For Good Measure: The Story of the Adoption of Linear Standards of Measurement for Surveying Purposes in NSW

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ABSTRACT

This paper is part of an anthology designed specifically to provide a contemporary focus for candidates preparing for the assessment procedures conducted by the Board of Surveying and Spatial Information (BOSSI) leading to the awarding of a Certificate of Competency and accompanying registration as a Land Surveyor under the provisions of the Surveying and Spatial Information Act 2002. The purpose of this paper is to provide a retrospect outlining the circumstances leading to the adoption of a State Primary Standard and legal traceability to the national standard of measurement of length. The calibration of modern Electronic Distance Measurement (EDM) equipment and verification of Global Navigation Satellite System (GNSS) instrumentation are sufficiently described in Surveyor General's Direction No. 5 (Verification of Distance Measuring Equipment) and Surveyor General's Direction No. 9 (GNSS for Cadastral Surveys), therefore requiring only brief discussion.

KEYWORDS: *Standards of measurement, state primary standard, legal metrology, history, New South Wales*.

1 INTRODUCTION

By action of the Parliament of the United Kingdom, section 51(XV) of the Commonwealth of Australia Constitution Act (63 & 64 Vic. c. 12) gave legislative power to the Parliament of the Commonwealth to make laws in respect of weights and measures. The National Measurement Institute (NMI) is responsible for establishing and maintaining Australia's units and standards of measurement and for co-coordinating Australia's national measurement system. NMI was formed by bringing together the National Measurement Laboratory (CSIRO), the National Standards Commission (NSC) and the Australian Government Analytical Laboratories and continues their work.

The National Measurement Act 1960 (Act No. 645 of 1960 as amended), administered by NMI, establishes the legislative framework for a national system of standards and prescribes the legal measurement units for all physical quantities. The unit of greatest interest to surveyors is the standard measure of length. The Act defines the State primary standard of measurement as a standard of measurement that has been approved by the Chief Metrologist and that is maintained, or caused to be maintained, by a State or Territory and that has been verified under section 9 by means of, by reference to, by comparison with or by derivation from an Australian primary standard of measurement or an Australian secondary standard of measurement.

The office of the Surveyor General of New South Wales (NSW) has been appointed by NMI as a verifying authority under the provisions of Clause 73 of the National Measurement Regulations, 1999. Surveyor General's Direction No. 5 (Verification of Distance Measuring Equipment) outlines in considerable detail the facilities maintained by the Surveyor General for the verification of survey measuring bands and Electronic Distance Measurement (EDM) equipment (LPI, 2009). This paper provides a retrospect outlining the circumstances leading to the adoption of a State primary standard and legal traceability to the national standard of measurement of length. The calibration of modern EDM instruments and verification of Global Navigation Satellite System (GNSS) equipment is described elsewhere and requires only brief discussion in this paper.

2 EUROPEAN SETTLEMENT

When Augustus Alt arrived in New South Wales with the First Fleet in 1788 as the Surveyor of Lands, he would have carried with him a Gunter's chain. This particular item of equipment had been used extensively and exclusively for the measurement of farmlands in Britain since its invention by Welsh polymath Edmund Gunter around 1620 (Figure 1). The best quality chains were constructed of thick steel wire, consisting of 100 main links connected together by about 300 smaller links, and with constant use and wearing taking place on about 800 surfaces together with distortion of smaller links out of round it would be expected that the length of the chain changed considerably over time. The instrument was adequate for the period however, and the need for a precise determination of the length of the chain by verification against a known standard was unnecessary.

Figure 1: Gunter's Chain.

The imperial system of weights and measures was introduced into England by an Act of Parliament in 1824. The Weights and Measures Act, 1824 (5 Geo IV c. 74) provided a simplified measurement system that was nevertheless capable of meeting the demands of the industrial revolution in the United Kingdom. It was adopted rapidly throughout the British Empire, partly as a result of the requirements of imperial trade and partly because of encouragement and direction from the Colonial Office and the India Office in London.

At the founding of the colony, the standard linear measure in the imperial system was the statute mile, so named because it was defined by an English Act of Parliament in 1592, during the reign of Queen Elizabeth I. It was defined as being 1,760 yards or 5,280 feet. For surveying, the statute mile is divided into eight furlongs, each furlong into ten chains, each

chain into four rods (also known as poles or perches), and each rod into 25 links. The first attempt to standardise measures in England was during the reign of Edward I (1272-1307) when, although rod lengths from 12 to 24 feet were consistently used throughout the Anglo-Norman period, the statute English rod was set at 16½ feet and at the same time the statute acre was set at 160 square rods, measured with the statute rod of 16½ feet.

The provisions of the Weights and Measures Act 1824 did not extend to the British colonies. The colonial administration was initially content to rely on the lineal standard in force and in use in the United Kingdom, and it was some time before the Governor-in-Council introduced the Weights and Measures Act 1832 (3 Wm. IV, No. 4). The preamble of that Act recited that "…certain weights and measures of the standard now in force and in use in the United Kingdom … now deposited in the Colonial Treasury … are hereby declared to be the standard weights and measures of New South Wales." In the Act, no distinct or direct reference was made to measures of land, the standard measures of length being limited to the yard, the foot and the inch. It would appear that the Act was intended solely to regulate the buying and selling of merchandise such as is exchanged in warehouses, shops and marketplaces.

The wording in a despatch from Governor Bourke to the Secretary of State advising him of this proposed new legislation clearly confirms that a standard set of imperial weights and measures had previously been sent out to the colony by the Lord Commissioners of the Treasury and held in the office of the Commissariat (see Bourke to Goderich, Despatch No. 110, 30 October 1832, *Historical Records of Australia*, Series I, vol. 16, 1923, p. 782). These standards had been procured and transferred to the Office of the Colonial Treasurer. A 'standard yard' was obtained from the Office of the Surveyor General. This is also the first evidence sighted thus far to confirm that the Surveyor General was in possession of an established standard even though it was only three feet in length.

Beaver (1953) noted, however, that Parramatta Observatory was established by Sir Thomas Brisbane at his own expense and under the supervision of the Government Astronomer, Mr. Russell. In 1828, Mr. Rümker, the then Astronomer, took delivery of the "requisite rods and cylinders for the trigonometrical survey", the survey being in conjunction with the measurement of an arc of the meridian which Mr. Rümker had agreed to carry out. (The measurement of the arc of the meridian was never performed.) It should be noted that Christian Carl Ludwig Rümker arrived in Sydney in 1821 and worked at Governor Brisbane's private observatory at Parramatta. On 21 December 1827, Governor (Sir) Ralph Darling appointed him Government Astronomer – he was the first to hold that title in Australia.

The primary standards of weight and length in England were preserved at Westminster. When the Houses of Parliament burned down in 1834, these standards were destroyed and new primary standards had to be prepared. A commission established to resolve the matter was slow to act and by 1844 little had been achieved. Forty bars in total were cast in 1845 of which one was selected as the primary of the Imperial Standard Yard. The one which matched best the standard that had been destroyed in the fire became the new Imperial Standard Yard, and the next best bars were approved as Parliamentary Copies and sent to major cities in the United Kingdom and British colonies.

In 1855, Parliamentary Copies No. 18 and 34 were supplied to the New South Wales and Victorian Governments and became the primary standard of their respective colonies. They are constructed of metal developed by British astronomer Francis Baily, made up of 16 parts copper, 2½ parts tin and 1 part zinc. The yard is measured between fine lines marked on a

gold pin in the well at each end of the bar. Bar No.18 is currently on loan from the National Measurement Laboratory (NML), Sydney to Sydney University Museum and Bar No. 34 is in the permanent custody of Museum Victoria (Figure 2).

Figure 2: Parliamentary Copy No. 34 – Museum Victoria.

A circular issued by Deputy Surveyor General S.A. Perry to licensed surveyors on 10 April 1848, outlining existing practice of the Surveyor General's Office, included inter alia the following instruction for survey and measurement of portions: "… and measurement of the lengths of the several boundary lines with a Gunter's chain, *verified by comparison with the standard measure*..." It is reasonable to conclude that licensed surveyors had for some time had access to a standard baseline – very likely the one in the front of the old Lands Office later referred to and possibly laid down with the 'standard yard' in possession of the Surveyor General referred to by Governor Bourke in 1832.

The arrival of new sets of standard weight and measures duly verified and stamped at the Exchequer at Westminster prompted the enactment of the Weights and Measures Act 1849 (13 Vic. No. 25) necessary for the adoption of these new sets, as described in an annexed schedule, as the standard weights and measures of NSW in lieu of the weights and measures deposited in the Colonial Treasury in Sydney. The units of linear measures were itemised as "one imperial yard bed and rod" and "one 3 feet scale containing the yard foot and inch". Each item was engraved with the name of the Colony.

The Weights and Measures Act 1852 (16 Vic. No. 34), in similar fashion to the 1832 Act it repealed, failed to make any reference to measures of land, simply repeating the standard measures of length as the yard, the foot and the inch. The administration's focus, it seems, was firmly fixed on the value of standard weights and measures only in so far as it affected trade and commerce. A 10-foot Geodetic Standard Bar, Ordnance Intermediate No. 4 (OI4) was sent to Sydney for the Government of New South Wales in December 1858, and a second similar bar, with no distinguishing mark or inscription but made by Troughton and Simms in 1881, was sent to the Colony in March 1884. A third Geodetic Standard Bar, identified as OI6 was sent out in March 1862 to Melbourne for the Government of Victoria.

When official instructions for the measurement of the baseline at Lake George for the triangulation of NSW were issued by the Department of Lands to Government Astronomer George R. Smalley on 16 January 1867, the 10-foot standard bar of the Colony was placed in his charge at the observatory. In preparation for the baseline measurement some well-seasoned pine poles, originally the property of NSW, were recovered from the Lands Office in Melbourne and tested by reference to this iron bar. Mr. Smalley having died soon after starting the work, progress was interrupted until the latter end of 1870, when Mr. Adams (the new Surveyor General), undertook supervision of the operations (Chesterman, 1924). As a

means of ensuring accuracy, Adams transported the iron bar to Lake George where it was housed in a specially constructed underground vault. Daily comparisons of the pine measuring poles were made with the iron standard at night and in the morning. Under the system pursued, the iron standard was depended upon entirely, the measuring apparatus being trusted for only a few hours at a time.

In 1887, the NSW Department of Lands was in possession of Standard Bar OI4 when it was sent to London for re-verification by the Warden of the Standards, England (Lucas, 1889). Mr. J. Brooks, who in 1890 was in charge of the geodetic surveys in NSW, asserted "as far as I am aware these are the only 10 ft. standards in Australia" (Brooks, 1889).

The NSW Geodetic Standard Bar Ordnance Intermediate No. 4 (OI4), prepared under the direction of Sir Henry James of the Ordnance Survey of Great Britain, was made of wrought iron and had as its section the form of a girder with equal flanges above and below. The breadth was 2.3 inches and the depth 2.95 inches. A groove 1.4 inches in breadth and about a third of an inch deep was planed out through the whole length of the upper surface. In the centre of the breadth of this groove, seven holes were drilled about a tenth of an inch diameter at 0, 3, 6, 7, 8, 9 and 10 feet. Into these holes were screwed small, cylindrical plugs whose heads were then filed off level with the upper surface of the bar, but raised above the bottom of the groove. Small silver plugs were then inserted into these plugs. The upper surface of the bar was thus divided into yards and feet, which were marked by fine dots on the silver plugs. The bar rested upon two cradles, each cradle consisting of two pairs of rollers, and each pair rested on a subsidiary cradle which in turn rested on another roller. It was provided with three thermometers, the curved ends of which were let into wells in the centre of the bar. When in use, these wells were filled with mercury (Brooks, 1889).

Currently there are two 10-foot standard bars in the collection of the Powerhouse Museum, Sydney: object B754 is described as "one 10 ft long surveyors standard measurement bar, 7 camels for supporting bed of instrument and 1 microscopic stand and carriage (SB) – surveyors testing instrument from the Observatory (LC)" and object H9151 as "standard bar, 10 ft, Great Britain, c. 1865 (LC)". There is good reason to believe that B754 is Ordnance Intermediate No. 4 and H9151 is the bar manufactured by Troughton and Simms, and sent to the Colony in 1881.

The Regulations for the employment of licensed surveyors issued by the Surveyor General's Department in 1864 prescribed in a "list of instruments to be provided by each licensed surveyor and to be subject to the approval of the Surveyor General" inter alia "1 chain, to be kept as a standard, and never used in survey". It is not expressly stated but it is clearly implied that any such (Gunter's) chain was to be compared with the Surveyor General's standard described by Bayliss (1957) as "a standard of 100 links ... established by cutting marks in the stone flagging in front of the old Lands and Survey Office in Bridge Street, Sydney, which according to one authority, was probably correct to within half an inch or so". There appears to be some conjecture as to whether Bridge Street represented "the front of the old Lands and Survey Office", as it is known that at an earlier time the staff of the Department was housed in the Surveyor General's Office, a two-storey building occupying part of the present Lands Office site but located at the corner of Gresham Street and Bent Street.

Sandwiched between the latter regulations and the general instructions issued to salaried surveyors in 1884 was an event that was a momentous leap in a surveyor's ability to measure with enhanced accuracy. In 1872, F.B.W. Woolrych introduced surveyors to the steel riband.

In rapid time the Gunter's chain became all but obsolete in regards to land surveying. The Gunter's chain remained in the 1886 Surveyor General's regulations but in addition to a Gunter's chain and a light steel riband, not less than 500 links long, each surveyor was required to possess "two steel ribands, 66 feet long; one to be used for adjusting and testing the riband and chain used for measuring."

General instructions issued in 1884 to salaried surveyors of the Department of Lands made provision for a standard length to be maintained near the District Surveyors' offices as follows (Marshall, 1999):

146 In order to ensure accurate survey it is advisable that a standard length be marked in some suitable place near the District Surveyor's office, for comparing and adjusting chains and steel ribands used in the process of measurement.

147 For the mode of marking such standard length, see Appendix I.

It was clearly intended that these standard lengths be laid down using a steel band tested at the Sydney Observatory. Appendix I unambiguously makes reference to "…the standard riband … having been tested at the Sydney Observatory" (Figure 3). The steel riband was clearly seen as the way to the future.

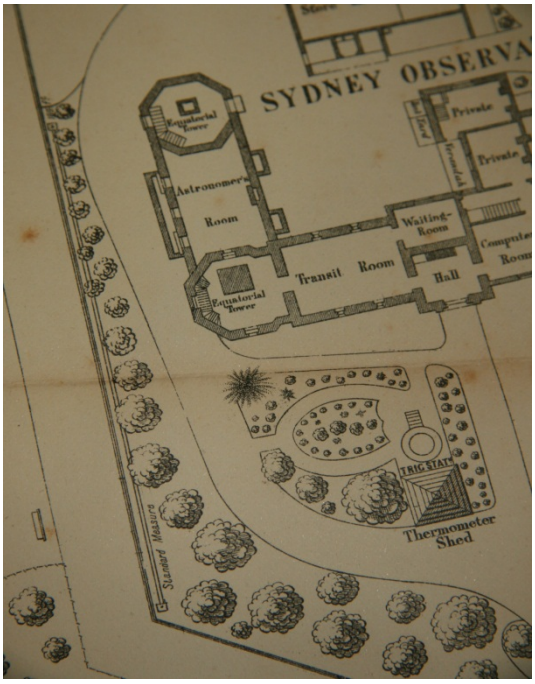

Figure 3: Sydney Observatory baseline.

Standards of 66 feet and 100 feet with stone terminals carrying the marks showing the distances had been laid down at Sydney Observatory around 1880 following the destruction of the one chain length in the pavement at the front of the Old Lands Office, Sydney. The pavement was destroyed to make way for the proposed new building. The image of Flagstaff Hill showing the location of the 'standard measure' in relation to the observatory depicted in Figure 3 is taken from a plan annexed to an 1881 publication by the Government Astronomer H.C. Russell entitled 'Results of Astronomical Observations made at Sydney Observatory – 1877 and 1878' and held at the Mitchell Library. Bayliss (1957) observed: "These standards were a distinct advance on the so-called standard in front of the old Survey Office, and proved to be of great service to surveyors generally. However, the observatory standards were apparently damaged by rough usage and were later found to be 0.04 inch short."

About this time, the newly formed NSW Association of Surveyors engaged in robust debate relating to the lack of satisfactory linear standards being available to the surveying profession. Herborn (1890) observed: "So far as I am aware, the only instruments or lengths used as standards are – the 10-feet Geodetic Bar, in the custody of the Survey Department; a 1-chain length laid down at the Observatory; a 1-chain length laid down at the Old Lands Office, and now destroyed; and the standard of Chesterman's tapes."

James Chesterman & Co. of Sheffield, England was noted for the manufacture of woven cloth tapes that incorporated strands of wire, and a process for heat treating long strips of steel patented in 1853, that led to the manufacture of steel tapes that remained unchanged for over 50 years. In particular, around the turn of the century, the company introduced tapes of steel alloy with very low coefficients of expansion. The tapes referred to by Herborn (1890) were later described by James Chesterman & Co. "…though correct for all practical purpose they are not made with the intention of being used as veritable standards … they are assumed to be correct at 62° Fahr" (Thomas, 1891).

The Association's deliberations resulted in (Sir) George Knibbs proposing on 11 March 1890 "that in the opinion of this Association it was desirable that the 10 feet geodetic standard bar OI. No. 4 be made the legal standard of the colony." The resolution passed at that meeting also provided for a request be made to the Surveyor General "that an accurate and convenient standard … be made available for the use of surveyors".

The Office of the Surveyor General continued to address the regulation of survey practice and in particular the integrity of measurement of surveys of land which was so crucial to the corresponding integrity of Torrens Title. Regulations for the employment of licensed surveyors issued in 1886 extended a concept first introduced in general instructions issued in September 1884 to government surveyors (Marshall, 1999). Regulation 53 prescribed that the accuracy of the survey of each portion should be determined by a method using latitude and departure, and provided a table showing the limit of allowable error in links, being the sums of the differences in latitude and departure, according to perimeter of the survey.

The accuracy of closure as provided for in this manner is not a statistically robust indication of the accuracy of a survey. In fact a loop survey in which all distances are measured with a 10% scale error will close perfectly, as would any loop survey in which all distances are measured with a consistent scale error. This concept was further developed over time providing surveyors with a simple but reasonable test of their field work. The technique used in boundary re-determination of maintaining angles and applying a determined scale factor to all lines between terminals established from marks found is wholly dependent on accurate closure of the original survey, a point obviously not lost on Phillip Francis Adams, who was Surveyor General at that time. Each surveyor however, as part of his instruments, was required to provide "two (2) steel ribands, 66 feet long; one to be used for adjusting and testing the riband and chain used for measurement".

3 THE INTERCOLONIAL CONFERENCE OF SURVEYORS, 1892

The first Intercolonial Conference of Surveyors in the southern hemisphere was convened in Melbourne on 31 October 1892. New South Wales was represented at the conference by Edward Twynam and R. McDonald, respectively Chief Surveyor and District Surveyor, Armidale, from the Lands Department, and G.H. Knibbs and T.F. Furber, President and

Secretary respectively of the Institution of Surveyors. It was a significant conference and possibly best remembered by the surveying profession for the establishment of the principle of reciprocal recognition by each jurisdiction of certificates of competency issued by the other jurisdictions. Besides reciprocity, there were a number of other principal objects the conference aimed at, including the adoption of uniform standard of length in each of the colonies.

Sir Augustus Charles Gregory, a prominent surveyor and politician representing Queensland, expressed an interesting opinion that English Statute law on the subject was in force in all the colonies. If any question arose as to the interpretation of weights and measures, the English law would prevail in the courts. Obviously confident in the protection afforded the matter by English Statute law, the conference resolved to recommend "that the measure of length used in all Australasian surveys being the English measure of length, as provided by English Statute law, standards 66 ft. and 100 ft. in length, in terms of such legal standard, should be established in the principal Australasian cities and adopted as the standard of surveys in all the colonies".

The Association's 1890 request that an accurate and convenient standard be made available, no doubt reinforced by the recommendation of the Melbourne conference, did not pass unheeded and upon completion of the Lands Office building, the baseline standard was restored to the Lands Office precinct but on this occasion it was laid down internally in the building. A 66-feet and a 100-feet standard were installed in the eastern corridor of the ground floor by cementing into the bedrock under the floor large blocks of trachyte (a form of volcanic rock) into which silver inserts had been embedded. The terminal plugs were protected by brass plates, which were removable to allow micrometer microscopes to be mounted over the terminals and a tension device to be set up.

In 1894, Edward Twynam, the Chief Surveyor of NSW, advised of a new acquisition by the Department of Lands (Lands, 1893): "An instrument named 'the comparator', designed by the late Surveyor General, has, under the supervision of the Government Astronomer, been completed at small cost; it is intended to facilitate the transfer of measure from the standard bar to a steel tape or other means of recording length, and it is found to operate in a satisfactory manner."

This newly-completed 'comparator' was used by D.M. Maitland in November 1894 to define on a steel band 66-feet and 100-feet lengths for laying down fixed standards in the Lands Office for adjusting surveying apparatus; these lengths were marked by very fine lines inscribed on silver bosses inserted in a steel band. The lengths were marked off by means of the 'comparator' from bar OI No. 4 (Lands, 1894). Having calibrated the steel tape, Maitland then proceeded to measure the distances between the terminal points established in the Lands Office corridor. The standard thereby created was known as the 'prime standard' and was very useful to surveyors but as it never made its way into legislation, it had no legal status.

Early in 1893, George Knibbs and D.M. Maitland gave important evidence in connection with making a legal standard of length for measuring land to a Board of Inquiry appointed to inquire into the administration of the Weights and Measures Act 1852. After a full inquiry into the operation of the existing Act, the Board recommended that a Bill be framed for submission to Parliament on the same lines as the United Kingdom legislation of 1878 and 1889 (Act 41 & 42, Vic. c. 49, and Act 52 & 53, Vic. c. 21 respectively) and that provision be made for the establishment in the colony of legal standards for land measurements (see

Report of Board of Inquiry appointed to inquire into the administration of the Weights and Measures Act, V.&P. Legislative Assembly, 1892-3, Vol. 8, p. 1051).

The 1878 imperial legislation referred to comprehensively provided for measurement of land by defining in section 11 not only the foot and inch, but also the rod, pole or perch, chain, furlong and mile, and in section 12 the rood and the acre. The resultant Weights and Measures Act 1898 (Act No. 19, 1898) contained no such provisions and simply perpetuated the "standard measures of length" as one yard, one foot and one inch.

4 POST FEDERATION

The Regulations for the Employment of Licensed Surveyors issued by the Department of Lands in 1901 and 1914 continued to make no specific instructions regarding the standardising of measuring tapes with the exception of the requirement that each surveyor was to provide a band "to be kept for adjusting and testing the chain used for measurements". The limits of "check closing and allowable error" were modified in the 1901 regulation and carried through to 1914.

The Weights and Measures Act 1915 (Act No. 10, 1915) further perpetuated the standard of the measurement of length as the yard but for the first time recognition was given to units used in the admeasurement of land. Clause 21 prescribed that "the units of weights and measure shall be those described in schedule C":

- The standard yard shall be the only unit or standard measure of extension, from which all other measures of extension, whether linear, superficial, or solid, shall be ascertained.
- One-third of the standard yard shall be the foot, and the twelfth part of such foot shall be an inch, and the rod, pole, or perch in length shall be five such yards and a half; and the chain shall contain twenty- two such yards, and the mile one thousand seven hundred and sixty such yards.
- The rood of land shall contain one thousand two hundred and ten square yards, according to the standard yard, and the acre shall contain four thousand eight hundred and forty such square yards being one hundred and sixty square rods, poles, or perches.

In July 1915, the Registrar General issued instructions specifically prepared for the information and guidance of surveyors specially licensed under the Real Property Act 1900. These instructions are recognised as the first attempt to regulate surveys carried out by private practicing surveyors. Regulation 41 required that "chains should be carefully adjusted to the standard at the Department of Lands", and Regulation 83, while retaining the principle of check closing and allowable error in the Lands Department's 1914 instructions, provided modified tables for limits of error not to be exceeded.

The Survey Practice Regulations 1933 under the Surveyors Act 1929 were gazetted on 12 May 1933 and applied to every survey made after that date. The Regulations for the Employment of Licensed Surveyors issued by the Department of Lands in 1914 continued in use as "the special requirements of the Department of Lands". In the absence of a State primary standard suitable for application to the surveying of land, recourse had to be had to the resources of the Office of the Surveyor General. Regulation 10 stated: "A surveyor shall make every survey … with a steel or invar band whose length is known in relation to the standard chain under the control of the Surveyor General."

Checking and accuracy of all measurements was provided for by a requirement of closure of latitudes and departures in Regulation 43, which prescribed that "a surveyor shall … check all measurements … by closure of the latitudes and departures of the lines … computed to two decimals of a foot if the survey is a city or suburban survey, or one place of decimals of a link if the survey is a country survey…" A table of the sums of the differences in latitude and departure that the perimeter could not exceed was provided and ranged from 1 link per mile crossing level country to 3 links per mile in mountainous country. This was amended in August 1934 so that the allowable misclose was expressed as a ratio, i.e. 1:8,000 for level country to 3:8,000 for mountainous country. Regulation 44 introduced the now familiar 'degree of accuracy' to survey practice by setting out a table of amounts of difference between the length of lines as measured and the correct length should not exceed. Allowable differences were identical to those stated in Regulation 43.

For operational reasons, it was decided by the Surveyor General in 1935 to install a new standard, known as the 'subsidiary standard', consisting of stainless steel plugs set in trachyte blocks. This new standard was marked and compared with the original 'prime standard' by means of an invar tape. A special invar tape, No. NPL 35A 58415, together with a Certificate of Examination issued by the National Physical Laboratory, Teddington was brought from England in 1936 but not used to verify the 'subsidiary standard'. Invar is a nickel-steel alloy invented by Swiss physicist and metrologist Charles Édouard Guillaume in 1896. It was named invar for its invariability under extremes of heat or cold; its coefficient of expansion is 15 times less than that of steel. He was awarded the Nobel Prize for Physics in 1920 "in recognition of the service he has rendered to precision measurements in physics by his discovery of anomalies in nickel steel alloys".

At a Council meeting of the Institution of Surveyors on 22 July 1938 "it was resolved to write to the Under Secretary for Lands asking that a standard be laid down on the southern face of the Showground boundary wall so that surveyors may test their long bands under working conditions, and that markings be placed at intervals of 100, 200, 300 and 500 links" (N.N., 1938). Surveyor General A. Max Allen responded on 20 December 1938 (N.N., 1939): "The provisions of a standard by this Department outside the precincts of its building cannot be favourably considered. Approval has been given to the laying down of a subsidiary standard in the basement of this building, which would be under proper and essential departmental supervision. Registered surveyors will be permitted to check their own chains, without charge, under such supervision as is deemed necessary – applications to be made to the Registrar, Surveyors' Board. If the Institute seriously considers that the provision of a standard in another location is necessary in the members' interests, the Institution should accept the responsibility to provide such standard and supervision at its own cost."

The special invar tape brought from England in 1836 was used to install this secondary or 'visual' standard intended for public use. Mr. Staff Surveyor F.C. Carr, who supervised the installation of this 'visual' standard, reported in 1939: "Unfortunately the pressure of work has been so great since the arrival of the special invar tape that there has been no opportunity to use it to check up on the soundness of our standards here, for which purpose the tape was procured. Because it is of invar which has a disposition to vary sometimes with age, even though not in use, I have felt obliged to accept the ascertained value of our standards, and, using the tape as a comparing medium, have deduced from that the values on the new (visual) standard." The intervals were measured as 66.00026 and 99.99961 feet and were accepted as 66.000 feet and 100.000 feet respectively for the special purposes of the 'visual' standard (Bayliss, 1957).

The decision to accept the public baseline as 66 feet and 100 feet respectively reflected a reasonable departmental view that the measurements were adequately expressed to satisfy the needs of the average practising land surveyors but not necessarily so for surveyors in the geodetic and mapping fields.

Section 51 of the Commonwealth of Australia Constitution Act 1900 (UK) deals with the legislative powers of the Commonwealth parliament (called 'specific powers'). These contain 'concurrent powers', in the sense that both the Commonwealth and States can legislate on these subjects, although federal law prevails in the case of inconsistency. Sub-section XV identifies 'weights and measures' as one of the matters subject to concurrent powers.

The National Mapping Council (NMC) was formed in 1945 and arose from the Commonwealth government's concern for the rehabilitation of various aspects of post-war Australia (Lines, 1992). It included representation from the Commonwealth and State Surveyors General and the Director of Army Survey. In July 1988, NMC was dissolved and replaced by the Inter-Governmental Advisory Committee on Surveying and Mapping (IGACSM). In 1991 it was enlarged to include a member from New Zealand, and this committee adopted a name change and became known as the Intergovernmental Committee on Surveying and Mapping (ICSM).

At the tenth meeting of the National Mapping Council held in April 1952, Resolution No. 94 was adopted and read as follows (NMC, 1952): "The Council recommends that as far as possible the States and Territories adopt uniform methods for the standardisation of survey tapes and to that end further recommends that the Commonwealth Scientific and Industrial Research Organisation be requested to investigate and advise on the most practicable method of setting up suitable working standards which will permit of certification of surveyor's (sic) tapes to an accuracy of 1 part in 500,000."

The Surveyor General (NSW), a party to that resolution, recommended appropriate changes be made to the Survey Practice Regulations 1933 and the Survey Co-ordination Regulations 1951. The amendments which accorded recognition to standards established by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) appeared in the Gazette of 4 February 1955.

It then became necessary to compare the existing Lands Department standards with those of the CSIRO and although the Certificate of Examination issued by the National Physical Laboratory, Teddington no longer had integrity, the special invar tape No. NPL 35A 58415 to which it belonged and brought from England in 1936 was selected for the comparison. In April 1956, the tape was compared against the 'subsidiary standard' and then forwarded to the National Standards Laboratory of the CSIRO for testing. The difference between the two standards was found to be approximately in the order of 1 part in 90,000 and a difference too great to be ignored. An extremely thorough investigation was then undertaken to eliminate any possible sources of error; among other changes made, new stainless steel caps were press-fitted over the existing terminal plugs. The marking of these new caps at precisely 66 feet and 100 feet was carried out by Mr. E. Esdaile Snr. of the highly regarded instrument firm of E. Esdaile & Sons Pty. Ltd. of Sydney. Subsequent measurements showed that the 100 feet base differed from standard by 1 part in 700,000 and the 66 feet standard by 1 part in 2,000,000.

Australia became a signatory to the Metre Convention in 1947, which made metric units legal for use in Australia. In June 1948, the Commonwealth government exercised its powers under

the Constitution to pass the Weights and Measures (National Standards) Act 1948 (No. 29 of 1948). It defined the roles of the National Standards Commission and CSIRO in Australia's system of weights and measures. In several respects, particularly in its flexibility, the Act was in advance of similar Acts in other jurisdictions around the world. It did not, for example, define any standards but gave power to the Government to make regulations under which standards could be defined, thereby permitting the changing of standards from time to time without changing the Act.

On 7 September 1984, the Commonwealth's Weights and Measures (National Standards) Act 1948 was replaced by the National Measurement Act 1960. "Australian primary standard of measurement" means a standard of measurement that is maintained, or caused to be maintained, by the Chief Metrologist as an Australian primary standard of measurement for the purposes of subsection 8(1) of the National Measurement Act 1960. This Act extends to all the Territories and consequently NSW was legally bound to accept the Australian primary standard of measurement as its primary standard.

In 1963, the Surveyor General of New South Wales was approved as a verifying authority under the Weights and Measures (National Standards) Act 1948 (Lands, 1963). This new authority of the Surveyor General was reflected in amendments to the Survey Practice Regulations on 19 June 1964 when Regulation 10 was substituted with a new regulation: "A surveyor shall make every survey … with a steel or invar band whose length is known in relation to a standard of measurement or a subsidiary standard of measurement established under the provisions of the Weights and Measures (National Standards) Act 1960, one such standard being under the control of the Surveyor General."

Regulation 43 was substituted by: "A surveyor shall ... check all measurements … by closure of the latitudes and departures of the lines … computed to two places of decimals of a foot if the survey is less than one, or at least one place of decimals of a link or foot if the survey comprises one acre or more." The tables of allowable misclose remained the same but a new requirement for calculating the misclose was introduced: "The misclose shall be determined as $\sqrt{(a^2 + b^2)}$, where a is the error in latitude and b is the error in departure." It will be readily perceived that the calculated misclose is the diagonal resulting from the application of a Pythagoras equation to the errors in each of the latitudes and departures. This practice has remained unchanged to the present day.

The tables in Regulation 44 were substituted with new values ranging from 1 part in 12,000 for level country and 1 part in 4,500 for mountainous country. The required accuracy of measure of length was thereby increased by 50% from the former values.

The Weights and Measures (Amendment) Act 1964 re-affirmed the Imperial Standard Yard as the predominant linear measure in the system but it did however finally give statutory recognition (by extension) to units of land measurement which had been in common usage in NSW since the proclamation of the colony in 1788. Recognition was also given inter alia to measures of length in the metric system.

Schedule C of the Act described the imperial system as follows:

- The imperial standard yard shall be the unit or standard measure of length from which all other imperial measures of extension, whether linear, superficial, or solid, shall be ascertained.

- One-third part of the standard yard shall be a foot; and the twelfth part of such foot shall be an inch.
- Five such yards and one-half shall be a rod, pole or perch; four such rods, poles or perches shall be a chain; ten such chains shall be a furlong; and eight such furlongs shall be a mile.
- One-hundredth part of such chain shall be a link.
- Ten square chains shall be an acre and one fourth part of such acre shall be a rood.

The metric system was described in Schedule C as:

- The standard metre shall be the unit or standard measure of length from which all other metric measures of extension whether linear, superficial, or solid, shall be ascertained.
- One thousand such metres shall be a kilometre; one hundred such metres shall be a hectometre; and ten such metres shall be a dekametre.
- One-tenth part of such metre shall be a decimetre, one-hundredth part of such metre shall be a centimetre; one-thousandth part of such a metre shall be a millimetre; and one-millionth part of such metre shall be a micron.
- For land measurement the square dekametre shall be an are; the square hectometre shall be a hectare; and the square metre shall be a centiare.

There were further amendments to the Weights and Measures Act in 1965, 1968, 1969, 1975 and 1980 but these amendments were all of a procedural nature and more particularly to recognise the dominant legislation of the Parliament of the Commonwealth of Australia.

In 1970 the Commonwealth's Metric Conversion Act 1970 (Act No. 16 of 1970) was passed. It was an Act to facilitate the adoption in Australia and in certain Territories of the metric system of measurement, and for that purpose to establish a Metric Conversion Board. The Metric Conversion Board was duly established and Australia proceeded down the path of change to metric units. On 1 July 1972, it became obligatory that plans for title purposes, intended to be lodged for registration at the Registrar General's Office, were required to show dimensions in metric units.

An amendment to the Survey Practice Regulations on 3 October 1970 heralded the arrival of technology of the modern era. Regulation 10 was extended with the additional words after the words 'Surveyor General': "or with electromagnetic distance measuring equipment properly calibrated by an authority recognised by the Board." The remaining amendments to the Survey Practice Regulations in 1972, 1973, 1975 and 1981 introduced no new principles regarding standards of measurement of surveys.

Finally, an amendment to section 3(1) of the National Measurement Act 1960 on 30 September 1984 provided a NSW primary standard suitable for adaptation to facilitate the surveying and measurement of land to a high degree of accuracy. The amendment states that "State primary standard of measurement" means a standard of measurement that has been approved by the Commission and that is maintained, or caused to be maintained, by a State or Territory and that has been verified under section 9 by means of, by reference to, by comparison with or by derivation from an Australian primary standard of measurement or an Australian secondary standard of measurement. On 25 March 2004 "the Chief Metrologist" was substituted in lieu of "the Commission" by the National Measurement Amendment Act 2004.

As a consequence of Surveyor General Don Grant's wide-ranging review of the survey systems of New South Wales in 1986, the Survey Practice Regulations were repealed and an

updated and a reorganised form was issued in 1990. The standard of accuracy of the measurement of length continued to be expressed as a proportion of measured distance relative to slope. The more widespread use of EDM equipment in survey practice was doubtless influence in the Surveyors (Practice) Regulation 1996 introducing "accuracy of length" being expressed as "6 mm + 30 ppm or better". The amendments in 2003 continued this practice but the Surveying and Spatial Information Regulation 2006 (formerly the Surveying Regulation 2006) introduced a paradigm shift that has continued into the current Surveying and Spatial Information Regulation 2012.

The current regulations are reliant for "accuracy of length measurements" on the Inter-Governmental Committee on Surveying and Mapping's (ICSM) publication Standards & Practices for Control Surveys (SP1) wherein "standards of class and order" are articulated in substantial detail. The maximum allowable error (r) is calculated using the following formula:

$$r = c\ (\ d + 0.2\ ) \tag{1}$$

where (in plain English):
r = maximum allowable error in millimetres.
c = a value assigned in Table 1 of the publication for the specific class of survey.
d = measured distance in kilometres.

The regulations simply state "length measurements must be made to an accuracy equal to or better than class C, for an urban survey, or class D, for a rural survey." The values of c assigned in the current publication for urban and rural surveys are 30 and 50 respectively.

5 CURRENT POSITION

The facility at the former Lands Office building in Bridge Street, Sydney now contains one departmental baseline for the exclusive use of the Surveyor General and one public baseline, each consisting of a zero terminal and successive terminals at:

- 20 metres.
- 1 chain (66 feet).
- 25 metres.
- 100 feet.

The two 20-metre baselines were the only intervals regularly verified by the Surveyor General in accordance with NMI requirements using a State primary standard. The primary standard used was a 6 mm wide stainless steel tape, which was verified in relation to the Australian primary standard of length every two years by the National Measurement Institute, Lindfield. As a consequence of modern surveying technologies such as EDM and satellite positioning replacing tape measures, Land and Property Information (LPI) has since discontinued maintaining and verifying these two baselines.

6 PRACTICAL APPLICATION OF TEST BASELINES

The 'statement of test' issued by the Surveyor General showed all information relating to the practising surveyor's tape such as nominal length, width, material, lengths tested and at what tension, conditions of support and test temperature. Recent practice was to provide printouts

of the various corrections to be applied under working conditions but in former times it was the surveyor's responsibility to compute the temperature at which the tape measures a standard length, the correction for catenary (or sag) and tension. The prudent surveyor has always taken sufficient steps to ensure that these calculations translate in practice by establishing test baselines and comparing the standardised tape adjusted by applying these calculated corrections. To this end, over time a number of test baselines were established. Some of the better known bases are described hereunder:

6.1 The Showground

This baseline was established on the Cook Road frontage of the Royal Agricultural Society showground by the eminent survey practice of Kent and Curdie about 1923 or 1924. It was Geoff Kent's and Jim Curdie's purpose to have a standard available to calibrate their working chains outside of normal Lands Department hours. The establishment method they adopted was for a one chain standard calibrated on the Lands Department baseline to be laid fully supported on the ground, corrections for tension and temperature applied and the terminals carefully marked. Then by means of a theodolite, those terminals were transferred to the adjacent wall at chest height and carefully marked. This then additionally enabled tension and sag corrections of a tape in catenary to be determined in a practical and accurate manner. The details of the baseline soon became shared knowledge and because of its convenience to Centennial Park for many years the scene of the Board of Surveyors' practical examination. Most candidates availed themselves of the opportunity of testing their tapes on this baseline before attending that examination.

As described earlier, the Institution of Surveyors unsuccessfully made representations to the Under Secretary for Lands in 1938 for the Department to establish a standard on the Showground's southern boundary wall to enable the testing of long bands under working conditions. Those representations resulted in a public baseline being laid down in the Lands Office building but it remained for the profession to establish and maintain any required working standards at no cost to the Department.

6.2 The Outer Domain

About 1950, the survey section of the Metropolitan Water Sewerage & Drainage Board (now known as Sydney Water) established a baseline on Mrs Macquarie's Point in the Sydney Outer Domain. It was on slightly undulating ground and about 400 feet long between the terminals which were marked with small brass triangles and pins in lead plugs set in sandstone bedrock. Broad arrows have been cut in the sandstone adjacent to these marks but the authority for its use is unknown. It was measured at 398.425 feet by the Board's Survey Branch and confirmed as 398.426 feet by Staff Surveyor L.H. Webber on 11 August 1953 with a first-order traverse specified in Regulation 12, Table 1, of the Survey Co-ordination Regulations 1951 (see Recorded Plan No. 55 in the Central Plan Register held in the offices of Survey Services Sydney at LPI). Webber's survey confirmed the integrity of the measurement made by the Board's survey staff; the baseline became very popular and was regularly used by public and private sector surveyors alike until the 1980s. The terminals remain in excellent condition and the base useable but the terminals themselves are no longer intervisible due to an increase in vegetation (Figure 4).

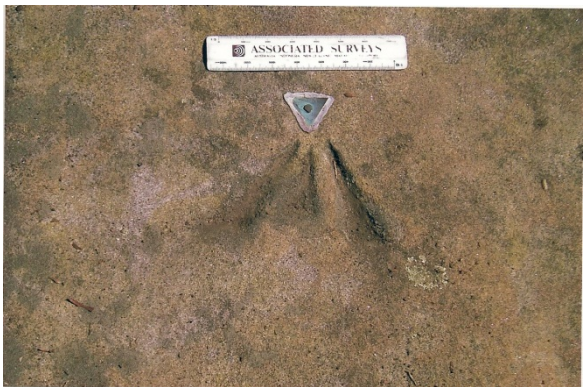

Figure 4: Southern terminal of the Outer Domain baseline (February 2013).

6.3 The University of New South Wales

The establishment of this 100-metre baseline located on the grounds of the University of New South Wales in 1969 is attributed in no small measure to the enthusiasm of Dr. George G. Bennett, former Head of the School of Surveying in the Faculty of Engineering, who was Senior Lecturer at the time. The baseline was established using a standard steel tape marked APT 3246 and calibrated in March 1969 at the National Standards Laboratory (CSIRO). It was considered that the baseline was accurate within plus or minus 1 part in 100,000. It was located on the retaining wall behind the Mechanical Engineering Workshop building. It was principally intended for use by students and staff of the University, however in due course its location became widely known and Bennett as Head of the School of Surveying found it necessary on 20 November 1979 to advise the broader profession of the implications associated with using the baseline (see Institution of Surveyors NSW Monthly Bulletin, January 1980): “Many surveyors use the above facility at Kensington for the standardisation of their surveying bands. However, it must be stressed that the results of these measurements have no legal standing and can only be used as a guide to standardisation characteristics.” The baseline was last used by students in 1986 and is no longer accessible.

6.4 Established Permanent Marks

By the 1980s the density of established permanent marks had increased and a plethora of test baselines became readily available to practising surveyors.

7 EDM CALIBRATION BASELINES

By the beginning of the third millennium, the emphasis had passed from effecting surveys with steel bands to measuring electronically. As indicated in the introduction, this paper does not intended to investigate the question of calibration of EDM instruments or validation of GNSS equipment. However, it is appropriate to mention that there are several EDM calibration baselines throughout New South Wales that are verified by the Surveyor General every two years.

8 GLOBAL NAVIGATION SATELLITE SYSTEMS

The use of the Global Positioning System (GPS) and other Global Navigation Satellite Systems (GNSS) for the measurement of land boundaries also emerged with the dawn of the

21st century. Based on precise time and orbital data signalled from rotating satellites and converted to positional coordinates with the help of ground tracking stations, it presented its own unique set of problems in terms of providing traceability to the national standard for Australian legal purposes. 'Position' was added to the list of physical quantities covered by the National Measurement Act 1960 and more than eighty precisely determined reference positions were established across the Australian continent, ten of these determined by multiple methods (Todd, 2004). In New South Wales, LPI's permanent GNSS network, known as CORSnet-NSW, provides fundamental positioning infrastructure across the State.

GNSS equipment must be validated against an approved GNSS test network. The Surveyor General has established a number of test networks, which may include pillars of existing EDM calibration baselines. However, GNSS equipment may be also validated over a local network of State survey control marks. Clause 14 of the Surveying and Spatial Information Regulation 2012 provides inter alia that any GNSS equipment to be used in making a survey must be verified against the State control survey by reference to at least three established survey marks with accurate Australian Height Datum (AHD) values on the basis that the State survey control network in itself has legal traceability.

There remains an element of uncertainty and whether the provisions of clause 14 are adequate to establish legal traceability, but this question will undoubtedly be resolved in due course, either by science or by a challenge in the courts.

9 CONCLUDING REMARKS

The landscape and settlement pattern of New South Wales bears testimony to the contribution made by members of the surveying profession. History has recorded a great many examples of the physical and mental difficulties they faced as they went about their allotted task. It was Surveyor General Major (Sir) Thomas Mitchell who in a circular to his survey staff in 1836 highlighted the importance of accuracy in the measurement of land surveys wherein he said (Marshall, 1999): "The measurements of the lands in question is altogether a different matter – the public being now purchasers at 1/- per acre from the Crown on whose faith they depend for the accuracy of the documents used in the progress of the sales – it is of the utmost importance that the most scrupulous exactness should obtain in these surveys."

For about the first 100 years or so, the legislature of New South Wales showed complete indifference to the circumstances that prevailed regarding not only the need for statutory recognition of units of measurement used in land surveying but also the provision of a suitable State primary standard of measurement capable of being physically extended to enable the measurement of land boundaries to be effected to a legally accepted standard of accuracy. In reaction, the surveying profession, in effect, became self-regulating and with the assistance and co-operation of the Office of the Surveyor General created a most adequate 'prime standard' on the ground floor of the Bridge Street Lands Office. The profession collectively and separately established test baselines throughout the metropolitan area and rural centres of the State. The aim, most responsibly motivated, was the pursuit of excellence in the measurement of property boundaries or in the words of Major Mitchell "the most scrupulous exactness".

The 'prime standard' was finally elevated to State secondary standard status in 1963 but the irony is that within two decades steel and invar tapes had all but been superseded by

electronic distance measuring devices. Technology has vastly improved since the 1980s and it is difficult to imagine a return to the use of steel or invar bands for the measurement of property boundaries.

The National Measurement Regulations 1999 define 'metre' as "the length of the path travelled by light in a vacuum during a time interval of 1/299 792 458 of a second". It has been scientifically determined that the most permanent and reproducible of all standards of length are not those made by etching fine lines on stable alloy bars, but those provided by nature herself in the form of the wave lengths of light emitted by excited atoms; from sources of light stationary with respect to the observer, these wave lengths, so far as is known, never vary.

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