DEPARTMENT OF MINERALS AND ENERGY
Secretary: Sir Lenox Hewitt O B E

DIVISION OF NATIONAL MAPPING
Director: B. P. Lambert OBE

TECHNICAL REPORT 12
SECOND EDITION

THE ADJUSTMENT OF THE AUSTRALIAN LEVELLING SURVEY 1970-1971

by

A. Roelse, H.W. Granger and J.W. Graham

CANBERRA, AUSTRALIA
MARCH 1975
First Edition June 1971
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PREFACE TO SECOND EDITION

Since the original adjustment of the levelling to produce the Australian Height Datum in May 1971, a number of changes in adjustment procedures and output have been introduced:

- LEVELONE has been rewritten for a Cyber 76 computer. Because of the larger high-speed store, the overlay structure of the original program is no longer required.

- In February 1974, LINADJ was amended so as to produce wholly metric output. At the same time, as there was little demand, the "simple" output was discontinued and new data sheets for the preparation of metric input were distributed.

As the result of new levelling, re-levelling to a higher standard, replacement of damaged marks, the establishment of additional marks, and in a few cases, the detection of errors in the data originally compiled by various authorities for the 1971 adjustment, revisions of AHD heights continue.

In Tasmania, the levelling is nearing completion. A tide gauge has been established at Granville Harbour on the west coast. It is expected that an adjustment of the Tasmanian levelling network and the establishment of the Australian Height Datum (Tasmania) will be completed in 1976.

In December 1972, the Department of National Development and the Department of the Interior were abolished. The Division of National Mapping is now in the Department of Minerals and Energy; and the Commonwealth Surveyor General is now the Surveyor General for Australia, and his office is the Australian Survey Office in the Department of Services and Property.

In this reprint, minor changes have been made to pages 1, 12, 24, 25, 43 and 59.

CONTENTS

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1. INTRODUCTION

1.1 From the commencement of European settlement onward, numerous levelling surveys have been made in Australia on various datums, and although professional surveyors from time to time advocated a national height datum based on mean sea level, no active move toward a national system of levels was undertaken until after the creation of a National Mapping Council in 1945.

1.2 In that year the Federal Prime Minister and the respective State Premiers agreed that a coordinated national scheme for the mapping of Australia was necessary and, to that end, approved of the formation of the National Mapping Council of Australia.

1.3 The present membership of the Council is the State Surveyors General and the following Commonwealth officers: the Director of National Mapping, Department of National Development (Chairman); the Commonwealth Surveyor General, Department of the Interior; the Hydrographer, Royal Australian Navy; and the Director of Military Survey.

1.4 At the time of the formation of the Council it was agreed that the Director of National Mapping would be responsible for the coordination of the activities of Commonwealth and State authorities in planning and carrying out the national mapping of Australia with full regard to the recommendations of the Council.

1.5 Working within this charter the Director and his officers in the Division of National Mapping have cooperated with other Council members and their officers in the planning and implementation of the National Levelling Survey, have undertaken or have arranged for the collection, analysis and processing of levelling and tide gauge data, and have adjusted it to form a single homogeneous network covering the whole of mainland Australia.

1.6 These joint activities culminated in 1970 with the completion of 60,472 miles (97,320 km) of 'primary' levelling and led to the adoption of an Australian Height Datum by the National Mapping Council at its 1971 meeting.

1.7 The completion of this adjustment, and the subsequent adjustment to the Australian Height Datum of further one and two way 'supplementary' levelling totalling about 50,000 miles (80,000 km) which has already been observed, will create one of the largest homogeneous systems of levelled heights in the world.

1.8 The purpose of this report is to review the history of the Australian National Levelling Survey and to report on the technical and mathematical procedures used in its adjustment.

2. HISTORY

2.1 The Australian Levelling Survey

2.1.1 In the period 1945 - 1950, following the creation of the National Mapping Council, the Australian Levelling Survey began to take shape and at the end of this period about 3,000 miles (4,800 km) of control levelling had been completed in three States of the Commonwealth. During this period the levelling carried out by State Authorities was of various standards, and levelling surveys for the control of gravity survey operations were commenced by the Department of the Interior. The Department of the Interior work utilised third order techniques but was levelled in one direction only using "Flood" reversible staves. These staves have normal foot graduations on one face and an offset foot scale, serving as a check, on the reverse. The marking of these surveys was not very satisfactory at this stage.

2.1.2 During the period 1956 - 1960 an additional 10,000 miles (16,000 km) were levelled. In 1961 the Commonwealth Government made special funds available to support the search for oil in Australia and approval was obtained for some of these funds to be allocated to surveys which would tie up the levelling within and between the various sedimentary basins. At that time the Director of National Mapping decided that if these surveys were to be of any practical value within a usable time scale then use would have to be made of contract surveyors using readily available equipment and working to third order standards of accuracy.

2.1.3 Between 1961 and 1966 the Assistant Director of the Division of National Mapping, in cooperation with the officers of the State Lands Departments, planned and organised these control levelling surveys and arrangements were made with the State Surveyors General for their staff to supervise the contract operations.

2.1.4 By 1965 the total amount of control levelling had reached 80,000 miles (129,000 km). In this same year the Minister for National Development was instructed to undertake a topographic mapping programme covering the whole of Australia at a scale of 1:100,000 and with a 20 metre contour interval. The opportunity was then taken to extend the existing third order levelling surveys into a national network. At the end of 1970, 100,000 miles (161,000 km) of levelling had been completed.

2.1.5 The maps on pages 3 to 7 illustrate the progress of the levelling surveys through the epochs 1950-1955, 1956-1960 and 1961-1966. The status of levelling at the end of 1970 is illustrated by Annex A.

AUSTRALIA

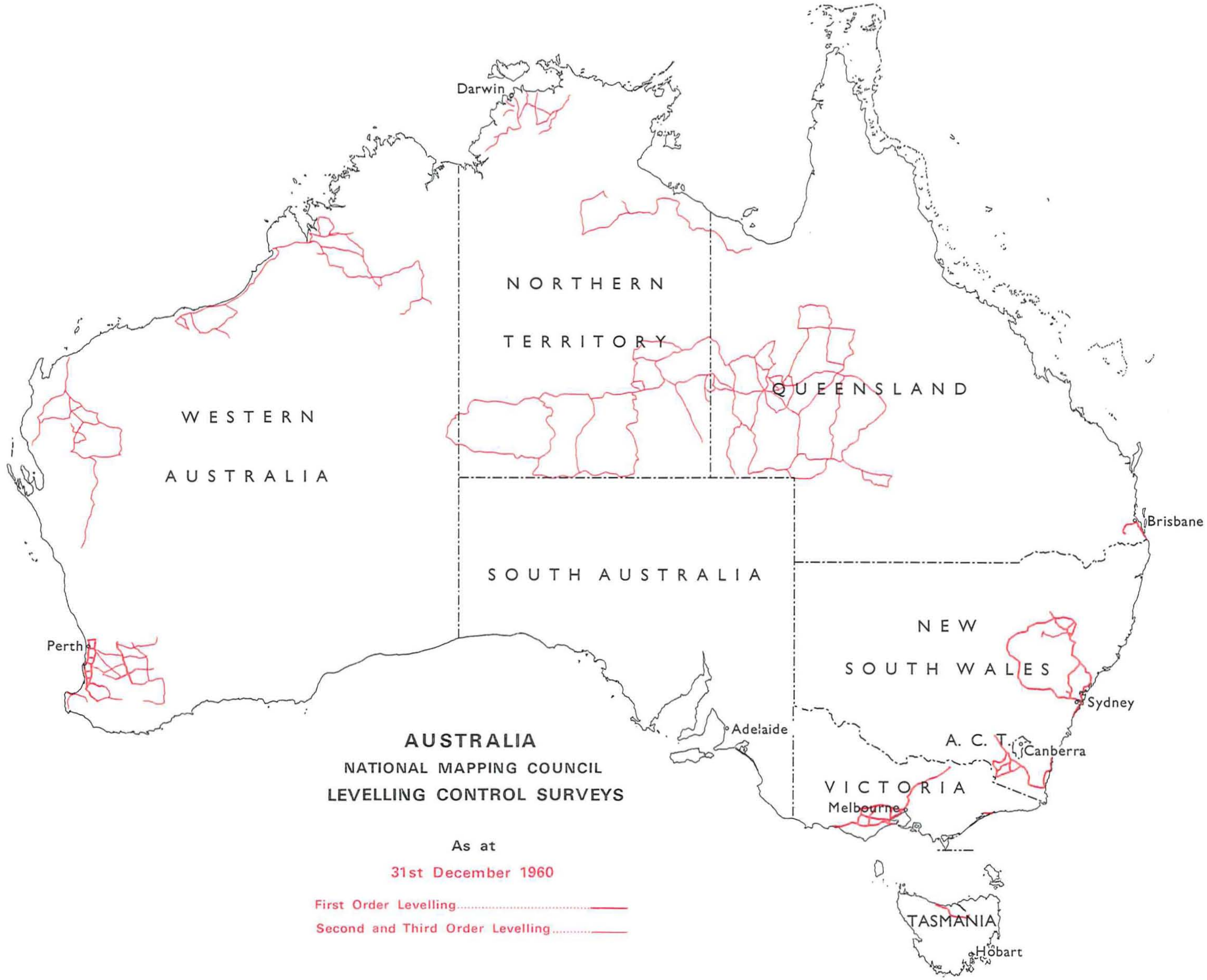
NATIONAL MAPPING COUNCIL

LEVELLING CONTROL SURVEYS

As at

31st December 1955

N.B. No Authority reported any levelling activity prior to the 1950-55 epoch



AUSTRALIA

NATIONAL MAPPING COUNCIL

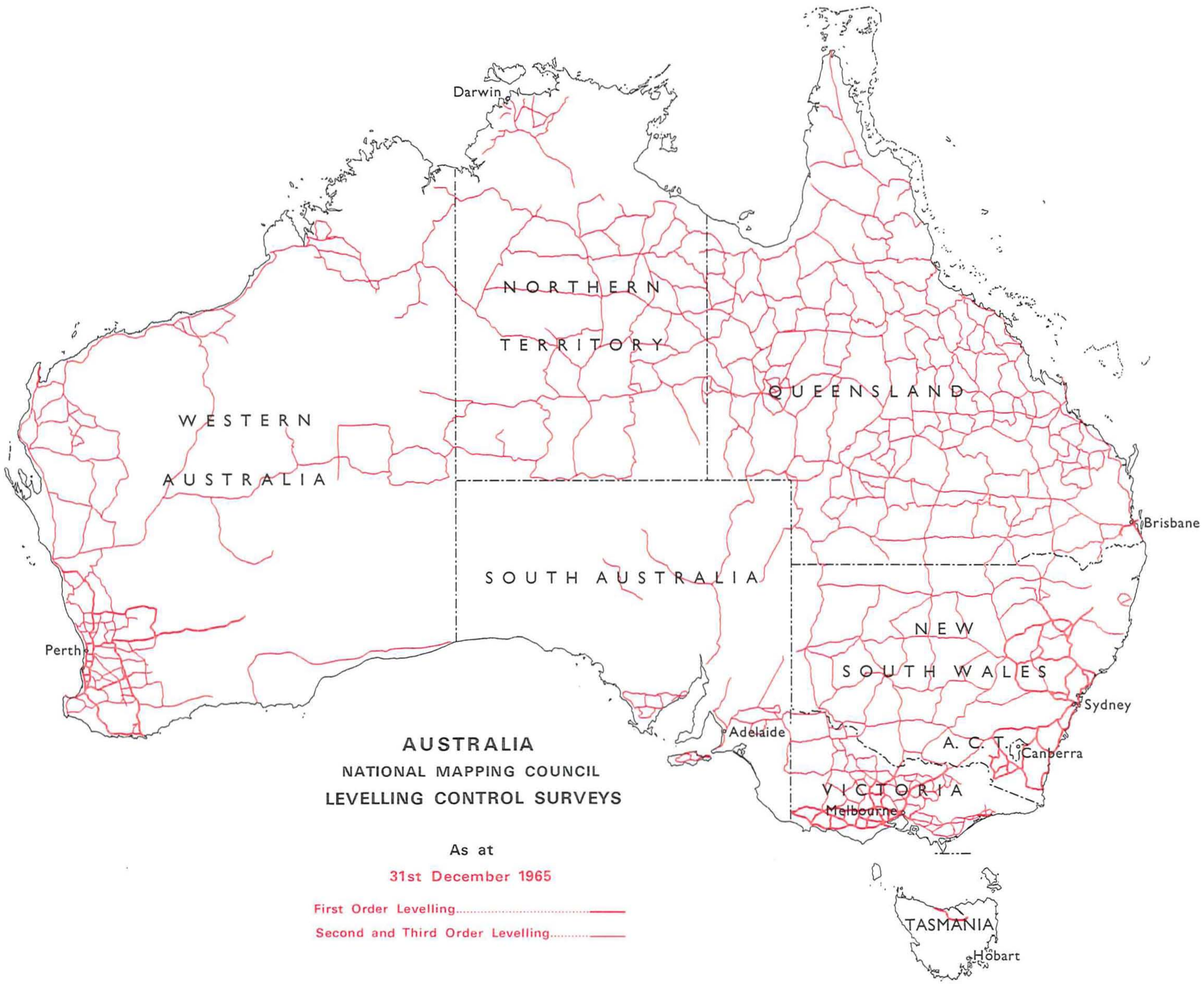
LEVELLING CONTROL SURVEYS

As at

31st December 1960

First Order Levelling..

Second and Third Order Levelling............



AUSTRALIA

NATIONAL MAPPING COUNCIL

LEVELLING CONTROL SURVEYS

As at

31st December 1965

First Order Levelling..

Second and Third Order Levelling..............

2.1.6 In 1966 a special Levelling Section of the Division of National Mapping was established. Its functions are to:

.1 Make precise differential levelling surveys and, in particular, undertake work required to complete the Australian levelling network for which contract levelling is not available; check the work of contractors; and connect the Australian levelling network to geodetic stations on the Australian Geodetic Datum.

.2 Arrange and supervise levelling surveys by contractors and, directly and through the Surveyors General of the States and Territories, examine and recommend payment of accounts.

.3 Arrange and supervise observations at tide gauges and the computation of tide gauge readings by contractors.

.4 Determine and periodically review mathematical models of the earth and compute and adjust all levelling surveys to produce an homogeneous series of heighted points over Australia on which mapping and other surveys can be based.

.5 Investigate new methods of levelling and computation.

.6 Make recommendations for, and assist in the drafting of, national specifications and recommend practices for geodetic levelling.

2.2 <u>National Specifications for Levelling</u>

2.2.1 The National Mapping Council has approved "Standard Specifications and Recommended Practices for Horizontal and Vertical Control Surveys" and these have been published in a document under that title, prepared on behalf of the Council by the Director of National Mapping. Extracts from these specifications relevant to vertical control surveys are attached as Annex H.

2.3 <u>Contract Levelling</u>

2.3.1 The first of the many contracts for bench marking and third order levelling throughout Australia was let to the Surveyor General of New South Wales in 1961. Although this $22,000 contract was let to the Surveyor General the work was carried out by private contract surveyors supervised by the Surveyor General. This system of contracting, as well as contracts let directly to contract surveyors nominated by the Surveyors General and supervised by the Division of National Mapping, was maintained until 1970 when the last of the contracts was completed.

2.3.2 A total of 232 contracts for marking and levelling were arranged at an overall cost of almost $2 million.

2.4 Participants in the Levelling Programme

2.4.1 Staff of the Division of National Mapping completed 2,819 miles (4,537 km) of third order levelling, many miles of check levelling of work carried out by contract surveyors, and inspected and reported on bench marks established by contractors.

2.4.2 All State Surveyors General and their respective staff, the Commonwealth Surveyor General and the staff of the Department of the Interior, the Snowy Mountains Hydro-Electric Authority, State Railways Departments and Irrigation and Water Supply Commissions each contributed to the successful completion of the National Levelling Network.

2.4.3 Much of the marking in the remote areas of the continent was carried out by personnel of the Weapons Research Establishment, Salisbury, SA, using equipment and funds provided by the Department of National Development through the Division of National Mapping.

2.4.4 The digitisation and computation of the results of tide gauge observations were carried out by the Horace Lamb Centre for Oceanographical Research at the Flinders University of South Australia.

3. FIELD WORK

3.1 Primary and Supplementary Levelling

3.1.1 The levelling which contributed to the determination of the Australian Height Datum has been termed 'Primary Levelling'. This term in no way reflects on the quality or accuracy of the levelling. 'Supplementary Levelling' is levelling additional to and dependent upon the primary levelling. Its adjustment to the Australian Height Datum as described in 6.6 is being carried out.

3.1.2 A total of 60,472.1 miles (97,320.4 km) of primary levelling contributed to the determination of the Australian Height Datum. Table 1 at page 12 shows the mileages of levelling observed by the different observing authorities.

3.2 Levelling by the Division of National Mapping

3.2.1 The Division's field activity in levelling the national network was mainly confined to areas where, because of access difficulties and remoteness, private surveyors could not be expected to operate; to the completion of border connections; and to check levelling and inspection.

3.2.2 In all, 389 sections totalling 3,851 miles (6,197 km) were check levelled and the marks on 1,717 miles (2,763 km) of traverses were inspected following reports of sub-standard marking. A large number of level books were examined, in some cases as an investigation of excessive discrepancies between forward and backward runs, and in others following suspected malpractice and non-compliance with specifications.

3.2.3 As a result of these investigations some 660 bench marks were replaced or improved by the contractors responsible for their original installation, some contractors were required to carry out complete re-levelling and payment to others was withheld.

3.2.4 The levelling parties of the Division, working under good weather conditions and in reasonably flat country, are each able to complete up to 22 miles (35 km) of one way third order levelling during a normal working day. Each party, consisting of an instrument man and two staff men, is equipped with two vehicles. The staff men, each driving a vehicle, "leap-frog" along the levelling route with the backsight staff man picking up and driving the instrument man to the next set-up before proceeding to his next forward staff position. A nylon rope 300 feet long is towed behind each vehicle as an indication to the party that this specified length of sight is not being exceeded and as a guide to instrument and staff positions but the true length of sight is observed by stadia and recorded in the level book.

TABLE 1

LEVELLING CONTRIBUTING TO THE DETERMINATION OF THE AUSTRALIAN HEIGHT DATUM

Observing Authority	Type of Levelling		
	Original one-way levelling	Second one-way levelling	First, second and third order two-way levelling
Department of the Interior	14,658.7 miles (23,590.0 km)		1,904.0 miles (3,064.2 km)
State Authorities	286.9 miles (461.7 km)	146.2 miles (235.3 km)	13,377.5 miles (21,529.0 km)
Snowy Mountains Hydro-Electric Authority			298.1 miles (479.7 km)
Contractors to the Division of National Mapping		12,187.3 miles (19,613.5 km)	29,740.4 miles (47,862.5 km)
Division of National Mapping		2,612.1 miles (4,203.8 km)	206.5 miles (332.3 km)
		14,945.6 miles (24,052.6 km)	45,526.5 miles (73,267.8 km)
		Total	60,472.1 miles (97,320.4 km)

3.3 Contract Levelling

3.3.1 About 81% of the second one-way levelling over Department of the Interior levelling and about 65% of the two-way levelling in the national network was observed by contract surveyors.

3.3.2 Contract levelling was divided into four phases: selection of levelling routes; marking; levelling; and supervision and checking.

3.3.3 The Division of National Mapping in conjunction with the State Surveyors General selected the routes for levelling. Well before the beginning of each financial year each Surveyor General submitted to the Director of National Mapping his proposed third order levelling programme. These were each considered from the points of view of usefulness to the national scheme and availability of funds. Approved schemes were included in the Department of National Development's budget proposals and the Surveyors General were then asked to supply detailed estimates of marking, levelling and supervisory costs.

3.3.4 After the budget had been approved by Parliament and procurement demands had been signed by the Minister for National Development, contracts were let through the District Contracts Boards of the Department of Supply to the Surveyors General or to contract surveyors recommended by the Surveyors General.

3.3.5 Usually, when a contract had been let to the Surveyor General, he invited private surveyors in his State to take part in the levelling programme and sub-contracts were offered to those interested. The work of these surveyors was fully supervised by Staff Surveyors of the different Lands Departments and 10% of their work was check levelled. After completion of the field work the contract surveyor submitted his field notes and other required information to the Surveyor General and if all appeared to be in order a progress payment of up to 90% of the contract price was made. The final 10% was paid after a thorough check of the work.

3.3.6 When contracts were let directly to the contract surveyors recommended by the Surveyors General their work was supervised and checked either by Lands Department Staff Surveyors or by Division of National Mapping personnel and payments made as described in 3.10.

3.3.7 Most of the contract surveyors operated with one observer, two staff men and two vehicles, arranging their work so that neither the staff men nor the surveyor had to walk between set-ups. They averaged about 14 miles per day.

3.4 Two-way Levelling

3.4.1 All the two-way third order levelling completed by contract surveyors and other observing authorities was carried out in accordance with the "Specifications for Contract Third Order Levelling" issued by the Division of National Mapping. These specifications are reproduced in Annex I.

3.4.2 A random check of at least 10% of all two-way levelling completed under contract to the Division of National Mapping was made either by Division of National Mapping personnel or by Staff Surveyors of the State Lands Departments.

3.4.3 Results of the levelling were extracted from the level books and entered on data forms, an example of which is shown on pages 39 and 40.

3.4.4 In addition to contract two-way levelling, State Authorities such as Lands Departments and Road, Railway and Water Supply Authorities contributed over 13,000 miles of first, second and third order to the network. All this work was observed by surveyors working to conditions and specifications laid down by their Departments. Almost 300 miles of first order levelling by the Snowy Mountains Hydro-Electric Authority has been included as primary levelling.

3.5 Levelling by the Department of the Interior

3.5.1 More than a quarter of the primary levelling was originally observed one-way by surveyors of the Department of the Interior and later re-levelled by other authorities or contractors to establish two-way levelling, as described in 3.6.

3.5.2 Almost all of this original one way levelling was carried out using automatic levels and reversible staves and, apart from the check provided by the reversible staves, no check on the accuracy of this levelling was made until complete loops had been observed.

3.5.3 Early levelling by the Department of the Interior was over bench marks established as the work progressed. These early marks were often benches cut in trees, bottles set in the ground or wooden posts and it was not until about 1964 that more stable marks, long steel star pickets with concrete collars and large concrete blocks with bronze plaques were installed.

3.5.4 Although this levelling might be regarded as rather crude by present standards it adequately served the purpose for which it was intended - the provision of heights for the Bureau of Mineral Resources Gravity Section - and only a very small percentage was found to be unacceptable when compared with the results of more modern levelling carried out some years later.

3.6 Re-levelling Over Department of the Interior Work

3.6.1 All this re-levelling was carried out in accordance with "Specifications for One-Way Foot-Metric, Contract, Third Order Levelling" issued by the Division of National Mapping in March 1968.

3.6.2 These specifications, although similar in most respects to the two-way instructions, contain a number of clauses only applicable to one-way levelling. These are:

.1 Alternate lengths of approximately 24 miles are to be levelled in opposite directions.

.2 The two levellings of a section, one in feet and the other in metres, between consecutive bench marks, shall not differ by more than $0.050 \sqrt{M}$ feet, where M is the distance in miles.

.3 When the mean difference in elevation between consecutive bench marks, as determined by the two levellings of a section, one in feet and the other in metres (and then converted to feet), differs from the original departmental levelling of this section by not more than $0.075 \sqrt{M}$ feet the work is acceptable and no further re-levelling is required.

.4 When this mean difference in elevation between consecutive bench marks of a section differs from the original departmental levelling of this section by more than $0.075 \sqrt{M}$ feet, levelling shall first proceed in the normal manner to the next forward bench mark.

.5 If the levelling of this forward section also fails to agree as specified but the levelling from end to end over the two sections does meet the specified accuracy of $0.075 \sqrt{M}$ feet and the two sections as a whole also fail to meet this accuracy then both sections shall be again re-levelled.

3.6.3 A small amount of the second levelling over Department of the Interior work was check levelled by either State Lands Department or Division of National Mapping personnel when the re-levelling had been carried out by contract surveyors.

3.6.4 Results of the one-way re-levelling were extracted from the level books returned by the surveyors and recorded on data forms, an example of which is given on pages 41 and 42.

3.7 Staff Calibrations

3.7.1 Almost all the staves issued by the Surveyors General and the Division of National Mapping for use by third order levelling contractors were calibrated in accordance with the procedures laid down by Mr E. Thwaite (1966) in his paper "Accuracy of Staff Calibrations to meet National Mapping Council Requirements". Staves found to have a random graduation error greater than 0.001 feet were rejected and withdrawn from use and all levelling observed with calibrated staves was corrected by applying the calculated "staff correction Factor". Computation of these calibration figures was carried out by the computer program STAFFCAL which has as part of its input the 30 measured random intervals.

3.7.2 In Western Australia a number of aluminium staves were used for some of the earlier third order levelling in that State. In all cases the levelling observed with these was in generally flat country, was carried out under conditions of fairly stable temperature and was considered acceptable.

3.8 The Johnston Origin Marks

3.8.1 The ground mark at the Johnston Geodetic Station was adopted as the origin for the Australian Height Datum. This mark, a 1¼" diameter brass plug cemented into solid rock, is in fact inaccessible without destruction of the cemented sandstone cairn which has been erected over it, but the three reference marks placed near the station are accessible and these were connected to the ground mark by levelling before the erection of the cairn.

3.8.2 In 1969 three additional permanent marks were established close to the base of the large rock outcrop on which the Johnston Geodetic Station is located. These marks each consist of copper coated tubular steel rods ("CUCLAD") driven to bedrock, fitted with a welded copper cap and protected by a concrete block and cast iron cover. A facsimile of the Johnston Geodetic Station summary, a bench mark sketch and photographs of some of the marks appear on pages 17 to 20.

3.8.3 Heights of the origin and near-by permanent marks based on the Australian Height Datum are given in Table 2.

TABLE 2

HEIGHTS OF MARKS AT THE ORIGIN
OF THE AUSTRALIAN HEIGHT DATUM

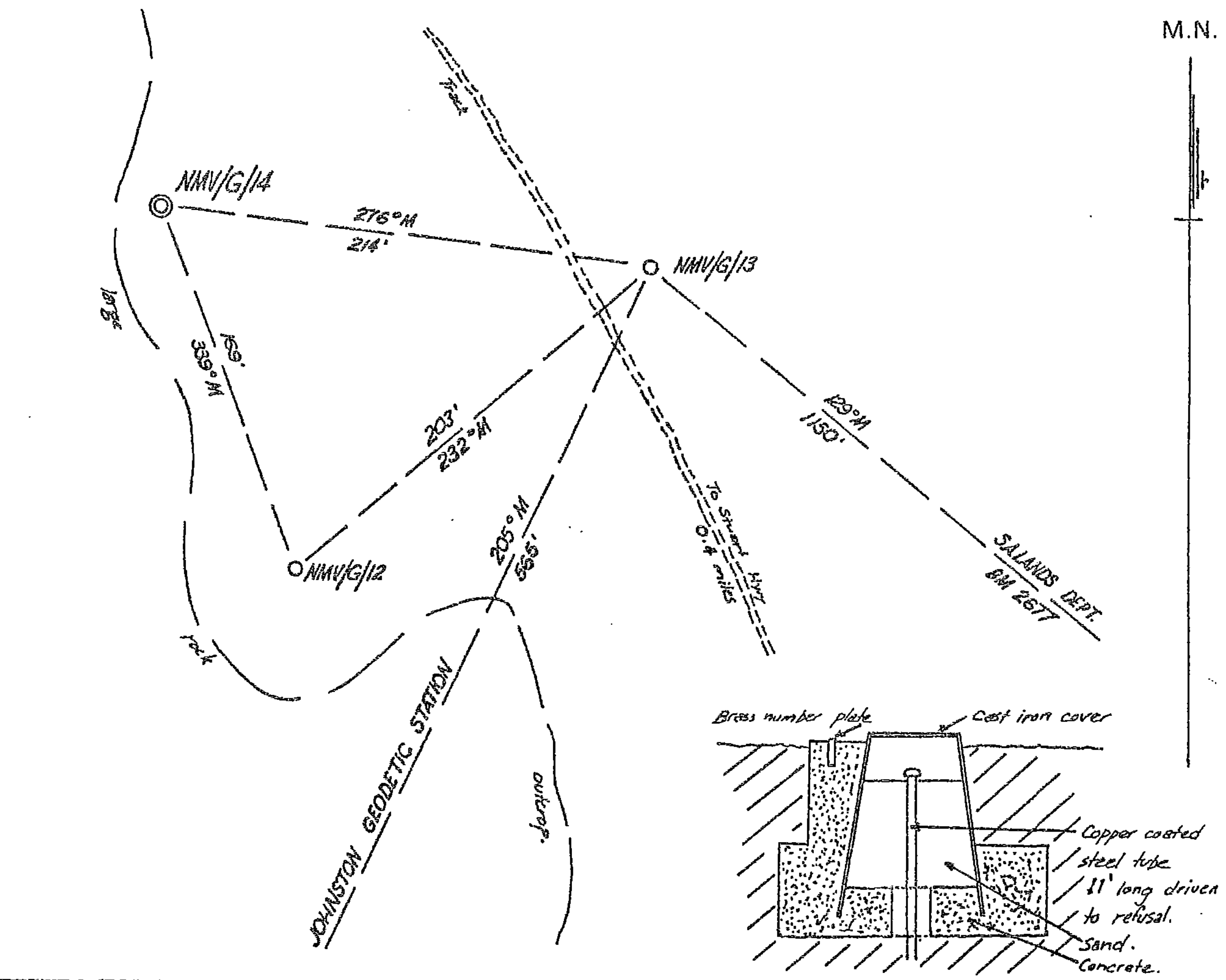
Mark	Height	
	International Feet	Metres
Johnston Origin	1857.94	566.300
Johnston ECCE RM	1858.66	566.520
Johnston RM 1	1858.32	566.414
Johnston RM 2	1857.45	566.152
NMV/G/12	1769.20	539.253
NMV/G/13	1867.88	538.851
NMV/G/14	1762.20	537.119
BM 2677	1747.89	532.755

PBM No. NMV/G/14

DEPARTMENT OF NATIONAL DEVELOPMENT
DIVISION OF NATIONAL MAPPING

PERMANENT BENCH MARK RECORD

Measurements in feet (not necessarily to scale)



Provisional Reduced Level: .... feet. Datum: ....

Established by: F.C.REARDON Date: 22/4/69

Under field supervision of: H.W.GRANGER Surveyor, Class 1

Sketch shown in Field Level Book No.: 7267

1:250,000 Map Sheet: G53/5,

Scaled Latitude: 25° 58' Scaled Longitude: 133° 13'

PHOTO IDENTIFICATION.

AERIAL, Area: .... Film No: .... Run No: .... Photo No: ....

TERRESTRIAL, Film No: .... Photo No: ....

Certified free of transcription errors: HW Granger Date: 28/1/70

Approved by: .... Date: ....

NATIONAL MAPPING COUNCIL OF AUSTRALIA
STATION SUMMARY

Serial No

Authority: DIVISION OF NATIONAL MAPPING

Station Number and Name: JOHNSTON GEODETIC STATION — Order: FIRST.

Original Station Established by: DIVISION OF NATIONAL MAPPING — Date: OCT. 1965

Existing Station Marked by: DIVISION OF NATIONAL MAPPING — Date: OCT. 1965

Reference Books:
TRIG: NM4949, NM4945
TELL: 4667, 4669, 4654
LEVEL: NM7491, NM7267.

Map Name: KULGERA, N.T. — Map Number: SG 53/5 — Scale 1: 250,000

DATUM: Australian Geodetic Datum, 1966

RECTANGULAR COORDINATES: Australian Map Grid. In Metres

GRID BEARING = ADJ AZIMUTH + CONVERGENCE. — HEIGHTS: In Metres above Mean Sea Level.

Cadastral Location: State — Country/District

Parish/Hundred — Allotment/Section/Portion

JOHNSTON ORIGIN — SECTION 4 121 — SERIAL 10

SOUTH LATITUDE	EAST LONGITUDE	ZONE	EASTING	NORTHING	CONVERGENCE	HEIGHT
25 56 54.5515	133 12 30.0771	53	320599.376	7128783.402	-0 47 3.00	571.2

TO	SERIAL	ADJ AZIMUTH	ADJ LENGTH
CAVENAGH	NM G 69 11	299 38 23.91	8801.518
CECIL	NM G 68 8	94 23 52.98	47769.189

Access and Locality Sketch: — Particulars of station marking and beacon:

STATION MARK: Drill hole in 1½" diam. brass plug cemented into solid rock and protruding 0.05' into bottom of beacon pole.

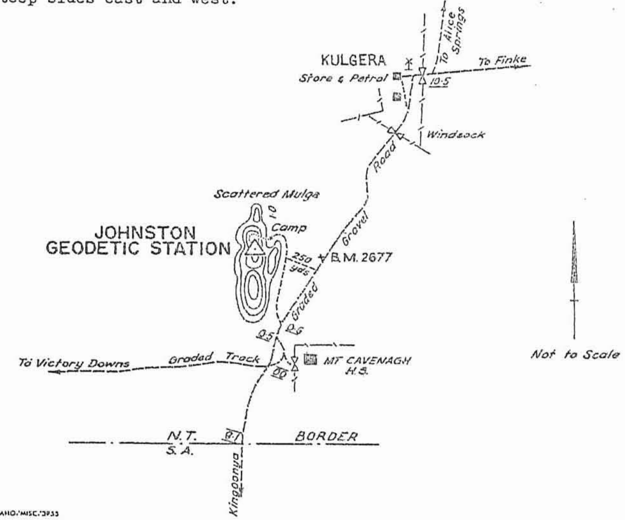
BEACON: 14'x4"x4" Galvanised steel pole and four galvanised steel vanes 4'x2'x3/32" painted black. Top of spike is 14.23' above trig. G.M.

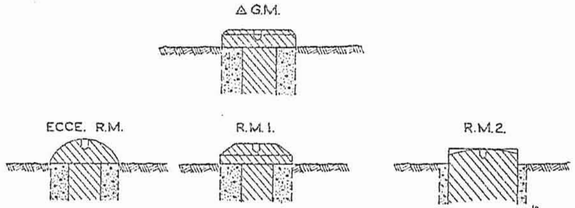
CAIRN: Cemented, sandstone faced, conical cairn 9' diam. and 10' high.

REFERENCE MARKS: Ecce R.M. is a drill hole in a domed brass plug 1½" diam. cemented into solid rock.
R.M.1. is a drill hole in a bevelled brass plug 1½" diam. cemented into solid rock.
R.M.2. is a drill hole in a square brass plug 1"x1" cemented into solid rock.

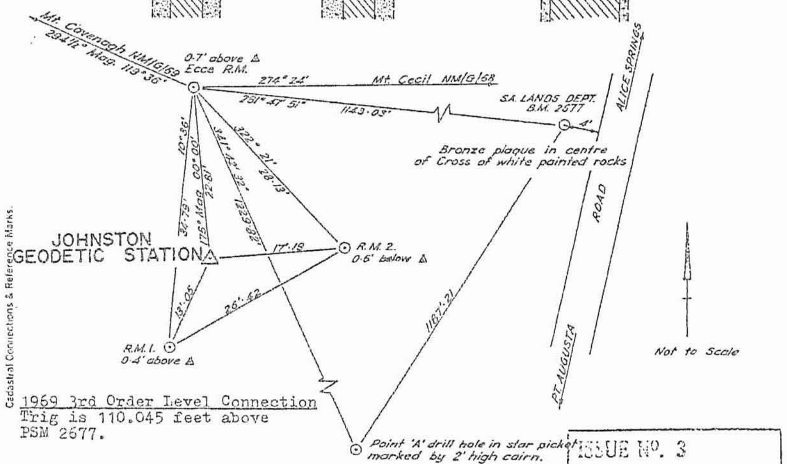
ACCESS: Approach from Mt. Cavenagh H.S. which is 10.5 miles south of Kulgera and 1.8 miles north of the N.T., S.A. border, at the junction of the Victory Downs, Mulga Park road and the main Pt. Augusta - Alice Springs road. The hill is visible from the road junction about 1 mile to N.W.

From road junction drive north along main road to wheel tracks at 0.6 miles. Follow track for 0.4 miles along eastern side of hill to campsite behind rock outcrop at N.E. side of hill. 5min. climb to trig. which is sited on a ridge of smooth granite with steep sides east and west.





Cadastral Connections & Reference Marks.



1969 3rd Order Level Connection
Trig is 110.045 feet above PSM 2677.

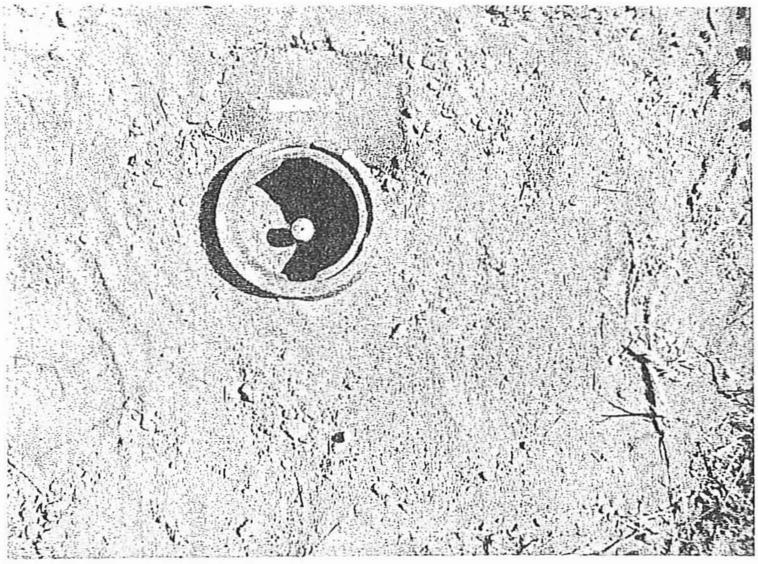
ISSUE NO. 3
DATE - 6 JUL 1970

Photo Identification:

Certified free of transcription errors: [signature] 6.7.70 — Date: 22/6/67

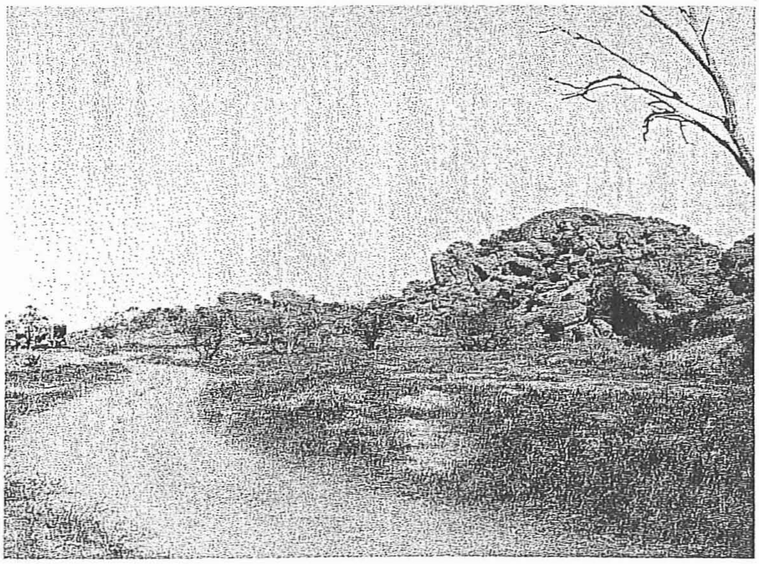
Approved by: H. A. Johnson — Date: 23 Jun 67

AMO/MISC/3933

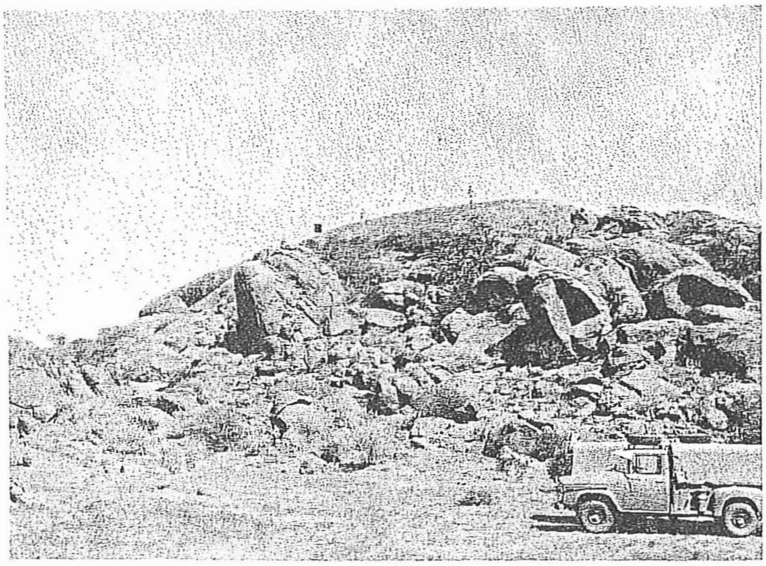


Bench mark NMV/G/14
Uncovered

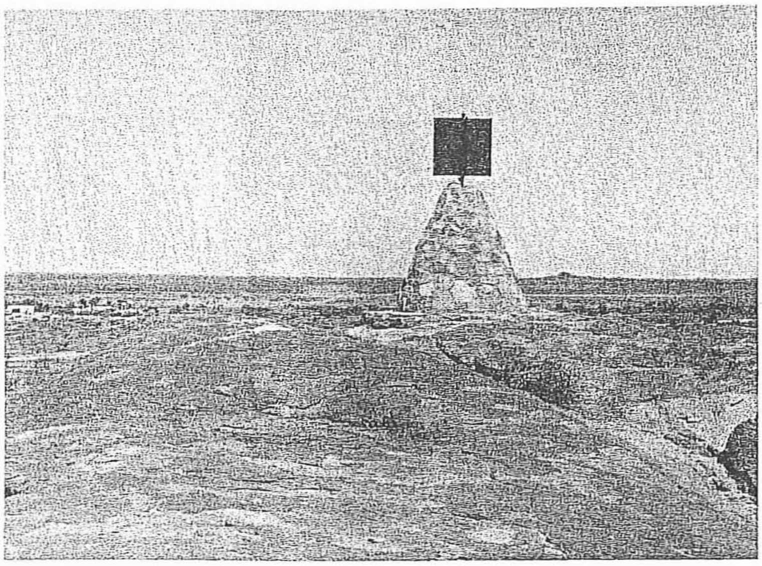
Bench mark NMV/G/14
with cover in place



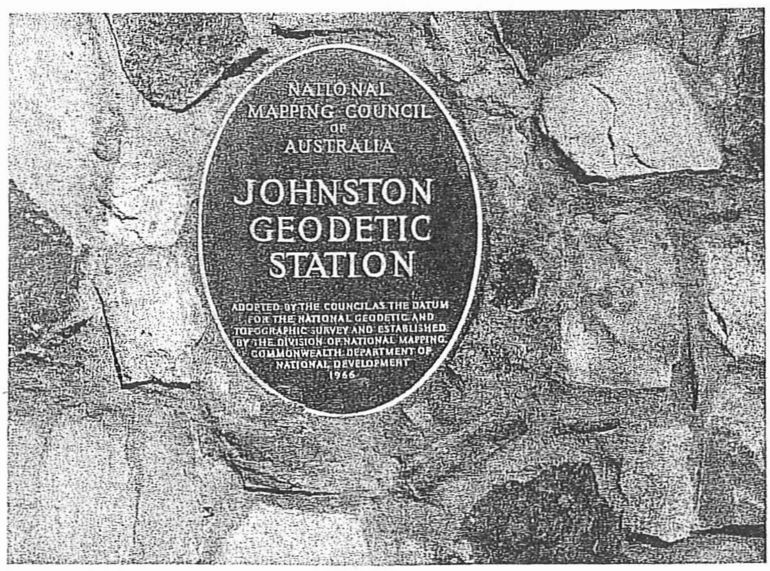
General view of
marks at Johnston
Geodetic Station



Levelling party at Johnston Geodetic Station.



Johnston Geodetic Station.



Plaque of the Johnston Geodetic Station.

3.9 Bench Marking

3.9.1 Bench marks used throughout the National Levelling Network vary from State to State and within States depending on the establishing party.

3.9.2 Most marks are concrete blocks from 5 to 9 inches square at the top, 9 to 13 inches square at the bottom and 18 to 27 inches deep, fitted with identification plaques. Other marks used range from plaques and plugs on structures or in rock, to "deep" bench marks. In rural areas all marks are indicated by a wooden or steel marker post, and many are marked by white painted circles or crosses of stone or by circular trenches.

3.9.3 "Deep" bench marks established by the Division of National Mapping and by some Lands Departments consist of copper coated or stainless steel rods driven to refusal, fitted with a suitable cap and protected by a concrete collar. "Deep" bench marks installed by the Weapons Research Establishment on behalf of the Division of National Mapping were established by drilling a 6 inch hole 12 feet deep with a "Proline" earth auger, placing 2 feet of concrete in the bottom of the hole, anchoring a $\frac{1}{2}$ inch bronze rod 12 feet long into the concrete, backfilling the hole with sand and fitting a concrete collar.

3.9.4 In areas where photo identification of the bench marks was difficult the marks indicated by the crosses, circles or trenches where spot photographed from altitudes of from 8,000 to 10,000 feet to produce vertical photos at a scale of about 1:20,000 from which it is possible, with the aid of a differential stereoscope, to transfer the position of the mark, visible on these photos, to the 1:80,000 mapping photography.

3.9.5 Clusters of three "reference bench marks" have been established in some areas at intervals of about 50 miles along traverses and at junction points. More will be installed when survey or making parties visit new areas.

4. TIDES AND TIDE GAUGES

4.1 Installation of Gauges

4.1.1 The earliest known automatic tide gauge to be installed in Australia is the gauge at Williamstown, Victoria, established in 1859. In 1866 the gauge at Fort Denison (Sydney), New South Wales, was established. These formed the basis for the nation's first two height datums.

4.1.2 Later installation of gauges at Port Adelaide, South Australia, at Brisbane, Queensland, and at Fremantle in Western Australia created other different and unconnected datums. Establishment of additional gauges, as new ports were developed along the coast of each State, and the adoption of local datums based on the different sea levels recorded by these stations confused the situation further.

4.2 National Mapping Council Resolutions on Tide Gauges

4.2.1 Perhaps the first practical step towards having the different datums, if not unified, at least compared came when the National Mapping Council, at its 13th meeting in 1955, resolved that:

> "The Council recommends that all States adopt Mean Sea Level as the State Level Datum and that States precise levelling programmes be so adapted as to facilitate comparison of level datums between adjoining States."

4.2.2 Another step forward was taken when, during its 22nd meeting in April 1964, the National Mapping Council adopted Resolution 282:

> "That Council considers that members should encourage responsible authorities to install tide gauges to enable simultaneous observations to be made with the object of obtaining Mean Sea Level on a national basis and that where possible each tide gauge should be joined to a permanent geodetic bench mark by special high precision levelling and periodically check-levelled. It should be a long range aim that all tide gauge stations be joined by high precision levelling. The Council further recommends that tide gauges be left continuously in operation for the longest period, in order to improve and refine the value of Mean Sea Level."

4.2.3 The National Mapping Council then directed that the Technical Sub-Committee investigate and advise on the practical application of Council Resolution 282 and, after considering its Technical Sub-Committee report and reports from the Surveyors General resolved (Resolution 290):

> "That Council considers that it is desirable that at least one year's continuous tide gauge readings be obtained in 1966 for the purpose of comparing Mean Sea Level values, and, if possible, to provide one national vertical datum.

The Council considers that, assuming all existing gauges shown on the accompanying map will be available, new gauges will be needed at least at the following locations:

Esperance, Eucla, Port Fairy, Bamaga (Cape York), the southern part of the Gulf of Carpentaria and Carnarvon.

The following conditions must be met if the readings are to be of value for the purpose in mind:

The gauges must be located in waters as freely open to the sea as possible and free of local geographical restrictions.

The gauge level must be compared to a bench mark at least once during 1966.

The gauges must be connected by levelling to the State system as soon as possible though this need not take place during 1966.

The Council considers that members should endeavour to cause a check to be made of the efficiency, location and details of the existing gauges shown on the accompanying map and listed in CSIRO Publication 15, "Australian Tide Recorders". "

The map which accompanied Resolution 290 and which shows gauges thought likely to be available, possible new gauges required and a gauge at which past readings might be used is on page 24.

4.2.5 The National Mapping Council later recommended at its 1966 meeting (Resolution 308) that, where possible, the tide gauges set up in terms of Resolution 290 should be maintained in continuous operation until a date close to the start of the National Levelling Adjustment.

4.3 Inclusion of Other Gauges

4.3.1 Tide gauges at Port Kembla (New South Wales), Wyndham (Western Australia), Melville Bay and Centre Island (Northern Territory) and Cooktown (Queensland) were later included in the tide gauge programme but of the then 35 gauges the three in Tasmania played no part in the determination of the Australian Height Datum, there being no overwater connection between Tasmania and the mainland; the gauge at Eden (New South Wales), from which very poor recordings were obtained, was excluded at the request of the Victorian and New South Wales Surveyors General; and Melville Bay could not be included in the final determination because it was not possible to complete the level connection.

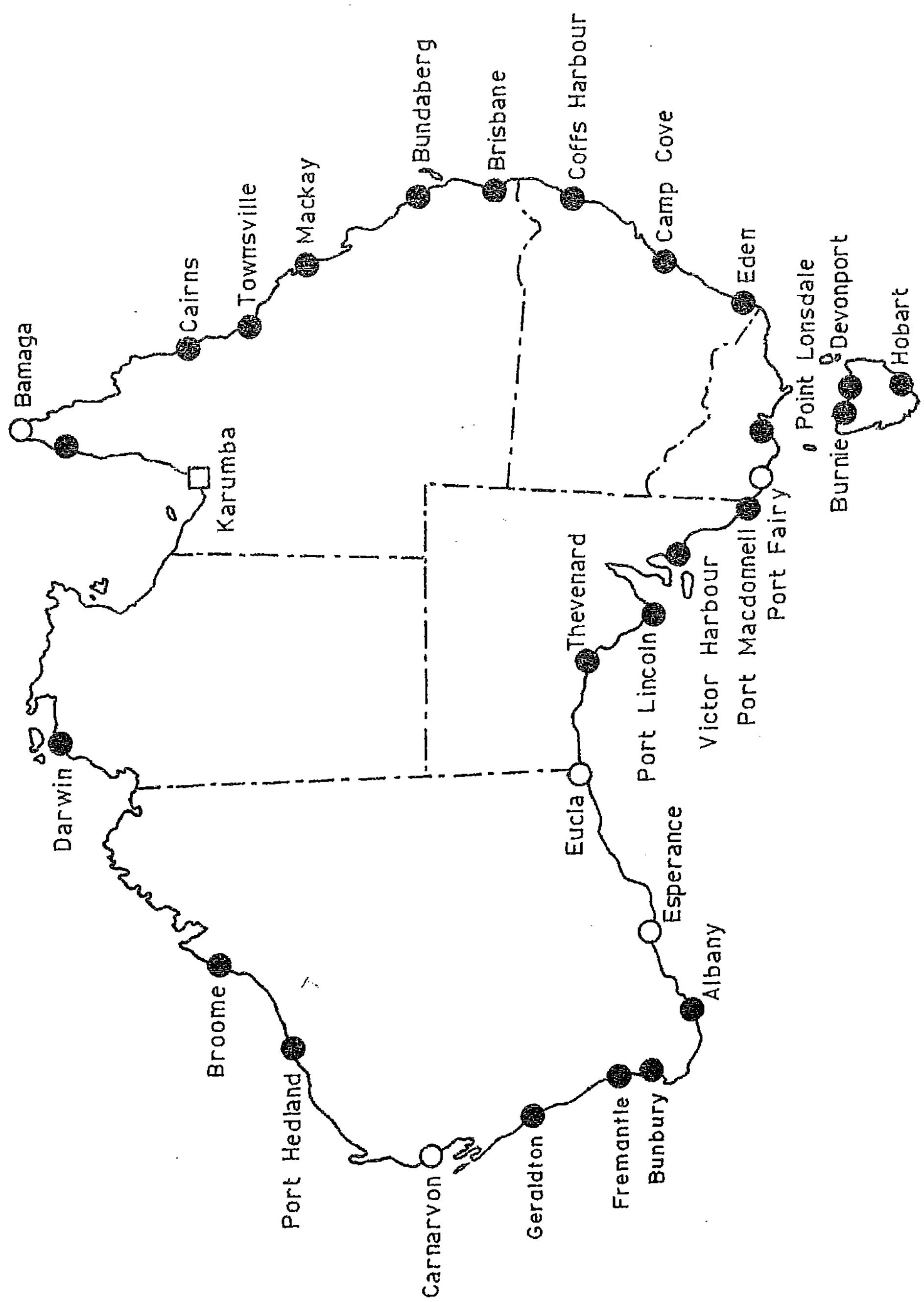
PROPOSED ONE YEAR TIDAL
OBSERVATION PROGRAMME

NATIONAL MAPPING COUNCIL RESOLUTION 290

● Tide Gauges likely to be available.

○ Possible additional Tide Gauges required.

□ Station at which past readings might be used.



4.4 The Tide Gauge Survey

4.4.1 In 1967 the Division of National Mapping, with the assistance of the Flinders University's Horace Lamb Centre for Oceanographical Research, State Surveyors General and the Works and Maritime Departments in each State, completed the survey of 26 of the mainland tide gauges.

4.4.2 The aim of the survey was to visit all mainland gauges included in the tide gauge programme and to:

.1 Calibrate the automatic tide recorder with a special device designed and built by the Horace Lamb Centre for Oceanographical Research.

.2 Determine the difference in elevation between the staff gauge and 3 permanent bench marks at each gauging station.

.3 Where necessary, establish additional permanent bench marks to bring the number of permanent bench marks in the vicinity of each tide gauge to at least three.

.4 Make a photographic record of the gauging station, the adjacent staff gauge and the three permanent bench marks.

.5 Prepare a plan of each installation showing the gauging station, the staff gauge and the three permanent bench marks in their proper relation to each other and to other prominent local features.

.6 Pinpoint the location of the gauging station and the three permanent bench marks on existing aerial photographs.

.7 Make contact with the operator of the tide gauge and discuss with him aspects of maintenance and operation of the gauge.

.8 Complete a "Record of Tide Gauge Station".

4.4.3 Commencing at Port Fairy (Victoria) the survey party of three men visited in turn Port MacDonnell, Victor Harbour, Port Lincoln, Thevenard (South Australia), Eucla, Esperance, Albany, Bunbury, Fremantle, Geraldton, Carnarvon and Port Hedland (Western Australia), Bundaberg and Brisbane (Queensland) and Coffs Harbour, Camp Cove and Eden (New South Wales).

4.4.4 Tide gauge surveys at Melville Bay, Darwin and Centre Island were later carried out by officers of the Northern Territory Administration, at Port Kembla by the New South Wales Department of Lands and at Wyndham by the Division of National Mapping.

4.4.5 Typical of the data acquired during the tide gauge survey is that for Wyndham shown on pages 26 to 34.

4.4.6 The survey of the 26 gauges carried out in 1967 was continually plagued by electronic and sensor troubles in the special calibrating device and at a number of gauges visual calibration, by comparison of the board gauge with the automatic recorder every quarter hour, was carried out.

RECORD OF TIDE GAUGE STATION

Name of station: WYNDHAM, W.A.

Latitude: 15° 28' S Longitude: 128° 08' E

Name of owner: PUBLIC WORKS DEPARTMENT, W.A.

Name, address and telephone number of operator: R. HARRIS
P.W.D. WYNDHAM
PHONE: WYNDHAM 28

Frequency of checks (height & time): MONTHLY

Method of checking accuracy of recorded height: VISUAL INSPECTION OF BOARD GAUGE NEAR AUTOMATIC RECORDER

Type of recorder & maker's name: LEUPOLD & STEVENS, TYPE A 35
SERIAL Nº 33772 - 62

Time scale (hours/inch): 2½ HOURS/INCH

Height scale (feet/inch): 2 FEET/INCH

Range of gauge: AUTOMATIC RECORDER -8' TO +32'
BOARD GAUGE 0' TO 26'·75

Diameter of float: 8" (INSIDE DIAMETER OF WELL 23")

Environmental effects on gauge: STRONG CURRENT (SEE BELOW)

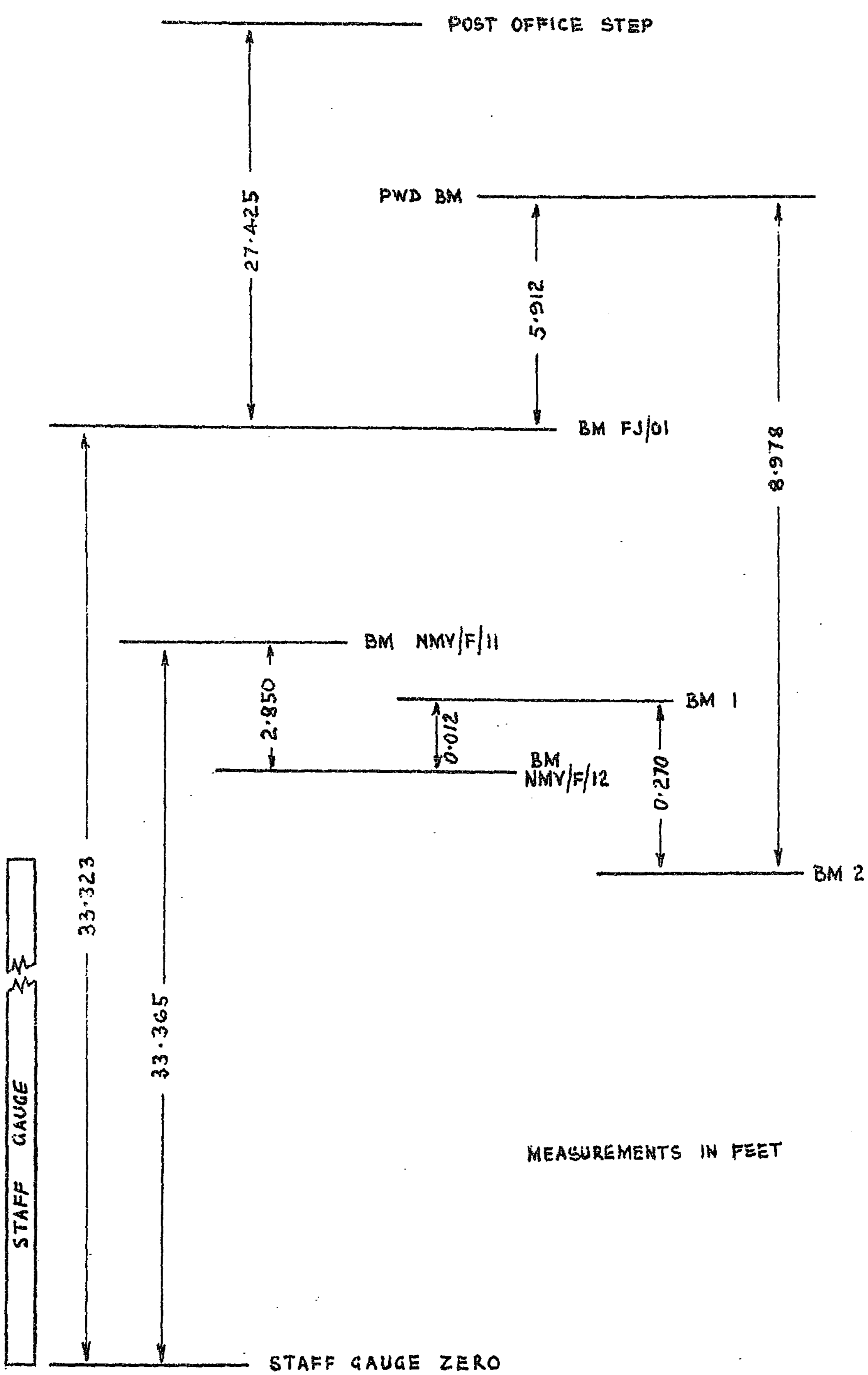
Height of permanent bench marks above zero of staff gauge

Number of PBM	Height above zero of staff gauge (feet)
NMV/F/11	33·365
NMV/F/12	30·515
PWD BM	39·235

General remarks: THE TIDE GAUGE IS SOME 60 MILES FROM THE OPEN SEA AND ON THE EASTERN SIDE OF THE WEST ARM OF CAMBRIDGE GULF WHERE THE GULF IS ONLY ABOUT 1¾ MILES WIDE.
STRONG CURRENTS (ABOUT 3½ FEET/SEC) FLOW PAST THE BOARD GAUGE WHICH IS FIXED TO JETTY PILE. CURRENT FLOW IS DISTURBED BY JETTY.

H. Granger
10/5/69

WYNDHAM TIDE GAUGE, WA.



DIVISION OF NATIONAL MAPPING

TIDE GAUGE CALIBRATION: WYNDHAM, WA SHEET 1 OF 5

TYPE OF RECORDER: LEUPOLD & STEVENS TYPE A35
SERIAL No. 33772-62

TIME			TIDE		WEATHER
DATE	WESTERN AUSTRALIAN STANDARD TIME	RECORDER TIME	RECORDER (FEET)	BOARD GAUGE (FEET)	
18/5/69	10 00	10 00	22.10	22.20	Clear, sunny, light SE breeze 93°F (air)
	10 15		21.50	21.50	
	10 30		20.60	20.65	
	10 45		19.60	19.65	
	11 00	11 00	18.50	18.55	
	11 15		17.40	17.40	
	11 30		16.30	16.35	
	11 45		15.30	15.30	
	12 00	12 00	14.20	14.20	
	12 15		13.20	13.20	
	12 30		12.20	12 20	94° F (air temp)
	12 45		11.30	11.30	
	13 00	13 00	10.40	10.45	95° F
	13 15		9.55	9.55	
	13 30		8.80	8.80	
	13 45		8.10	8.10	
	14 00	14 00	7.45	7.45	
	14 15		6.85	6.80	
	14 30		6.50	6.50	93° F
	14 45		6.20	6.20	
	15 00	1500	6.15	6.20	
	15 15		6.35	6.40	
	15 30		6.85	6.90	92° F
	15 45		7.55	7.65	
	16 00	1600	8.45	8.55	91° F

OBSERVERS: [signature] Granger TIME: 1000 – 1400

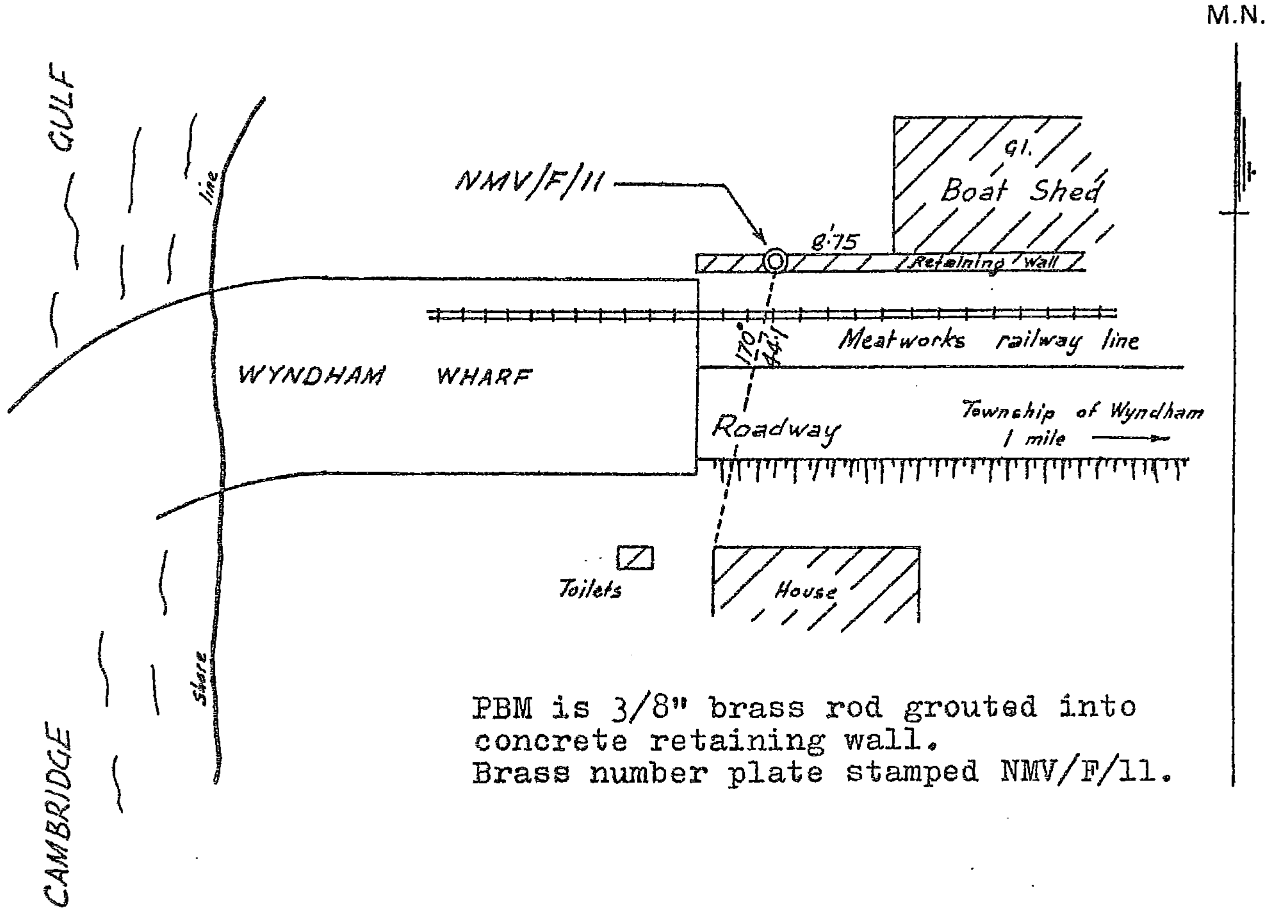
[signature] Gray 1400 – 1600

PBM No. NMV/F/11

DEPARTMENT OF NATIONAL DEVELOPMENT
DIVISION OF NATIONAL MAPPING

PERMANENT BENCH MARK RECORD

Measurements in feet (not necessarily to scale)



PBM is 3/8" brass rod grouted into concrete retaining wall.
Brass number plate stamped NMV/F/11.

Provisional Reduced Level: .... feet. Datum: ....

Established by: F.C. Reardon, Division of National Mapping Date: 19-May 1969

Under field supervision of: H.W. Granger Surveyor, Class 1

Sketch shown in Field Level Book No.: 7267

1:250,000 Map Sheet: Cambridge Gulf D52-14

Scaled Latitude: 15° 28' south Scaled Longitude: 128° 08' east

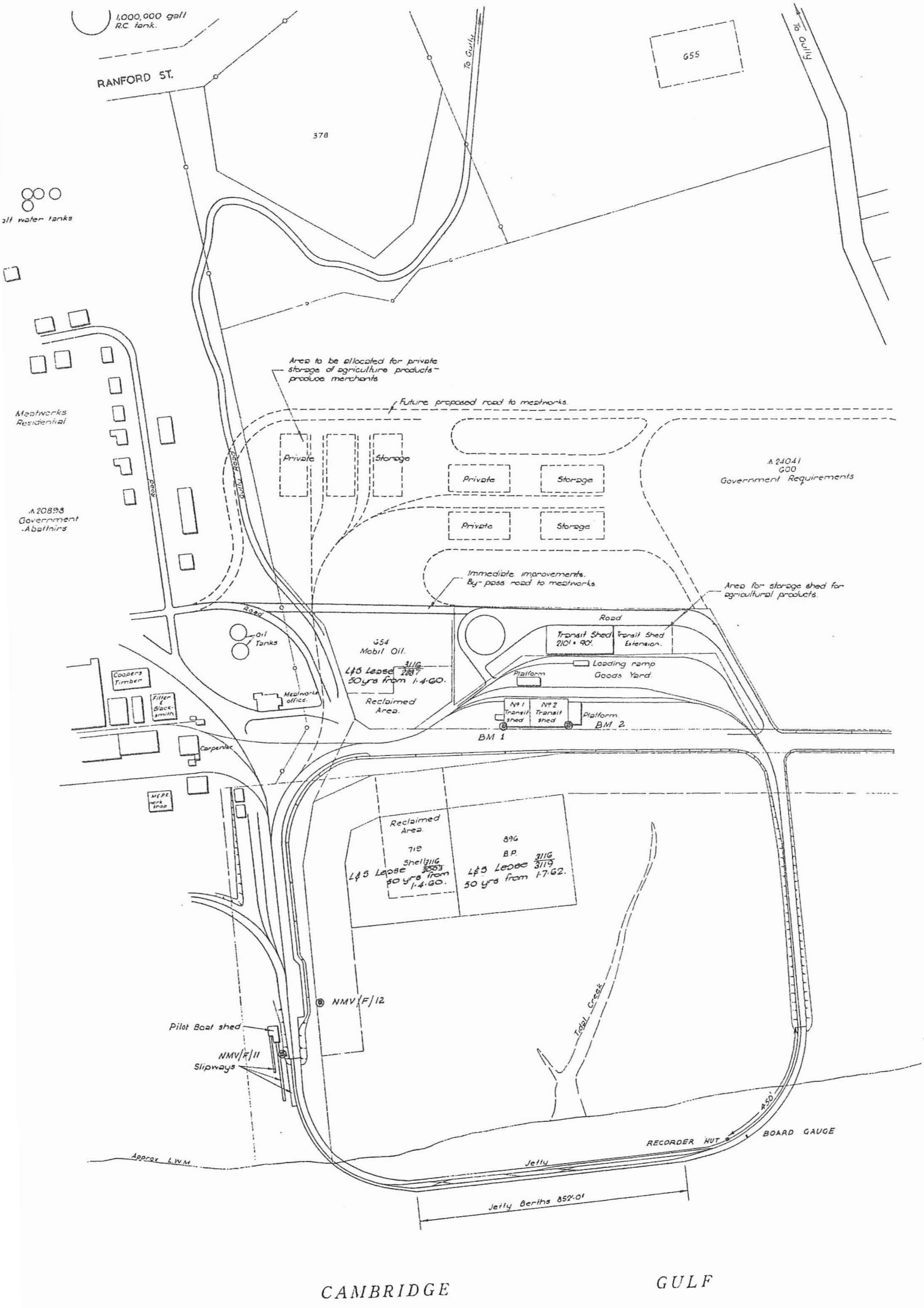
PHOTO IDENTIFICATION.

AERIAL, Area: .... Film No: .... Run No: .... Photo No: ....

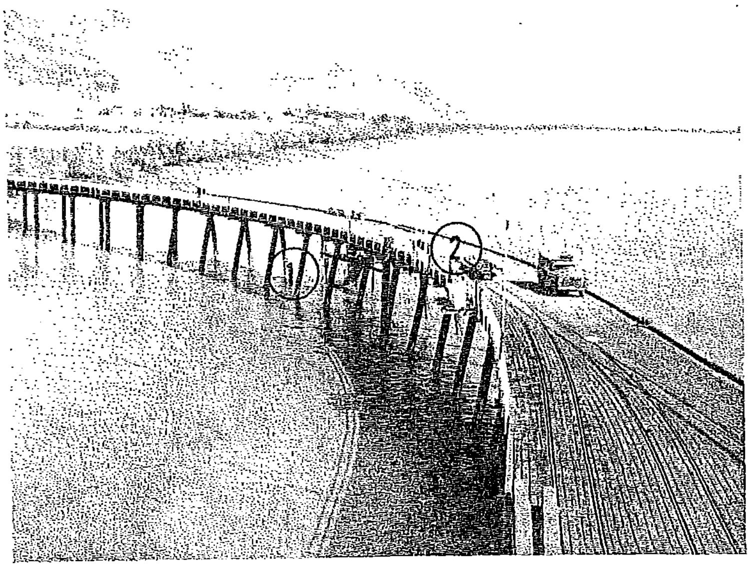
TERRESTRIAL, Film No: G/10 Photo No: 25, 28, 29.

Certified free of transcription errors: [signature] Date: 24/10/69

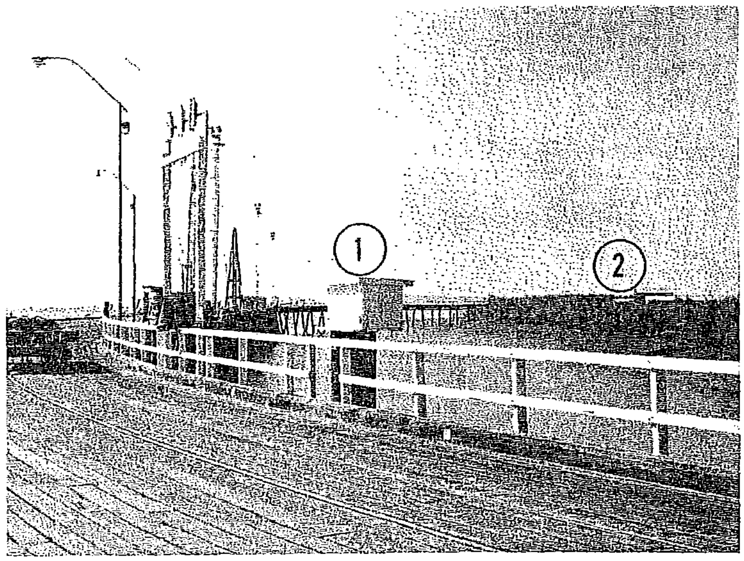
Approved by: .... Date: ....



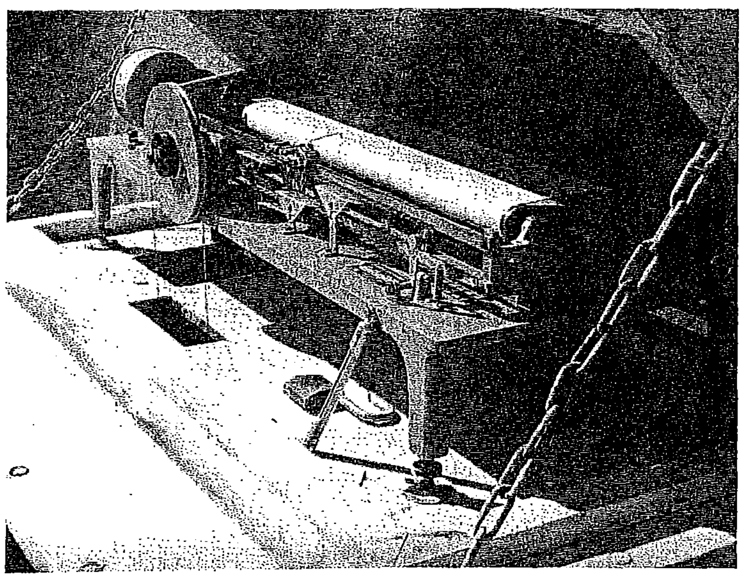
1,000,000 gall R.C. tank.
RANFORD ST.
To Gully
To Gully
G55
378
salt water tanks
Meatworks Residential
A 20898 Government Abattoirs
Road
Gully Road
Area to be allocated for private storage of agriculture products - produce merchants
Future proposed road to meatworks.
Private
Storage
Private
Storage
Private
Storage
A 24041 G00 Government Requirements
Immediate improvements. By-pass road to meatworks
Area for storage shed for agricultural products.
Road
Road
Oil Tanks
G54 Mobil Oil.
L&S Lease 3116/2887 50 yrs from 1.4.60.
Reclaimed Area.
Transit Shed 210' x 90'.
Transit Shed Extension.
Loading ramp
Goods Yard.
Platform
No 1 Transit shed
No 2 Transit shed
Platform
BM 2.
BM 1
Coopers Timber
Fitter & Blacksmith
Meatworks office.
Carpenter
M.E.P.E. work shop
Reclaimed Area.
719 Shell 3116/3503
L&S Lease 50 yrs from 1.4.60.
896 B.P.
L&S Lease 3116/3119 50 yrs from 1.7.62.
NMV/F/12
Pilot Boat shed
NMV/F/11
Slipways
Tidal Creek
450'
RECORDER HUT
BOARD GAUGE
Approx. L.W.M.
Jetty
Jetty Berths 852.01
CAMBRIDGE GULF



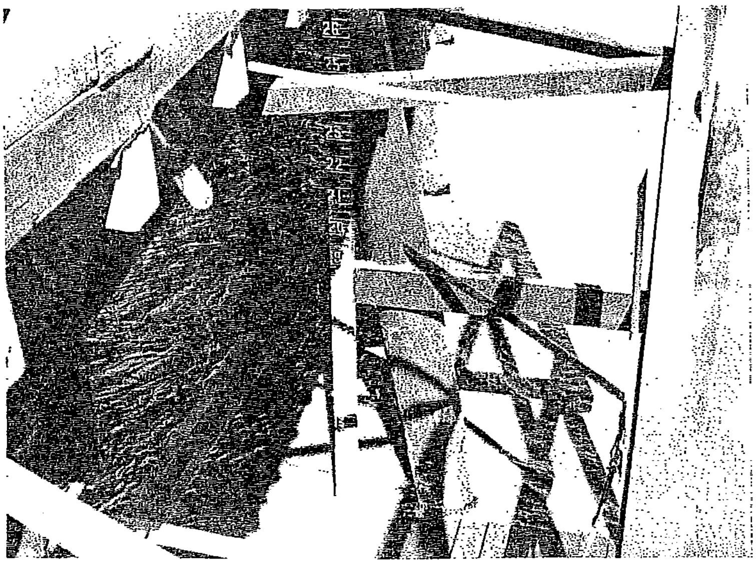
General view of Wyndham jetty showing: (1) board gauge, (2) recorder hut.



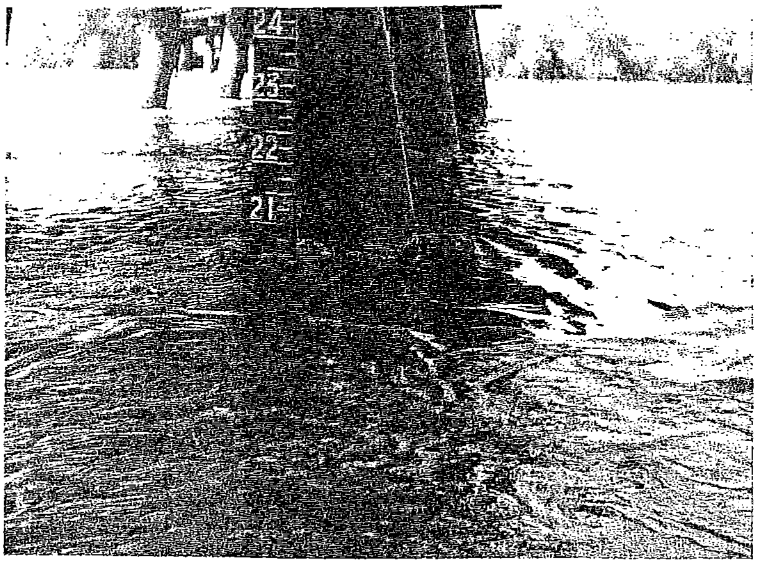
Wyndham jetty area showing: (1) recorder hut (2) position of bench mark. NMV/F/11.



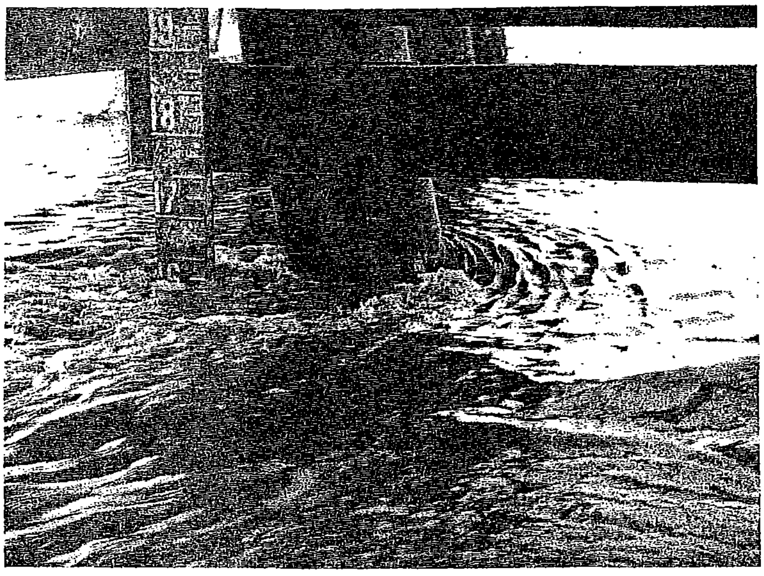
Wyndham tide recorder.



Wyndham board gauge

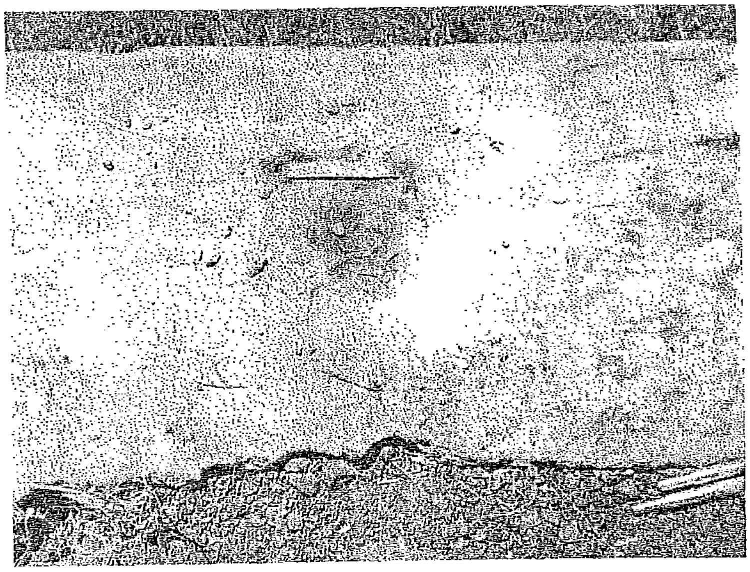


Wyndham board gauge at 1033 hrs on 18/5/69 showing disturbed current flow.

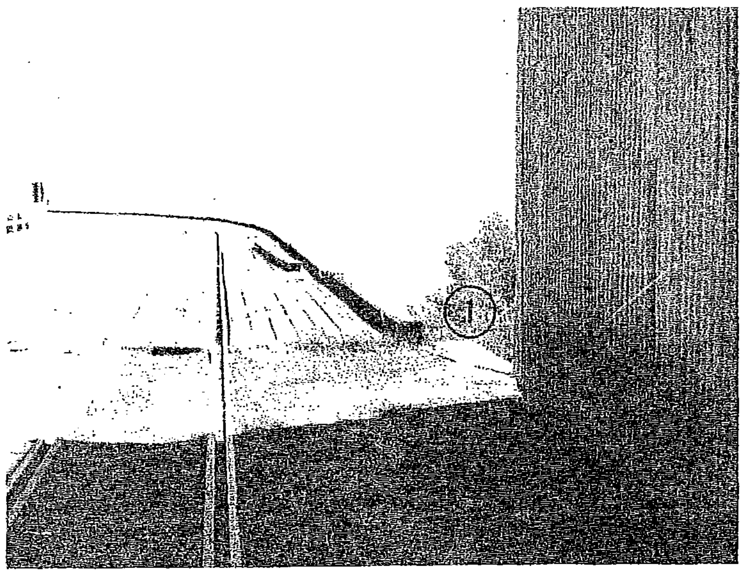


Wyndham board gauge at 1133 hours on 18/5/69 showing disturbed current flow.

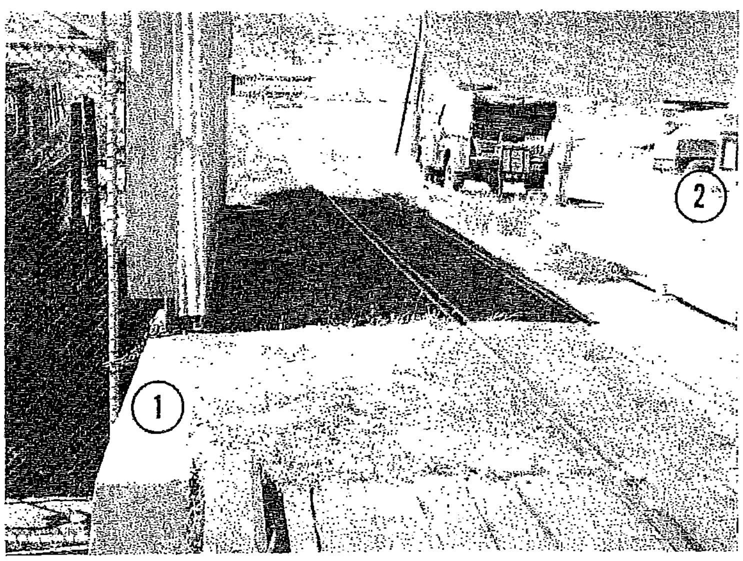
Bench mark NMV/F/11
on concrete retaining
wall Wyndham

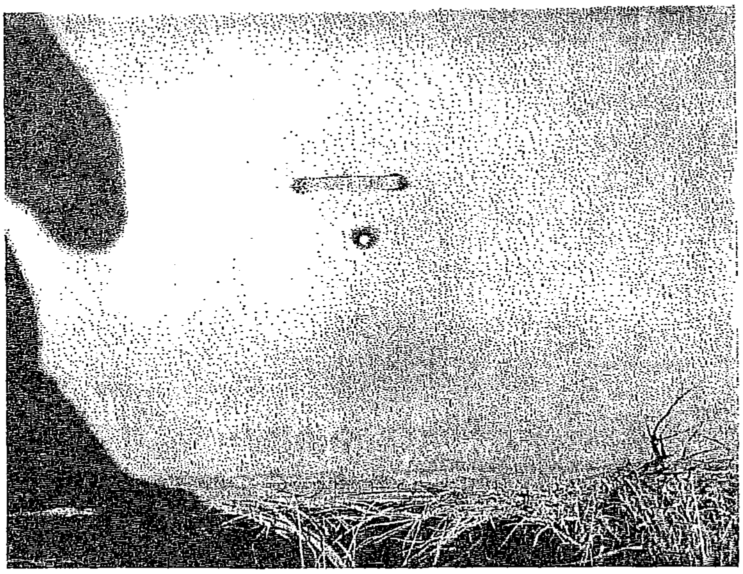


(1) Bench mark NMV/F/11
Wyndham

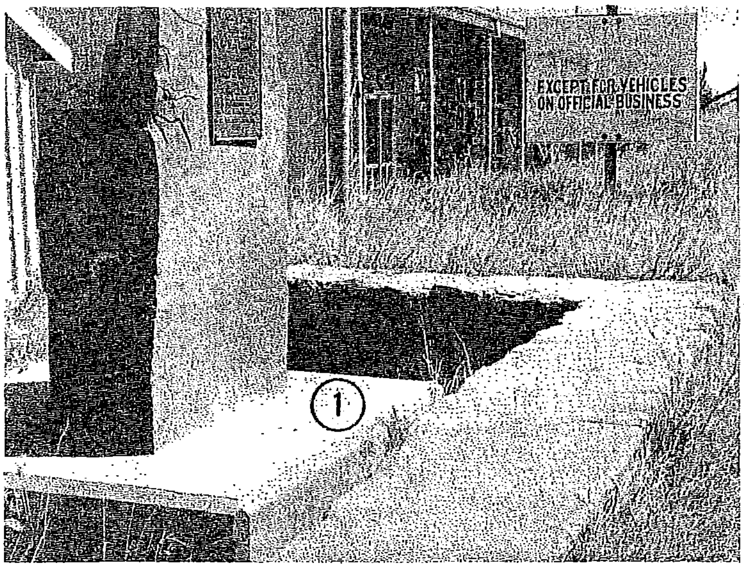


(1) Bench mark NMV/F/11
(2) Bench mark NMV/F/12
Wyndham

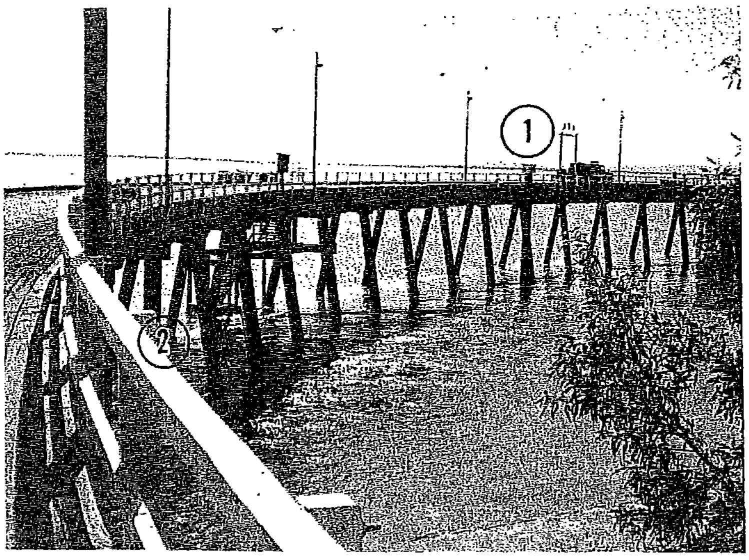




Bench mark NMV/F/12
on memorial plinth
Wyndham



(1) Bench mark NMV/F/12
Wyndham



Wyndham jetty showing:
(1) Recorder hut
(2) Board gauge

4.4.7 The special calibrating device was devised and built at the Flinders University of South Australia. It consisted of a clockwork driven rotating chart drum with two recording pens. Each pen was connected by insulated leads to their activating pressure sensor heads. The sensor heads detected changes in the pressure through sensitive membranes and could determine the height of water above each sensor. One sensor was placed near the bottom inside the tide gauge float well and the other outside the well at the same height as the inner sensor. From the resulting chart the differences in height between the water inside and outside the well could be compared and frequency responses determined.

4.4.8 Results of the 1967 tide gauge survey are contained in Survey Paper 6, "A Handbook of Selected Australian Tide Gauges" by A. K. Easton of the Horace Lamb Centre for Oceanographical Research and in Research Paper 24, "The Frequency Response of Selected Australian Tide Gauges" by A. K. Easton.

4.4.9 One problem found common to a large number of the remoter gauges visited was vandalism. Bullet holes were plentiful. Vandalism reached a climax when, in 1968, the gauge at Eucla was stolen complete with 3 months of data.

4.4.10 During 1968 and 1969 the Division of National Mapping completed the connection of a number of gauges to the levelling network where this connection from the three tide gauge bench marks to a levelling traverse had been too long or too difficult for the tide gauge survey party to undertake.

4.5 Analysis and Evaluation of Tide Gauge Records

4.5.1 Copies of the recorder charts from all tide gauges in the programme were sent by the operators to the Horace Lamb Centre for Oceanographical Research at the Flinders University of South Australia where hourly heights of sea level were extracted and all computations of mean sea levels and tidal constants were carried out.

4.5.2 A complete report of the results of the 1966-1968 tide gauge programme is given in "Tidal Program 1966-1968, Memorandum 5" by Alan Easton and Rainer Radok of the Horace Lamb Centre.

4.5.3 Mean sea level at Karumba was determined by the Queensland Department of Harbours and Marine from recordings made by them during the four year period 1957-1960.

4.5.4 Details of tide gauge bench marks, mean sea level values adopted for the determination of the Australian Height Datum and the height of the tide gauge bench marks above mean sea level at each station are given in Table 3 on page 36.

TABLE 3

HEIGHT OF MEAN SEA LEVEL ABOVE ZERO OF STAFF GAUGE, TIDE GAUGE BENCH MARKS AND HEIGHT OF BENCH MARKS ABOVE MEAN SEA LEVEL

Station	Tide Gauge Bench Mark	Height of Mean Sea Level above Zero of Staff Gauge (Feet)	Height of Bench Mark above Mean Sea Level (Feet
Port Macdonnell	NMV/E/11	2.010	6.908
Victor Harbour	NMV/E/13	1.900	12.645
Port Lincoln	NMV/E/16	3.330	11.718
Thevenard	NMV/E/18	3.250	15.863
Eucla	PWD BM	2.370	13.305
Esperance	NMV/F/2	1.820	11.521
Albany	HR 2	2.530	10.640
Bunbury	NMV/F/5	2.100	7.231
Fremantle	NMV/F/6	2.350	10.659
Geraldton	NMV/F/7	2.780	6.041
Carnarvon	NMV/F/9	2.670	11.115
Port Hedland	PWD PH1	10.350	14.889
Broome	EP 1	14.640	29.055
Wyndham	NMV/F/11	13.760	19.605
Darwin	BM 252	13.050	20.985
Centre Island	AHS 1	9.820	4.920
Karumba	SBM 10222	5.360	15.170
Weipa	NMV/B/304A	5.080	4.510
Bamaga	PBM 3931	4.500	10.160
Cooktown	NMV/B/307	4.370	22.912
Cairns	PSM 16253	4.700	10.910
Townsville	NMV/B/309	5.350	14.840
Mackay	NMV/B/311	9.650	25.110
Bundaberg	PSM 3853	4.420	14.335
Brisbane	TG BASE	3.590	18.610
Coffs Harbour	NAIL	2.680	18.350
Camp Cove	PM 84	3.040	4.983
Port Kembla	BM 6	2.880	13.710
Point Lonsdale	NW CNR	2.830	42.388
Port Fairy	TG BM	2.280	10.832

Epoch of mean sea level at Karumba 1.1.57 to 31.12.60.

Epoch for all other gauges 1.1.66 to 31.12.68.

5. LEVELLING DATA COLLECTION AND PREPARATION

5.1 Data Forms

5.1.1 Two data forms, one printed in grey and intended for the recording and analysis of two way levelling, and the other in red for new one way foot-metric levelling run over old one way levelling were designed by the Division of National Mapping and accepted for use by all observing authorities.

5.1.2 Each form was set out with numbered columns in which were entered data to be punched on computer cards. In addition to these numbered columns other space was provided for the analysis of levelling results and for recording instruments and staves used, staff calibration details and surveyors' names.

5.1.3 On the back of the forms were explanatory notes setting out details of how the sheets were to be completed. An example of each type of form is on pages 39 and 41.

5.2 Data Collection

5.2.1 Each observing authority accepted responsibility for collecting and recording the results of levelling carried out by them or under their supervision and control.

5.2.2 The writing up by the States of traverses terminating at a border went only as far as the last mark on that State's traverse. The Division of National Mapping determined which mark was to be a junction where traverses in different States met at borders, and wrote up the data on border connections observed by them.

5.2.3 In March 1969 a supply of data forms, three sets of maps covering each State and notes for the guidance of officers filling in the forms were sent to each Surveyor General. They were asked to return one marked-up map showing level traverses which they wanted included in the primary adjustment and to nominate an officer and a deputy to be contacted directly by the Division of National Mapping on matters of technical detail in connection with the adjustment.

5.2.4 The maps returned from the States were used for the compilation of the base map described in 6.1 showing all primary levelling.

5.2.5 Much time was saved by the arrangement of contact officers, many queries of a technical nature being answered in a few minutes over the telephone.

5.2.6 The first of the completed data sheets arrived in the office of the Division of National Mapping in September 1969 and they continued to come in from various sources until February 1971 when the last of the sheets covering primary levelling were received.

5.3 Data Preparation - Two Way Levelling

5.3.1 Results of two way levelling were recorded on the grey forms and only observed results were used. An example of a completed data sheet is on page 41.

5.3.2 In the recording of precision levelling the completion of the statistical part of the form, columns 8 - 11 and 15 - 18, was not required and rises and falls from other surveys were not incorporated unless they too were of precision standard.

5.4 Data Preparation - One Way Levelling

5.4.1 In the analysis of one way foot-metric levels and other one way levels on the red form the only values used in the initial stages of the adjustment were those between marks levelled twice in the course of the two separate level runs. Marks placed after the original one way levelling and subsequently levelled only one way during the later foot-metric levelling were included in a subsidiary adjustment called LINADJ which is described in 6.2.5. An example of a completed form is on page 39.

5.4.2 To avoid the preparation of two sets of data sheets for each such section the one way results between marks levelled once were entered at the first writing up of the form. The overall result of two way levelling between marks levelled twice was entered as a summary line, this line being marked by an asterisk in the left hand margin of the sheet. Where a number of marks levelled only one way intervened between two way levelled marks the intermediate distances were required to total the distance between the marks levelled two ways and, except for rounding off figures and differences between the two levellings, the sums of the intermediate rises or falls were equal to the total rises or falls between twice levelled marks.

5.4.3 Results of levelling from other surveys were entered into column 12 of the form. These other surveys included check levelling by Lands Departments and the Division of National Mapping as well as the original levelling. All available results were incorporated in the final calculation of the adopted mean rise or fall.

5.4.4 Where the difference between the original levelling and second levelling exceed 0.075 $\sqrt{M}$ the surveyor was required by specification to re-level. The results of each run of the re-levelling were usually entered into columns 8 and 9 and these only were used in the calculation of the adopted mean.

5.5 Filling-in of Data Sheets

5.5.1 Only observed rises or falls were entered on the data sheet. No adjustments or orthometric corrections were applied at this stage of the work.

5.5.2 Where some of the information required to complete the top part of the form, field book numbers, staff constants, etc, were not readily available, the completion and submission of the levelling information was not delayed by extensive search and in some cases this relatively unimportant record data was not supplied.

BER 1968

280-281

① STATE	② SECTION	③ N.M. SEC
QLD	108	3049

SBM 10186 IS GRAVITY STN DK/21

p 1 of 1

AUSTRALIAN LEVELLING SURVEY

ANALYSIS OF ONE WAY, FOOT/METRIC CHECK LEVELS AND OTHER ONE WAY LEVELS

LOCALITY	BENCH MARKS	FIELD BOOK	INSTRUMENT	SURVEYOR (S)
From: GIN GIN	From: 10186	No: 507	Type: ZEISS Ni2	N. H. MILLER
To: BØØYAL	To: DE/06	Pages:	No: 39430	Date: MAY 1966

CALIBRATION OF STAFF INTERVAL — Type of Staves: WATTS

Staff No.	Date	Feet	Metric	Date	Feet	Metric
136	21-4-66	0·9997	—			
137	22-4-66	0·9997	—			

Mean of Staff Intervals "C" = 1·0

INITIAL HEIGHT ㉓ (61–68):

	From ④	Serial No. ⑤	To ⑥	Serial No. ⑦	Observed rise or fall: Foot staff feet ⑧	Metric staff feet ⑨	Mean rise or fall ½(8+9) feet ⑩	Corrected rise or fall (10 × 'C') feet ⑪	Rise or fall from other surveys feet ⑫	Miles M ⑬	Discrepancy D1 (8-9) ⑭	D1/√M ⑮	D2 (11-12) ⑯	D2/√M ⑰	± ⑱	Adopted mean rise or fall feet ⑲	Latitude deg.	Latitude min. ⑳	Longitude deg.	Longitude min. ㉑	Preliminary reduced level feet ㉒	Locality ㉔
*			10186	80													25	00	151	57	222	GIN GIN
*	10186	80	DE/10		70·830	70·792	70·811		70·860	3·7	·038	·020	·049	·025	—	70·827	25	02	151	59	151	
	DE/10		13110		1·115	1·119	1·117			—·—	·004	—			—	1·117	25	02	151	59	150	
	13110		DE/09		34·945	34·904	34·925			3·0	·041	·024			—	34·925	25	05	151	59	115	
*	DE/10		DE/09		36·060	36·023	36·042		36·080	3·0	·037	·021	·038	·022	—	36·055	25	05	151	59	115	
	DE 09		13109		45·805	45·827	45·816			1·4	·022	·019			—	45·816	25	05	152	00	69	
	13109		DE/08		64·765	64·694	64·730			2·4	·071	·046			+	64·730	25	07	152	00	134	
*	DE/09		DE/08		18·960	18·867	18·914		18·910	3·8	·093	·047	·004	·002	+	18·913	25	07	152	00	134	
	DE/08		13108		6·645	6·631	6·638			·8	·014	·016			—	6·638	25	08	152	00	127	
	13108		DE/07		202·960	202·970	202·965			3·4	·010	·005			+	202·964	25	10	152	01	330	
*	DE/08		DE/07		196·315	196·339	196·327		196·260	4·2	·024	·012	·067	·033	+	196·305	25	10	152	01	330	
	DE/07		13107		0·430	0·430	0·430			—·—	—	—			—	·430	25	10	152	01	330	
	13107		9145		53·955	53·908	53·931			3·1	·047	·027			—	53·931	25	13	152	02	276	
	9145		DE/06	79	16·400	16·398	16·399			·1	·002	·006			+	16·399	25	13	152	02	292	NEAR BØØYAL
*	DE/07		DE/06	79	37·985	37·940	37·962		38·010	3·2	·045	·025	·048	·027	—	37·978	25	13	152	02	292	NEAR BØØYAL

TOTALS CHECKED +70·358

ANALYSIS 1127 +70·357

Reduced Levels in column ㉒ are based on Mean Sea Level at BRISBANE

Certified free from copying errors: [signature]

Date: 7-1-1970

AUSTRALIAN LEVELLING SURVEY

Analysis of One-Way, Foot Metric Check Levels
and other One-Way Levels

EXPLANATORY NOTES

General : Fill in all details required to complete the heading of the form.

On the main body of the form where spacing is set out, characters must be entered in the spaces provided and the entry must not contain more characters than spaces.

Entries in columns 1, 2, 4, 6, and 24 should be made left justified i.e., entered from the left hand space towards the right. Entries in all other spaced columns must be right justified i.e., with the last figure in the right hand space. Decimal points must be retained in the positions shown.

On the first line of the form enter the first Bench Mark of the section in column 6 and complete columns 20, 21, 22 & 24 for that Bench Mark.

Calibration of Staff Interval : Enter results of Staff Calibrations in the spaces provided. "Mean of Staff Intervals, 'C' " is to be the mean of all calibrated staff constants.

Columns 1 & 2 : Enter "State" and "Section" number, left justified.

Column 3 : This space is to be left blank for the allotment of a number in the adjustment programme.

Columns 4 & 6 : Enter Bench Mark numbers in sequence between section terminals, left justified.

Columns 5 & 7 : These columns must be left blank until required for the adjustment programme.

Column 8 : Enter the rise or fall between Bench Marks obtained from readings of the foot staff. Prefix rises + and falls -.

Column 9 : Convert the rises and falls obtained from readings of the metric staff to feet and enter foot rises and falls. Observe signs.

Column 10 : Enter the mean of the figures in columns 8 & 9 using the same + or - prefixes.

Column 11 : Multiply the figure in column 10 by the Mean of Staff Intervals "C" and enter result. Prefix + or - as in column 10.

Column 12 : Enter rises and falls between Bench Marks as determined from other surveys. Prefix rises + and falls - figured in the same direction of run as check levels.

Column 13 : Enter the distance between Bench Marks in miles to the nearest 1/10 mile. Distances are reckoned along the levelling route.

Column 14 : Subtract the figure in column 9 from the figure in column 8 taking into account prefix signs. Prefix results + or -.

Column 15 : Divide the figure in column 14 by the square root of M in column 13 and enter result.

Column 16 : Subtract the figure in column 12 from the figure in column 11. Observe signs.

Column 17 : Divide the figure in column 16 by the square root of M in column 13 and enter result.

Column 18 : Place + or - in this column according to whether Adopted Mean Rise or Fall (Column 19) is a rise or fall.

Column 19 : If the figure in column 17 is less than or equal to 0.050 add the figure in column 12 to twice the figure in column 11, divide by three and enter result. If the figure in column 17 is greater than 0.050 but less than or equal to 0.075 add the figure in column 12 to four times the figure in column 11, divide by five and enter result. If the figure in column 17 is greater than 0.075 enter the figure in column 11 into column 19.
Results are to be entered to the nearest third decimal.

Columns 20 & 21 : Enter the latitude and longitude (Degrees and Minutes only) of those Bench marks shown in column 6. These latitudes and longitudes are to be determined by inspection of the plotted positions of the Bench Marks on the appropriate Australia 1:250,000 map sheet.

Column 22 : Enter the reduced level of the Bench Mark (shown in Column 6) to the nearest foot. Reduced levels are to be based on a Mean Sea Level datum. Complete the statement re Mean Sea Level at the bottom of the form.

Column 23 : This space must be left blank until required for an adjustment programme.

Column 24 : Enter the location names, left justified, of the starting and finishing points of the section. Important points within the section, such as towns, may be entered as required.

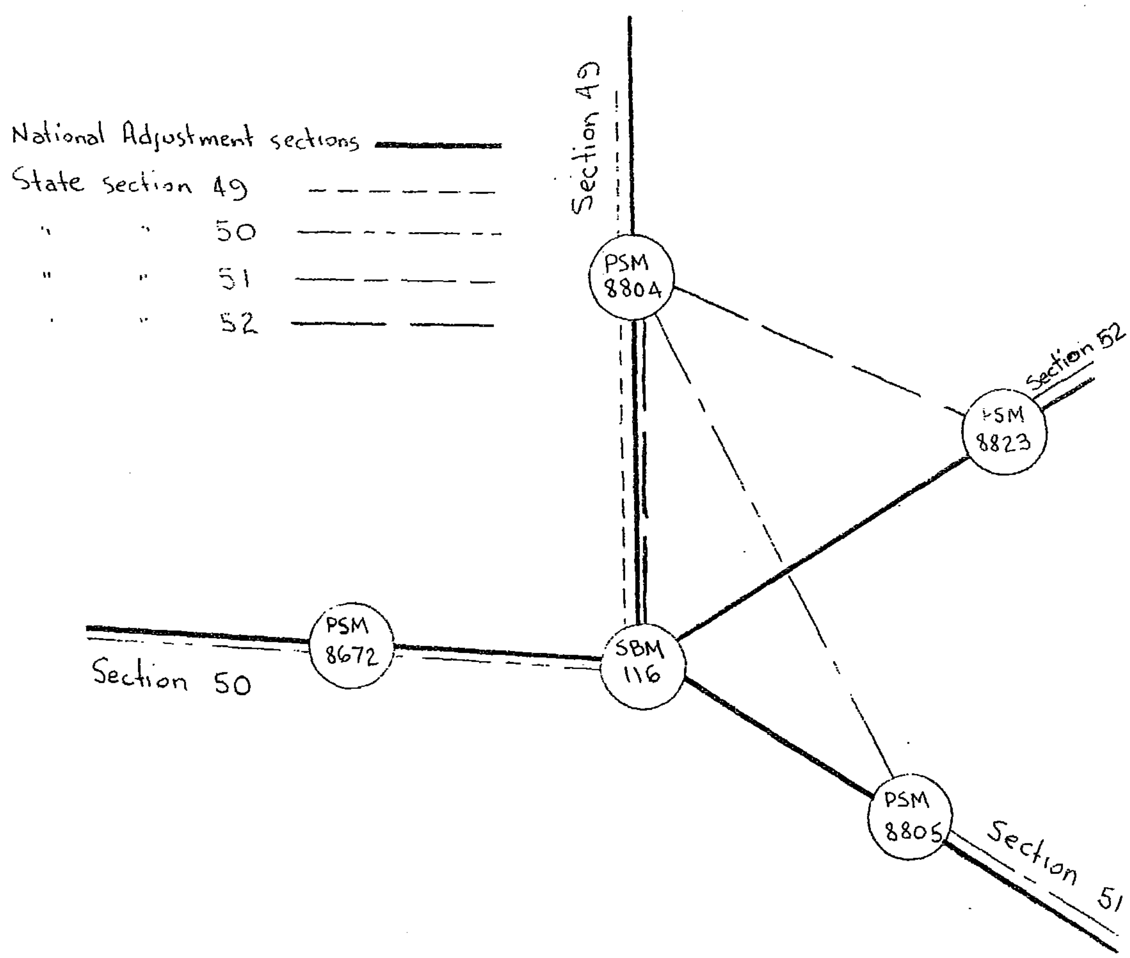
5.5.3 If several levellings between two bench marks had been made and all the results occupied more than one line of the data sheet the bench mark numbers were entered only on the line on which the adopted mean rise or fall was written and this line only was punched on a card.

5.5.4 National Mapping section numbers and junction point serial numbers were left blank by the State and other observing authorities and were completed by the Division of National Mapping.

5.6 <u>Junction Points</u>

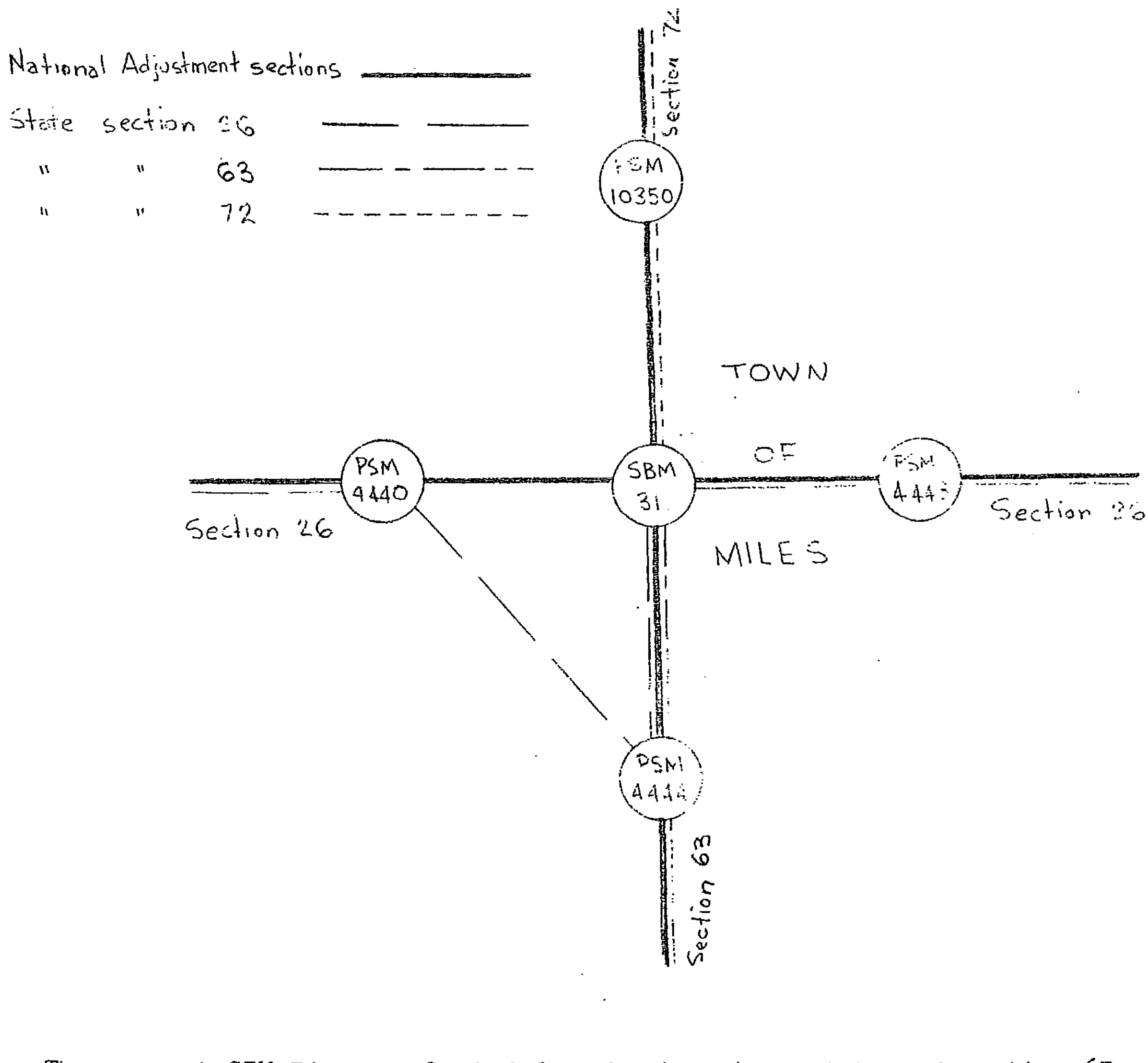
5.6.1 In order to substantially reduce the number of actual junction points where perhaps four or five lines of levelling each entered a town from a different direction and the traverses did not all meet at one point; or to avoid having the same bench marks appear in more than one traverse where the lines of levelling met just outside a town and then each continued along the same route, picking up the same marks to one central point; some modification of traverses had to be made. Examples of such modifications are given in 5.6.2 and 5.6.3.

5.6.2 In the case illustrated the original State sections 49, 50 and 52 terminate at SBM 116 although section 52 includes in it PSM 8804, already part of section 49. Original State section 51 terminates at PSM 8804, which is already included in sections 49 and 52.



The mark at SBM 116 was chosen as the junction point, and sections 49 and 50 required no modification. Section 51 was made to terminate at SBM 116 by excluding from the section the interval PSM 8805 to PSM 8804 and entering on the analysis sheet the difference in height between PSM 8805 and SBM 116 calculated from the observed differences in height for the intervals PSM 8805 to PSM 8804, from section 51, and PSM 8804 to SBM 116, from section 49 and 52. The distance entered on the analysis form for the interval PSM 8805 to SBM 116 was the distance between these two marks via PSM 8804. Section 51 was left to terminate at SBM 116 but the two intervals PSM 8823 to PSM 8804 and PSM 8804 to SBM 116 were replaced by one calculated interval, PSM 8823 to SBM 116.

5.6.3 At Miles, in Queensland, the original State sections 63 and 72 terminated at SBM 31 but section 26 extended in two directions from SBM 31 and also included PSM 4444, already part of section 63.



The mark at SBM 31 was selected for the junction point, and section 63 and 72 required no amendment. In section 26 the two intervals PSM 4440 to PSM 4444 and PSM 4444 to SBM 31 were replaced by one calculated interval PSM 4440 to SBM 31. Because the State section 26 continued beyond the junction point this section was given two National Mapping section numbers when these numbers were allotted in the adjustment.

6. DATA PROCESSING

6.1 Base map, regions and overlays

A 1:2,500,000 map of Australia was mounted on an 8 foot by 10 foot board and used as a base map. The primary level traverses were marked in orange on a continental overlay, along with their state bench mark numbers at the junction points, which were circled in black.

6.1.1 As there were too many junction points to enable a continental adjustment to be carried out in one operation on the available computer, a series of preliminary adjustments, called regional adjustments, were made. The continent was split into five regions, roughly along State borders, each with its own origin.

Region Number	Area	Region Origin
1	SA and NT	Johnston Origin
2	WA	Fremantle
3	Qld	Brisbane
4	NSW	Sydney
5	Vic	Point Lonsdale

6.1.2 The boundaries of these regions had to pass through junction points and no section could appear in more than one region. The regions were arranged in such a way that no region contained more than 139 junction points or 216 sections joining junction points.

6.1.3 Each region had its own independent National Mapping (NM) numbering system for both sections and junction points. These systems were distinct from the State numbering system and also from the final NM numbering system (see 6.4). The section numbering system commenced with 001 and was prefixed by the region number e.g. NM section 80 in region 4 was numbered 4080. Sections were numbered randomly. The junction point numbering system commenced with number 1 at the region origin and the other junction points were numbered consecutively and radially from south clockwise. This method of numbering made the ray numbering easier (see 6.2.9). These section and junction point numbers were added to the continental overlay in blue.

6.1.5 There was also an overlay provided for each region (regional overlay). As each section progressed through various stages of the adjustment, the regional overlays were marked with various colours.

6.2 Stages of the adjustment

6.2.1 On arrival at the Division of National Mapping from the various State and Government Authorities, the data sheets (see page 39) were allotted their NM junction point and section numbers. These numbers were written into the appropriate columns of the sheets. A Xerox copy was then made of every sheet and the duplicates filed and stored in another building. These sheets were filed according to their region and by their region section number. The regional overlays were then changed to red.

6.2.2 The information on the data sheets was punched onto data cards (one card per line, i.e. one card for each bench mark). These cards were filed by NM section numbers and the overlay for that section was changed to blue.

6.2.3 The cards were then run through program ORTHO1 which computed the orthometric correction to the observed differences in elevation between benchmarks along each section (see page 47). When sufficient sections had been run to form a loop, the orthometrically corrected levelling was used to determine the loop closure figure, (D). This figure, along with mileage (M) of the perimeter of the loop and the $D/\sqrt{M}$ figure was written inside the loop. The $D/\sqrt{M}$ figure for third order levelling, as laid down by the National Mapping Council, must be not more than 0.05 and where this figure was exceeded, exhaustive clerical checks were carried out in order to find the cause of the trouble. In some cases, re-levelling was necessary.

6.2.4 The computer produced two copies of the output from program ORTHO1. The duplicates were sent to the respective States for checking and if any errors were found the section was re-run and corrections made. The original was filed by region and NM section numbers.

6.2.5 As well as the printed output, ORTHO1 produced a punched card output in two parts. The first was the punched input for program LINADJ which linearly adjusted the intermediate bench marks along sections between two heighted junction points held fixed (see 8.12). This deck was very similar to the original data deck, except that it had the orthometrically corrected difference in height between adjacent bench marks punched on each card. The last two cards were section summary cards with total mileage, total rise or fall, both observed and orthometrically corrected, between junction points. These two cards were simply the reverse of each other in the direction of the levelling, and either one was used as input for program LEVELONE which simultaneously adjusted the junction points in each region, held fixed at only one point, the region origin (see 8.9).

6.2.6 When all the sections in a particular region had been run through ORTHO1, the section summary cards (LEVELONE input) were punched with a weight factor, varying from 1 for normal third order levelling to 9 for first order levelling, assembled in order of section numbers and run through LEVELONE.

6.2.7 The printed output of LEVELONE was filed by region. It consisted of two parts. The first was a list of the adjusted heights of each junction point(JP) in the region, adjusted to the local origin and in numerical order. The second part was a printout of the data along with the amount of adjustment given to each section.

6.2.8 The punched output of LEVELONE also consisted of two parts. The first part was the ADJ matrix cards, the first of which was numbered 1 and contained the difference in height between JP 2 and the region origin, the second was numbered 2 and contained the difference in height between JP 3 and the region origin, etc. This tied up with the ray numbering system (see 6.2.9). The second part of the output was the covariance matrix. For the final LEVELONE runs, the covariance matrices were stored on magnetic tape and called directly off the five tapes as input for program LEVEL 2 which simultaneously adjusted all junction points by condition equations (see 8.10).

PROGRAM ORTHO1

STATE	SECT	NMSECT	FROM BM	NO	TO BM	NO	DIST	MEAN	OC	MEAN+OC	LAT	LONG	HT	LOCALITY
NSW		4080			PM5541	50					32 53	144 17	282	IVANHOE
NSW		4080	PM5541	50	PM5542		0.9	-5.535	-0.000	-5.535	32 54	144 18	276	
NSW		4080	PM5542		SSM4041		2.0	8.682	-0.000	8.682	32 55	144 19	285	
NSW		4080	SSM4041		SSM4042		2.0	3.372	-0.000	3.372	32 56	144 21	288	
NSW		4080	SSM4042		SSM4043		2.1	1.768	-0.001	1.767	32 58	144 22	290	
NSW		4080	SSM4043		SSM4044		2.0	22.240	-0.000	22.240	32 59	144 24	312	
NSW		4080	SSM4044		SSM4045		2.2	-22.118	-0.000	-22.118	33 00	144 26	290	
NSW		4080	SSM4045		SSM4046		2.1	-5.425	-0.000	-5.425	33 01	144 27	285	
NSW		4080	SSM4046		SSM4047		2.1	2.288	-0.000	2.288	33 02	144 28	287	
NSW		4080	SSM4047		SSM4048		2.0	3.118	-0.000	3.118	33 03	144 30	290	
NSW		4080	SSM4048		SSM4049		2.1	3.275	-0.001	3.274	33 05	144 31	293	
NSW		4080	SSM4049		PM5543		2.0	2.947	-0.000	2.947	33 06	144 32	296	
NSW		4080	PM5543		SSM4050		2.0	0.892	-0.001	0.891	33 08	144 33	297	
NSW		4080	SSM4050		SSM4051		1.9	1.348	-0.001	1.347	33 10	144 34	298	WILLANDRA CK
NSW		4080	SSM4051		SSM4052		2.1	-1.695	-0.000	-1.695	33 11	144 34	297	
NSW		4080	SSM4052		SSM4053		2.0	2.032	-0.001	2.031	33 13	144 33	299	
NSW		4080	SSM4053		SSM4054		2.1	-0.082	-0.000	-0.082	33 14	144 34	299	
NSW		4080	SSM4054		PM5890	47	0.8	-1.445	-0.000	-1.445	33 15	144 34	297	MOSSGIEL

NSW		4080	PM5541	50	PM5890	47	32.4	15.662	-0.009	15.653	33 15	144 34	297	MOSSGIEL

6.2.9 At this stage, two more overlays, covering the whole of the continent, were required, showing the region boundaries and junction points. Rays were drawn from each region origin to the junction points within that region including points common to two or more regions. These rays were numbered consecutively from 1, so that Ray 1 went from JP 1 to JP 2 etc, until Ray 111 went from JP 1 to JP 112 in region 1 then Ray 112 went from JP 1 to JP 2 in region 2 etc. This numbering system was continued until each junction point was connected to the origin in the region in which it occured, and to both origins if the junction point fell on a region boundary.

6.2.10 Each condition to be fulfilled in the network adjustment was numbered. These conditions joined adjacent region origins via the junction points on the region boundary, common to both regions. The conditions were a number of four sided figures formed by the rays, with opposite corners at the region origins and the two adjacent junction points on the region boundary. There was a total of 33 such conditions in the adjustment. These figures were numbered where they crossed the region boundaries. This data was used to form the condition equation matrix (AMAT MATRIX) as part of the input for LEVEL 2.

6.2.11 The overlay used for the formation of the condition equations was also used to number all the junction points in the continent. Commencing with the network origin at Johnston Geodetic Station which had to be junction point 1, all junction points were numbered consecutively and randomly without consideringregions. Each junction point was connected to the network origin by a ray or through a region origin by a series of rays. Thus this data provided a connection between the ray numbering system or the initial regional junction point numbering, as from the punched output from LEVELONE (see 6.2.8), and the network junction point numbering system and was called the DEL MATRIX and used as part of the input for LEVEL 2.

6.2.12 Two LEVEL 2 adjustments were carried out.

The first was a "free" adjustment with only the Johnston Geodetic Station held fixed at an arbitary height (see ANNEX C).

The second was a "fixed" adjustment holding the height of sea level at 0.000 feet at the 30 tide gauge stations around the coast (see 6.3.3).

The input for both the LEVEL 2 adjustments was magnetic tape and punched cards from the five LEVELONE outputs. The output of both was a listing of the adjusted heights of the 497 junction points, arranged in numerical order.

6.3 The Australian Height Datum

6.3.1 The Australian Height Datum (AHD) 1971 is the datum surface derived from a simultaneous adjustment of the two way levelling network holding 30 tide gauges fixed at their mean sea level values. The adjusted height of the ground mark at the Johnston Geodetic Station is 1857.94 feet (566.300 metres). Observations for the determination of mean sea level were carried out from 1 January 1966 to 31 December 1968 at 29 tide gauges and from 1 January 1957 to 31 December 1960 at Karumba tide gauge.

6.3.2 The method used was to introduce, at the LEVELONE stage of the adjustment, an extra section at each tide gauge which ran from a permanent benchmark, close to the tide gauge itself, to mean sea level for the epoch. A large weight was given to this section so that no adjustment would occur.

6.3.3 The "fixed" LEVEL 2 adjustment was carried out by using Port Macdonnell as the nominal origin with a height of 0.000 feet and introducing zero condition equations between Port Macdonnell and the other 29 tide gauge stations, thus holding the "height" of mean sea level for the three year epoch at 0.000 feet at each tide gauge, and warping the land based levelling to fit this figure. The extra conditions were added to the condition equation matrix (see 6.2.10).

6.4 Filing system

6.4.1 At this stage, the whole filing system was changed to one using only junction point numbers to define sections which were referred to as say, section 336-339 with the lowest numbered JP first, regardless of the direction in which the levelling ran.

6.4.2 This entailed the refiling of all data sheets, data cards, ORTHO1 output sheets and LINADJ cards (see 6.2.5). New overlays were drawn showing thick lines as primary sections with thin lines as supplementary sections. Whenever supplementary sections met primary sections, a new junction point was introduced and a junction point number added. This addition of junction points was completely random.

6.5 Published output (primary levelling)

6.5.1 When the heights of the primary JPs in the network had been computed, two cards had to be punched for each section with information about the terminal JPs such as JP number, local bench mark number, locality description, latitude, longitude and adjusted height, which were included in the data deck for each section to be adjusted by program LINADJ.

6.5.2 The final count was some 37000 cards and since these would take more than 30 minutes to read by even the fastest card readers available, it was decided to transport all the data cards to Sydney and run them through the CDC 6600 computer at North Sydney. The cards were read on to magnetic tape, called from the tape via program LINADJ to an out-file tape, and printed out on the line printer.

6.5.3 The print run took over two hours, and the output was returned to Canberra for checking. All obvious mistakes were corrected and the cards repunched where necessary. The whole run was repeated and the final output printed on 21 May 1971. This output was checked and the go-ahead given to CDC in Sydney to print another nine copies which were delivered to the Division of National Mapping and then distributed to various State and Federal Authorities.

PROGRAM AMENDED 18/12/70
COMPUTED 21/05/71

NATIONAL LEVELLING ADJUSTMENT OF AUSTRALIA
LINEAR ADJUSTMENT BETWEEN PREVIOUSLY ADJUSTED JUNCTION POINTS 339 AND 336

SECTION 336- 339
THIRD ORDER LEVELLING
PRIMARY SECTION

AUSTRALIAN HEIGHT DATUM
NEW SOUTH WALES

BENCHMARKS FROM A	TO B	DISTANCE MILES	KM	HEIGHT DIFFERENCES (INTERNATIONAL FEET) OBSERVED	ORTHOMETRIC	ADJUSTED	CORR	LAT OF B	LONG OF B	LOCATION OF B	ADJUSTED HEIGHT OF B INT FT	METRES
	PM5541							32 54	144 17	IVANHOE	280.96	85.637
PM5541	PM5542	.9	1.4	-5.535	-5.535	-5.535	-.000	32 54	144 18		275.42	83.949
PM5542	SSM4041	2.0	3.2	8.682	8.682	8.681	-.001	32 55	144 19		284.11	86.595
SSM4041	SSM4042	2.0	3.2	3.372	3.372	3.371	-.001	32 56	144 21		287.48	87.623
SSM4042	SSM4043	2.1	3.4	1.768	1.767	1.766	-.001	32 58	144 22		289.24	88.161
SSM4043	SSM4044	2.0	3.2	22.240	22.240	22.239	-.001	32 59	144 24		311.48	94.939
SSM4044	SSM4045	2.2	3.5	-22.118	-22.118	-22.119	-.001	33 00	144 26		289.36	88.198
SSM4045	SSM4046	2.1	3.4	-5.425	-5.425	-5.426	-.001	33 01	144 27		283.94	86.544
SSM4046	SSM4047	2.1	3.4	2.288	2.288	2.287	-.001	33 02	144 28		286.22	87.241
SSM4047	SSM4048	2.0	3.2	3.118	3.118	3.117	-.001	33 03	144 30		289.34	88.191
SSM4048	SSM4049	2.1	3.4	3.275	3.274	3.273	-.001	33 05	144 31		292.61	89.188
SSM4049	PM5543	2.0	3.2	2.947	2.947	2.946	-.001	33 06	144 32		295.56	90.086
PM5543	SSM4050	2.0	3.2	.892	.891	.890	-.001	33 08	144 33		296.45	90.358
SSM4050	SSM4051	1.9	3.1	1.348	1.347	1.346	-.001	33 10	144 34	WILLANDRA CK	297.79	90.768
SSM4051	SSM4052	2.1	3.4	-1.695	-1.695	-1.696	-.001	33 11	144 34		296.10	90.251
SSM4052	SSM4053	2.0	3.2	2.032	2.031	2.030	-.001	33 13	144 33		298.13	90.870
SSM4053	SSM4054	2.1	3.4	-.082	-.082	-.083	-.001	33 14	144 34		298.05	90.844
SSM4054	PM5890	.8	1.3	-1.445	-1.445	-1.445	-.000	33 15	144 34	MOSSGIEL	296.60	90.404
SUMMATION		32.4	52.1	15.662	15.657	15.640	-.017					

PROGRAM AMENDED 18/12/70
COMPUTED 21/05/71

NATIONAL LEVELLING ADJUSTMENT OF AUSTRALIA
LINEAR ADJUSTMENT BETWEEN PREVIOUSLY ADJUSTED JUNCTION POINTS 339 AND 336

SECTION 336- 339
THIRD ORDER LEVELLING
PRIMARY SECTION

AUSTRALIAN HEIGHT DATUM
NEW SOUTH WALES

FIXED POINTS

NM JP NO	STATE BM NO	LAT	LONG	LOCATION	HEIGHT INT FEET	HEIGHT METRES
339	PM5541	32 54	144 17	IVANHOE	280.96	85.637
336	PM5890	33 15	144 34	MOSSGIEL	296.60	90.404

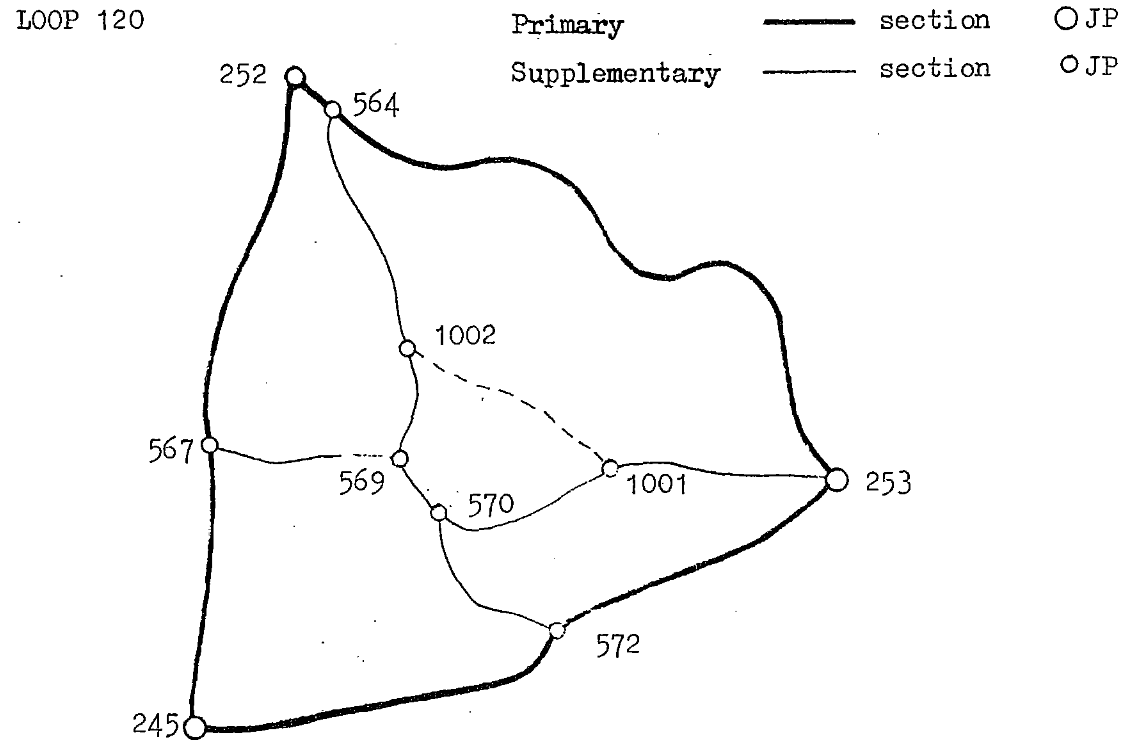
ADJUSTED POINTS

BENCHMARK	LAT	LONG	LOCATION	ADJUSTED HEIGHT INT FEET	ADJUSTED HEIGHT METRES
PM5541	32 54	144 17	IVANHOE	280.96	85.637
PM5542	32 54	144 18		275.42	83.949
SSM4041	32 55	144 19		284.11	86.595
SSM4042	32 56	144 21		287.48	87.623
SSM4043	32 58	144 22		289.24	88.161
SSM4044	32 59	144 24		311.48	94.939
SSM4045	33 00	144 26		289.36	88.198
SSM4046	33 01	144 27		283.94	86.544
SSM4047	33 02	144 28		286.22	87.241
SSM4048	33 03	144 30		289.34	88.191
SSM4049	33 05	144 31		292.61	89.188
PM5543	33 06	144 32		295.56	90.086
SSM4050	33 08	144 33		296.45	90.358
SSM4051	33 10	144 34	WILLANDRA CK	297.79	90.768
SSM4052	33 11	144 34		296.10	90.251
SSM4053	33 13	144 33		298.13	90.870
SSM4054	33 14	144 34		298.05	90.844
PM5890	33 15	144 34	MOSSGIEL	296.60	90.404

6.5.4 For every section, two outputs of different format were printed (see pages 50 and 51). The reason for this was that the simpler printout with only the bench mark number, latitude, longitude, locality and height in both feet and metres is sufficient for a surveyor, whereas the more complex printout is useful for research and analysis.

6.6 Adjustment of supplementary levelling

6.6.1 In many cases the supplementary levelling formed a complex net inside a primary loop. An adjustment using program LEVELONE was carried out. All the primary JPs and previously adjusted JPs were held fixed by giving the differences in height between them a large weight, thus giving homogenous heights for the supplementary JPs inside the primary loop.



A. Junction points 245,252 and 253 were adjusted by program LEVEL 2.

B. Junction points 564,567 and 572 were adjusted by program LINADJ between previously adjusted junction points (A).

C. Junction points 569 and 570 were adjusted by program LEVELONE, holding the whole perimeter fixed.

D. All benchmarks along supplementary traverses were adjusted, between the now heighted terminals, by program LINADJ.

E. If, in the future, levelling is carried out from JP 1001 to JP 1002 then the previously heighted bench marks corresponding to 1001 and 1002 will be used as terminal JPs and be held fixed and the new levelling will be run through program LINADJ.

6.6.2 The supplementary levelling was adjusted by LINADJ in the same way as the primary levelling (see 6.5) with two cards heading each section, punched with the junction point information. In this case the height of the JP was either an original LEVEL 2 adjusted height or the adjusted height of a bench mark on a primary traverse which the supplementary section was connected to.

6.6.3 The printed computer output of the supplementary levelling was dealt with in the same way as the primary levelling, both in the correction and distribution.

6.7 Metropolitan adjustment

6.7.1 So that the heights of bench marks within the metropolitan areas of Sydney and Perth need not change from their long established heights which are only trivially different from the newly adjusted values it was agreed at the 1971 National Mapping Council meeting that the old heights could be retained within clearly defined "metropolitan zones". These heights would be accepted as being on the AHD.

6.7.2 A "metropolitan zone" is the area, nominated by the State, in which the State desired to retain heights on a previously accepted datum. States were required to assign heights to all marks in this zone which were then quoted as being on the AHD.

6.7.3 The heights adopted in Sydney and Perth, although not directly computed as part of the National Levelling Adjustment, are sufficiently close for all practical purposes. The difference in heights determined from the adjustment and those adopted by the States in their metropolitan zones had to be absorbed in "buffer zones" in order to prevent abrupt datum changes at the edge of the metropolitan zones.

6.7.4 A "buffer zone" is the area, extending from the edge of the metropolitan zone generally to the next primary junction point, in which differences between State heights of "terminal bench marks" and NLA heights assigned to primary bench marks was distributed. The greater the distance between the metropolitan zone and the outer edge of the buffer zone the smaller the corrections between individual bench marks in the buffer zone. The adjustment of the levelling within the buffer zone will be undertaken by the Division of National Mapping.

6.7.5 "Terminal Bench Marks" are those marks at the edge of the metropolitan zone where level traverses passed from the metropolitan zone into the buffer zone. Heights of these marks were assigned by the States.

7. SOME ASPECTS OF OBSERVED AND ADJUSTED DATA

7.1 Two Way levelling

7.1.1 The figure on page 55 shows a plot of the accumulated discrepancy between forward and backward runs of two-way levelling, against the distance. This section shows a large systematic error in the levelling which, although no thorough analysis of all two-way levelling has yet been carried out, does seem to be quite common. There are various reasons for this but probably the main cause is the systematic compensation error in automatic levels.

7.1.2 National Mapping lays down in its specifications for third order levelling that a strict procedure in levelling with automatic levels must be adhered to; i.e. if two staves are being used then the instrument must be levelled with the telescope pointing towards the same staff at all times. Also, after the instrument has been levelled, and prior to every reading, the telescope is turned slightly in one direction and then the other.

7.1.3 Many contract surveyors, brought up on spirit levels and for the first time using automatic levels, are believed to have ignored these instructions with the result that sections of one way levelling tend to suffer from this systematic error. Of course if both the forward and backward runs of two way levelling were levelled under the same conditions and in the same manner then the mean would be correct but there is an indication that less care is taken with the backward run than the forward run and where this has happened then a systematic accumulation of error occurs.

7.2 Loop closes

7.2.1 All of the 261 loops, formed by the 757 primary sections, in the adjustment were closed in a clockwise direction using orthometrically corrected levelling. The rejection criteria for the loop closure figure i.e. $D/\sqrt{M}$, was 0.050 feet $/\sqrt{\text{mile}}$. Where this figure was exceeded, re-levelling over suspect parts of the section was carried out until the loop closed. However in some instances, due to lack of time for complete re-levelling, the offending section was rejected from the primary net and included in the supplementary net.

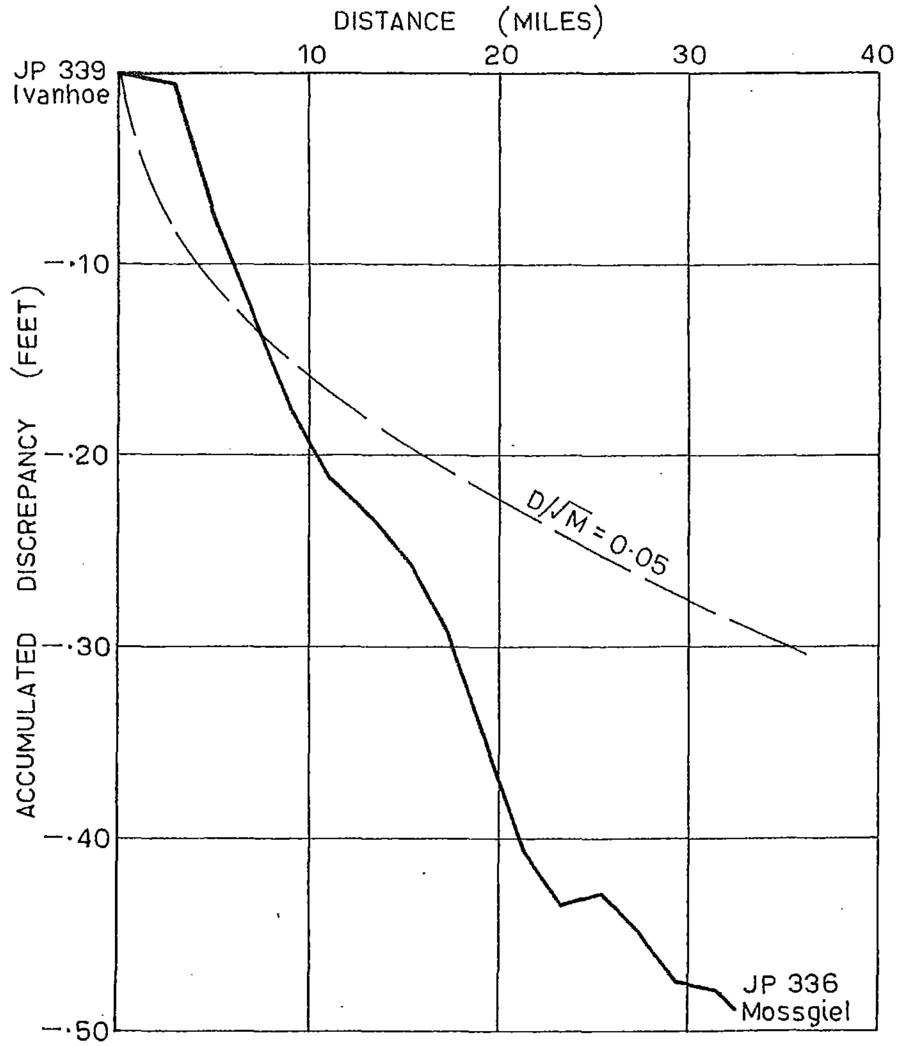
7.2.2 The largest closure was +1.494 feet in a loop of circumference 1055.2 miles ($D/\sqrt{M} = 0.046$).

7.2.3 There were 12 loops with a circumference in excess of 1000 miles, the largest being 1897.9 miles.

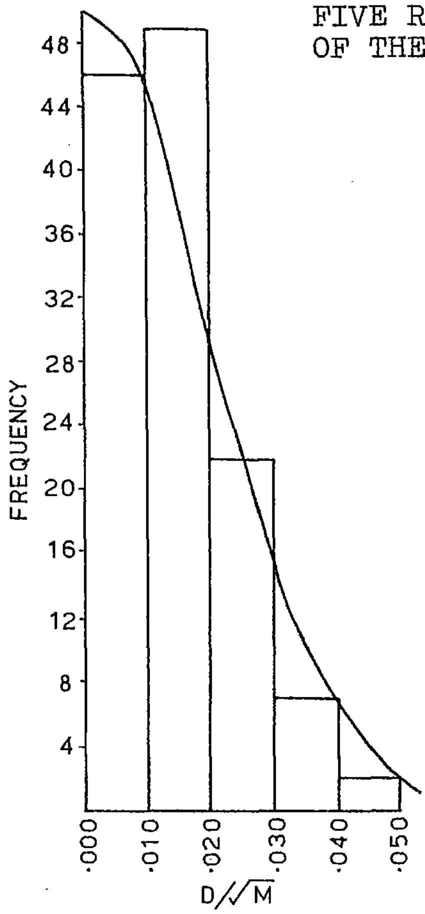
7.2.4 The smallest loop circumference was 47.2 miles.

7.2.5 The mean loop closure was $D/\sqrt{M} = 0.024$ (see Annex B).

A PLOT OF THE ACCUMULATED DISCREPANCY (IN FEET) BETWEEN THE FORWARD AND BACKWARD RUNS OF TWO-WAY LEVELLING AGAINST THE DISTANCE (IN MILES). THE CURVE FOR A DISCREPANCY OF 0.050 $\sqrt{M}$ WHERE M IS IN MILES IS ALSO PLOTTED.

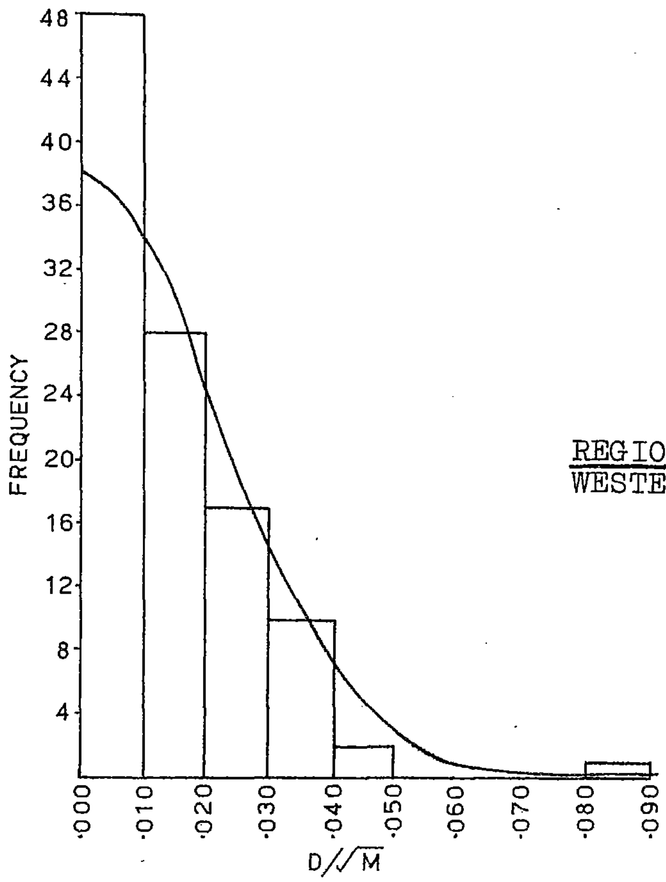


HISTOGRAMS AND NORMAL DISTRIBUTION CURVES OF THE AMOUNT OF ADJUSTMENT (D) IN FEET DIVIDED BY THE SQUARE ROOT OF THE LENGTH (M) IN MILES OF ALL ADJUSTED SECTIONS IN EACH OF THE FIVE REGIONS AT THE LEVELONE STAGE OF THE ADJUSTMENT.



REGION ONE
SOUTH AUSTRALIA AND NORTHERN TERRITORY

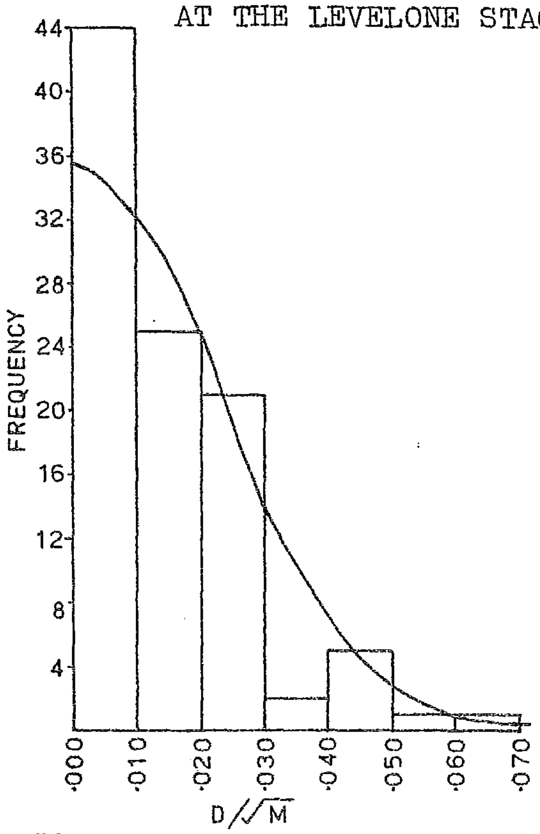
ADJUSTED SECTIONS	126
UNADJUSTED SECTIONS	21
	147
MEAN ADJUSTMENT	0.014
STD. DEVIATION	0.023



REGION TWO
WESTERN AUSTRALIA

ADJUSTED SECTIONS	106
UNADJUSTED SECTIONS	25
	131
MEAN ADJUSTMENT	0.015
STD. DEVIATION	0.025

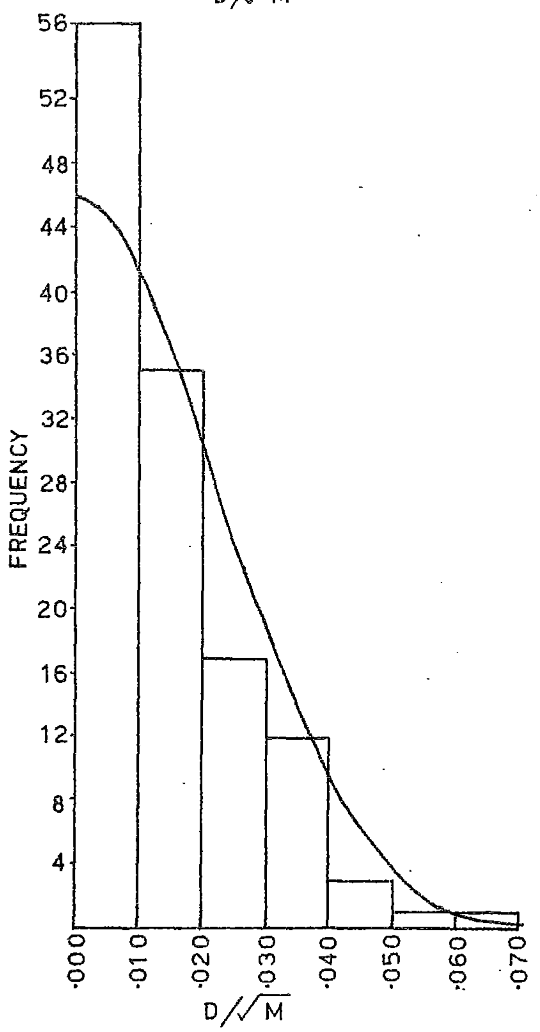
HISTOGRAMS AND NORMAL DISTRIBUTION CURVES OF THE AMOUNT OF ADJUSTMENT (D) IN FEET DIVIDED BY THE SQUARE ROOT OF THE LENGTH (M) IN MILES OF ALL ADJUSTED SECTIONS IN EACH OF THE FIVE REGIONS AT THE LEVELONE STAGE OF THE ADJUSTMENT.



REGION THREE
QUEENSLAND

ADJUSTED SECTIONS	99
UNADJUSTED SECTIONS	26
	125

MEAN ADJUSTMENT	0.015
STD. DEVIATION	0.025

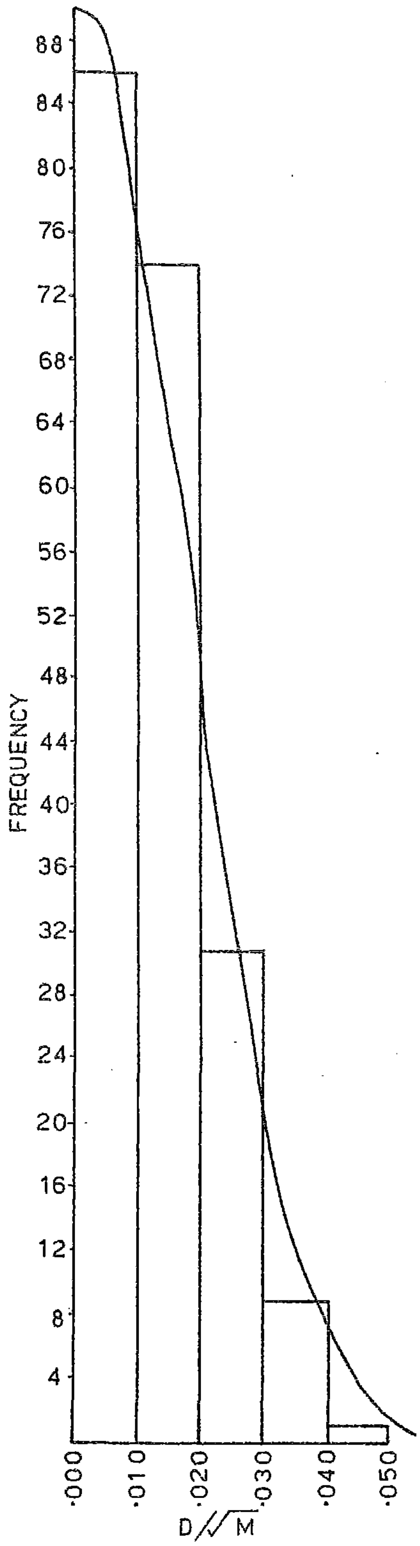


REGION FOUR
NEW SOUTH WALES

ADJUSTED SECTIONS	126
UNADJUSTED SECTIONS	19
	145

MEAN ADJUSTMENT	0.014
STD. DEVIATION	0.024

HISTOGRAMS AND NORMAL DISTRIBUTION CURVES OF THE AMOUNT OF ADJUSTMENT (D) IN FEET DIVIDED BY THE SQUARE ROOT OF THE LENGTH (M) IN MILES OF ALL ADJUSTED SECTIONS IN EACH OF THE FIVE REGIONS AT THE LEVELONE STAGE OF THE ADJUSTMENT.



REGION FIVE
VICTORIA

ADJUSTED SECTIONS	201
UNADJUSTED SECTIONS	8
	209
MEAN ADJUSTMENT	0.013
STD. DEVIATION	0.020

7.3 LEVELONE adjustment

7.3.1 The histograms on pages 56 to 58 show the amount of adjustment (D) divided by the square root of the length of the section. They give a general idea of the amount of adjustment given to sections by LEVELONE. It does fall down in certain instances, e.g. with two adjacent loops which close with a D M of say 0.050, but with opposite sign, then most of the adjustment will be forced into the common section and if the line is short then the D M figure will be large. This is noticeable in the histogram for region 2.

7.4 The effect of the fixed adjustment

7.4.1 ANNEX C is a graph of the "heights" of sea level at the 30 tide gauge stations around Australia which were computed by the free LEVEL 2 adjustment.

7.4.2 The prominent slope up the Queensland coast from Brisbane to Cooktown is confirmed by not only the coastal levelling (+4.583 ft) but also an inland levelling route (+4.199 ft). This check cannot be carried out from Cooktown to Bamaga as the levelling follows a spur line but the gradient is consistent with that from Brisbane to Cooktown.

7.4.3 A summary of the levelling along the coastal and inland route is:

HEIGHTS OF MEAN SEA LEVEL

	Inland route (feet)	Coastal route (feet)
MSL Brisbane	0.000	0.000
MSL Bundaberg	+ 0.607	+ 0.669
MSL Mackay	+ 2.127	+ 2.192
MSL Townsville	+ 2.078	+ 2.989
MSL Cairns	+ 3.483	+ 3.074
MSL Cooktown	+ 4.199	+ 4.583

7.4.4 ANNEX D is a contoured plot of the differences between the free and the fixed heights of every primary junction point in Australia and shows the strain put on the mathematical model of the land based levelling by the fixed adjustment.

7.4.5 ANNEX E is another representation of ANNEX C. An ellipse, centered on the Johnston Origin and roughly following the outline of Australia was chosen to represent the zero contour around the coast as computed from the fixed LEVEL 2 adjustment. Lines were drawn, radiating from the origin, towards each tide gauge but stopped where they met the zero contour. From this point on the ellipse, perpendiculars were drawn at a scale of 1 mm to 0.2 ft representing the free adjustment heights of mean sea level, at each tide gauge. When the ends of these lines were joined an outline depicting the prominent coastline features was apparent.

8. COMPUTER PROGRAMS - INTRODUCTION

8.1 General outline of program system

The raw data supplied by various agencies throughout Australia had to be checked, summarised and updated to a manageable form for entry into the actual adjustment programs.

8.1.1 The most important data preparation program is ORTHO 1, which, among other things, punches out the final input data deck for the Phase I adjustment program LEVELONE.

8.1.2 Program LEVELONE makes a least squares adjustment by observation equations of height differences in a network with one fixed origin.

The output produced by this program consists of adjusted differences in elevation between the variable points in a network and its origin, as well as a full variance-covariance matrix which is buffered out on magnetic tape in binary mode, odd parity.

In this system the observed and orthometrically corrected height differences between consecutive junction points in the first phase of the adjustment are in effect replaced by adjusted differences in elevation between the origin of the network and all junction points within this net.

The network of traverses of "derived observations" for the Phase II adjustment therefore consists of lines diverging from the various regional Phase I origins.

8.1.3 The second phase of the adjustment is executed by program LEVEL 2.

It adjusts by condition equations, where the conditions provide a link between the Phase I origins of the individual LEVELONE networks to bring the latter onto a common, continental datum. This is the case in the "free" continental adjustment.

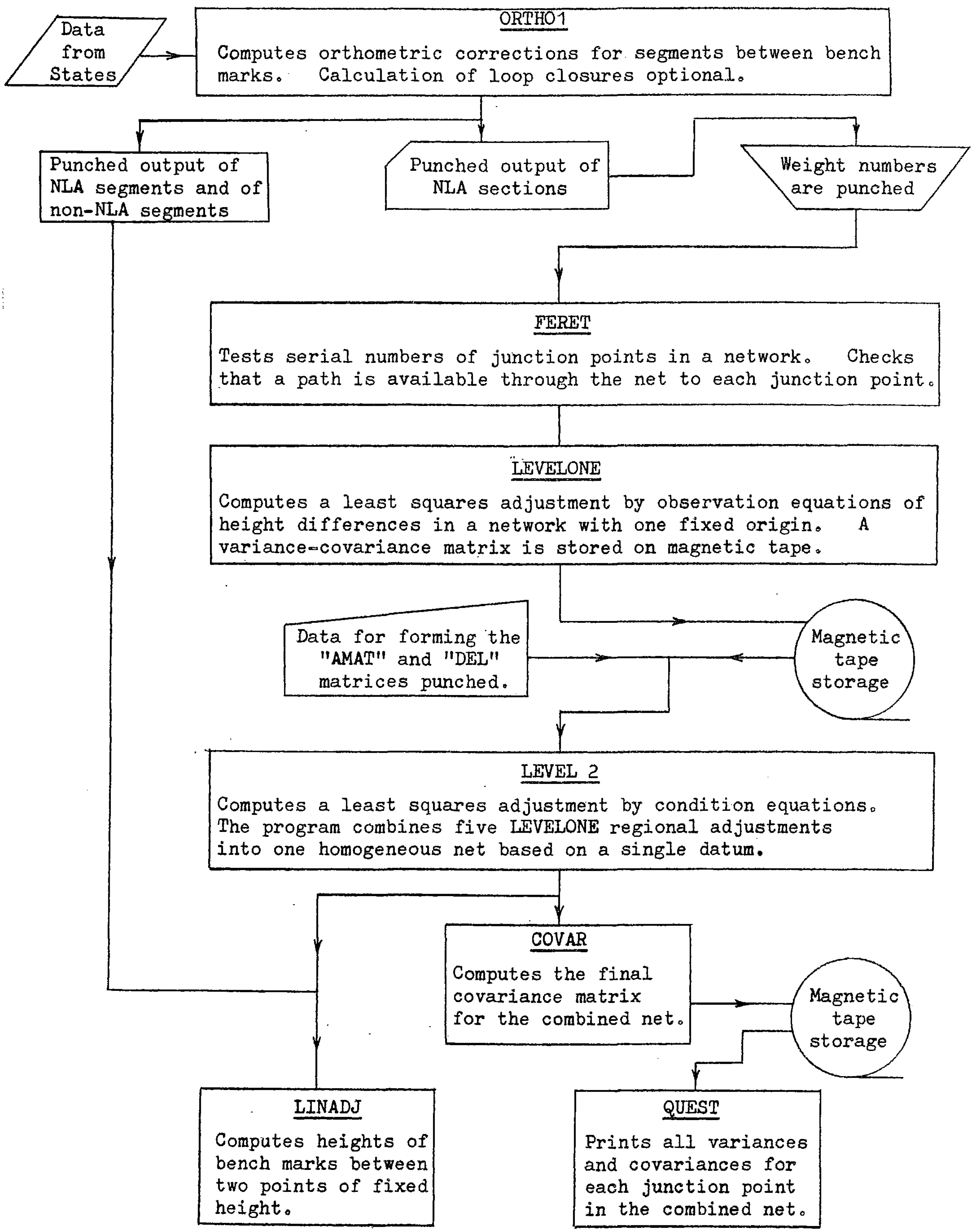
For the "fixed" continental adjustment additional conditions between tide gauges are introduced, so as to force the entire levelling net to a perimeter held sea level surface, thus warping the network and establishing a height for the Johnston Station based on this external datum, the Australian Height Datum.

For both "free" and "fixed" adjustments, full variance-covariance matrices of the individual Phase I adjustments are read in. The resulting Phase II adjustment is therefore completely rigorous. Output of LEVEL 2 together with LEVELONE covariance matrices on magnetic tape is input for program COVAR.

8.1.4 Program COVAR computes the final variance-covariance matrix for the national net, and outputs this matrix on magnetic tape.

8.1.5 All intermediate bench marks along primary levelling traverses, as well as bench marks along supplementary traverses can be brought onto the Australian Height Datum by a simple interpolation program LINADJ.

8.2 System design for the National Levelling Adjustment (NLA)



8.3 Advantages of the program system

The main advantage resulting from this design is that an orderly, well indexed system of data preparation can be initiated, where each step in the data preparation is checked and analysed efficiently before the next step is attempted.

Errors can therefore be discovered at an early stage of data processing.

To take full advantage of the system, a base map with various overlays and progress diagrams, which are updated as each step is completed, are essential attributes.

A full description can be found in paragraph 6.1 of this report.

8.4 Adjustment in phases and weighting

The principles of phased adjustment are well known.

Any adjustment can be done by phases rigorously, as long as in the various consecutive phases fully correlated observations are used.

The initial observations entered into LEVELONE, however, are taken to be uncorrelated. This is a valid assumption.

The difference in elevation as measured between points A and B (d_{AB}) can be considered independent from an observed height difference between B and C (d_{BC}). If d_{AB} is measured to a higher standard of accuracy than d_{BC}, and the distances from A to B and B to C are equal in length a higher weight is assigned to d_{AB}.

To achieve this, a weighting system was introduced where the weight of the observed height difference over a section is a function of a weight number (1 for third order sections, and 9 for first order, with variations within the range) and the distance between the end points of the section, thus,

$$\text{weight} = \text{weight number/distance.}$$

As no correlation exists between observations the weight matrix is diagonal and in the program replaced by a column vector.

8.5 Data and basic formulae in phased adjustment

8.5.1 Phase I

The data deck consists of a card which contains the origin name and its adopted, preliminary height, then the KLS-card with the number of observations K, the number of variable points L and the square root of an estimator of the variance factor S, followed by all observation cards. The deck is completed with an information card on which the name of the region, the origin, its height and the name of the local datum appear.

The observation cards contain the serial numbers of bench marks between which the difference in elevation is observed, the distance along the levelling traverse connecting these bench marks, the orthometrically corrected height difference. All this information is automatically punched on the cards by ORTHO1. A weight number is added later.

.1 Main formulae in matrix notation

Observations	$\underline{O}_I$
Weights	G
Observation equations	$A\underline{d}=\underline{O}_I+\underline{V}_I$
Normal equations	$A^T GA\underline{d}=A^T G\underline{O}_I$
Solution	$\underline{d}=(A^T GA)^{-1}A^T G\underline{O}_I$
A minimum	$\underline{O}_I{}^T G\underline{O}_I-A^T G\underline{O}_I\underline{d}$

8.5.2 Phase II

The input consists of Phase I adjusted differences in elevation between benchmarks in the various networks and their respective origins, covariance matrices as output from all Phase I adjustments, punch card information to form the condition equations and DEL matrix information to relate all bench marks in the combined network to the same origin.

.1 Main formulae

Observations (derived)

$$\underline{O}_{II}=\begin{pmatrix} \underline{O}_{II} \text{ region } 1 \\ \underline{O}_{II} \text{ region } 2 \\ \cdot \\ \cdot \\ \underline{O}_{II} \text{ region } 5 \end{pmatrix}$$

Weight co-efficient matrix of the derived quantities

$$B=\begin{pmatrix} B_{\text{region }1} & 0 & 0 & 0 & 0 \\ & B_{\text{region }2} & 0 & 0 & 0 \\ & & B_{\text{region }3} & 0 & 0 \\ & & & B_{\text{region }4} & 0 \\ & & & & B_{\text{region }5} \end{pmatrix}$$

Condition equations	$C(\underline{O}_{II}+\underline{v}_{II})=0$
Normal equations	$CBC^T\underline{AK}=-C\underline{O}_{II}=-\underline{AD}$
Correlates	$\underline{AK}=-(CBC^T)^{-1}\underline{AD}$
Solution (Phase II correction)	$\underline{v}_{II}=BC^T\underline{AK}$
A minimum	$\underline{AK}^T\underline{AD}$ multiplied by the variance factor
Covariance matrix	$DEL\ B\ DEL^T-DEL\ B\ C^T(CBC^T)^{-1}C\ B\ DEL^T$

8.6 The computer and its peripherals

The original programs were written for a Control Data Corporation 3600 computer. Program LINADJ and a LEVELONE version were converted for use on a CDC 6600.

The effective high speed store of the CDC 3600 can contain about 22,000 words, each of 10 floating point decimal digits.

Peripheral equipment used by the various programs consisted of a card reader, a card punch, five magnetic tape units, a line printer, while as backing store either drums or discs were employed.

9. COMPUTER PROGRAMS - INDIVIDUAL PROGRAMS

9.1 Program ORTHO1

9.1.1 Purpose

ORTHO1 computes the orthometric corrections to be applied to adopted means of differences in elevation between consecutive bench marks in a levelling traverse.

9.1.2 Formula

The orthometric correction is computed from a formula as given by Rapp:

$OC = (AH + BH^2 + CH^3)\,d\phi$, where

OC = orthometric correction over a section (feet)

H = mean height of the two end points of a section (feet)

$d\phi$ = difference in latitude of the end points (minutes of arc)

A, B and C are coefficients varying with latitude.

The terms used in calculating the A, B and C coefficients are based on the Geodetic Reference System 1967.

The C-term was considered to be negligible under Australian conditions and the formula adopted in ORTHO1 was therefore reduced to $OC = (AH + BH^2)\,d\phi$.

In this formula:

$$A = 2 \sin 2\phi\, \alpha' \left(1 + \cos 2\phi \left(\alpha' - \frac{2K}{\alpha'} - 3K \cos^2 2\phi\right)\right) Q, \text{ and}$$

$$B = 2 \sin 2\phi\, \alpha' t_2 \left(t_3 + \frac{t_4}{2\alpha'} + \cos 2\phi \left(\frac{3}{2} t_4 + 2\alpha' t_3 - \frac{2Kt_3}{\alpha'}\right)\right) Q,$$

where ϕ is the mid-latitude of the two terminals of a section

$$\alpha' = \frac{\beta}{2+\beta+2\varepsilon}$$

$$K = \frac{-2\varepsilon}{2+\beta+2\varepsilon}$$

$$t_2 = \frac{2(1+\alpha+c')}{a(1+\frac{\beta}{2}+\varepsilon)}$$

$$t_3 = 1 - \frac{(3\alpha-2.5c')}{2}$$

$$t_4 = 1 - t_3$$

β and ε are the gravity formula constants

α is the spheroid flattening

$c' = \omega^2 a^3/k^2 M$

ω is the angular velocity of the earth's rotation

a is the equatorial radius of the reference spheroid

k^2 is the gravitational constant

M is the mass of the earth

Q is the value of 1 minute of arc in radians

9.1.3 Options

There are two options written into the program:

Option a

Corrections for a loop closure and the loop closure coefficient are computed. This option is used to check levelling and to detect errors outside acceptable limits. If the loop closure coefficient is less than 0.05, the sections in the loop are accepted; if the loop closure coefficient is larger than 0.05, each section in the loop is investigated and, after being corrected, re-run with Option a.

Option b

Corrections are computed for an unlimited number of sections and a punched card output is produced, containing information which is an accumulation of data of State sections into so-called national sections. This data deck is input for program LEVELONE. At the same time the program produces punched card output for all individual State sections.

The latter data deck will be processed by LINADJ to interpolate heights on the AHD of all bench marks which are not junction points in the national adjustment.

With both options a listing of observed and corrected data is produced.

9.2 Program FERET

FERET makes several checks on the data which has been assembled from the output of ORTHO1, Option b, for input into LEVELONE:

.1 FERET checks that the origin bench mark number is not 0;
.2 " " " no bench mark serial number is 0;
.3 " " " the origin number only appears on the first card in the second serial number column (BMB) and that all bench mark serial numbers used appear at least once in the BMB column;
.4 " " " a continuous path to each junction point is available.

9.3 Program LEVELONE

The standard program consists of a main program and four overlays.

Two versions of the program are in use for the geoid adjustment and the adjustment of trigonometrically determined height differences, called DETERGEN and TRIGHT respectively.

9.3.1 Main - LEVMAIN

The main program reads in two cards, the first card with information regarding the origin station, the second card containing the number of observations and variables.

The most important function of the main program is to call the various overlays into the high speed store as independent programs.

9.3.2 Overlay 1 - FORMAW

All observation cards are read in, serial numbers and their related observations are sorted, the observation equation coefficients matrix is formed internally and part of the normal equations is formed through sub-matrices.

All matrices formed from the data read off the observation cards as well as the intermediate computed matrices are stored on three random access drums with continual addressing. These matrices are returned to the high speed store in following overlays.

.1 Matrix formation and calculation

Observations (absolute terms) TREAL = -TORTHO

Weights GVECTR

No correlation exists between observations, therefore GVECTR is a diagonal matrix, which is replaced by a column matrix in the calculations.

Observation coefficients matrix AREAL

The matrix is formed internally through the serial numbering system.

Parameters ADJMEAN

Least squares corrections to the observations TREAL as defined v

Observation equations AREAL.ADJMEAN+TREAL=v

Formation of normal equations $AREAL^T.GVECTR.AREAL.ADJMEAN+AREAL^T.GVECTR.TREAL=0$

The second term is computed by submatrices of $AREAL^T$, GVECTR and TREAL in two stages, and stored on drum as AGT.

The second term of a minimum is calculated in a similar manner from $\underline{\text{TREAL}}^T$, GVECTR and $\underline{\text{TREAL}}$.

An intermediate matrix WREAL is stored on drum and used in overlay 2 to compute the first term of the normal equations:

$$\text{WREAL}=\text{AREAL}^T.\text{GVECTR}$$

and is formed through sub-matrices.

9.3.3 Overlay 2 - VARCOV

Part of the first term of the normal equations is computed from the matrices AREAL and WREAL in full. Although these matrices were computed in FORMAW in the form of sub-matrices, by taking advantage of the continuous addressing system, both are called from drum as full matrices. This requires only two transfers.

$$\text{QREAL}=\text{WREAL}.\text{AREAL}$$

QREAL is subsequently inverted by the subroutine OURINV, a pivoting inversion routine, which is a modified version of the CSIRO designed MATINV.

The equivalenced QREAL is not transferred to drum but kept in the high speed store common block and used in overlay 3.

9.3.4 Overlay 3 - DIFFHT

The solution of the normal equations is computed from the inverted QREAL of the previous overlay and $\underline{\text{AGT}}$ as determined in overlay 1, thus

$$\underline{\text{ADJMEAN}}=-\text{QREAL}.\underline{\text{AGT}}$$

For a basic statistical test a minimum is computed:

$$\text{AM}=(\text{AREAL}^T.\text{GVECTR}.\underline{\text{TREAL}})^T.\underline{\text{ADJMEAN}}+\underline{\text{TREAL}}^T.\text{GVECTR}.\underline{\text{TREAL}}$$

or $$\text{AM}=(\text{AGT}^T.\underline{\text{ADJMEAN}})+\text{TGT}$$

The matrix QREAL is multiplied by a factor SSQ which is the variance factor, the square of the figure entered on the second card of the data deck, the so-called KLS card (8.5.1).

In the national adjustment S = 0.03 feet.mile$^{1/2}$

An estimate SBARSQ for the variance factor SSQ was obtained by dividing AM by the number of redundancies AKL = K-L.

The matrix QREAL, after multiplication by SSQ, is buffered out on magnetic tape to form part of the data input for LEVEL 2 and COVAR.

The printed output of this overlay consists of (optionally) an estimate of the variance-covariance matrix as buffered out on magnetic tape, AM, SBARSQ and TEST (=SBARSQ/SSQ) which can be used in a simple F-distribution test:

$$TEST \leq F_{(1-a;r_1,r_2)}$$

where a is the confidence interval and r_1 and r_2 are the degrees of freedom to determine SBARSQ and SSQ respectively; r_2 is assumed to approach infinity.

After the height of all bench marks are computed in relation to the adopted origin height, a list of the serial numbers of bench marks, their adjusted heights and the standard deviations in relation to the origin are also printed out.

The standard deviations are computed as the square roots of the main diagonal term elements of the final QREAL.

9.3.5 Overlay 4 - FINOUT

Most data stored in overlay 1 is now called off the drums for the complete print-out of sections after adjustment. Several column matrices are computed which are required for the final listing.

The last operation completed by the program is the punching of adjusted differences in elevation between all junction points and the origin of the network, which output at a later stage is used as input for LEVEL 2.

9.4 Program LEVEL 2

The program equips five magnetic tapes of input and three random access drums.

It consists of a main program and eighteen overlays.

9.4.1 Main - TWOMAIN

The main program reads in one card containing KA, L, LA, S, KAV, KAS, KAW, KAQ, KAN, LL and LLL, where

L is the total number of condition equations in Phase II,
KA=KAV+KAS+KAW+KAQ+KAN,

KAV is the total number of variable	points in	Phase I of	region	1
KAS	"	"	"	2
KAW	"	"	"	3
KAQ	"	"	"	4
KAN	"	"	"	5

LA=KA-L, if L is the number of conditions between the Phase I origins only, ie, as in a free adjustment based on one origin.
If $L \leq 33$, LL=L and LLL=0.
If $L > 33$, LL=33 and LLL=L-33.

This was introduced to accommodate sub-matrices in overlay 1 stepwise, necessary due to limited core storage.

TWOMAIN calls the various overlays when required.

.1 Matrix formation

The weight coefficient matrix is built up from co-variance matrices from the five Phase I adjustments. In Phase II these matrices are sub-matrices along the main diagonal of the weight coefficient matrix, thus

$$CM = \begin{pmatrix} QREAL_1 & 0 & 0 & 0 & 0 \\ 0 & QREAL_2 & 0 & 0 & 0 \\ 0 & 0 & QREAL_3 & 0 & 0 \\ 0 & 0 & 0 & QREAL_4 & 0 \\ 0 & 0 & 0 & 0 & QREAL_5 \end{pmatrix}$$

The condition equations have the following form:

$$AMAT.\ (\underline{ADJ}+\underline{corr}) = 0,$$

where AMAT is the condition equation coefficients matrix which is formed internally in the same way as AREAL was set up in LEVELONE. ADJ is the vector matrix of all "derived" observations in all five Phase I nets.

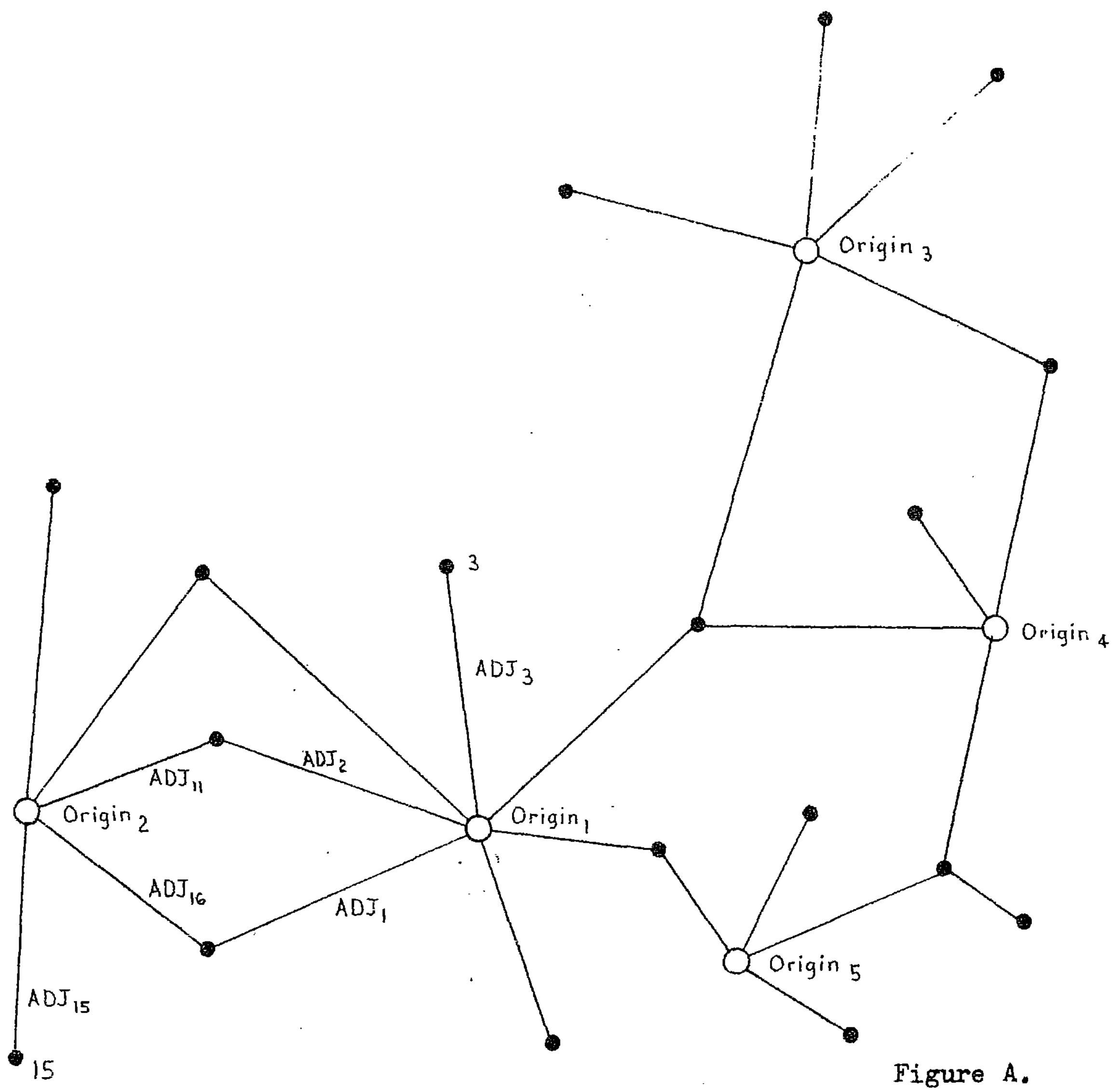


Figure A.

Two types of conditions were used in the national adjustment:

a. between Phase I origins (in both the free and the fixed adjustment)

b. between tide gauges (fixed adjustment only)

Both are zero conditions as conditions a. are closed loop conditions and conditions b. relate "derived" observations to the adopted sea level surface.

The conditions can be written as:

$$-AMAT.\underline{corr} = +AMAT.\underline{ADJ} = \underline{AD}$$

Normal equations $AMAT.CM.AMAT^T\underline{AK} = -\underline{AD}$

Temporary matrix $TA=AMAT.CM$

Before inversion $AN=TA.AMAT^T$

All matrices are computed in several overlays as sub-matrices.

AN is inverted: $AN=AN^{-1}$

The correlate equations are now of the simple form:

$$\underline{AK}=-AN.\underline{AD}$$

A temporary matrix TB is computed in five overlays as sub-matrices:

$$TB=CM.AMAT^T$$

Correction equations $\underline{V}=TB.\underline{AK}$ in five parts

$$\underline{ADD}=\underline{ADJ}+\underline{V}$$

The final heights of all junction points are to be computed in relation to the national origin.

In Figure A, $origin_1$ is taken as the national origin. The adjusted height differences of bench marks 3 and 15 in relation to $origin_1$ can be found from simple equations:

$$q_3=(adj_3+v_3)$$

$$q_{15}=(adj_2+v_2)-(adj_{11}+v_{11})+(adj_{15}+v_{15})$$

The coefficients matrix DEL of this equation system is formed internally row by row from data cards formatted similar to the data to set up AREAL and AMAT matrices.

In matrix notation the equation system takes the form:

$$\underline{Q}=DEL.(\underline{ADJ}+\underline{V}),$$

or when final heights in relation to the national origin are computed:

$$\underline{P}=DEL.\underline{ADD}+\text{adopted height of origin}_1.$$

9.4.2 Overlay 1 - COMPAD

The condition equation coefficients matrix is formed as five sub-matrices and stored on drum.

ADJ is read in and AD is computed in one or two parts depending on the size of L, the number of conditions, as explained under 9.4.1.

9.4.3 Overlays 2-6, TATEMP-TATNSW

The temporary matrix TA is computed consisting of five sub-matrices from Phase I co-variance matrices which are buffered in from magnetic tape and the COMPAD formed matrix AMAT.

9.4.4 Overlays 7-11, FORMANVI-FORMANNS

The matrix AN, which inverse is part of the correlate equation, is computed stepwise in these five overlays.

In overlay 11, FORMANNS, the final AN is inverted by subroutine OURINV also used in LEVELONE, paragraph 9.3.3.

Correlates AK are computed and a Phase II minimum calculated

$SSQ.\underline{AK}^T.\underline{AD}$.

9.4.5 Overlays 12-16, TEMPBMAT-TEMPBNST

The temporary matrix TB is computed similar to TA, paragraph 9.4.3.

9.4.6 Overlay 17 - VVIC

Three sections of the column matrix V are computed only, due to lack of space in the high speed store.

9.4.7 Overlay 18 - VNSW

The remaining two sections of V are calculated, and ADD is formed.

DEL is set up row by row and Q is computed in this manner.

The final heights are calculated and are printed out under a heading.

9.4.8 Backing storage

In all overlays extensive use is made of drums as random access backing stores.

The major advantage of using drum random access is the continuous addressing system available. Although some matrices are built up from sub-matrices formed in separate overlays, in subsequent overlays the full matrix can be called off the respective drums. The sub-matrices can be stored without gaps in the record and as long as the common block dimension in the overlay in question is correct, the entire matrix can be called off the drum as one record.

No use was made of variable dimensions, the program having been written for a specific set of data.

9.5 Program COVAR

A program was written to compute the final covariance matrix for the combined network based on the formula in paragraph 8.5.2.

The program has eleven overlays and uses disc backing store. Numerous disc transfers are required due to the extremely large matrices involved. The final matrix is stored on magnetic tape which is interrogated and edited by a small program QUEST.

The results are easy to interpret for a free adjustment based on a single origin, however, when introducing the set of zero conditions between the tide gauges in the fixed adjustment, the interpretation is more complicated.

One of the tide gauges - Port Macdonnell in South Australia - was adopted as the origin of the fixed adjustment with a height of 0.00 feet.

The variances in the COVAR-produced matrix are in relation to the Port Macdonnell tide gauge zero and not to the mean sea level datum around Australia.

Values indicating the relative precision for all adjusted points in the network can be computed but they are not required. The main interest lies in determining standard deviations of a number of points in central Australia in relation to the external datum.

As program COVAR runs for more than five hours on the CDC 3600 and the resulting variances are ambiguous for the fixed adjustment case, it was decided to estimate the required standard deviations from available Phase I covariance matrices, the Phase I and II estimate of S^2 and the scaled-off distances to the coast.

9.6 Program LINADJ

The program computes heights of points between two fixed stations by linear interpolation.

The output consists of a listing of all input and interpolation data for each section, and a separate listing of interpolated heights for all points in the levelling traverse between the two fixed terminal stations.

The program stores all information for the print-out on an outfile, and one copy of output is produced for checking purposes. If all information is certified to be free of errors, multiple copies are run off-line.

The interpolation formula used is of the form A. Dist/D

where A is the misclose of the fixed difference in height between the terminal stations and the levelled difference in elevation,

Dist is the distance between consecutive bench marks,

and D is the total distance along the levelling traverse between the two terminals.

10. ACCURACY; PRECISION AND STATISTICAL TESTS

10.1 General

Apart from some first order levelling in eastern New South Wales, parts of Victoria and south and east of Perth in Western Australia, most of the levelling in the network was observed to third order standard.

The instruments used by the various observing authorities throughout Australia were mainly of the automatic type. The most popular of these levels were the Hilger and Watts Autoset, the Zeiss Ni2 and the Jena Koni 007.

The accuracy of each State network can reasonably be assumed to be homogeneous, but there are significant differences in precision which are shown by a number of statistical tests when comparing the several Phase I and Phase II adjustments.

10.2 Weights and variance factor

After investigating sections of first, second and third order levelling, a ratio of the estimated variances per mile of levelling was adopted, $^1/r_1 : {}^1/r_2 : {}^1/r_3 = 9:2:1$.

The weight formula is $g_k = S^2/D_{r_k}$ for k = 1, 3

or $g_1 = 9S^2/D$ for first order levelling,

$g_2 = 2S^2/D$ for second order levelling and

$g_3 = S^2/D$ for third order levelling,

where S^2 is the variance factor and D is the distance along the levelled section.

A value of 0.0009 was adopted for S^2, after studying the available estimated variances per mile of levelling and the distribution of the network.

10.3 Tests

The minima in Tables 4 and 6 are calculated by the formulae given in paragraphs 8.5.1 and 8.5.2.

$\bar{S}^2$ is an unbiased estimator of S^2 and is calculated from the minimum and the degrees of freedom in an adjustment.

$F_{b,\infty}$ has a known probability distribution, the F-distribution, of which the expectation is 1. If model or systematic errors occur, the expectation of $\bar{S}^2$ is greater than S^2, and therefore $\bar{S}^2$ is generally larger than S^2. Victoria with $\bar{S}^2/S^2 = 0.94$ is the only exception.

A one-sided 5% critical region was adopted for the initial tests. The critical region contains all F-values greater than the critical value of $F_{0.95;b,\infty}$.

A danger with a so-called one-sided test is that, if $F_{b,\infty} > F_{0.95;b,\infty}$ as in New South Wales, one is inclined to reject the hypothesis of non-occurence of model errors. If the variance per mile of levelling is calculated too low, ie, an over-estimation of accuracy and precision in a State network, $\bar{S}^2$ will be too high. The testing on model errors may in that case be made difficult because of the adoption of an inaccurate estimation of the variance for the State in question.

Tables II and IV were drawn up to investigate the matter more closely, using a two-sided test, with a 2½% critical region at both tail ends of the F-distribution.

$\bar{S}_1^2$ is an estimate of S^2 in network 1 and $\bar{S}_2^2$ an independent estimate of the same S^2 from network 2.

By always using the highest $\bar{S}^2$ in the numerator, a one-sided test can be used with a 2½% critical region on the right hand side only,

$$F_{b_1,b_2} = \bar{S}_1^2/\bar{S}_2^2, \text{ if } \bar{S}_1^2 > \bar{S}_2^2$$

A nomogram is available to determine $F_{0.975;b_1,b_2}$,

where b_1 and b_2 are the degrees of freedom in network 1 and 2 respectively.

The results computed for the "two-sided" tests are listed in Tables II and IV.

The tests fail when comparing NSW with SA-NT and NSW with VIC, probably due to the fact that the estimate of the variance for the NSW net is too optimistic and the estimates of the variances for SA-NT and VIC are too pessimistic.

10.4 Conclusion

10.4.1 Free adjustment

To evaluate the precision of the results of the combined network adjustment $S^2=0.0009$ appears to be too small and an S^2 of 0.001256 has been used. This is equivalent to 0.0338 ft.mile^{½}. Although this will introduce a rather large safety margin for standard deviations in Victoria, it will still show slightly optimistic standard deviations for New South Wales. This appears a reasonable compromise.

10.4.2 Fixed adjustment

All tests but one fail when the Phase I nets are compared with the fixed Phase II.

Holding sea level - as revealed by the 30 tide gauges - fixed, appears to strain the levelling network.

Further investigations into several aspects of the mathematical model of tide gauge zeros need to be made in the future when more statistical data is available.

Combined and State Net Adjustments	Degrees of freedom or number of conditions b	"Minimum"	$\bar{s}^2$	s^2	$F_{b,\infty} = \frac{\bar{s}^2}{s^2}$	$F_{0.95;\ b,\infty}$
South Australia - Northern Territory	147-111= 36	0.033989	0.000944138	.0009	1.05	1.42
Western Australia	131- 96= 35	0.045837	0.001309640	.0009	1.46	1.43
Queensland	125- 93= 32	0.037674	0.001177311	.0009	1.31	1.45
New South Wales	145-101= 44	0.100342	0.002280495	.0009	2.53	1.38
Victoria	209-128= 81	0.068665	0.000847711	.0009	0.94	1.28
Total Phase I	228	0.286507	0.001257	.0009	1.40	1.22
Phase II (free adj.)	33	0.041265	0.001250	.0009	1.39	1.44
Mainland free adjustment	261	0.327772	0.001256	.0009	1.40	1.22

Table 5

Net 1 - Net 2	$\frac{\bar{s}_1^2}{\bar{s}_2^2} = F_{b_1,b_2}$	$F_{0.975;\ b_1,b_2}$	Net 1 - Net 2	$\frac{\bar{s}_1^2}{\bar{s}_2^2} = F_{b_1,b_2}$	$F_{0.975;\ b_1,b_2}$
NSW - WA	1.74	1.98	WA - II free	1.05	2.10
NSW - QLD	1.94	1.99	QLD - SANT	1.25	2.00
NSW - SANT	2.42	1.97	QLD - VIC	1.39	1.80
NSW - VIC	2.69	1.70	II free - QLD	1.07	2.00
NSW - II free	1.82	1.98	SANT - VIC	1.11	1.75
WA - QLD	1.11	2.00	II free - SANT	1.32	2.00
WA - SANT	1.39	2.00	II free - VIC	1.47	1.80
WA - VIC	1.55	1.80	I - II free	1.00	1.80

Table 6

Combined Net Adjustment	Degrees of freedom or number of conditions b	"Minimum"	$\bar{S}^2$	s^2	$F_{b,\infty} = \frac{\bar{S}^2}{s^2}$	$F_{0.95;\, b,\infty}$
Total Phase I	228	0.286507	0.001257	.0009	1.40	1.22
Phase II (fixed adj)	62	0.242761	0.003915	.0009	4.35	1.30
Mainland fixed adjustment	290	0.529268	0.001825	.0009	2.03	1.22

Table 7

Net 1 - Net 2	$\frac{\bar{S}_1^2}{\bar{S}_2^2} = F_{b_1,b_2}$	$F_{0.975;\, b_1,b_2}$
II fixed - NSW	1.72	1.80
II fixed - WA	2.99	1.88
II fixed - QLD	3.32	1.91
II fixed - SANT	4.15	1.87
II fixed - VIC	4.62	1.61
II fixed - I	3.11	1.52

11. CONCLUSION

11.1 The Australian Height Datum provides us with an accurate and homogeneous levelling system of great value for mapping, engineering and scientific purposes.

11.2 Some of the levelling was observed with automatic levels before any investigation of the systematic errors in these instruments had been carried out. Most of it was observed with wooden staves. Many miles of two-way levelling had the 'forward' and 'backward' runs observed in the same direction several years apart. Nevertheless, the estimated standard error of adjusted heights in the centre of Australia relative to sea level is only 1.1 feet. This accuracy is sufficient for all practical purposes.

11.3 Levelling has sometimes been regarded by surveyors as a task of less interest, requiring less skill, than some other forms of survey. The experience of the officers of the Division of National Mapping who were responsible for the supervision of contract levelling, the analysis of levelling results, and all the other aspects of the adjustment of the Australian Levelling Survey, is that the skill and perseverance needed by surveyors in the field to produce results acceptable for a national levelling survey of high accuracy, is often under-estimated.

REFERENCES

Campbell, W.D.: "A Mean Sea Level Datum for Australia", paper read before the Victorian Institution of Surveyors, April 1916.

Division of National Mappping: "Specifications for Contract Third Order Levelling", Department of National Development, Canberra, 1967.

Division of National Mapping: "Specifications for One Way, Foot-Metric, Contract, Third Order Levelling", Department of National Development, Canberra, March 1968.

Division of National Mapping: "The Use of Copper-Coated Steel Rods in the Construction of Deep Bench Marks", Department of National Development, Canberra, July, 1968.

Easton, A.: "The Frequency Response of Selected Australian Tide Gauges", Research Paper No 24, Horace Lamb Centre for Oceanographical Research, The Flinders University of South Australia, December 1968.

Easton, A.: "A Handbook of Selected Australian Tide Gauges", Survey Paper No 6, Horace Lamb Centre for Oceanographical Research, The Flinders University of South Australia, December 1968.

Easton, A., and R. Radok: "Tidal Program 1966 - 1968", Memorandum No 5, Horace Lamb Centre for Oceanographical Research, The Flinders University of South Australia, January 1970.

Leppert, K.: "Proceedures and Instruments for Third Order Levelling", paper read before the Institution of Surveyors, Australia, 8th Survey Congress, April 1965.

Leppert, K.: "The Levelling Survey of Australia", Report to the Fifth United Nations Regional Cartographic Conference for Asia and the Far East, Canberra, March 1967.

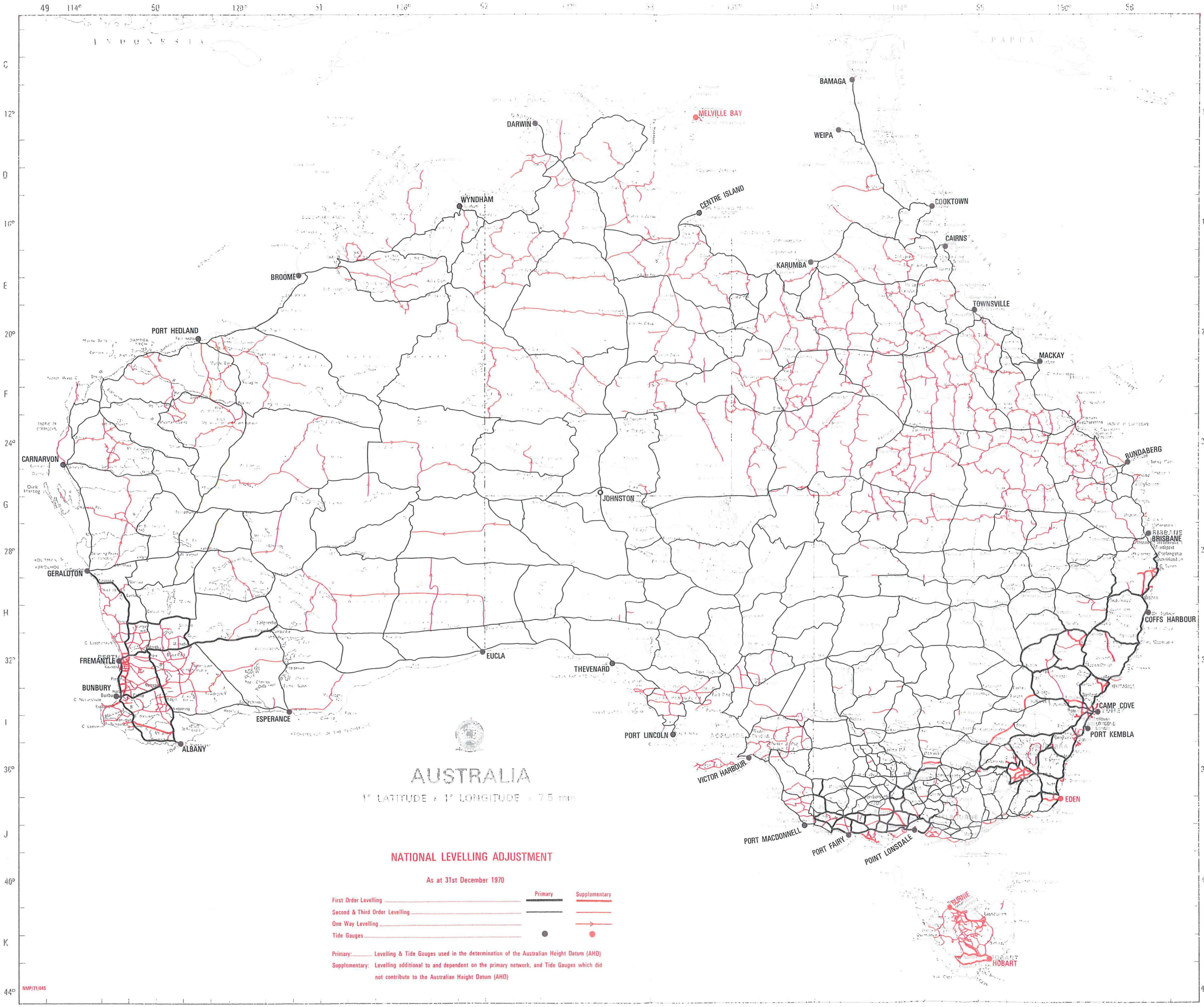
Marmer, H.A.: "Tidal Datum Planes", Special Publication No 135, United States Department of Commerce, Coast and Geodetic Survey, (Revised (1951) Edition.

Murray, S.: "The Surface of Mean Sea Level as a Datum for Levels", paper read before the Victorian Institution of Surveyors, September 1914.

National Mapping Council of Australia: "Standard Specifications and Recommended Practices for Horizontal and Vertical Control Surveys", Division of National Mapping, Department of National Development, Canberra, reprinted with amendments November 1970.

Rapp, R.H.: "The Orthometric Height", thesis, The Ohio State University, USA, 1961.

Thwait, E.: "Accuracy of Staff Calibration to Meet National Mapping Council Requirements", National Standards Laboratory, Commonwealth Organisation, 1966.



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LOOP CLOSURE FIGURES OF 261 LOOPS FORMED BY 757
PRIMARY SECTIONS

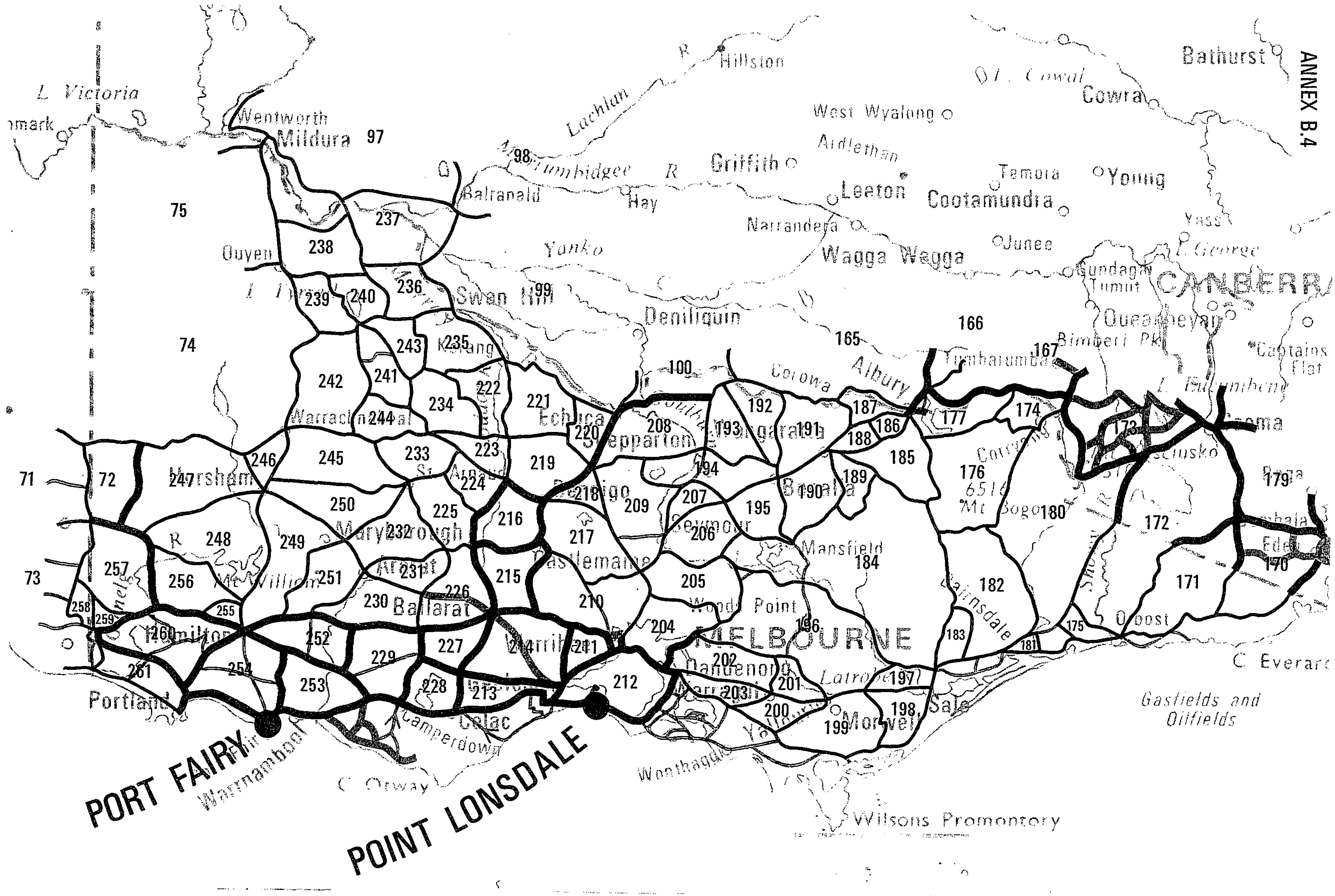
LOOP NO.	MISCLOSE (D) FEET	PERIMETER (M) MILES	$D/\sqrt{M}$
1	+1.323	739.5	+0.049
2	+1.337	812.6	+0.047
3	-1.000	1552.9	-0.025
4	+0.597	1245.2	+0.017
5	+0.119	1026.1	+0.004
6	-0.946	797.9	-0.033
7	+0.383	295.7	+0.022
8	+0.071	831.2	+0.002
9	+0.539	668.3	+0.021
10	-1.066	461.8	-0.050
11	+1.309	950.0	+0.042
12	+0.074	529.9	+0.003
13	+0.123	409.7	+0.006
14	+0.514	543.9	+0.022
15	+0.150	497.1	+0.007
16	-0.167	378.5	-0.008
17	+0.320	287.2	+0.019
18	-0.194	391.8	-0.010
19	-1.280	683.6	-0.049
20	+1.098	505.1	+0.049
21	-1.165	684.8	-0.044
22	-1.153	622.8	-0.046
23	-0.136	543.9	-0.006
24	-0.293	294.0	-0.017
25	-0.001	397.3	0.000
26	-0.802	376.2	-0.041
27	+0.976	1268.7	+0.027
28	+1.188	742.3	+0.044
29	+0.994	938.2	+0.032
30	+0.223	487.8	+0.010
31	-0.657	460.4	-0.031
32	+0.433	516.1	+0.019
33	+0.398	384.7	+0.020
34	-1.466	1011.8	-0.046
35	+1.494	1055.2	+0.046
36	-0.100	577.1	-0.004
37	+0.461	825.9	+0.016
38	-0.863	1187.7	-0.025
39	-0.816	1897.9	-0.019
40	+0.864	1040.3	+0.027
41	+1.148	1121.5	+0.034
42	-0.777	858.7	-0.026
43	-0.012	739.6	0.000
44	+1.153	1310.5	+0.032
45	-1.198	796.7	-0.042
46	-0.530	737.0	-0.020
47	+0.001	737.9	0.000
48	-1.071	739.9	-0.039
49	-0.799	728.1	-0.030
50	-0.022	835.1	-0.001
51	+1.213	594.8	+0.050
52	+0.589	292.1	+0.034
53	+0.748	445.0	+0.035
54	+1.078	557.3	+0.046
55	-0.313	850.1	-0.017
56	+0.293	483.0	+0.013
57	-0.578	649.8	-0.023
58	-0.774	337.1	-0.042
59	-0.227	646.6	-0.009
60	+0.500	292.4	+0.029
61	-0.812	370.7	-0.042
62	+0.142	414.5	+0.007
63	-0.215	565.8	-0.009
64	-0.169	487.8	-0.008
65	-0.191	526.5	-0.008
66	+1.206	768.9	+0.043
67	+0.405	436.3	+0.019
68	-0.880	540.2	-0.038
69	+1.058	531.6	+0.046
70	-0.442	244.3	-0.028
71	+0.483	366.6	+0.025
72	-0.222	121.5	-0.020
73	-0.476	305.7	-0.027
74	+0.377	367.6	+0.020
75	+0.030	341.8	+0.002
76	+0.835	562.6	+0.035
77	-0.444	361.1	-0.023
78	+1.060	503.6	+0.047
79	-0.357	760.7	-0.013
80	-0.362	626.8	-0.014
81	+0.901	883.3	+0.030
82	-1.017	1335.2	-0.028
83	-1.025	843.9	-0.035
84	-0.711	342.9	-0.038
85	+0.607	316.3	+0.034
86	+1.184	838.5	+0.041
87	-0.922	703.0	-0.035
88	+0.337	685.3	+0.013
89	-0.092	1061.8	-0.003
90	-0.424	719.1	-0.016
91	+1.090	583.5	+0.045
92	+0.964	507.9	+0.043
93	-1.070	478.3	-0.049
94	+0.934	389.3	+0.047
95	-0.489	270.3	-0.029
96	-0.056	421.1	-0.003
97	+1.085	469.2	+0.050
98	-0.455	358.7	-0.024
99	-0.410	366.0	-0.021
100	+0.535	181.8	+0.040

LOOP CLOSURE FIGURES OF 261 LOOPS FORMED BY 757
PRIMARY SECTIONS (CONT)

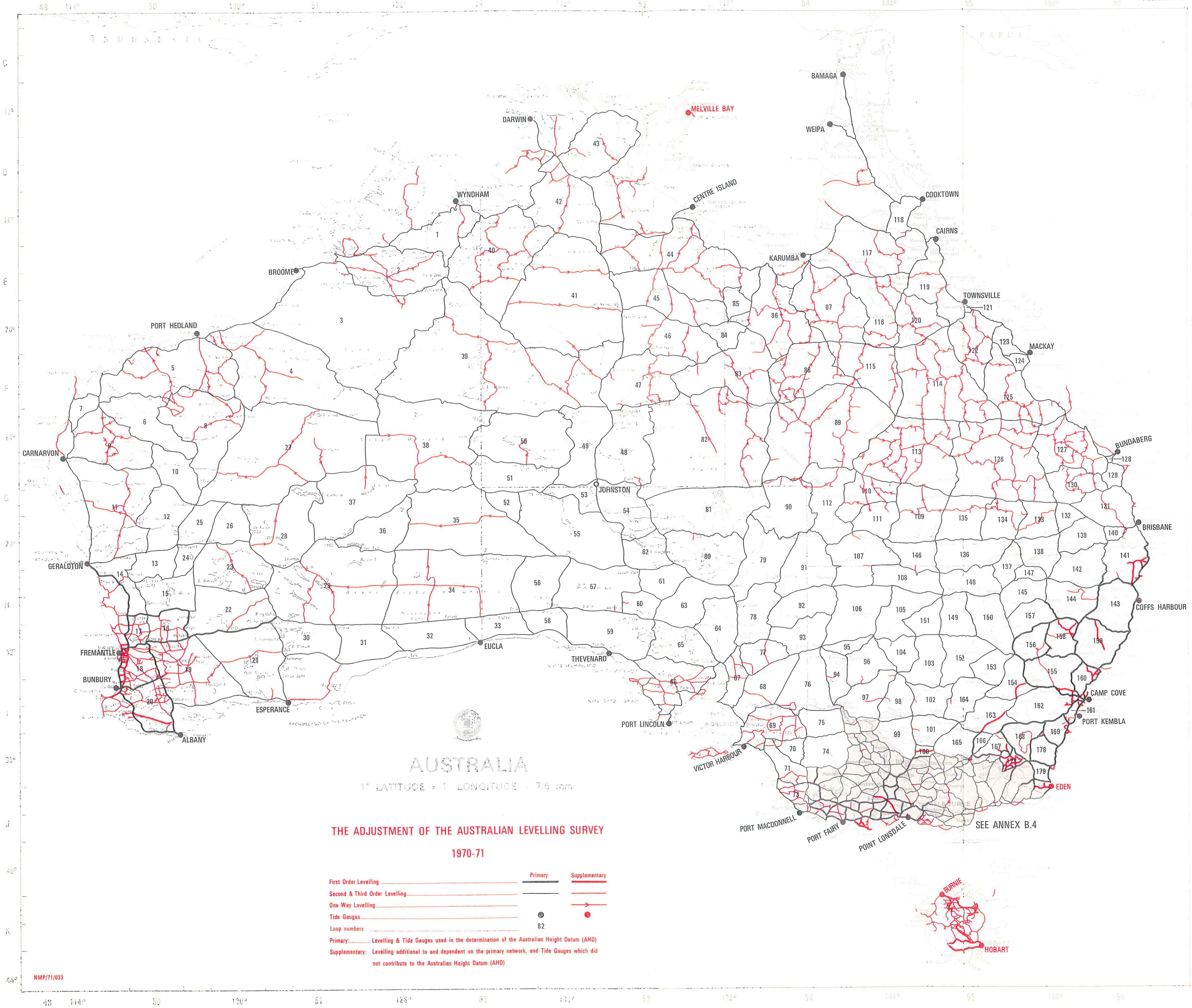
LOOP NO.	MISCLOSE (D) FEET	PERIMETER (M) MILES	D/√M	LOOP NO.	MISCLOSE (D) FEET	PERIMETER (M) MILES	D/√M
101	+0.793	310.6	+0.045	151	-0.158	334.5	-0.009
102	-0.997	395.1	-0.050	152	-0.592	484.5	-0.027
103	+0.141	423.7	+0.007	153	-0.526	313.0	-0.030
104	-0.127	325.3	-0.007	154	+0.040	404.7	+0.002
105	-0.042	572.4	-0.002	155	+1.013	509.4	+0.045
106	+0.644	604.4	+0.026	156	-0.445	338.2	-0.024
107	-0.185	633.2	-0.007	157	+0.291	399.4	+0.014
108	-0.573	471.4	-0.026	158	-0.695	372.7	-0.036
109	-1.172	550.5	-0.050	159	+0.436	489.6	+0.020
110	-0.961	539.3	-0.041	160	+0.008	325.9	0.000
111	-0.639	365.2	-0.033	161	-0.203	240.6	-0.013
112	+1.267	785.7	+0.045	162	+0.078	504.5	+0.003
113	+0.112	842.2	+0.004	163	-0.594	458.1	-0.028
114	+0.021	919.7	+0.001	164	+0.427	414.1	+0.021
115	+0.020	641.5	+0.001	165	-0.651	362.5	-0.034
116	+1.248	631.0	+0.050	166	+0.334	185.2	+0.024
117	+0.181	885.2	+0.006	167	-0.781	287.6	-0.046
118	-0.794	434.1	-0.038	168	-0.437	393.3	-0.022
119	+1.324	770.1	+0.048	169	+0.252	271.6	+0.015
120	+0.734	522.8	+0.032	170	+0.386	189.6	+0.028
121	+0.216	86.6	+0.023	171	-0.388	211.9	-0.027
122	-0.725	609.7	-0.029	172	-0.606	345.8	-0.032
123	-0.337	327.7	-0.019	173	+0.058	242.2	+0.004
124	+0.469	211.4	+0.032	174	+0.054	102.2	+0.005
125	-1.123	734.3	-0.041	175	-0.297	80.8	-0.033
126	-0.082	946.5	-0.003	176	-0.419	422.4	-0.020
127	+0.708	676.5	+0.027	177	+0.284	154.3	+0.023
128	-0.270	100.2	-0.027	178	+0.668	293.6	+0.039
129	+0.019	261.1	+0.001	179	+0.198	227.0	+0.013
130	+0.173	486.6	+0.008	180	+0.756	407.9	+0.037
131	-0.081	502.5	-0.004	181	+0.266	47.2	+0.040
132	-0.318	233.9	-0.021	182	+0.582	232.9	+0.038
133	+0.748	410.2	+0.036	183	-0.334	75.2	-0.039
134	-0.093	378.8	-0.005	184	+0.956	455.2	+0.044
135	-0.923	481.8	-0.042	185	+0.453	150.3	+0.037
136	+0.637	522.8	+0.028	186	-0.159	58.0	-0.021
137	-0.510	361.1	-0.027	187	+0.019	84.3	+0.002
138	-0.987	410.4	-0.049	188	-0.304	61.9	-0.039
139	+0.756	366.8	+0.039	189	+0.248	103.8	+0.024
140	+0.323	188.1	+0.024	190	+0.504	143.6	+0.042
141	+0.508	564.2	+0.021	191	+0.427	129.9	+0.037
142	-0.468	460.0	-0.022	192	+0.241	118.0	+0.022
143	-0.098	507.5	-0.004	193	+0.238	142.5	+0.020
144	+0.624	463.7	+0.029	194	-0.149	136.2	-0.013
145	+0.295	387.0	+0.015	195	-0.210	108.9	-0.020
146	+0.619	431.5	+0.030	196	-0.710	311.2	-0.040
147	-0.073	223.5	-0.005	197	+0.121	90.3	+0.012
148	+1.031	440.3	+0.049	198	+0.110	117.3	+0.010
149	-0.715	387.7	-0.036	199	-0.194	164.6	-0.015
150	+0.479	508.0	+0.021	200	+0.284	126.5	+0.025

LOOP CLOSURE FIGURES OF 261 LOOPS FORMED BY 757 PRIMARY SECTIONS (CONT)

LOOP NO.	MISCLOSE (D) FEET	PERIMETER (M) MILES	D/√M	LOOP NO.	MISCLOSE (D) FEET	PERIMETER (M) MILES	D/√M
201	-0.071	90.3	-0.007	231	-0.123	98.4	-0.012
202	+0.026	138.2	+0.002	232	-0.198	145.6	-0.016
203	+0.179	92.1	+0.019	233	+0.394	117.7	+0.036
204	-0.193	183.0	-0.011	234	+0.527	117.8	+0.049
205	+0.386	200.5	+0.027	235	+0.516	124.6	+0.046
206	-0.356	109.8	-0.034	236	-0.120	119.9	-0.011
207	+0.282	87.8	+0.030	237	-0.575	257.9	-0.036
208	+0.127	168.0	+0.010	238	-0.166	127.9	-0.015
209	+0.456	174.7	+0.034	239	-0.258	116.9	-0.024
210	+0.563	185.1	+0.041	240	-0.315	126.9	-0.028
211	-0.144	121.1	-0.010	241	+0.131	110.2	+0.012
212	+0.143	157.5	+0.011	242	-0.098	158.6	-0.008
213	-0.068	122.6	-0.006	243	-0.092	105.5	-0.009
214	-0.259	156.0	-0.021	244	-0.262	99.8	-0.026
215	-0.138	146.4	-0.011	245	-0.118	164.9	-0.009
216	+0.156	112.2	+0.015	246	+0.170	85.2	+0.018
217	-0.232	145.4	-0.019	247	+0.367	194.1	+0.026
218	-0.094	93.9	-0.010	248	+0.386	189.7	+0.028
219	+0.043	116.6	+0.004	249	-0.446	209.7	-0.031
220	-0.240	92.1	-0.025	250	+0.085	162.3	+0.007
221	+0.027	129.6	+0.002	251	+0.572	130.5	+0.050
222	+0.001	140.9	+0.000	252	-0.027	123.5	-0.002
223	+0.036	100.7	+0.004	253	+0.068	133.0	+0.006
224	+0.187	86.7	+0.020	254	-0.199	158.6	-0.016
225	-0.225	111.7	-0.021	255	-0.285	70.7	+0.034
226	+0.145	141.7	+0.012	256	-0.069	153.5	-0.006
227	+0.143	109.1	+0.014	257	-0.182	141.7	-0.015
228	+0.117	101.5	+0.012	258	-0.013	115.7	-0.001
229	+0.122	129.3	+0.011	259	+0.148	80.4	+0.016
230	+0.044	128.9	+0.004	260	-0.301	164.5	-0.023
				261	+0.203	137.8	+0.017



PORT FAIRY
POINT LONSDALE
L. Victoria
Wentworth
Mildura
Balranald
Hay
Hillston
Lachlan
Murrumbidgee R
Griffith
West Wyalong
Ardlethan
Leeton
Narrandera
Cootamundra
Temora
Young
Junee
Wagga Wagga
Cowra
Bathurst
Yass
Gundagai
Tumut
CANBERRA
Queanbeyan
Captains Flat
Bimberi Pk
Tumbarumba
Ouyen
Swan Hill
Kerang
Deniliquin
Yanko
Corowa
Albury
Echuca
Shepparton
Wangaratta
Benalla
Bendigo
Seymour
Mansfield
Castlemaine
Maryborough
Ararat
Ballarat
Horsham
Mt William
Hamilton
Portland
Warrnambool
Camperdown
Colac
C. Otway
Woods Point
MELBOURNE
Dandenong
Latrobe
Morwell
Sale
Wonthaggi
Wilsons Promontory
Orbost
Eden
Bega
Cooma
Kosciusko
Mt Bogong
6516
C. Everard
Gasfields and Oilfields



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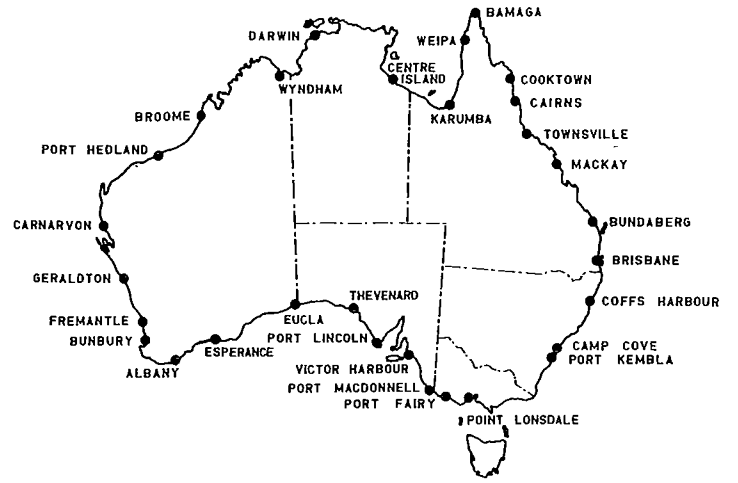
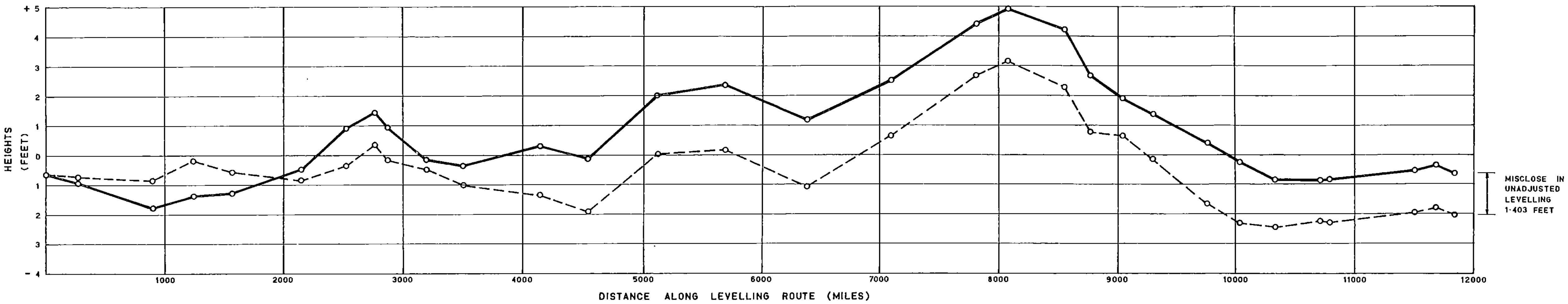
MEAN SEA LEVEL HEIGHTS

AS DETERMINED BY LEVELLING AND FREE ADJUSTMENT

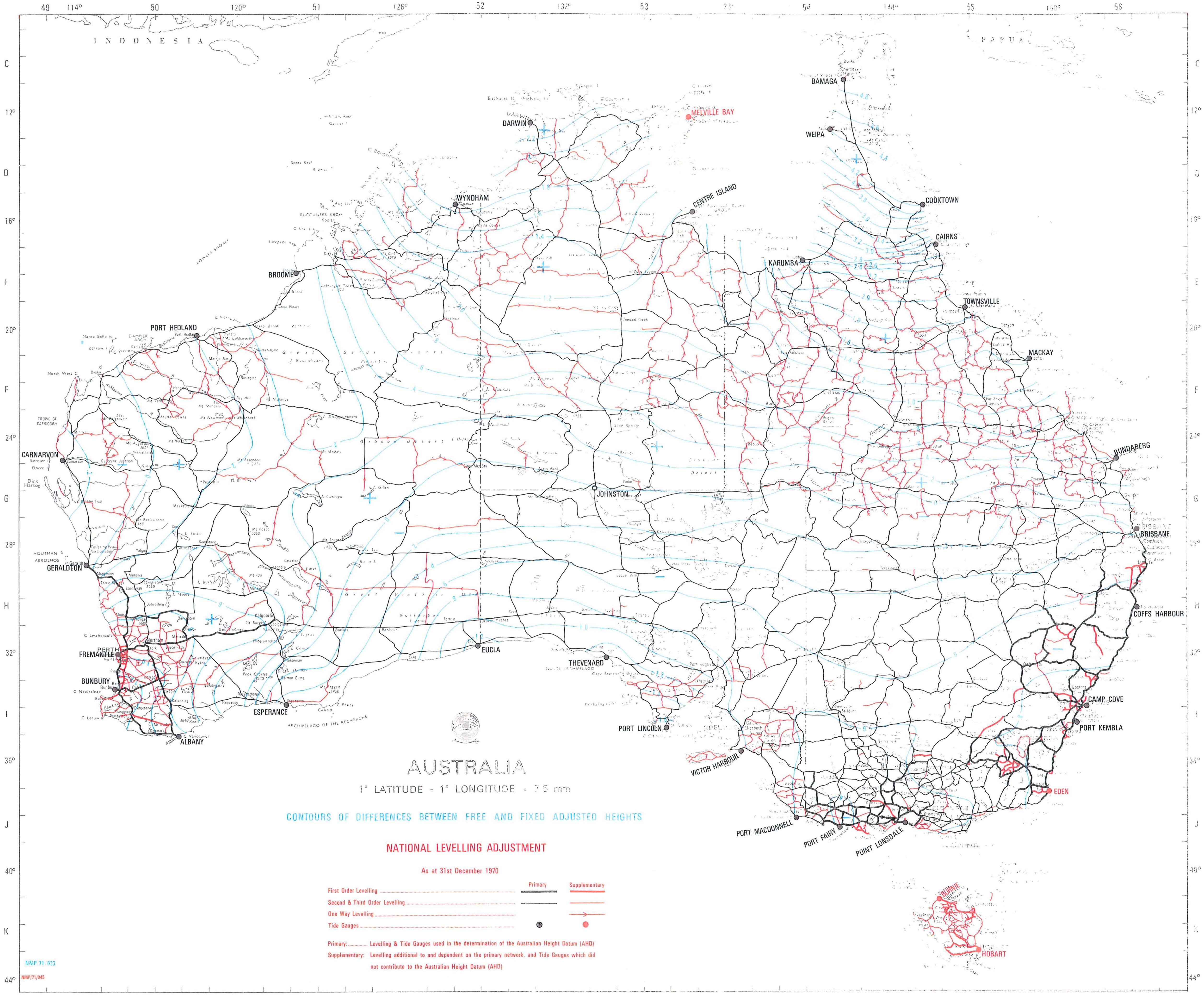


HEIGHTS DERIVED FROM FREE CONTINENTAL ADJUSTMENT ————

ORTHOMETRICALLY CORRECTED OBSERVED HEIGHTS (UNADJUSTED) – – – –



Station	Distance along levelling route (miles)	Ortho corrected observed heights (feet)	Differences	D/√M	Free adjustment heights (feet)	Differences	D/√M
PORT MACDONNELL	270·1	−0·611	−0·126	0·008	−0·611	−0·300	0·018
VICTOR HARBOUR	632·5	−0·737	−0·107	0·004	−0·911	−0·875	0·035
PORT LINCOLN	344·7	−0·844	+0·665	0·036	−1·786	+0·395	0·021
THEVENARD	324·1	−0·179	−0·406	0·023	−1·391	+0·113	0·006
EUCLA	576·9	−0·585	−0·247	0·010	−1·278	+0·792	0·033
ESPERANCE	375·9	−0·832	+0·504	0·026	−0·486	+1·387	0·072
ALBANY	242·5	−0·328	+0·693	0·045	+0·901	+0·534	0·034
BUNBURY	100·8	+0·365	−0·524	0·052	+1·435	−0·486	0·048
FREMANTLE	324,3	−0·159	−0·316	0·018	+0·949	−1·064	0·059
GERALDTON	306·3	−0·475	−0·532	0·030	−0·115	−0·237	0·014
CARNARVON	649·5	−1·007	−0·352	0·014	−0·352	+0·641	0·025
PORT HEDLAND	391·0	−1·359	−0·548	0·028	+0·289	−0·412	0·021
BROOME	584·0	−1·907	+1·926	0·080	−0·123	+2·118	0·088
WYNDHAM	572·9	+0·019	+0·160	0·007	+1·995	+0·380	0·016
DARWIN	691·0	+0·179	−1·229	0·047	+2·375	−1·257	0·048
CENTRE ISLAND	706·8	−1·050	+1·698	0·064	+1·118	+1·408	0·053
KARUMBA	712·9	+0·648	+2·017	0·076	+2·526	+1·884	0·071
WEIPA	265·2	+2·665	+0·496	0·030	+4·410	+0·517	0·032
BAMAGA	481·9	+3·161	−0·884	0·040	+4·927	−0·726	0·033
COOKTOWN	215·9	+2·277	−1·509	0·103	+4·201	−1·531	0·104
CAIRNS	273·1	+0·768	−0·085	0·005	+2·670	−0·769	0·047
TOWNSVILLE	254·2	+0·683	−0·797	0·050	+1·901	−0·514	0·032
MACKAY	466·3	−0·114	−1·523	0·071	+1·387	−1·002	0·046
BUNDABERG	274·3	−1·637	−0·669	0·040	+0·385	−0·629	0·038
BRISBANE	301·1	−2·306	−0·172	0·010	−0·244	−0·568	0·033
COFFS HARBOUR	381·0	−2·478	+0·232	0·012	−0·812	−0·052	0·003
CAMP COVE	79·6	−2·246	−0·035	0·004	−0·864	+0·021	0·002
PORT KEMBLA	714·6	−2·281	+0·330	0·012	−0·843	+0·323	0·012
POINT LONSDALE	177·3	−1·951	+0·178	0·013	−0·520	+0·166	0·012
PORT FAIRY	156·4	−1·773	−0·241	0·019	−0·354	−0·257	0·021
PORT MACDONNELL		−2·014			−0·611		



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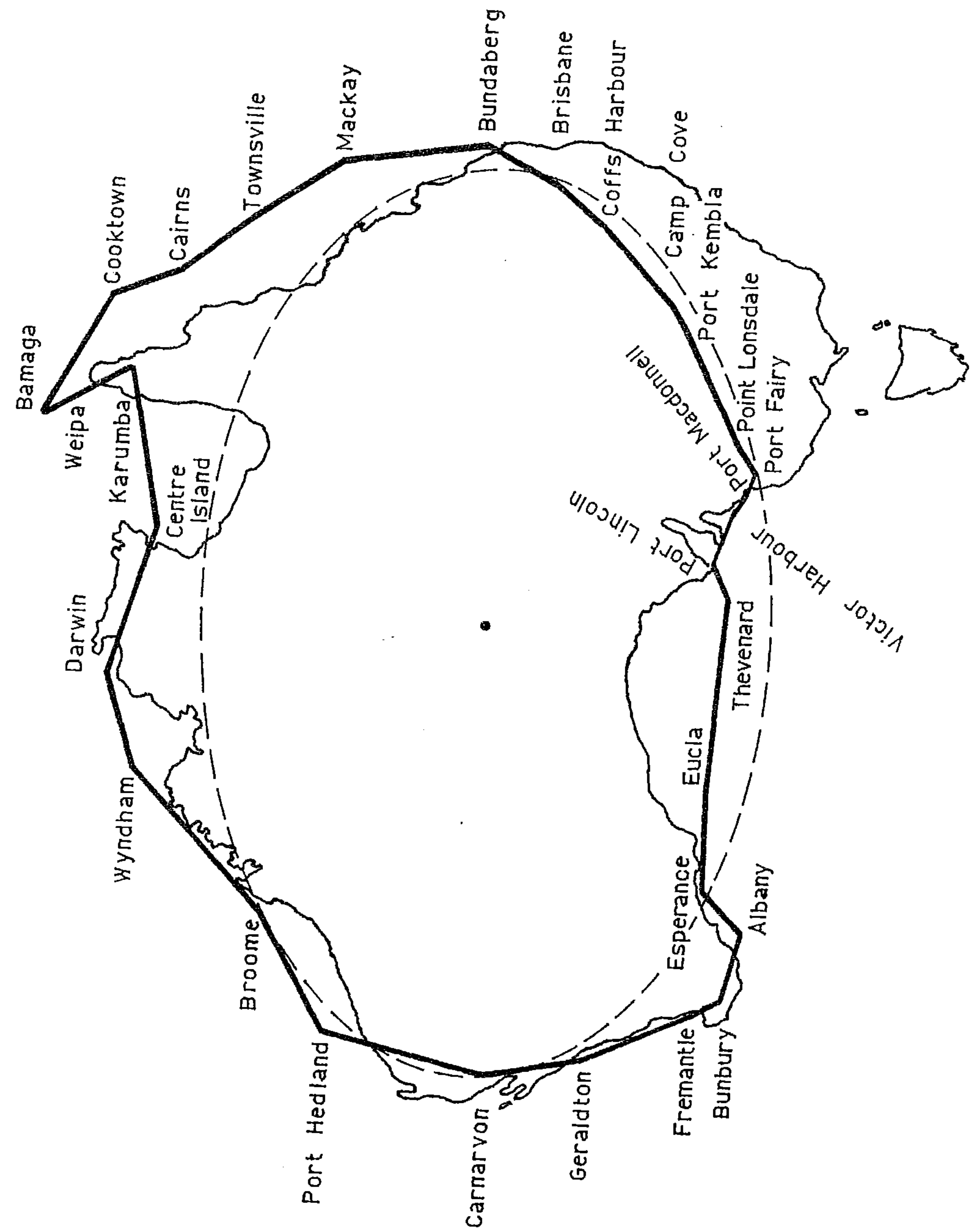
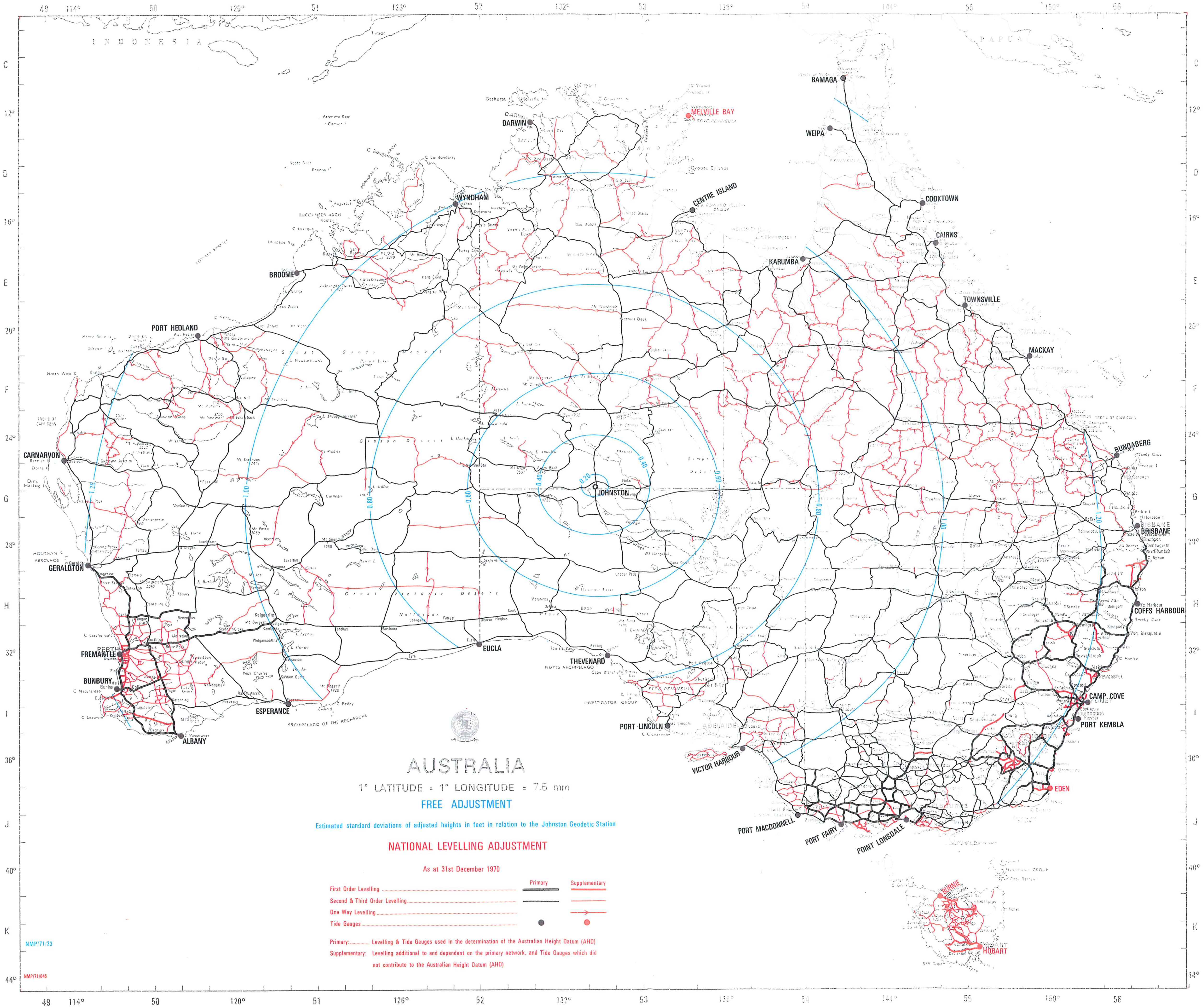
ANNEX E

COMPARISON OF MEAN SEA LEVEL HEIGHTS

PROJECTION CENTERED ON THE JOHNSTON GEODETIC STATION.





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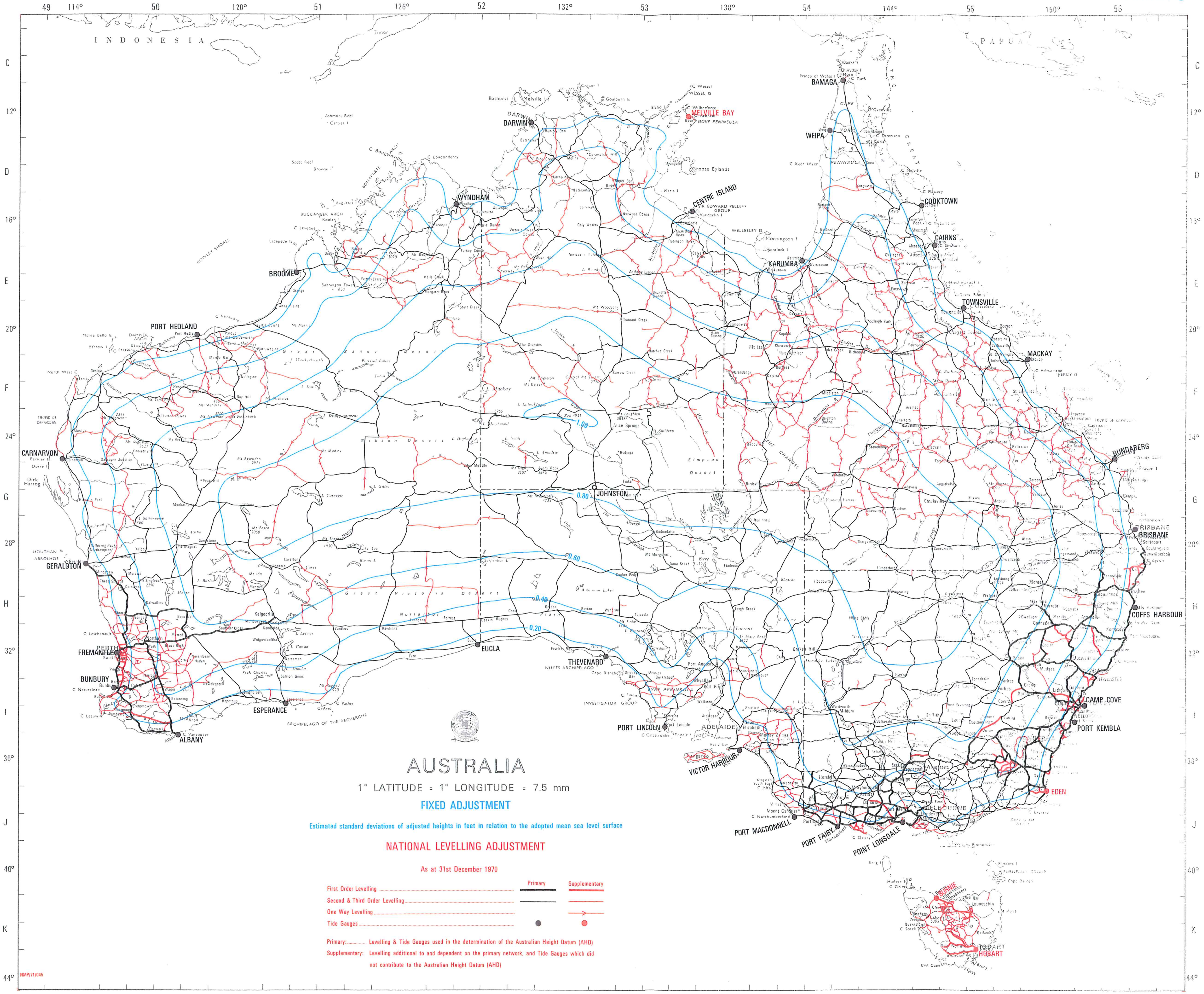
ANNEX G



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NATIONAL MAPPING COUNCIL OF AUSTRALIA

EXTRACTS FROM STANDARD SPECIFICATIONS AND RECOMMENDED PRACTICES FOR HORIZONTAL & VERTICAL CONTROL SURVEYS

VERTICAL CONTROL

4.1 Vertical control will be provided by differential levelling to first, second or third order accuracy, using appropriate survey equipment, or to fourth order accuracy by differential levelling, measurement of vertical angles, deduction from determinations of atmospheric pressures, or tacheometric methods.

4.2 Datum for Elevations

All elevations should preferably be based on mean sea level datum. When based on an alternate datum, such datum should be clearly defined and the correction to be applied to reduce the elevations to mean sea level datum should in all cases be clearly stated.

4.3 Accuracy - Requirements

4.3.1 Vertical

Vertical control surveys shall conform to the following standards of accuracy:

Class of Survey	Accuracy Requirement
1st Order	The two levellings of each section between permanent bench marks shall not differ by more than ($0.017\sqrt{M}$) feet or ($4\sqrt{K}$) mm where M(K) is the distance in miles (kilometres) between bench marks measured along the levelling route. Circuit closures shall not exceed this same limit, where M(K) is the length of the circuit in miles (kilometres) along the levelling route.
2nd Order	The two levellings of each section between permanent bench marks shall not differ by more than ($0.035\sqrt{M}$) feet or ($8.4\sqrt{K}$) mm where M(K) is the distance in miles (kilometres) between bench marks measured along the levelling route. Circuit closures shall not exceed this same limit, where M(K) is the length of the circuit in miles (kilometres) along the levelling route.

Class of Survey	Accuracy Requirement
3rd Order	The two levellings of each section between permanent bench marks shall not differ by more than $(0.050\sqrt{M})$ feet or $(12\sqrt{K})$ mm where M(K) is the distance in miles (kilometres) between bench marks measured along the levelling route. Circuit closures shall not exceed this same limit, where M(K) is the length of the circuit in miles (kilometres) along the levelling route.
4th Order	Sufficient to control contouring of area to be mapped.

4.4 Accuracy - Evaluation after completion of Field Work

Levelling may be classified by international standards by evaluation of the probable total limiting error per kilometre. See International Association of Geodesy, Resolutions relative to Precision Levelling, at Schedule 1, Part 2.

NATIONAL MAPPING COUNCIL OF AUSTRALIA

EXTRACTS FROM SCHEDULE 3 OF STANDARD SPECIFICATIONS AND RECOMMENDED PRACTICES FOR HORIZONTAL & VERTICAL CONTROL SURVEYS

DIFFERENTIAL LEVELLING

3.1 First Order

3.1.1 Instruments

3.1.1.1 Approved auto collimating or precision spirit level with parallel plate refractor should be used for first order levelling.

3.1.1.2 Recognized invar staves or precision folding staves should be used. Staves should be numbered and calibrated before use and re-calibrated at approximately three monthly intervals when in use.

3.1.2 Levelling Practice

3.1.2.1 Setting up the level

The level should always be set up to ensure maximum stability during observations. When using precision spirit level it should at all times be shaded.

When using automatic levels the unsystematic procedure of centering the circular bubble is to be adhered to. That means if instrument stations in a levelling run are numbered in sequence the circular bubble is to be centred at:

(a) odd numbered stations with telescope pointing in the direction of the backsight and at

(b) even numbered stations with telescope pointing in the direction of the foresight or vice versa.

Prior to the first reading at any instrument station the telescope is to be turned slightly first in one direction then the other.

3.1.2.2 Use of Staves

Differential levelling should be observed by use of two staves. Bases of staves should be inspected and cleaned if necessary at every change point. At each change point the staff should be placed on a metal ground plate firmly set so that no settlement can occur during the period of time taken for the required back sight and fore sight. Metal spikes driven firmly and securely into the ground may be used in lieu of ground plates. When observations are being made the staff shall be held vertical by reference to the circular bubble which should be checked each day for verticality. This test should be made indoors to avoid sun and wind effects.

3.1.2.3 Collimation

At least once during each day's work a test for error in collimation of the level should be made and recorded in the level book. Collimation error should be adjusted where it exceeds 0.01 ft in a distance of 200 feet. The collimation error should be observed and recorded after adjustment.

3.1.2.4 Length of sight

The length of any levelling sight should be such as to permit the certain reading of the staff to the required accuracy and should not exceed 132 ft. Back sight and fore sight should be equal in length.

Where terrain difficulties do not permit equal sights an explanatory note relevant to the entries of distances should be made in the level book. Efforts should be made to equalise total backsight and foresight distances during the last few observations between permanent bench marks. The total length of backsights should in no case differ from the total length of foresights by more than 50 ft.

3.1.2.5 Refraction

In order to avoid some of the effect of abnormal refraction due to a line of sight grazing the ground surface, no sight line between level and staff shall be less than one foot above ground surface.

3.1.2.6 Readings

3.1.2.6.1 When using metric staves, observations and recordings of the centre wire only should be made to 0.0003 metre either by use of a parallel plate refractor or by three readings through a plain telescope.

3.1.2.6.2 When using English feet staves, observations and recordings of the centre wire only should be made to 0.001 foot either by use of a parallel plate refractor or by three readings through a plain telescope.

3.1.2.7 Procedure

3.1.2.7.1 The second levelling of a section should proceed in the reverse direction to the first levelling and should preferably be performed by a different survey party equipped with a second complete set of instruments.

3.1.2.7.2 For all levelling, the foresight staff must remain at the change point, and the same staff used for the next backsight.

3.1.2.8 Accuracy

3.1.2.8.1 The two levellings of each section between permanent bench marks shall not differ by more than ($0.017\sqrt{M}$ feet or ($4\sqrt{K}$) mm where M(K) is the distance in miles (kilometres) between bench marks measured along the levelling route. Circuit closures shall not exceed this same limit, where M(K) is the length of the circuit in miles (kilometres) along the levelling route.

3.1.2.9 Records

3.1.2.9.1 All recording of observations in level books should be made in ink. The level book should record each day: the date, the collimation test, the details of the section of levelling, the names of the personnel in the survey party, the serial numbers of the instruments and staves, the observing conditions, the air temperature observed at commencement, estimated middle and end of day's operations, and

3.2 Third Order Levelling

3.2.1 Instruments

3.2.1.1 A suitable auto collimating or spirit level should be used for THIRD ORDER LEVELLING.

3.2.1.2 Staves constructed of a suitable material should be used. They should be numbered and calibrated before use and preferably re-calibrated at six monthly intervals.

3.2.2 Levelling Practice

3.2.2.1 Setting up the level -

The level should always be set up to ensure maximum stability during observations. When using a spirit level it is desirable that it be shaded. When using automatic levels the unsystematic procedure of centering the circular bubble is to be adhered to. That means if instrument stations in a levelling run are numbered in sequence the circular bubble is to be centred at:

(a) odd numbered stations with telescope pointing in the direction of the backsight and at

(b) even numbered stations with telescope pointing in the direction of the foresight or vice versa.

Prior to the first reading at any instrument station the telescope is to be turned slightly first in one direction then the other.

3.2.2.2 Use of Staves

It is considered that the use of two staves is good practice. Bases of staves should be inspected and cleaned if necessary at every change point. Change points should be so selected as to ensure stability of the staff during observations.

When observations are being made the staff shall be held vertical by reference to a circular bubble which should be checked periodically for verticality.

3.2.2.3 Collimation

A test for collimation error should be made preferably each day but not less than every third day and recorded in the level book. Collimation error should be adjusted where it exceeds 0.01 ft in a distance of 200 feet. The collimation error should be observed and recorded after adjustment.

3.2.2.4 Length of sight

The length of any levelling sight should be such as to permit the certain reading of the staff to the required accuracy and should not exceed 300 feet. Backsight and foresight should be preferably equal in length. Where terrain difficulties do not permit equal sights efforts should be made to equalise total backsight and foresight distances during the last few observations between permanent bench marks. Between bench marks the total length of backsights should not differ from the total length of foresights by more than 150 feet.

3.2.2.5 Refraction

In order to diminish the effect of abnormal refraction due to a line of sight grazing the ground surface, no line of sight between level and staff should be less than one foot above the ground surface.

3.2.2.6 Readings

English foot staves should be observed and recorded to 0.005 foot. Metric staves should be observed and recorded to 0.001 metre.

3.2.2.7 Procedure

3.2.2.7.1 All sections must be check levelled preferably by a second survey party.

3.2.2.7.2 For all levelling, the foresight staff must remain at the change point, and the same staff used for the next backsight.

3.2.2.8 Accuracy

The two levelling of each section between permanent bench marks shall not differ by more than $(0.050 \sqrt{M})$ feet or $(12 \sqrt{K})$ mm where M(K) is the distance in miles (kilometres) between bench marks measured along the levelling route. Circuit closures shall not exceed this same limit, where M(K) is the length of the circuit in miles (kilometres) along the levelling route.

3.2.2 Records

3.2.3.1 All recording of observations in level books must be made in ink. The level book should record each day: the date, the collimation test, the details of the section of levelling, the names of the personnel in the survey party, the serial numbers of the instrument and staves, the observing conditions and the time of beginning and ending of each flight of levels between bench marks.

3.3 Correction for nonparallelism of level surface

The decision whether to make the National Levelling Adjustment of Australia in Dynamic or Orthometric heights need not be made until the adjustment is about to be undertaken. Agencies wishing to adjust their levels prior to the National Levelling Adjustment should apply an Orthometric correction to their observed height differences in accordance with the methods given in Special Publications No 240 of the United States Coast and Geodetic Survey. Observed, uncorrected height differences between bench marks should be tabulated and kept readily available for use in the National Levelling Adjustment.

NATIONAL MAPPING COUNCIL

TECHNICAL SUB-COMMITTEE

Report on Levelling Staff Calibration

(a) Determination of the Overall Length of Precision Staves

When a precision staff is initially calibrated by CSIRO it will be necessary for the true length of one nominated interval, preferably the overall length or close thereto, to be quoted.

This nominated interval should be remeasured from time to time during field measurements to ensure that no significant change has taken place. Any change should not exceed say, 0.0002 ft/ft if the requirements for Precision Levelling are to be continued to be met.

While it would be fundamentally better to remeasure the nominated interval on the staff as a single entity there are a number of practical difficulties in carrying this out in the field.

A determination that entails the measurement of a number of contiguous sub-intervals (say three) of the nominated interval should be satisfactory, however, provided an accuracy of 0.00 1 ft/ft is achieved. A 3 ft (1 m) scale, preferably of invar, bevel-edged and subdivided throughout (or with subdivisions adjacent to the terminal lines) to 0.001 ft (0.25 mm) and used with a magnifier of a power at least x 10, should be adequate for this purpose. Account should of course be taken of the temperature during measurements.

If the field measurements indicate that the nominated interval has changed in excess of 0.000 2 ft/ft it would, of course, be possible to proceed with an adjusted value of the "mean staff interval" on the assumption that the change has occurred reasonably uniformly along the staff.

(b) Calibration of 3rd Order Staves

In considering 3rd order staves the working group decided to look into both initial calibration and subsequent field checks.

Initial Calibration

Whilst, on theoretical grounds, a calibration in accordance with Mr Thwaite's procedure and based on a random selection of intervals is safer, practical considerations and experience suggest that a method which requires simpler equipment may well meet the calibration needs of 3rd order staves.

A number of lengths (say ten) are to be measured on each section of the staff using a 3 ft (1 m) bevelled edged scale, subdivided throughout to 0.001 ft (0.25 mm), and a magnifier (x 10). The intervals measured should not be systematic in length and should include long and short intervals. The staff may be vertical or horizontal.

The estimate of the "staff interval" (foot or decimetre) is to be based on these measurements alone. As these measurements do not include any joints the errors in the joints should be of the same order as those encountered in the staff subdivisions, neither very much greater or smaller.

A nominated interval on each section of the staff, together with a small interval bridging each joint, should be measured for comparison with subsequent field checks.

Particular attention must be paid to the joints in the staff. Measurement of a small interval bridging a joint can be readily measured on a folding staff with a short bevel-edged scale; for telescopic staves a scale with adjustable off-set should be used (see NSL drawing M900-2). It is important that all measurements across the joints be made with the staff vertical.

An observational standard deviation for the measurements of 0.001 ft, with a systematic error not exceeding ± 0.000 2 ft/ft should be achieved.

The "staff interval" is assessed from the sum of measured lengths of the intervals, excluding measurements over the joints, divided by the sum of the nominal lengths. Using this value the evenness of subdivision is obtained by comparison with the measured intervals and a standard error of graduation computed.

Field Checks

As in the case of precision staves the field checks are intended to ensure that no significant change has taken place.

Each nominated interval should be measured from time to time using a bevelled edge scale and magnifier similar to those described for use in field checks on precision scales. The accuracy of measurement should be ± 0.000 2 ft/ft or better and if there is a change in the remeasured interval, from its initial calibration, in excess of say 0.000 4 ft/ft, an adjustment to the estimate of the "staff interval" (foot or decimetre) should be made or the staff should be withdrawn from use.

General

The various types of staves available, and in use throughout Australia, indicate that the initial purchase is not governed primarily by the needs of control levelling circuits.

TECHNICAL REQUIREMENTS

2. Datum

The Datum of the levels shall be the level value of an originating Permanent Bench Mark as supplied by the Surveyor General. Levelling operations shall commence at this originating Permanent Bench Mark and all levels shall be determined in reference to this Datum.

3. Equipment

All levelling shall be carried out with modern levels of the automatic collimation type and with high quality calibrated staves. Levels proposed to be used on the Contract are to be approved by the Surveyor General prior to the commencement of the Contract. For the purpose of approval levels shall either be submitted for inspection by the Surveyor General or fully described in writing to the Surveyor General indicating the Manufacturer, Type, Number, etc., of the level to be used. Only those levels that are approved are to be used in the Contract. Only those automatic levels fitted with a viewing mirror or prism viewer to enable the circular bubble to be observed free from parallax will be approved. Staves will be supplied to the Contractor by the Surveyor General and these staves shall be made available to the Surveyor General for calibration at intervals not exceeding three (3) months or as required and at the completion of the Contract.

4. Lines of Levelling

The levels shall be run in Sections along the lines set out in the accompanying Schedule. The levelling of each Section shall be carried out twice. This shall be done in both forward and backward direction at substantially different times (preferably one way in the morning and the reverse in the afternoon). The two staff method shall be employed and the interval of time between consecutive sights at each set up of the level shall be kept to a minimum. All Bench Marks shall be change points.

5. Bench Marks

The Contractor shall locate Permanent Bench Marks indicated in the accompanying Schedule and effect levelling to each of such marks. Where any Permanent Bench Mark is destroyed, damaged, or not located the circumstances are to be reported to the Surveyor General.

In these instances a substitute Bench Mark is to be established - without additional fee - in proximity to the reported position of the destroyed, damaged or lost Permanent Bench Mark.

Substitute Bench Marks established for this purpose shall take the form of a galvanised iron fencing dropper five feet six inches (5'6") long driven with the top at least one inch (1") below the surface of firm ground and surrounded by a circle of rocks. If, for any reason, the dropper cannot be driven for its full length and provided that at least three (3) feet of the dropper is below ground level the top may be neatly cut off at a point one inch (1") below ground level. The new substitute Bench Mark shall be further indicated by another galvanised iron fencing dropper driven to within about two feet of the ground surface and within one (1) foot of the substitute Bench Mark.

Each substitute Bench Mark is to be fully described in the field level book and allocated an identification number. The Surveyor General shall supply to the Contractor a list of Identification Numbers permitted to be used. The Identification Number allocated to each substitute Bench Mark is to be legibly stamped on a metal plate and this metal plate is to be firmly attached to the indicator dropper.

Diagrams of Bench Marks in the field level books are to be on separate pages and are to be free from all levelling information.

When a Bench Mark at the end of a Section is reached entries on that page of the book are to be discontinued, and a fresh start made on a new page for the beginning of each new Section.

6. Recovery Data

The Contractor will examine the numbering of each Permanent Bench Mark found and ensure agreement exists with the provided diagram, sketch or description. He shall annotate each diagram or sketch with further information should such be necessary to facilitate location of the mark on future occasions.

7. Accuracy

The two levellings of each Section between Permanent Bench Marks shall not differ by more than $0.05\sqrt{M}$ feet where M is the distance between Permanent Bench Marks in miles measured along the levelling route.

When levelling fails to reach the specified accuracy and is repeated an entirely separate record is to be entered in the field level book and appropriate cross references made. Complete relevelling must be made for a complete Section between Bench Marks or substitute Bench Marks established under Clause 5 where levelling fails to reach specified accuracy.

If relevelling in one direction agrees satisfactorily with either of the previous two levellings the work may be accepted.

8. Records

All level observations and relevant survey observations taken in the field are to be properly recorded in blue or black ink or ball point pen in the numbered field level books provided. All notations in field level books, other than actual observed readings are to be neatly made in pencil to avoid confusion with observed readings.

Only original field notes will be accepted. Transcription of original notes is expressly forbidden.

No adjusting of recorded readings shall be made. Final adjustment of levels to a common datum will be arranged by the Surveyor General.

No field notation is to be over-written. Incorrect readings may be lightly ruled through in blue or black ink, or ball point pen with the corrected field reading noted in blue or black ink or ball point pen on the next line below the cancelled reading.

Location sketches adequate to define the general location of each line of levels shall be drawn in each field level book unless such a sketch has been supplied with the instructions.

Totals of the backsight and foresight columns are to be shown at the bottom of each page.

9. Reports

The Contractor shall supply to the Surveyor General on completion of the work copies of his report on the whole of the survey, neatly bound in a properly fitted foolscap size folder and which shall include:

(a) in chronological order, a brief description of all work done on each day of the survey with appropriate cross references to the field level books.

(b) a consecutive list of Bench Marks showing;

(i) the respective differences in height between successive Bench Marks, including Main Roads, Irrigation and Water supply and Railway Bench Marks levelled en route, referred to the originating Bench Mark.

(ii) the adopted mean value of these differences of height in feet.

(iii) the reduced level of all Bench Marks, including Main Roads, Irrigation and Water Supply and Railway Bench Marks levelled en route, referred to the originating Bench Mark.

(iv) the recorded vehicle mileage read to the nearest one tenth(1/10) of a mile in respect of each successive Bench Mark commencing with zero at the originating Bench Mark.

(c) unused level books, maps, diagrams, sketches as provided with the original instructions for survey.

(d) a statement that the work was done by him or under his continuous personal supervision.

10. Recommended Practices

The Contractor shall ensure that the levelling required to be completed in terms of this Specification and attached Schedule is carried out in conformity with the following recommended practices.

11. Instruments

Levelling instruments used in the work shall be maintained in correct adjustment at all times. Vertical collimation error of instruments should at no time exceed ten (10) seconds of arc. Field tests for vertical collimation error shall be made daily before work is commenced.

Such field tests are to be properly recorded in the field level books, the results to indicate error before and residual error after adjustment together with distances over which the tests were conducted. A complete page of the field level book is to be used for each vertical collimation test.

The Contractor will assume full responsibility for the performance of the level instrument used, whether such be his own property or on hire from any source.

12. Use of Automatic Collimation Levels

Each time the level is set to take readings the dislevelment indicated by the circular bubble shall not exceed the tolerance laid down in the manufacturer's handbook. The level must always be set firmly so as to ensure complete stability during observations. The circular bubble must be in precise adjustment at all times.

To mitigate systematic error due to dislevelment of the horizontal plane definition, the following routine is to be adhered to:-

(i) ensure that the circular bubble is in correct adjustment and level carefully at each station.

(ii) at consecutive bays level the instrument with the telescope pointing in opposite directions. For example at 1st and 3rd stations the telescope should point towards the backsight and at the 2nd and 4th stations the telescope should point towards the foresight when levelling the instrument. When staffmen are "leap frogging" this is resolved by always pointing the telescope to the same staff when levelling the instrument.

Prior to every reading the telescope is to be turned slightly in one direction then the other.

13. Staves

The staves used must be handled with care and every effort made to preserve the markings from defacement. Only the staves supplied by the Surveyor General are to be used.

14. Lengths of Sight

The length of any sight shall be such as to allow the positive resolution of staff graduations and no sight shall exceed three hundred (300) feet, even under very good visibility conditions.

Foresights and backsights shall, as far as practicable, be of equal length. The lengths of foresights and backsights shall be measured by measuring tape, pacing, Stadia measurement or by any means of similar accuracy. In all cases the respective lengths on the foresights and backsights shall be recorded in the field level book in blue or black ink or ball point pen and shall be indicated to the nearest foot.

The total length of foresights shall not differ from the total length of backsights in any Section between Bench Marks by more than one hundred and fifty (150) feet.

15. Placement of Staves

Bases of staves are to be inspected and, if necessary, cleaned at every change point. When setting the staff for a levelling sight it shall be placed on a stable footing consisting of either a firmly driven peg with a galvanised roofing nail driven into and projecting slightly from the top or a steel pin or steel spike driven firmly into the ground or a metal footplate approved by the Surveyor General and at each point firmly set so that no settlement can occur during the course of an observation. The staff shall be held vertical in accordance with sound survey practice. In no instance are nails or other marks to be left where they may constitute a danger to vehicular traffic or to the public generally.

When turning the staff on a change point care should be taken to ensure that no undue weight is placed on the staff thereby causing settlement of the change point mark.

There is always to be an even number of instrument stations between two consecutive Bench Marks so that the same staff is placed on the starting mark as backsight staff and on the next Bench Mark as foresight staff. This will eliminate any zero errors in the graduations of the two staves.

16. Times of Observation

Levels shall only be taken when atmospheric and weather conditions allow reading of the staff with certainty. If unfavourable conditions are encountered the length of sight shall be reduced until certainty can be achieved, or work discontinued.

17. Readings

The staff readings shall be recorded to the nearest 0.005 feet.

18. Temperature and Refraction

The temperature of the air shall be recorded together with the time of reading at the commencement, at the middle and at the conclusion of each day's work.

All sight lines shall clear the intervening ground between the level and staff by at least one (1) foot. Staff readings of less than one (1) foot will not be accepted.

19. Holding Marks

When levelling operations are to be suspended for a period, a holding mark shall be established from which to resume levelling operations. Such holding mark shall consist of a length of metal piping driven firmly into the ground or a stoutly driven peg with a galvanised roofing nail driven into and projecting slightly from the top or other mark of similar stability.

Where circumstances oblige a holding mark to be in use overnight or for longer periods a subsidiary Bench Mark shall be established - such to be fully described in the field level book.

20. Certification

Immediately on completion of each page of the field level book the Surveyor doing the work shall certify on that particular page as follows:

"The observations recorded on this page
were made by me / in my presence.

........................Surveyor."

Each level book and all reports required in the terms of this Specification and accompanying Schedule shall be certified by the Contractor and such certificate shall declare that all the work has been carried out strictly in conformity with this Specification and the attached Conditions of Contract.

21. Description of Schedule

The accompanying Schedule "A" consists of:

(a) illustrative maps setting out diagrammatically the lines and Sections to be levelled.

(b) a list of equipment which the Surveyor General will make available to the Contractor in terms of clause 1(b) (iii) of this Specification.

(c) a list of numbers permitted to be used for the identification of substitute Bench Marks.