# NEXT GENERATION HEIGHT REFERENCE FRAME

## PART 1/3: EXECUTIVE SUMMARY

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## Motivation

Within five years everyone in Australia will have the capacity to position themselves at the sub-decimetre level using mobile Global Navigation Satellite Systems (GNSS) technology augmented with corrections delivered either over the internet or via satellite. This growth in technology will provide efficient and accurate positioning for industrial, environmental and scientific applications. The Geocentric Datum of Australia 2020 (GDA2020) was introduced in 2017 in recognition of the increasing reliance and accuracy of positioning from GNSS. GDA2020 is free of many of the biases and distortions associated with Geocentric Datum of Australia 1994 (GDA94) and aligns the datum to the global reference frame in which GNSS natively operate.

For all the benefits of GDA2020, it only provides accurate heights relative to the ellipsoid. Ellipsoidal heights do not take into account changes in Earth's gravitational potential and therefore cannot be used to predict the direction of fluid flow. For this reason, Australia has a physical height datum, known as the Australian Height Datum (AHD) coupled with a model known as AUSGeoid to convert ellipsoidal heights from GNSS to AHD heights.

The Australian Height Datum (Roelse et al., 1971) is Australia's first and only national height datum. It was adopted by the National Mapping Council in 1971. Although it is still fit for purpose for many applications, it has a number of biases and distortions which make it unacceptable for some industrial, scientific and environmental activities. The primary bias is due to the manner in which AHD zero was realised, where the Australian National Levelling Network (ANLN) was fixed to mean sea level (MSL) observed during 1966-1968 at 30 tide gauges around the Australian mainland. Due to the effect of the ocean's time-mean dynamic topography (MDT), AHD is about 0.5 m above the gravimetric geoid in north-east Australia and about 0.5 m below the gravimetric geoid in south-west Australia (e.g. Featherstone, 2004, 2006). Secondary effects are uncorrected gross, random and systematic errors in the ANLN (e.g., Roelse et al., 1971; 1975; Morgan, 1992; Filmer and Featherstone, 2009) and the use of modified normal-orthometric corrections applied to levelling data based on the GRS67 model ellipsoid (Holloway, 1988). Ignoring the primary bias from MDT, the secondary effects reveal the mean standard deviation of AHD heights used in the development of AUSGeoid2020 is ±0.038 m (Featherstone et al., 2017), but can reach ±0.5 m in some regions (Filmer and Featherstone 2009). Uncertainty in the national vertical datum of this magnitude may make AHD inappropriate for some applications that require more accurate heighting because the data will be superior to the datum. It is therefore an appropriate time to engage with stakeholders and investigate their current and future requirements for physical heighting in Australia.

## Purpose and Scope

The purpose of this study was to assess both the **User Requirements (Part 2/3)** for height determination and the **Technical Options (Part 3/3)** which could be implemented to meet the identified user requirements.

The only other user requirements study of physical heights in Australia was undertaken in 1988 (Kearsley, 1988) which predates the widespread use of GNSS. Given the technological advances of the past three decades and the modern methods some now use to access physical heights, we felt it necessary to reach out to the user community to assess their needs for physical heights now and into the future.

The results of the user requirements study should be reviewed in conjunction with the technical options report which reviews the height system and height datum options which could be implemented in Australia based on current and future data holdings.

The objective is to identify what requirements users have for height datums in Australia and what can technically be developed to provide users with what they need. The **Executive Summary (Part 1/3)** brings the recommendations of both reports together to describe the preferred options to satisfy the needs of users for physical heights in Australia.

## User Requirements

The user feedback was captured via a Google Form survey sent out by Geoscience Australia on June 6, 2018 and closed on July 6, 2018. Over 300 stakeholders were contacted (organisation representatives and individuals) based on recommendations from state, territory and Commonwealth spatial representatives. Broadly speaking, the survey was based around a person's role within the spatial industry, the activities they required height for, how well AHD suited their activities and what they would like to see in a height reference frame in the future.

The survey received 172 responses with the respondents primarily being in more senior positions within industry or government. Analysis of the respondents suggests there are broadly two groups of respondents:

- **Group A**: cadastral, civil engineering, construction and mining, and
- **Group B**: environmental studies (e.g. flood, storm modelling), geodesy, hydrography or other research.

**Table 1 Summary of responses from Group A and Group B. Green indicates satisfaction with AHD, yellow indicates issues / problems with AHD and red indicates more serious issues / problems.**

| | Group A | Group B |
|---|---|---|
| **Respondents** | 56% | 44% |
| **Satisfaction** | 87% | 61% |
| **Access and efficiency** | 78% | 53% |
| **Accuracy** | Absolute: 72% need better than 5 cm;<br>Relative: 85% need better than 5 cm | |
| **Why use AHD?** | High need to align spatial data: 70% | High need to align spatial data: 85% |

- The common problems identified by respondents with AHD were reliability (e.g. stability of benchmarks, internal consistency of the datum over long distances) and limited access to benchmarks.
- Combined results of satisfaction with AHD and efficiency of AHD indicate that AHD is fit for purpose for tasks over short distances (< 10 km) while users are less satisfied and find it less efficient when working over larger areas (>10 km).
- **75%** of respondents have tasks which require absolute accuracy better than ±5 cm, with **27%** requiring better than ±1 cm.
- **86%** of respondents have tasks which require relative accuracy better than ±5 cm, with **47%** requiring better than ±1 cm.
- AHD has a one sigma accuracy of ±4 cm for absolute heights. This makes it very difficult to achieve the ±1 cm absolute accuracy requirement **27%** of respondents need.

- AUSGeoid2020 is only capable of computing absolute AHD heights with accuracy of ±5 - 13 cm (Brown et al. 2018). This almost rules out the use of AUSGeoid2020 for absolute heighting for **75%** of tasks described by respondents. Given that more than **50%** of respondents use AUSGeoid to observe / transfer heights, this highlights a potential problem for the industry and demonstrates that further education on the use of AUSGeoid is required.
- **63%** of respondents still expressed a **high** requirement to have heights aligned to MSL, while **50%** of respondents expressed a **high** requirement to have heights aligned to a truly level surface. There seems to be a need for further information / education on this topic including advice on conversion between the gravimetric quasigeoid, AHD, tidal datums and the uncertainties associated with the conversions.
- **Group B (70%)** have a slightly greater requirement than **Group A (85%)** to align spatial data. Group B who generally have tasks which cover larger areas (>10 km) and use "big data", have more problems with AHD.
- **56%** of users who are likely to adopt an alternative height reference frame rated alignment to MSL as **high**. This indicates that if the alternative height reference frame is not directly aligned to MSL, a conversion surface should be supplied and education material to describe the difference is required.
- Respondents remarked that an alternative height reference frame based on a gravity model only would provide:
    - improved access;
    - higher accuracy;
    - increased efficiency;
    - reference surface without the known errors of the levelling network;
    - compatibility with GNSS; and
    - national consistency (including seamless onshore – offshore).
- Respondents were asked whether or not they would be happy to compute height from a model as opposed to bench marks.
    - **33%** of users indicated that deriving height from a geoid model is preferable over heights from ground marks;
    - **24%** indicated they may be able to use it depending on the task being performed, and
    - **27%** preferred using ground marks.

## Technical Options

If an alternative height reference frame was to be established in Australia, a realisation of a normal height system would be the best option. We recommend the Australian Gravimetric Quasigeoid 2017 (AGQG2017) model (Featherstone et. al. 2017) is used as the initial release of an alternative height reference frame and refined over time as more data becomes available.

AGQG2017 is the gravimetric component of the AUSGeoid2020 model and is based on EGM2008 enhanced with local gravity data. It is aligned with the internationally agreed geoid reference potential $W_0$(=62,636,856.0 m$^2$s$^{-2}$) value and provides a seamless physical reference surface onshore and offshore.

Given that AGQG2017 is only a model and heights are not provided on benchmarks, levelling users will need GNSS heights to access the alternative height reference frame. They can use the quasigeoid model value to derive normal heights. These can then be used as reference heights / starting points for levelling surveys.

For levelling users operating in a normal height system, Filmer et al. (2010) investigated 1,366 mostly third-order levelling loop closures in Australia to assess the difference in misclosure achieved by applying either normal or normal-orthometric corrections. The results indicate there is negligible benefit to applying normal corrections compared to applying normal-orthometric corrections in Australia. This is most likely attributable to the errors in the third-order levelling at heights <1,000 m being of larger magnitude than the height corrections. This indicates that observing surface gravity values at benchmarks along the levelling traverse to apply normal corrections to levelling in Australia cannot be justified, certainly below heights of 1,000 m, which is most of Australia.

Clear communication on the differences between derived normal heights from AGQG2017 and AHD heights will be required given that existing AHD benchmarks heights are not the same as normal heights derived from AGQG2017 (having differences of up to approximately 0.5 m). Benchmark height values could potentially be provided at permanent GNSS antennas using a quasigeoid model to convert the GNSS heights to normal heights.

# Recommendations and Action Plan

## Choice of reference frame

1. Adopt a two-frame approach for height in Australia. AHD (realisation of a normal-orthometric height system with known biases and distortions) should remain as the national height datum, and a quasigeoid model (normal height system) should be developed and made publicly available as an alternative height reference frame for those who need it.
2. The initial release of the alternative height reference frame should be the Australian Gravimetric Quasigeoid 2017 (AGQG2017), which should be refined over time as more data becomes available.
3. AGQG2017 meets the key criteria identified in the user requirements study:
    a. cost-effective to develop and implement;
    b. nationally consistent;
    c. reliable and robust model to transform heights from GNSS ellipsoidal heights to physical heights with uncertainty over large regions (10s-100s km);
    d. compatible with GDA2020, GDA94, International Terrestrial Reference Frame (ITRF) realisations and Australian Terrestrial Reference Frame (ATRF);
    e. easily used to connect onshore and offshore heights;

## Name of reference frame

4. The name of the alternative height reference frame should be decided as part of a specifically designed communications strategy.

## Communication and Education

5. The release of the alternative height reference frame should be clearly communicated to users based on a defined strategy and stakeholder management plan.
6. Education material demonstrating the benefits of the alternative height reference frame should be released with the reference frame to allow users to make informed decisions and maximise the number of users likely to adopt the alternative height reference frame.

7. Education is required on the uncertainties associated with AHD and AUSGeoid. The statistics reported in the user requirements study suggest there are a large number of users who believe AHD and AUSGeoid are more accurate than they are. Given that AGQG2017 is only a model and heights are not provided on benchmarks, levelling users will need GNSS heights to access the alternative height reference frame. They can use the quasigeoid model value to derive normal heights. These can then be used as reference heights / starting points for levelling surveys.
8. Clear communication on the differences between derived normal heights from AGQG2017 and AHD heights will be required given that existing AHD benchmark heights will not be the same as normal heights derived from AGQG2017 (having differences of up to approximately 0.5 m). Benchmark height values could potentially be provided at permanent GNSS antennas using a quasigeoid model to convert the GNSS heights to normal heights.

## Tools / Products

9. To make the alternative height reference frame as user friendly as possible, a conversion model between AHD and the alternative height reference frame the should be made available to users.
10. The alternative height reference frame should be periodically refined and improved with time as new data and development techniques are available.

## Future Work

11. A follow up user feedback survey should be completed to assess changes in user requirements and their opinion of the alternative height reference frame a couple of years after it has been made public.

## References

Brown NJ, McCubbine JC, Featherstone WE, Gowans N, Woods A and Baran I (2018) AUSGeoid2020 combined gravimetric–geometric model: location-specific uncertainties and baseline-length-dependent error decorrelation, Journal of Geodesy, 92:1467, https:// doi.org/10.1007/s00190-018-1202-7.

Featherstone WE (2004) Evidence of a north-south trend between AUSGeoid98 and the AHD in southwest Australia. Surv. Rev. 37(291):334–343. https://doi.org/10.1179/sre.2004.37.291.334.

Featherstone WE (2006) Yet more evidence for a north-south slope in the AHD. J Spatial Sci 51(2):1–6 (corrigendum in Journal of Spatial Science, vol. 52, no. 1, pp. 65–68).

Featherstone WE, McCubbine JC, Brown NJ, Claessens SJ, Filmer MS, and Kirby JF (2017) The first Australian gravimetric quasigeoid model with location-specific uncertainty estimates, Journal of Geodesy, 92(2): 149-168, doi: 10.1007/s00190-017-1053-7.

Filmer MS, Featherstone WE (2009) Detecting spirit-levelling errors in the AHD: recent findings and some issues for any new Australian height datum. Aust J Earth Sci 56(4):559–569. https://doi.org/10.1080/08120090902806305.

Filmer MS (2010) An examination of the Australian Height datum (Doctoral dissertation, Curtin University).

Holloway RD (1988) The integration of GPS heights into the Australian Height Datum, UNISURV Report S33, School of Surveying, The University of New South Wales, Sydney, Australia, 151 pp.

Kearsley A H W, Rush GJ and O'Donnell PW (1988) The Australian height datum problems and proposals, Australian Surveyor, 34:4, 363-380, DOI: 10.1080/00050326.1988.10438540.

Morgan PJ (1992) An analysis of the Australian Height Datum: 1971. Aust. Surv., 37, 46-63.

Roelse A, Granger HW and Graham JW (1971) The adjustment of the Australian levelling survey 1970–1971. Technical Report 12. Division of National Mapping, Canberra.

Roelse A, Granger HW, Graham JW (1975) The Adjustment of the Australian Levelling Survey 1970 – 1971, Technical Report 12 – Second Edition, Division of National Mapping, Canberra, pp. 81.