Surveyor General

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Calibration of Electronic Distance Measuring (EDM) Equipment

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Calibration of Electronic Distance Measuring (EDM) Equipment

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Cover photograph shows Lethbridge Park EDM Baseline

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Customer Support - EDM Calibration & Baseline Booking System.
For access to legislation in force in NSW go to the official NSW Government website for online publication of legislation at legislation.nsw.gov.au.

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Contents

1. Introduction

The Surveyor-General, as a verifying authority for Reference Standards of Measurement, Length, provides the infrastructure for surveyors to verify their Electronic Distance Measuring (EDM) equipment in accordance with the National Measurement Act 1960. Consequently, surveyors are required by the Surveying and Spatial Information Regulation 2017, Clause 14, to verify their measuring equipment in relation to an Australian or State Primary Standard of measurement of length, and thereby achieve legal traceability of length.

It should be noted that Legal Traceability of length measurement is not confined to cadastral surveys, as any length measurement stated by a surveyor could be subject to dispute and subsequent litigation.

This direction outlines the facilities maintained for the verification of EDM equipment and the procedures required to comply with the Surveying and Spatial Information Regulation 2017.

1.1 Background and Definitions

The National Measurement Act 1960 establishes the legislative framework for a national system of standards and prescribes the legal measurement units for all physical quantities. Length measurement, while being a fundamental element of survey work, is only one of more than thirty physical quantities covered by the Act.

The National Measurement Act 1960 is administered by the National Measurement Institute (NMI) which may in turn appoint organisations as a Verifying Authority under the provisions of Clause 73 of the National Measurement Act 1960. The Surveyor-General of NSW has been so appointed.

The appointment of the Surveyor-General as a Verifying Authority is reviewed every eighteen months. The review consists of an audit of the quality management system and procedures against AS ISO/IEC 17025 and is undertaken by the National Association of Testing Authorities (NATA) and NMI.

Legal Traceability of length measurement refers to the legal hierarchy of measurement standards traceable through an unbroken chain of verifications from the most precise standard (e.g. National Standard) down through the subsidiary standards to the working standard, being the surveyor's EDM instrument. In particular the National Measurement Act 1960, Section 10, requires that all measurements of physical quantities are to be ascertained in accordance with appropriate Australian or State standards of measurement. Consequently, the requirements of the National Measurement Act 1960 which are relevant to surveyors are incorporated in the Surveying and Spatial Information Regulation 2017.

Precision is generally defined as the repeatability of readings as displayed by measuring equipment, or the internal consistency of a measuring procedure, and would usually be quantified in terms of the standard deviation or uncertainty of a set of observations.

Accuracy is the closeness of the measured value to the `true' value.

The Surveying and Spatial Information Regulation 2017, Clause 24 requires that both the accuracy of the calibration and the field measuring technique is to be such that any length measurement made with the equipment will achieve an accuracy of 10mm + 50ppm or better at a confidence interval of 95%.

Surveyors have generally used the traverse closure as an indicator of survey accuracy, however this is only a measure of internal consistency or precision.

Verification is a test to confirm that the accuracy attained by a measuring instrument is within allowable accuracy limits as defined in a specification or as required by legislation.

Calibration is the determination of instrument errors by comparing the value indicated by the measuring equipment with the known or true value. Consequently corrections must be applied to all measurements made with the equipment in order to obtain `true' measurements.

2. Procedures

The Surveying and Spatial Information Regulation 2017, Clause 14 requires surveyors to verify their EDM equipment in relation to the State primary standard of measurement of length at least once every year and immediately after service or repair.

2.1 Description of EDM Baseline Facilities

Commencing in the early 1980s a total of eighteen EDM testlines were established throughout NSW to enable the calibration of EDM equipment of that era. The Office of the Surveyor-General continues to upgrade the original 4-pillar "Testline" facilities to six or seven pillar Baselines to provide an increased accuracy for the calibration of EDM equipment. Three of the original 4-pillar facilities continue to be maintained until they are either upgraded or replaced with a 7-pillar facility.

Note, any reference in this direction to EDM Baseline also refers to EDM Testline.

The Surveyor-General currently maintains eleven concrete pillared EDM baselines throughout NSW

Schedule of EDM Baselines.

The NSW baselines use the Heerbrugg (Schwendener) design which enables the computation of the additive constant without reference to the published inter-pillar distances, therefore avoiding the effect that pillar movement can have on the computation of the additive constant.

Each pillar contains a stainless steel plate with a 5/8" Whitworth screwed spigot to receive the tribrach. The spigot is protected by a PVC cap secured by three bolts which require the use of a 3/8inch or 10mm Allen key for their removal. The PVC caps and bolts must be replace securely to minimise damage caused by vandalism. Damaged or missing caps and bolts should be reported immediately to Customer Support, so repairs can be undertaken promptly.

2.2 Access to EDM Baselines

Use of all baselines is provided free of charge for the calibration of EDM equipment and access to all EDM baselines must be booked using the online EDM Baseline Booking System.

2.3 Verification of EDM Baselines by the Surveyor-General

EDM baselines are currently verified using a Leica TS30 EDM instrument. This instrument has an accuracy specification of ± (0.6mm + 1ppm) and is verified annually by the National Measurement Institute (NMI) Lindfield, and issued a Regulation 13 Certificate, as a Reference Standard of measurement.

Each of the EDM baselines is re-verified within a two-year period in accordance with NMI recommendations.

2.4 Calibration of EDM Equipment by the Surveyor

EDM instruments have three inherent systematic errors. These are additive constant, scale factor and cyclic error and the surveyor must solve for all three errors to achieve legal traceability of distance measurements made with the equipment.

Verification of EDM equipment in NSW is to be carried out in relation to the State Primary Standard of length measurement in the form of pillared EDM baselines. By using these baselines the surveyor will be able to determine the magnitude of the instrument errors and apply corrections where necessary to calibrate the EDM instrument and thereby achieve legal traceability of distance measurements.

The following is a summary of the steps required to verify EDM equipment. For a complete description of EDM instrument verification and calibration refer to the following publications:

'Instructions on the verification of electro-optical short-range distance meters on Subsidiary Standards of length in the form of EDM calibration baselines', (1984), J.M. Rüeger, School of Surveying, UNSW. Available here.

'Electronic Distance Measurement - An Introduction', (1996, 4th edition), J.M. Rüeger, Springer-Verlag, Berlin Heidelberg. Available here.

2.4.1 Preparation of the Equipment

The following procedure is to be adopted for preparation of equipment:

- Obtain the latest EDM Baseline Measurement Report detailing the current distances, reduced levels and access details from EDM Baseline Certificates and Links.
- Check the levelling bubbles on all tribrachs and adjust if necessary before observing the distances. Levelling of the instrument and reflectors is critical during verification.
- Verify the thermometers and barometer against a certified standard.
- All reflectors should be marked with a unique identification number. Only **one** of these reflectors is to be used for the verification observations.
- The field recording sheet EDM Calibration Recording Sheet is recommended for the recording of baseline observations
- The EDM battery should be fully charged prior to carrying out the verification.

2.4.2 Observation Procedure

The following procedure is to be adopted for all EDM baselines in NSW:

- Before commencing measurement ensure that the inter-pillar line of sight is clear of obstructions, particularly long grass or other vegetation blowing across the line.
- The EDM instrument should be carefully levelled and allowed a `warm up' period if recommended by the instrument manufacturer.
- The instrument and meteorological equipment should be shaded by an umbrella.

  Note that most EDM instrument specifications refer to a temperature range of -20°C to +50°C. However the temperature inside an EDM instrument in direct sunlight on a hot summer's day can exceed this temperature range.
- Set the atmospheric correction (ppm) and instrument / reflector constant to **zero**. Some EDM instruments will only accept the input of ambient temperature and pressure readings in lieu of a ppm setting. When calibrating these instruments the operator should refer to the instrument manual and input a temperature and pressure which corresponds to the reference refractive index for that particular instrument. This is the temperature and pressure at which the instrument applies a zero ppm correction to measured distances.
- The height of the instrument and the height of the reflector above the pillar plate are to be measured to an accuracy of one millimetre. This can be achieved by first setting the footscrews of the tribrach to their mid-run position and accurately measuring the heights of the instrument and reflector. Note that when setting up at each pillar the instrument and reflector must be levelled with the footscrews commencing at their mid-run position. These heights are combined with the height of the pillar plate to reduce distances to the horizontal. See section 2.4.4.1 for an explanation of the reduction of measured slope distances.

- All measurements should be made to **one**, uniquely numbered reflector. Note that a separate tribrach may be fixed to each of the pillars and the single reflector located in each tribrach in turn. Centring errors caused by the tribrach are very small in relation to the magnitude of other instrument and reflector errors and may be ignored.
- Point the instrument as prescribed by the manufacturer in order to maximise the return signal strength. For long range instruments an attenuator should be fitted where appropriate.
- The observation sequence should be chosen so that the shorter lines are measured first and last. On a 7-pillar baseline the observation sequence is:
- 1-2, 1-3, 1-4, 1-5, 1-6, 1-7;
  2-7, 2-6, 2-5, 2-4, 2-3
  3-4, 3-5, 3-6, 3-7;
  4-7, 4-6, 4-5;
  5-6, 5-7;
  6-7;

  where '1-2' is the observation from pillar No.1 to pillar No.2 etc. This procedure allows the instrument to `warm up' if necessary and also facilitates the comparison of the remaining reflectors on the shorter line where the uncertainty of the distance measurement due to atmospheric conditions is minimised.

  We recommend when verifying an instrument on a 4-pillar "Testline" that the inter-pillar distances are measured in both directions to improve the redundancy of measurements.

  In general the verification should not be carried out in the early morning or late afternoon when the air temperature may be unstable or changing more rapidly along the measuring path than can be monitored accurately with the thermometers.

  A minimum of five individual **slope** distances should be measured to the same single reflector, re-pointing after each measurement. This will allow the instrument to go through the initialisation procedure and reset the signal strength for each measurement. The instrument should not be set to display the mean of a set of five measurements in lieu of five individual readings unless this procedure is repeated five times independently.

  Horizontal distances are computed more accurately using the known pillar heights. Recording of the horizontal distance displayed by the instrument or reducing the slope distances to the horizontal using the zenith angle should only be used for a check on field procedure or the onboard computation of horizontal distance.

  The following sources of error may occur if horizontal distances are calculated from zenith angles either manually or by automatic reduction in the EDM instrument:

  - pointing error
  - vertical circle index error
  - variation in reduction formula used in different instruments
  - round off errors after automatic computation in the EDM instrument.
- The temperature and pressure at both the instrument and the reflector should be measured to an accuracy of 0.5°C and 1 millibar or hectopascal (hPa) respectively. Temperatures should be measured at the height of instrument and reflector to minimise the effect of radiated heat from the ground.

  Note that pressure may be measured at the instrument only and the pressure at the reflector calculated from the height difference between pillars where the difference is considered significant. For example, at 1025mb and 30°C, a height difference of 30 metres would result in a pressure difference of 3.5mb, (Change in Pressure Corresponding to Change in Height). Note that an error in measurement of 1°C in temperature or 3 millibars in pressure will make a corresponding error in the reduced distance of approximately 1 part per million (ppm).

- When transporting the instrument between pillars, ensure that it is kept shaded from direct sunlight.
- Once all inter-pillar distances have been measured to the **one** uniquely numbered reflector, compare this reflector with the remaining reflectors by measuring to each in turn. This should be carried out on the shortest line and by comparing the slope distances. However if the reflectors vary in height, measurements should be reduced to the horizontal before the comparison is made. This comparison is important when using different makes of reflector but can also be significant when different reflector holders of the same make are used, e.g. single reflector holders compared with triple reflector holders.

  Where found to be significant, variations should be applied as corrections to the additive constant for each reflector concerned. It is for this reason that all reflectors should be uniquely numbered.

  Subsequent verifications of the EDM instrument should be performed using the same uniquely numbered reflector where possible in order to compile a verification history for the instrument/reflector combination.
- Use of Automatic Target Recognition (ATR) while verifying an instrument is not recommended. If used it must be - checked and adjusted in accordance with manufacturer's specifications; line of sight visually inspected to ensure it is free of obstructions; only one uniquely numbered reflector used; a minimum of five individual distances measured; and re-pointing after each measurement.

2.4.3 Data Recording

All field notes and calculations relating to the verification are to be retained by the surveyor in order to maintain legal traceability of distance measurements.

2.4.3.1 Manual Recording

The field recording sheet EDM Calibration Recording Sheet is recommended for the recording of baseline observations. All data entry fields should be completed. Although the recording sheet is self-explanatory the following is a brief explanation of what details to record:

- The make, model and serial number of the instrument and the reflector used in the verification.
- The make, serial number and correction to the thermometers and barometer used.
- 'Weather' - record the weather as it applies to the Baseline, noting the cloud cover, wind speed and direction and the presence of heat shimmer, fog or rain if applicable.
- CHECK: Instrument, Reflector and Met equipment shaded, ppm set to zero, Inst / Ref constant set to zero.
- Enter Pillar numbers in the 'From' and 'To' columns. Each pillar has a unique PM number fixed to the front of the pillar.
- 'H.I.' and `H.R.' are the instrument and reflector heights above the pillar plate, read to an accuracy of 1 millimetre.
- The recorded temperature and pressure as read. The correction to each reading is to be applied when reducing observations.
- **'Slope Distance'** measurements - the first column is for the whole distance and the other four columns are for the millimetres only.
- Observations should be dated and signed by the observer.

2.4.3.2 Electronic Recording

It is acceptable to use an electronic data recorder to record observations. However slope distances should be recorded in preference to the horizontal distances automatically reduced by the EDM. All other observations made including heights of the instrument and the reflector as well as temperature and pressure readings should be recorded.

2.4.4 Data Processing

There are a number of alternative spreadsheet and software solutions currently available that will determine the additive constant, scale factor and cyclic error. Please contact Customer Support for advice on which software would best suit your requirements and the baseline you are using.

The following information is included as reference material and for those wishing to process the observations manually. Note that the order in which the corrections are presented is generally the order in which they should be applied.

2.4.4.1 Initial Processing

First Velocity Correction

The First Velocity correction (ppm correction) is applied because the ppm correction was set to zero in the instrument at the time of verification. The formula is generally in the form:

$$d^1 = d_{meas} + K_a$$

$$K_a = \left[C - \frac{D * p}{273.15+t} + \frac{11.27\, e}{273.15+t} \right] 10^{-6}\, d_{meas}$$

Where 'p'= pressure in millibars; 't'= temperature in °C; 'e'= partial water vapour pressure (mb).

'C' and 'D' are parameters specific to the modulation frequency and the carrier wavelength respectively of the EDM instrument. Refer to the instrument manual for the relevant parameters.

For example, with the Leica TS series of instruments the following parameters are applicable:

C = 286.34 D = 80.68

Note that in all but precise EDM calibrations the second term, relating to partial water vapour pressure in the above equation, may be omitted or an approximate value of e = 15mb may be adopted.

Slope Correction

The measured distances are then reduced to the horizontal at the mean elevation of the two pillars using the following formula:

$$d_{hor} = d_1 + S_{cor}$$

$$S_{cor} = \frac{\Delta h^2}{2d_1} + \frac{\Delta h^4}{8d_1^3} + \frac{\Delta h^6}{16d_1^5}$$

Where Δh = Height difference between the instrument and the reflector. For inter-pillar distances with a gradient of less than 4% the third term may be ignored. That is:

$$S_{cor} = \frac{\Delta h^2}{2d_1} + \frac{\Delta h^4}{8d_1^3}$$

The distances are reduced to the horizontal using published pillar heights and the height of the instrument and reflector.

Note that in the case of a telescope-mounted EDM instrument the slope distance measured from EDM does not differ from the slope distance computed at the height of the theodolite by more than 1mm for distances in excess of 10 metres irrespective of the slope of the line. Therefore reducing the measured distance using the height of the theodolite rather than the height of the EDM avoids the necessity to calculate a tilt correction for the EDM slope distance.

An estimate of the additive constant should be applied to the observed distances before applying

the slope correction if the magnitude of the additive constant or the grade of the baseline makes the correction significant.

Height Correction

The horizontal distances at mean elevation are reduced to the height of the lowest pillar. The magnitude of this correction becomes significant on the steeper baselines. The effect of not applying this correction to the mean elevation distance is an error of 1 ppm for each 6.37 metre height difference between the height at the mean elevation of a pair of pillars and the height of the lowest pillar.

$$d = d_{hor} \frac{*R + h_o}{R + h_m}$$

Where R = 6 370 100m (Radius of Earth)
h_o = height of lowest pillar
h_m = height at mean elevation
d_{hor} = horizontal distance at mean elevation

2.4.4.2 Solving for the Instrument corrections

As stated previously, in order to achieve legal traceability of distance measurements all three instrument corrections, additive constant, scale factor and cyclic error must be determined. Using the NSW 7-pillar baselines it is possible to solve for all three corrections, however when using the 4-pillar "testlines" the cyclic error should be determined independently as detailed below.

Additive Constant

The additive constant is generally computed using the 'parts to the whole' method. As an example, a four pillar baseline would give the following combinations for additive constant (C):

$$2C_1 = -(d_{12} + d_{23} + d_{34} - d_{14})$$
$$C_2 = -(d_{12} + d_{23} + d_{13})$$
$$C_3 = -(d_{23} + d_{34} + d_{24})$$
$$C_4 = -(d_{13} + d_{34} + d_{14})$$
$$C_5 = -(d_{12} + d_{24} + d_{14})$$

Where 'd12' is the mean of the two reduced horizontal distances measured between pillar one and pillar two, etc.

The additive constant should be computed using the closed least square solution as detailed for various configurations of baseline in Rüeger (1996) section 13.2.4.4.

In the case of a four-pillar baseline the additive constant is given by:

Additive Constant: $C = -0.5\ (d_{12} + d_{23} + d_{34} - d_{14})$

To confirm that the constant has been determined correctly, re-compute the parts to the whole, using the corrected distances.

Scale Factor

The scale factor for the instrument is determined by computing the ratio of each of the inter-pillar distances (reduced to the horizontal at the height of the lowest pillar and corrected for additive constant) with the corresponding known distances shown on the baseline certificate.

On a four pillar baseline the scale factor is determined using the weighted mean of the six inter-pillar distances. However an estimate of the scale factor can be determined by comparing the unweighted mean of three inter-pillar distances with the published values, for example:

Scale factor	=	known distance ⁄ observed distance
	=	650.500 / 650.502
	=	0.999 9969
	=	-3.1 ppm.

Cyclic Error

Using the NSW 7-pillar baselines it is possible to solve for cyclic error, however when using the 4-pillar "testlines" the cyclic error should be determined as detailed below.

Although cyclic error may be significant in older instruments, modern instruments generally have a cyclic error of less than 1mm. Despite the small magnitude, cyclic error must be determined through verification in order to achieve legal traceability of distance measurements.

Note that cyclic error, if found to be significant, must be applied to the original measured distances before the other instrument corrections are determined.

In its simplest form the test consists of laying out a calibrated tape horizontally along the top of a low wall for a distance corresponding to the unit length of the instrument, at 50 to 70 metres distant from the EDM instrument.

A reflector, mounted in a tribrach, is moved to each successive interval along the tape, corresponding to subintervals of the Unit Length (equal to half wavelength) of the instrument. Both the EDM distance and the tape distance is recorded. The two sets of measurements are then compared.

Example for an instrument with a Unit Length = 10m:

EDM	=	50.125; 51.126...........	59.124; 60.123
TAPE	=	2.000; 3.000...........	11.000; 12.000
Cyclic Error	=	+0.000; +0.001...........	-0.001; -0.002

For a detailed description of the procedure for determining cyclic error refer to Rüeger (1996).

2.4.5 Analysis of the Calibration Results and Application of Instrument Corrections

On completion of the EDM calibration the three instrument corrections of additive constant, scale factor and cyclic error should be known to sufficient accuracy such that the total instrument correction has an uncertainty not exceeding ±(5.0mm + 30ppm) at the 99% confidence level. Note that this accuracy specification was agreed in a meeting of Surveyors General and NMI in 1983 to satisfy cadastral requirements. Current survey projects generally specify higher accuracy, and modern instruments can achieve a higher accuracy if calibrated correctly.

2.4.5.1 Cyclic error

Cyclic error is generally insignificant in modern instruments and consequently not applied to the measured field distances. However its magnitude must be determined in order to achieve legal traceability of distance measurements.

Note that cyclic error if found to be significant, should be applied as a correction to the measured slope distances prior to reduction of the distances to the horizontal and the determination of additive constant and scale factor.

2.4.5.2 Additive constant

The NSW baselines are based on the Heerbrugg (Schwendener) design and therefore the additive constant can be determined without reference to the published inter-pillar distances. The advantage of this baseline design is that the computed additive constant will not be influenced by changes in the "true" distances caused by pillar movements occurring since the baseline was last verified.

The additive constant is primarily a correction for the combined physical offset of the reflector and the offset of the electrical centre of the instrument and unlike scale factor should not be influenced by a change in the ambient temperature. Consequently the additive constant should not vary significantly in subsequent verifications given the same reflector and EDM combination.

The additive constant should be applied to all measured field distances either manually or by setting the constant in the instrument after the verification. Once set in the instrument, a known distance should be re-measured to ensure the sign (+ or -) of the constant has been correctly applied.

2.4.5.3 Scale factor

The scale factor will generally vary for subsequent verifications within the accuracy specification of the instrument (e.g. ±3ppm or ±5ppm). This is because the scale factor is dependent on the modulation frequency which may change with variations in the ambient temperature. To a lesser extent the scale factor can also change as a result of frequency drift and aging of the frequency oscillator.

Consequently if the scale factor falls within the instrument's specification it should not be applied as a correction to measured field distances.

If the scale factor falls outside the instrument's specification the instrument should be returned to the manufacturer for service. However it is advisable to repeat the verification under different weather conditions both to confirm the result and to observe if the scale factor changes with different ambient temperatures. The thermometers and barometer used in the calibration should also be re-verified against a certified standard as an error in temperature and pressure readings will contribute to the scale error of measured distances.

2.4.5.4 Uncertainty of the Instrument Correction

A working party of the former National Standards Commission and Surveyors General recommended in 1983 that the minimum standard for the uncertainty of calibration of an EDM instrument should be ± (5mm+30ppm) at a 99% confidence interval. This uncertainty is equivalent to ± (4mm + 24ppm) at a 95% confidence interval.

The uncertainty of the instrument correction, in relation to the National Standard, includes the uncertainty of the verified baseline distances as shown in the baseline Measurement Report, currently stated as a minimum of ± (0.5mm+1.3ppm) at a 95% confidence interval.

Note that all statements of uncertainty are now required to be shown at the 95% confidence interval to achieve international uniformity in accordance with the International Organisation for Standardisation (ISO).

The reader is referred to Rüeger (1984) for details on the calculation of the uncertainty of the instrument correction. The computation of this uncertainty, which varies with the distance range measured, is quite complex and therefore beyond the scope of this document.

2.4.5.5 Error analysis of the field measurement technique

The Surveying and Spatial Information Regulation 2017 requires surveyors to make distance measurements to an accuracy (uncertainty) of ± (10mm + 50 ppm) or better at a confidence level of 95%.

The reader is referred to Rüeger (1991) for a detailed example of the calculation of the 'error budget' for measurements made using an EDM instrument given the required uncertainties for the instrument calibration and the accuracy of the measurement technique.

3. Conclusion

The Surveying and Spatial Information Regulation 2017 requires that the length stated by a surveyor should not differ from the true value by more than ±(10mm + 50ppm). The required accuracy or uncertainty is to include the uncertainty of the length measurement arising from all possible sources.

In addition to the uncertainty of calibration, including the uncertainty of the State primary standard, length measurements made with an EDM instrument are subject to errors arising from the centring of the instrument and reflector, measurement of the atmospheric conditions and those associated with the reduction of the slope distance to the horizontal.

It is therefore essential that **all** ancillary equipment is calibrated and in good adjustment and that an appropriate measuring technique be adopted in order to achieve the required result.

For further information, please contact: Customer Support.

4. Acronyms

AGAL = Australian Government Analytical Laboratories

EDM = Electronic (Electromagnetic or Electro-Optical) Distance Measurement

ISO = International Organisation for Standardisation

NATA = National Association of Testing Authorities

NMI = National Measurement Institute (comprising the former AGAL, NML and NSC)

NML = National Measurement Laboratory

NSC = National Standards Commission

PPM = Parts Per Million

5. References

List, R.J. (1971) `Smithsonian Meteorological Tables’, Smithsonian Institute.

National Standards Commission (1988) `Verifying Authorities Handbook’.

Rüeger, J.M. (1984) `Instructions on the verification of electro-optical short-range distance meters on Subsidiary Standards of length in the form of EDM calibration baselines’, School of Surveying, UNSW. Available here.

Rüeger, J.M. (1991) `Legal Calibration of Electronic Distance Meters in Australia’, The Australian Surveyor, Vol 36, Sept 1991, pp195-212. Available here.

Rüeger, Jean M. (1996) `Electronic Distance Measurement - An Introduction’, 4th edition. Springer-Verlag, Berlin Heidelberg. Available here.

6. Appendices

6.1 Schedule of EDM Baselines

The location and configuration of EDM Baselines in New South Wales are as follows:

Baseline	Locality	Total Dist (m)	No. of Pillars
Armidale	Grafton Road	600	4
Coffs Harbour	Dowsett Drive, Coffs Harbour Airport	921	7
Dubbo	Dunedoo Road	765	6
Eglinton	Thomas Drive	849	7
Kingscliff	Marine Parade	721	7
Lethbridge Park	Bougainville Road	984	7
Nowra	Flinders Road	581	4
Seaham	Croft Road	867	7
Ulan Coal	Ulan Rd, Ulan	650	6
Wagga Wagga	Stanley Street, Kooringal	535	5
Wollongong	Sir Thomas Dalton Park, Elliotts Rd	600	4

6.2 Change in Pressure (Millibars) Corresponding to Change in Height of 10 Geopotential Metres

Temp	Pressure in Millibars								
°C	1050	1000	950	900	850	800	750	700	600
-10	1.3622	1.2974	1.2325	1.1676	1.1028	1.0379	0.9730	0.9082	0.7784
0	1.3124	1.2499	1.1874	1.1249	1.0624	0.9999	0.9374	0.8749	0.7499
10	1.2660	1.2057	1.1454	1.0852	1.0249	0.9646	0.9043	0.8440	0.7234
20	1.2228	1.1646	1.1064	1.0481	0.9899	0.9317	0.8735	0.8152	0.6988
30	1.1825	1.1262	1.0699	1.0136	0.9573	0.9010	0.8446	0.7883	0.6757
40	1.1447	1.0902	1.0357	0.9812	0.9267	0.8722	0.8177	0.7632	0.6541
50	1.1093	1.0565	1.0037	0.9508	0.8980	0.8452	0.7924	0.7395	-

Reproduced from Smithsonian Metrological Tables, (1971) R.J. List

End of Direction