The Australian Height Datum

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Abstract

On 5th May, 1971, the Division of National Mapping, on behalf of the National Mapping Council of Australia, carried out a simultaneous adjustment of 97,320 kilometres of the two-way levelling in Australia, holding mean sea level fixed at zero at thirty tide gauges around the mainland coast.

The resulting datum surface, with minor modifications in two metropolitan areas, has been called the Australian Height Datum (AHD) 1971. This datum has been adopted by the National Mapping Council as the datum to which all vertical control for mapping is to be referred.

Completion of this "primary" adjustment and the subsequent adjustment to the Australian Height Datum of further "supplementary" levelling has created one of the largest homogeneous systems of levelled heights in the world.

The purpose of this paper is to provide a general description of the Australian levelling network and its adjustment. A more detailed description is given in "The Adjustment of the Australian Levelling Survey, 1970–1971", Technical Report 12, published by the Division of National Mapping.

The Australian Levelling Survey

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 4,800 kilometres of control levelling had been completed. By the end of 1960 a total of about 21,000 kilometres had been levelled.

Most of this work consisted of one-way levelling carried out by the Department of the Interior, under the direction of the Commonwealth Surveyor General, for the gravity surveys of the Bureau of Mineral Resources of the Department of National Development.

Because of the urgent requirement for levelling for both mapping and gravity surveys, and taking advantage of funds made available through an accelerated Commonwealth oil search programme, the Director of National Mapping in 1961 initiated a third-order levelling programme designed to quickly provide levelling within and between the likely oil bearing sedimentary basins.

The State Surveyors General gave their support to this project, and the Commonwealth provided funds for contracts to private

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surveyors who carried out the work under the supervision of the Surveyors General.

The plan was to provide a network of two-way levelling along new lines of survey, and additional one-way levelling over lines previously levelled one-way by the Department of the Interior.

Conventional two-way levelling was to conform to the National Mapping Council's "Standard Specification and Recommended Practices for Horizontal and Vertical Control Surveys" which requires, among other things, that the two levellings of a section between permanent bench marks shall not differ by more than $12\sqrt{K}$ millimetres where K is the distance in kilometres between bench marks measured along the levelling route. The additional one-way levelling was carried out in accordance with specifications issued by the Division of National Mapping which require the surveyor to carry out further checks if the difference between the original and the new levelling exceeds $18\sqrt{K}$ millimetres.

Most of the levelling was observed using well seasoned, calibrated wooden staves and automatic levels. For the one-way levelling, staves with foot graduations on one face and metric on the other were used.

Such a network was accepted by the National Mapping Council as suitable for a national levelling survey and they took over the operation, arranged for a tide gauge survey and for the adjustment of the levelling to provide a nationally acceptable Australian Height Datum.

With all this activity, between 1960 and 1965 no less than 101,000 kilometres were levelled and by the end of 1970 there was a total of 161,000 kilometres of levelling in the network.

This levelling network, as at December, 1970, is illustrated in the centrepiece map.

The Division of National Mapping, the Commonwealth Surveyor General and the staff of the Department of the Interior, all State Surveyors General and their respective staffs, the Snowy Mountains Hydro-Electric Authority, the Weapons Research Establishment, State Railway Departments and Water Supply and Irrigation Commissions, the Horace Lamb Centre for Oceanographical Research of the Flinders University of South Australia, contract surveyors and many other organizations and individuals, each contributed to the successful completion of the National Levelling Survey and its adjustment.

The Division of National Mapping was responsible for the co-ordination of the project and provided the major part of the funds.

Field work

Levelling which contributed to the determination of the Australian Height Datum has been termed "primary levelling". Levelling subsequently adjusted to the Australian Height Datum has become known as "supplementary" levelling.

All primary levelling was two-way, some conventional two-way levelling and the rest one-way foot-metric levelling run over old Department of the Interior one-way levelling. The supplementary levelling consists of both one and two-way levelling.

The amount of primary two-way levelling carried out by the different observing authorities is shown in Table 1.

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	Two-way levelling
Department of the Interior	23 590 km		3 064 km
State authorities	462 km	235 km	21 529 km
Snowy Mountains Hydro-Electric Authority			480 km
Private surveyors under contract to Division of National Mapping, supervised by Surveyors General		19 614 km	47 863 km
Division of National Mapping		4 203 km	332 km
		24 052 km	73 268 km
		Total:	97 320 km

The Division of National Mapping's field activity in levelling the national network was mainly confined to areas where, because of remoteness and difficult access, private surveyors could not be expected to operate, to the tide gauge survey, to the completion of border connections, and to check levelling, supervision and inspection.

In some instances there was a tendency on the part of individual surveyors to underestimate the skill and perseverance needed to achieve levelling of third-order accuracy and, as a result, the Division of National Mapping was called on to check level about six per cent of the levelling in order to correct excessive loop misclosures.

In all, 389 sections totalling 6 197 kilometres were check levelled and the marks on 2 763 kilometres of traverses were inspected. A large number of level books were examined, in some cases to investigate excessive discrepancies between forward and backward runs, and in other cases following suspected malpractice or non-compliance with specifications.

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.

Tides and tide gauges

The early establishment of tide gauges at ports in each State led to the adoption of local heights based on differing values for sea level.

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, recommended that all States adopt Mean Sea Level as the State Level Datum and that State's levelling programmes be so adapted as to facilitate comparison of level datums between adjoining States.

In 1964 the Council resolved that members should encourage responsible authorities to install tide gauges to enable mean sea level to be determined from observations taken simultaneously throughout Australia.

During the 3 years 1966–1968 simultaneous observations were made at all the gauges shown in figure A except at Karumba where recordings taken during 1957–1960 were accepted. There were many interruptions to the recordings due to theft, vandalism and faulty gauges, but acceptable results were obtained from the thirty gauges shown as primary gauges in the centrepiece map.

In 1967 the Division of National Mapping, with the assistance of the Flinders University of South Australia, completed a survey of twenty-six mainland gauges, calibrating the automatic recorders, determining the difference in height between the staff gauge zeros and three permanent bench marks at each gauge and completing other survey work. Surveys at other gauges were later carried out by the Northern Territory Administration, the New South Wales Department of Lands and the Division of National Mapping.

Levelling data collection and preparation

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

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

The first of the completed data sheets arrived in the office of the Division in September, 1969 and they continued to come in until February, 1971, when the last of the primary levelling data was received.

Data processing

As there were too many junction points in the network to enable a continental adjustment to be carried out in the one operation on the CSIRO's CDC 3600 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	*Area*	*Region Origin*
1	S.A. and N.T.	Johnston
2	W.A.	Fremantle
3	Qld	Brisbane
4	N.S.W.	Sydney
5	Vic.	Point Lonsdale

The regions were arranged in such a way that no region contained more than 139 junction points or 216 sections joining junction points.

In the continental adjustment, the adjustments of each region were linked together to obtain identically the same result as if a single rigorous adjustment had been made.

Computer programs

The system design for the National Levelling Adjustment is shown in Figure 1. The main advantage of the system is that an orderly, well indexed system of data preparation was maintained. Each step in the data preparation was checked and analysed before the next step was taken.

The most important data preparation programme was ORTHO 1. Using theoretical values of gravity it computed orthometric corrections for the levelling between bench marks, computed the total difference in height between junction points, and punched out the final input data deck for the Phase 1 adjustment programme LEVELONE. With the output from ORTHO 1 it was possible to close loops, detect blunders and assess the quality of the levelling.

Programme LEVELONE made a least squares adjustment, by observation equations, of height differences in each regional network with one point, the region origin, held fixed.

The second phase of the adjustment was executed by programme LEVEL 2. This was a least squares condition equation adjustment where the conditions provided a link between the Phase 1 origins and the common continental origin.

Two continental LEVEL 2 adjustments were run. The first holding only one point, Johnston, fixed gave levelled heights for mean sea level at each tide gauge and enabled the quality of the levelling to be assessed.

The second adjustment was run on 5th May, 1971, holding mean sea level at thirty tide gauges fixed at zero and this established the Australian Height Datum.

System design for the National Levelling Adjustment (NLA)

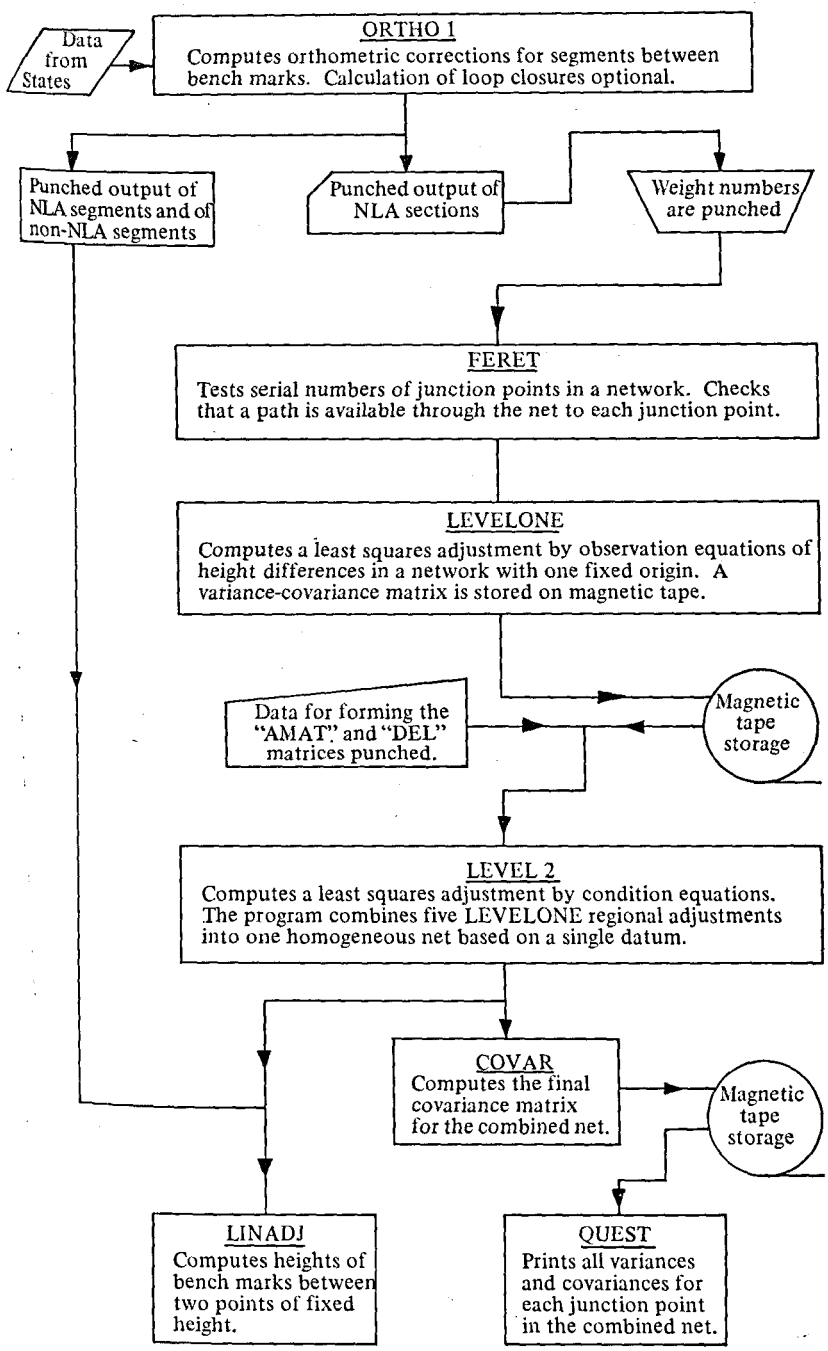


Figure 1

The heights of individual bench marks were then adjusted to the junction point values determined by LEVEL 2 by a programme called LINADJ.

Estimated standard error

Relative to mean sea level the estimated standard error of adjusted heights in the centre of Australia is 0·34 metres. This accuracy is sufficient for all foreseeable purposes. The estimated standard deviations of adjusted heights in metres in relation to the adopted mean sea level surface is illustrated in the centrepiece map.

Published output

For every section two outputs on different format are available. The simpler output with only bench mark numbers, approximate latitude and longitude, locality, and height in feet and metres, is sufficient for survey purposes; while the more complex printout is useful for research and analysis.

Examples of the two different formats of published results are given in Figures 2 and 3.

Copies of the published output have been supplied to the Surveyors General of each mainland State from whom information on AHD heights may be obtained.

Levelling in Tasmania has not been adjusted to the Australian Height Datum because levelling over long sea gaps is not yet possible. A good deal of levelling has already been completed in Tasmania and more is likely to be carried out in the next year or two. The Division of National Mapping will co-operate with the Surveyor General and adjust the Tasmanian levelling to mean sea level at tide gauges in that State.

Metropolitan zones

In Perth and Adelaide, the new AHD heights differed very little from the heights previously adopted. So as not to change these long established heights by trivial amounts, it was agreed at the 1971 meeting of the National Mapping Council that the old heights could be retained within clearly defined "Metropolitan Zones". These heights were then accepted as being on the Australian Height Datum.

In order to prevent abrupt changes the small differences in height at the edges of the Metropolitan Zones were adjusted out in "Buffer Zones".

Adjustment of supplementary levelling and trigonometrical heights

Where the supplementary levelling formed a net inside a primary loop, an adjustment of the supplementary junction points was carried out using programme LEVELONE and holding fixed the primary levelling around the supplementary network.

PROGRAM AMENDED 16/12/70
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

Figure 2

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	DISTANCE KM	HEIGHT DIFFERENCES OBSERVED	ORTHOMETRIC	ADJUSTED INTERNATIONAL FEET	CORR	LAT OF B	LONG OF B	LOCATION OF B	ADJUSTED HEIGHT INT FT OF B	ADJUSTED HEIGHT METRES OF B
	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					

Figure 3

Individual traverses of supplementary levelling were adjusted by programme LINADJ.

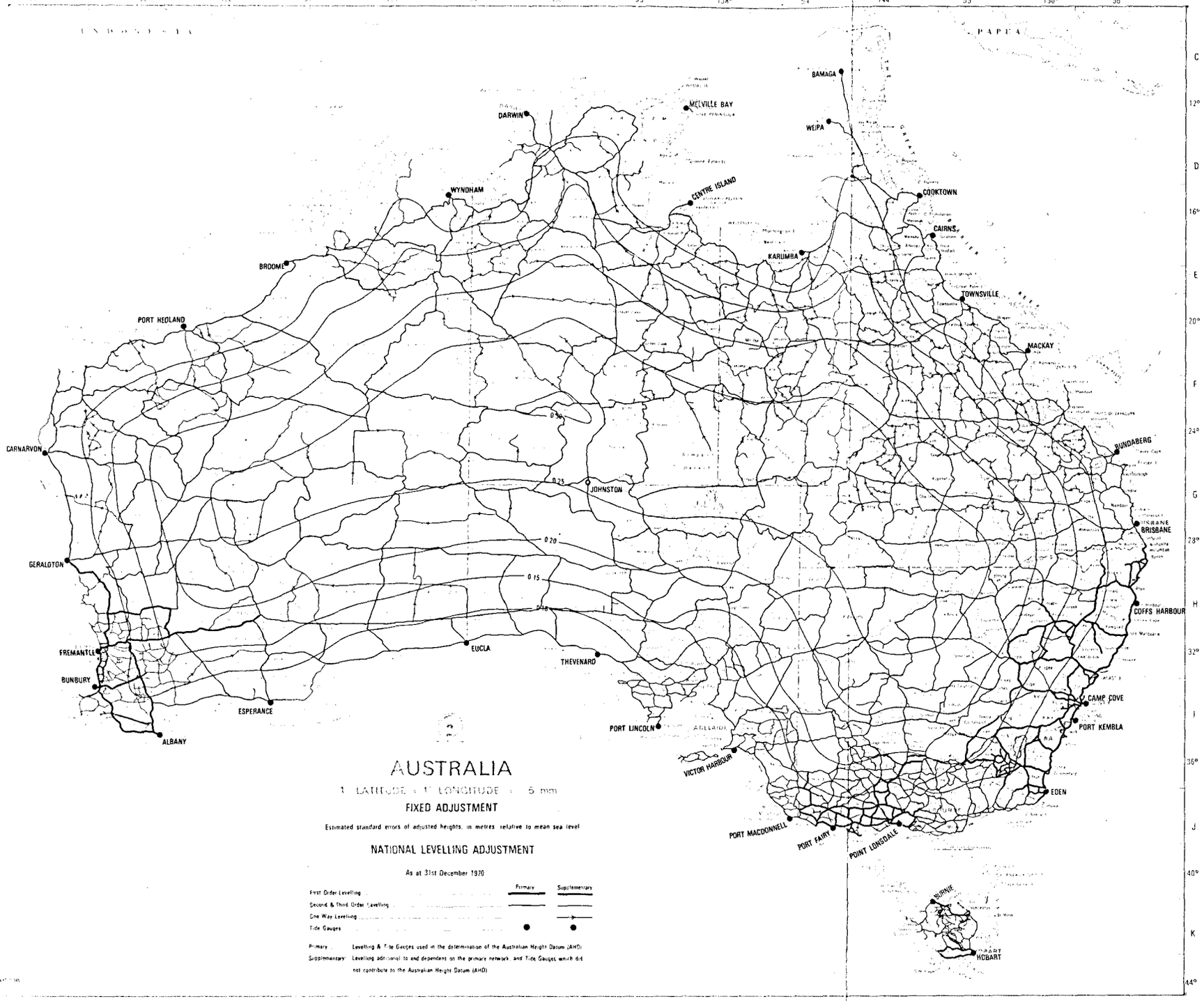
This supplementary adjustment is a continuing process. As new levelling of topographic value is completed, it is adjusted to the Australian Height Datum as supplementary levelling.

The height of trigonometrical stations in the 1966 Australian Geodetic Datum adjustment have been recomputed and adjusted to the Australian Height Datum. The adjustment of trigonometrical heights in supplementary sections is continuing.

Conclusion

The Australian Levelling Survey and the establishment of the Australian Height Datum provides a first rate example of a practical co-operative effort that can be organized through the National Mapping Council, and of the feasibility of concentrating the resources of Commonwealth and State mapping organizations and private surveyors on the rapid solution of a national survey task.

FIGURE A



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