indicate the instrument is working correctly. After a successful test, the tape which is connected to the float and weight should be inspected for any signs of fatigue or kinks (bends) in the tape that may produce a problem.

9.3.5.2.4 Maintenance Procedures

Field maintenance of the ACRO optical shaft encoders is a simple matter of assuring that all signal cable connections are clean of corrosion and making proper contact. Inspect the pulley and shaft assembly to ensure that the combination is allowed to spin freely. The metal tape connected to the float and weight should be inspected for signs of fatigue or kinks (bends) in the tape that may produce a problem. Replace any suspect field equipment.

9.3.5.3 Handar Model 436 Incremental Shaft Encoder

9.3.5.3.1 Manufacturer's Specifications

The Model 436 is a rugged and reliable incremental shaft encoder which may be used with a pulley, tape, and float arrangement to measure stream stage or other fluid levels, and may be coupled to any rotating or translating mechanical system to provide a measurement of position changes. Accumulating position change output in a data logger or computer will allow readings of absolute positions. The resolution of the encoder is 1/100 revolution (3.6º); when used as a stream stage indicator with a standard 1.00 ft. circumference pulley, the resolution of the system is 0.01 ft.

The encoder uses a 50-pole magnet fixed to a shaft. As the shaft rotates, the magnetic poles are sensed by a pair of Hall Effect devices which change state when the magnetic flux switches direction. The outputs of the two devices provide 100 counts per revolution; the relative phase of the two signals indicates the direction of rotation. Adding the received counts to the accumulated value for one direction of rotation and subtracting the counts for the other direction leaves a net count which represents the current level of the surface or position of the object being measured.

There are no mechanical contacts involved in the measurement process; the only contacting moving parts are the precision shaft bearings. The starting torque is low - 0.65 inch-oz. (47cm-g) or less - and the system is not sensitive to vibration. It is housed in a black-anodized aluminum case, and may be installed in exposed locations. It is tested to operate from -20°C to +55°C, and up to 100 percent relative humidity.

Models of the 436

The Model 436 sensor series has seven members which provide combinations of three different types of output and two different shafts. Both shafts are stainless steel; one is 0.375 inches diameter unthreaded; the other terminates in a 5/16 x 24 thread with flats for set screws.

The Model 436A and 436A-1 Shaft Encoders have an output which provides a dual square wave signal from a pair of Hall Effect devices for the dedicated Incremental Encoder input. The data logger or computer counts edges of the square waves, and interprets the phase relationship between the two waves as indicating the sense of rotation. This output is called "436A-type" output.

The Model 436B series Shaft Encoders include a serial output option with an on-board microcontroller which reads the shaft rotation; each pulse adds or subtracts a user-defined increment to a stored value representing the position of the shaft. In the standard application with a 1.0 ft-circumference pulley and tape, the accumulated count can directly indicate a fluid level in feet if the factory-set increment is used. The output of the microprocessor is a number in serial ASCII code equal to the position value stored in the internal register. Communication with a data logger or computer is according to the SDI-12 protocol.

Models 436B, B-1, B-2, and B-3 encoders may be connected to a serial data communications line configured according to the SDI-12 standard; the Model 436B-4 requires an RS485 communications line. The SDI-12 line uses a single wire for data and is limited to 200 feet in length, while an RS485 line uses a two-wire differential circuit for data and may be up to 4,000 ft. long. The number of sensors which may be attached to a single data line depends on the capabilities of the data logger in addressing, processing data from, and powering multiple sensors.

Table 9.2 lists the seven models of the Model 436 Incremental Shaft Encoder; each has one of the two available shaft types and one or two outputs; the two outputs may be either both 436-A-type outputs or one output of each type. The two outputs are always entirely independent; they may be connected to separate data loggers or one may be used as a backup in case of damage to the other. The 436A series has only 436A-type outputs and threaded shafts; 436B series members have at least one serial output, and are available with both types of shafts. Table 9.2 shows the physical differences between the models.

Model / Shaft	No. of Outputs	Remarks

	436-A	SDI - 12	RS485	
436A Threaded	1	0	0	Basic Incremental Shaft Encoder
436A-1 Threaded				Two Identical Outputs
		0	1	
	2			Intelligent Shaft Encoder
436B Unthreaded				Combination output
		1	0	
				Same output as B
436B-1 Unthreaded	0			
				Same output as B-1
436B-2 Threaded				
		1	0	RS485 data line, SDI-12
436B-3 Threaded				
		1	0	
				command set
	1			
436B-4 Threaded				
		1	0	
	0			
		0	1	
	1			
	0			

Table 9.2 Handar Model 436 Incremental Shaft Encoders

9.3.5.3.2 Installation Procedures

Any model Incremental Shaft Encoder may be attached to a flat surface using 1/4 - inch bolts or screws through the four holes in the L-shaped cover plates of the Encoder housing. A common application is the measurement of stream or lake stage (water level) by means of a float and pulley as is discussed in more detail below. The Shaft Encoder may be used to indicate the position of any shaft which can be coupled or geared to the encoder shaft. Carefully matched high-quality mechanical components will be required to match the Shaft Encoder resolution.

The sensor may be installed in any orientation that a particular application may require. Weights or other mechanical loads at right angles to the shaft center line should not exceed 10 pounds. Larger loads will distort the bearings, increase the starting torque, and decrease the bearing life.

Caution: Shaft encoders on long signal lines are subject to lightning damage. Be sure that there is no ground path through the mechanical connection from the shaft to the object being measured, such as a water surface. Use insulating components in the mechanical linkage. Protect the encoder by using surge arresters on the signal and power lines.

Water level (stage) measurement:

Figure 9.12 shows a possible arrangement of components with a stilling well. A standard pulley is attached to the shaft, and a tape running over the pulley is attached to a float at one end and a counterweight at the other. The float is projected from the action of waves and currents by a stilling well, and the whole may be enclosed in a gauge house. The pulley is 1.00 ft. circumference, with each step of shaft rotation corresponding to a water level change of 0.01 ft.

Attach the pulley to the encoder shaft; there is no need for any type of pulley-to-shaft adjustments. With the encoder in a monitor mode, the reading can be set to any value with the software.

In planning your Shaft Encoder installation, keep in mind that, as indicated in Figure 9.12, if the float rises and meets the counterweight falling, the counterweight will not clear float, and the interference may cause bad readings. If the 8-inch float is used, the interference will be less than with the 10-inch float, but it will not be absent. The 4-inch float should eliminate the interference, but may not be heavy enough to keep the tape tight if a long tape is used.

One way to avoid the problem with the larger floats is to set the encoder high enough above the water so that the entire range of water level can be accommodated with the float in the lower half of its travel (between the point

Figure 9.12   General Arrangement of Handar Model 436 Shaft Encoder where the counterweight reaches the pulley and the point where it hits the float). Another way to keep the counterweight clear of the float is to install an idler pulley (components may be bought in most hardware stores) which would guide the tape clear of the float. If such a pulley were included in the installation shown in Figure 9.12, it would be mounted to the right of the encoder on the supporting shelf and pull the tape and counterweight to the right to clear the float.

Cut the float tape to the required length with metal shears, and fasten a hook to each end as shown in Figure 9.12. Clamp the hook assembly to the end of the tape by inserting the tape between the hook body and the clamp plate and tightening the two screws. Force one hook open with the hand or pliers and place it over the eye on the float at one end of the tape, and open the other hook and place it over the eye of the counterweight. Bend both hooks closed so that the float and counterweight cannot accidentally come off the tape. Place the tape over the encoder pulley (and idler pulley if used) so that the holes in the tape engage the pins in the surface of the encoder pulley. Note the direction (clockwise or counterclockwise) in which the encoder shaft rotates as the water rises; you will need this information for programming the data logger.

> **Note:** Most tape pulley components are electrically conductive and will provide a dangerous ground path for lightning surges picked up by long signal lines as mentioned above. If you use long data lines, non-conductive pulleys and/or tape are strongly recommended.

Connectors

Members of the Model 436 series of encoders utilize three different types of data lines; each line has a different connector mounted on the side of the Encoder case (see Figure 9.13). Table 9.3 lists the pin functions for the three different types of connectors. The first column lists the type of signal line and type of connector used; the second column lists the model numbers which use the connector, and the last two columns give the pin label and the function associated with the pin.

Some data loggers, when used with the 436A-type output, do not allow programming the direction of rotation of the encoder shaft which increases the current position indication. If necessary, the direction of rotation for increasing readings can be reversed by interchanging the two signal leads on pins D and E of the connector.

> **Caution:** The Encoder is internally protected against transient voltages and lightning surges on the signal line. However, IT IS ESSENTIAL TO ADD EXTERNAL LIGHTNING PROTECTION.

Figure 9.13 Handar Model 436 A/B Series Incremental Shaft Encoders

Line/Connector Type	Models	Pin	Function
436A-type 6-pin circular	436A, A-1, B-1, and B-3	A B C D E F	Not Used Not Used 5 V Strobe Signal, phase 2 Signal, phase 1 Ground
SDI-12 data/power 4-pin circular	436B series except B-4	A B C D	Data +12V supply Ground Not Used
RS485 data/power 6-pin circular	436B-4 only	A B C D E F	Data - +12V supply Data+ Earth Ground Ground Ground

Table 9.3 Handar Model 436 Line/Connector Types

Multiple Sensors on Serial Data Lines

Models 436B, B-1, B-2, and B-3 encoders may be connected to a serial data communications line configured according to the SDI-12 standard; the Model 436B-4 requires an RS485 communications line. The SDI-12 line uses a single wire for data and is limited to 200 feet in length, while an RS485 line uses a two-wire differential circuit for data and may be up to 4,000 feet long. The number of sensors which may be attached to a single data line depends on the capabilities of the data logger in addressing, processing data from, and powering multiple sensors.

When the data logger sends out any SDI-12 command, each sensor on the line is awakened and receives the message. The data logger communicates with the individual sensor by the address. When the data logger request information (data value) from sensor with address 1, only the sensor programmed address 1 will respond. The number of sensors that can be connected to the data logger is dependent on the software of the data logger and the sensor. The normal configuration is for addresses to be single digit numbers (0...9) limiting the number of requests to 10.

Because of the great variety of possible arrangements for deploying Shaft Encoders along a serial communications line, it is not feasible to offer standard communications cables. Specific suggestions for Model 436B-series sensors attached to long data lines, and lightning protection for long data lines are discussed below.

Considerations for Long Data Lines

The following considerations are most important when using the Model 436B-4 Incremental Shaft Encoder, since RS485 lines may extend to 4,000 feet from the data logger. This section provides some specific recommendations for this sensor; these will also apply to an SDI-12 line except that, at a maximum of 200-foot length, neither wire resistance nor lightning protection will be as serious a problem. The wire gauge calculations described below may be used for any cable length. Lightning protection will be given in a special section and should be sufficient for SDI-12 lines.

The two data lines may be a 24 AWG twisted pair; color coding is required since the signal pair is polarized.

A system consisting of a number of Model 436B-4 sensors along a single data line will draw 100 mA per sensor each time a command is sent by the data logger; the segment of the power and ground lines between the data logger or other power source and the first sensor will carry the total current for all of the sensors, and the voltage drop along this segment will be the total current times the wire resistance.

Figure 9.14 shows a generalized wiring diagram for a number of Model 436B-4 Sensors attached to a data logger. Each sensor must be provided with at least 6V between the +V and ground pins (connector pins B and D, E, or F; see Table 9.3) in order to operate. The current for all three sensors flows through the wires between Sensor 0 and the data logger. The figure shows lightning protection arrangements which are commercially available.

The +12V and ground lines must be of the proper gauge to limit the voltage drop on the line at the furthest point to no more than 3V each in the two sides of the circuit. The maximum wire resistance which can be tolerated in the +12V and ground lines can be calculated from the formula

Install Equation Editor and double-
click here to view equation.

where L is the effective length of the cable in feet, calculated by adding the distance of each sensor from the data logger. For example, if three sensors are deployed at distances of 2,000, 3,000, and 4,000 ft. from the data logger, the

Figure 9.14   Schematic Wiring Diagram for Multiple Model 436B-4 Sensors value of L=2000 + 3000 + 4000 = 9000 ft. R is therefore approximately 3 ohms per 1000 ft. A standard wire table may be consulted to determine the smallest wire which may be used. That table shows that 15 AWG or larger wire must be used for the +12V and ground lines in this example.

Alternate wiring schemes may be used. One scheme would be to separate wires from the data logger to each sensor; in such a case, the above formula would apply separately to each cable. The wires to a sensor 4,000 ft. from the data logger could be up to 5 ohms per 1000 ft., which would require 17 AWG or larger, while the wires to a sensor 2,000 ft. distance could be up to 10 ohms per 1000 ft., which would allow 20 AWG or larger.

If power is not to be supplied by the data logger, the actual cable lengths to the battery should be considered. For example, if sensors located at 2,000, 3,000, and 4,000 feet from the data logger are supplied by a battery located near the middle sensor, no sensor is more than 1,000 feet from the battery, and relatively light wires would be needed. Such a battery could be charged by its own regulated solar panel.

Lightning Protection

Extremely long signal lines, such as might be used for Model 436B-4 Incremental Shaft Encoders, may pick up strong voltage surges due to both direct and nearby lightning strikes. Such surges can destroy circuit components in both the sensors and the data logger, therefore, it is imperative to take adequate protective measures. Surge protection is built into the equipment, but additional steps are required. A direct lightning strike on the data logger or sensor will unavoidably cause damage, but protection against the more likely event of a nearby strike is possible as described below.

It is important that protection be installed at every sensor and at the data logger.

It is essential that there be no conducting paths to ground other than the ground rods and connecting braided cables. When installing Model 436-series shaft encoders, be sure that the mechanical linkage to the sensor shaft does not provide a ground path. Nonconducting pulleys, tape, chain, or other components may be used to ensure that only the intended ground path will be followed by lightning surges reaching the equipment. Please refer to special operating procedure on lightning protection.

9.3.5.3.3 Calibration Procedures

The Model 436 A&B incremental encoders are calibrated either by the circumference of the tape pulley or by a multiplier programmed in the datalogger. The output of the encoder is 100 increments per shaft revolution, when used with a 1 ft. circumference pulley each increment measured will indicate a movement of 0.01 ft. When this configuration is used with a float, tape and counterweight, each .01 ft. of water level change will be noted by changing the count by one increment. When using different size pulley's, a multiplier must be used to correct the output to read water level in feet. The multiplier can be determined by the formula M = R/C where M = multiplier, C = circumference of pulley in feet and R = number of revolutions. If the readings increase for decreasing water level the shaft rotation must be reversed. This can be accomplished manually by reversing the float tape on the pulley, or by changing the +/- sign of WL reading in the datalogger software.

9.3.5.3.4 Maintenance Procedures

There is very little maintenance required for this device. The only moving part is the shaft which rotates on steel roller bearings. The bearings should be lubricated with a light oil during scheduled maintenance. Keep the stilling well clear of obstructions for free float and counterweight movement. Make sure the pulley is secured to the shaft and the float and counterweight are secure to the tape.

9.4 Instrumentation--Pressure Transducers

9.4.1 Principle of Operation

Various kinds of pressure transducers are available for sensing water level fluctuations throughout a variety of specified pressure ranges. Many of these transducers are submersible and are small enough to install in 1.25-inch diameter wells. They are well suited for use with digital data loggers, which can provide constant DC voltage to the transducer, convert the analog signal from the transducer to a digital value, and store the data. Many transducers can measure water level changes of less than 0.01 foot.

Liquid level is often measured in terms of head, the height of a liquid column at the base of which a pressure, p_l is developed. When the specific weight of the liquid, w, is known, the level, h, above the point at which p_l is measured can be determined from the difference between the pressure on the surface, p_n and the pressure, p_l by the equation:

$$h=(p_l - p_n)/w;$$

The pressure difference (p_l-p_n) is customarily measured by a differential pressure transducer pneumatically connected with atmospheric pressure and the sensor at a given depth. For a liquid of any given specific weight, the output of this transducer is then directly proportional to level.

A transducer is a device that converts one physical quantity (such as pressure from a column of water) into another physical quantity with more usable output characteristics (such as height of water column above the sensor). Electric impulses generated by various means from pressure transducers are transferred to a slider in a potentiometric circuit device which operate by Ohm's law. Variations in physical energy (e.g. pressure) change the ratio of output resistance to total circuit resistance. According to Ohm's law, output voltage varies proportionally with resistance changes. The pressure transducer output voltage is directly proportional to pressure applied to the sliding tap mechanism. In the potentiometer pressure transducer pressure variations generate analogous change in resistance, hence in output voltage. Three general types of pressure transducers are used, and all convert the signals to meaningful values in basically the same fashion.

Bonded strain-gauge pressure transducers have an etched metal foil strain gauge intimately bonded to a sensing element. The strain gauge is fashioned into a full, four arm Wheatstone bridge. These pressure transducers are designed so that the fluid contacts either a stiff diaphragm or a small-volume pressure-sensing tube. When pressure causes the sensing element to deflect, the variable arm of the bridge is stressed. Stress deformation causes a change in electrical resistance, producing a change in electrical output signal that corresponds to the change in pressure. Since there must be a diaphragm to bond to the strain-gauge resistor, the diaphragm also isolates the resistors for the working medium. The diaphragm dimensions (diameter and thickness) determine the pressure range of the transducer.

Piezoelectric sensors utilize a piece of quartz or polycrystalline ceramic to generate a small electric charge when strained by changes in pressure. These sensors require no external power are used for dynamic measurements, and are capable of measuring very fast pressure changes. By stacking thin crystal wafers in series (negative surface of one crystal in contact with the positive surface of the next crystal) sensitivity is increased. A single electric contact is made from the crystal through a connector with the housing acting as the signal return. As pressure is applied to the diaphragm, a compression force is applied to the crystal element, generating a charge proportional to the pressure. Since the output of the crystal is a charge, not a voltage, special charge amplifiers are used to signal-condition the sensors.

Piezoresistive sensors are silicon-based devices that operate on the principle that electrical resistance changes as a function of applied pressure. They utilize diaphragms constructed of precisely machined and etched wafers of hyperpure silicon. Thickness of the diaphragm determines the sensitivity of measurements. Electrical connections are made to the Wheatstone bridge circuit on the chip by depositing metal traces on the outer perimeter of the chip and welding a gold or aluminum wire to the trace. To measure pressure, the medium must come into contact with the chip or be coupled through an inert liquid. Many dies are covered with a silicon-based gel that protects the bonding pads from high humidity atmospheres. Piezoresistive sensors are generally fabricated by sealing two wafers together, creating a reference chamber between them. The top wafer has the bridge resistors implanted, and a back side diaphragm is sealed to a second wafer. This results in a chip with an active component on the top surface, a reference cavity in the center that is vented to the atmosphere, and a second constraint wafer. Temperature-induced errors of piezoresistive sensors take two forms: those effects on offset (change in the DC output voltage with no pressure applied) and span (sensitivity to applied pressure) Accurate sensors must compensate for these temperature effects.

The pressure range given for a pressure transducer is the pressure at which the device has been calibrated and tested. In general, the smaller the pressure rating, the greater the sensitivity of the sensor.

9.4.2 Maintenance

The electrical signal from pressure transducers commonly drifts with time. Drift is a change in the transducer output signal that is not a function of a change of the water level. To mitigate signal-drift errors, pressure transducers require regular recalibration of ensure accuracy during a long period.

9.4.3 Sensors Used

9.4.3.1 Sierra-Misco Model 5050LL-PTF Pressure Transducer

The 5050LL-PTF Pressure Transducer consists of a pressure transducer and signal conditioning circuit in a separate housing and comes complete with a length of signal cable and connector. The all-stainless steel Submersible Pressure Transducer is used to measure liquid levels. It is designed to be directly submerged in liquids compatible with 316L stainless steel and polyethylene (cable jacket). The high pressure design allows the sensor to be submerged beyond its operating range without damage. Its small diameter (1.25") makes this sensor usable in places other sensors cannot reach. It is designed to fit into a 2" pipe, and with sufficient mass to sink to required depths. The output of the 5050LL-PTF is compatible with Sierra-Misco's transmitters, the Mempak series Solid State Recorders, 60000 series Recorders and various standard data loggers.

9.4.3.1.1 Manufacturer's Specifications

Power Required:	12VDC, 10mA
Turn-on Time:	Less than 20 milliseconds
Accuracy:	±.5% of transducer range (includes hysteresis, linearity, and repeatability)
Over Pressure:	100% rated
Response Time:	100 milliseconds for changes in pressure
Range:	Various ranges are available; minimum 0-1 psi, maximum 60 psi
CMRR:	Greater than 90dB
Size:	3.25" long by 1.3" diameter
Weight:	32 oz.
Signal Out:	0-5 VDC standard
Maximum Cable Length:	1000 feet
Operating Temperature Range:	-40° to +120°C
Compensated Temperature Range:	-28° to 82° C

Temperature Performance:	0.0224% per °C
Barometric Compensation:	Vented to atmosphere

9.4.3.1.2 Installation Procedures

River Gauges

The pressure transducer should be installed in such a manner that it will not be damaged by debris under high and low water flows and that it will not silt up excessively. Two mounting accessories are available: the Model 5050LL-PT-BM which is a bracket for bolting the sensor to a concrete abutment and a Model 5050LL-PT-CAB which is a concrete anchor for mounting the sensor out in the river. Although waterproof vented cable is supplied with the transducer, additional protection against cable damage can be achieved using plastic conduit pipe.

Well Sites

When using the 5050LL-PTF to measure well water depth, it is usually lowered directly into the well. The cable and strain reliefs are able to withstand up to 200 pounds of tension and the cable will not stretch. This will hold the pressure transducer at the required depth.

Refer to Figure 9.15. The transducer is excited by a 1.5mA constant current generated by U1 through R1 at J1-3 returning to ground at J1-4. The transducers differential output is sensed at J1-1, and J1-2. The integrated circuit U2 will convert the differential signal to a single ended signal, rejecting the common components to ratio 1 part in 1 billion. This signal (typically 0-100 mV) is then applied to amplifier stage U3. Gain is set by the ratio of resistors R5, R6, and span adjust pot R7. Zero is adjusted at pot R4. Capacitors C7 and C10 provide frequency compensation. Output clamping is accomplished with R9, CR2, CR3, and CR4. This circuit will not allow the output to rise above 5.1 V. A small negative reference is generated at U2-15 to allow the output of amplifier U3's output to swing all the way to zero.

Transmitter

When operating the pressure transducer with the transmitter, the transducer is connected to the four-pin Analog port. It can also be connected to the four-pin Barometric Pressure port by rotating the index slot of the connector.

Whenever the transmitter turns on, the voltage (12 Volts) energizes the transducer. The output of the transducer is converted by the signal conditioning into a 0-5 volt signal and the transmitter converts this into a 0 to 255 decimal value. (If zero is read then no data is transmitted.) When the signal is received at the base station, the computer processes the information and converts it to engineering units.

To properly base set the pressure transducer, consult the operating manual for the base station and the calibration curve supplied with the transducer.

Recorder

When operated with recorders the transducer is constantly energized and an output reading is continuously logged on the recorder. Zero volts equals zero, and five volts equals full scale calibration; refer to the calibration curve supplied with the specific unit being installed.

9.4.3.1.3 Calibration Procedures

The 5050LL-PTF is factory calibrated and supplied with a calibration curve. Calibration can be checked using a water column. When used with a transmitter, adjustments can be made in the computer for slight changes in calibration. Since the calibration board is mounted in a desiccant box at the end of the cable, the zero point can be fine tuned from this location without removing the transducer from the water.

In order to adjust the calibration, open the desiccant box to gain access to the signal conditioning board. Using a digital volt meter, set the zero pot so that it is just above 0.00 Volts. Put a head of water (or apply air pressure) equal to at least 80 percent of the full scale range and adjust the span pot so the voltage reads accurately. Whenever the span potentiometer is adjusted, you should check to be sure the zero is still set at zero. Check several points on the curve by adjusting the water column height and taking readings. As a final check, adjust the pressure transducer with the device it is going to be used with, such as a recorder or transmitter.

Figure 9.15 Sierra-Misco 5050LL-PTF Schematic Drawing

If data from the pressure transducer seems high, check for silting around the sensor. If other erroneous readings occur, check to see if the transducer is mounted securely and that its position has not changed. If the cause of the erroneous data is not the physical surroundings of the transducer, then the next step is to determine if the transducer is faulty or the transmitter is faulty. Isolate the problem by checking the voltage at the connector (J2) while holding the Reset Button of the transmitter down. Be sure the supply voltage (12 Volts) at V IN is at least 11.5 volts; if 12 volts is low, there is a problem with the transmitter. Measure the head on the transducer and compare it to the output signal. If the output vs the water pressure as compared on the calibration curve is correct, the problem is in the transmitter. When ever the gauge is serviced, the transducer should be checked to ensure that it is free from silt and its mounting in the river is secure.

To determine if the transducer is at fault, an ammeter can be inserted between J1-3 and the red wire, and should read approximately 1.5 mA and should not fluctuate. (Do not forget to provide continuous power to the signal conditioning board.) If the supply current is good, reconnect the red wire to J1-3 and measure the output of the transducer by placing the leads of a voltmeter across J1-1 and J1-2. The output of the transducer is 0-1--mV which corresponds to 0-full range of the transducer. Since 27.68 inches (.70307 meters) equals 1 psi, the full range of the transducer is calculated by multiplying the psi range of the transducer by 27.68. For example, if using a 15 psi transducer, then the full range is 15 x 27.68 = 415.2 inches. If the transducer is submerged in 150 inches of water, then its output should be approximately 150/415.2 x 100 m V = 36 M v. This will help determine if the problem is in the signal conditioning or in the transducer.

9.4.3.1.4 Maintenance Procedures

The pressure transducer is designed to be used with a minimum of maintenance. Whenever the site is visited to service the transmitter, the pressure transducer should also be checked. Visually check to see if the cables are in good condition. Check to see that the transducer has not moved and that it is still securely in place. Clear any silt or debris away from the transducer.

9.4.3.2 Design Analysis WaterLog H-300

The WaterLog H-300 is a submersible pressure transducer, designed specifically to monitor water pressure (pressure is converted to head, or distance from sensor to surface). With the transducer positioned at a precise elevation inside a ground water well, stilling well or open body of water, the water level can be calculated by knowing the pressure of the water over the sensor. The H-300 is available in three output versions; Frequency, SDI-12, and RS232. This procedure is limited to the SDI-12 version.

WaterLog is easy to use and works with many data recorders. Its internal microprocessor automatically compensates for error due to offset, non-linearity, and temperature changes. WaterLog outputs pressure and temperature measurements in psi units and degrees centigrade.

> **SPECIAL NOTE**: The WaterLog instrument uses special temperature sensing circuitry. For the most accurate readings from the WaterLog, allow 15 to 20 minutes after installation for the system to come to a thermal equilibrium with the water.

Since data recording devices differ widely, you must prepare your data recorder to receive and display WaterLog's signals according to manufacturer's directions.

User requirements also differ. Users may program their data recorders individually for such variables as sampling rates.

The SDI-12 programming procedures will be discussed in detail under a separate heading.

9.4.3.2.1 Manufacturer's Specifications

Temperature Range:	-5° C to 50° C (non-freezing)
Compensated Range:	-5° C to 50° C
Storage:	-10°C to 75° C
Output:	SDI-12
Baud Rate:	1200
Accuracy (maximum percent of error in measuring pressure):	<0.02% over temperature range referenced to a straight line stretched from zero psi to maximum pressure
Protocol:	SDI-12, 8-Bit, Even Parity
Material:	Stainless steel barrel with PVC end caps and polyethylene vent tubing
Weight:	1.83 pounds
Size:	1.25 inches diameter x 13.75 inches long
Resolution (smallest pressure change detectable in output signal):	1 part in 5,000
Pressure Fitting:	1/8" tubing fitting
Linearity:	Less than 0.005% deviation from a straight line referenced to end points
Pressure Overload:	Less than 3 times the rated pressure
Site-Specific Items:	Standard 50-foot cable with polyethylene tubing (or longer as required by specific site characteristics)

Pressure Hysteresis:	Less than 0.01%
Response Times Frequency:	2 second update
Long Term Stability:	Less than 0.2% drift in accuracy per year
SDI-12:	30 second measurement sequence
RS232:	30 second measurement sequence
Media Compatibility:	Liquids and gases compatible with glass, ceramic, silicon, RTV, and nickel.
Pressure Ports:	3 Mesh Stainless Screens, field replaceable
Power Supply Voltage:	9.6 to 16.0 volts DC
Supply Current (Sleep Mode):	1 milliamperes max.
Supply Current (Active):	50 milliamperes max.

9.4.3.2.2 Installation Procedures

Unpacking

Remove the WaterLog pressure transducer, three-wire, shielded hook-up cable, and cleaning brush for the stainless steel screens from the packing box.
Be sure that the vented cable is long enough to reach the location selected for the junction box and that the hook-up cable is long enough to reach from the junction box to your data recorder.

Before installing the WaterLog, check the model number, the range, and the output information engraved on the electronics enclosure to be sure that you have received the instrument you ordered.

Testing

Before installing the WaterLog in the field, you may wish to test the system by hooking up the WaterLog with your data recorder (as explained in this manual). Then place your WaterLog in a convenient test environment, such as a pail of water, and observe your data recorder's readings.

Do not, of course, use a pressure hose to test the system, since it would be likely to subject the instrument to more pressure than it is designed to bear.

Installation

Place the WaterLog and the vented junction box in your chosen locations. Connect one end of the hook-up cable at the junction box and the other end to your data recorder.

Notice that the WaterLog has a bail for securing a mounting line. It also has a ballast hook for securing a weight, if needed, as shown in Figure 9.16. **We do not recommend hanging WaterLog on the vented cable.**

Use Table 9.4 to determine the maximum depth at which your WaterLog model will measure pressures accurately. **Do not place your WaterLog at more than twice the rated depth for your model, or the instrument will be damaged.** The junction box should be placed in a dry, accessible location within the distance allowed by the length of the vented cable.

Model	Pressure Range	Depth Range*
H-300-5	0 - 5 psi	0 - 11.533 feet
H-300-15	0 - 15 psi	0 - 34.60 feet
H-300-30	0 - 30 psi	0 - 69.20 feet
H-300-100	0 - 100 psi	0 - 230.66 feet

Table 9.4 Pressure Ratings of WaterLog Transducers

*NOTE: Depth calculations are derived from the standard equation that one psi is generated by a column of water 27.680 inches deep at 39 degrees F.

Figure 9.16 WaterLog H-300 showing Ballast Hook and Bail

Figure 9.17 WaterLog H-300 Junction Box Detail

Connecting the Hook-Up Cable

To connect the hook-up cable that will go from the junction box to your data recorder, refer to Figure 9.17 and follow these steps:

1. Remove the lid from the junction box by loosening the two corner screws.

2. Remove the desiccant packs from the junction box.

3. Loosen the gland nut on the data recorder end of the junction box.

4. Pull enough cable to work with through the bulkhead fitting and then through the opening to the inside of the junction box, and strip the PVC coating from the cable end (about a half-inch).

5 Strip the coating from the end of each of the conductor wires (about one-eighth inch). Now you are ready to connect the three conductor wires and the shield wire inside the vented junction box. Notice that the slots in the junction box are numbered to show which wire should be put in each slot. Use the following wire insertion order:

Slot 5	Power Wire (Red)
Slot 6	Ground Wire (Black)
Slot 7	Data Wire (White)
Slot 8	Shield Wire (No covering)

NOTE: If you are using your own hook-up cable, make certain you identify the color coding of your wires before proceeding.

6. With a small screwdriver, loosen the screw to open each slot where you want to insert a wire.

7. Insert the wires.

8. Tighten the screws down while holding the wires in place.

9. Check to make sure each wire is connected securely in the correct slot.

10. Tighten the gland nut so it grips your hook-up tightly.

11. Replace the desiccant packs. Placement of the packs is important. Be sure they are directly under the vent.

12. Screw the lid back on the junction box.

Connecting The Data Recorder

Your data recorder must be capable of reading the output by your specific WaterLog.

Connect the hook-up cable coming from the junction box to the appropriate port of your data recorder.

The letter D in the model number on the electronics enclosure of your WaterLog tells you the type of signal output is SDI-12.

F means Frequency

D means SDI-12

R means RS232

9.4.3.2.3 Calibration Procedures

Calibration of the H-300 with SDI-12 is reasonably simple as follows:

1. Convert the H-300s output from pressure (PSI) to feet of water, by multiplying the range (PSI) times 2.30667 (the PSI of one (1) ft. of water).

2. Determine the datalogger program multiplier by dividing the excitation voltage (usually 12 VDC) into the range in feet (computed in step 1) of the transducer being used.

3. **EXAMPLE:**

   When available, historical data should be used to determine a pressure transducer rating that is greater than the water level fluctuations to be monitored. In the example that follows (Figure 9.18), a Model H-300-15 was selected. The sensor range is 15 x 2.30667 = 34.60 feet, this will cover the water level fluctuations in the example (30 feet). 34.60 / 12 = 2.88 (multiplier).

4. Lower the sensor into the well below the minimum expected water level and wait the appropriate settling time. Make a distance-to-water (DTW) measurement and apply the correct offset to the datalogger.

5. The offset is a value that is added to the datalogger reading to make the datalogger reading match the required datum value for the water level. This is accomplished by subtracting the datalogger reading from the actual water level accomplished by subtracting the data logger reading from the actual water level and using this difference as the offset.

9.4.3.2.4 Maintenance Procedures

Sustained operation is almost maintenance-free, however, moisture creates the biggest problem. Therefore, monitoring the desiccant is of prime importance. Desiccant in the vented junction box should be changed or dried out periodically.

If the vent tube should become disconnected from the instrument it can be easily reconnected using standard quarter-inch tubing fittings. Occasionally the stainless steel screens (Figure 9.19) may need to be rinsed out. To clean these screens, take the WaterLog out of the water, unscrew the ballast hook plug, back flush the screens to rinse out mud, algae, or other debris, and replace the end cap. Or, using the cleaning brush provided, you may clean the screen while they are still in place (without unscrewing the ballast hook plug). Replacement screens are available.

> **CAUTION: Do not over-pressure the instrument by attempting to flush the screens before removing the ballast hook plug.**

Maintaining Desiccant Packs

If the desiccant in the vented junction box becomes saturated with moisture, its color turns from blue to pink. The color of the desiccant in the packs shows through transparent strips. Moisture not absorbed because the desiccant has become saturated will move down the vented tube from the junction box to the WaterLog by atmospheric pumping. The sensor won't operate properly if it gets wet.

Remove moist desiccant packs from the junction box, and dry them out before replacing them, or replace them with new desiccant packs. The lid to the junction box can easily be removed and replaced by loosening the two corner screws. How frequently you should check the desiccant depends upon the environment where your junction box is located. Maintenance schedules will vary according to individual conditions.

Figure 9.18   Computation of Offset in WaterLog H-300

Figure 9.19 Location of Stainless Steel Screens on WaterLog H-300

9.5 Instrumentation--Ultrasonic Level Sensors

9.5.1 Principle of Operation

An ultrasonic level sensor is a device that measures time travel of an ultrasonic pulse to accurately compute linear distances in a homogenous medium. This is accomplished by emitting an ultrasonic pulse at scheduled intervals. The measured time difference between the emitted pulse and the return pulse (travel time) is proportional to the actual distance traveled. This distance, when divided by two equates to the distance from the face of the transducers to the target. The target can be any object or media of a different density. The greater the difference in density will equate to a stronger reflected signal.

An important principle to remember when using ultrasonic sounding is that the velocity of the pulse through the media is assumed constant. Stratification of temperature and humidity will effect the velocity of the ultrasonic pulse in transit. Temperature causes the most dramatic change in velocity. Density effects velocity proportionately. Some manufacturers include a thermistor to measure the temperature and correct for the speed of the pulse. This approach has yielded much more accurate distance measurements. Again this assumes that the temperature through the travel path is identical to the temperature at the thermistor. Any environmental influences that directly effect the density of the medium needs to be compensated for in order to achieve the greatest accuracy.

9.5.2 Maintenance

This type of pulse emitting instrument is generally very reliable and requires minimal maintenance. The transducer is usually a ceramic element in a rugged housing.

It is important to keep the measurement area free from debris that could reflect the ultrasonic pulses. Reflections from tree limbs and floating debris will result in distances to the debris to be measured rather than the distance to the target. The transducer face should also be checked for fouling and infestation and cleaned accordingly. If the unit is equipped with a thermistor or temperature probe, it should be calibrated and checked for proper operation.

Care should be taken when handling the transducer. Ceramic transducers require high voltage levels (low current) for greater signal strength. Ceramic elements are capable of maintaining a charge for extended periods. They should be handled like a large capacitor when not in operation.

9.5.3 Sensors Used

9.5.3.1 Lundahl DCU-7 Ultra Sonic Sensor

The Lundahl DCU-7 sensor measures water surface elevations ranging from 2 to 10 feet away from the sensor. The sonic sensor outputs 0 to 5 volts to the data logger which supplies 5 volts input voltage. The distance to water measurements must be temperature-compensated for accurate readings. The DCU-7 has an accuracy of 99.8 percent with a 1/400 foot resolution.

9.5.3.1.1 Manufacturer's Specifications

Supply Voltage:	4.7 to 5.3 VDC; Optional 10 - 30 VDC
Analog Options	0 to 5 volts (from 0 - 10 feet)
Transducer Operating Range	
Electrostatic:	1 to 10 feet
Ceramic Environmental:	2 to 10 feet
Resolution:	1/400 feet, over full range
Accuracy:	± 0.25% of range with no gradient
Total Current Draw:	23 mA (typical 25 mA at 5 volts)
Temperature Compensation:	N/A (recommended use of external temperature sensor for compensation)
Operating Temperature:	-30° to +70° C
Sample Rate:	8 Hz
Case:	304 stainless steel housing
End Plates	Nickel-plated glass epoxy
Cable:	4 conductor, 6 foot length
Dimensions:	2-3/8 inch diameter by 5-1/4 inch length
Adjustments:	Blanking and sensitivity (for wave guide capability)

9.5.3.1.2 Installation Procedures

The sensor should be equipped with a wave guide and a protective back cover before field installation. The wave guide reduces the divergence angle of the sound wave transmission and allows for the sensor to be installed in a small stilling well. The protective back cover helps protect the instrument from accumulating moisture and debris on the sensor.

1. Connect the wiring in the following order:

Black	Power Ground
Green	Analog Ground

Red	+5 Volts Excitation
White	Voltage Output

2. Mount the sensor vertically over the water surface. The expected water levels must be between 2 and 10 feet from the sensor at all times. Mount the sensor inside a stilling well for accurate readings. The sensor can easily be installed inside a 2-inch PVC-pipe stilling well.

3. Mount a thermistor or other temperature probe within 2 feet below the DCU-7. The output of the temperature probe will be used for temperature compensation.

4. The equation on the data logger should be similar to:

$$E_w = E_s - 2\,(V_o)\,[(c + 273)/273]^{1/2}$$

Where, E_w = water elevation

E_s = sensor elevation

V_o = Output Voltage, and

C = the measured temperature (in degrees Celsius) inside the stilling well.

5. Compare the sensor reading to the staff gauge or other water level reference.

9.5.3.1.3 Calibration Procedures

Using the data recorder, view and write down the current sensor reading on the solid state recorder sheet. Compare this reading to the staff gauge, the manual distance-to-water measurement or other accurate recorder reading. If the sensor reading is not within 0.03 feet of the more accurate reading, the sensor needs to be recalibrated.

9.5.3.1.4 Maintenance Procedures

1. Record the present or last recorded reading of the DCU-7 and compare to the staff gauge or other water level reference.

2. Ensure that the sensor is mounted securely and the stilling well wall is free from obstructions.

3. Check wiring connections and the overall condition of cable assemblies. Verify that the sensor is getting the proper input voltage and is returning a realistic output voltage for the present water level.

4. Ensure that the air temperature probe inside the stilling well is above the water surface and operating properly. Check the current temperature readings and compare to present conditions.

9.6 Instrumentation--Displacement Transducers

9.6.1 Principle of Operation

A displacement transducer is a device designed for measuring linear position and/or low velocity movement. This is accomplished by monitoring the extension rate and distance of the instrument's stainless steel lanyard. The external end of the lanyard is attached to the moving body or object to be measured, and the transducer housing is attached to a fixed surface. As the moving body moves to and from the transducer housing, an electrical signal proportional to the linear extension of the lanyard is provided for display, recording, feedback or input to a controller.

Spring-stored energy provides retraction tension for the lanyard. The spring is directly shaft-coupled to a ten-turn potentiometer, and indirectly drive-coupled to the lanyard storage drum. The lanyard is wrapped around the storage drum. As the lanyard extends the storage drum rotates thus rotating the potentiometer that provides the proportional output signal.

9.6.2 Maintenance

Resistive instruments are in general very reliable and require minimal maintenance. Other than badly worn sensor replacement, general cleanliness like dusting and the removal of such residue as dirt and spider webs is usually the only required routine maintenance. Where applicable, specific maintenance practices are discussed in detail under each individual instrument.

9.6.3 Sensors Used

9.6.3.1 Celesco Displacement Transducer Model PT-101

The Celesco Displacement Transducer is a device designed for measuring linear position and/or low velocity. This is accomplished by monitoring the extension rate and distance of a stainless steel lanyard. The external end of the lanyard is attached to the moving body or object to be measured, and the transducer housing is attached to a fixed surface. As the moving body moves to and from the transducer housing, an electrical signal proportional to the linear extension of the lanyard is provided for display, recording, feedback or input to a controller.

Spring stored energy provides retraction tension for the lanyard. This spring is shaft coupled to a ten turn potentiometer, and drive coupled to the lanyard storage drum. The lanyard is wrapped around the storage drum. As the lanyard extends the storage drum rotates thus rotating the potentiometer there by providing the proportional output signal.

9.6.3.1.1 Manufacturer's Specifications

Shock endurance:	2000 G's for 6 ms.
Vibration:	10 G's 10-2000 Hz.
Accuracy:	0.01% standard
Resolution:	0.001 inch standard
Ranges:	0-2 to 0-1000 inches
Sensing System:	Precision potentiometer
Electrical Connector:	MS3102E-14S-6P
Input impedance:	500 ohms standard (options available)
Excitation Voltage:	25 volts max
Thermal effects:	Zero and Span 0.002% per °F
Temperature Range:	0°F to 200°F
Humidity:	Up to 90%

9.6.3.1.2 Installation Procedures

When installing the Celesco Displacement Transducer, position the instrument upside down above the stilling well such that the float will deploy straight down without touching the sides of the stilling well or any part of the mounting platform throughout the instrument operating range. Mount the instrument above the stilling well a distance sufficient to allow the float installation without removing the transducer.

The installation will require a spacer leader to allow the instrument to operate within its desired range.

Determine Leader Length

Measure current distance to water (DTW). Subtract DTW from the measuring point to determine the present water level reference to National Geodetic Vertical Datum (NGVD). Determine period-of-record water level fluctuations around present water level. Determine the middle of the period-of-record water level referenced to NGVD. Subtract the middle period-of-record level NGVD from the current level NGVD and add the distance between the instrument lanyard clip and the MP. This "sum" becomes the length of the leader needed for addition to the lanyard, to ensure the instrument will always operate within its limits.

9.6.3.1.3 Calibration Procedures

Sensor sensitivity is noted on the identification tag mounted on housing of each instrument. Typical sensitivity is: 6.14mV/V/in. This means the instrument will produce 6.14 millivolts output for each volt of applied excitation voltage per inch of deployment.

Example

Sensitivity = 6.14mV / V / in.

Excitation Voltage = 5 volts

Deployment distance = 4 feet

Output in mV = 6.14 X 5 X 48 = 1473.6 mV = 1.474 volts

Perform routine site visit calibrations by first reading the recorder as found. Then carefully and accurately raise the float 12 inches and read the recorder again. The recorder must indicate a 12-inch rise in water level or you must investigate the error.

Perform annual calibrations by removing the instrument from the shelter and to an area which will allow full deployment. The annual calibration should incorporate lanyard extension points at 0 percent, 25 percent, 50 percent, 75 percent, and 100 percent of full deployment.

9.6.3.1.4 Maintenance Procedures

Maintenance of this instrument consists of routine cleaning of dirt and removal of spider webs from the lanyard. Spider webs are especially troublesome as they will collect at the lanyard exit orifice during retraction and apply pressure on the lanyard. At times this pressure is enough to over come the retraction tension and actually seize the lanyard preventing movement in either direction.

9.6.3.2 Balluff Inc. Linear Displacement Transducer BTL

The Balluff Linear Displacement Transducer (BTL) is a rugged linear positioning device for use over stroke positioning lengths of 5.9 inches to 10.5 feet. A traveling magnetic ring is used as a positioning marker to determine the measuring point. The signal generating and processing electronics is contained in the handle of the unit.

Metal is a very good conductor of sound. Metal conducts sound without the influences of air pressure, humidity, and in this case, temperature. This characteristic is exploited by the BTL. It uses as a basis, the travel time of an ultrasonic pulse over a metal conductor to determine the path length. The accuracy of this process is established by detecting the leading edge of the ultrasonic pulse as it arrives at the receiver.

The ultrasonic pulse is generated directly in the conductor (or wave guide) following the principles of magnetostriction. The waveguide therefore must be constructed of magnetostrictive material such as nickel-iron alloy. The proper alloy has a crystalline structure deformed along the axis of the magnetic field. This deformation will induce a mechanical wave or torsional pulse in the wave guide with a frequency in the ultrasonic range. The measured position is marked on the wave guide by the magnet field of the four magnets embedded in the float ring. The field runs axially in opposite directions. Another magnetic field is formed when the current pulse is sent through the wave guide. At the point of intersection of the two magnetic fields an ultrasonic pulse is formed by means of magnetostriction. The pulse is propagated in both directions of the waveguide at a speed determined by the alloy.

The pulse which reaches the end of the waveguide is absorbed by the damping zone. The pulse going in the other direction is detected by the receiver and converted to an electrical signal.

The time between the origination of the current pulse and the reception of the leading edge of the torsion pulse is directly proportional to the measurement length.

9.6.3.2.1 Manufacturer's Specifications

Power Requirements:	24 Volts DC @150 mA
Noise:	5% max 20 mV
Output Signal:	BTL-A 0 to 10V BTL-B 0 to 20 mA BTL-C 4 to 20 mA
Output Load Capacity:	Voltage out 20 mA max Current out 50 mA max
Operating Temperature:	0°to 60° C
Storage Temperature:	-25° to +80° C

9.6.3.2.2 Installation Procedures

If this instrument is operating in a hostile environment the handle (housing the electronics) must be installed in a water proof enclosure (factory option). Use a drying agent such as desiccant inside the enclosure to assist in moisture control.

It is recommended that the mounting surface for this instrument be made of non ferrous materials such as aluminum, brass, copper, or stainless steel.

Mount the BTL away from pulse-loaded power supply lines. Do not run cables parallel with any noisy electrical lines. Use twisted and **braided** shielded wire. Use 22 or larger gauge twisted pair for all power and ground lines.

9.6.3.2.3 Calibration Procedures

Field calibration of this instrument is best accomplished by changing the base value in the data logger. If a span calibration is required, remove the instrument to a suitable electronics lab and consult the manufacture's service manual.

9.6.3.2.4 Maintenance Procedures

This instrument requires a minimal amount of maintenance. Perform preventative maintenance at approximately 60-day intervals in the form of general cleaning, drying agent rejuvenation, and installation inspection. Ensure that all magnetic materials are more than 15 mm away from the positioning magnet and electronics head. Verify that instrument supply voltage is 24 Volts DC ± 10 percent and is not shared by other devices.

No field adjustments are permitted. Instrument zero and span adjustments require accurate measurement conditions in a clean service area.

Velocity/Discharge Monitoring

10.0 Velocity Measurements

10.1 Introduction

10.1.1 Theory

Discharge, or streamflow (or rate of flow), is defined as the volume of water, including sediment and other dissolved or mixed solids, that passes a particular reference section in a unit of time. The unit of discharge generally used in the United States is the cubic foot per second (cfs)

There are a number of different methods of measuring discharge at any given site. The method that is used depends largely on the conditions found at the site. Most of the methods are based on the measurement of velocity and the cross-sectional area of the reference section. The most common method involves dividing the cross section into a number of sub-sections, determining the average velocity in each sub-section, and summing the products of the sub-sectional areas and the average velocities.

Periodic measurements are generally made at a given reference section in order to determine the functional relationship between the stage (water surface elevation) and discharge. The stage-discharge relationship is then used with a continuous record of stage to generate a continuous record of discharge.

The importance of maintaining continuous records of discharge is very well recognized by the water management districts. Records of discharge are the basis for regulating flows to and from lakes, reservoirs, and water conservation areas as well as for monitoring the major water quality indices, such as phosphorus and nitrogen, in the streamflow. The Florida Water Management Districts are increasingly assuming the responsibility of making streamflow measurements in the canals, creeks, and rivers which fall within their respective jurisdictions, a task which was previously undertaken primarily by such agencies as the U.S. Geological Survey and the U.S. Army Corps of Engineers.

There are various instruments which measure the velocity at a point in a cross section of a stream. The purpose of such measurements is to estimate the mean velocity of a vertical in a cross section by measuring representative point velocities along the vertical or to estimate the mean velocity of the stream by developing a relationship between the local velocity and the mean velocity of the stream.

Methods of estimating mean velocity along a vertical

To properly evaluate the mean velocity along the vertical of a stream gaging cross section, it is necessary to measure ten or more point velocities on the vertical. This procedure, although accurate, is time consuming and impractical for the purpose of measuring discharge in streams. Instead, an estimation technique is used which reduces the amount of time necessary for the measurement, while still providing sufficient accuracy.

In these methods, the depth of the vertical is the distance from the water surface to the bottom of the stream. The observation depth (0.2, 0.6, and 0.8) is measured from the water surface.

The three-point method is usually the most accurate of these velocity estimation methods.

Six-Tenths Method

The mean velocity along a vertical is estimated by making a point velocity measurement at six-tenths of the depth of the vertical. This method is used under two special circumstances:

1. Shallow vertical. The depth of the channel is too small for an 0.8 depth measurement. For example, if the closest distance the current meter can get to the bottom of the stream is 0.5 feet, then depths below 2.5 feet must be estimated using the six-tenths method. In this example, the 0.8 depth would correspond to 2.0 feet from the water surface, leaving exactly 0.5 foot distance from the meter to the bottom of the stream.

2. Fast measurement. The stage in the stream is rising or falling rapidly and a fast measurement must be performed. The six-tenths method, together with 20-second point velocity measurements (half counts), can be combined to measure the discharge in a stream in about 20 minutes depending on the physical properties of the stream, equipment, weather conditions, etc.

Two-Point Method

The two-point method for estimating the mean velocity at a vertical is the standard method. Two point velocity measurements are made at 0.8 and 0.2 of the depth of the stream. These two velocities are averaged to obtain the estimate of the mean velocity.

The two-point method should only be used when:

- The 0.2 velocity is higher than the 0.8 velocity, but not more than two times higher;

- The vertical is sufficiently deep to make the 0.8 measurement. For example, for a 15-pound sounding weight and a Price AA current meter, the minimum distance from the meter to the bottom of the bed is 0.5 foot. A measurement of the 0.8 depth cannot be made for a vertical depth less than 2.5 feet;

- The stage and other conditions affecting the flow of water are fairly steady;

Three-Point Method

The three-point method for estimating velocity consists of measuring point velocities at 0.2, 0.6, and 0.8 vertical depths. The mean velocity is calculated as follows:

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or:

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or when it is desired to give more weight to the 0.2 and 0.8 method the arithmetical mean of the three observations may be used.

The three point method should be used whenever:

- The 0.2 velocity is lower than the 0.8 velocity;

- The 0.2 velocity is more than two times the 0.8 velocity;

- The stage and other conditions controlling the flow of water are fairly steady;

- The depth is greater than 2.5 feet;

10.1.2 Instrument Siting and Exposure

The following criteria should be used when choosing a cross section:

- Select a section where the measurement will represent the flow for the gauge location. Any tributary or distributary between the gauge and measuring location will also require measurement. Changing stage is also a factor and storage changes for areas between the gauge and measurement section may be required to adjust the measurement to the gauge location.

There are times when a measurement cross section must be used which contains minor obstructions such as bridge piers or embedded logs or small areas of reverse (negative) flow. If an object is in the cross section, determine the width and adjust adjacent section widths accordingly. If flow is in a negative direction, it should be subtracted. Make appropriate notes about such conditions in the measurement.

- Look for uniform flow. The flow lines along the cross section should be parallel to each other. Circular flow or converging flow should be avoided when possible.

- Avoid turbulent flow. Turbulent flow occurs when horizontal as well as vertical velocities are present. Price AA current meters should be used only when the vertical velocity is negligible compared to the horizontal velocity. For significant vertical velocity, use an Ott current meter.

- Accessibility. Find a cross section which is easily accessible. Look for banks which are not too steep.

- Standard vertical velocity profiles. Perform a 10-point velocity test along three verticals spread evenly in the cross section. Plot the velocity profiles to show whether the mean velocity can be accurately estimated by standard methods.

Once the cross section has been selected, write down all the necessary information regarding the cross section, such as name of gaging station, geographical location, including narrative, distance to nearest water control structure or landmark, and travel information

Selection of Verticals

The number of verticals in a stream gaging cross section, regardless of the width of the cross section, should be between 25 and 30. This allows measuring the discharge with a 2.2 percent statistical error.

When performing a **fast** measurement, due to a rapidly rising or falling stage, the minimum number of verticals can be dropped to 17. This increases the statistical error to 5 percent, but it avoids a larger error because of the falling or rising stage.

Ideally, no partial section should account for more than 5 percent of the total discharge. To achieve an even distribution of discharge among the partial sections, it may be necessary to spread the verticals unevenly. For example, if discharge is observed to be mostly concentrated near the middle of the stream, the verticals near the middle of the stream should be closer to each other than the verticals near the banks.

Additional sections may be taken at appropriate locations after the measurement is completed and totaled. A quick review of the partial discharges will reveal whether additional sections should be taken. These sections can be added at the end of the notes. Previous widths, areas and discharge will need to be recomputed. Record the time at each added section.

The location of the verticals may be improved by using the information from the first measurement to establish the actual distribution of discharge along the cross section.

10.1.3 Measurement Standards

Stage Measurements

If the change in stage during the discharge measurement is uniform and less than about 0.15 ft, then only the stage readings for the beginning and end of the discharge measurement are necessary.

However, if the change in stage is not uniform or is greater than about 0.15 ft, then additional readings should be taken. When a recording chart is available, the breaks in the slope of the stage graph should be noted. If a punch tape is used, the readings punched during the measurement are read. If only a staff gauge is available, the discharge measurement should be stopped every 15 or 20 minutes to read the gauge, or someone else should be assigned to read the gauge.

Since it is usually not known in advance whether the stage will be uniform and steady, the discharge measurements notes should include time readings every 15 or 20 minutes. This will facilitate computing flow-weighted mean stage.

Duration of Discharge Measurement

The duration of the discharge measurement may be planned by evaluating the stage and other conditions controlling the flow. There are three basic time frames to perform a discharge measurement. Total time required in each case will depend on physical characteristics of the cross section and equipment used.

> **Short Duration**. If the stage is changing rapidly or if anything controlling the flow is not steady, the discharge measurement may be performed using the short method. This method allows for 20-second point-velocity readings at six-tenths depths. The total duration of a discharge measurement using this method is about 20 minutes.
>
> **Standard Duration**. When changes in stage of other factors influencing flow can be accounted for, such as weighted mean stage calculation, the standard method is used. The duration of a discharge measurement using the standard method is between 1 to 1.5 hours. The smallest error in discharge estimation using the standard method is 2.2 percent, on the average
>
> **Long Duration**. This method should only be used when it has been shown that a systematic error exists when using the two-point method for mean velocity estimation. For example, a preliminary study has shown that the mean velocity in some canals in South Florida is underestimated with the two-point method by about 4 percent. The three-point method appears to be more robust for some canals. By using the three-point method, the duration of the discharge measurement may extend beyond 1.5 hours.

Boat Measurement

A boat is used to traverse the width of the cross section. The cross section is defined by a steel tag line tied to stakes which are planted in the banks. The tag line should be tight enough to maintain the boat steady during velocity measurements. The tag line should be secured at the same height as the top of the boat. If the tag line is secured higher than the top of the boat, the boat will be elevated slightly near the banks and the depths will be inaccurately recorded.

Bridge Measurement
A crane is used to hold the sounding equipment and to traverse the width of the cross section. The position of the verticals is marked on the bridge. It is a good practice to zero the sounding gauge at every vertical. The reason is because the

bridge may not be horizontal, or the surface where the crane rests on may not be horizontal. If the boom of the crane rests on the bridge, the elevation of the boom above the water surface will not be consistent. In addition, the distance to water will change with changing stage.

Verticals should be chosen away from bridge piers. Flow contracts near piers and this affects the direction of the flow lines. Choose verticals only in locations where flow lines are straight. Record any horizontal angle which you may observe.

Wading Measurement

This measurement is performed in shallow streams which can be traversed by walking. A wading rod is used to hold the current meter, measure the depth, and set the depth of observation. A pygmy meter is used for very shallow water (depths of 1.5 feet or less).

> **CAUTION.** In some instances danger exists in being able to stand in fast-moving water. When the depth times velocity approaches a factor of 10, the hydrographer is in danger of losing his footing.

Choosing a sounding weight

The rule of thumb for selecting the sounding weight for a given stream is:

weight (pounds) > max. depth (ft) x max. velocity (fps)

For example, if the maximum depth of a stream is 10 feet, and the maximum velocity in the stream is 2.5 fps, then the weight used should be greater than 25 pounds, therefore use a 30-pound weight. The function of the sounding weight is two-fold: (1) it is used to sound the bottom of the stream and (2) it keeps the current meter at a fixed position relative to the boat. A weight which is too light will allow the current meter to be pushed by the current, causing inaccuracies both in measuring the depth and in measuring the point velocities.

Correction of Discharge for Storage During Measurement

When it is necessary to make measurements a significant distance from the gauge during changing stage, the measured discharge will not be the same as that passing the gauge because of the effect of channel storage between the measurement section and the gauge.

Channel storage can be adjusted for by applying the quantity being stored or released to that measured using the equation:

$$Q_c = Q_m \pm WL(\Delta h/\Delta t)$$

Where:

Q_c = discharge passing the gauge control (cfs),

Q_m = measured discharge (cfs),

W = average width of stream between measurement section and gauge control (ft),

L = length of reach between measurement section and gauge control (ft),

Δh = average change in stage in reach L during measurement (ft),

and

Δt = elapsed time during measurement (in seconds).

Adjustments for measurements made on rising stage above gauge control will be negative and those made on falling stage above gauge control will be positive. Adjustments for measurements made in rising stage below gauge control will be positive and those made on falling stage below control will be negative.

10.2 Instrumentation -- Vertical Axis Current Meter

10.2.1 Principle of Operation

The velocity of the water is proportional to the speed of the rotor.

10.2.2 Maintenance

The meter should be cleaned and oiled regularly. A spin test is the best way to test the condition of the meter. It is important to secure the raising nut before storing the meter in its case. Because of the rigid control used in the manufacture of the small Price and Pygmy meters, virtually identical meters are produced, and for practical purposes, their rating equations are identical.

There is, therefore, no need to calibrate each meter individually. A standard rating is established by calibrating a large number of meters that have been constructed to rigid specifications and supplying a standard rating with each meter. A standard meter can be recognized by an 'S' stamped on top of the bucket wheel along with a year of manufacture.

Rating was formerly done by the National Bureau of Standards by towing the meter in two directions at constant velocities from 0.25 to 8.0 feet per second in a 400-foot long, sheltered tow basin. Sixteen observations of the velocity of the tow car and the bucket wheel are used to determine two linear equations furnished on standard rating tables.

10.2.3 Sensors Used

10.2.3.1 Price AA Current Meter

This meter can be used with a wading rod or with sounding equipment. Two contacts are provided. One makes contact every revolution, while a reduction gear causes a second contact every five revolutions. This meter is calibrated from 0.25 fps to 8 fps.

The Price Pygmy Current Meter is a 2/5 scale version of the Price AA meter. It can only be used with a wading rod and is intended for shallow streams.

Low Velocity Measurement

The normal rating for a Price AA current meter is 0.25 to 8 fps. For velocities under 1.0 fps, a low-velocity Price AA current meter is recommended. The low-velocity meter is rated from .20 to 2.5 fps. Accuracy decreases rapidly below 0.1 fps. The only difference between the normal and the low-velocity meters is that the penta-gear is removed in the low-velocity meter, offering less resistance to flow and allowing a lower rating. The low-velocity meter may also have 2 contacts per revolution.

The pygmy meter is not a low-velocity meter. Its size is convenient for shallow water but it offers more resistance to flow than a normal Price AA meter and has a higher stall speed which limits its use for low velocities.

Another concern in low-velocity flow is a lack of force from the water movement to overcome the cable torque, which may cause misalignment of the current meter. This misalignment may incorrectly be reported as a horizontal angle. Research is being conducted to develop a connection between the sounding cable and the sounding bar which will be torque-free, while at the same time provide electrical continuity.

10.2.3.1.1 Manufacturer's Specifications

To properly use and care for a current meter, the user must be familiar with all of its parts, as well as with the assembled meter. If any part fails completely because of excessive wear or damage, the condition is usually obvious, but small irregularities that may introduce large percentage errors in velocity determinations are not always readily detected. For this reason the parts of the type-AA meter and their functional characteristics are described below.

Yoke

The yoke is a 1-piece horseshoe-shaped casting made of chromium-plated bronze. A short horizontal rear extension contains a hole for connection of the tailpiece. This extension contains two bosses--one which is slotted vertically and drilled horizontally for the hanger and hanger screw, and one which is drilled vertically for the tailpiece keeper screw. The slot for the tailpiece is designed to limit the tilting of the hanger so that neither the yoke nor the tailpiece will strike the weight. The upper arm of the yoke is drilled to receive the stem of the P-shaped contact chamber; the lower arm is drilled to receive the pivot. These holes are coaxial so as to properly align the rotor assembly and the pivot. The contact chamber and pivot are held in position by a keeper screw having a knurled fillister head.

Tailpiece

The tailpiece is made of a hard-rolled nickel-plated brass, and it consists of two separate vanes which, when assembled, are locked together at right angles to each other by means of a lever. This two-piece construction permits the tailpiece to be taken apart for convenience in packing. The nosepiece of the tail fits into the rear extension of the yoke. A means to balance the meter assembly is provided in the lower part of the tailpiece by a long horizontal slot containing one or more short heavy screws that may be adjusted to the proper position to obtain the desired balance while suspended in water.

Bucket wheel

The bucket wheel consists of six cone-shaped cups soldered to a frame to form a symmetrical and balanced assembly 5 inches in diameter and 2 inches high. The cups and frame are made of nickel-plated hard rolled brass. The frame is centrally drilled for the shaft and notched for a dowel pin. The letter "S" is stamped on the frame to identify the top side of the bucket wheel. The year of manufacture is also identified--S-67, S-68, for example.

Bucket-wheel hub

The bucket-wheel hub encases the pivot bearing and the lower end of the shaft and supports the bucket wheel. The hub is threaded in three places: (1) for the bucket-wheel hub nut, (2) for the bucket-raising nut, and (3) for the shaft. A small dowel pin maintains the bucket wheel in a fixed position with reference to the bucket-wheel hub. The bucket-raising nut is provided so that the pivot bearing can be raised from the pivot when the meter is not in use.

Shaft

The shaft is made of stainless steel and is of sufficient length to extend from the bucket-wheel hub to a point 0.008 inch below the cap of the contact chamber. The upper one-half inch of the shaft is turned to 0.125-inch diameter and is rounded at the top to provide a smooth bearing surface for the thrust of the shaft against the bottom of the contact-chamber cap. An eccentric is cut in the 0.125-inch diameter part of the shaft to provide a means for making an electrical contact for each revolution of the bucket-wheel hub. The shaft also contains an acme thread that meshes with the penta gear within the contact chamber. A small hole is drilled at about the midpoint of the shaft to facilitate the use of a pin for tightening the shaft into the bucket-wheel hub.

Pivot

The pivot is made of tempered, precipitation-hardening stainless steel. The upper end of the pivot is ground and polished to form an angle of 90 degrees and the point rounded to a radius of 0.005 inch. The lower end of the pivot is threaded to provide for the hexagonal stainless-steel nut that is used to adjust the clearance between the pivot point and the pivot bearing. A slightly tapered flat surface on the pivot above the threads serve as a contact surface for the pivot-keeper screw.

Pivot bearing

The pivot bearing is made of tungsten carbide and has highly polished bearing surfaces. It is pressed into the cylindrical recess in the lower end of the bucket-wheel hub. The bearing being of greater hardness than the pivot causes the major part of the wear to take place on the pivot which is easily replaceable.

Penta gear

The penta gear is made of stainless steel and is fitted to mesh smoothly with the acme threads on the shaft. The gear makes one complete revolution for each 10 revolutions of the bucket wheel. Two gear teeth, 180 degrees apart, are extended beyond the others to provide a means for making two electrical contacts for each revolution of the gear, with the result that contacts are made at each fifth revolution of the bucket wheel. The gear is mounted in a bronze frame in a horizontal position, and the assembly is housed in the contact chamber where it is held in place by means of a brass screw. The base of the frame through which this screw passes is slotted to permit the adjustment of the gear teeth with the worm on the shaft.

Contact chamber

The contact chamber is a P-shaped chromium-plated brass unit which houses the penta gear, the upper part of the shaft, the shaft bearing, and the single- and penta-contact binding posts. The upper end of the chamber is drilled and threaded internally to carry a knurled cap. A small phosphor-bronze lug brazed to the chamber wall, serves as the upper bearing for the shaft. The stem of the contact chamber extends through the upper arm so that the shaft can pass into the chamber with ample clearance. The cap is tightly fitted so that the chamber serves as an air trap to prevent silty water from entering the bearing.

Binding posts

Two stainless-steel binding posts are placed at the rear of the contact chamber. One post is designed to contact the eccentric of the shaft and the other to contact the two extended teeth of the penta gear. They are identical in construction except for the lengths of the slender stainless wire through which the contacts are made. Each binding post is insulated from the contact chamber by a bushing made of nylon.

10.2.3.1.2 Installation Procedures

The type-AA meter and the Pygmy meter require a suspension mechanism for the purpose of maintaining the heading into the flow and accounting for vertical position. Sounding (determination of depth) is commonly done mechanically. The equipment used depends on the type of measurement being made. Depth and position in the vertical are measured by a rigid rod or by a sounding weight suspended from a cable. The cable is controlled either by a reel or by a handline.

Sounding equipment is described in the following categories: wading rods, sounding weights, sounding reels, and handlines.

Wading rods

The two types of wading rods commonly used are the top-setting rod and the round or ice rod. The top-setting rod is preferred because of the convenience in setting the meter at the proper depth and because the hydrographer can keep their hands dry. The round rod can be used where depths are greater and can be taken apart in one-foot lengths for storing.

Both the type-AA and Pygmy meters can be used with wading rods. The meter is attached to the sliding support using the set screw provided. The vertical axis of the meter should be aligned parallel to the rod to help in keeping vertical alignment in the water. The tail fin may be used to help keep the meter pointed into the flow and for balance.

The top-setting rod is placed in the stream so the base plate rests on the streambed, and the depth of water is read on the graduated main rod. When the setting rod is adjusted to read the depth of water, the meter is positioned automatically for the 0.6 depth method. When the water depth is divided by two and the setting is made, the meter is 0.2 up from the bottom or at the 0.8 observation depth. When the water depth is doubled and the setting is made, the meter is 0.8 up from the bottom or at the 0.2 observation depth. The latter two positions are referred to as the 0.2 and 0.8 depth method.

The round rod must be removed from the stream to set observation depths directly. The round rod may be used when depths are too great to wade but not more than about 8 feet and a boat or low bridge is available for the measurements.

Sounding weights and accessories

If a stream is too deep or too swift to wade, the current meter is suspended in the water from a boat, bridge, or cableway. A sounding weight is suspended below the current meter to keep it stationary in the water. The weight also prevents damage to the meter when the assembly is lowered to the streambed.

Sounding weights are streamlined to offer minimum resistance to flowing water. Each weight has a vertical slot and a drilled horizontal hole to accommodate a weight hanger and securing pin. The weight hanger has holes at different levels to properly position the meter depending on weight size and stream velocity.

Sounding reels

A sounding reel has a drum for winding the sounding cable, a crank and ratchet assembly for raising and lowering the weight or holding it in any desired position, and a depth indicator. Reels are available in several sizes to accommodate conditions. The A-pack reel is light, compact, and ideal for use at sites a considerable distance from the highway. It can be used on cableways, cranes, bridgeboards, and boat booms. The B-reel can handle all but the heaviest weights and can be used with a handcrank or power equipment. The E-reel is the largest of the reels commonly used for current-meter measurements. The E-reel will handle the heaviest sounding weights and is designed exclusively for use with power equipment. Different cable sizes are also available for different conditions and weight sizes.

Depth indicators

A computing depth indicator is used on the A, B, and E reels. The main dial is graduated in feet and tenths of a foot from 0 to 10 feet. The depth is indicated by a pointer. Tens of feet are read on a numbered inner dial through an aperture near the top of the main dial. The main dial has a spiral to indicate directly the 0.8-depth position. The 0.2-depth is set directly on the main dial.

Distance from the bottom of the weight to the center of the meter must be added to the depth observed on the reel depth indicator to obtain correct depths. Meter position is maintained by setting the depth indicator to zero when the meter is centered at water surface.

Handlines

Handlines are devices used for making discharge measurements from bridges using a 15- or 30-pound sounding weight. The advantages of the handline are that it is easily set up, that it eliminates the use of a sounding reel and supporting equipment, and that it reduces the difficulty in making measurements from bridges which have interfering members or no handrail. The disadvantages of the handline are that there is greater possibility of making errors in determining depth because of slippage of the handline or measuring scale or tape and that it requires more physical exertion especially in deep streams.

10.2.3.1.3 Calibration Procedures

The principal of operation of a rotating-element type velocity meter is based on the proportionality between the local flow velocity and the resulting angular velocity of the meter rotor. The velocity of the water is determined by counting the number of revolutions of the rotor during a measured interval of time and consulting the meter calibration table.

If an ideal current meter, that is, one equipped with a correctly shaped rotor and a frictionless bearing mechanism, were to measure the flow velocity of a perfect liquid, the relation between the flow velocity and the rotor speed would be very simple:

$$V=KN$$

where

V = local flow velocity,

K = a proportionality constant, and

N = rotor speed expressed in revolutions per unit time.

In actual practice there are resistances opposing rotation caused by friction between the liquid and the rotor and by the mechanical friction of the bearings. Consequently, this simple relationship does not exist, and one must be determined empirically. The establishment of this relation, known as "rating the current meter" was formerly done by the National Bureau of Standards. This procedure is now done by the U. S. Geological Survey at its Hydrologic Instrumentation Facility (HIF) in Mississippi.

The current-meter rating station operated by the HIF is similar to that operated by the National Bureau of Standards in Washington, D.C., and consists of a sheltered reinforced concrete basin 400 feet long, 6 feet wide, and 6 feet deep. Atop the vertical walls of the basin and extending its entire length are steel rails that carry an electrically driven rating car. This car is operated to move the current meter at a constant rate through the still water in the basin. Although the rate of travel can be can be accurately adjusted, the average velocity of the moving car is determined by making an independent measurement of the distance it travels during the time that the revolutions of the bucket wheel are electrically counted. A scale graduated in feet and tenths is used for this purpose.

A small Price meter is rated by towing it at eight different velocities (0.25, 0.50, 0.75, 1.10, 1.50, 2.20, 5.00, and 8.00 feet per second). A pair of runs are made at each velocity. A pair consists of two traverses of the basin, one in each direction. The data obtained consists of 16 observations of the velocity of the car (V) and revolutions per second of the rotor (N). The meter rating is determined from these data and is expressed as two linear equations:

For N less than 1.00,

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For N greater than 1.00,

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Where

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Because there is rigid control in the manufacture of the small Price meter, virtually identical meters are produced and, for all practical purposes their rating equations are identical.

Therefore there is no need to calibrate each meter individually. Instead, a standard rating is established by calibrating a large number of meters that have been constructed according to specifications, and the rating is then supplied with each meter.

To ensure that all small Price meters are virtually identical, dies and fixtures for their manufacture were purchased by the Water Resources Division and supplied to the manufacturer in 1967 for use in constructing meters. These same dies and fixtures will be supplied to the successful bidder in subsequent years. All rotors manufactured by the use of the standard dies and fixtures are stamped "S" on top of the bucket wheel along with the year of manufacture. To further ensure that all meters are identical, quality control procedures are followed, including the rating of a sample of meters from each new group procured.

For convenience in field use, the data from the current-meter ratings are reproduced in tables. The velocities corresponding to a range of 3-350 revolutions of the bucket wheel within a period of 40-70 seconds are listed in the tables. This range in revolution and time has been found to cover general field requirements. to provide the necessary information for the few instances where extensions are required, the equations of the rating table are shown in the spaces provided in the heading. Because of limited space, the equations are presented in an abbreviated form.

The expression V = 2.180R + 0.020 (2.200) V = 2.170R + 0.030 shown in the heading of Standard Rating No.1 is to be interpreted as follows:

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for velocities less than 2.200, or

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for velocities greater than 2.200

where:

V represents velocity in feet per second,

R represents the number of revolutions of the bucket wheel, and

T represents time in seconds observed for R.

The term within the parenthesis (2.200) is the velocity common to both equations.

Data do not indicate that there is any significant difference between a rod rating and a cable suspension rating when Columbus-type weights and hangers are properly used with the meter. Therefore no suspension coefficient is indicated, and none should be used.

10.2.3.1.4 Maintenance Procedures

To provide the proper care to a current meter, which is of extreme importance, each field person should become thoroughly familiar with all component parts as well as with the assembled meter. They should also be familiar with the steps outlined below, which are necessary to assemble or disassemble a meter.

Assembly

The procedure in assembling the small Price current meters may best be done in the following order:

1. Assemble the two vanes of the tailpiece and lock together with the locking lever.

2. Insert the tailpiece assembly, with balance weight underneath, into the yoke and tighten the tailpiece screw.

3. Place the bucket wheel onto the bucket-wheel hub with the side marked "S" upward, and with the dowel pin on the hub fitting the notch in the bucket-wheel frame. These parts are held together by means of the bucket-wheel hub nut.

4. Place the bucket-wheel assembly within the arms of the yoke and pass the shaft through the hole in the upper arm of the yoke. Screw the shaft directly into the bucket-wheel hub, then insert a pin into the hole in the shaft and use the pin to tighten the shaft hub.

5. Loosen the penta gear in the contact chamber by a **single** turn of the small screw that passes through the adjusting slot of the gear pad. **Do not remove this screw completely as it is difficult to replace.**

6. Slip the contact chamber, with the cap removed over the upper end of the shaft and into the hole in the upper limb of the yoke. This should be done with great care in order not to damage either the threaded shaft or the penta gear.

7. Align the contact chamber with the yoke by making the centerline of the yoke bisect the angle formed by the two contact binding posts. Some meters have been provided with grooved marks on the front of the contact chamber and on top of the upper yoke; making these marks coincide ensures the proper alignment.

8. Tighten the yoke set screw to hold the contact chamber in place.

9. Screw the cap onto the contact chamber.

10. Insert the pivot through the hole in the lower arm of the yoke after placing a drop of oil in the lower bearing and on the pivot.

11. Adjust the pivot as described in "Adjustment of pivot" below. This adjustment allows a vertical play of 0.008 inch, the amount of play used when the meter is rated.

12. Return the meter to an upright position, and remove the cap from the contact chamber. Adjust the penta gear to mesh properly with the threads on the shaft and tighten the small screw which holds the penta gear assembly.

13. Spin the bucket wheel rapidly while watching the action of the penta gear to make sure that there is complete freedom of action between the gear and the threads on the shaft. Then apply oil to the penta gear and to the three bearing surfaces (one drop on the vertical shaft and two on the horizontal shaft that supports the penta gear).

14. Adjust the contact wires so that these wires touch the edge of the single and penta eccentrics very lightly. Then replace the cap on the contact chamber and listen with a headset for a sharp click.

15. Place the assembled meter on a solid surface with the shaft vertical, and make a spin test as described in "Spin test" below.

Adjustment of pivot

Follow sequence exactly.

1. Make sure that the meter has been properly oiled; then hold meter in inverted position with pivot uppermost.

2. Release keeper screw for pivot adjusting nut and unscrew the nut a few turns.

3. Release pivot-keeper screw and advance pivot until all vertical play of the hub assembly is eliminated.

4. Tighten pivot-keeper screw temporarily and advance pivot adjusting nut until it touches the yoke.

5. Release pivot-keeper screw (not too far because the pivot should not revolve) and advance the pivot adjusting nut one-fourth turn. Tighten keeper screw.

6. Push the pivot inward as far as it will go and tighten bottom yoke set screw.

Disassembly

In general, the disassembly of small Price current meters offers no difficulties and hence it will not be described in detail. The following precautions, however, should be observed.

Removal of the contact chamber from the yoke should be done carefully and without exerting appreciable force, so that the penta gear and shaft will not be damaged.

The contact-chamber cap should never be unscrewed when the upper end of the shaft bears forcibly against its underside, a condition which exists if the bucket-wheel raising nut has been previously tightened, and if the pivot adjustment has been made so tight that there is no play between the end of the shaft and the underside of the cap.

When the bucket-raising nut has been tightened, the upper end of the shaft bears against the underside of the cap at a point that is about three-sixteenths of an inch "off center" with respect to the center of the cap. If these two parts are in contact with each other when the cap is loosened, a severe bending force occurs at the point where the upper end of the shaft emerges from the upper bearing. Lack of attention to this subject is a common cause for "bent shafts" on Price-type current meters.

When the bucket-wheel-and-hub assembly is raised from the pivot by means of the raising nut, the bucket wheel should always be held stationary and the raising nut should be turned by hand. The bucket wheel should never be spun with the raising nut held stationary, as this method may cause several excess turns which may result in the shaft becoming bent or the yoke becoming sprung.

Inspection and Repair

To make sure that the current meter is in good condition and is properly lubricated, the operator should examine it, both before and after each discharge measurement, with regard to the details under the heading immediately following. Because all meter parts are manufactured to be interchangeable without affecting the calibration of the meter, replacement of any of the component parts can be made in the field.

Rotor and shaft alignment

By spinning the bucket wheel slowly and then watching the metal frame to which the cups are fastened, eccentricity in the bucket-wheel-and-hub assembly may be readily detected. If eccentricity is observed while making this test, either the wheel or shaft is bent, and further tests should be made to find the source of eccentricity. The cap should be removed and the movement of the shaft inside the contact chamber should be observed. If, while the bucket wheel is rotating, any eccentricity in the top of the shaft is observed, the shaft should be removed from the assembly and should be further tested by observing its performance while rolling it on a clean flat surface. Any meter found to have a bent shaft should be repaired by replacing that shaft with a new one. If eccentricity is not found in the shaft, it may be present in the bucket wheel. Should the fault lie there, the rotor should be replaced with a new one.

Sprung yoke

The yoke may become sprung so that the distance between the upper and lower arms is too small or too great to permit proper adjustment of the rotor assembly within this space. It may also be distorted so that the coaxial holes will no longer properly align the rotor assembly and the pivot. If either of these conditions is suspected, the alignment and spacing should be checked with a special yoke alignment gauge that is available from the HIF. In addition to the above, the stem of the yoke (that part from the slot for the hanger to the end onto which the tailpiece fits) occasionally becomes bent. A bent stem causes the bucket wheel to assume a position that is out of proper alignment with flow lines of the water. If amount of distortion in the yoke is minor and can be properly straightened, this should be done; if not, the yoke should be replaced with a new one.

Damaged cups

The bucket wheel and cups have more influence on the meter rating than any other components. Cups should therefore be examined closely as any small distortion will cause a change in rating. Only for the most minor dents where the cups can be straightened to "like new" condition should repairs be attempted; otherwise the bucket wheel should be replaced with a new one.

Damaged tailpiece

The tailpiece should be examined for damage. It may be straightened if the damage in not too serious; otherwise it should be replaced with a new one.

Contact chamber

The contact chamber should be examined for proper meshing of the penta gear with the acme thread on the shaft and for proper adjustment of contact wires. Proper adjustment of these parts should be maintained at all times. It should also be inspected for excessive wear of the upper bearing. Any missing or damaged parts such as screws, chamber cap, or binding posts should be replaced. Should the need arise, the entire contact chamber may be replaced with a new one.

Pivot and bearings

The pivot should be examined with a magnifying glass to see whether the point is fractured, rough, or worn flat at the apex. The point of a new pivot is rounded to a radius of approximately 0.005 inch; wear resulting in a radius greater than 0.010 inch is excessive. If any of these conditions exist, the pivot should be replaced with a new one.

To examine the pivot bearing conveniently, the contact chamber should be removed carefully and the bucket-wheel-and-hub assembly should be tilted to one side so that the lower arm of the yoke will not obstruct examination. The pivot bearing should then be examined for possible fracture, pits, or roughness. If any of the above are found, the entire hub assembly should be replaced with one containing a new pivot bearing.

No current meter should be packed or transported with the pivot bearing resting on the pivot. The pivot and pivot bearing should always be separated by the raising nut.

Cleaning and Lubrication

All bearing surfaces should be inspected to see that they have a thin coating of instrument oil. The small Price current meter has bearing surfaces above the bucket wheel in addition to the pivot bearing. These consist of (1) the bearing surfaces between the penta gear and the acme threads on the shaft, (2) the cylindrical bearing of the shaft of the penta gear, (3) the cylindrical bearing of the shaft within the bearing lug, and (4) the thrust bearing between the shaft and the cap.

At the end of each day's use, the meter should be thoroughly cleaned and oiled. The pivot and pivot bearing need special attention; unlike all other parts of the meter they are subject to rusting and, therefore, it is desirable that they be dried before they are oiled.

The outline below gives a step-by-step process for the cleaning and oiling of current meters. The following supplies are required for this purpose: Large soft cloth for absorbing water and wiping the outer surfaces of the meter, cotton-tipped swabs for cleaning the bearing surfaces, and a supply of instrument oil.

1. Dismantle the current meter as follows:

    A. Release the raising nut.

    B. Release the two set screws in the yoke, holding the contact chamber and the pivot in place with forefinger and thumb.

    C. Remove the contact chamber from the yoke slowly and carefully. Do not remove the cap at this time.

    D. Remove the pivot from the yoke.

2. Clean the parts as follows:

    A. Clean and dry the air pocket and the pivot bearing, using a cotton-tipped swab; Inspect the pivot bearing.

    B. Swab the pivot hole with a cotton-tipped swab.

    C. Clean and dry the shaft--particularly the acme threads.

    D. Wipe the pivot until it is thoroughly dry.

    E. Remove the cap and shake out any water that may be trapped within the contact chamber. Occasionally, clean the chamber thoroughly by allowing hot water to flow into it under pressure. A jet of water such as that issuing from a hot-water tap is recommended. Hoppe's powder solvent has been used successfully to remove gummed oil if cleaning with hot water is not successful.

F. Wipe the interior of the stem of the contact chamber.

G. Swab the hole in the bearing lug by means of a cotton tipped swab inserted through the stem of the contact chamber. Cleaning the hole in the bearing lug **from the top** frequently causes the contact wires to bend and eventually break, whereas cleaning it **from the bottom** neither bends the wires nor affects their adjustment.

3. Oil as follows:

A. Apply a thin film of oil to (1) the acme threads (liberally, so that the excess oil will later spread over the penta gear and the penta shaft), (2) the area that enters the bearing lug, and (3) the uppermost end of the shaft.

B. Apply a drop of oil to the sides of the hole through which the pivot passes.

C. Apply a thin film of oil to the pivot.

4. Reassemble as follows:

A. Replace the pivot and tighten the set screw that holds it in place. Make sure that the pivot lock nut bears against the yoke, and that the set screw bears against the flattened part of the pivot.

B. Fit the contact chamber over the end of the shaft and into its hole in the upper arm of the yoke. Do this slowly and carefully without much force, otherwise the penta gear or shaft may become damaged.

C. Align the contact chamber on the yoke, and tighten the set screw holding the contact chamber in place.

D. Check the contact wires. The adjustment of both the single- and penta-contact wires should be examined to be sure that the adjustments are as light as possible without impairing the electrical contact.

E. Replace the cap on the contact chamber.

F. Move the bucket-wheel-and-hub assembly up and down to determine whether the pivot adjustment is correct.

G. Check the operation of the current meter with a spin test.

H. Unless the current meter is to be used immediately, raise the pivot bearing off the pivot by means of the bucket-raising nut.

Spin Test

The meter should be placed so that the bucket wheel is in a vertical position and protected from air currents. The bucket wheel is then given a quick turn by hand to start it spinning. The spin time is checked by stopwatch. Spin time for the Price AA should be approximately 4 minutes and in no case less than 1.5 minutes. The spin is carefully observed as it nears the stop point to see if stop is gradual or abrupt. If stop is abrupt, the cause must be found and corrected before the meter is used. A spin test log should be maintained for each meter and spin test times should be posted on the discharge measurement notes.

For the Pygmy Current Meter, the duration of the spin test should be approximately 1.5 minutes and in no case less than half a minute.

For the Low-velocity Price meter, the duration of a normal spin should be 4.5 to 5 minutes and in no case less than 2.5 minutes. This meter is factory calibrated and a velocity rating is provided.

10.3 Instrumentation -- Electromagnetic Current Meter

10.3.1 Principle of Operation

This meter is a point or local velocity meter. It measures the velocity near the meter by indexing the amount of magnetic field disturbance to water movement. The meter is used mainly in culverts. It is placed in a position which is most representative of the mean velocity in the cross section area.

10.3.2 Maintenance

Maintenance requirements vary with the instrument and sensor type used. Specific maintenance will be discussed within the individual instrument and sensor section. In general, the instrument or electronics interface will be maintained the same as any other electronics device used in the field. The only field maintenance required is for the sensor which is submerged. The sensor should be kept clear of conductive obstructions such as steel structures and braces, or confined inside steel pipes. Conductive objects interfere with the magnetic field produced by the sensor. Additionally the sensor electrodes should be kept clear of any non-conductive material that may shield an electrode from the liquid medium it is measuring. Shielding materials include oil, biological growth and debris that may float around the sensor such as paper, plastic or large plant leaves. The sensor should be inspected routinely for evidence of any of the above problems.

10.3.3 Sensors Used

10.3.3.1 Marsh-McBirney Model 201D

The Marsh-McBirney flow meters are currently used to measure water velocities. Equipped with a digital readout, the model #201D flow meter measures the velocity of a conductive fluid, such as water, using an electromagnetic sensor. Marsh-McBirney electromagnetic sensors have an accuracy of ± 2 percent of the reading(i.e.: ± 0.02 fps for 1 fps flow). The Marsh-McBirney electromagnetic flow meter is calibrated by the manufacturer prior to shipment. The 0 to 2 Volts output corresponds to a range of 0 to 20 feet per second water velocity. The readings produced by the Marsh-McBirney sensor can be checked by using an accurate portable flow meter.

The flow meter measures water velocity using the Faraday principle which states that as a conductor moves through and cuts the lines of magnetic flux, a voltage is produced. The magnitude of the generated voltage is directly proportional to the velocity at which the conductor moves through the magnetic field. The 201D sensor is equipped with an electromagnetic coil that produces the magnetic field and a pair of electrodes that measure the voltage produced by the velocity of the water.

For canals and rivers in southern Florida, velocities will typically be between 0 and 3 fps. Negative velocities may be recorded at locks and some gates. Higher velocities will be recorded at control structures because the channel is typically narrower at such structures. Flow velocities can change more rapidly near structures due to gate and pump operations. Negative velocities occur when the flow direction changes such as when excessive pumping occurs upstream or when wind forces water to one side of a large water body.

Rapid fluctuations in the readings might indicate poor wire connections, weak power supply, wave action, poor installation or even debris wrapped around the sensor. Long trends (e.g. month) of increasing or decreasing readings should be easier to explain than rapid changes in the readings. The point source velocity measurement may not produce an accurate stream flow rate, but can be used as a indicator of other environmental conditions such as rainfall, gate openings and pump operations.

10.3.3.1.1 Manufacturer's Specifications

VELOCITY MEASUREMENT:

Method: Electromagnetic (Faraday principle)

Range: Meter Dial -0.5 to + 10 ft/sect
Digital -0.5 to +20 ft/sec

Zero Suitability: ±0.05 ft/sec

Accuracy: ± 2 % of reading

OUTPUTS:

Meter Dial: Switch-selectable ranges of 2.5 (75), 2 (150), and 10 (300), ft (cm) per sec

Digital: Three one-half digit display in feet, meters per sec or knots;

Input/Output: Connector provides 0.1V per 1 ft/sec input power +8 to +12 VDC @ 40 mA avg

MATERIALS:

Sensor: Polyurethane exposed to flow

Sensor Cable: Twinax polyurethane outer jacket exposed to flow

Meter Enclosure: Dustproof polyurethane foam

ENVIRONMENTAL CONDITIONS:

Sensor: Flow temperature range 32°F to 160°F (0°C to 65°C)

Meter Enclosure Temperature limits 30°F to 112°F (-1°C to +40°C)

POWER REQUIREMENTS:

Batteries: Six D cells provide 100 hrs continuous operation

External: Requires +8 to +12 VDC @ ±40 mA avg (optional)

10.3.3.1.2 Installation Procedures

The water velocity meter consists of an electromagnetic probe and a meter equipped with a display. The sensor is securely installed beneath the water surface where the sensor is free from debris accumulation or damage. The sensor produces a 0 to 2 Volt output signal read by the data logger and converted to a velocity reading. The installation criteria for the sensor are described below.

Install the sensor in the stream or channel where the water is flowing, free from obstructions, and the cross sectional area is known. Avoid areas of unpredictable flow such as behind a structure, around pilings, and near flow boundaries. The sensor should be placed at about two thirds of the average water depth below the surface to ensure a representative velocity reading. Surface water may have higher or lower velocities than the overall channel cross section. Areas of water near the shore and near the channel bottom will have velocities lower than the cross sectional average.

A simple way to satisfy the above criteria is to mount the sensor on a small rod which can be mounted to a platform or fixed structure over the water surface. With the sensor fixed to a rod, the depth of the sensor can be changed easily and is precisely known. Orient the sensor so the electrodes (round end of sensor) face the flow of water.

The mounting of the probe must allow easy access for calibration checks and cleaning. A platform extending from the shore facilitates easy access and also provides an adequate mounting surface.

Wiring:

The power-in/signal-out connector has six connections. With the top terminal labeled 'A' and proceeding clockwise to terminal 'F', the connections are described below.

A Not connected

B Positive 9 Volts DC (+8 to +12 Volts)

C Negative 9 Volts DC

D Not connected

E Output Signal (Signal not reference to negative supply)

F Signal Ground for recorder (Do not connect to negative supply)

NOTE: To prevent panel meter over-ranging, do not turn the unit on with the sensor disconnected, or turn the selector switch past the CAL position with the sensor out of the water.

10.3.3.1.3 Calibration Procedures

The calibration check is performed using a portable water velocity meter of known calibration and performance. A new Marsh-McBirney flow meter would be appropriate.

1. Locate the existing flow sensor mounted at the site. Verify that the sensor is in working order and free from debris or other interference. Check all cable connections and other electrical connections. To test for electronics failure or low battery, move the selector switch to the CAL position and the time constant switch to 2. After approximately ten seconds, the readout should be between 9.8 and 10.2.

2. Temporarily install the portable flow meter sensor within two feet of the existing flow sensor and in a stable position. This will limit the measured flow differences due to the velocity profile of the channel.

3. With the Easy Logger display or comparable display attached to the data logger, note the water velocity readings and compare them to those of the portable meter. Make several comparisons and develop an average velocity reading over a period of time, because instantaneous velocity measurements can be affected by eddies and other small scale water currents.

4. The installed sensor and the calibration water velocity sensor should produce similar readings ± 0.1 fps. If this criterion is not met, the installed sensor should be replaced and returned to the manufacturer for recalibration.

10.3.3.1.4 Maintenance Procedures

Routine maintenance of the sensor unit involves cleaning the sensor with clean water or a mild soap to keep the carbon electrodes free of nonconductive grease or oils. Do not use hydrocarbon solvents on the sensor. The sensor must be kept free of algae or debris for accurate readings. Check the internal wiring of the meter using the calibration check built into the electronics.

10.4 Instrumentation -- Acoustic Velocity Meters

10.4.1 Principle of Operation

An acoustic velocity meter (AVM) measures the velocity of flowing water by means of a sonic or ultrasonic signal that moves faster downstream that upstream. An AVM system is useful in determining discharge at streamflow gauging sites where the relationship between discharge and stage varies with time because of variable backwater conditions resulting from the operation of gates, dams and locks and also from the influence of tides and winds. The AVM is also useful for measuring discharge in extremely slow-flowing waters and in very large rivers. An AVM system supplies a measurement of line velocity along an acoustic path that can be related to the mean velocity of the stream and hence to the discharge.

AVM systems operate on the principle that point-to-point travel time of sound is longer upstream than downstream and that travel times can accurately be measured by electronic devices. An AVM measures the time it takes a transmitted sonic or ultrasonic pulse to travel from one transducer to another with and against the streamflow. The line between the two transducers is called the acoustic path. Because both forward and reverse times are necessary to compute velocity, transducers must be placed on a diagonal to the streamlines of flow. The angle of the acoustic path is critical and affects the system resolution and performance. AVM systems normally operate with acoustic path angles of 30 to 45 degrees.

When a sound pulse is transmitted downstream along a diagonal path, the pulse travel time is computed as the path distance (B) divided by the sum of the speed of sound (C) and the velocity of the water along the acoustic path (V_p). Similarly, the travel time in the upstream direction is computed using a negative stream velocity component. Using the two equations, the path velocity is solved in terms of travel times. Stream velocity is then resolved into line velocity (V_l) by applying the cosine of the angle between the acoustic path and the streamlines of the flow.

Mean velocity is related to the AVM line velocity as a function of many variables including stage, wind, tides, bed roughness, aquatic biota and the magnitude of the line velocity itself. Discharge at the stream gauging site is computed as a function of the mean velocity and cross-sectional area.

AVM systems range from a simple velocity meter to complex computerized systems that compute and transmit real-time discharges. At some sites, a single-signal path is adequate whereas at others, multiple signal paths are required.

The accuracy and performance of AVM systems are limited by various factors, the most important four of which are the:

- location of the acoustic path with respect to the water surface and the streambed, which provide reflective surfaces for multi-path interference;

- density gradients (usually caused by different temperatures or salinities) which cause the acoustic path to bend (refraction);

- concentrations of sediment, air bubbles, organic materials and organisms, all of which attenuate the acoustic signal; and

- streamflow variability, which causes the angle between the acoustic path and the flow streamlines to change. For many streamflow situations, single-path AVM systems can attain an accuracy of 3 percent whereas multiple-path systems can obtain an accuracy to within 1 percent.

AVM system error can be attributed to three sources:

- Timing error as defined by the resolution of travel time which can range from +/- 0.03 m/s to +/- 0.1 m/s depending on whether or not a signal-quality check is employed.

- Angularity error as defined by the orientation of the streamflow to the acoustic path. For every degree of uncertainty in path angle, there is approximately a 1-percent uncertainty in velocity measurement.

- Deflection error as defined by acoustic ray bending. For paths less that 300 m, the error is usually less than 3 percent.

The acoustic path must be analyzed for multi-path interference. For every 100 m of acoustic path, approximately 1 m of depth is required to prevent multi-path interference. The acoustic path should be at least one-half meter below the water surface in slow-moving water to prevent the signal from bending due to solar heating. Situations where the acoustic signal is bent so drastically that it reflects from either the water surface of the streambed or both should be avoided.

The acoustic path must also be analyzed for signal attenuation. The normal sediment concentration that can safely be tolerated by most AVM systems is approximately 2,000 mg/l, but this is dependent on system frequency, particle size, and path length. Situations where air entrainment can be a problem should be avoided.

10.4.2 Maintenance

AVM systems are relatively sophisticated electronic devices and as such require that specially trained personnel be available for equipment operation and maintenance. AVM systems require in-house expertise in setting up and working with electronic probes, servo systems, minicomputer and microcomputer systems, and data loggers. Proper test equipment and spare parts are necessary to achieve minimal downtime. Error (or fault indications) are normally displayed in most AVM systems. When operation is relatively fault-free, then yearly examinations will be adequate to ensure proper system performance. Procedures specified by the manufacturer in the operation and maintenance manual should be followed. Newer microprocessor systems have diagnostic messages to help identify system failures, including power supply losses, signal losses due to obstruction of transducers by deposited silt or debris and due to other causes, and microprocessor errors. An oscilloscope may be necessary sometimes to view received pulses in order to determine signal degeneration and observe trigger-level operation. Manufacturers will usually provide trouble-shooting procedures.

All data retrieved from the AVM system should be inspected as soon as possible after collection to detect spurious data or determine whether periods of malfunction have occurred. The AVM site should be visited regularly. The interval between visits should be consistent with the period for which loss of data is acceptable to the user.

In the course of routine visits, the following procedure should be observed:

1. Note the malfunction of any signal path, as indicated by the built-in self-check facilities;

2. Check the sonic pulse travel times; these should be compared with the expected values for the current temperature;

3. Note the proportion of successful to unsuccessful determinations of signal timings;

4. Compare water depth recorded by the AVM system against that indicated by an independent determination (e.g. staff gauge);

5. Check the individual water velocities for each acoustic path, noting their relative consistency;

6. Note the variability between successive velocity determinations, each averaged over a short period of time (e.g. 1 min.); excessive variability (e.g. +/-20 percent) almost certainly indicates an equipment fault.

In the absence of any indication of malfunction, detailed inspections of the equipment to identify deterioration should be made at intervals not exceeding six months. Ideally, such inspections should be scheduled to coincide with period of extreme water stage, flow or weed-growth. The inspection should include a visual check of the transducers, and of the amount of weeds or debris which might obstruct the sonic signals in the river.

10.4.3 Sensors Used

10.4.3.1 EG&G Smart Acoustic Current Meter

The ACM is manufactured by EG&G Marine Instruments. It is designed to be deployed in the ocean for oceanographic applications, and has been adopted for stream gaging applications. It can measure water speed, direction and temperature at rates of up to two sets of measurements per second, using acoustic measurement techniques. Sampling rate, sampling schedule, and data averaging method may be defined and programmed by the user. Figure 10.1 illustrates the typical configuration for Model SACM-3.

10.4.3.1.1 Manufacturer's Specifications

Water Velocity:

Range:	0-360 cm/sec (0-11.8 fps)
Resolution:	0.1 cm/sec (0.003 fps)
Accuracy:	± 1 cm/sec (0.03 fps)
Response:	0.2 sec

Compass:

Range:	0-360 degrees
Accuracy:	± 5 degrees
Response:	0.2 sec

Temperature:

Range:	-2 to 35 degrees C
Accuracy:	± 0.05 degrees C
Response:	1 minute

Miscellaneous:

Clock:	Real or elapsed time with delayed start. User selectable.
Data Storage:	Main board has 512K bytes of battery backed Solid-state storage.

Communication: RS-232 (1200 -> 57,600 baud)

Mechanical Dimensions:

Overall Length:	29.0" (737mm) without frame, 39.8"(1011mm) with frame
Maximum Diameter:	4.9" (125 mm) instrument only; 10.87 (276 mm) with frame

Materials:

Housing:	Glass filament-wound reinforced epoxy.
Endcaps:	316 stainless
Sensor Pedestal:	Type 316 stainless steel
In-line Mooring Frame:	Type 316 stainless steel

Maximum In-line Tension: Rated at 4,000 lbs (1,800 kg).

Yield begins at 6,000-8,000 lbs (2700-3600 kg)

Ultimate failure at 16,000 lbs (7,200 kg)

Weight: 35 lbs in air (with frame and batteries)

Options Available:

- Pressure
- Conductivity
- FSK communication/power link
- SALL communications/power link
- In-situ Data Processing
- Conditional threshold sampling

10.4.3.1.2 Installation Procedures

The following equipment is required to operate ACM for stream gaging:

Portable field computer, with auxiliary battery packs, or with DC/AC converter, for charging the computer battery in field operation;

Acoustic Current Meter (Factory-calibrated, ready to use);
12V DC power (such as the 6.5 AHr. pack), for supplying the ACM;

Connection box with the signal cable (black), and the power cable (gray);

Sounding reel; other equipment to position the ACM, such as a bridge apparatus.

1. Connecting the Instrument

   A Check the power switch on the connection box, make sure it is 'OFF';

   B. Connect the connection box with the computer;

   C Connect the connection box with the ACM; **NOTE**: Pull out the dummy cable plug; **DO NOT TWIST THE PLUG! JUST PULL IT OUT GRADUALLY!**

   D. Connect the connection box with the battery;

   E. Make sure the connection switch on the connection box is 'ON'.

2. Operating

   A. Turn on the power switch;

   B. On the computer, change directory to EG&G (non-case sensitive);

   C. Type: ACM, and hit ENTER;

   D. Use arrow key '->' to move to option 'ONLINE';

   E. Select 'REALTIME' from the 'ONLINE' menu;

   F. Select 'NO' for not capturing the data file;

   G. After seeing the settings displayed at the right hand side of the screen, turn the connection switch 'OFF';

Figure 10.1 A Typical Configuration for SACM-3

H. Now the ACM is working automatically to collect the data. It will collect data at the given position. (you can just sit back and take a break for about one minute);

I. After seeing the data displayed in the MODE 1 window, write down the data for VelN and VelE. This is the flow velocity data at the given location. The data interpretation will be discussed in the next section;

J. Turn the connection switch 'ON';

K. Move the ACM to next measuring point;

L. When ready to measure, turn the connection switch 'OFF';

M. Repeat step 8 through step 12, until all data are collected;

N. Turn the power switch 'OFF', and exit the program by pressing the 'ESC' key, and follow the menu to exit to DOS.

3. Data Interpretation

A. Calculate the magnitude of the velocity at point N by using the f
o
l
l
owing equation:

Install Equation Editor and double-click here to view equation.

where $VelN_N$ and $VelE_N$ are the data recorded at point N.

B. When the compass reading COMP equals 0º, the arrow mark on top on the ACM is pointing at magnetic north.

C. The flow direction reading DIR (see command Cal, S in next section) has the following indications:

DIR = 0°, the flow is towards NORTH;
DIR = 180°, the flow is towards SOUTH;
DIR = 270°, the flow is towards WEST;
DIR = 90°, the flow is towards EAST;

D. At real-time display (see next section, paragraph 2), VelN > 0, means the flow component is moving towards North;

VelN < 0, means the flow component is moving towards South;

VelE > 0, means the flow component is moving towards East;

VelE < 0, means the flow component is moving towards West.

E. Compass reading DIR does not affect the flow direction.

4. Other Features

A. Command STAT, used to show the instrument status. Use under the prompt: xxxxxACM> .

B. Command CAL, and selection S, used for real-time display. For our instrument, only the reading VelN, VelE, (or Speed, Dir, when Speed option is chosen, see next paragraph), Temp(temperature reading), and Comp(compass reading) is valid, ignore the other readings.

C. In order to see the real-time display of speed and flow direction, type: speed on, under xxxxxACM prompt.

10.4.3.1.3 Calibration Procedures

Towing Tank Test

This requires special facilities and personnel. It is recommended to have the meter tested once a year at the United States Geological Survey, Hydrologic Instrument Facility.

Electrical Calibration

For our case, only the velocity and temperature sensors need to be calibrated. From manufacturer's experience, these two sensors generally will remain accurate for at least two years. A detailed electrical calibration procedure for these sensors is beyond this guideline (refer to manufacturer's manual).

10.4.3.1.4 Maintenance

1. Verify mechanical integrity and operation of the instrument. Check for tightness of jam nut on Crouse-Hinds underwater pluggable connector on top end-cap.

2. Replace zinc anodes as necessary.

3. Inspect, clean or replace, and replace with correct replacements parts as required.

4. Inspect all external hardware and replace with correct replacements parts as required.

5. Inspect fiber-wound epoxy housing for any signs of serious deterioration.

10.4.3.2 Direct Reading Broadband Acoustic Doppler Current Profiler (ADCP)

The ADCP is an acoustic current meter that uses the Doppler effect to measure the motion of the water. The Doppler effect refers to the shift in frequency of the transmitted sonar signal caused by the relative motion between the ADCP and the scattered material in the water column. The difference between the ADCP and conventional current meters is the ADCP's ability to measure a profile of the water column.

ADCP measures water velocity, velocity relative to the river bed, water depth, and echo intensity. Water velocity is measured in a series of equal-thickness layers called depth cells. Due to the transducer immersion and blanking, water velocity near the water surface is not computed. Water velocities near-shore and near the river bottom are not computed because of side-lobe interference and transmitter processing.

Two types of ADCPs are available. The Narrow Band (NBADCP) and the Broad Band (BBADCP). A Narrow Band ADCP transmits a single long tone burst of duration T_p, and the returned signal is compared to itself at a specified time lag, T_L. Instead of one long pulse, the BBADCP transmits a series of short pulses. This allows the separation of pulse width and lag. Therefore, longer lags can be chosen and velocity measurement is more reliable. The following sections concern the BBADCP only.

10.4.3.2.1 Manufacturer's Specifications

Broad Band ADCPs used for river measurements are part of a large family of ADCPs used in oceanographic, speed log, and other applications. While all the Broad Bands have the same fundamental measurement capabilities, river Broad Bands have been specifically adapted to the requirements of river measurements. The complete line of Broad Bands include six frequencies (75, 150, 300, 600, 1200, and 2400 kHz)for different ranges and resolutions. Lower frequencies produce greater range whereas higher frequencies produce finer resolution. The precision of the ADCP relative to system frequency is summarized in Table 10.1. The following specifications are common to all six standard frequencies.

Velocity range: ± 20 m/s (65.6 feet/second)

Velocity accuracy: ± 0.2% ± 0.20 cm/s (0.007 feet/second)

Number of depth cells: 1 to 128

Depth cell size: 0.12 to 32 m (0.40 to 105 feet)

Temperature(operating): -5 to 60°c (23 to 140°F)

Temperature(storage): -50 to 80°c (-58 to 176°F)

Discharge accuracy: ± 2% (for rivers with an average depth less than ten times the smallest depth cell size)

Loss of profiling range near a boundary:

- 30° beam angle: 13.4% of range to boundary + one depth cell
- 20° beam angle: 6% of range to boundary + one depth cell

10.4.3.2.2 Installation Procedures

Deployment possibilities of the ADCP include: ships, small boats, radio-controlled boats and bridges. A river Broad Band can be installed in a well, on the bow, or on the side of a boat. Mounting the Broad Band on the bow will usually allow it to get closer to shore. The transducer should be deep enough to ensure that bubbles do not get under the transducer face when the boat is underway. This depth depends on the speed of the boat and the condition of the water surface, but it is reported that 0.20-0.50 m has worked successfully in the past. The flux-gate compass mounted in the transducer module should be kept as far as possible from ferromagnetic metals such as the boat engine.

Depth cell size(m)	System Frequency (kHz)					
	75	150	300	600	1200	2400

0.12	-	-	-	-	-	4
0.25	-	-	-	-	10	3
0.50	-	-	-	10	4	1
1	-	-	10	4	2	1
2	-	10	4	2	1	-
4	15	4	2	1	-	-
8	5	2	1	-	-	-
16	3	1	-	-	-	-

Table 10.1 BBADCP's Precision (cm/s) Relative to System Frequency

10.4.3.2.3 Calibration Procedures

The purpose of the calibration is to ensure that the instrument is working properly and systematic errors associate with ADCP's biases are maintained within acceptable limits. It is recommended to calibrate the ADCP once a year. The ADCP calibration can be done either by RD Instruments, the ADCP's manufacturer, or the USGS Hydrologic Instrumentation Facility in Mississippi. Users cannot adjust or otherwise affect measurement calibration other than post-calibration for sound speed variation and for flow estimation in the missing parts of the velocity profile. However, it is recommended that the users check the performance and the reliability of the instrument, particularly when it is received for the first time, before each deployment or every six months, or when problems are suspected. Two types of tests are recommended by the manufacturer: Modular ADCP tests and practice deployment for testing.

The modular ADCP tests diagnose thoroughly the ADCP instrument, using direct commands with a dumb terminal or emulator program such as BBTALK.EXE, provided by the manufacturer. These tests include: primary test setup, internal diagnostics tests, internal sensors tests, and external sensors tests.

The practice deployment consists of placing ADCP on a laboratory bench or a tank filled with circulating water and have it transmit data for an extended period of time. The purpose of the practice deployment is to confirm that the pre-established setup can indeed collect the expected data. The practice deployment for testing is run before each deployment.
It is good practice to check the reliability of the instrument when ADCP is received for the first time. Concurrent deployment of ADCP and other conventional current meters can help achieve that objective. Both discharges and velocity profiles obtained from the ADCP deployments are compared to those obtained from the other current meters. Also, concurrent deployments of ADCP,

Price AA meter and ACM can help evaluate the approaches used by the manufacturer to estimate velocities in the missing parts of the velocity profiles.

The same way, the ADCP limitations regarding canal size, environmental factors (salinity and temperature gradient) can be evaluated. Appropriate strategies should be developed to evaluate random uncertainties and systematic errors. Random uncertainties are due to the instrument's inability to accurately measure the vessel velocity, the depth of the subsections, and to the estimation of the depth-weighted mean velocity cross products. Random uncertainties can be substantially reduced by increasing the number of independent measurements averaged together in every depth cell.

Systematic errors due to the ADCP biases, are significant because they cannot be reduced by averaging. The approach used to estimate velocities in the missing parts of the velocity profile, improper beam profiler geometry, mispositioning of receiver tracking filters, profiler transmit-filter skew, etc., are major sources of systematic errors. These biases can be evaluated using other conventional current meters along with the ADCP.

10.4.3.2.4 Maintenance Procedures

ADCP is a very complex instrument. To reduced the risk of being damaged, its maintenance as well as its operation should be done by trained or experience personnel. The instrument preparation, maintenance, and repair procedures are described with great details in the technical manual provided by the manufacturer. This section provides information only on the physical recovery of the ADCP and the required initial maintenance.

Cleaning the BBADCP Exterior

After the physical deployment of the ADCP and before processing with any other action, the ADCP should be rinsed with fresh, soapy water to remove soft-bodied marine growth. This also helps prevent the formation of salt crystals. Foreign materials from the transducer faces should be removed as soon as possible. Some critical areas, such as the pressure case flange, the transducer assembly, and the I/O cable connector. The ADCP exterior has to be dried with low-pressure compressed air or soft lint-free towels.

Removing the I/O Cable

Unless proper precautions are taken, water can drip into the connector when the cable is removed. Water within the connector can cause corrosion or break down the connector's dialectic. Before removing the cable, one must be sure that the ADCP exterior is dry. It is important that the ADCP be laid on its side on some protective padding so the I/O connector end of the ADCP points down. The protective dummy plug on the ADCP's I/O connector, should be carefully installed in such a way to avoid any damage of the connector pins.

Removing the Pressure Case

Removing the pressure case is not necessary, but it can be done if performing an interior inspection of the ADCP is desired.

10.4.3.3 Ultrasonic Velocity Meter

This standard operating procedure provides a standardization and documentation to estimate discharge records. Guidelines are provided for UVM sites inspections, discharge measurements, data collection, data analysis and miscellaneous maintenance procedures for UVMs.

10.4.3.3.1 Documentation

Maintain a supply of inspection sheets (Table 10.2) at the gauge house to document UVM operations, thereby providing a record of activities related to UVM installation, calibration and maintenance. The inspection sheet will comprise location and structure information such as culverts, weirs, pumps, etc. During each site visit all problems or activities, such as equipment changes, observations, malfunctioning of equipment, culvert stop log elevation, and inflow pump discharge, should be noted in the inspection sheet. The inspection sheet should be taken back to the office for review by a Civil Engineer. The information on the sheet should then be filed into the current year record in a hydrologic database.

10.4.3.3.2 Gauge Inspections

1. During each site visit the following observations should be made and reported on the inspection sheet :

   A. Time of inspection

   B. Outside gauge reading

   C. Datalogger reading

   D. Tape pointer, if shaft encoder is used to obtain stage
   E. Battery voltage

   F. Stop log elevation for culverts

   G. Inflow pump discharge

   H Outflow pump discharge

I. State of solar panels, junction boxes, culvert platforms and open channel walkways.

The above information should be reported at least once on the inspection sheet (Table 10.2) during a routine inspection. In the event that discharge measurements are made, the information related to discharge estimations should be reported before and after the measurement.

2. Every quarter, the UVM program memory should be checked against a master listing which will be kept in the gauge house. The program deals with characteristics of the UVM such as path lengths, path angles, signal delays, and number of measurements. The thresholds for these parameters will be established after UVM installation and calibration.

3. On annual basis two data acquisition should be done manually as described in the UVM operations Manual, section 5 (Scott Gain, 1993). All the acceptance limits of the data acquisition will be made available in the UVM operations Manual at the gauging site or at the office.

4. Before data collected by the UVM are downloaded on a PC, stage and velocity data should be carefully checked to ensure that the readings are reasonable. If abnormalities in the data are found they must be immediately corrected (with 24-hour period if possible). These abnormalities will be determined by comparison of the new data to the historical record of the data available for that UVM site.

10.4.3.3.3 Routine Discharge measurements

After a pre-defined number of discharge measurements are used to define the original UVM rating, three additional measurements should be collected to check the reliability of that rating on a yearly basis. The number of data points necessary for the original rating depends on the stage ranges to be expected at the site. The larger the range, the more data are needed to define the original UVM rating and vice versa. The three yearly measurements should be done with a Price AA meter for flows higher than 0.25 fps. Velocities lower that 0.25 fps should be measured with the ACM (Acoustic Current Meter) or the ADCP (Acoustic Doppler Current Profiler) if they are available.
The following procedures suggested by the USGS, shall be followed when discharge data are collected at UVM sites:

1. Read and record stage data from staff gauges, inside gauges and datalogger for both culverts and open channel UVM sites.

2. Download data into PC.

3. Change UVM measurement interval to 5-minute from 15-minute interval.

4. Make discharge measurement

5. Re-perform task step 1 after measurement.

6. Download 5-minute data that were recorded during measurement.

7. Reset UVM to 15-minute measurement interval

8. Make one manual data acquisition to ensure that the UVM is working properly (see section 5 UVM Operations Manual).

Detail information on how to perform these tasks will be available at the UVM site or at the office (in the UVM user manual). The above tasks should be performed by an engineer, if possible.

Time of Inspection	Outside Gauge Reading (ft)	Datalogger Reading	Shaft Encoder Tape Pointer	Battery Voltage (V)	Stop Log Elevation (ft)	Inflow Pump Discharge (cfs)	Outflow Pump Discharge (cfs)	Site Condition

Table 10.2 UVM Site Inspection Sheet

10.4.3.3.4 Calibration Discharge measurements

When discharge measurements are made for calibration purposes, stage and UVM velocity shall be collected every 2 minutes. This procedure will increase the accuracy of data required for calibration. Therefore the data obtained through calibration will be closer to real-time data. The average of all UVM velocities and stages measured during one discharge measurement will define the UVM line-velocity and stage data for that measurement. The ratio of the average velocity obtained from measurement and the average of UVM line-velocity is equal to the velocity correction factor K for that measurement. By performing several discharge measurements, and several UVM velocities and stages, it becomes possible to establish the function K = K(stage) and A= A(stage), where A is the channel cross-sectional area. Once these two functions are established for a given stage value h, the discharge Q (h) can be obtained by $Q(h) = K(h) V_{uvm} A(h)$, in which V_{uvm} is the average of all the UVM velocities collected during the discharge measurement.

10.4.3.3.5 Routine Maintenance

1. Transducers should be inspected at least once a year or more frequently if aquatic plant growth is a problem. This inspection is done by removing the transducer out of the water and by visually examining it to see if they are debris attached to it.

2. Check voltage on the memory circuit board annually (voltage should be about 12 volts).

3. Run levels at the time of installation to verify the position of various devices. Run levels again one year later and every three years thereafter. Deviations should be within ± 0.05 ft of the initial value.

4. Check lightning rods and junction boxes for possible damage.

5. Inspect UVM system electronics for moisture accumulation at each site visit. Open UVM console to remove moisture out of the system.

6. The engineer or technician in charge of maintenance must be aware of the following:

   A. The contractor will provide maintenance service for six (6) UVM failures per year and five (5) transducers failures per year for three years dating from the installation of the UVMs.

   B. The contractor will also collect at least three (3) discharge measurements per year for each of the thirty (30) culverts and each of the three (3) open channel sites for three years.

10.4.3.3.6 Continuous Data Recording

1. Non-telemetric data should be downloaded at least bi-monthly, or at a rate judged adequate by the Civil Engineer. That rate will be determined according to data based upon historical data gathered at that site. Stage and velocity data should be processed to eliminate abnormalities in the data. Steps shall be taken to correct the discrepancies, if possible within 24 hours.

2. Data downloaded into PC should be processed within a week to avoid backlogging the data. The data processed shall be loaded into a corporate hydrologic database.

3. In case telemetry is used, data should be checked on daily basis.

10.4.3.3.7 Data Processing and Analysis

1. The UVM stage and velocity data should undergo all the data verification scheme available at the agency department responsible for data collection and archival.

2. A computer program may be written to combine stage and point velocity data to obtain mean velocities and instantaneous discharge data.

3. Daily values may be plotted and reviewed by various plotting package such SAS.

4. A detailed station analysis should be written every year for each site. This analysis should address issues such: (1) periods of no records and their causes, (2) periods of abnormalities in the data collected for various parameters and steps taken to correct them.

5. The detailed analysis should contain database information of the UVM location, the location of the transducers with respect to the UVM, the path length between transducers, and the angle of the acoustic path with the flow.

6. The analysis should contain a paragraph defining the equations used to compute discharges using the UVM and the relationship of the line velocity to mean velocity. Give details of various calibration activities.
7. All primary computations of daily mean discharge, current documentation of stage-area and stage-K_{value}, a summary of discharge measurements, and up-to-date summary of data collected and processed should be kept in the current year record.

10.4.3.3.8 General Safety Guidelines

For safety purposes, the following measures should be adhered to when working at a UVM site:

- Field work, such as inspection of transducers, installation of UVMs and boat flow measurement should be done by at least two people at all times.

- No field work should be performed during a thunderstorm or impending lightning.

- Personnel on boat should always wear a life jacket.

- Auxiliary oxygen lines or tanks should be provided to people working inside dewatered culverts.

- Cellular phone or other means of communication to emergency rescue should always be available to field personnel

- Contact with wildlife, specially snakes and alligators, should be avoided

- The District's drug-free and smoke-free (in office spaces) workplace regulations should be adhered to at all times.

10.4.3.4. Accusonic Ultrasonic Velocity Meter (Model No. 7300)

10.4.3.4.1. Manufacturer's Specifications

The Accusonic (Model 7300) is a battery-powered flow meter capable of measuring and reporting average velocities on one or more acoustic paths. Any acoustic path may be turned on or off through parameter settings.

The flow meter supports both active and passive transducer types with provisions for simple changeover in the field. In the active mode, the transducers use a transmitter and a receiver pre-amplifier located within the transducer body. Active mode is normally used for path lengths greater than 60 ft., and for sites where electromagnetic interference can be a problem. Passive transducers contain a piezoelectric crystal and rely on the electronics in the meter unit itself for a high voltage transmission pulse and for the received signal amplification. Configured for the passive mode, the transducer bypasses the internal electronics and thereby provides a direct connection to the piezoelectric crystal.

The flow meter can be easily interfaced to data loggers which request data through several resident interfaces, RS-232C, 0 to 5-volt analog outputs, visual displays, or the SDI-12 interface. The SDI (Serial Data Interface) complies with the USGS specification SDI-12 of May 1988 (amended in May 1989). As related to this specification, the Model 7300 flow meter is an "SDI sensor" in that it responds to external commands and returns data. Normally, this transfer takes place at 1200 baud.

The specifications of the Model 7300 UVM (for clean water and indicating the minimum path length to avoid receiver overload) are as follows:

+12-volt battery input:	+10 to +18 volts DC
Operating temperature:	-20°C to +60°C
Storage temperature:	-30°C to +60°C
Protection:	fused battery inputs ; high and low thermal switches
Number of paths:	4 max, 0 min
Transducer frequency:	80 to 500 kHz
Transducer-mode selection:	active/passive by jumper
Passive mode path length:	20 to 3200 ft
Active mode path length:	60 to 3200 ft

10.4.3.4.2. Installation Procedures

Site Selection

The following is a list of site conditions to be avoided wherever possible as they can cause poor quality acoustic signal levels:

- air entrained in the water caused by dams, pumps, etc.
- heavy sediment loads
- boat mooring areas
- temperature or salt gradients
- seasonal fish schooling areas
- areas of extreme aquatic growth
- areas of possible acoustic noise (caused by pumps, etc)
- areas of high electrical noise

Detailed information about suitable site selection can be obtained from, "Techniques of Water-Resource Investigations of the United States Geological Survey: Acoustic Velocity Meter Systems", Book 3, Chapter A17.

Transducer Mode Selection

The Model 7300 flow meter supports the use of either active or passive mode transducers by a set of configuration plugs. Note that the meter electronics and all transducers must use the same mode. Use of passive transducers is possible for any path length. Active transducers contain electronics which reduce signal loss and improve the signal-to-noise ratio. Under normal conditions, active transducers are limited to path lengths of 60 ft of longer. Model 765X transducers can alternate between active and passive modes in the field.

On-site Installation and Measurements

After installation of the transducers, accurate measurements of path length (in feet or meters) and path angle (in degrees) must be taken and entered into the meter as parameters (site definitions). Land surveying techniques are used to determine path lengths. The average signal travel time is used to determine path length when the water temperature is known by multiplying the travel time by the speed of sound in water at the given temperature. Planning should include a means of making these measurements.

Mounting the Electronics Enclosure

Mount the electronics enclosure in a sheltered location. Avoid locations that expose the electronics to direct sunlight, temperature extremes, and electrical interference. The enclosure must be mounted in a vertical position.

The following equipment is not supplied with the Model 7300 meter, but is required for installation:

- +12-volt storage battery with a fuse at the positive terminal. A +12-volt, 20-ampere-hour storage battery is usually sufficient for 90 days of unattended operation.

- RS-232C terminal. Parameters (operation definitions) are set and variables (calculated results) can be obtained through the RC-232C interface.

- Transducer connection cable. The Model-7300 meter uses twisted shielded cable, which has a characteristic impedance of 78 ohms. Specify "RG-108 A/U HDPE JACKETED" when the cable will likely be placed in a wet area. If running the cable in a moisture-free conduit, "RG-108 A/U" may be used. Avoid splices, as they can reduce signal strength and admit noises of all types. Cables to each transducer should be run via the shortest distance and as far away from any source of electrical interference as possible.

- Transducer mounts. The transducers should be mounted in a manner that allows both horizontal and vertical adjustment with the face of each transducer of a given path pointing directly at the face of the other.

- Additional transducers. The Model-7300 supports one or two acoustic paths without modification; thus the addition of a second set of transducers at a later date is possible, if desired.

- Expendable 180-volt battery to replace the one supplied with the meter after about 2 to 5 years, dependent on use.

Installing the Flow Meter

The major steps required to install the Model-7300 flow meter are as follows:

1. Installing, aligning and measuring the acoustic path(s)

   Mount the transducers in place and perform both a horizontal and vertical visual alignment. The faces of each transducer of a given path should point directly at each other.

2. Connecting the 7300 to its transducers and other equipment

   Complete the wiring back to the 7300 electronics. Measure and record the length of cable to each transducer. If intermediate junction boxes are used, maintain proper polarization by ensuring that tracer leads are used as reference.

   A. Mount the 7300 electronics on a vertical surface. Connect the transducer cables to the 7300 electronics using tracers wires to maintain correct transducer polarity.

   B. Connect the RS-232C terminal and configure the terminal's baud rate (1200 baud rate is standard) to match the meter's baud rate.

   C. Match the 7300 electronics to the frequency of the transducers.

   D. Connect the 7300 to an external data logger.

   E. Connect the 7300 to an external battery, ensuring that the battery has a fuse at the positive terminal.

F. Once the connection and configuration processes are complete, perform initial electrical and operational tests as per instructions in the operator's manual.

3. Configuring the 7300 electronics

The Model-7300 flow meter requires that all transducers be of the same frequency and configured to the same mode. For Model 765X transducers, an active mode for path lengths of 60 ft or more should be used. For path lengths of less than 60 ft (and where the signal-to-noise ratio is adequate), the passive mode should be used.

A. Locate the model number marked on each transducer. Using Table 10.3, note the frequency that will be required when setting parameters:

Model	Frequency
7651-B	100 kHz
7652-B	200 kHz
7655-B	500 kHz
7650-B	200 kHz

Table 10.3 Frequencies Used by Accusonic Transducers

B. Configure each transducer to either the active or passive mode of operation

4. Setting parameters (site definitions)

Set the following parameters (site-specific definitions): path in use, path length, and path angle. Then set instrument operation parameters as outlined in the operator's manual, e.g. forward and reverse signal delays, maximum allowable velocity, number of measurements per burst, measurement repetition interval, estimated velocity of sound, SDI sensor address (if an SDI interface is used), site number, etc.

5. Fine-tuning the acoustic path alignment

Fine-tune the acoustic path alignment, i.e. ensure that each of the two transducers forming each path points directly at the face of the other by adjusting the transducers in both horizontal and vertical axes (see operator's manual for details).

10.4.3.4.3 Calibration Procedures

In general, acoustic flow meters, like the Model 7300, should be sent back to the manufacturer for calibration. Alternatively, arrangements can be made with the USGS to have the meter calibrated at their Hydrologic Instrumentation Facility (HIF).

10.4.3.4.4 Maintenance Procedures

Aquatic plant and algae growth on the face of the transducers may reduce signal level. Transducers may be knocked out of alignment by objects carried by the water. These effects can easily be monitored by viewing the variables and parameters set at installation and noting the change from previous readings.

Clean the transducer-face areas using water and a mild dish-washing soap. If scrubbing is necessary, a mildly abrasive pad used to clean Teflon surfaces is acceptable.

Monitor the battery stack voltages during each site visit.

10.5 Instrumentation--Closed Pipe Flow Meter

10.5.1 Principle of Operation

These instruments are designed for accurate metering of flow inside a closed conduit. See specific sensors for detailed principles of operation.

10.5.2 Maintenance

Proper maintenance of these instruments is essential for accurate metering. See specific sensors for detailed maintenance procedures.

10.5.3 Sensors Used

10.5.3.1 Water Specialties Model OF-11

The principle of operation of the OF-11 meter is a flow driven conical shaped three blade propeller which is centered in the conduit and pointed upstream. The flow in the conduit drives or rotates the propeller at a speed proportional to the rate of flow. This propeller is magnetically coupled to a sealed metering mechanism which drives a meter head totalizer. This magnetic coupling completely eliminates the possibility of water entering the drive assembly or the need for any packing gland.

Units designed for up to 48-inch conduits utilize water lubricated ceramic sleeve bearings that ride on a ceramic coated stainless steel spindle.

The totalizer is hermetically sealed and magnetically coupled to the driving mechanism. It features a three inch diameter six digit totalizer displayed with 100 divisions and includes a center sweep dial that permits very accurate measurements for timing flow rates.

10.5.3.1.1 Manufacturer's Specifications

Accuracy:	± 2% of actual flow within the range specified for each meter size.
Temperature Range:	140°F max
Minimum Flows:	As shown for each meter size and construction. See flow chart.
Maximum Flows:	As shown for each meter size and construction. See manufacturer's flow chart.
Intermittent Flow:	As shown for each meter size are rated for 10% to 15% of the total meter operating time. Consult the factory for High Velocity construction if intermittent flows are higher than shown on manufacturer's flow chart.
Materials:	Magnets--Permanent type
Interior Bearings:	shielded stainless steel.
Propeller:	ceramic sleeve type for conduits up to 48'.
Propeller Spindle:	Ceramic coated stainless steel.
Propeller:	Injection molded thermoplastic.
Gearbox:	Cast bronze.
Shafts and Bolts:	Stainless steel.
Drop Pipe:	Bronze.
Meter Head:	Cast Bronze.
Mounting Brackets:	Cast Bronze.

10.5.3.1.2 Installation Procedures

Installation can be made to any wall or vertical structure which will center the propeller in the flow measuring area. The meter location must have a controlled flow measuring area and a full flow of liquid for proper accuracy. Valves, fittings, or other obstructions that tend to set up flow disturbances should be a minimum of ten pipe diameters upstream from the meter. Installations with less than ten pipe diameters of straight pipe require straightening vanes.

10.5.3.1.3 Calibration Procedures

Flowmeters should be returned to the manufacturer for calibration. Calibration should be performed at three year intervals to maintain accurate operation.

10.5.3.1.4 Maintenance Procedures

The corrosive effects of the meter's operating environment will determine the amount and type of maintenance these instruments will require.

The unit should be removed and inspected on an annual basis. Inspect the mounting hardware for signs of corrosion and replace as required. Spin the propeller and observe for friction. Inspect the unit for any signs of corrosion and remove or treat as required. Check the lower unit to ensure that it contains the proper amount of lubricant and is free of water.

10.5.3.2 Water Specialties Model ML-23

The principle of operation of the ML-23 meter is a flow driven conical shaped three blade propeller which is centered in the conduit and pointed upstream. The flow in the conduit drives or rotates the propeller at a speed proportional to the rate of flow. This propeller is magnetically coupled to a sealed metering mechanism which drives a meter head totalizer. This magnetic coupling completely eliminates the possibility of water entering the drive assembly or the need for any packing gland.

Units designed for up to 48" conduits utilize water lubricated ceramic sleeve bearings that ride on a ceramic coated stainless steel spindle.

The totalizer is hermetically sealed and magnetically coupled to the driving mechanism. It features a three inch diameter six digit totalizer display with 100 divisions and includes a center sweep dial that permits very accurate measurements for timing flow rates.

10.5.3.2.1 Manufacturer's Specifications

Accuracy:	± 2% of actual flow within the range specified for each meter size.
Temperature Range:	140°F max
Minimum Flows:	As shown for each meter size and construction. See flow chart.
Maximum Flows:	As shown for each meter size and construction. See manufacturer's flow chart.
Intermittent Flow:	As shown for each meter size are rated for 10% to 15% of the total meter operating time. Consult the factory for High Velocity

	construction if intermittent flows are higher than shown on manufacturer's flow chart.
Materials:	
Magnets:	Permanent type
Interior Bearings:	shielded stainless steel.
Propeller:	ceramic sleeve type for conduits up to 48'.
Propeller Spindle:	Ceramic coated stainless steel.
Propeller:	Injection molded thermoplastic.
Gearbox:	Cast bronze.
Shafts and Bolts:	Stainless steel.
Drop Pipe:	Bronze.

10.5.3.2.2 Installation Procedures

Installation can be made to any standard manhole saddle which will center the propeller in the flow measuring area. The meter location must have a controlled flow measuring area and a full flow of liquid for proper accuracy. Valves, fittings, or other obstructions that tend to set up flow disturbances should be a minimum of ten pipe diameters upstream from the meter. Installations with less than ten pipe diameters of straight pipe require straightening vanes.

10.5.3.2.3 Calibration Procedures

Flowmeters should be returned to the manufacturer for calibration. Calibration should be performed at three year intervals to maintain accurate operation.

10.5.3.2.4 Maintenance Procedures

The corrosive effects of the meter's operating environment will determine the amount and type of maintenance these instruments will require.

The unit should be removed and inspected on an annual basis. Inspect the mounting hardware for signs of corrosion and replace as required. Spin the propeller and observe for friction. Inspect the unit for any signs of corrosion and remove or treat as required. Check the lower unit to ensure that it contains no water and that it does contain the proper amount of lubricant.

10.6 Other Velocity Measurement Techniques

10.6.1 Rod Floats

Rod floats are useful in measuring very low velocities when a meter which will measure the low velocity is not available. Winds must be calm, flow direction parallel, and cross section uniform and clear of obstructions.

It is preferable to use a boat for placing and retrieving the floats. A scale can be marked on the side of the boat or two parallel tag lines may be used to measure the travel distance and distance from the edge. Travel time is measured by stop watch. Velocity is computed by dividing the distance in feet by time in seconds. It may be impractical time-wise to obtain the same distance for each observation.

A rod float should be of a length which is about nine-tenths of the depth of the water in the stream where it is to be used. Such a length will tend to integrate the vertical velocity and minimize the necessity for applying a method-coefficient.

When measuring, the float should be placed at a point upstream of the section so that uniformity of movement has been attained when the timing is started. Timing should be for a minimum of 20 seconds. For the two tagline method, an observer on the bank should do the timing.

A rod float can be constructed from a 1.5-inch diameter round wood dowel or 1.25-inch PVC pipe. Add weight to one end of the rod to obtain a vertical attitude and minimal protrusion above the water surface when floating. Add a small diameter wire bale at the top to allow retrieval by a boat hook or similar device. The amount of weight can be calculated based on water displacement area of the material used so that only about one inch of the float protrudes from the water when floating. Several lengths should be constructed to be useful for different depths in the cross section. PVC pipe with capped ends works well and allows coupling for different lengths. The hollow pipe will allow weight adjustment within the pipe.

The rod float can also be helpful when making standard measurements where bottom and top flow directions could be different and not observable. The float can be placed in the water as an indicator for such a condition. The observer would note that the float leans or moves in the wrong direction.

When rod floats are expected to be used, an effort needs to be made to determine a method-coefficient for the floats by making comparative velocity measurements using an acceptable method.

10.6.2 Portable Weir Plate

A portable weir plate is useful for determining discharge for very small streams where depths are too shallow and velocities too slow for a current-meter measurement. A 90 degree V-notch weir is sensitive to low flows.

Ten to sixteen gauge galvanized metal or aluminum is used to construct the weir plate. A 90-degree V-notch cut in the plate is not beveled but is left with flat even edges. A staff gauge is attached to the upstream side of the plate with zero at the elevation of the notch. The staff gauge should be installed at a distance twice the possible head on the notch to avoid the effects of drawdown.

The weir plate is pushed vertically into the streambed. A carpenters level should be used to assure that the top and face of the plate are level.

Rods are driven into the streambed to brace the plate and maintain a level attitude. Streambed material is packed around the plate to prevent leakage under and around the weir. Canvas may be placed on the downstream side to prevent undercutting by the flow jet.

The equation for flow over a sharp-edged 90 degree V-notch weir which is not submerged is

$$Q = Ch^{1.5}$$

where

Q = discharge in cubic feet per second,

h = static head in feet above the bottom of the notch, and

C = coefficient of discharge

A weir is not submerged when there is free circulation of air on all sides of the nappe.

Each weir should be rated to determine the coefficient of discharge by measuring volumetrically at different heads if possible. A value of 2.47 may be used for C in the equation if measurement is not possible. No readings should be made on the gauge until the pool elevation above the weir has stabilized. Read the head at half-minute intervals for 3 minutes and average the readings after a stable condition has occurred. The weir plate may be removed after recording readings under stable conditions.

10.6.3 Volumetric

Volumetric measurement of discharge is usually only applicable to very small discharges, but is the most accurate method for small flows. The time required to fill or partly fill a volume-calibrated container is observed. These observations are then used to calculate discharge.

Volumetric measurements of larger flows are possible for broad-crested weirs where the head is too shallow to obtain an accurate current-meter measurement.

A sharp-edged rectangular spout of known width is held so that one end butts tightly against the downstream face of the weir just below the crest. The other end of the spout leads to a container of calibrated volume. Timed samples of the flow are taken at sufficient intervals to define total discharge per foot of width. Observation times should be a minimum of 10 seconds to avoid large errors for timing efficiency. Practice is required for efficient placing and removal of the container and stopwatch timing.

A 1-foot square container is useful for ease of volume calculation. The depth of water collected in the container amounts to the volume in cubic feet. The spout width is usually a smaller portion of the foot. An example is a spout width of 3 inches (1/4 foot). The volume collected by the 1/4-foot spout is 1/4 of the volume which would be collected for the full 1-foot width. Calculation requires that the volume be multiplied by 4 to obtain the discharge per foot of width.

A table of discharge per foot of width can be computed for different times and depths. The equation required for the computation should also be noted on the table.

Widths are determined by the mid-section method used for standard current meter measurements. The section width is multiplied by the discharge per foot of width to obtain a total for each section. Individual sections are summed for a total measured flow.

The container may also be used to collect the entire flow for extremely small flow jets such as that from a weir plate. The spout equation would not be used in calculations for that condition.

10.6.4 Tracer Dilution

In this method, a solution such as fluorescent dye is injected into the stream to be diluted by the discharge of the stream. Discharge is computed from measurement of the rate of injection, the concentration of the tracer in the injected solution, and the concentration of the tracer at a sampling cross section downstream from the injection point.

Fluorescent analysis may be used to determine concentrations of background samples and stream dilution samples. Stream turbidity, loss of tracer between injection site and the downstream sampling site, and incomplete mixing throughout the stream sampling cross section are factors which affect accuracy of dilution methods of measuring discharge.
Reference texts should be consulted before a decision is made to use tracer dilution methods.

Flow Control Structures

11.0 Flow Control Structures Monitoring

11.1 Introduction

Flow control structures are used to regulate both discharge and water levels. Typical control structures are culverts, spillways, weirs, flumes, and pump stations. Each of these structures has its own advantages.

11.1.1 Theory

Flow control structures are located at sites where water level control or discharge regulation is required. Such sites are often at outlets of water bodies or near canal or river junctions. Theoretical or empirical rating curves are developed for each structure. Theoretical rating curves are usually based on steady-state conditions and assume streamflow velocities approaching the structure are negligible. Structures with manual or automatic control such as spillways, gated culverts, and pump stations require more monitoring than weirs or flumes.

11.1.2 Instrument Siting and Exposure

Upstream water levels should be measured sufficiently far enough away from the control structure such that they are not in the draw down area for "free flow" regimes. Backwater curve analysis should be performed to help ensure proper location. Failure to locate the level monitoring location away from the structure invalidates the theoretical rating curve. Extensive streamflow measurements are required to calibrate the rating curve if monitoring locations are not appropriately placed. Downstream monitoring locations should be located sufficiently far away from the structure to avoid excessive turbulence. The possibility of vandalism must be considered in the choice and location of instrumentation.

11.1.3 Measurement Standards

Structures and associated monitoring equipment should be designed in such a manner that water levels can be measured within 0.02 ft of the ambient level and discharge can be measured within 5 percent of it true value 95 percent of the time.

11.2 Instrumentation--Pump Operation Measurements

11.2.1 Principle of Operation

The pump rotational speed (in revolutions per minute) is used to calculate discharge. The rotational speed of the pumps is measured by magnetic sensors. These sensors are installed on the pump shaft, between the motor and pump, even if the pump is equipped with a tachometer. By using the sensors, rotational speeds and/or corresponding flow rates can be stored on the data loggers.

Electric and Diesel pumps start up quickly and reach their operating speeds in just a minute or two. Most pumps used by the Districts will pump at least 100 gpm (gallons per minute) and up to 47,000 gpm. Rotational speed may be between 200 and 900 RPM for the pumps. In general the motor speeds are higher than the pump speeds.

The magnetic sensors are more correctly described as magnetic switches. The magnetic switch is mounted near a shaft with a well defined bolt pattern. Each time a bolt head passes by the magnetic switch, a pulse is observed by the data logger. By simply counting the number of bolts which will pass close to the magnet head per revolution, the revolutions per time period is calculated by dividing the total number of pulses observed by the number of pulses per revolution. RPM = pulses / # minutes / (pulses/rotation).

11.2.2 Maintenance

Verify that the sensor is properly mounted on the pump shaft. Tighten the bolt to ensure that the device adhere adequately to the shaft. Make sure that the sensor records one closure for each bolt per revolution. Randomly check the reading of the sensor with a portable tachometer. If the readings of the tachometer and the sensor are off by more than five (5) percent, replace the sensor.

11.2.3 Sensors Used

11.2.3.1 Induction Switch

The AIRPAX passive sensor is an example of induction sensor. It can also be described as a magnetic switch. The switch is mounted near a shaft with a well defined bolt pattern as described in the previous section on the principle of operation of magnetic switches. Each time a bolt head passes by the magnetic switch, a pulse is observed at the A/D converter, which can be a datalogger or any other measuring device. There are two types of AIRPAX sensors; the General Purpose sensor and the High Sensitivity sensor. The difference resides in the fact that the High Sensitivity sensor has a better measurement resolution.

11.2.3.1.1 Manufacturer's Specifications

General Purpose AIRPAX Sensors:

Standard Output Voltage: 40.0 Volts

Guaranteed Point Output Voltage:	3.4 Volts
DC Resistance:	130 Ohms (Max)
Typical Inductance:	33 mH
Output Polarity:	Pin 'B' Positive
Operating Temperature:	-55 to +107° C

High Sensitivity AIRPAX Sensors:

Standard Output Voltage:	150 Volts
Guaranteed Point Output Voltage:	12.9 Volts
DC Resistance:	1500 Ohms (Max)
Typical Inductance:	360 mH
Output Polarity:	Pin 'B' Positive
Operating Temperature: -	55 to +107° C

11.2.3.1.2 Installation Procedures

The sensors are mounted on the pump shaft between the motor and the pump. The data logger is hooked to the sensors to obtain the speed readings.

11.2.3.1.3 Calibration Procedures

The distance of the magnetic switch from the bolt pattern or reference must be maintained. If the sensor is too far away the switch may never close or only close when certain bolts pass by. This will cause inaccurate readings. The switch must make a closure when all intended objects pass in front of it. The sensor should record one closure for each bolt per revolution. For example: if eight bolts pass in front of the sensor, make sure the sensor records eight bolts. Accuracy of the sensors can be checked in the field by using a hand held timing light or a portable tachometer.

11.2.3.1.4 Maintenance Procedures

11.3 Instrumentation--Gate Position Measurements

11.3.1 Principle of Operation

Since many different instruments are used in gate position measurements, their principles of operation will be discussed under the individual instruments later in this chapter.

11.3.2 Maintenance

Since many different instruments are used in gate position measurements, their maintenance requirements differ accordingly. These maintenance requirements will be discussed under the individual instruments later in this chapter.

11.3.3 Sensors Used

11.3.3.1 Celesco Displacement Transducer

The Celesco Displacement Transducer is a device designed for measuring linear position and/or low velocity. This is accomplished by monitoring the extension rate and distance of a stainless steel lanyard. The external end of the lanyard is attached to the moving body or object to be measured, and the transducer housing is attached to a fixed surface. As the moving body moves to and from the transducer housing, an electrical signal proportional to the linear extension of the lanyard is provided for display, recording, feedback or input to a controller.

Spring stored energy provides retraction tension for the lanyard. This spring is shaft coupled to a ten turn potentiometer, and drive coupled to the lanyard storage drum. The lanyard is wrapped around the storage drum. As the lanyard extends the storage drum rotates thus rotating the potentiometer there by providing the proportional output signal.

11.3.3.1.1 Manufacturer's Specifications

Shock endurance:	2,000 G's for 6 ms.
Vibration:	10 G's 10-2000 Hz.
Accuracy:	0.01% standard
Resolution:	0.001 inch standard
Ranges:	0-2 to 0-1000 inches
Sensing System:	Precision potentiometer
Electrical Connector:	MS3102E-14S-6P
Input impedance:	500 ohms standard (options available)
Excitation Volts:	25 volts max
Thermal effects:	Zero and Span 0.002% per °F
Temp Range:	0°F to 200°F
Humidity:	Up to 90%

11.3.3.1.2 Installation procedures

This transducer works best for gate monitoring when it is attached to the gate lifting hydraulic ram. When installing the transducer, position the instrument on its side such that the lanyard will deploy along the same horizontal axis as the ram without touching any part of the mounting platform throughout the instrument operating range. Mount the instrument base to the ram base bracket and the lanyard clip to the moving ram bracket.

11.3.3.1.3 Calibration procedures

Sensor sensitivity is noted on the identification tag mounted on housing of each instrument.

Typical sensitivity is 6.14 mV / V / in.

This means the instrument will produce 6.14 millivolts output for each volt of applied excitation voltage per inch of deployment.

Example: Sensitivity = 6.14mV / V / in.

Excitation Voltage = 5 volts

Deployment distance = four feet

Output in mV = 6.14 X 5 X 48 = 1473.6 mV = 1.474 volts

Perform routine site visit calibrations by first reading the recorder as found. Then carefully and accurately extending the lanyard 12 inches and read the recorder again. The recorder must indicate a movement in the gate equivalent to a 12 inch movement in the hydraulic ram or you must investigate the error.

Perform annual calibrations by removing the instrument from the shelter and to an area which will allow full deployment. The annual calibration should incorporate lanyard extension points at 0, 25, 50, 75, and 100 percent of full deployment.

11.3.3.1.4 Maintenance procedures

Maintenance of this instrument consist of routine cleaning of dirt and removal of spider webs from the lanyard. Spider webs are especially troublesome as they will collect at the lanyard exit orifice during retraction and apply pressure on the lanyard. At times this pressure is enough to over come the retraction tension and actually seize the lanyard preventing movement in either direction.

11.3.3.2 Environmental Sensing Devices, Inc.

This instrument is a magnetically actuated potentiometric linear position sensor designed to measure the physical location of a magnetic actuator. The instrument consists of a lineal length of resistive wire, a lineal length of conductive fingers (adjacent but very close to the resistive wire), and a block actuator magnet. The resistive wire and conductive fingers (100 fingers per foot) are housed inside a long sealed and pressurized stainless steel sheath. The block actuator magnet fits around this steel sheath. As the magnet moves along the sheath it pulls the conductive fingers (one at a time) into contact with the resistive wire. The lineal length of conductive fingers are connected as if they were the wiper of a potentiometer. As the conductive fingers contact the resistive wire, the instrument outputs an electrical signal proportional to the linear position of the block actuator. The block actuator is connected to the gate staff pointer such that the gate and magnetic actuator move in direct incidence.

11.3.3.2.1 Manufacturer's Specifications

Device Type:	Three wire potentiometric
Internal impedance:	200 ohms per foot standard
Size:	0.5 inch by 1.0 inch rectangular tube, length to customer order
Length:	Up to 250 inches standard
Material:	316 stainless steel
Connector:	Mil Spec 27471 Hermetically sealed 3-pin connector
Resolution:	0.08 inch steps

Temperature Range:	from - 0.5°C to +50°C
Temperature effect:	accuracy is effected less than 0.007% / °C
Block actuator size:	2.25" x 3" rectangular
Block actuator construction:	structural foam
Block guides:	Teflon
Block active device:	encapsulated horseshoe magnet

11.3.3.2.2 Installation Procedures

First assemble the instrument.

Install the block actuator by removing the 9/16" hex nut and large washer from the bottom of the sensor. Slide the block actuator onto the sensor tube such that the word "TOP" on the actuator faces the round flange and connector t the top of the sensor. The word "TOP" on the actuator **must** be on the same side of the sensor tube as the connector.

If the sensor is equipped with the optional longitudinal bracket, a type "B" block actuator must be used. If the sensor has no longitudinal bracket, use a type "A" block actuator. This is important because the type "A" actuator has a smaller opening than the type "B".

Mount the sensor either with a longitudinal mounting bracket or with top and bottom angle brackets. Install the sensor adjacent and parallel to the movement path of the gate staff pointer. The block actuator must be connected to the gate staff pointer in such a manner as to allow it to float or move freely along the length of the sensor. Any binding of the block actuator with the sensor will cause excessive ware and severely reduce the life of the instrument.

To calibrate the sensor to a known position after installation, first calculate the **Unit Voltage.**

Unit Voltage = Active Length/(Full Scale V - Offset V)

Then with the sensor installed and the actuator at a known position (the calibrate position), read the voltage between the white and black wires. This voltage is the **calibration point voltage**.

The actuator position relative to the calibration position is then given by the following formula:

AP = [CP + UV] [VR - CPV]

where:

AP =Actuator Position

CP = Calibration Position

UV = Unit Voltage

VR = Voltage Reading

CPV = Calibration Point Voltage

11.3.3.2.3 Calibration Procedures

The connecting cable supplied with the instrument has three color coded wires: red, white, and black. To calibrate the sensor connect a regulated voltage source (usually +5 volts DC from the recording device) to the red wire, and common or ground of that source to the black wire. For most accurate calibration, the regulated voltage source and total circuit wiring for the sensor calibration should be the same source and wiring that will be connected to the sensor during field operation.

Place the block actuator against the bottom stop (round washer). Read and record the voltage measured between the white and black wires (white is [+] and black is [-]). This voltage should be very low, but probably not zero. This is the **offset** voltage.

Move the block actuator along the sensor tube until it touches the round flange at the top of the sensor. At this position read and record the voltage between the same white and black wires. This voltage should be slightly less than the regulated supply voltage and is the **full scale voltage**.

The sensor is now calibrated. The position of the actuator at any point along the sensor can be calculated by reading the voltage between the white and black wires and applying the following formula:

AP = SL x [VR-OV]/[FSV-OV]

Where:

AP = Actuator Position

SL = Active Sensor Length

VR = Voltage Reading at Actuator Position

OV = Offset Voltage

FSV= Full Scale Voltage

The Active Sensor Length is the distance the actuator can travel on the sensor tube and is given in the sensor part number. Example: LPS-120I sensor has a 120 inch active length.

11.3.3.2.4 Maintenance Procedures

Observe the block actuator for cracks in the foam, loose attachment screws, or badly worn Teflon guides. Check the mounting brackets and remove any visible corrosion.

11.3.3.3 Lundahl DCU-7 Ultra Sonic Sensor

The Lundahl DCU-7 sensor measures water surface elevations ranging from 2 to 10 feet away from the sensor. The sonic sensor outputs 0 to 5 volts to the data logger which supplies 5 volts input voltage. The distance to water measurements must be temperature-compensated for accurate readings. The DCU-7 has an accuracy of 99.8 percent with a 1/400 foot resolution.

11.3.3.3.1 Manufacturer's Specifications

Supply Voltage:	4.7 to 5.3 VDC; Optional 10 - 30 VDC
Analog Options	0 to 5 volts (from 0 - 10 feet)
Transducer Operating Range	
Electrostatic:	1 to 10 feet
Ceramic Environmental:	2 to 10 feet
Resolution:	1/400 feet, over full range
Accuracy:	± 0.25% of range with no gradient
Total Current Draw:	23 mA (typical 25 mA at 5 volts)
Temperature Compensation:	N/A (recommended use of external temperature sensor for compensation)

Operating Temperature:	-30° to +70° C
Sample Rate:	8 Hz
Case:	304 stainless steel housing
End Plates	Nickel-plated glass epoxy
Cable:	4 conductor, 6 foot length
Dimensions:	2-3/8 inch diameter by 5-1/4 inch length
Adjustments:	Blanking and sensitivity (for wave guide capability)

11.3.3.3.2 Installation Procedures

The sensor should be equipped with a wave guide and a protective back cover before field installation. The wave guide reduces the divergence angle of the sound wave transmission and allows for the sensor to be installed in a small stilling well. The protective back cover helps protect the instrument from accumulating moisture and debris on the sensor.

1. Connect the wiring in the following order:

Black	Power Ground;
Green	Analog Ground;
Red	+5 Volts Excitation;
White	Voltage Output;

2. Mount the sensor vertically over the water surface. The expected water levels must be between 2 and 10 feet from the sensor at all times. Mount the sensor inside a stilling well for accurate readings. The sensor can easily be installed inside a 2-inch PVC-pipe stilling well.

3. Mount a thermistor or other temperature probe within 2 feet below the DCU-7. The output of the temperature probe will be used for temperature compensation.

4. The equation on the data logger should be similar to:

   $$E_W = E_S - 2[V_{OUT}][((C+273)/273)^{0.5}]$$

   where

   E_W = water elevation,

E_S = sensor elevation ,

V_{OUT} = Voltage Output and

C = measured temperature inside the stilling well (in degrees Celsius).

5. Compare the sensor reading to the staff gauge or other water level reference.

11.3.3.3.3 Calibration Procedures

Using the data recorder, view and write down the current sensor reading on the solid state recorder sheet. Compare this reading to the staff gauge, the manual distance-to-water measurement or other accurate recorder reading. If the sensor reading is not within 0.03 feet of the more accurate reading, the sensor needs to be recalibrated.

11.3.3.3.4 Maintenance Procedures

1. Record the present or last recorded reading of the DCU-7 and compare to the staff gauge or other water level reference.

2. Ensure that the sensor is mounted securely and the stilling well wall is free from obstructions.

3. Check wiring connections and the overall condition of cable assemblies. Verify that the sensor is getting the proper input voltage and is returning a realistic output voltage for the present water level.

4. Ensure that the air temperature probe inside the stilling well is above the water surface and operating properly. Check the current temperature readings and compare to present conditions.

11.4 Instrumentation--Lock Operations Measurements

11.4.1 Principle of Operation

The amount of water released through locks is needed to compute accurate discharges. Three values are needed to compute the amount of water that passes through a lock during one complete lockage, the area of the lock, the headwater elevation, and the tailwater elevation. The difference between the headwater and tailwater level times the area will give the volume of water that passes through the lock during one lockage. When the lock area is known and the headwater and tailwater levels are recorded, the discharge can be computed later or in real time when using a datalogger. The datalogger must be programmed to determine when a lockage has occurred. This can be accomplished by monitoring drastic changes in either the rising or falling water level inside the chamber.

11.4.2 Maintenance

Maintenance should be the same as required for the surface followers used to measure the headwater, tailwater and chamber water levels.

11.4.3 Sensors Used

11.4.3.1 Surface Followers

The sensors required to make the measurements for lock operations have already been discussed under the surface followers section of this manual. Most lock structures have water level sensors installed for headwater and tailwater measurements. If not, they should be installed using standard operating procedures outlined in this manual or other manuals used for that purpose. A pressure transducer or resistive tape type sensor is suggested for measuring the chamber level. Most locks have cut-outs along the side of the chamber to hold ladders etc. These cut-outs can be used to install sensors that can be installed inside 2-inch or smaller pipe. The cut-outs will give protection from boats moving through the lock chamber. Care must be used in selecting a sensor that can resolve rapid changes in water level or pressure, as would be expected in lock operations.

11.4.3.1.1 Manufacturer's Specifications

Please see specifications listed for the sensor used.

11.4.3.1.2 Installation Procedures

Please see installation procedures for sensor used.

11.4.3.1.3 Calibration Procedures

Please see calibration procedures for sensor used.

11.4.3.1.4 Maintenance Procedures

Please see maintenance procedures for sensor used.

11.5 Instrumentation--Fuel Reserve Measurements

11.5.1 Principle of Operation

Most remote sensing instruments used in measuring liquid petroleum gas (LPG) reserves are devices which measure the physical location of a magnet. This magnet is attached to the indicator end of a float arm.

11.5.2 Maintenance

Maintenance of liquid petroleum gas measuring instruments will be discussed in the individual instrument procedures later in this chapter.

11.5.3 Sensors Used

11.5.3.1 Squibb - Taylor Model 136619

The Squibb - Taylor #136619 stationary LPG tank monitor consist of a level sensing device (LPG sender) and an annunciator. The LPG sender is located at the tank and is physically attached to the top of the level float indicator. The annunciator is installed at some remote location where the LPG level is to be monitored.

The LPG sender measures the position of the magnet which is mounted opposite the float on the level sensing arm inside the tank. This sensor is attached to the outside of the float level indicator.

The annunciator enclosure contains:

- A multi-colored bar graph which indicates the present level inside the tank.
- A green LED which indicates that the present LPG level in the tank is **above** the Low Level Alarm Set Point (LLASP).
- A red LED which indicates that the present LPG level in the tank is **below** the LLASP.
- An adjusting knob for adjusting the LLASP.
- A buzzer (with reset button) that sounds when the LPG level in the tank is below the LLASP.
- A control relay for user use.
- Output module which outputs an analog signal of 0 to 5 volts proportional to LPG level in the tank.

11.5.3.1.1 Manufacturer's Specifications

Power Requirements:	+9 to +16 volts DC @ 0.2 mA
Alarm Relay:	Two DPDT contacts rated @ 5 amps
Analog Output:	0 to 5 volts adjustable @ 5 mA
Operating Temperature:	0° to 70°C

11.5.3.1.2 Installation Procedures

Install and test the annunciator before installing the sending unit.

Annunciator Installation:

1. Remove the cover from the annunciator.
2. Mount the annunciator housing using the cover attachment screw holes.
3. Temporarily connect the two sender wires to the two terminals of P2 at the lower right corner of the enclosure. The two wires of the sending unit are **not** polarity sensitive.
4. Make other connections such as power, analog output, relay, etc. as shown in the instruction manual.
5. Apply power to the unit.

6. The sender unit can be activated manually by holding a small magnet at the bottom of the sender and rotating it clockwise and counterclockwise such that the orange indicator follows the magnet. Observe the bar graph on the annunciator. It must correspond to the orange indicator of the sending unit.

7. The alarm relay can be set to latch or unlatch upon alarm by changing the position of the shorting jumper at J3 located in the center of the enclosure adjacent to the alarm set point adjusting knob. The shorting jumper in position B for latching and in position A for non-latching.

8. Rotate the low level alarm set point adjustment screw to the desired set point and use the magnet to move the orange pointer of the sender unit back and forth near the set point. The following should happen:

   - The **Red LED** turns **on** when the sender level is lower than the set point setting.

   - The **Green LED** turns **on** when the sender level is higher that the set point setting.

   - The **Relay** activates when the sender level is lower than the set point setting.

   - The **Buzzer** should sound when the sender level is lower than the set point setting. It can be reset by pressing the reset button labeled **Buzzer Reset**. To disable the buzzer, disconnect the cable between the buzzer and the PC board.

9. Monitor the analog voltage output of Terminal Board TB2 with a voltmeter across pin 10 (using the positive lead) and pin 11 (using the negative lead). The output voltage should indicate the same proportional percentage as does the Bar Graph on the monitor and the orange indicator on the sending unit. The output voltage scale can be adjusted to the users desire by adjusting gain potentiometer R6.

10. Remove power from the annunciator and remove temporary sending unit connection.

Sending Unit Installation:

1. Install the LPG sending unit on the float gauge on top of the LPG storage tank.

2. Install and connect a cable between the sending unit and the monitor. This cable should be no smaller than 20 gauge in size and shielded against inducible transients.

3. Apply power to the monitor and observe that the Bar Graph is indicating the actual level observed at the tank.

11.5.3.1.3 Calibration Procedures

Before performing any type of calibration of this instrument, perform a routine as found operational check by comparing the orange indicator at the sending unit with the Bar Graph on the monitor. Next perform the following test:

1. Remove power from the monitoring unit.

2. Remove both the sending unit from the top of the tank (without disconnecting the wires), and the cover from the monitor unit.

3. Apply power to the unit.

4. Activate the sender unit manually by holding a small magnet at the bottom of the sender and rotating it clockwise and counterclockwise such that the orange indicator follows the magnet. Observe the bar graph on the annunciator. It must correspond to the orange indicator of the sending unit.

5. Use the magnet to move the orange pointer of the sender unit back and forth near the set point. The following should happen:

   - The **Red LED** turns **on** when the sender level is lower than the set point setting.

   - The **Green LED** turns **on** when the sender level is higher that the set point setting.

   - The **Relay** activates when the sender level is lower than the set point setting.

   - The **Buzzer** should sound when the sender level is lower than the set point setting. Reset by pressing the reset button labeled **Buzzer Reset**.

6. Monitor the analog voltage output of Terminal Board TB2 with a voltmeter across pin 10 (using the positive lead) and pin 11 (using the negative lead). The output voltage should indicate the same proportional percentage as does the Bar Graph on the monitor and the orange indicator

on the sending unit. The output voltage scale can be adjusted to the users desire by adjusting gain potentiometer R6.

7. Remove power from the annunciator and reinstall the sending unit and monitor cover.

8. Apply power to the monitor and verify that the Bar Graph indicator shows the same as the orange indicator on the sending unit at the tank.

11.5.3.1.4 Maintenance Procedures

Perform routine maintenance of this unit at two month intervals. Clean and remove any accumulated corrosion. Inspect the sending unit for moisture inside the sending unit enclosure. Verify that the Bar Graph on the monitor shows the same as the orange indicator of the sending unit.

11.6 Instrumentation--Stop Log Measurements

11.6.1 Principle of Operation

There has been an increasing necessity to compute discharge at stations with boards (stoplogs). To compute discharge accurately, the elevation of the top of the boards is an absolute requirement. Field technicians can calculate the elevation of the top of the boards by subtracting the distance to the boards from the reference elevation.

To obtain the elevation of the top of the boards, **the vertical distance from the reference point to the top of the boards must always be measured directly**. These measurements, the date, and the time must all be recorded on the Operation Log , for each bay, whenever boards are added or removed. The reference point is typically at the top of the channel section into which the boards are placed but may differ depending upon the specific site.

The number of boards in place, the number of boards pulled out, and the number of boards put in do not indicate adequately the information required to determine the elevation of the top of the boards.

By completing the Operation Logs as completely and accurately as possible, interpretation of the Operation Logs is simplified and the reliability of the discharge computation is maximized.

A correctly completed sample Operation Log is given in Figure 11.1. Please refer to this example whenever necessary.

11.6.2 Maintenance

The site should periodically be checked to ensure that the boards are sound and not suffering from rot or splitting. Care must be made to ensure that the boards used are as level as possible, and are of consistent width. Boards that are of uneven shape or suffering from distress should be replaced.

Figure 11.1 Sample Operation Log

Data Acquisition

12.0 Methods of Data Acquisition

12.1 Introduction

The Florida Water Managements Districts use four primary methods of acquiring hydrometeorological data. Manually measured and logged, mechanically and electro-mechanically measured and logged, electronically measured and logged, and telemetry measured and logged.

12.2 Manual Data Acquisition

Manual data acquisition consist of two basic methods. The first is when manual measurements made by a service technician, the results recorded as field notes, then a data technician records these field notes to a Scientific Database. The second method of manual data acquisition is the use of outside or civilian observers. The observer performs the requested observations or measurements and records the results as field notes. These notes are then telephoned and/or mailed to the appropriate District staff for entry to a Scientific Database.

12.3 Mechanical Recorders

Mechanical data acquisition is exemplified by the Leupold & Stevens Model A and 2A35 Graphical Recorders. These instruments measure water levels using counterbalanced float technology while simultaneously recording the results as an ink trace onto a graphical chart. Power for operation of these instruments is derived from the stored energy of an on board hand windup spring.

Electro-mechanical data acquisition is exemplified by the Stevens Model 7001 Punched Paper Tape Recorder. This instrument measures water levels using counterbalanced float technology. It records these measurements by punching holes in a paper tape in binary arithmetic format at strategically selected times. The timer is either electronic or electro-mechanical and the punching mechanism and tape are driven by a direct current motor with power supplied by an on board battery.

The Omnidata Easy Logger is a typical example of an electronic data logger. It's batteries are the power source for its attached instruments and it measures sensor generated voltages which are proportional to monitored parameter. This instrument has on board processing capability and a nonvolatile ram for data storage.

The coming of age data acquisition method is telemetry. This is measuring from a distance in real time or near time conditions. Most remote telemetry (terminal) units (RTU's) are also electronic data loggers. They have an on board processor and the ability to store data at the remote site. They measure the parameter as instructed by the on board program, store the data in its memory, and then forward these data through an electronic transport to the central database processing station. This electronic transport may in the form of a cellular telephone network, a overland radio frequency repeater network, or radio beamed satellite network.

12.4 Electronic Data Recorders and Loggers

12.4.1 Data Loggers

The Easy Logger Recording System manufactured by Omnidata International Inc. is the primary stand alone electronic data logger used by The St. Johns River Water Management District. The Easy Logger has on board processing and a plug in nonvolatile data storage package. This data storage pack is removed at selected intervals for processing and archival. The on board processor is fully programmable from the Easy Logger Field Unit.

The most critical element supporting electronically logged data integrity is careful documentation of station calibration and maintenance. This careful documentation is easily afforded by the following Omnidata Easy Logger Site Check QA Log.

The creation of this QA Log is an effort to standardize the service an Omnidata Easy Logger Site will receive when visited by authorized personnel.

This procedure should be followed at each visit regardless of the purpose of the visit.

Each site visit requires the completion of a Omnidata Easy Logger Site Check QA Log with entries into all appropriate blank spaces. Assure that this form is of the latest revision.

It is very important that as found readings are entered into the QA Log before manual measurements and/or sensor tests are performed. Also that manual measurements and sensor tests are performed before as left readings are entered into the QA Log.

OMNIDATA EASY LOGGER SITE CHECK QA LOG

Site Name:____________________________ Site Number:_______
Date _____________ Time ___________(EDT/EST) Technician ___________
Purpose of Visit: Routine ____ Off Line ____ Other ________________

Visual Inspection: Fence ____ Shelters ____ Solar Panel ____ Wires,
Cables & Connections ____ Ionizer ____ Battery Box ____Sensors ____
Equip. Id #'s:
Battery Voltage: Option 32 (As Found) Internal _____ External _____
Battery Changed ? (y/n)___ (As Left) Internal _____ External _____
Clock: (option 20) As found _______@_____EST Year____ Reset (y/n)__
DSP Status: (Opt 41) Size _____K %_____ Used _______ Left _______
DSP Pulled: (y/n) _____
(New DSP) Size _____K %_____ Used _______ Left _______

Note All Dry Conditions (Note time of tape down in right margin)
Manual Water Level Measurements (minimum 2 per ID# within 0.01 ft)
Before Water Quality
ID#____MP____Ho____Cut____DTW____MSL____Ho____Cut____DTW____MSL____
ID#____MP____Ho____Cut____DTW____MSL____Ho____Cut____DTW____MSL____
ID#____MP____Ho____Cut____DTW____MSL____Ho____Cut____DTW____MSL____
After Water Quality
ID#____MP____Ho____Cut____DTW____MSL____Ho____Cut____DTW____MSL____
ID#____MP____Ho____Cut____DTW____MSL____Ho____Cut____DTW____MSL____
ID#____MP____Ho____Cut____DTW____MSL____Ho____Cut____DTW____MSL____
Staff Readings: Up Stream_____/datum_____ Down Stream____/datum_____
Test Sensors (Option 30) **As Found** **As Left**
Parameter ID___________ Test V_____Data _____ Test V_____Data _____
Parameter ID___________ Test V_____Data _____ Test V_____Data _____
Parameter ID___________ Test V_____Data _____ Test V_____Data _____
Parameter ID___________ Test V_____Data _____ Test V_____Data _____
Parameter ID___________ Test V_____Data _____ Test V_____Data _____
Parameter ID___________ Test V_____Data _____ Test V_____Data _____
Float/Counterweight Sensor Calibrations(Readout from Data Logger)
ID#______ (found) MSL Balanced______ One Turn Up_____ Balanced_____
(left) MSL Balanced______ One Turn Up_____ Balanced_____
ID#______ (found) MSL Balanced______ One Turn Up_____ Balanced_____
(left) MSL Balanced______ One Turn Up_____ Balanced_____
ID#______ (found) MSL Balanced______ One Turn Up_____ Balanced_____
(left) MSL Balanced______ One Turn Up_____ Balanced_____

Show Data: (option 40) Report 1____________________________________
Log Run/Stop: (Option 00) Running (y/n)___ Stop (y/n)___ Time _____
Delayed Log: (Option 01) Start ____ Time ____ (Check Option 50)
(Option 50) Yes ____ Next Scan Time________ Ok? ___

Sensor/Option Comments (Formula Changes, Logger Malfunction, etc.)

___________ ____

___________ ____

___________ ____

____

___________ ____
Rev 1002 OMNIDATA QA.LOG 6/01/93

12.4.1.1 Visual Inspection at Data Logger Sites

Each site visit should start with a preliminary visual inspection as the technician is driving up to the site. Look for things such as birds perching atop the ionizers or on the antenna and solar panel. Observe any animals that may adversely affect the site's integrity or any fast growing trees or shrubs that may soon become obstructions to the precipitation, wind, or radiation instruments.

Upon arrival at the site, perform a detailed visual inspection. Observe and/or confirm:

- that the solar panel still facing south;
- that the antenna horizontal to the ground and pointing toward the proper station and the antenna mounting pole is vertical;
- that the ionizer is pointing up and the fine wires atop the ionizer are still in place and show no damage from birds;
- that the exposed wires and cables are secure and not able to move in the breeze;
- the fence for any damaged;
- for any evidence of vandalism. Take pictures, determine the cost of damages, and contact your supervisor regarding any noted vandalism.

Upon completion of visual inspection, start entries into the Omnidata Easy Logger Site Check QA Log.

1. Enter the station name and number and the date and time of your arrival with the appropriate EDT/EST time designation.
2. Enter the purpose of your visit. **Routine** if the visit is for standard two months interval service. **Off line** if the station was not reporting. **Other** if the station is reporting intermittently, a parameter is not reporting, base station data from this site appears unusual, etc.
3. Enter your name in the blank beside Technician.
4. Clean the solar panel with a soft, moist, non-abrasive cloth, then complete the inspection part of the QA Log in the blanks after fence, ionizer, antenna, wires, RTU, and solar pan. If these items passed inspection, indicate by placing check mark or OK in the blank beside each item.
5. Observe the weather conditions at the time of your visit. Record these conditions in the QA Log under weather. Record your estimated percent of cloud cover. Record your estimate of wind speed as L (light), M

(medium), or H (heavy). Note and record the direction from which the wind is blowing (N,NE,E,SE,S,SW,W,NW).

12.4.1.2 Data Logger Station Checks/Tests

12.4.1.2.1 Housekeeping Checks

After completing a visual inspection of the station, connect the hand terminal to the Easy Logger and perform the necessary housekeeping checks as exemplified by the following section of the QA Log.

Battery Voltage: Option 32 (As Found) Internal_____ External_____
Battery Changed ? (y/n)___ (As Left) Internal_____ External_____
Clock: (option 20) As found ______@_____EST Year___ Reset (y/n)__
DSP Status: (Opt 41) Size _____K %_____ Used ______ Left ______

Record option 32 (battery voltage), option 20 (clock date and time), and option 41 (DSP status).

Note: If the logger is stopped logging, note this stop and start time on the DSP form.

12.4.1.2.2 Parameter Checks

After completing the housekeeping checks, check option 50 (next scan time) to ensure sufficient time remains before next scan to perform the parameter tests as required.

Perform the **manual measurement**, **test sensors**, and **float/counterweight sensor calibration** tests as exemplified by the following section of the QA Log.

Note All Dry Conditions (Note time of tape down in right margin)
Manual Water Level Measurements(minimum 2 per ID# within 0.01 ft)
Before Water Quality
ID#____MP____Ho____Cut____DTW___MSL____Ho____Cut____DTW____MSL___
ID#____MP____Ho____Cut____DTW___MSL____Ho____Cut____DTW____MSL___
ID#____MP____Ho____Cut____DTW___MSL____Ho____Cut____DTW____MSL___
After Water Quality
ID#____MP____Ho____Cut____DTW___MSL____Ho____Cut____DTW____MSL___
ID#____MP____Ho____Cut____DTW___MSL____Ho____Cut____DTW____MSL___
ID#____MP____Ho____Cut____DTW___MSL____Ho____Cut____DTW____MSL___
Staff Readings: Up Stream____/datum____ Down Stream____/datum_____
Test Sensors (Option 30) **As Found** **As Left** Parameter ID_________ Test V_____Data _____
Test V_____Data _____
Parameter ID_________ Test V_____Data _____ Test V_____Data _____
Parameter ID_________ Test V_____Data _____ Test V_____Data _____
Parameter ID_________ Test V_____Data _____ Test V_____Data _____
Parameter ID_________ Test V_____Data _____ Test V_____Data _____
Parameter ID_________ Test V_____Data _____ Test V_____Data _____
Float/Counterweight Sensor Calibrations(Readout from Data Logger)
ID#______ (found) MSL Balanced_____ One Turn Up_____ Balanced____
(left) MSL Balanced_____ One Turn Up_____ Balanced____
ID#______ (found) MSL Balanced_____ One Turn Up_____ Balanced____
(left) MSL Balanced_____ One Turn Up_____ Balanced____
ID#______ (found) MSL Balanced_____ One Turn Up_____ Balanced____
(left) MSL Balanced_____ One Turn Up_____ Balanced____

Note all dry well and stilling well conditions and time of manual measurements in the margins adjacent to the appropriate manual measurement on the QA Log.

Perform the **as found** portion of the float/counterweight calibrations (float one turn up test) and record in the QA Log before proceeding with the test sensors and manual measurements.

Perform the **as found test sensors** and manual measurements test and record results in the QA Log. Complete these tests one parameter at a time before proceeding to the next parameter. If more than three minutes are required to perform these tests for each parameter, then the tests must be repeated to ensure that the water level did not change during the test.

If the station has a rain gauge, then a rain gauge test must be performed. Stop the logger from logging (option 00) and tip the rain gauge one time and test sensor to ensure the tip was registered. Repeat this test a minimum of five times.

12.4.1.2.3 Data Logger Site Departure Check

Upon satisfactory completion of all test and before leaving the station perform the following procedures:

1. Ensure the station is logging.

2. Exit the hand terminal control, disconnect the hand terminal from the Easy Logger, and replace serial port cover.

3. Renew desiccant packs and pest strips as required.

4. Lock all appropriate equipment enclosures, battery and ZapNot boxes. Renew moisture absorbent materials and pest strips as needed. Check locks for proper lubrication.

5. Perform site maintenance as required. Cut the grass, secure weed mat, collect debris, etc.

6. Verify inventory if station service required any equipment change out.

7. Inspect fence integrity and repair as needed. Ensure fence gate is locked.

8. Verify proper completion of QA Log and sign your name with date and time in the comments section of the form.

9. Perform a last general site inspection for tools, parts, or materials that could be left behind.

12.4.2 Data Recorders

The Stevens Model 7001 Punched Paper Tape Recording System manufactured by Leupold and Stevens Inc. is the primary stand alone data recorder used by The St. Johns River Water Management District. The Stevens utilizes counter weighted float technology to measure water levels and records the results on a paper tape through a series of holes which are punched in a binary format. This data storage tape is removed at selected intervals for processing and archival.

The most critical element supporting mechanically recorded data integrity is careful documentation of station calibration and maintenance. This careful documentation is easily afforded by the following site visitation procedures.

The creation of this procedure is an effort to standardize the service an Analog to Digital Recorder Site (Stevens 7001) will receive when visited by authorized personnel.

12.4.2.1 Visual Inspection at Data Recorder Sites

Each site visit should start with a preliminary visual inspection as the technician is driving up to the site. Look for things such as birds perching atop the ionizers or on the antenna and solar panel. Observe any animals that may adversely affect the site's integrity or any fast growing trees or shrubs that may soon become obstructions to the precipitation, wind, or radiation instruments.

Upon arrival at the site, perform a detailed visual inspection. Observe and/or confirm:

- that the solar panel still facing south;
- that the antenna horizontal to the ground and pointing toward the proper station and the antenna mounting pole is vertical;
- that the ionizer is pointing up and the fine wires atop the ionizer are still in place and show no damage from birds;
- that the exposed wires and cables are secure and not able to move in the breeze;
- that the stilling well, well casing, or instrument shelter do not require painting;
- the fence for any damaged;
- for any evidence of vandalism. Take pictures, determine the cost of damages, and contact your supervisor regarding any noted vandalism.

12.4.2.2 Data Recorder Site Tests/Calibrations Checks

Upon completion of visual inspection, proceed with routine site tests/calibrations, including documentation via field notes and entries onto the Stevens tape leader.

Each site visit requires entries onto the Stevens tape leader. Nonscheduled visit entries are made in the appropriate space on the back side of the tape leader. Scheduled recorder maintenance visit entries are made on the front side of the tape leader, including appropriate tape installation and removal information.

Each site visit requires appropriate documentation (either tape leader or field notes) which include the following:

1. Enter the station name and number and the date and time of your arrival with the appropriate EDT/EST time designation.

2. Enter the purpose of your visit. **Routine** if the visit is for standard two months interval service. **Off line** if the station was not reporting. **Other** if the station is reporting intermittently, a parameter is not reporting, base station data from this site appears unusual, etc.

3. Enter your name in the blank beside Technician.

4. Purpose of visit -- Observed outage, routine maintenance, etc.

5. Staff gauge information -- Staff range, Datum, Staff reading, and MSL.

6. Manual measurement -- Measuring point, hold, cut, DTW, and water level MSL. **Document two manual measurements within 0.01'.**

7. Comments detailing general site integrity, battery condition, and instrument timing.

8. Comments detailing manual measurement vs instrument reading.

9. Comments detailing a float/pulley calibration test of one turn up compared with the instrument dial.

10. Comments verifying the cleaning of the solar panel.

11. Document the memory spring status. Check the memory spring by holding the float wheel stationary while turning the encoding drum drive gear about 20° in both directions and releasing. The encoding drum should return to the same value as before the test. If not, then adjustment or replacement of the memory spring is necessary.

12. Ensure that the float wheel is vertical (check with level) and that float wheel spines were engaged in tape holes before and after instrument test.

13. Ensure that tape take up spring is in its groove and functioning properly.

14. Ensure that the encoding drum gear and the float wheel drive gear are meshing with properly and that their teeth are free of all dirt, grease or other foreign material.

15. Ensure that the battery has sufficient reserve to last through to next scheduled visit. Replace the battery if its voltage drops more than 0.3 volts during a punch cycle.

12.4.2.3 Punched Tape Removal/Installation

To remove the punched tape from the recorder

1. Empty and reinstall the chad tray. Pull enough slack tape from the supply roll to permit the tape to disengage from the spines of the tape advance roller assembly. Lift the tape free of that roller and pull enough through to permit all the punched tape to be wound onto the take-up drum. Cut the tape several inches after the last punch entry and roll the tape tightly onto the take-up drum. Gently pull the tape from the take-up drum (a finger access slot is provided in the drum to permit gripping the coil with the thumb and forefinger).

2. Check the supply roll to ensure enough tape remains for the next recording period and reload the tape as described previously.

3. A tape leader must be completed in **all respects** and attached to the end of each tape as it is removed from the recorder and carefully transported to District Headquarters for data reduction.

12.4.2.4 Loading or replacing the punch paper tape

1. Ensure that the chad tray is installed correctly before threading paper tape. A retainer clip is located on the bottom of the chad tray. Press this clip over the guide rod until it rests between the guide rod collars. Push the tray straight up until the ears snap into place in the openings on the stripper bracket.

2. Twist the locking knob or keeper of the supply roll stud 1/4 turn. Remove the tape roll retainer. Place a roll of recording tape on the spindle so that the paper will feed from the bottom of the roll when mounted on the recorder. Check that the sides of the roll are smooth and flat (telescoping rolls will cause excessive drag). Replace the retainer and turn the keeper knob 1/4 turn.

   Unroll approximately 18 inches of tape. Write the site name and number along with the date and time within the first 18 inches of tape. Pass the tape below and around the guide rod. Insert it through the slot in the punching head. Pull the tape up and over the tape advance roller assembly meshing the projecting pins in the center of the drum with the holes in the center of the tape. Insert the end of the tape in the slot of the take-up drum. Turn the take-up drum counterclockwise to take up the remaining 8 to 10 inches of slack tape, thus securing the tape. Push and hold the test switch until the instrument has punched a minimum of four times. **Test punches must be consecutive up to begin time (no spaces).** Check that the tape has smoothly engaged the spines of the tape advance roller and that the rows of punched holes are evenly spaced. This checks that the tape is correctly threaded and is feeding properly.

12.4.2.5 Timing the Instrument

The Stevens Solid State Timer electronically initiates the punch cycle at time intervals as selected by the operator. Intervals are selected in 5 minute increments from 5 to 60 minutes. The preset button is used to synchronize the timer.

Most instruments in service are synchronized with the time of day; for instance on the hour. The preset feature saves the operator a long wait while synchronizing. While the timer is establishing the synchronizing period the minutes knob can be set to the operating punch interval.

Begin the timer set up by applying power to the recorder. Determine the time when you wish the timer to start. Rotate the minutes knob to a number less than the waiting period. For example, if the starting time is 1:00 PM and it is now 18 minutes until 1:00, set the knob to 15. Wait until 15 minutes to 1:00 and press the preset button. The recorder will immediately begin its punch cycle, including a pause of up to 7 seconds while the electronics package resets.

When the punch cycle is completed, set the knob to the punch interval desired. Example: each hour on the hour set the knob to 60. Do not turn the knob until the recorder has completed its punch cycle as this will **spoil the preset time interval.** No further time adjustment is necessary. The timer will operate the recorder at 1:00 and every 60 minutes thereafter.

12.4.2.6 Data Recorder Site Departure Check

Upon satisfactory completion of all tests and before leaving the station, perform the following procedures:

1. Ensure the instrument is properly logging.

2. Lock all appropriate equipment enclosures, battery and ZapNot boxes. Renew moisture absorbent materials and pest strips as needed. Check locks for proper lubrication.

3. Perform site maintenance as required. Cut the grass, secure weed mat, collect debris, etc.

4. Verify inventory if station service required any equipment change out.

5. Inspect fence integrity and repair as needed. Ensure fence gate is locked.

6. Verify proper completion of punch tape leader and miscellaneous field notes.

7. Perform a last general site inspection for tools, parts, or materials that could be left behind.

12.5 Telemetry of Data

The Sierra-Misco telemetry system is the primary radio telemetry system used by The Southwest Florida Water Management District and The St. Johns River Water Management District. The Model 0850 RTU's have on board processing and memory storage. The processor is fully programmable via software called Field Command either on site or remotely through the electronic transport from the central processing station. The Sierra-Misco telemetry system utilizes proprietary Sierra-Misco DataCommand software installed aboard a multi function/multi tasking QNX operating platform. As an extremely versatile system, all DataCommand operations focus on the storage of device data in the database.

The most critical element supporting telemetry acquired data integrity is careful documentation of station calibration and maintenance. This careful documentation is easily afforded by the following Telemetry Site Check QA Log.

The creation of this QA Log is an effort to standardize the service a Sierra-Misco 0850 Telemetry Site will receive when visited by authorized personnel and to carefully document the stations calibration and maintenance history. Without this documentation, accurate data verification would be hopeless.

The following procedures should be followed at each site visit regardless of the purpose of the visit.

Each site visit requires the completion of a Telemetry Site Check QA Log with entries into all appropriate blank spaces. Assure that this form is of the latest revision.

It is very important that as-found readings are entered into the QA Log before manual measurements and/or sensor tests are performed. Also, be certain that manual measurements and sensor tests are performed before as-left readings are entered into the QA Log.

TELEMETRY SITE CHECK QA Log Station Name___________________#__________

Date_______Time______EDT/EST,Purpose of Visit____________,Technician__________
Inspection:Fence_____Ionizer_____Antenna_____Wires_____RTU_____Solar Pan______
Weather:Cloud Cover(%)_____________,Wind:Speed(L,M,H)__________,Dir___________

As Found **As Left**

Data Logging:________________________________/________________________________
When Full, Discard:___________________________/_______________________________
Self Report Path:_____________________________/_______________________________
Report Path:_________________________________/________________________________
Report Format:_______________________________/________________________________
Report Data Type:____________________________/________________________________
Remote Clock Time:___________________________/________________________________

UpOnly 1(WD1) Parameter(Wind Speed)Sensor **Calibration found / left**

Periodic Data found/left Multiplier Value ________/___________
Report Sample Time _____/____ h/m/s/ Divisor Value ________/___________
Report Change Over _____/____ units Base Value ________/___________
Event Data found/left Cal/Raw Value _____/____//_____/____
Pre-divide Counter ______/______ counts **Report Methods found / left**

Event Report Change_____/____ units Device Active ________/___________
Alarm Report Change_____/_____ units Log Data ________/___________
Transmit Data ________/___________
Device Type/ID# ___________/______ Transmit Zeroes ________/___________
Transmit Events ________/___________

UpOnly 2(WD2) Parameter(Rain)Sensor Calibration found / left

Periodic Data found/left Multiplier Value ________/___________
Report Sample Time _____/____ h/m/s/ Divisor Value ________/___________
Report Change Over _____/____ units Base Value ________/___________

Event Data found/left Cal/Raw Value _____/____//_____/____
Pre-divide Counter _____/____ counts **Report Methods found / left**
Event Report Change_____/____ units Device Active _______/___________
Alarm Report Change_____/_____ units Log Data _______/___________
Transmit Data _______/___________
Device Type/ID#__________/____ Transmit Zeroes _______/___________
Count Test 5 Counts _______________ Transmit Events _______/___________

Analog( ) Parameter( ) Sensor Calibration found / left

Multiplier Value _______/___________

Periodic Data found/left Divisor Value _______/___________
Report Sample Time _____/____ h/m/s Base Value _______/___________
Report Change Over _____/____ units Cal/Raw Value _____/____//_____/____

Event Data found/left **Report Methods found / left**
Event Sample Time _____/____ h/m/s Device Active _______/___________
Event Report Change_____/____ units Log Data _______/___________
Alarm Report Change_____/____ units Transmit Data _______/___________
Device Type/ID# ____________/_______ Transmit Zeroes _______/___________
Tm______MP_____HO_____CUT_____DTW_____MSL_____HO_____CUT_____DTW_____MSL______
Tm______MP_____HO_____CUT_____DTW_____MSL_____HO_____CUT_____DTW_____MSL______
Staff Reading:__________/Datum____________
Calibration:(found) MSL Balanced_________ One Turn Up________ Balanced________
(left) MSL Balanced_________ One Turn Up________ Balanced________

Analog( ) Parameter( ) Sensor Calibration found / left

Multiplier Value ________/___________

Periodic Data found/left Divisor Value ________/___________
Report Sample Time _____/____ h/m/s Base Value ________/___________
Report Change Over _____/____ units Cal/Raw Value _____/____//_____/____

Event Data found/left **Report Methods found / left**
Event Sample Time _____/____ h/m/s Device Active ________/___________
Event Report Change_____/____ units Log Data ________/___________
Alarm Report Change_____/____ units Transmit Data ________/___________
Device Type/ID# _____________/______ Transmit Zeroes ________/___________
Tm______MP_____HO_____CUT_____DTW_____MSL_____HO_____CUT_____DTW_____MSL______
Tm______MP_____HO_____CUT_____DTW_____MSL_____HO_____CUT_____DTW_____MSL______
Staff Reading:__________/Datum____________
Calibration: (**found**) MSL Balanced_________ One Turn Up_______ Balanced_______
(**left**) MSL Balanced_________ One Turn Up_______ Balanced_______

Comments:____
____
____
____
____
____

Analog( ) Parameter( ) Sensor Calibration found / left

Multiplier Value _______/___________

Periodic Data found/left Divisor Value _______/___________

Report Sample Time _____/____ h/m/s Base Value _______/___________

Report Change Over _____/____ units Cal/Raw Value _____/____//_____/____

Event Data found/left **Report Methods found / left**

Event Sample Time _____/____ h/m/s Device Active _______/___________

Event Report Change_____/____ units Log Data _______/___________

Alarm Report Change_____/____ units Transmit Data _______/___________

Device Type/ID# ____________/_______ Transmit Zeroes _______/___________

Tm______MP_____HO_____CUT_____DTW_____MSL_____HO_____CUT_____DTW_____MSL______

Tm______MP_____HO_____CUT_____DTW_____MSL_____HO_____CUT_____DTW_____MSL______

Staff Reading:__________/Datum____________

Calibration: (found) MSL Balanced________ One Turn Up________ Balanced________

(left) MSL Balanced________ One Turn Up________ Balanced________

UpDown 1(D1) Parameter( ) Sensor Calibration found / left

Multiplier Value _______/___________

Periodic Data found/left Divisor Value _______/___________

Report Sample Time _____/____ h/m/s Base Value _______/___________

Report Change Over _____/____ units Cal/Raw Value _____/____//_____/____

Report Methods found / left

Event Data found/left Device Active _______/___________

Event Mode _____/____ 4 or 5 Log Data _______/___________

Event Report Change_____/____ units Transmit Data _______/___________

Alarm Report Change_____/____ units Transmit Zeroes _______/___________

Device Type/ID#________________/______ Transmit Events _______/___________

Tm______MP_____HO_____CUT_____DTW_____MSL_____HO_____CUT_____DTW_____MSL______

Tm______MP_____HO_____CUT_____DTW_____MSL_____HO_____CUT_____DTW_____MSL______

Staff Reading:________/Datum_________

Calibration: (found) MSL Balanced________ One Turn Up________ Balanced________

(left) MSL Balanced________ One Turn Up________ Balanced________

UpDown 2(D2) Parameter( ) Sensor Calibration found / left

Multiplier Value _______/___________

Periodic Data found/left Divisor Value _______/___________

Report Sample Time _____/____ h/m/s Base Value _______/___________

Report Change Over _____/____ units Cal/Raw Value _____/____//_____/____

Report Methods found / left

Event Data found/left Device Active _______/___________

Event Mode _____/____ 4 or 5 Log Data _______/___________

Event Report Change_____/____ units Transmit Data _______/___________

Alarm Report Change_____/____ units Transmit Zeroes _______/___________

Device Type/ID# ____________/_______ Transmit Events _______/___________

Tm______MP_____HO_____CUT_____DTW_____MSL_____HO_____CUT_____DTW_____MSL______

Tm______MP_____HO_____CUT_____DTW_____MSL_____HO_____CUT_____DTW_____MSL______

Staff Reading:__________/Datum____________

Calibration: (found) MSL Balanced________ One Turn Up________ Balanced________

(left) MSL Balanced________ One Turn Up________ Balanced________

Analog(8) Parameter(RTU Battery) Sensor Calibration found / left

Multiplier Value ______/___________

Periodic Data found/left Divisor Value ______/___________

Report Sample Time _____/____ h/m/s Base Value ______/___________

Report Change Over _____/____ units Cal/Raw Value _____/____//_____/____

Event Data found/left **Report Methods found / left**

Event Sample Time _____/____ h/m/s Device Active _______/___________

Event Report Change_____/_____ units Log Data _______/___________

Alarm Report Change_____/_____ units Transmit Data _______/___________

Device Type/ID#___________/_____ Transmit Zeroes _______/___________

Hydrometer Check: Average Reading__________

Internal Battery Voltage: W/Ext V ___________ W/O Ext V __________

External Battery Voltage: W/O Fuse_____ Fuse Ok_____ Liquid Ok_____

Comments:____

____

Analog( ) Parameter(Air Temp) Sensor Calibration found / left

Multiplier Value _______/___________

Periodic Data found/left Divisor Value _______/___________

Report Sample Time _____/____ h/m/s Base Value _______/___________

Report Change Over _____/____ units Cal/Raw Value _____/____//_____/____

Event Data found/left **Report Methods found / left**

Event Sample Time _____/____ h/m/s Device Active _______/___________

Event Report Change_____/____ units Log Data _______/___________

Alarm Report Change_____/____ units Transmit Data _______/___________

Device Type/ID#______________/_______ Transmit Zeroes _______/___________

Manual Measurement: (found)_________ (left)________

Analog( ) Parameter(Dewpoint Temp) Sensor Calibration found / left

Multiplier Value _______/___________

Periodic Data found/left Divisor Value _______/___________

Report Sample Time _____/____ h/m/s Base Value _______/___________

Report Change Over _____/____ units Cal/Raw Value _____/____//_____/____

Event Data found/left **Report Methods found / left**

Event Sample Time _____/____ h/m/s Device Active _______/___________

Event Report Change_____/____ units Log Data _______/___________

Alarm Report Change_____/____ units Transmit Data _______/___________

Device Type/ID#_____________/_______ Transmit Zeroes _______/___________

DP Cal: (found) Dry Bulb______ Wet Bulb______ Depression______ = DP______

(left) Dry Bulb______ Wet Bulb______ Depression______ = DP______

Mirror Cleaned:(y/n)____ **Adjustment:** Coarse(y/n)____ Fine(y/n)____

Analog( ) Parameter(Water Temp) Sensor Calibration found / left

Multiplier Value _______/___________

Periodic Data found/left Divisor Value _______/___________

Report Sample Time _____/____ h/m/s Base Value ________/___________

Report Change Over _____/____ units Cal/Raw Value _____/____//_____/____

Event Data found/left **Report Methods found / left**

Event Sample Time _____/____ h/m/s Device Active _______/___________

Event Report Change_____/____ units Log Data _______/___________

Alarm Report Change_____/____ units Transmit Data _______/___________

Device Type/ID# ____________/_______ Transmit Zeroes _______/___________

Manual Measurement: (found)________ (left)________

Analog( ) Parameter(Evaporation) Sensor Calibration found / left

Multiplier Value _______/___________

Periodic Data found/left Divisor Value _______/___________

Report Sample Time _____/____ h/m/s Base Value _______/___________

Report Change Over _____/____ units Cal/Raw Value _____/____//_____/____

Event Data found/left **Report Methods found / left**

Event Sample Time _____/____ h/m/s Device Active _______/___________

Event Report Change_____/____ units Log Data _______/___________

Alarm Report Change_____/____ units Transmit Data _______/___________

Device Type/ID#__________/______ Transmit Zeroes _______/___________

Hook Gauge Measurement: as found______ as left______ Water Added ?_____

Analog( ) Parameter(DP Batt) Sensor Calibration found / left

Multiplier Value _______/___________

Periodic Data found/left Divisor Value _______/___________

Report Sample Time _____/____ h/m/s Base Value _______/___________

Report Change Over _____/____ units Cal/Raw Value _____/____//_____/____

Event Data found/left **Report Methods found/left**

Event Sample Time _____/____ h/m/s Device Active _______/___________

Event Report Change_____/_____ units Log Data _______/___________

Alarm Report Change_____/_____ units Transmit Data _______/___________

Device Type/ID#______________/______ Transmit Zeroes _______/___________

Hydrometer Check: Average Reading__________

Battery Voltage: External_________ Internal +24 Volts_________

Comments:____

____

____

____

____

Analog( ) Parameter( ) Sensor Calibration found / left

Multiplier Value _______/___________

Periodic Data found/left Divisor Value _______/___________

Report Sample Time _____/____ h/m/s Base Value _______/___________

Report Change Over _____/____ units Cal/Raw Value _____/____//_____/____

Event Data found/left **Report Methods found / left**

Event Sample Time _____/____ h/m/s Device Active _______/___________

Event Report Change_____/____ units Log Data _______/___________

Alarm Report Change_____/____ units Transmit Data _______/___________

Device Type/ID# ____________/_______ Transmit Zeroes _______/___________

Tm______MP_____HO_____CUT_____DTW_____MSL_____HO_____CUT_____DTW_____MSL______

Tm______MP_____HO_____CUT_____DTW_____MSL_____HO_____CUT_____DTW_____MSL______

Staff Reading:__________/Datum____________

Calibration: (found) MSL Balanced________ One Turn Up________ Balanced________

(left) MSL Balanced________ One Turn Up________ Balanced________

Analog( ) Parameter( ) Sensor Calibration found / left

Multiplier Value _______/___________

Periodic Data found/left Divisor Value _______/___________

Report Sample Time _____/____ h/m/s Base Value _______/___________

Report Change Over _____/____ units Cal/Raw Value _____/____//_____/____

Event Data found/left **Report Methods found / left**

Event Sample Time _____/____ h/m/s Device Active _______/___________

Event Report Change_____/____ units Log Data _______/___________

Alarm Report Change_____/____ units Transmit Data _______/___________

Device Type/ID# _____________/______ Transmit Zeroes _______/___________

Tm______MP_____HO_____CUT_____DTW_____MSL_____HO_____CUT_____DTW_____MSL______

Tm______MP_____HO_____CUT_____DTW_____MSL_____HO_____CUT_____DTW_____MSL______

Staff Reading:__________/Datum____________

Calibration: (found) MSL Balanced________ One Turn Up________ Balanced________

(left) MSL Balanced________ One Turn Up________ Balanced________

Analog( ) Parameter( ) Sensor Calibration found / left

Multiplier Value _______/___________

Periodic Data found/left Divisor Value _______/___________

Report Sample Time _____/____ h/m/s Base Value _______/___________

Report Change Over _____/____ units Cal/Raw Value _____/____//_____/____

Event Data found/left **Report Methods found / left**

Event Sample Time _____/____ h/m/s Device Active _______/___________

Event Report Change_____/____ units Log Data _______/___________

Alarm Report Change_____/____ units Transmit Data _______/___________

Device Type/ID# _____________/______ Transmit Zeroes _______/___________

Tm______MP_____HO_____CUT_____DTW_____MSL_____HO_____CUT_____DTW_____MSL______

Tm______MP_____HO_____CUT_____DTW_____MSL_____HO_____CUT_____DTW_____MSL______

Staff Reading:__________/Datum____________

Calibration: (found) MSL Balanced________ One Turn Up________ Balanced________

(left) MSL Balanced________ One Turn Up________ Balanced________

COMMENTS:____

12.5.1 Visual Inspection

Each site visit should start with a preliminary visual inspection as the technician is driving up to the site. Look for things such as birds perching atop the ionizers or on the antenna and solar panel. Observe any animals that may adversely affect the site's integrity or any fast growing trees or shrubs that may soon become obstructions to the precipitation, wind, or radiation instruments.

Upon arrival at the site, perform a detailed visual inspection. Observe and/or confirm:

- that the solar panel still facing south;
- that the antenna horizontal to the ground and pointing toward the proper station and the antenna mounting pole is vertical;
- that the ionizer is pointing up and the fine wires atop the ionizer are still in place and show no damage from birds;
- that the exposed wires and cables are secure and not able to move in the breeze;
- the fence for any damaged;
- for any evidence of vandalism. Take pictures, determine the cost of damages, and contact your supervisor regarding any noted vandalism.

Upon completion of visual inspection, start entries into the Telemetry Site Check QA Log.

1. Enter the station name and number and the date and time of your arrival with the appropriate EDT/EST time designation.

2. Enter the purpose of your visit. **Routine** if the visit is for standard two months interval service. **Off line** if the station was not reporting. **Other** if the station is reporting intermittently, a parameter is not reporting, base station data from this site appears unusual, etc.

3. Enter your name in the blank beside Technician.

4. Clean the solar panel with a soft, moist, non-abrasive cloth, then complete the inspection part of the QA Log in the blanks after fence, ionizer, antenna, wires, RTU, and solar pan. If these items passed inspection, indicate by placing check mark or Ok in the blank beside each item.

5. Observe the weather conditions at the time of your visit. Record these conditions in the QA Log under weather. Record your estimated percent of cloud cover. Record your estimate of wind speed as L (light), M

(medium), or H (heavy). Note and record the direction the wind is blowing **from** (N,NE,E,SE,S,SW,W,NW).

12.5.2 Field Command

Attach the laptop computer cable to the RTU serial port, boot up the SM Field Command Software in the laptop. Log in as mngr and perform the following task:

1. Select Field Command Program No.1 Program Sensors.

   A. From the menu bar, pull down **Select** to identify the station to which you wish to communicate.

   B. Esc to the menu bar and pull down **Station**. Observe and record in QA Log the following **as-found** information:

	(**should read**)
Data Logging:____________	enable
When Full, Discard:______	oldest data
Self Report Path:________	(self report path)
Report Path:_____________	use report path
Report Format:_______	16 bit binary calibrated
Report Data Type:_______	current reading
Remote Clock Time:_____	(time and date in EST)

12.5.2.1 Recording Parameter Set-Ups

A telemetry site is visited for a number of different reasons. The purpose of a site visit may be routine maintenance service, outage service, calibration service, or a drop by visit because the technician was in the area on other business. Whatever the purpose of the visit, it is important that a QA Log be completed for each visit.

After completing the **as-found** portion of the **station** set-ups, escape to the menu bar of Field Command and pull down **Device**. Complete the appropriate parameter set-up portion of the QA Log. This should be performed one parameter at a time as follows:

1. Record the **as-found** readings for the parameter.

2. Disable all report methods for the parameter being attended.

3. Perform the required testing or calibration and record the results of such tests or calibration.

4. Record the **as-left** readings for the parameter.

5. Enable the attended parameter after parameter test are performed and **as-left** adjustments made.

The **as-found**, test results, and **as-left** portions of the QA Log should be completed for each parameter before moving to the next parameter.

It is important that the as-found readings and the test results for each parameter be tied together. Perform appropriate tests very soon after as-found readings are logged and record any necessary as-left error adjustments as quickly as is practical. Timeliness in this effort is very important as most of these tests are actually instrument calibrations. In the case of manual water level measurements where the levels are changing rapidly, just five minutes between as-found, manual measurement, and as-left corrections can cause a sizable error in the station calibration. Further discussions of this subject are included under the specific parameters following in this chapter.

12.5.2.1.1 UP Only 1 (WD1)

In almost all cases the RTU channel WD1 is used for measuring wind velocity. The District uses two different types of wind sensors, both from the same manufacturer. These sensor types are R. M. Young Model 05103 Wind Monitor and R. M. Young Model 03001 Wind Sentry. Each of these sensors require different parameter set-ups. These different set-ups are discussed under the (*) notation below.

The District uses two different methods of measuring wind velocity: the measurement of wind speed and the measurement of wind run. The measurement of wind speed is in the form of miles or kilometers per hour. The measurement of wind run is the amount of time required for a given volume of air to move a distance of one mile. These two methods also require different parameter set-ups and are discussed under the (**) notation below.

Note: Disable all report methods before performing any tests or calibrations.

The following set-ups are typical for this channel.

UpOnly 1(WD1) Parameter(Wind Speed)Sensor Calibration found/left
Periodic Data found/left Multiplier Value _1___/_1__
Report Sample Time __**__ / __**__ h/m/s/ Divisor Value _1___/_1__

Report Change Over __0__/_0__ units Base Value _0___/_0__
Event Data **found/left** Cal/Raw Value _____/____
Pre-divide Counter ****/**** counts **Report Methods found/left**
Event Report Change **/ ** units Device Active __E__/_E__
Alarm Report Change32768/32768 units Log Data __E__/_E__
Transmit Data __E__/_E__
Device Type/ID# ___________/______ Transmit Zeroes __E__/_E__
Transmit Events __E__/_E__

===

Periodic Data

Report Sample Time: This is the length of time between data reports.

** -- Wind Speed MPH = 15 minutes

** -- Wind Run = 1 hour

Report Change Over: The "0" here means that the RTU will report on its scheduled time even if no change has occurred since its last report.

Event Data

Pre-divide Counter: The entry here must correspond to the number of pulses output from the sensor per desired measurement increment (the particular instrument in miles per hour, kilometers per hour, feet per second, knots, etc).

* -- Model 05103 wind speed 15 minute report Pre-divide counter = 4105 counts.

* -- Model 03001 wind speed 15 minute report Pre-divide counter = 533 counts.

** - Model 05103 wind run 1 hour report Pre-divide counter = 16420 counts.

** - Model 03001 wind run 1 hour report Pre-divide counter = 2130 counts.

Event Report Change: This number indicates the number of calibrate value increments that must occur before an event report will take place.

** - For wind speed measurements this number should be very large. The value is not critical but an event report is not desired when measuring wind velocity.

** - For wind run this number must be 1 because the wind run time is measured by the report interval between calibrate value increments.

Alarm Report Change: This number indicates the number of calibrate value increments that must occur before an alarm report will take place. This number should be very large. The value is not critical but an event report is not desired when measuring wind velocity.

Device Type/ID# Record sensor type here. Prop or Cup.

Example: Model 05103 is a propeller (prop) type.

Model 03001 is a (cup) type.

Note: The device type is very important in determining the Per-divide Counter value.

Sensor Calibration

Multiplier Value: Should always be 1 for wind.

Divisor Value: Should always be 1 for wind.

Base Value: Should always be 0 for wind.

Cal/Raw Value: Cal Value = Multiplier Value X Raw Value, Divided by the Divisor Value, then add or subtract the Base Value. Cal = [(Mult x Raw)/Div] + (± Base).

Report Methods

Device Active	Enable when in service.

Log Data	Enable when in service.

Transmit Data	Enable when in service.

Transmit Zeroes	Enable when in service.

Transmit Events	Enable when in service.

Note: Enable all report methods before proceeding to the next parameter.

12.5.2.1.2 UP Only 2 (WD2)

In almost all cases the RTU channel WD2 is used for measuring precipitation. The District uses tipping bucket type rain gauges with 1mm and 0.01 inch per tip increment.

Note: Disable all report methods before performing and tests or calibrations.

The following set-ups are typical for this channel.

UpOnly 2(WD2) Parameter(Rain)Sensor Calibration found/left
Periodic Data found/left Multiplier Value__1__/_1__
Report Sample Time _6h__/_6h_ h/m/s/ Divisor Value__1__/_1__
Report Change Over __0__/_0__ units Base Value__0__/_0__
Event Data found/left Cal/Raw Value_____/____
Pre-divide Counter __1__/_1__ counts **Report Methods found/left**
Event Report Change__1__/_1__ units Device Active__E__/_E__
Alarm Report Change 1130/ 1130 units Log Data__E__/_E__ Transmit Data__E__/_E__
Device Type/ID#__________/____ Transmit Zeroes__E__/_E__
Count Test 5 Counts _______________ Transmit Events__E__/_E__

===

Device Type/ID# Record here the type of rain gauge. Sierra-Misco model 2500, Weathermeasure, Rainwise, Sutron, etc.

Count Test 5 Counts

Use a Qualimetrics Inc. rain gauge calibrator to perform this test. First ensure that all report methods for the rain gauge channel (WD2) are disabled in the RTU and note the calibrated/raw value prior to the tip test.

Perform this test before anything is done to the rain gauge. No removal of screens or funnels, no cleaning, no inspection, no adjustment, no anything. This test will often inform you as to the integrity of the rainfall measurement at this site since the last visit.

Allow the water from the calibrator to enter the outer funnel while touching as little of the outer screens as possible. Some insect screens can wick and hold as much as 0.03 inch of water.

The calibrator drip rate is approximately 2.00 inches per hour or about 18 seconds per tip. Drip-pour the water past the screens until one bucket tip is heard then remove the calibrator. If water is drip-poured into the funnel for a period longer than one minute without a tip then discontinue the test and take the necessary action to free the tipping bucket. After the tip is heard, read parameters via the laptop to verify that the tip was registered. Repeat this test five times. All five tips must register for proper operation.

Should it be necessary to perform this bucket tip test manually, the tipping action must be done slowly. Be very careful not to let the bucket move backward once the forward motion has started. This backward movement may allow the magnet to double trip the micro switch. Read parameters after each tip.

After successfully completing the tip test, inspect the gauge. Clear the screens, drains, inner and outer funnels, and tipping bucket of all debris and obstructions and wipe clean. Be especially observant for spider webbing on the sides of the tipping bucket.

Move the bucket from side to side to ensure that the pivot pen has enough play for it not to bind yet is tight enough for it not to fall out. Renew the insect repellant as needed.

Check the rain gauge for level and adjust as necessary.

Note: Enable all report methods before proceeding to the next parameter.

12.5.2.1.3 Analog Stage

A variety of electrical analog sensors are used for measuring surface water stage and ground water levels. All these sensors follow the same basic set-up protocol in the RTU.

Note: Disable all report methods before performing any test or calibrations.

The following set-ups are typical for an analog stage channel.

Analog(2) Parameter(BR-402) Sensor Calibration found/left
Multiplier Value_____/____
Periodic Data found/left Divisor Value_1023/1023
Report Sample Time _1h__/_1h_ h/m/s Base Value_____/____
Report Change Over _0___/_0__ units Cal/Raw Value_____/____
Event Data found/left **Report Methods found/left**
Event Sample Time _15m_/15m_ h/m/s Device Active__E__/_E__
Event Report Change_25__/_25_ units Log Data__E__/_E__
Alarm Report Change_75__/_75_ units Transmit Data__E__/_E__ Device Type/ID#
____________/_______ Transmit Zeroes__E__/_E__
Tm_____MP____HO____CUT____DTW____MSL____HO____CUT___DTW___MSL____
Staff Reading:__________/Datum____________
Calibration:(found)MSL Balanced____ One Turn Up____ Balanced_____
(left) MSL Balanced_____ One Turn Up_____ Balanced_____

==

Device Type/ID#

Record here some descriptive term of the sensor being used for this parameter such as: Celesco, Pot Stand, Metritape, Balluff, Lyndal, etc.

Multiplier Value

Record here the rated full measuring range of the sensor in whole numbers of the resolution desired.

Examples: Pot Stand (ten turn), range 10 feet, resolution 0.01 ft, multiplier value is 1000.

Celesco, range 83.33 ft, resolution 0.01 ft, multiplier value is 8333.

Divisor Value

Record here the desired full measurement binary value of the analog to digital converter of the RTU.

Example: The full scale range of the 10 bit A/D converter in the RTU is +5 VDC input. This 10 bits = full scale binary value of 1023.

Therefore, if the full scale output of the sensor is +5 VDC, then the Divisor Value for the parameter should be 1023.

Base Value

This applies to all analog channels. After the multiplier and divisor values are properly entered, changing the base value becomes the only correct way of manually adjusting the calibrate value. Record here the value required to cause the correct calibrate value.

Calibrate/Raw Value

Recording both calibrate and raw values is important. The raw value relationship with base, divisor, and multiplier values determines the calibrate value, and thus the integrity of the parameter itself.

Calibrate value = [(raw value x mult value)/divisor value] + (± base value)

Report Methods

All report methods (device active, log data, transmit data, and transmit zeros) must be enabled when parameter is in operation.

Perform a manual water level measurement at all stations monitoring **stage** or **ground water levels.**

Analog( ) Parameter( ) Sensor Calibration found/left
Multiplier Value_____/____
Periodic Data found/left Divisor Value_____/____
Report Sample Time _____/____ h/m/s Base Value_____/____
Report Change Over _____/____ units Cal/Raw Value_____/____
Event Data found/left **Report Methods found/left**
Event Sample Time _____/____ h/m/s Device Active_____/____
Event Report Change_____/____ units Log Data_____/____
Alarm Report Change_____/____ units Transmit Data_____/____ Device Type/ID# ____________/________ Transmit Zeroes_____/____
Tm_____MP____HO____CUT____DTW____MSL____HO____CUT___DTW___MSL____
Staff Reading:__________/Datum____________
Calibration:(found)MSL Balanced_____ One Turn Up____ Balanced____
(left) MSL Balanced_____ One Turn Up____ Balanced____
==

Just before making the manual measurements, read parameters of the corresponding device and note the calibrated/raw values. These are the **as-found** values for the QA Log.

Record manual water level measurements in the QA Log under the appropriate parameter starting with the time (Tm) of the measurements. These manual readings require a minimum of two measurements which are repeatable to within 0.01 ft. This information should be entered in the blanks of the QA Log as highlighted in **bold print** in the preceding example.

Tm This is the starting time of the manual measurements. Record this in Eastern Standard Time (EST).

MP Measuring Point (MP) is the reference elevation for the manual measurement. Usually the elevation of the instrument platform or shelter floor.

Ho Hold (Ho) is the measurement point of the steel tape which you hold to the MP during a manual measurement.

Cut This is the point where the water level intersects the chalked steel tape during a manual measurement. This tape reading is subtracted from the Ho (hold) reading to equal DTW.

DTW Down To Water (DTW) = Ho - Cut. DTW is subtracted from MP to equal MSL (mean sea level).

MSL Mean Sea Level (MSL) = MP - DTW. The term used to reference water levels. A measurement of 10' MSL means the water level is 10 ft above Mean Sea Level. A measurement of -5 ft MSL means the water level is 5 feet below Mean Sea Level.

After completing the manual water level measurement, compare the as found calibrated value with the manual reading MSL. If the values differ by more than 0.01 feet then change the base value until the calibrated value is equal the manually measured value. Save these changes and this then becomes the **as left** entry into the QA Log.

Remember there are no decimals in the calibrated value. If the calibrated value is 2544, this means the water level is 25.44 ft MSL. A calibrated value of 23 would be .23 ft MSL.

Note: It is very important that the lapse time between the RTU as found and manual measurement be as short as is practical. If the water level changes between the RTU as found reading and the manual measurements, then editing errors can occur in the QA process.

Staff Reading

Record the staff reading for all stations with staff gauges. Record all appropriate readings including the datum of the staff gauge.

Calibration

Float/Counter Weight Sensor Calibrations are measured through the RTU via the laptop. The calibration information is entered in the QA Log as is highlighted in **bold print** in the following example. The balanced water level MSL is entered in the QA Log before and after the entry representing one full turn of the pulley in the direction which raises the float.

Analog( ) Parameter( ) Sensor Calibration found/left
Multiplier Value_____/____

Periodic Data found/left Divisor Value_____/____
Report Sample Time _____/____ h/m/s Base Value_____/____
Report Change Over _____/____ units Cal/Raw Value_____/____
Event Data found/left **Report Methods found/left**
Event Sample Time _____/____ h/m/s Device Active____/____ Event Report Change_____/____ units Log Data_____/____
Alarm Report Change_____/____ units Transmit Data_____/____ Device Type/ID# ____________/______ Transmit Zeroes_____/____
Tm_____MP____HO____CUT____DTW____MSL____HO____CUT___DTW___MSL____
Staff Reading:__________/Datum____________
Calibration:(found)MSL Balanced_____ One Turn Up____ Balanced____
(left) MSL Balanced____ One Turn Up____ Balanced_____
===

It is important that when rotating the pulley for this test, the direction of rotation always raises the float. If the pulley is rotated in the direction to raise the counterweight then slack is created in the tape just above the float, thus allowing for the possibility of the attachment clip hanging in the float eyelet and causing an error in future data.

Note: This is an extremely important test. It determines if the increase and decrease of the calibrate/raw value follows in the same direction of the water movement and by the proper amount.

Note: Enable all report methods before proceeding to the next parameter.

12.5.2.1.4 Wind Direction

The District uses two different types of wind sensors both from the same manufacturer. These sensor types are R. M. Young Model 05103 Wind Monitor and R. M. Young Model 03001 Wind Sentry. Both sensors are analog potentiometric output and require the same RTU set-ups.

Note: Disable all report methods before performing any tests or calibrations.

Typical parameter set-ups for this device are as follows:

Analog( ) Parameter( ) Sensor Calibration found/left
Multiplier Value 360 / 360 **Periodic Data found/left** Divisor Value1023 /1023
Report Sample Time 1h / 1h h/m/s Base Value 0 / 0
Report Change Over 0 / 0 units Cal/Raw Value 0 / 0
Event Data found/left **Report Methods found/left**
Event Sample Time 0s / 0s h/m/s Device Active E / E
Event Report Change23062/23062 units Log Data E / E
Alarm Report Change23062/23062 units Transmit Data E / E Device Type/ID# Cup or Prop Type/____ Transmit Zeroes E / E
Tm_____MP____HO____CUT____DTW____MSL____HO____CUT___DTW___MSL____
Staff Reading:__________/Datum____________
Calibration:(found)MSL Balanced_____ One Turn Up____ Balanced____
(left) MSL Balanced____ One Turn Up____ Balanced_____
===

The sensor measures wind direction in a 360 degree arc with a measurement resolution of one degree. Therefore the multiplier value is 360.

The sensor output is 0 to 5 VDC representing an azimuth 0 to 360 degrees respectively. Therefore the divisor value is the full scale 10 bit binary value of 1023.

Perform a one point field calibration on the wind direction sensor by using a magnetic compass to determine the direction the wane is pointing. Read parameters of the wind direction device and compare the RTU reading with the manual observation.

Note: Enable all report methods before proceeding to the next parameter.

12.5.2.1.5 Digital Stage D1 and D2

The District uses two types of digital water level sensors for telemetry. The optical shaft incremental encoder and the magnetic switch incremental encoder. The device set-ups for both sensors are the same.

Note: Disable all report methods before performing any tests or calibrations.

Typical parameter set-ups for this device are as follows:

UpDown 1(D1) Parameter(Well Br-549) Sensor Calibration found/left

Multiplier Value 100 / 100

Periodic Data found/left Divisor Value 300 / 300

Report Sample Time 1h / 1h h/m/s Base Value 0 / 0

Report Change Over 0 / 0 units Cal/Raw Value_____/____

Report Methods found/left

Event Data found/left Device Active E / E

Event Mode 4 / 4 4 or 5 Log Data E / E

Event Report Change 25 / 25 units Transmit Data E / E

Alarm Report Change 75 / 75 units Transmit Zeroes E / E

Device Type/ID#________________/______ Transmit Events E / E

Tm_____MP____HO____CUT____DTW____MSL____HO___CUT___DTW____MSL____

Staff Reading:________/Datum_________

Calibration:(found)MSL Balanced_____ One Turn Up____ Balanced____

(left) MSL Balanced_____ One Turn Up____ Balanced____

==

Device Type/ID#

Record here some descriptive term of the sensor being used for this parameter, such as: Charlie Wheel, shaft encoder, etc.

Event Mode

Event mode values 4 and 5 determine the direction of calibrate value progression as the sensor pulley is rotated. If the event mode value is 4 and the pulley is rotated in the direction raising the float, the calibrate value should increase. If the calibrate value decreases when raising the float then change the event mode value to 5.

Multiplier Value

Record here the circumference of the pulley used on the sensor. Usually 12 inches for sensors measuring in English units. This value should be in whole numbers of the resolution desired.

Examples: Incremental encoders with pulley circumference of 12 inches and desired resolution of 0.01 ft. Multiplier value = 100.

Divisor Value

Record here the number of increments produced by the encoder for each full revolution of the sensor pulley.

Example: Incremental encoders with an output of 300 increments per shaft rotation. The divisor value = 300.

Base Value

This applies to channels D1 and D2 only. After the multiplier and divisor values are properly entered, required corrections of the calibrate/raw value should be made directly to the calibrated/raw value and not by adjusting the base value.

Report Methods

All report methods (device active, log data, transmit data, and transmit zeros) must be enabled when parameter is in operation.

Note: Disable all report methods before performing any tests or calibrations.

Perform a manual water level measurement at all stations monitoring stage or ground water levels.

UpDown 2(D2) Parameter(   ) Sensor Calibration found/left
Multiplier Value_____/____
Periodic Data found/left Divisor Value_____/____
Report Sample Time _____/____ h/m/s Base Value_____/____
Report Change Over _____/____ units Cal/Raw Value_____/____
Report Methods found/left
Event Data found/left Device Active_____/____
Event Mode _____/____ 4 or 5 Log Data_____/____
Event Report Change_____/____ units Transmit Data_____/____
Alarm Report Change_____/____ units Transmit Zeroes_____/____
Device Type/ID# _____________/_______ Transmit Events_____/____
Tm_____MP____HO____CUT____DTW____MSL____HO____CUT____DTW___MSL___
Staff Reading:__________/Datum____________
Calibration:(found)MSL Balanced_____ One Turn Up____ Balanced____
(left) MSL Balanced_____ One Turn Up____ Balanced____

Just before making the manual measurements, read parameters of the corresponding device and note the calibrated/raw values. These are the **as-found** values for the QA Log.

Record manual water level measurements in the QA Log under the appropriate parameter starting with the time (Tm) of the measurements. These manual readings require a minimum of two measurements which are repeatable to within 0.01 ft. This information should be entered in the blanks of the QA Log as highlighted in **bold print** in the preceding example.

Tm This is the starting time of the manual measurements. Record this in Eastern Standard Time (EST).

MP Measuring Point (MP) is the reference elevation for the manual measurement. Usually the elevation of the instrument platform or shelter floor.

Ho Hold (Ho) is the measurement point of the steel tape which you hold to the MP during a manual measurement.

Cut This is the point where the water level intersects the chalked steel tape during a manual measurement. This tape reading is subtracted from the Ho (hold) reading to equal DTW.

DTW Down To Water (DTW) = Ho - Cut. DTW is subtracted from MP to equal MSL (mean sea level).

MSL Mean Sea Level (MSL) = MP - DTW. The term used to reference water levels. A measurement of 10' MSL means the water level is 10 ft above Mean Sea Level. A measurement of -5 ft MSL means the water level is 5 ft below Mean Sea Level.

After completing the manual water level measurement, compare the as found calibrated value with the manual reading MSL. If the values are different by more than 0.01 ft then directly change the calibrated value to equal the manually measured value. Save these changes and this then becomes the **as left** entry into the QA Log.

Remember there are no decimals in the calibrated value. If the calibrated value is 2544, this means the water level is 25.44 ft MSL. A calibrated value of 23 would be .23 ft MSL.

Note: It is very important that the lapse time between the RTU as found and manual measurements be as short as is practical. If the water level changes between the RTU as found reading and the manual measurements, then editing errors can occur in the QA process.

Staff Reading

Record the staff reading for all stations with staff gauges. Record all appropriate readings including the datum of the staff gauge.

Calibration

Float/Counter Weight Sensor Calibrations are measured through the RTU via the laptop. The calibration information is entered in the QA Log as is highlighted in **bold print** in the following example. The balanced water level MSL is entered in the QA Log before and after the entry representing one full turn of the pulley in the direction which raises the float.

UpDown 2(D2) Parameter( ) Sensor Calibration found/left
Multiplier Value_____/____
Periodic Data found/left Divisor Value_____/____
Report Sample Time _____/____ h/m/s Base Value_____/____
Report Change Over _____/____ units Cal/Raw Value_____/____
Report Methods found/left
Event Data found/left Device Active_____/____
Event Mode _____/____ 4 or 5 Log Data_____/____
Event Report Change_____/____ units Transmit Data_____/____
Alarm Report Change_____/____ units Transmit Zeroes_____/____
Device Type/ID# _____________/_______ Transmit Events_____/____
Tm_____MP____HO____CUT____DTW____MSL____HO____CUT____DTW___MSL___
Staff Reading:__________/Datum____________
Calibration:(found)MSL Balanced_____ One Turn Up____ Balanced____
(left)MSL Balanced_____ One Turn Up____ Balanced____

===

It is important that when rotating the pulley for this test, the direction of rotation always raises the float. If the pulley is rotated in the direction to raise the counterweight, then slack is created in the tape just above the float, thus allowing for the possibility of the attachment clip hanging in the float eyelet and causing an error in future data.

Note: This is an extremely important test. It determines if the increase and decrease of the calibrate/raw value follows in the same direction of the water movement and by the proper amount.

Note: Enable all report methods before proceeding to the next parameter.

12.5.2.1.6 Analog 8 RTU Battery

Analog channel 8 is an internally wired housekeeping channel for the RTU that measures the stations +12 VDC power source. This channel is pre-wired by the manufacturer and is designed to measure DC voltages between 9 and 16 volts.

Note: Disable all report methods before performing any tests or calibrations.

The following are typical set-ups for this channel.

Analog(8) Parameter(RTU Battery) Sensor Calibration found/left

	Multiplier Value 15677/15677
Periodic Data found/left	Divisor Value 10000/10000
Report Sample Time 1h / 1h h/m/s	Base Value 0 / 0
Report Change Over 0 / 0 units	Cal/Raw Value_____/____
Event Data found/left	**Report Methods found/left**
Event Sample Time 0s / 0s h/m/s	Device Active E / E
Event Report Change 28333/28333 units	Log Data E / E
Alarm Report Change 28333/28333 units	Transmit Data E / E
Device Type/ID#___________/_____	Transmit Zeroes E / E

Hydrometer Check:__________

Internal Battery Voltage: W/Ext V__________ W/O Ext V___________

External Battery Voltage: W/O Fuse____ Fuse Ok_____ Liquid Ok____

==

Batteries must receive proper care if they are to render adequate service. Perform the following checks at each routine site visit.

- Check the fluid level of each battery cell and acknowledge in the QA Log. If the level is below the notch in the cell, add **distilled** water until fluid level reaches the **bottom** of the notch. **Do not** over fill the cell. Over filling can cause electrolyte over flow during charging.

- Remove any corrosion on the battery terminals and in the fuse holder. Apply a terminal protecting grease or spray if needed. Remove any evidence of electrolyte overflow.

- Using a hydrometer, check the specific gravity of each cell and record the average in the QA Log Hydrometer Check. If any cell measures a specific gravity less than 1200, the battery must be replaced.

- Measure the internal battery voltage with the external battery connected and record the value in the QA Log.

- Measure the internal battery voltage with the external battery disconnected and record the value in the QA Log.

- Measure the external battery voltage without its fuse and record the value in the QA Log.

  Note: Enable all report methods before proceeding to the next parameter.

12.5.2.1.7 Analog Ambient Temperature

Air temperature can be measured with any analog channel.

Note: Disable all report methods before performing any tests or calibrations.

Typical RTU set-ups for a temperature sensor with a range of 0°F to 100°F and output of 4 ma to 20 ma are as follows.

Analog( ) Parameter(Air Temp)Sensor Calibration found/left
Multiplier Value 125 / 125
Periodic Data found/left Divisor Value1023 /1023
Report Sample Time 1h / 1h h/m/s Base Value -25 / -25
Report Change Over 0 / 0 units Cal/Raw Value_____/____
Event Data found/left **Report Methods found/left**
Event Sample Time 5m / 5m h/m/s Device Active E / E
Event Report Change 41 / 41 units Log Data E / E
Alarm Report Change 82 / 81 units Transmit Data E / E
Device Type/ID# Dew 10 Temp /_______ Transmit Zeroes E / E
Manual Measurement: (found)_________ (left)_______
==

Notice that the sensor output is not a voltage output. It is a current output of 4mA to 20mA. The analog to digital converter will not accept a current input therefore the current must be changed to DC voltage. This current output is converted to a DC voltage by installing a 250 ohm resistor across the output leads of the sensor. By Ohm's Law, voltage = current X resistance (E = I x R).

The voltage corresponding to 4mA is:

E = 4mA x 250 ohms= .004 x 250 = 1VDC

The voltage corresponding to 20mA is:

E = 20mA x 250 ohms = .02 x 250 = 5VDC.

Note: The multiplier value in this case represents the range of the analog to digital converter rather than the sensor. Sensor range = 0 to 100°F and A/D range = 0 to 125°F. By installing a base value of -25, both the sensor and A/D ranges become 0 to 100°F.

Device Type

It is important that the Device Type of this instrument be noted in the QA Log. Each different temperature sensor usually requires a different multiplier value and base value.

Manual Measurement

Using an accurate thermometer, make a manual measurement of the ambient temperature and record the results in the QA Log manual measurement.

Note: Enable all report methods before proceeding to the next parameter.

12.5.2.1.8 Analog Dewpoint Temperature

Dewpoint temperature can be measured with any analog channel.

Note: Disable all report methods before performing any tests or calibrations.

Typical RTU set-ups for a dewpoint temperature sensor with a range of 0°F to 100°F and output of 4 ma to 20 ma are as follows.

Analog( ) Parameter(Dewpoint Temp)Sensor Calibration found left
Multiplier Value 125 / 125
Periodic Data found/left Divisor Value 1023/1023
Report Sample Time 1h / 1h h/m/s Base Value -25 / -25
Report Change Over 1h / 1h units Cal/Raw Value_____/____
Event Data found/left **Report Methods found/left**
Event Sample Time 5m / 5m h/m/s Device Active E / E
Event Report Change 41 / 41 units Log Data E / E
Alarm Report Change 41 / 41 units Transmit Data E / E
Device Type/ID# Dew-10 Temp /_______ Transmit Zeroes E / E **DP Cal:(found)**Dry Bulb_____ Wet Bulb_____ Depression____ = DP____
(left) Dry Bulb_____ Wet Bulb_____ Depression____ = DP____
Mirror Cleaned:(y/n)____ **Adjustment:** Coarse(y/n)___ Fine(y/n)___

==

Notice that the sensor output is not a voltage output. It is a current output of 4mA to 20mA. The analog to digital converter will not accept a current input therefore the current must be changed to DC voltage. This current output is converted to a DC voltage by installing a 250 ohm resistor across the output leads of the sensor. By Ohm's Law, voltage = current X resistance (E = I x R).

The voltage corresponding to 4mA is:

E = 4mA x 250 ohms = .004 x 250 = 1VDC

The voltage corresponding to 20mA is:

E = 20mA x 250 ohms = .02 x 250 = 5VDC

Note: The multiplier value in this case represents the range of the analog to digital converter rather than the sensor. Sensor range = 0 to 100°F and A/D range = 0 to 125°F. By installing a base value of -25, both the sensor and A/D ranges become 0 to 100°F.

Device Type

It is important that the Device Type of this instrument be noted in the QA Log. Each different dewpoint temperature sensor usually requires a different multiplier value and base value.

Manual Measurement

Using an accurate psychrometer, make a manual measurement of the dewpoint temperature and record the results in the DP Cal section of the QA Log manual measurement.

The theory of wet and dry bulb thermometers is based on the evaporative cooling effect of the wet bulb. The drier the surrounding air the more rapidly the water on the wet bulb sock will evaporate. This causes the wet bulb to depress in temperature until a balance is reached between the cooling effect and the heat of the ambient air. The psychrometric formula relates the temperature depression and the dry bulb temperature to the amount of moisture in the air. This can be expressed in relative humidity, dewpoint temperature, or vapor pressure.

Mirror Cleaned

If the dewpoint sensor is a chilled mirror type then the mirror must be periodically cleaned in order to maintain proper operation. Mirror cleaning intervals should be no longer than 2 months although cleaning monthly will afford better accuracy.

Make entries into the QA Log for mirror cleaning and any adjustments made to the sensor.

Note: Enable all report methods before proceeding to the next parameter.

12.5.2.1.9 Analog Water Temperature

Water temperature can be measured with any analog channel.

Note: Disable all report methods before performing any tests or calibrations.

Typical RTU set-ups for a water temperature sensor with a range of 0°C to 50°C (32-122°F), respective output of 0 to 5 VDC, and desired resolution of 0.1, are as follows.

Analog( ) Parameter(Water Temp)Sensor Calibration found/left
Multiplier Value 900 / 900
Periodic Data found/left Divisor Value1023 /1023
Report Sample Time 1h / 1h h/m/s Base Value 320 / 320
Report Change Over 0 / 0 units Cal/Raw Value_____/____
Event Data found/left **Report Methods found/left**
Event Sample Time 0 / 0 h/m/s Device Active E / E
Event Report Change 7830/7830 units Log Data E / E
Alarm Report Change 7830/7830 units Transmit Data E / E Device Type/ID#______________/_______ Transmit Zeroes E / E
Manual Measurement: (found)_________ (left)________

===

Device Type

It is important that the Device Type of this instrument be noted in the QA Log. Each different temperature sensor usually requires a different multiplier value and base value.

Manual Measurement

Using an accurate thermometer, make a manual measurement of the water temperature and record the results in the QA Log manual measurement.

Multiplier Value

Notice the multiplier value of this sensor. The sensor range is 50°C but the desired unit of measurement is °F. When converted, the 0°C to 50°C range becomes 32°F to 122°F, a range of 90°F. With a desired resolution of 0.1 °F, the multiplier then becomes 900.

Divisor Value

A base value of 320 is required to cause a correct calibrate value. Base value of 320 represents 0°C at 0.1°F resolution.

Note: Enable all report methods before proceeding to the next parameter.

12.5.2.1.10 Analog Pan Evaporation

Pan evaporation can be monitored with any very accurate stage measuring instrument. The District uses a magnetostrictive waveguide instrument manufactured by Balluff Inc. This instrument measures over a range of 0 - 150 mm for an output of 0 - 5 VDC.

Note: Disable all report methods before performing any tests or calibrations.

Typical RTU set-ups for a pan evaporation sensor with a range of 0mm to 150mm, respective output of -5 VDC to 5 VDC, and desired resolution of 1mm, are as follows.

Analog( )Parameter(Pan Evaporation)Sensor Calibration found/left
Multiplier Value 75 / 75
Periodic Data found/left Divisor Value 1023 / 1023
Report Sample Time 1h / 1h h/m/s Base Value 0 / 0
Report Change Over 0 / 0 units Cal/Raw Value_____/____
Event Data found/left **Report Methods found/left**
Event Sample Time 15m / 15m h/m/s Device Active E / E
Event Report Change 4 / 4 units Log Data E / E
Alarm Report Change 4 / 4 units Transmit Data E / E Device Type/ID#__________/______
Transmit Zeroes E / E
Hook Gauge Measurement: as found____ as left____ Water Added ?___

==

Device Type

It is important that the Device Type of this instrument be noted in the QA Log. Each different stage sensor may require a different multiplier value and base value.

Manual Measurement

Using the hook gauge located in the center of the evaporation pan, make a manual measurement of the water level and record the results in the QA Log Hook Gauge measurement. Also, note if water was added.

Multiplier Value

The total instrument range in this case is 150mm with an output of -5 VDC to +5VDC. Since the A/D converter will measure only 0 to + 5 VDC, only the 75mm portion of the instrument corresponding to this 0 to + 5 VDC output will be used. Therefore, the multiplier value is 75.

Note: Enable all report methods before proceeding to the next parameter.

12.5.2.1.11 Analog Dewpoint Battery

A special voltage divider is installed for the purpose of monitoring the + 12 VDC from the dewpoint battery. It designed to measure DC voltages between 9 and 16 volts.

Note: Disable all report methods before performing any tests or calibrations.

The following are typical set-ups for this channel.

Analog( )Parameter(Dewpoint Battery)Sensor Calibration found/left
Multiplier Value1448 / 1448
Periodic Data found/left Divisor Value1000 /1000 Report Sample Time 1h / 1h h/m/s
Base Value 0 / 0
Report Change Over 0 / 0 units Cal/Raw Value_____/____
Event Data found/left **Report Methods found/left**
Event Sample Time 0s / 0s h/m/s Device Active E / E
Event Report Change32768/32768 units Log Data E / E
Alarm Report Change32768/32768 units Transmit Data E / E
Device Type/ID#___________/_____ Transmit Zeroes E / E
Hydrometer Check:__________
Battery Voltage: External________ Internal +24 Volts________

==

Batteries must receive proper care if they are to render adequate service. Perform the following checks at each routine site visit.

- Check the fluid level of each battery cell and acknowledge in the QA Log. If the level is below the notch in the cell, add **distilled** water until fluid level reaches the bottom of the notch. **Do not** over fill the cell. Over filling can cause electrolyte overflow during charging.

- Remove any corrosion on the battery terminals and in the fuse holder. Apply a terminal protecting grease or spray if needed.

- Using a hydrometer, check the specific gravity of each cell and record the average in the QA Log Hydrometer Check. If any cell measures a specific gravity less than 1200, the battery must be replaced.

- Measure the external battery voltage and record the value in the QA Log.

- Measure the internal +24 VDC from the DC to DC converter and record the value in the QA Log.

  Note: Enable all report methods before proceeding to the next parameter.

12.5.3 Changing Stage Calibrate Values at Negative MSL Sites

There are two methods for changing the calibrated value. For RTU channels D1 and D2 the calibrated value is changed by entering the MSL value (no decimal) directly into the Calibrate Value. For the Analog channels adjust the Base Value (up or down) to change the Calibrate Value. In either case **do not** attempt to change the Raw Value. The Raw Value is the actual count of the A/D converter and is a direct measurement of the sensor output.

> **Important Note:** If the monitoring levels are expected to drop below Mean Sea Level then a suitable Base Value **must** be entered in the appropriate channel to allow the Cal Value to indicate negative (-) numbers. This is accomplished as follows.

1. For D1 and D2 channels:

   A. Determine the distance below MSL the water level is expected to go. For instance, 5.00 ft.

   B. Determine present water level. For instance 37.55 ft.

   C. Enter Cal Value as item a) plus item b), i.e., 5.00 + 37.55 = 42.55. The RTU takes no decimals so the entry is 4255.

   D. Enter the distance expected to go below MSL in the Base Value (no decimal -500). Note that upon entering the Base Value of -500 the Cal Value will immediately change to 3755.

2. For Analog channels:

   A. Adjust the Base Value until the Cal Value indicates the present water level.

B. Determine the distance below MSL the water level is expected to go. For instance, 5.00 ft.

C. Determine the present water level. For instance, 37.55 ft.

D. Disengage the float tape from the spines of the sensor pulley. Rotate the sensor pulley until the Cal Value indicates 4255. Reinstall float tape onto the sensor pulley.

   Note that the Cal Value may have changed slightly after float tape is installed. This is caused by the spines of the pulley and the holes in the tape not meshing exactly to allow the proper Cal Value at counterweight balance. This is corrected in item E below.

E. Adjust the Base Value downward until the Cal Value indicates 3755. This downward adjustment will be approximately 500.

12.5.4 Telemetry Site Departure Check

Upon satisfactory completion of all tests and before leaving the station, perform the following procedures:

1. Enable all active devices.

2. Exit the Field Command Software, remove the laptop from the RTU and replace serial port cover.

3. Lock the RTU, battery box, and all instrument enclosures. Renew moisture absorbent materials and pest strips as needed. Check locks for proper lubrication.

4. Inspect ZapNot enclosure for leaks and repair if necessary. Replace moisture absorbent materials is needed and reseal the ZapNot enclosure cover.

5. Perform site maintenance as required. Cut the grass, secure weed mat, collect debris, etc.

6. Confirm proper antenna cable connection at the RTU.

7. Inspect to confirm proper operation of the dewpoint shelter vent motor.

8. Verify inventory if station service required any equipment change out.

9. Inspect fence integrity and repair as needed. Ensure fence gate is locked.

10. Verify proper completion of QA Log and sign your name with date and time in the comments section of the log.

11. Perform a last general site inspection for tools, parts, or materials that could be left behind.

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Work Group 2, 1980, National Handbook of Recommended Methods for Water-data Acquisition, Ground Water.

Appendices

Appendix A--Manufacturer Information

ITEM	DEVICE	DEVICE TYPE	MANUFACTURER
1	Sierra-Misco Mod 5050T	Air Temp	Sierra-Misco Inc. 14100 Parke Long CT Chantilly, VA 22021
2	Belfort Mod 594 Hygrothermograph	Temp/RH	Belfort Instrument 1600 S. Clinton St. Baltimore, MD 21224
3	Campbell Scientific Mod HMP35C Hygrothermograph	Temp/RH	Campbell Scientific 815W. 1800N Logan, UT. 84321-1784
4	General Eastern Dew-10 Dewpoint Hygrometer w/Temp	DP/AT	General Eastern Instruments, 50 Hunt St Watertown, MA 02172
5	Sierra-Misco Mod 2046 RH/Temp	Temp/RH	Sierra-Misco Inc. 14100 Parke Long CT Chantilly, VA 22021
6	Weathermeasure Mod 5045-B Hygrothermograph	Temp/RH	Qualimetrics, Inc. 1165 National Dr. Sacramento, CA. 95834
7	Princo Mod 469 Mercury Barometer	Atmospheric Pressure	Princo Instruments Southhampton, PA
8	Sierra-Misco Mod 1522 Barometer	Atmospheric Pressure	Sierra-Misco Inc. 14100 Parke Long CT Chantilly, VA 22021
9	Vaisala Mod PTA-427 Analog Output Barometer	Atmospheric Pressure	Campbell Scientific 815W. 1800N Logan, UT. 84321-1784
10	Weathermeasure Mod 7105-A Analog output Barometer	Atmospheric Pressure	Qualimetrics, Inc. 1165 National Dr. Sacramento, CA. 95834
11	Balluff Linear Displacement Transducer	Evaporation/Water Level	Balluff Inc. PO Box 937, 8125 Holton Drive Florence, KY 40142
12	Belfort Evaporation Station	Evaporation	Belfort Instrument 1600 S. Clinton St. Baltimore, MD

ITEM	DEVICE	DEVICE TYPE	MANUFACTURER
			21224
13	Campbell Scientific Mod 237 Leaf Wetness Sensor	Leaf Wetness	Campbell Scientific 815W. 1800N Logan, UT. 84321-1784
14	Belfort Mod 5-780 Weighing Bucket Rain Gauge	Rainfall	Belfort Instrument 1600 S. Clinton St. Baltimore, MD 21224
15	Handar Mod 444A Tipping Bucket Rain Gauge	Rainfall	Handar, 1288 Reamwood Ave., Sunnyvale, CA 94089
16	Calibrated Stilling Well Leupold & Stevens Mod 2A35 Dual Graphic Recorder	Rainfall	Leupold & Stevens PO Box 688 Beaverton, Oregon 97005
17	Tru-Check Rain Gauge	Rainfall	Edwards Manufacturing Co., Box 166, Albert Lea, Minnesota 56007
18	Sierra-Misco Mod 2500 Tipping Bucket Rain Gauge	Rainfall	Sierra-Misco Inc. 14100 Parke Long CT Chantilly, VA 22021
19	Sierra-Misco Mod 2501 Tipping Bucket Rain Gauge	Rainfall	Sierra-Misco Inc. 14100 Parke Long CT Chantilly, VA 22021
20	Weathermeasure Mod P-501 Tipping Bucket Rain Gauge	Rainfall	Qualimetrics, Inc. 1165 National Dr. Sacramento, CA. 95834
21	Eppely PIR Radiation Sensor	Infrared Radiation	
22	Eppely PSP Radiation Sensor	Sun + Sky Total Rad	
23	LI-COR PAR Radiation Sensor	Photosyn-thetically Active Radiation	LI-COR PO Box 4425 4421 Superior St. Lincoln, Nebraska 68504
24	LI-COR Mod Li-200S Pyranometer	Sun/Sky Rad	LI-COR PO Box 4425 4421 Superior St. Lincoln, Nebraska 68504
25	LI-COR Mod Li-500 Integrator	Integrator	LI-COR PO Box 4425 4421 Superior St. Lincoln,

ITEM	DEVICE	DEVICE TYPE	MANUFACTURER
			Nebraska 68504
26	Pump Operation Sensor	RPM Monitor	
27	Celesco Gate Sensor	Gate Position	Par Associates Tampa, FL
28	ED (Hersey) Gate Sensor	Gate Position	Environmental Sensing Devices Inc PO Box 12805 Raleigh, NC
29	Lundahl Ultra Sonic Sensor	Gate Position	
30	Lock Operation Sensor	Gate Position	
31	Squibb-Taylor Mod 136619 LPG Sensor	LPG Tank Capacity	Squibb Taylor 10807 Harry Hines Blvd. Dallas Texas, 75200
32	ED (Hersey) Stop Log Sensor	Stop Log Position	Environmental Sensing Devices Inc PO Box 12805 Raleigh, NC
33	Water Specialties ML-23 Flowmeters	Closed Pipe Flow	Water Specialties 191 W. Poplar Ave. Porterville, CA 93257
34	Water Specialties OF-11 Flowmeters	Closed Pipe Flow	Water Specialties 191 W. Poplar Ave. Porterville, CA 93257
35	Price AA Current Meter	Channel Flow Vertical Axis	
36	Marsh-McBirney Mod 201D	Channel Flow Electromagnet	
37	EG&G Acoustic Current Meter	Channel Flow Acoustic Velocity	
38	Doppler Current Meter	Channel Flow Acoustic Velocity	
39	ADCP	Channel Flow Broadband Acoustic Velocity	

ITEM	DEVICE	DEVICE TYPE	MANUFACTURER
40	R. M. Young Wind Monitor Model 05103	Wind Speed & Direction	R. M. Young Co. 2801 Aero Park Dr. Traverse City, MI 49684
41	R. M. Young Wind Sentry Model 03001	Wind Speed & Direction	R. M. Young Co. 2801 Aero Park Dr. Traverse City, MI 49684
42	Qualimetrics Skyvane Model 2100	Wind Speed & Direction	Qualimetrics, Inc. 1165 National Dr. Sacramento, CA.
43	Belfort Model 5-349C Totalizing Anemometer	Wind Speed	Belfort Instrument 1600 S. Clinton St. Baltimore, MD 21224
44	Weathermeasure Model 2510 Totalizing Anemometer	Wind Speed	Qualimetrics, Inc. 1165 National Dr. Sacramento, CA. 95834
45	Stevens Mod 7001 Punched Paper Tape Recorder	Liquid Level	Leupold & Stevens PO Box 688 Beaverton, Oregon 97005
46	Belfort Mod 35-1542 Punched Paper Tape Recorder	Liquid Level	Belfort Instrument 1600 S. Clinton St. Baltimore, MD 21224
47	Stage Potentiometer	Liquid Level	
48	Metritape	Liquid Level	
49	ED (Hersey Bar)	Liquid Level & Stop Log	Environmental Sensing Devices Inc PO Box 12805 Raleigh, NC
50	Sierra-Misco Mod 5050LL-FT	Liquid Level	Sierra-Misco Inc. 14100 Parke Long CT Chantilly, VA 22021
51	Acro Shaft Encoder	Liquid Level	Acro Systems, P. O. Box 250, Silver Springs , NV 89429
52	Handar Mod 436 Incremental Shaft Encoder	Liquid Level	Handar, 1288 Reamwood Ave, Sunnyvale CA 94089
53	Sierra-Misco Mod 5050 LL-PTF Pressure Transducer	Liquid Level	Sierra-Misco Inc. 14100 Parke Long CT Chantilly,

ITEM	DEVICE	DEVICE TYPE	MANUFACTURER
			VA 22021
54	Design Analysis WaterLog H-300	Liquid Level	

Appendix B--Index of Sensor Users

ITEM	DEVICE	DEVICE TYPE	USERS
1	Sierra-Misco Mod 5050T	Air Temp	SJRWMD, SWFWMD
2	Belfort Mod 594 Hygrothermograph	Temp/RH	
3	Campbell Scientific Mod HMP35C Hygrothermograph	Temp/RH	SFWMD
4	General Eastern Dew-10 Dewpoint Hygrometer w/Temp	DP/AT	SJRWMD
5	Sierra-Misco Mod 2046 RH/Temp	Temp/RH	SJRWMD
6	Weathermeasure Mod 5045-B Hygrothermograph	Temp/RH	SFWMD
7	Princo Mod 469 Mercury Barometer	Atmospheric Pressure	SJRWMD
8	Sierra-Misco Mod 1522 Barometer	Atmospheric Pressure	SJRWMD
9	Vaisala Mod PTA-427 Analog Output Barometer	Atmospheric Pressure	SFWMD
10	Weathermeasure Mod 7105-A Analog output Barometer	Atmospheric Pressure	SJRWMD
11	Balluff Linear Displacement Transducer	Evaporation/Water Level	SJRWMD
12	Belfort Evaporation Station	Evaporation	SFWMD
13	Campbell Scientific Mod 237 Leaf Wetness Sensor	Leaf Wetness	SFWMD, SWFWMD
14	Belfort Mod 5-780 Weighing Bucket Rain Gauge	Rainfall	SFWMD, SWFWMD
15	Handar Mod 444A Tipping Bucket Rain Gauge	Rainfall	
16	Calibrated Stilling Well Leupold & Stevens Mod 2A35 Dual Graphic Recorder	Rainfall	SFWMD
17	Manual Rain Gauge	Rainfall	SFWMD, SJRWMD,

ITEM	DEVICE	DEVICE TYPE	USERS
			SWFWMD
18	Sierra-Misco Mod 2500 Tipping Bucket Rain Gauge	Rainfall	SWFWMD, SJRWMD
19	Sierra-Misco Mod 2501 Tipping Bucket Rain Gauge	Rainfall	SJRWMD
20	Weathermeasure Mod P-501 Tipping Bucket Rain Gauge	Rainfall	SJRWMD, SFWMD
21	Eppely PIR Radiation Sensor	Infrared Radiation	SJRWMD, SFWMD
22	Eppely PSP Radiation Sensor	Sun + Sky Total Rad	SJRWMD, SFWMD
23	LI-COR PAR Radiation Sensor	Photosynthetically Active Radiation	SFWMD, SJRWMD
24	LI-COR Mod LI-200S Pyranometer	Sun/Sky Rad	SWFWMD, SJRWMD, SFWMD
25	LI-COR Mod LI-500 Integrator	Integrator	SJRWMD, SFWMD
26	Pump Operation Sensor	RPM Monitor	SFWMD
27	Celesco Gate Sensor	Gate Position	SWFWMD, SJRWMD
28	ED (Hersey) Gate Sensor	Gate Position	SFWMD, SJRWMD
29	Lundahl Ultra Sonic Sensor	Gate Position	SFWMD, SJRWMD
30	Lock Operation Sensor	Gate Position	SFWMD
31	Squibb-Taylor Mod 136619 LPG Sensor	LPG Tank Capacity	SJRWMD
32	ED (Hersey) Stop Log Sensor	Stop Log Position	
33	Water Specialties ML-23 Flowmeters	Closed Pipe Flow	SJRWMD
34	Water Specialties OF-11 Flowmeters	Closed Pipe Flow	SJRWMD
35	Price AA Current Meter	Channel Flow Vertical Axis	SFWMD, SJRWMD

ITEM	DEVICE	DEVICE TYPE	USERS
36	Marsh-McBirney Mod 201D	Channel Flow Electromagnet	SFWMD, SJRWMD
37	EG&G Acoustic Current Meter	Channel Flow Acoustic Velocity	
38	Doppler Current Meter	Channel Flow Acoustic Velocity	
39	ADCP	Channel Flow Broadband Acoustic Velocity	
40	R. M. Young Wind Monitor Model 05103	Wind Speed & Direction	SWFWMD, SFWMD, SJRWMD
41	R. M. Young Wind Sentry Model 03001	Wind Speed & Direction	SJRWMD, SFWMD
42	Qualimetrics Skyvane Model 2100	Wind Speed & Direction	SFWMD
43	Belfort Model 5-349C Totalizing Anemometer	Wind Speed	SFWMD
44	Weathermeasure Model 2510 Totalizing Anemometer	Wind Speed	
45	Stevens Mod 7001 Punched Paper Tape Recorder	Liquid Level	SWFWMD, SFWMD, SJRWMD
46	Belfort Mod 35-1542 Punched Paper Tape Recorder	Liquid Level	SWFWMD, SFWMD
47	Stage Potentiometer	Liquid Level	SWFWMD, SJRWMD, SFWMD
48	Metritape	Liquid Level	SFWMD, SJRWMD
49	ED (Hersey Bar)	Liquid Level & Stop Log	SFWMD, SJRWMD
50	Sierra-Misco Mod 5050LL-FT	Liquid Level	SJRWMD, SWFWMD
51	Acro Shaft Encoder	Liquid Level	SFWMD,

ITEM	DEVICE	DEVICE TYPE	USERS
			SWFWMD, SJRWMD
52	Handar Mod 436 Incremental Shaft Encoder	Liquid Level	SFWMD
53	Sierra-Misco Mod 5050 LL-PTF Pressure Transducer	Liquid Level	SWFWMD
54	Design Analysis WaterLog H-300	Liquid Level	SFWMD
55	KPSI 730-130-0015 Pressure Transducer	Water Level	SWFWMD
56	Design Analysis H340	Rainfall	SWFWMD
57	Handar 436-B-2	Liquid Level	SWFWMD
58	Hagstrom Mod 1928 Bucket Raingauge	Rainfall	SWFWMD
59	Vitel VLT100	Temperature	SWFWMD
60	Vitel STU-Y100	Temperature	SWFWMD
61	Vaisala HMP 45C	Temperature/RH	SWFWMD
62	Li-Cor LI-200X Pyranometer	Sun/Sky Rad	SWFWMD
63	Texas Instruments TE525	Rainfall	SWFWMD
64	Campbell Scientific Instruments CS-AT3 Anemometer	Wind Speed	SWFWMD
65	Vaisala 425A Ultrasonic	Wind Direction	SWFWMD
66	Campbell Scientific Instruments CSI-KH20 Krypton Hygrometer	RH	SWFWMD
67	REBS Q-7.1 Net Radiometer	Solar Rad	SWFWMD
68	Campbell Scientific Instruments HF-3 Soil Heat Flux Probe	Soil Heat Flux	SWFWMD
69	Campbell Scientific Instruments CS615-L Soil Moisture Sensor	Soil Moisture	SWFWMD
70	Campbell Scientific Instruments	Soil Temp	SWFWMD

ITEM	DEVICE	DEVICE TYPE	USERS
	TCAV-L Soil Temperature Probe		
71	Campbell Scientific Instruments CS547 Conductivity and Temperature Probe	Conductivity/Water Temperature	SWFWMD

Appendix C--Frequency of Sensor Calibration

ITEM	DEVICE	DEVICE TYPE	CALIBRATE INTERVAL
1	Sierra-Misco Mod 5050T	Air Temp	1 yr with 2 month manual tests
2	Belfort Mod 594 Hygrothermograph	Temp/RH	1 yr with 2 month manual tests
3	Campbell Scientific Mod HMP35C Hygrothermograph	Temp/RH	1 yr with 2 month manual tests
4	General Eastern Dew-10 Dewpoint Hygrometer w/Temp	DP/AT	1 yr with 2 month manual tests
5	Sierra-Misco Mod 2046 RH/Temp	Temp/RH	1 yr with 2 month manual tests
6	Weathermeasure Mod 5045-B Hygrothermograph	Temp/RH	1 yr with 2 month manual tests
7	Princo Mod 469 Mercury Barometer	Atmospheric Pressure	Verify cal at each reading
8	Sierra-Misco Mod 1522 Barometer	Atmospheric Pressure	1 yr
9	Vaisala Mod PTA-427 Analog Output Barometer	Atmospheric Pressure	1 yr
10	Weathermeasure Mod 7105-A Analog output Barometer	Atmospheric Pressure	1 yr
11	Balluff Linear Displacement Transducer	Evaporation/Water Level	1 yr with 2 month Hook Gauge tests
12	Belfort Evaporation Station	Evaporation	Calibration not required
13	Campbell Scientific Mod 237 Leaf Wetness Sensor	Leaf Wetness	1 yr
14	Belfort Mod 5-780 Weighing Bucket Rain Gauge	Rainfall	1 yr
15	Handar Mod 444A Tipping Bucket Rain Gauge	Rainfall	1 yr
16	Calibrated Stilling Well Leupold & Stevens Mod 2A35 Dual Graphic Recorder	Rainfall	1 yr

ITEM	DEVICE	DEVICE TYPE	CALIBRATE INTERVAL
17	Manual Rain Gauge	Rainfall	Not Required
18	Sierra-Misco Mod 2500 Tipping Bucket Rain Gauge	Rainfall	1 yr
19	Sierra-Misco Mod 2501 Tipping Bucket Rain Gauge	Rainfall	1 yr
20	Weathermeasure Mod P-501 Tipping Bucket Rain Gauge	Rainfall	1 yr
21	Eppely PIR Radiation Sensor	Infrared Radiation	3 yr
22	Eppely PSP Radiation Sensor	Sun + Sky Total Rad	3 yr
23	LI-COR PAR Radiation Sensor	Photosynthetically Active Radiation	3 yr
24	LI-COR Mod Li-200S Pyranometer	Sun/Sky Rad	3 yr
25	LI-COR Mod Li-500 Integrator	Integrator	1 yr
26	Pump Operation Sensor	RPM Monitor	1 yr
27	Celesco Gate Sensor	Gate Position	1 yr
28	ED (Hersey) Gate Sensor	Gate Position	1 yr
29	Lundahl Ultra Sonic Sensor	Gate Position	1 yr
30	Lock Operation Sensor	Gate Position	1 yr
31	Squibb-Taylor Mod 136619 LPG Sensor	LPG Tank Capacity	1 yr
32	ED (Hersey) Stop Log Sensor	Stop Log Position	1 yr
33	Water Specialties ML-23 Flowmeters	Closed Pipe Flow	3 yr with 6 month field calibrations
34	Water Specialties OF-11 Flowmeters	Closed Pipe Flow	3 yr with 6 month field calibrations
35	Price AA Current Meter	Channel Flow Vertical Axis	Dynamic Spin Tests before each Daily Use
36	Marsh-McBirney Mod 201D	Channel Flow Electromagnet	?
37	EG&G Acoustic Current Meter	Channel Flow Acoustic Velocity	?

ITEM	DEVICE	DEVICE TYPE	CALIBRATE INTERVAL
38	Doppler Current Meter	Channel Flow Acoustic Velocity	?
39	ADCP	Channel Flow Broadband Acoustic Velocity	?
40	R. M. Young Wind Monitor Model 05103	Wind Speed & Direction	1 yr
41	R. M. Young Wind Sentry Model 03001	Wind Speed & Direction	1 yr
42	Qualimetrics Skyvane Model 2100	Wind Speed & Direction	1 yr
43	Belfort Model 5-349C Totalizing Anemometer	Wind Speed	1 yr
44	Weathermeasure Model 2510 Totalizing Anemometer	Wind Speed	1 yr
45	Stevens Mod 7001 Punched Paper Tape Recorder	Liquid Level	Each Site Visit
46	Belfort Mod 35-1542 Punched Paper Tape Recorder	Liquid Level	Each Site Visit
47	Stage Potentiometer	Liquid Level	1 yr
48	Metritape	Liquid Level	1 yr
49	ED (Hersey Bar)	Liquid Level & Stop Log	1 yr
50	Sierra-Misco Mod 5050LL-FT	Liquid Level	Each Site Visit
51	Acro Shaft Encoder	Liquid Level	Each Site Visit
52	Handar Mod 436 Incremental Shaft Encoder	Liquid Level	Each Site Visit
53	Sierra-Misco Mod 5050 LL-PTF Pressure Transducer	Liquid Level	2 months
54	Design Analysis WaterLog H-300	Liquid Level	1

Appendix D--Instrument Sensitivity Standards

ITEM	DEVICE	DEVICE TYPE	INSTRUMENT SENSITIVITY
1	Sierra-Misco Mod 5050T	Air Temp	± 4°F
2	Belfort Mod 594 Hygrothermograph	Temp/RH	2°F & 1% RH
3	Campbell Scientific Mod HMP35C Hygrothermograph	Temp/RH	± .2°C & 1% RH
4	General Eastern Dew-10 Dewpoint Hygrometer w/Temp	DP/AT	± 1°F both Temp & Dewpoint
5	Sierra-Misco Mod 2046 RH/Temp	Temp/RH	± 4°F & 2% RH
6	Weathermeasure Mod 5045-B Hygrothermograph	Temp/RH	2°F & 1% RH
7	Princo Mod 469 Mercury Barometer	Atmospheric Pressure	1 mB
8	Sierra-Misco Mod 1522 Barometer	Atmospheric Pressure	1 mB
9	Vaisala Mod PTA-427 Analog Output Barometer	Atmospheric Pressure	.6 mB
10	Weathermeasure Mod 7105-A Analog output Barometer	Atmospheric Pressure	1 mB
11	Balluff Linear Displacement Transducer	Evaporation/Water Level	1 mm
12	Belfort Evaporation Station	Evaporation	.1 inches
13	Campbell Scientific Mod 237 Leaf Wetness Sensor	Leaf Wetness	
14	Belfort Mod 5-780 Weighing Bucket Rain Gauge	Rainfall	0.01"
15	Handar Mod 444A Tipping Bucket Rain Gauge	Rainfall	0.01"
16	Calibrated Stilling Well Leupold & Stevens Mod 2A35 Dual Graphic Recorder	Rainfall	0.01"
17	Manual Rain Gauge	Rainfall	0.01"

ITEM	DEVICE	DEVICE TYPE	INSTRUMENT SENSITIVITY
18	Sierra-Misco Mod 2500 Tipping Bucket Rain Gauge	Rainfall	0.01"
19	Sierra-Misco Mod 2501 Tipping Bucket Rain Gauge	Rainfall	0.01"
20	Weathermeasure Mod P-501 Tipping Bucket Rain Gauge	Rainfall	0.01"
21	Eppely PIR Radiation Sensor	Infrared Radiation	typically 5 microvolts per w^2
22	Eppely PSP Radiation Sensor	Sun + Sky Total Rad	typically 9 microvolts per w^2
23	LI-COR PAR Radiation Sensor	Photosynthetically Active Radiation	typically 8µA per 1000µmol/sm²
24	LI-COR Mod Li-200S Pyranometer	Sun/Sky Rad	typically 50µA/1000Wm²
25	LI-COR Mod Li-500 Integrator	Integrator	1%-5%
26	Pump Operation Sensor	RPM Monitor	1 RPM
27	Celesco Gate Sensor	Gate Position	0.01'
28	ED (Hersey) Gate Sensor	Gate Position	0.01'
29	Lundahl Ultra Sonic Sensor	Gate Position	0.01'
30	Lock Operation Sensor	Gate Position	0.01'
31	Squibb-Taylor Mod 136619 LPG Sensor	LPG Tank Capacity	5% of full scale
32	ED (Hersey) Stop Log Sensor	Stop Log Position	0.01'
33	Water Specialties ML-23 Flowmeters	Closed Pipe Flow	100 gal
34	Water Specialties OF-11 Flowmeters	Closed Pipe Flow	100 gal
35	Price AA Current Meter	Channel Flow Vertical Axis	0.25 FPS
36	Marsh-McBirney Mod 201D	Channel Flow Electromagnet	?
37	EG&G Acoustic Current Meter	Channel Flow Acoustic Velocity	?

ITEM	DEVICE	DEVICE TYPE	INSTRUMENT SENSITIVITY
38	Doppler Current Meter	Channel Flow Acoustic Velocity	?
39	ADCP	Channel Flow Broadband Acoustic Velocity	?
40	R. M. Young Wind Monitor Model 05103	Wind Speed & Direction	2.2 mph
41	R. M. Young Wind Sentry Model 03001	Wind Speed & Direction	2.9 mph
42	Qualimetrics Skyvane Model 2100	Wind Speed & Direction	2 mph
43	Belfort Model 5-349C Totalizing Anemometer	Wind Speed	3 mph
44	Weathermeasure Model 2510 Totalizing Anemometer	Wind Speed	2 mph
45	Stevens Mod 7001 Punched Paper Tape Recorder	Liquid Level	0.01'
46	Belfort Mod 35-1542 Punched Paper Tape Recorder	Liquid Level	0.01'
47	Stage Potentiometer	Liquid Level	0.01'
48	Metritape	Liquid Level	0.01'
49	ED (Hersey Bar)	Liquid Level & Stop Log	0.01'
50	Sierra-Misco Mod 5050LL-FT	Liquid Level	0.01'
51	Acro Shaft Encoder	Liquid Level	0.01'
52	Handar Mod 436 Incremental Shaft Encoder	Liquid Level	0.01'
53	Sierra-Misco Mod 5050 LL-PTF Pressure Transducer	Liquid Level	0.05% of range
54	Design Analysis WaterLog H-300	Liquid Level	0.02% of range