# AHD Turns 50: Saving AHD

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The Australian Height Datum (AHD) has been Australia's first and only legal vertical datum, celebrating its 50th anniversary this year. The adjustment of the Australian National Levelling Network (ANLN) in May 1971 provided, for the first time, a nationwide network of physical AHD heights. For most surveyors, AHD has been ubiquitous for the entire duration of their professional careers, being the vertical datum of choice because it was the only one.

This article describes the datum maintenance and modernisation efforts undertaken by DCS Spatial Services, a business unit of the NSW Department of Customer Service (DCS), through our ongoing Saving AHD projects. As AHD is showing its age and slowly deteriorating, these projects aim to not only preserve but improve access to AHD.

In our last article, we celebrated the achievements and longevity of AHD, outlined its shortcomings and looked ahead to a new era of vertical datum determination based on Global Navigation Satellite System (GNSS) observations and airborne gravity, culminating in the Australian Vertical Working Surface (AVWS) as an alternative for those who need it.

Readers will recall that today's surveyor regularly works with two types of heights: ellipsoidal heights referred to the Geocentric Datum of Australia (GDA2020) and physical heights referred to AHD. Both are available through the NSW Survey Control Information Management System (SCIMS), the state's database containing approximately 250,000 survey marks on public record.

## Present challenges

Over the last half century, surveyors have continued to extend and propagate AHD, primarily in urban regions, along transport corridors and within large infrastructure projects. However, large sections of the state, particularly rural and remote NSW, and even some suburbs of Sydney, have never had AHD established. When it does exist in these areas, it has been derived from GNSS.

One important issue affecting the availability of AHD is mark destruction. Despite the best efforts in the Preservation of Survey Infrastructure (POSI), entire sections of original ANLN spirit-levelled AHD have been destroyed. Mark destruction is far higher in eastern NSW, with some level runs completely lost in city regions or along highways. In rural and remote areas, marks often still exist but can be difficult to find due to the removal of all physical connections listed on locality sketch plans (road mile posts, telegraph lines and relocated fences and gates) and road realignments, which alter chainages or deviate far from the original road corridors.

Fortunately, with enough effort and skilled crews, many ANLN marks previously identified as destroyed or not found in SCIMS are being successfully recovered in good condition, maintained and upgraded using Geoscience Australia's free online GPS processing service, AUSPOS. On some level runs in the Central West, DCS Spatial Services field crews report a recovery rate of 20% or better for such lost marks. Finding marks that had reference blazes cut on trees is even more successful.

Another challenge is mark movement. How well has the mark been able to hold its initial AHD height over 50 years? Thankfully, Australia enjoys rather stable tectonics, where vertical movements are generally infrequent and not substantial. However, there are exceptions, most notably in (usually very localised) subsidence areas caused by mining, major construction activities or reactive soils.

While AHD has been lost in regions of reactive black soil and any new value would soon be invalid following the next wet or drought season, problems also occur in less obvious regions. For example, a recent investigation into a height anomaly of about 0.14 m at the NSW-Victoria border revealed that issues arise with constraining ANLN junction points when new levelling observations are taken between them. Allowing for apparent mark instability at one junction point and using the new levelling data resulted in the discrepancy to be reduced by more than 50%. Such mark movement supports the notion that, after several years, first-order levelling surveys may tend to deteriorate to much the same order of accuracy as third-order levelling, which becomes apparent when runs are re-levelled.

The next challenge for AHD is technology itself. The era of GNSS technology led to the development of geoid or quasigeoid models to convert GNSS-derived ellipsoidal heights to physical heights, including the current AUSGeoid2020. Particularly over longer distances, this has made height determination and transfer more efficient than with the traditional techniques employed in the 1970s and 1980s.

While the role of DCS Spatial Services is to maintain NSW's survey control network, in the last 10 years it has taken on a more active role in both POSI and its effort towards saving AHD. To this end, several projects have been undertaken.

## Tide gauge monitoring

AHD was constrained by 30 tide gauges. DCS Spatial Services has continued to monitor the stability of tide gauges via precise optical levelling, then digital

levelling and recently precise EDM height traversing. Generally conducted every two to five years, these surveys monitor the stability of the tide gauge compared to a near array of stable survey marks. Port Kembla tide gauge has been regularly monitored for more than 20 years, while Fort Denison tide gauge has been resurveyed across 600 m of water from the island in Sydney Harbour to Mrs Macquarie's Point (and then back to the survey plug, now PM50000, installed in 1882 on the external northern wall of the former Department of Lands building). More recently, Eden tide gauge has been similarly connected.

Five GNSS Continuously Operating Reference Stations (CORS) were either specifically built or adopted to augment long-term monitoring of tide gauges located along the NSW coast in order to support sea-level studies: Fort Denison, Port Botany, Newcastle East, Port Kembla and Eden. This helps answer the question "Is the sea level rising or the land falling, or both?"

## Sampling ANLN level runs with AUSPOS

AHD is not homogenous. While multiple ANLN level runs may meet at a junction point, each level run has its own characteristics and behaves differently. Level runs may include (positive or negative) systematic errors, one-foot blunders, and may have been subject to mark movement over the last 50 years. Transferring or linking AHD heights from different ANLN runs can lead to serious complications. Sampling is therefore required to model these issues.

In a dedicated large-scale effort, AHD marks were sampled across NSW, as quickly as possible, for improvement of the national AUSGeoid model to provide a better connection between GNSS-derived ellipsoidal heights and AHD heights. This was conducted in a series of Saving AHD AUSPOS survey campaigns, starting in 2015 and employing multiple crews from all DCS Spatial Services survey offices.

In the first pass, every level run was investigated and sampled. A single field day was invested in each level run, while the longest runs out west (e.g. Broken Hill to Mildura) were allocated two days. Each crew typically had five to six GNSS receivers that were deployed over the length of the level run, predominately at Permanent Marks (PMs). While harder to locate, PMs were believed to be more stable than State Survey Marks (SSMs). Each mark was maintained (cleared, painted, and protected using generally three painted star pickets), photographed, observed by an overnight AUSPOS session, and SCIMS was updated with current metadata.

As part of NSW's contribution to the development of AUSGeoid2020, DCS Spatial Services collected more than 2,500 extended GNSS datasets (at least 6 hours but generally 12-24 hours duration) for AUSPOS processing on levelled benchmarks across NSW. These GNSS datasets informed the geometric ('sliver') component of AUSGeoid2020, thereby helping to provide a much better connection to AHD for GNSS-based height transfer, noting that its predecessor AUSGeoid09 was based on only 100 such control points in NSW. For many of these old benchmarks, GNSS datasets also improved their horizontal position, which was initially obtained by scaling off a map, often resulting in positioning errors of several hundred metres. This not only improved user access, but also allowed preservation efforts to be undertaken (you can only protect a mark if you know where it is).

## Observing FBMs and GBMs with AUSPOS

Meanwhile, a dedicated campaign is underway to find, maintain and collect AUSPOS datasets on Fundamental Bench Marks (FBMs) and Geodetic Bench Marks (GBMs), which were installed in the 1970s. These high-stability marks were specifically designed to maintain height, whether it be AHD, ellipsoidal or AVWS height.

## Recovering lost levelling

Noting the high quality and higher expense of good-quality spirit levelling, DCS Spatial Services has invested significant resources to recover lost levelling. A good example is the first-order levelling from the Snowy Mountains Hydro-Electric Authority (SMA), which included some 1,000 marks over 1,000 km from Cooma to Tumut and on to the Victorian border, surveyed in

the days of the Snowy Mountains Hydro-Electric Scheme (construction from 1949 to 1974). Unfortunately, none of these marks were ever entered into SCIMS. To date, nearly 15% of these marks have been recovered, maintained and observed by DCS Spatial Services, which is a great result considering that SCIMS basically held no levelled heights at all in Kosciuszko National Park, and these marks are now 70 years old.

In a similar fashion, DCS Spatial Services continues to recover, on an ad-hoc basis, 1950s National Mapping Division levelling. As a bonus, this data is predominately located in remote regions, with level runs reaching out to a graticule of 1° map corners, which are often located amongst a few scattered bushes in the middle of an outback paddock.

DCS Spatial Services was also planning a similar project to recover Rural Bench Marks (RBMs) with accurate AHD heights, installed by the Australian Capital Territory (ACT) at the same time AHD was being observed. While about 450 of the 1,200 RBMs installed are in NSW, only a handful are included in SCIMS. A planned joint project with the ACT Office of the Surveyor-General to recover these RBMs was cancelled in 2020 due to the COVID-19 pandemic. It has now been pencilled in for the 2021/22 financial year.

## High fidelity (HiFi) Saving AHD

In the Central West, DCS Spatial Services is nearing completion of its HiFi Saving AHD project. In this area, every rural ANLN mark has been searched for, then maintained and upgraded (including a 6+ hour AUSPOS session). To date, approximately 1,200 km of levelling has been audited and surveyed, while another 400 km is planned in the next few months.

All work has been conducted via day trips, usually by a single crew, one week of every month or so. The number of recovered ANLN marks has exceeded expectations, with evidence that some have been used by other surveyors. Whilst it is fortunate to recover these marks, it is disappointing that surveyors have not reported these finds (e.g. via the NSW Survey Marks Mobile App), so they can be shared for everyone's benefit in SCIMS. DCS Spatial Services is considering expanding this project to its other survey offices including Lismore, Coffs Harbour, Newcastle, Sydney and Nowra.

Overall, the ongoing Saving AHD campaigns have to date yielded 900 additional extended GNSS datasets on levelled benchmarks since the computation of AUSGeoid2020 on 1 February 2018 (Figure 1). While the Intergovernmental Committee on Surveying and Mapping (ICSM) currently does not plan to update AUSGeoid2020 into the future, these datasets will be very valuable for the continuing improvement of AVWS. (Figure 1)

## Digitising historical levelling records

In NSW, AHD is simply a set of numbers printed on some 3,600 cardboard sheets, which are now safely stored in State Archives. These levelling cards summarise each level run and are abstracts of the original field notes. At some stage, these AHD values were manually typed into SCIMS (naturally including unknown typos associated with all manual data entries), and an electronic master version does not exist. In fact, despite the efforts by academics and federal agencies over the years, the original AHD values cannot be reproduced. The value on the card is AHD, warts and all.

The historical levelling cards, detailing the measured and adjusted height differences between benchmarks and junction points, are progressively being preserved and digitised. The first and now completed step was to scan all cards into TIF and PDF versions, safely archived in a digital environment. The intent was to convert these files to smart digital files, but unfortunately Optical Character Recognition (OCR) failed. Therefore, each card was manually converted to Excel files (one per level run), which was an enormous and time-consuming task but well worth the effort. Quality assurance of this manual data entry process is currently underway.

Once complete, the values in SCIMS can themselves be checked to remove any typos that have lain dormant for decades. Using all original ANLN levelling, supplemented with all digital levelling archived from internal and external organisations, combined with 3D GNSS observations and AUSGeoid2020, we can then detect and correct AHD blunders and issues. All data will be combined into the all-in-one state adjustment and complement each other. The enormity of this task and its outcomes should not be underestimated. While Victoria has already completed a state-wide levelling adjustment, other jurisdictions are now also starting similar projects.

## Building the NSW levelling adjustment

Together with the results of data-mining existing levelling files in the DCS Spatial Services archive, the digitised historical levelling data is being used to generate a single, state-wide levelling adjustment for NSW. This work is still ongoing, but clearly it will provide huge benefits to the profession in regard to accessing height

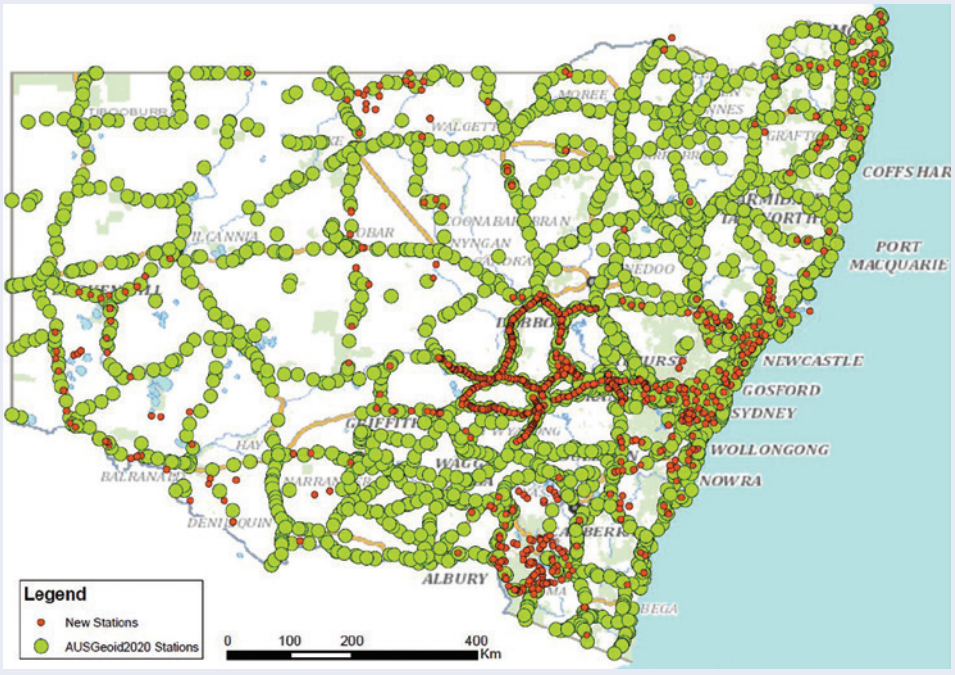


Figure 1: GNSS datasets of at least 6 hours duration on levelled marks observed by DCS Spatial Services, including those contributing to AUSGeoid2020.

information across the state. Currently, the NSW levelling adjustment comprises about 132,000 measurements and 98,000 stations (Figure 2).

It should be emphasised that there are no plans to readjust AHD. Under the original rules, jurisdictions cannot modify the height of junction points without federal approval. The height of intermediate marks can be updated if a blunder or mark movement is detected and proven, which is part of the day-to-day maintenance.

## Ongoing datum modernisation efforts in NSW

DCS Spatial Services is responsible for the maintenance of the NSW survey control network. Datum modernisation and further improvement of survey infrastructure is required to accommodate the increasing accuracy and improved spatial and temporal resolution available from modern positioning technologies such as GNSS to an ever-broadening user base.

This has led to the establishment of CORSnet-NSW, Australia's largest state-owned and operated GNSS CORS network. CORSnet-NSW is not only the backbone of GDA2020 across the state but also provides fundamental positioning infrastructure that is authoritative, accurate, reliable and easy-to-use for a wide range of applications. Furthermore, with all sites contributing to AUSPOS, it comprises a fundamental, high-density and long-term component of AUSPOS infrastructure within NSW.

Consequently, AUSPOS campaigns have developed into a capable and reliable alternative to traditional static GNSS baseline surveys, simplifying field work logistics and reducing processing times. This has substantially accelerated the process of including additional survey marks into the GDA2020 state adjustment to improve user access to GDA2020 coordinates and uncertainties on public record through SCIMS. AUSPOS has become the primary survey technique used by DCS Spatial Services to preserve AHD.

In support of these datum modernisation efforts, DCS Spatial Services is currently building an updated passive survey control network (in the Eastern and Central Divisions) with a minimum of one fundamental survey mark observed by 6+ hour AUSPOS every 10 km. Its vision is to ensure that any future user is no further than 5 km (and often much less) from such a fundamental mark providing direct connection to datum. Similarly, levelled AHD marks are observed by 6+ hour AUSPOS every 10 km, often at far greater density. This will allow users to achieve DCS Spatial Services' vision of a Positional Uncertainty (PU) of 20 mm in the horizontal and 50 mm in the vertical (ellipsoidal height) component anywhere in the state and easily apply transformation tools to move between current, future and various historical datums and local working surfaces (such as Standard Datum or Railway Datum).

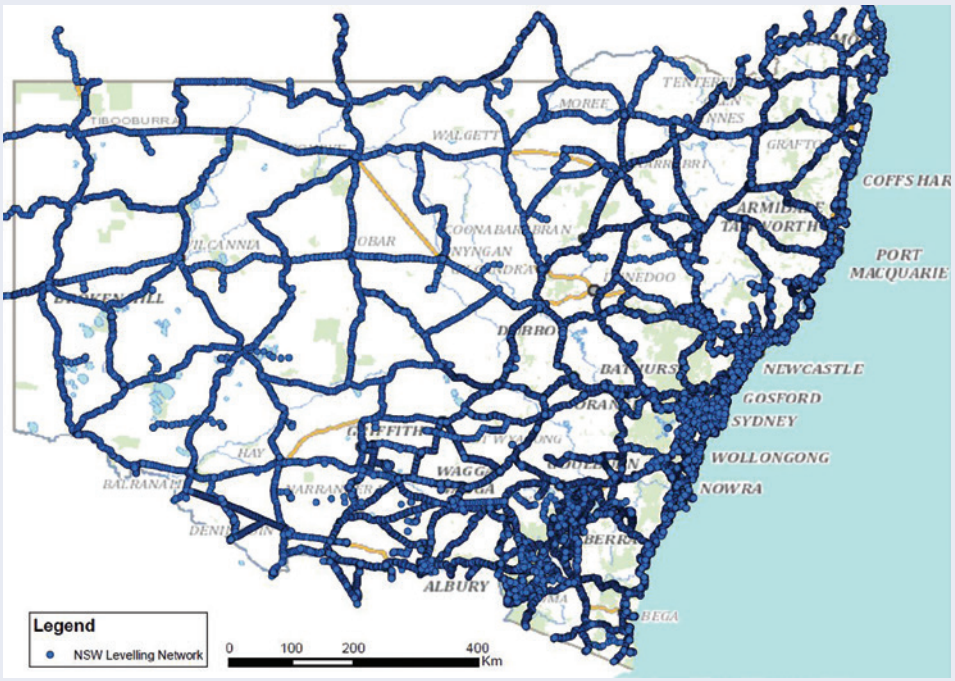


Figure 2: Location of benchmarks included in the NSW levelling adjustment.

## Fifty more years ahead?

As AHD celebrates its 50th anniversary this year, efforts continue to be undertaken for its maintenance and modernisation in NSW, not only preserving but also improving user access. Through its Saving AHD projects, DCS Spatial Services helps ensure that users have continued and easy access to AHD, while also providing a solid foundation for the continuing improvement of AVWS as an alternative for those requiring higher-quality physical heights.

There can be only one legal vertical datum, and currently there is no planned push to replace AHD. DCS Spatial Services has yet to implement AVWS but continues to investigate and contribute towards it. Our Saving AHD projects ensure that users have access to their vertical datum of choice. These efforts may also help AHD celebrate more milestones in the future.

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