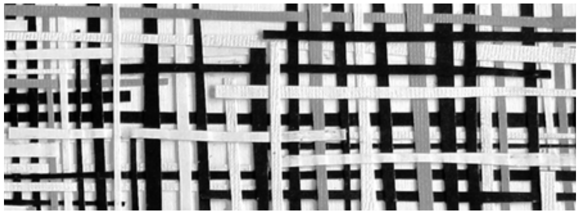

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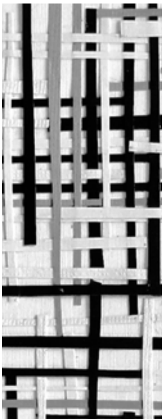

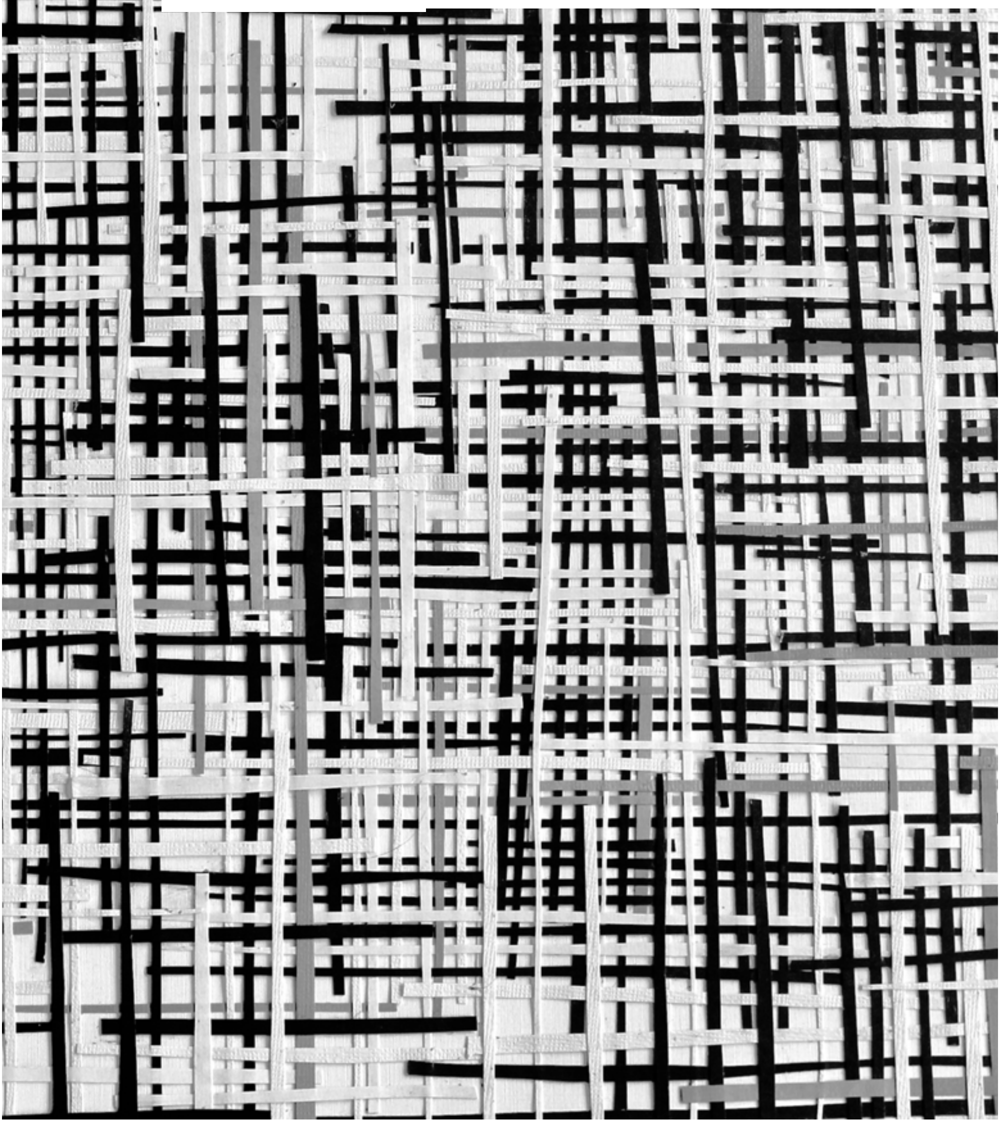

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Book Review: *Semut*, by Christine Helliwell

Peter Knight

I received an email from Christine Helliwell in May of 2020 wondering whether there was any chance of obtaining an article that had appeared in the New Zealand Surveyor in December 1946, and for which she had been searching to no avail.[1] She wrote that she was at the Australian National University in Canberra and writing a book, "… on an Australian special operation that took place behind Japanese lines in Borneo during WWII. The operation's commanding officer was a New Zealand surveyor named G.S. (Toby) Carter, who worked in Borneo for Shell Oil before the war. He was a remarkable man who has never received his proper due." I called our National Operations Manager Jan Lawrence in Wellington, who was able to reach for the issue in question from the bookcase in her office. In gratitude for receiving the article Christine kindly sent me a proof of her book *Semut, The Untold Story of a Secret Australian Operation in WWII Borneo.*

I am aware of three published book reviews of *Semut*[2], and another by Gordon Andreassend is to appear in Survey and Spatial in March 2022. These reviews serve well to describe much of the book's coverage of the military operation conducted by Z Special Unit during the months prior to the Japanese surrender in 1945, and led by Major Gordon 'Toby' Carter. Twenty-three other New Zealanders, and Australian surveyor Keith Barrie were among the hundreds involved in the parachuting of guerrilla soldiers into the upland jungle of Sarawak 1000 miles distant from the nearest allied base. Helliwell, a New Zealander herself, has helped provide new and overdue recognition in both Australia and New Zealand of the heroic achievements of the Semut operatives. Grateful for the reviews so far, I would like to take a somewhat different approach in my review, noting that Helliwell has not only given us a historical account of the first order, but her breadth of knowledge, and understanding and experience as an anthropologist has produced a multilayered book that I believe full of meaning relevant to our relationships with place, our relationships with each other—particularly cross-cultural relationships—and perhaps something about transcending or transforming the influences on our thought attributable to the societies in which we live.

Helliwell describes the forest environment in which the story takes place.

> Massive trees, often hundreds of years olds, blanketed vast areas, their huge symmetrical trunks rising like sculpted pillars before proliferating far overhead into a canopy of green, broken only here and there by patches of light torn by those that had fallen. Climbers such as lianas and rattans used the trees as supports, twining themselves round and round trunks and trailing from branches in endless matted webs, in some cases—as with the aptly named strangling fig—choking their hosts to eventual death in a tremendous efflorescence of sun-seeking foliage and aerial roots.
>
> Ferns dotted the ground as well as tree trunks and the canopy itself, creating their own miraculous hanging gardens extending up to several metres in diameter. Mushrooms and other fungi grew in profusion among the rotting vegetation and undergrowth of the forest floor, often displaying a vivid, almost incandescent beauty. And everything was forever wet, captive to the frequent downpours and incomparable humidity that characterise this equatorial region
>
> In spite of the shadows cast by the giant trees, the jungles were places of interminable sound and movement. Birds flashed and darted overhead, Monkeys swung themselves from branch to branch with astonishing agility, and butterflies—sometime huge and brilliantly coloured—fluttered in murky glades. Not all life here was benevolent; crocodiles skulked around rivers, streams and the frequent marshy areas, and snakes—including the deadly king cobra, which can 'stand' to a height of a metre or two—lurked out of sight. Add to these various species of deer, wild pigs, sun bears, the beautiful secretive clouded leopards, orangutans and their relative the gibbons, and you gain some sense of the bewildering abundance of the life the jungles sheltered.[3]

An idea of the topography is provided by the Encyclopaedia Britanica:

> The general character of the island is mountainous. The highest peak is Mt. Kinabalu 13,455 ft. A great jagged outcrop of granite emerging out of a sandstone formation almost from sea level to form

> the highest mountain in southeast Asia and one of the splendid mountains of the world.
>
> Seen from the summit of Kinabalu or any other of the high mountains, Borneo appears as a confused, irregular tangle of ranges, hillocks and great winding valleys with none of the symmetry characteristic of Burma or Java, Sumatra or Malaya. Thus it is one of the hardest countries in the world to move around in on foot. To follow a compass bearing is an unbearable experience; it will inevitably involve crossing and recrossing stream after stream and climbing hillsides, gullies and landslides in wearisome succession. The stranger to Borneo who is fortunate enough to get off the beaten track is usually irritated by the tortuous trails which the native peoples use to travel vast areas of jungle. But from centuries of experience and an unsurpassed feeling for jungle life, these people—once head-hunters, now peaceable—have usually worked out the best routes, however indirect these may appear.[4]

The jungle of Borneo is the home of the many and various groups of indigenous Dayak people who have inhabited the forest for untold centuries. Helliwell speaks of, " … the astounding intricacy and beauty of their carvings, weavings and painting—which now sells or staggering prices in the galleries of the West—and the genius of their environmental adaptions."[5] As a student Helliwell lived in the jungle for 20 months in a Dayak longhouse. Over the course of many years and much time spent in Borneo she has become widely recognised for her knowledge of its indigenous people. This knowledge of people and place is embedded in *Semut*; it is not promoted or overstated, but accounts for the creative insight that gives the story its depth and range.

Helliwell states that, "My aim is not only to describe and assess the operation, but also to convey something of how it felt for the operatives—and also sometimes the Dayaks—who took part."[6] The Semut operation was an incredible situation in anthropological terms bringing together warriors from two completely different races in an extraordinary balance. In the jungle there was no question of the superiority of the Dayak in almost every facet of guerrilla warfare and the total dependence of the Semut operatives upon them. What the Dayak must have known, however, about these awkward men, was that the Semut soldiers were connected to great powers, as evidenced by their, dramatic arrival from the air, and their ability to summon further men and materials by the same means. The great powers, were nevertheless very distant, and the operatives were humble enough to understand that an equal exchange was taking place. The emotional experience of this exchange is one that Helliwell would like to convey to the reader. This is because it is our personal experiences, registered in our hearts and minds that constitute the thing we value the most, the truth. We cannot deny that we are emotional beings, creatures of love, and that this is where the real power lies. This is not to say that personal experience may not be corrupted, and become false, but when that happens it is most likely to be due to our need to conform to the meanings and interpretations prevalent in our society.

Helliwell shows Carter to be a true hero and to have defended the Dayak with every ounce of his power and strength. Working with Carter's army the Dayak would, '… regain their freedom'.[7] Carter notes that, '… we were never short of local food supplies …', and that the Dayak were, '… Nature's gentlemen and the soul of hospitality to the traveller'.[8] Carter also informs us, in his humble way that, 'It is not possible for a white man to carry heavy loads for long in the tropics …', and that Dayak porters, including women porters carried their packs for them. However, in the same article for the New Zealand Surveyor in 1946, Carter refers to the Japanese as, ' … a barbarous Asiatic race',[9] and felt that the Dayak, ' … held no half-baked ideas of political independence.'[10] In the latter two quotes Carter's tone of superiority is false. I am not disparaging Carter, we are all a mixture of truth and falsity, I am signalling that when reviewers speak of Helliwell, setting the record straight,[11]it is more than historical accuracy that comes into play. Helliwell tells of certain Dayak warriors receiving decorations (as did Carter) after the war for their roles in Semut. The recognition and reward are good and honourable (hence true) gestures toward the Dayak, but neither empire, commonwealth nor the independent nation states of Malaysia or Indonesia who govern the forests of Borneo, have preserved the forests upon which the Dayak depend (and hence have not been true to the Dayak).[12]Many of us may feel how small and vulnerable we are, how much we need the Dayak, how wonderful the relationship is both culturally and personally, between us and the forest dwellers. It is the false superiority of power wielded from a distance that needs overcoming, and a true story might go some way toward accomplishing this.

The adventure Helliwell writes about is not over; the struggle for survival of the characters of *Semut* is the struggle now being waged all over the world, and in all our hearts. As in Semut we must accept the help of those who know how to live in ways that might allow us creative insight for our future. From facts to meaning is a transition Christine encourages when she writes that she in interested in conveying her story in such a way that we might share the feelings of the participants.[13] She wants us to share these feelings not for our entertainment—though that is not excluded—but as part of the thrust of the book in its anthropological sense. The book carries an important message, and Helliwell has written it so well the message has a chance of reaching a great many at this critical time.

Notes

[1] Carter, G. S. (December 1946). *Sarawak Adventure*. New Zealand Surveyor. Institute of New Zealand Surveyors. **19** (3): 246–257.

[2] Byrne, Peter (2021) *Semut The untold story of a secret Australian operation in WWII Borneo, Position,* Issue 115, Oct/Nov 2021. P.41. https://issuu.com/theintermediagroup/docs/position_115_october-november_2021?fr=sOTc3NjQyODQxNjI

McRae, Andrew (2022) *Book details young NZ soldiers' role in foiling Japanese army in Borneo,* Radio New Zealand, 8:23pm 16th January 2020. https://www.rnz.co.nz/news/national/459655/book-details-young-nz-soldiers-role-in-foiling-japanese-army-in-borneo

Hill, David (2021) *Jungle Saviour*s, Listener, December 18th 2021, Issue 51, 2021, p.57

[3] Helliwell, Christine (2021) *Semut, The untold story of a secret Australian operation in WWII Borneo,* Michael Joseph, Penguin Random House Australia, p.17.

[4] *Encyclopædia Britanica*, 1969, Volume 3, p.961-962.

[5] Helliwell, *Semut*, 27.

[6] Ibid., 15.

[7] Ibid., 251.

[8] Ibid, 251.

[9] Carter, *Sarawak Adventure*, 246.

[10] Ibid., 251.

[11] Hill, *Jungle Saviour*s, 57 (see note 2 above).

[12]'In the 1980s and 1990s, the forests of Borneo were levelled at a rate unprecedented in human history, burned, logged and cleared, and commonly replaced with agriculture. The deforestation continued through the 2000s at a slower pace, alongside the expansion of palm oil plantations. Half of the annual global tropical timber procurement is from Borneo. Palm oil plantations are rapidly encroaching on the last remnants of primary rainforest. Much of the forest clearance is illegal.' https://en.wikipedia.org/wiki/Deforestation_in_Borneo. Accessed February 2022.

[13] Helliwell, *Semut*, p.15.

Reconfiguring Land and Property: What is a Subdivision ?

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Introduction

Several cases brought to the courts recently have allowed for some interesting discussions about what is, and what is not, a subdivision. The word subdivision has a common language use and meaning that concerns division of a parcel of land for separate use, development or occupation. The Resource Management Act 1991 provides a 'precise transactional'[1] definition consisting of several types of subdivision which has been examined in the context of a variety of interests less than fee simple. The discussions and decisions have significance or surveyors.

This paper analyses three recent case decisions related to the various definitions of subdivision. The case decisions question statutory and common use definitions of the term. Their findings are important because they determine whether various types of land development will be subject to statutory regulation (RMA 1991 and district plan consent process). The cases also reference different, and special land tenure arrangements which might provide new opportunities for viewing a range interests in land and property in current contexts.

Subdivision Defined

The use of the terms 'allotment' and 'subdivision' is so central to the activities of a professional and cadastral surveyor that their meaning appears to go without saying. So accepted and unquestioned is the word subdivision that legal property texts only explain it (if at all) by reference to its context—the regulation of the subdivision process. Even the few survey law texts that do mention subdivision (Kelly 1937, NZIS 1990, McKay 2009), only describe the regulation and processes of subdivision and not the meaning of the term. Furthermore, as observed in one of the cases discussed below,[2] the court even had difficulty finding parties interested in engaging with the question.

To some extent the lack of precise legal attention to the definition of subdivision is surprising since cross lease developments which are essentially a legal and administrative work-around to avoid the appellation of subdivision, were being used from the 1950s. The primary incentive for cross leases was that they were not subdivisions in the regulatory sense, even though separate interests in land were recorded and separate certificates of title were issued. There might have been plenty of opportunity then, since the 1950s to examine what was, and what was not a subdivision, but this has not been the case, and it has been left to posterity; now in fact, to raise these questions. Several recent court cases have explicitly focused on the definition of subdivision in various contexts.[3] These cases suggest that there are practical and non-trivial issues at stake, with significant consequences to land tenure arrangements.

Some earlier case decisions have also commented on what defines a subdivision. In Re An Application by Hamilton City Council [4] a subdivision to create an allotment is characterised such that: "It is separately defined, … and it is intended that it may be dealt with separately."[5] In the Court of Appeal in Waitemata County v Expans Holdings Ltd[6] the different judges stated, " … one has to fall back on the commonly accepted meaning of the word."[7] The judges furthermore noted "By reference to the plan they can be separately described and dealt with in law."[8] and " … it must be accorded common sense meaning which will conform to the context in which it is used."[9] The Court of Appeal, in re Transfer to Palmer,[10] stated:

> The phrase "subdivision into allotments" has no legal meaning, nor is it a term of art. The section refers to dealings with land, and the phrase must be understood in a way in which persons who are in the habit of dealing with land would understand it … . The ordinary meaning of the term "subdivision into allotments" is that there is either an actual demarcation of the allotments on the ground, or, at any rate, a plan of the land showing the allotments as subdivided – something, in short, to show clearly to a purchaser that he is purchasing an allotment of land which has been subdivided into allotments.[11]

The elements of a subdivision, therefore, seem to be: 1) the identification of a parcel of land, and 2) the ability to claim that parcel under a defined tenure arrangement in the name of identified interest holders.[12] The professional responsibilities for land subdivision are clear: surveyors identify and define land parcels and conveyancing solicitors apply for title recording the tenure in the land and the proprietor—these are the people, " … who are in the habit of dealing with land."

The Purpose of Subdivision

The purpose of subdivision is to provide land allotments of a size and location suitable for use and occupation. Any land development proposal firstly relies on the identification of a parcel of land (an allotment) upon which development can take place. To create appropriate allotments for occupation, use and development, land parcels are usually divided (subdivided) according to location, size, shape, access, etc., by the process of subdivision. A subdivision is a division of a parcel of land that has previously been divided. For example, in New Zealand we may consider an original Crown Grant to have arisen from a division of land that may (by various means) have been acquired from original customary Maori owners, to provide for separate ownership and new uses. Subsequent divisions are therefore subdivisions.

The division of land by the surveying of discrete parcels, and having them granted by the Crown as estates in fee simple to registered proprietors, provided the basis for the encouragement of settlement in New Zealand and the development of a property market. Subdivision (and the consequential issue of a title) feeds the property market and supports the security of subsequent investments in land. Furthermore, because of the powerful influence of the property market on national and personal wealth, there is a very strong reliance on property law in New Zealand. Equivocation in the application of legal terms in our property law requires resolution through clear judicial decisions providing guidance on the application of terms used in the vocabulary of property-rights.

Control of Subdivision

The regulation of subdivision of land has generally been within the jurisdiction of local authorities, initially to ensure adequate access and services but more recently to manage the extended effects of the intensification of land use resulting from subdivision.[13] Planning legislation, as developed throughout the 20th Century, has provided local government with the means to regulate the use, occupation, development and subdivision of land. For example, the Town and Country Planning Act 1977 states that, 'control of subdivision' is a matter to be dealt with in District Schemes.[14] However, by 1991, with the enactment of the Resource Management Act, it was apparent that land development was becoming more varied, and that the definition of subdivision and allotment needed to reflect alternative rights in property. Primarily, a subdivision required the identification of a parcel of land over which a Certificate of Title could be issued, and this could allow for either fee simple tenure or various lease arrangements. Cross leases, Unit titles and other leases which "…could be for 20 years or longer …"[15] were incorporated as separate definitions of subdivision.

Statutory Definitions - subdivision

There have been some definitions of the term subdivision in earlier legislation. The Land Subdivision in Counties Act 1946 s 2 (2) stated: "For the purposes of this Act any division of land, whether into two or more allotments, shall be deemed to be a subdivision of that land for the purposes of sale if at least one of those allotments is intended for sale." The Municipal Corporations Act 1954 s 350 s (2) stated: "For the purposes of this Part of this Act any land in a district shall be deemed to be subdivided if,

> (a) Being land subject to the Land Transfer Act 1952, and comprised in one certificate of title, the owner thereof, by way of sale or lease, or otherwise howsoever, disposes of any specified part thereof less than the whole, or advertises or offers for disposition any such part, or makes application to a District Land Registrar for the issue of a certificate of title for any part thereof … ."

In the Land Transfer Act 1952 subdivision is not given a specific definition, although the context suggests that a subdivision is used to describe the separation of one or more parcels of land.[16]

There are, moreover, different contexts and uses of the word subdivision, such that the Local Government Act 1974 refers to a subdivision in this sense: "… **ward** means a subdivision, for electoral purposes, of the district of a territorial authority." Clearly this use of subdivision does not refer to a separate allotment, nor to a parcel under defined ownership.

The Property Law Act 2007 uses subdivision in the slightly different sense of a development of land that has created separate uses likely to be held under separate tenure arrangements, with a separate Record of Title and different uses. For example, roads, accessways, reserves, and fee simple estates.[17] It is the Resource Management Act 1991 which provides for the explicit meaning of subdivision, and therefore, this Act has the clearest definition of subdivision.

Resource Management Act 1991 s 218 Meaning of subdivision of land

> *(1) In this Act, the term* ***subdivision of land*** *means -*
> *(a) the division of an allotment -*
> *(i) by an application to the Registrar-General of Land for the issue of a separate certificate of title for any part of the allotment; or*
> *(ii) by the disposition by way of sale or offer for sale of the fee simple to part of the allotment; or*
> *(iii) by a lease of part of the allotment which, including renewals, is or could be for a term of more than 35 years; or*
> *(iv) by the grant of a company lease or cross lease in respect of any part of the allotment; or*
> *(v) by the deposit of a unit plan, or an application to the Registrar-General of Land for the issue of a separate certificate of title for any part of a unit on a unit plan; or*
> *(b) an application to the Registrar-General of Land for the issue of a separate certificate of title in circumstances where the issue of that certificate of title is prohibited by section 226, -*
>
> *and the term* ***subdivide land*** *has a corresponding meaning.*

The further part of s 218 defines the term 'allotment' which is relevant to the definition of subdivision of land, but not specifically part of the judicial decisions nor of this analysis. Legislative interpretations are usually statute specific, and one of the lessons of the cases examined in this paper is that judicial interpretations may look beyond this statutory definition to other contexts and extrinsic evidence. It is the applicability of the above RMA definitions of the types of subdivision of land which becomes the focus of this case law analysis. Let us now examine some relevant case law to illustrate how the courts have decided the question of interpretation and application of the term, 'subdivision of land'.

Covenants - Congreve v Big River Paradise

In 2005 a dispute arose about the interpretation and enforcement of a covenant which limited the extent to which a parcel of land could be subdivided.[18] In this case a covenant was registered on the servient title to restrict the development potential of a lot to enable a maximum of 3 allotments with one dwelling on each allotment.[19] The covenant was writte

> No subdivision of the servient lot shall permit the creation of more than three separate allotments nor permit more than one dwelling to be erected on each such lot.

Big River Paradise Ltd was the servient/burdened tenement on the north bank of Te Mata-au (Clutha River). The Congreve Family Trust was the owner of the dominant/benefited tenement on the south bank of the river. Implicit in the purpose of the covenant was the protection of a semi-rural outlook across the river.

Big River Paradise had obtained a land use consent for earthworks, infrastructure and design controls for the establishment of 52 dwellings on land parcels to be leased for a period of less than thirty years. Because of the leasehold tenure proposed, this development did not constitute a subdivision (as defined by s 218 RMA 1991), so needed no subdivision consent. The leases were explicitly a device of this development to get around the RMA definition of subdivision thereby avoiding the regulatory intervention of the territorial authority, the Queenstown Lakes District Council.[20]

Congreve objected to the land use consent approval and the case was extensively examined in the Environment Court; three hearings at the High Court; an appeal to the Court of Appeal, and a further Congreve objected to the land use consent approval and the case was extensively examined in the Environment Court; three hearings at the High Court; an appeal to the Court of Appeal, and a further appeal to the Supreme Court of New Zealand.[21] At least ten judges at different levels of the court hierarchy passed judgement on this case. The Environment Court case questioned the identity and names of the parties involved - the application for consent was made in the name of a non-existent entity - and the condition that the houses would have to be removed after 30 years. The Environment Court is focused on resource management, land use and the sustainable management of natural and physical resources. It is, of course, beyond the jurisdiction of the Environment Court therefore, to consider private property law.[22] The higher courts questioned the interpretation and application of the covenant.

After reviewing multiple precedent cases, and observing that statutory definitions may change,[23] Williams J. would not thereby allow that the application of a covenant should also change. In the High Court (Williams J.) concluded " … that the construction of the covenant is not limited by the definitions of 'subdivision of land' and 'allotment' in the RMA s 218."[24] The term 'subdivision' in the covenant, therefore, was to be " … accorded a common sense meaning which will conform to the context in which it is used …",[25] or as the commonly accepted everyday meaning. The proposal for 52 leasehold sites therefore, " … went well beyond what the covenant allowed and amounted to a subdivision of that land, even though not a 'subdivision of land' for the purposes of s 218 of the RMA … ."[26]

Big River Paradise appealed to the Court of Appeal whichsupported the High Court's conclusion that the proposal was a subdivision in the ordinary sense of the word:

> The Resource Management Act defines 'subdivision of and' for the specific purpose of identifying the types of subdivision which are subject to control under that Act. There is no obvious logic in applying that definition to 'subdivision' when used in the restrictive covenant given the very different context.[27]

A further appeal to the Supreme Court of New Zealand [28] was also unsuccessful. It is relevant here to quote another precedent case, as it has relevance to the discussion about the Clearspan and Cross lease decisions below. *Re Application by Hamilton City Council* [29] was brought to decide about the power of a local authority to levy a reserve contribution for a cross lease development and to decide whether additional lots are created:

> To adapt the provision for conventional subdivisions for application to cross lease subdivision, one should consider the reality of dwelling houses, or sites for dwelling houses, that are capable of being dealt with and disposed of separately. For that purpose *it is of no consequence* that what is dealt with or disposed of is not a freehold estate in one lot, but an undivided joint interest in a freehold estate, together with a leasehold lease in the defined site of a building and any consequential covenants about exclusive and common use of the grounds.[30] (emphasis added)

This case is further evidence that definitions (e.g. of 'subdivision') are often context specific, so in Application by Hamilton City Council, for the purpose of assessing reserve contributions, a cross lease was a subdivision.

Alternative Tenure arrangements - a) Cross Lease

Cross leases were a common form of land development since the middle of the 20th century - usually arrangements to allow for multiple dwelling units within one building or separately on one parcel of land.[31] Cross leases were a convenient form of development because they were not defined as subdivisions of land under legislation and regulation applicable at that time; surveys were simply required to illustrate buildings that were subject to a lease, and some exclusive occupation or shared spaces. The primary purpose of the cross lease plan is to illustrate the property boundaries. Infrastructure servicing could be combined and was therefore cheaper, and planning consent was not required. On the other hand, the property rights acquired were often misunderstood and caused some conflict amongst owners and perhaps also devalued the property.[32] In the RMA 1991 cross leases were incorporated into the definition of a subdivision, which meant that subdivision consent was required to create cross lease titles.

The cross lease arrangement consists of an undivided share of the underlying estate of fee simple as tenants in common,[33] along with a lease of the physical extent of (usually) a dwelling unit for 999 years (effectively perpetual), and (also usually) a covenant assigning exclusive occupation to an area around the dwelling. This allows for separate titles to be issued to all parties (a cross lease composite title) that can be transacted as freely as any other form of title. Along with other subsequent issues with this form of tenure,[34] many owners believed that they were buying an unencumbered fee simple title to their flat, and had similar freedoms to manage their flat and land.

The lease of a cross lease title is of the three dimensional building envelope as it is at the time of the lease creation. This is a boundary fixed by the permanent structure rather than by a survey fix,[35] and it is illustrated as a building outline on the survey plan. One of the key problems with Cross lease ownership is that any alteration of the structure outside of the original structure is therefore outside of the lease, and makes the structure an illegal intrusion into jointly owned land. Similarly, if the structure is destroyed then the lease is no longer valid—the structure no longer matches the lease.[36]

The survey plans that depict this cross lease arrangement show a divided parcel: a lease area corresponding to the buildings; a covenant area corresponding to the exclusive use areas;[37] and if necessary, common land. Furthermore, if an exclusive use area is defined on a plan it is not a legal boundary and can be altered by agreement of the joint tenants.[38] Under all the relevant legislation prior to the RMA, this did not amount to a subdivision, so local authority regulations regarding allotment sizes, infrastructure services and access were avoided. However, to all intents and purposes, the land was subdivided, separate parcels could be transacted, and the land use changes resulted in increased urban residential density.

In 1991, the Resource Management Act specifically included cross leases into the s 218 definition of a subdivision.[39]

> **RMA s 2. cross lease** means a lease of any building or part of any building on, or to be erected on, any land -
> (a) that is granted by any owner of the land; and
> (b) that is held by a person who has an estate or interest in an undivided share in the land

This closed the loophole that allowed such developments to avoid the regulatory control of territorial authorities, and must necessarily have slowed the use of this tenurial device.

In 1999 the Law Commission recommended the phasing out of cross leases and conversion of their titles to separate fee simple titles or to Unit Titles.[40] The legislature chose not to intervene to promote this recommendation, but many land professionals have made efforts to avoid cross leases and to convert cross lease titles to fee simple allotments.

The efforts to convert cross lease created new problems of having to comply (often retrospectively) with council subdivision standards. However given that the effects of this tenure change had no impact on site occupation or urban density, nor any additional impacts on urban infrastructure, many surveyors thought it was reasonable to assert that cross lease conversion to fee simple titles did not amount to a subdivision.

Progress through the conversion process has been slow; partly because of apathy by cross lease proprietors, but partly because of the barrier of requiring a subdivision consent to acquire new fee simple titles. In the past, territorial authorities have allowed cross leases as a way to increase urban density and to allow shared services, so arguably, the conversion process is just a tenure issue rather than a resource management issue where the sustainable management of natural and physical resources and the effects of activities needs to be considered.

Alternative Tenure arrangements—b) Exclusive use covenants

Cellphone towers are an essential part of our physical and social infrastructure, and a network of towers is required across the countryside. An easy way to accommodate the property interests of cellphone tower sites is to subdivide a utility parcel (which is often exempted from normal subdivision rules by district plans) and provide for fee simple ownership of such (usually) small parcels. Alternatively, and in order to avoid having to subdivide an allotment, telecommunication companies often enter into an occupation lease with property owners over a small parcel of their land, for less than 35 years[41] (otherwise, again the arrangement would be captured within the s 218 definition of subdivision), and also presumably for an annual lease fee to the fee simple owner.

The primary test case is *Spark v Clearspan*. This case addresses the question about whether divisions of interests in land amount to a subdivision of land. A company, Clearspan, is in the business of acquiring interests in land upon which telecommunication (telco) companies have established their cellphone towers. The company actively seeks out parcels of land encompassing cellphone infrastructure. By aggregating their interests in these parcels, they expect to benefit from their enhanced negotiating position to profit from the occupation and use leases.

The Clearspan arrangement

Under this arrangement, Clearspan acquires a share as tenant in common of the whole parcel of land and enters into covenants which identify exclusive-use areas. The original land owner has the exclusive use of the primary parcel and Clearspan has the exclusive use of the small parcel of land subject to the lease for the cellphone tower site. In effect, Clearspan then takes over as the lessor of the land to the telco company. The original owner gets a lump sum payment for providing a tenancy in common interest (the share is related to the relative size of the leased land) over all their land, and Clearspan purchases the tenancy in common interest and gains the annual lease fee, and presumably, the ability to negotiate favourable terms for lease renewals. A survey plan must be deposited to record the exclusive use covenant areas, so in effect separate parcels are created in an identical way as is illustrated on a cross lease plan. A difference is that the lease is between one tenant in common (who has the exclusive occupation area) and an external lessee (the telco).

The telcos seem to be generally happy with the arrangements they make with each individual landowner. There are around 4000 sites around New Zealand, so there is quite an administrative burden. However, presumably there exists some threat from the increasing bargaining power of Clearspan that the telcos wish to limit. Just as cross leases were developed as a legal device to utilise different tenure possibilities and avoid costs and regulation, these arrangements are now being registered which allow for the transfer of a defined (proportional to the area provided as exclusive use) but undivided share of the fee simple title as tenants in common and the identification of exclusive possession areas for telecommunications infrastructure. A barrier to further lease takeovers is to have such tenancy in common and covenant arrangements declared as subdivisions, and therefore being subject to territorial authority regulation. This would mean that subdivision consents would be required and then territorial authorities could impose conditions including right of way easements to be registered, accessways to be formed, and development contributions to be paid. It is, therefore, no surprise that a court challenge was brought by the telcos to seek a determination that the arrangement was in fact a subdivision.

Analysis of case decisions – Clearspan

An application was made initially to the Environment Court, heard by two Environment Judges, then appealed to the High Court, with one judge, then appealed further to the Court of Appeal, heard by three judges. This all took nine months; clearly a matter of great importance to the parties, but also for an analysis of legislation, and an understanding of the effects of different tenure arrangements. All three courts observed that the arrangement was clearly designed as a device to avoid the legal definitions of land subdivision; this in spite of Clearspan's documentation (legal deeds headed Clearspan Subdivision) and advice to clients that used the term subdivision to describe the arrangement. It seems that these courts were largely dismissive of such labelling; other courts have been free to reclassify an arrangement "… irrespective of the precise label accorded it."[42]

The Environment Court concluded that there was a division of the allotment: the sale and purchase agreement indicated an intent to create a separate allotment; the deposited survey plan defines separate parcels; the tenants in common share is exactly proportional to the defined areas; the covenants divide the operational responsibility and the exclusive occupation for each parcel;[43] and the titles were intended to be dealt with separately.[44]

Clearly the arrangement creates two (or more) separate allotments[45] from the underlying allotment: (RMA s 218 (2)) - two parcels of land of a continuous area whose boundaries are shown separately on a survey plan. Therefore, there is a division of the original allotment. Furthermore, the arrangement is certainly a disposition of land as defined by s 4 Property Law Act 2007 ('… the creation of any other interest in property'). The arrangement establishes a legal right of exclusive possession. It is certainly a subdivision of the land into parcels under separate possession, however, it is not clear that it is the type of subdivision which is subject to the RMA (or in other words; to be regulated by the territorial authorities). It would seem however that it is not a subdivision of the kind listed in s 218 (1) (a). But the question could still remain about whether it is a subdivision of a kind listed in s 218 (1) (b), that is it could be a subdivision by application to the RGL for a certificate of title that is otherwise prohibited by s 226.

A tenancy in common provides for unity of possession, but the arrangements here specifically deny unity of possession.[46] The transfer of the tenancy in common of the fee simple title cannot occur without the survey plan defining the exclusive use parcels and therefore the proportionate share of the tenancy in common. The arrangement "… involves the partitioning of the land, the creation of a new allotment being part of the existing allotment. And different rights attracting to each part. It is founded, essentially, upon the plan agreed and the subsequent survey and deposited plan. It intends that these be registered with LINZ and that certificates of title be issued. It turns on a distinction between shares in the land, (with a tenant in common holding an undivided share) and the effective transfer of a share of the land in terms of part of the allotment."[47] This persuaded the Environment Court that the arrangement is a subdivision.

Why does subdivision need legislation and regulation?

On the one hand, land subdivision merely involves creating invisible boundaries on the land and has no further effect on the natural and physical resources, and on the other hand, the purpose of subdivision is to change and/or intensify land use which clearly has effects.[48] The court concludes that "… it is clear that subdivision is not a purely technical matter and that a council is entitled to consider an application in light of the impact the subdivision will have on the management of associated resources."[49]

On appeal

It would seem reasonable to argue that the definition s 218 (1) (a) (i) ("… the issue of a separate certificate of title for any part of the allotment … .") could incorporate arrangements that provide for a part share of the interest as tenants in common, and the spatially separated exclusive covenant areas. However, the inclusion of cross lease in the alternative definition of a subdivision in s 218 (1) (a) (iv) suggests that cross lease is not captured by that earlier definition. Therefore, this arrangement is also not captured by the definition and so the appeal courts viewed the situation differently.[50]

The Court of Appeal, recognised that the statutory definitions around subdivisions and allotments are sometimes circuitous. The definition of an allotment talks of the division of land being shown on a survey plan (s 218 (2) (a)[13], and a survey plan being defined as "… a cadastral survey dataset of subdivision of land… ." (RMA s 2). The definition further includes a cross lease plan which would seem unnecessary given that a cross lease is also a subdivision. The Court has therefore sometimes resorted to common sense or dictionary meanings to words that might otherwise be defined in the Act, but the statutory statements are still heavily relied on.

The Court of Appeal concluded: firstly, Parliament chose transactional language in s 218 such that not every division of an allotment is a 'subdivision';[51] secondly, Parliament could have chosen an inclusive clause to incorporate all divisions of land, but chose not to, recognising that "... a significant number of transactions creating an interest in land would not fall within its definition.";[52] thirdly, because of the purpose of the RMA, the definition includes "… only those transactions with material environmental implications."; [53] and fourthly, there was no sale of the fee simple estate and the exclusive use covenants are encumbrances which "… are personal in nature, do not run with the land and are vulnerable to discharge or deregistration in the usual way of such charges … ."[54], "For these four reasons we conclude that the arrangement is not a 'subdivision of land' for the purpose of s 218, because the sale was not 'of the fee simple to part of the allotment'."[55]

How is this like a cross lease?

The Clearspan arrangement is similar to a cross lease in all except for the 999 year lease of the dwelling structure. If the arrangement is not a subdivision of land, then such a contrivance [56] could be used to produce the same effect as a cross lease - a division of title by sharing as tenants in common, and a division of the parcel by reciprocal covenants providing for separate exclusive use areas. It would seem possible that this device could be used for flats, and therefore only building consent (not subdivision consent) could be required.

Notwithstanding that cross leases are generally considered to be unsatisfactory forms of title division, the lease (that is, the reciprocal grant of a 999 year lease that is registered upon a title) does not seem to be critical to a division of title that allows a development where separate owners have exclusive occupation of a site and a separate CT is granted by way of exclusive use covenant (as is the situation with the Clearspan arrangement). In other words the effect of a cross lease title could be achieved without the actual lease. In fact this could avoid the issues that arise when a proprietor alters the footprint of a building defined by a lease document.

Is there anything different in practice between a fee simple subdivision and a tenancy in common with exclusive occupation area?

In the Clearspan arrangement, there is a clear spatial division of the underlying allotment which creates separate and distinct allotments with surveyed and recorded boundaries (as defined in RMA 1991 s 218 (2) (a) - any parcel of land … that is a continuous area and whose boundaries are shown separately on a survey plan). The title that is then issued for these parcels is a composite title including the tenancy in common of the underlying lot and an encumbrance; the reciprocal covenant allocating exclusive possession rights to the separate areas. It also includes a reciprocal deed of covenant to ensure the arrangement continues to be recorded on titles. This composite title is only different from a cross lease composite title in the absence of a registered lease.

In the Clearspan case, there is a well-defined allocation of property rights - all entitlements are completely specified (universality), ability to freely buy and sell (transferability), ability to hold possession exclusively (exclusivity), all rights are secure from seizure or encroachment and enforceable under the law (enforceability), ability to take income from (profitability), ability to grant separate subsidiary interests like leases and easements (dividability) and ability to mortgage (security). The covenant agreement separately requires all parties to ensure that the arrangement is retained as an encumbrance of future transactions, so it is effectively perpetual. Furthermore, the purchase price for the Clearspan arrangements would appear to be directly proportionate to the full fee simple value of the underlying property.

The courts have recognised that the list of arrangements that make up a subdivision in s 218 RMA are "… discrete and different in kind to one another … ." [57] A subdivision of one sort does not imply a subdivision of another sort.

So a potential argument that if a cross lease is already a subdivision then the further conversion to fee simple title may not also be a subdivision is untenable. A cross lease is one type of subdivision, then if established as a fee simple title it is a different type of subdivision.

Cross lease litigation - Analysis of case decisions - Re McKay

Don McKay, a fellow of the NZIS, sought a declaration from the Environment Court that "… the conversion of cross lease titles to fee simple titles do not constitute a subdivision within the meaning of section 218 Resource Management Act 1991."[58] In receiving this application the Environment Court was concerned that due to the effect its decision would have on so many cross lease proprietors that the hearing should be, if not adversarial, at least independent and widely discussed. It is interesting to observe that the Court invited participation of Ministry for the Environment (MfE), Land Information New Zealand LINZ), Local Government New Zealand (LGNZ) and the New Zealand Institute of Surveyors (NZIS),[59] and then from the Auckland Council (given that a large proportion of cross leases are in the Auckland region). To the surprise of the Court, only NZIS accepted the invitation. The Court therefore found it necessary to appoint an amicus curiae (Dr K Palmer) to assist the court with legal issues and additional submissions.

The Court described the issue as "… deceptively simple in its terms …", but "… not as straightforward as it might appear."[60] The arguments brought to the Court seemed quite compelling: no additional environmental effects were introduced in the conversion process, and as a cross lease was already a subdivision (providing for separate composite titles to be issued defining exclusive interests over separate parcels), the further title conversion was not an additional subdivision.

The Court stated that "While the plan of the cross leases may show separate areas of the allotment, those divisions are for the purposes of the lease and are not of the fee simple of the allotment." [61] The court focused on the division of the underlying fee simple title (which is shared as tenants in common), rather than the spatially separated encumbering interests.

The Court examined the statutory regime in detail, particularly RMA s 218. The Court again acknowledged that there is some circularity in the RMA definitions that link subdivision, allotment and survey plan such that they each define each other. This required the court to sometimes treat the word subdivision to just mean division of land. The Court also clarified "… the five methods listed in s 218 (1) (a) are not equivalent with each other except as being [different] types of subdivision." [62]

The court summarised these provisions as: "No person may divide a parcel of land of continuous area and whose boundaries are shown separately on a survey plan by applying for a separate certificate of title for part of that parcel unless allowed by a district rule or a resource consent and is shown on a survey plan suitable for deposit under the Land Transfer Act 1952."[63]

The Court recognised that the issue being brought before it was both a strict legal issue and that it had wider practical issues relating to cross leases. It is therefore, worth noting that the composite cross lease titles are supported by a cross lease survey plan, which clearly identifies the spatial extent of the lease, the exclusive covenant area, the common area and the area of the fee simple title held as tenants in common. These boundaries can be used for the fee simple boundaries, so no new parcels or boundaries need be created (although they would need to be shown on a new survey plan as allotments). However, the court returned to statutory definitions: "… it thus constitutes the division of a parcel of land shown separately on a survey plan and therefore is the subdivision of land within the meaning of s 218 (1) (a)." [64] The court refused the application for the declaration as applied for, and confirmed that the conversion of a cross lease to fee simple title was a subdivision that required a resource consent.

However, the court proceeded to comment on the practical issues raised, to suggest that the existing use of a cross lease development and the fact that no practical effects were involved might be a way to encourage consent for a conversion. It stated that planning consent conditions must: a) be imposed for the purposes of the RMA and not for any ulterior purpose; b) fairly and reasonably relate to the development; and c) not be unreasonable. Furthermore, "… the consent authority should generally approach such an application in a way that is mindful of the possibility that there may be few, if any, material environmental implications warranting a full-scale assessment." [65] The next step might be to try and get territorial authorities to record cross lease conversions as permitted activities and therefore exempt from the consenting conditions.

This case has clarified the legislation and provided implicit guidance to councils to facilitate cross lease conversions. The judge's statements in the previous paragraphs should be relied upon to support any subdivision consent application for a cross lease conversion. It is to be hoped, therefore, that in line with the Law Commission's views, the conversion of cross lease titles to separate fee simple titles is greatly facilitated.

Discussion

The establishment of a cross lease is a subdivision of land because it is specifically stated to be so in RMA s 218 (1) (a) (iv). [66] The conversion of a cross lease to a fee simple title is also a subdivision (of a different type - s 218 (1) (a) (i)) because it spatially separates the interests in the land in separate fee simple titles. In spite of the fact that the Clearspan arrangement has essentially the same effect as a cross lease (spatial division defined on a plan and separate exclusive interests defined in separate titles which can be bought and sold), it is not a subdivision because it does not precisely fit in any of the s 218 definitions; specifically it does not create new fee simple parcels.

There is enough doubt about judicial interpretations to assume that all three cases discussed herein could have been decided differently. The Congreve decision takes a common sense view of interpreting 'subdivision' and upholds the intent of the arrangement to put limits on land development. But that court could have taken a more expansive view of s 218 and concluded it to be a subdivision of land under the RMA. The Clearspan arrangements clearly serve to create separate interests in land which can be exclusively used and managed by defined parties and which can be bought and sold as separate cadastral interests, and yet do not come under the court's interpretation of subdivision—rather, they are based on contractual documents which both parties are expected to understand and apply. No doubt similar arrangements will be used in future to create separate interests without the necessary oversight of a subdivision consent. It is entirely possible that if the Clearspan device (or anything similar) is used regularly and in new contexts such that it is seen by the legislature to be a regulatory evasion, the legislature may add additional clauses to s 218 to include such a device in the same way that cross leases were brought within the 'subdivision' definition in the RMA. The McKay decision, if decided in the opposite way, could have facilitated a transition towards more secure and clearer tenure of cross lease properties.

It would be useful for the government to reconsider the statutory details of s 218. It must be seen as regrettable, that the government chose not to take up the 1999 Law Commission's recommendations to facilitate cross lease tenure upgrade and that the court decided that a tenure conversion was a subdivision under the RMA (so the effects have to be regulated), even though the effects were established in the past and cannot be undone.

The cases discussed above illustrate different ways of understanding words. In Congreve, 'subdivision' is given a meaning that is a common sense meaning. In Clearspan, 'subdivision' is given a strict statutory meaning that excludes the type of division of a parcel and issue of distinct title rights provided in the arrangement. In Re McKay, 'subdivision' is also given a strict statutory definition, that clearly identifies that s 218 lists separate and distinct types of subdivision, such that a subdivision under one definition is different to a subdivision under another definition.

The use of words and their interpretations in legal contexts is a key role of our judicial system. Legal word interpretations may always be challenged, and there are numerous opportunities to argue for alternative interpretations. Statutory definitions only apply to specific statutory considerations. Contractual arrangements can be devised to avoid statutory implications. The cases discussed herein demonstrate interpretative uncertainties that will have significance for surveyors and for the creation of new land parcels and land titles.

Notes

1 *Spark v Clearspan* Court of Appeal [2018] NZCA 248 at [24].

2 *Re Application by Donald McKay* [2018] NZEnvC 180.

3 This text constitutes an analysis of the multiple hearings of the cases: *Big River Paradise v Cosgrove, Clearspan v Spark, and Re Application by Donald McKay.*

4 *Re An Application by Hamilton City Counc*il (1993) 1A ELRNZ 428.

5 *Ibid* at p.441.

6 *Waitemata County v Expans Holdings Ltd* [1975] 1 NZLR 34.

7 *Ibid* at p.36.

8 *Ibid* at p.44.

9 *Ibid* at p.48.

10 *In re Transfer to Palmer* (1903) 23 NZLR 1013.

11 *Ibid* per Williams J. at p.1020.

12 I have specifically avoided using the term 'ownership' as that term has its own definitional issues.

13 In other words: " …the sustainable management of natural and physical resources." (RMA s 5).

14 Town and Country Planning Act 1977 Schedule 2 s 6.

15 s 218 (1) (a) (iii) RMA 1991. This RMA section was amended in 2003 to read "could be for a term of more than 35 years."

16 Land Transfer Act 1952: s 70 – "… separation of a parcel of land … ", s 89A "… in every allotment of a subdivision … ", s 167 "… a plan of the land or subdivision … ". In the Land Transfer Act 2017: s 184 "… lots in the subdivision … "

17 Property Law Act 2007 s 4 "… a separate allotment in the subdivision … "

18 It is worth noting firstly, that a covenant is a form of privately accepted regulation of land use which restricts the use of land for activities that would otherwise be legal. In other words, while regulatory land use restrictions imposed by local authorities provide minimum rules of compliance, a covenant may impose many other restrictions or enforcement opportunities for higher levels of amenity. Gray & Gray (1998:22 at

FN146) note that "… private restrictive covenants often came to operate as a localised form of private legislation, preserving various kinds of residential and environmental amenity for future generations of successive owners."

[19] Registered under the Land Transfer Act 1952, and note that covenants were subject to s 126 Property Law Act 1952 (now Part 5 Sub-part 4 Property Law Act 2007).

[20] Lang J. records that the commissioner hearing the consent application observed that '… the application was "carefully crafted" so as not to offend against "… the letter of the covenant" … and whilst the proposal did not offend the literal wording of the covenant, it may nevertheless fall outside the spirit and overall meaning to be ascribed to it'. (*Congreve* 2005 at para [40]).

[21] See the list of case citations in the Reference List.

[22] Lang J. quoted a previous decision (*Sanders v Northland Regional Council* 1998): "… a resource consent application is not concerned with private property rights at common law. … Actions for enforcement of private property rights are not within the jurisdiction of the Environment Court" (*Congreve* 2005 at para [26]).

[23] The 2003 RMA amendment changed the lease period of a subdivision from 20 years to 35 years (s 218 (1) (a) (iii)).

[24] *Congreve* 2005 at para [54] Williams J. decision as quoted from *Waitemata County v Expans Holdings Ltd* [1975] 1 NZLR 34 at 48.

[25] *Ibid* at para [62].

[26] *Ibid* at para [70].

[27] *Congreve* [2008] NZCA 78 at para [32], [2008] 2 NZLR 402.

[28] *Congreve* [2008] NZSC 51, (2008) 9 NZCPR 327.

[29] *Re Application by Hamilton City Council* (1993) 1A ELRNZ 428.

[30] Quoting the Planning Tribunal *Re Application by Hamilton City Council* (1993) at 438. Note: this was quoted slightly differently by Williams J. in *Congreve* 2005 at para [63].

[31] For a simple explanation of cross leases, see Ryder (2017).

[32] The tenancy in common does not provide the freedom of use usually associated with fee simple.

[33] A tenancy in common is a division of title usually by a defined share (not a division of the parcel).

[34] See Law Commission 1999. Shared Ownership of Land.

[35] In other words it is not fixed by polar or rectangular coordinates of a survey.

[36] It is, however, worth pointing out that in Christchurch, if a cross lease structure moves with surface ground shift, the lease boundary moves with the structure, even though it may appear in a different location than shown on the plan. See Canterbury Property Boundaries and Related Matters Act 2016 s 8 (2) "The boundaries are deemed to have

moved or to move with the movement of land caused by the Canterbury earthquakes (whether the movement was horizontal or vertical, or both)."

[37] The cross lease can be completed without defining any exclusive use covenant area.

[38] See also statements made by counsel (although not necessarily confirmed by the Environment Court judge): "a survey plan for cross leasing could be deposited without detailing exclusive or common areas and … those involved could alter the boundaries of exclusive or common areas by agreement" (*Re An Application by Hamilton City Council* (1993) 1A ELRNZ 428 at 438). I make a similar assertion in a summary of *Boyer v McCracken* [2017] NZHC 755 – questioning whether the line shown on a cross lease plan showing the exclusive use area was legally a boundary. I suggest that the boundary was the existing and long-accepted fence (in other words, the evidence of possession) rather than the line shown on the plan (Strack, M. 2018. Cross lease boundaries. *Surveying+Spatial*. 93:41-42).

[39] Note, under the Town and Country Planning Acts, cross leases were not defined as subdivisions.

[40] New Zealand Law Commission, 1999. Shared Ownership of Land. Summary of Recommendations: 33.

[41] In one example used in the *Clearspan* case, the lease was for 12 years - CT1073/298.

[42] See Gray & Gray 1998;6 at FN30. Furthermore, Gray & Gray state, with respect to an analogous case about what was a lease and what a licence: "The courts are therefore empowered to overturn an superficial label which falsely describes the parties' legal relationship, and any contractual terms which are blatantly or cynically inconsistent with the reasonably practical circumstances of an agreed occupancy are liable to be discarded as 'pro non scripto'" at p7.

[43] Note the very strong priority in the common law of a property right proven by exclusive possession. Gray & Gray 1998:5 FN20, quote a judicial statement: "Exclusive possession de jure or de facto, now or in the future, is the bedrock of English land law." Common law exclusive possession as indication of property is perhaps more accepted in the UK, while here in New Zealand, statutory interruption of the common law is more arguable, given that the purpose of the Land Transfer Acts was to establish a new and different basis of title to land. The status of fee simple property in New Zealand is as granted by the issue of a Record of Title (the terminology of the Land Transfer Act 2017) explicitly stating that the identified proprietor is 'seized of an estate in fee simple' (the terminology of earlier LT Acts). Note however that the Acts do not provide a definition or interpretation of fee simple. However, the common law recognised fee simple proprietorship irrespective of the issue of a registered or documented interest. Perhaps the *Clearspan* case could have been argued on the basis of what is the reality of possession rather than the label accorded to the arrangement.

[44] see *Hamilton* case FN 32 above.

[45] See for example the plan of Land Covenants; Areas A-E on DP 450 403.

[46] See *Spark v Clearspan* 2016 Env Court at para [43].

[47] *Spark v Clearspan* 2016 Env Court at para [39].

[48] see Environment Guide n.d.

[49] quoting *Mawhinney v Waitakere City Counci*l [2009] NZCA 335 at para 27.

[50] The final appeal judgement is *Spark NZ Trading Ltd v Clearspan Property Assets Ltd* [2018] NZCA 248.

[51] *Ibid* at para [22].

[52] *Ibid* at para [23].

[53] *Ibid* at para [24].

[54] *Ibid* at para [27] It is worth noting that as part of the composite title arrangement and the covenant, any new party to the arrangement is required to carry the arrangement documents forward, ensuring the agreement runs with the land and is effective and perpetual (for as long as the Telco tower is required).

[55] *Ibid* at para [28].

[56] The High Court [2017]NZHC 277 at [52] described the arrangement as an "artificial contrivance to avoid an undesired set of regulatory requirements."

[57] *Spark v Clearspan* 2018 at para [46].

[58] *Re Application by Donald McKay* [2018] NZEnvC 180 at [1]. This case was also discussed in Strack (2018b).

[59] Now Survey and Spatial New Zealand.

[60] *McKay* at [17].

[61] *Ibid* at [46].

[62] *Ibid* at [46].

[63] *Ibid* at [31].

[64] *Ibid* at [40].

[65] *Ibid* at [55].

[66] even though most cross lease titles became subdivisions retrospectively with the introduction of the RMA 1991.

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Land Transfer Act 1952

Land Transfer Act 2017

Local Government Act 1974

Municipal Corporations Act 1954

Property Law Act 1952

Property Law Act 2007

Resource Management Act 1991

Town and Country Planning Act 1953

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Forensic Analysis of the 1944 Datum Shift at the Wellington Tide Gauge

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Introduction

Correctly interpreting historic tidal records from tide gauges at New Zealand's ports takes on particular importance when determining long-term changes in mean sea level (MSL). Datum changes that can occur when gauges are renewed, replaced or reset cause particular problems. Such is the case with early sea level measurements in the Wellington harbour basin.

The first automatic tide gauge (TG) in Wellington was installed on Jervois Quay in 1887 (Adams, 1909). While it seems to have operated satisfactorily for a number of decades, in late 1944 it was replaced with a new gauge installed on the nearby Queens Wharf. The sea level data files archived by the former Department of Lands & Survey indicate that this new gauge began operation on 18th November 1944. It was Lands & Survey that had the responsibility for establishing regional/local mean sea level (MSL) height datums, both for mapping purposes and for infrastructural development (e.g., Jenks, 2006).

In the case of the Wellington MSL datum, correspondence files not only mention the installation of the new 1944 gauge, but also note an apparent, but unmeasured step change in Mean Tide Level (MTL)[1] of about 0.2 feet[2] concurrent with its installation. This indicates the possibility of a datum discontinuity or a datum offset when the gauge was installed. While not considered to be a vital matter at the time, the issue has gathered importance over the last few decades due to its influence on determining long-term sea-level change. Unfortunately, there is no record of the procedures followed when the new (1944) gauge was installed, nor any written comment as to how datum continuity might have been maintained and/or to what accuracy. All such records have been lost. The only data available are the measurements from the former TG on Jervois Quay (recorded as either annual MTLs or MSLs) and from the new TG at Queen's Wharf (recorded as hourly MSLs from 18 November 1944).

Due to this uncertainty, all the sea level trend analyses undertaken to date using the historical Wellington sea level data (e.g., Hannah, 1990), have included two datum offset parameters in the multi-variate least-squares solution for long-term trends, one for the period 1891-1944, and the other from 1945 – present day. The data from the old gauge on Jervois Quay have been assumed to be on a different datum from those collected after the 1944 Queens Wharf TG installation. Both datum parameters have been treated as unknowns and determined as part of the analysis. Because the annual MSL data file itself is discontinuous due to this datum offset, interpretation problems have been created for those unfamiliar with the issue and the analysis methodology.[3]

In this paper, various estimates for this datum offset are derived and a final value selected. It is intended that this value be applied to all pre-1944 data so as to move the entire MSL time series in Wellington to a single, continuous datum. This is little different to what has already been done to other annual MSL data sets (e.g. Auckland and Lyttelton) to compensate for their well documented datum changes.

Estimating the Datum Offset

Due to the lack of written documentation and the different data records available before and after the 1944 TG installation, some methods of determining a datum offset fail. Some analysis packages such as HECTOR (Bos et al., 2013) require homogeneous data throughout the time series while others simplify the process by using hourly tide data before and after the supposed datum discontinuity. Neither approach is applicable here. Furthermore, the situation is made even more complex due to the fact that Wellington not only has the usual inter-annual climate variability in sea-level records, but it is also a seismically and tectonically active region.

Taking these factors into account, three different approaches to the problem have been used. Because of the neglect of the unknown correlations between consecutive years of MSL or MTL data, the derived standard deviations will be indicative of the relative strength of each solution rather than an indication of their absolute value.

Approach 1. Using a Full Least Squares Analysis with an Abbreviated MSL Data Set.

The model used for this analysis is as documented in Hannah (1990). In the model a total of 9 parameters are used, two datum parameters (one for the period 1944-1981, and the other for the period 1945-1990), a sea level trend, the inter-annual anomalous response of MSL to annual mean barometric pressure and temperature changes, plus two parameters for the 8.6-year lunar tide and a further two parameters for the 18.6-year lunar tide.

The data set selected extended from 1891-1990. The aim here was twofold. Firstly, to have approximately equal years of data on the same datum (i.e., the number of years of pre-1944 data to be very close to the number of years of post-1944 data). Secondly, to avoid possible data complexities caused by slow slip inter-seismic events that are known to have occurred from 1997 onwards (Denys et al., 2020). The two datum parameters determined from the least-squares analysis (with standard deviations in brackets) for the two epochs are as follows:

1891 – 1944	0.541 (0.010) m
1945 – 1990	0.576 (0.020) m

<u>Datum Change = 0.035 (0.022) m.</u>

While this method of analysis gives both the flexibility to weight any given year of MSL data according to its quality, plus the ability to model many of the systematic effects found in these types of datasets, it has a number of weaknesses. Firstly, it assumes that there has been a single linear MSL trend throughout the period covered by the data set. It further assumes that there have either been: i) no significant non-linear effects (due, for example, to unknown tectonic motion); and ii) that the length of the data sets has allowed them to effectively bridge the inter-annual climate variability that arises mainly from the dominant 2–4 year El Niño Southern Oscillation (ENSO) and the smaller 20-30 year Inter-decadal Pacific Oscillation (IPO) influences on annual MSL (Hannah & Bell, 2012).

Approach 2. Use of the Two Lunar Nodal Tide Cycles both Before and After Nov. 1944.

In this approach MSL is calculated for the full 19-year lunar nodal-tide cycle prior to November 1944 and the full lunar cycle after November 1944. In the absence of any bias created by short-term climate-cycle variability, the difference between the two numbers, once adjusted for any assumed linear rise in MSL, should reflect the datum change. However, there is likely to be some bias from the IPO which has a 20–30 year periodicity. A previous analysis of the climate-cycle variability in annual MSL time series of the 4 main ports in New Zealand was undertaken by Hannah & Bell (2012). Here a reconstructed sea-level principal component (or Empirical Orthogonal Function EOF) was extracted from the de-trended data. Their Figure 4 indicates that the annual MSLs, arising from climate-cycles such as ENSO and the IPO, appear to be higher in the 19 years after 1944.Taking a mean of this EOF (Mode 1) over the two 19-year periods (1926-1944 and 1945-1963) for Wellington, results in a slightly higher bias in MSL in the latter period by 0.02 m over the former period. The following were calculated:

MSL (1926-1944) = 0.594 (0.008) m with a mid-point of 1934 (EOF-1 = –0.019 m)

MSL (1945-1963) = 0.671 (0.007) m with a mid-point of 1953 (EOF-1 = +0.0012 m)

Difference = 0.077 (0.011) m, EOF-1 difference = 0.02 m.

However, the simple linear MSL trend from 1891–1945 = 0.7 (± 0.42) mm/yr or, 13 (± 8.0) mm over a 19-year tidal cycle.

<u>Datum Change = 0.077 m – 0.02 m (ΔEOF-1) – 0.013 m = 0.044 (0.014) m.</u>

While this approach depends upon an assumed constant linear sea level trend over the period of the analysis, the relatively short time (19 years) renders it relatively weakly dependent upon the accuracy of that number. For example, an error of 0.5 mm/yr in the linear trend would equate to an error of 9.5 mm in the derived datum offset. This approach, however, eliminates many of the disadvantages of the first approach.

Approach 3. Comparison with MSLs at Lyttelton and Auckland

In this approach a direct comparison is undertaken between the 1944 and 1945 MSLs at Wellington with those at Auckland and Lyttelton. While simple, this approach not only depends upon consistency of bias between the MSLs as recorded at the three tide gauges, but it also relies heavily upon the accuracy of the specific annual MSLs used.

The calculated values are as follows:

	MSL Wellington	MSL Auckland	MSL Lyttelton
1944	0.595 (0.04) m	1.890 (0.025) m	0.969 (0.025) m
1945	0.640 (0.03) m	1.901 (0.025) m	0.978 (0.025) m
Diffence	+ 0.045 (0.05) m	+0.011 (0.035) m	+0.009(0.035) m

<u>Datum Change = 0.045 m – 0.010 m (mean for other 2 ports)</u>
<u>= 0.035 (0.053) m</u>

To gain at least some idea of the accuracy of the process, the data histories at all three ports were examined and a sample of eleven years of consecutive annual MSL data were extracted. The data had to be for the same years, as close as possible in time to 1944, and had to be of high quality i.e., had to have standard deviations for the annual mean of 0.03 m or better. The period 1959-1970 was selected and the above calculations performed at each port for each consecutive data pair. The average difference between Wellington and Auckland proved to be 0.003 m whilst the average difference between Wellington and Lyttelton was -0.007 m. On two out of 20 occasions, outliers of 0.040 m and 0.042 m occurred. It needs to be understood that this method, while indicative, certainly lacks the statistical strength of the other two.

Discussion

While each of the three approaches have their strengths and weaknesses, they are all consistent in their conclusion, namely that a significant datum offset occurred when the TG was moved to Queens Wharf in November 1944. Depending upon the approach adopted, this movement is calculated as being between 0.035 m and 0.044 m. A simple rounded number of 0.04 m has been adopted. This is consistent with a setting and reading accuracy of the new 1944 gauge of ± 0.01 m as noted on the old Department of Lands & Survey files. In order to derive a single data set referenced to the same TG zero, 0.04 m has been added to all the annual MSL values prior to and including 1944.

With this parameter now given a fixed value (rather than being estimated each time a new trend analysis is undertaken), new MSL trends at Wellington trends have been calculated using the same model as described under Approach 1 and for the same time periods used in Hannah (2019). The trend using the full MSL data set (1891-2018) now becomes 1.93 (± 0.09) mm/yr whilst the trend from 1891-1960 becomes 1.00 (± 0.26) mm/yr.

The trend from 1961-2018 is unaffected, remaining at 2.74 (± 0.20) mm/yr. The new Wellington MSL data set, known as the Datum Corrected data set, together with the above trend lines is shown in Figure 1.

Notes

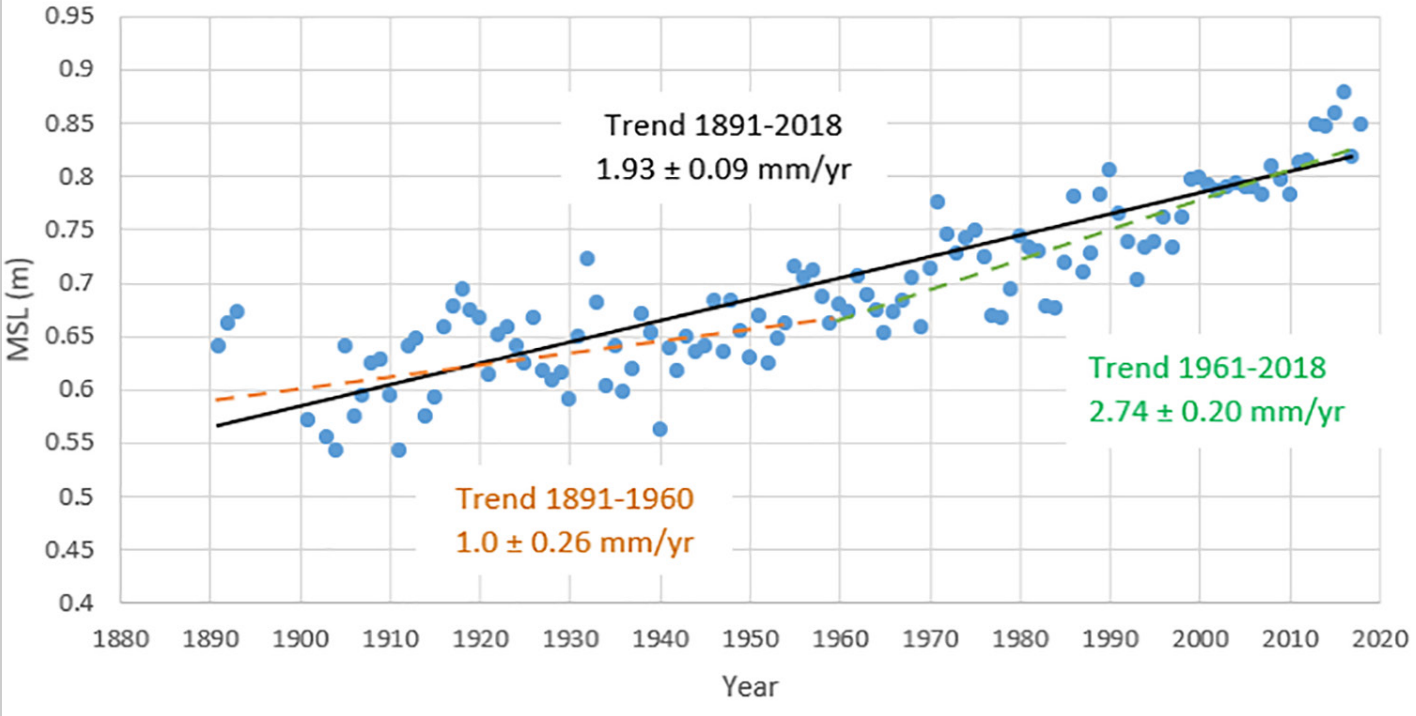
[1] Note: Mean Tide Level (MTL) is a simple average of high and low tides, and would have included weather influences such as storm surge and set-down during anticyclones.

[2] Equivalent to ~0.06 m.

[3] Including annual MSL data on MfE/StatsNZ web site:

https://www.stats.govt.nz/indicators/coastal-sea-level-rise.

Figure 1. Wellington Datum Corrected MSL Data Set



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On the problem of the transformation between the official Hellenic Geodetic Datum and the 'Old Bessel' or Old Greek Datum. A case study in the Serres region (Northern Greece).

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Keywords: Geodetic datum, coordinate transformation, residuals, least squares adjustment, Greek Datum.

Abstract

We describe two different solutions to the transformation between the official geodetic datum of Greece, the Hellenic Geodetic Reference System of 1987 (HGRS1987), and a historic, but still used version of the Old Greek Datum (GR-Datum) called the 'Old Bessel' datum. The Old Greek Datum, the previous officially accepted datum in Greece, consists of two different versions: the 'Old Greek Datum' ('Old Bessel') and the 'New Greek Datum' ('New Bessel'). The alignment of the 'Old Bessel' version of GR-Datum to the Hellenic Geodetic Reference System of 1987 remains a crucial issue in Greece, and there is no officially accepted technical solution. Our case study in Serres (northern Greece) tests two different transformations: 2D similarity, and 2nd degree polynomial and evaluates the accuracy of each in providing a connection between the the Old Bessel version of the GR-Datum, and HGRS1987. The study relies on control stations of the state's triangulation network that have published coordinates in both systems. The control stations were identified on the ground and surveyed using RTK-GNSS.[1] For the case of the 2D similarity transformation, we find a consistency of 1.2M in our results, while the 2nd degree polynomial transformation has an improved consistency of 0.8M.

Introduction

Greece has a variety of different geodetic reference systems. Historically, the first geodetic reference systems were realized using the Bessel ellipsoid (HEMCO 1987, Fotiou 2007). After the Second World War, there was an effort to modernize the geodetic and mapping infrastructure. In 1987 the new official geodetic reference system, the Hellenic Geodetic Reference System 1987 (HGRS 1987) was established (the Greek Cadastre refers to this reference system). We will briefly describe the geodetic reference systems used by the civil services in Greece (see also Ampatzidis and Melachroinos 2017, Kalamakis et al. 2017 and Moschopoulos et al. 2020, Kalamakis 2020).

(i) The Hellenic Terrestrial Reference System of 2007 (HTRS07) (Katsambalos et al. 2010). HTRS07 is a densification of the European Terrestrial System of 1989. It uses the GRS80 spheroid and the Transverse Mercator projection (one zone, central meridian at 24 degrees).

(ii) The Hellenic Geodetic Reference System of 1987 (HGRS1987) (HEMCO 1987, Veis 1996). HGRS1987 combines classical and satellite observations (SLR, GPS and TRANSIT). It is connected through special procedures (an initial Helmert transformation and subsequently a grid based transformation—the application of national grids) to the HTRS07 with an accuracy of 8.3cm nationwide (Katsambalos et al. 2010). HGRS1987 uses the GRS80 spheroid, and the Transverse Mercator projection (the whole country is included in one zone that extends from 19° to 28° East). HGRS1987 is the official geodetic reference system of Greece

(iii) Two versions of the Old Greek Datum (GR-Datum): the 'Old Bessel' and the 'New Bessel' (Takos 1989):

(a) The 'New Bessel' (or the new version of GR-Datum) was established in the mid-80s (Takos 1989). The Bessel spheroid of 1841 is used, and the associated projection is Hatt's (Mugnier 2002). Hatt's is an equidistant projection. The country was divided into spheroidal trapezoids of 30' x 30' (1:100000 scale, see Figure 1). In total, 137 map sheets were released. Each map sheet has a different origin of coordinates, causing a lot of confusion for surveyors. The new version of GR-Datum is directly connected to HGRS1987 through 2nd degree polynomials referred to each sheet (HEMCO 1995).

(b) The'Old Bessel' (or old version of GR-Datum), was established before the Second World War and carries with it significant inconsistencies and systematic effects. The great majority of the rural areas in the northern part of the country refer to the 'Old Bessel'. It uses the Bessel 1841 spheroid and was realized by the division of the northern part of the country into spheroidal trapezoids of 6' x 6'. The derived mapping infrastructure of the 'Old Bessel' datum, were topographic maps of 1:1000, 1:2000 and 1:5000 scales. Each of the 6' x 6' trapezoids is a unique coordinate system, as each map sheet has a unique origin of coordinates. The 'Old Bessel' thus produced a very large mosaic of different coordinate systems. Unfortunately, there is no officially accepted transformation/transition algorithm to connect the 'Old Bessel' to either the 'New Bessel' or to HGRS1987.

Transforming Old Bessel to HGRS87

For the surveyor and cartographer the transformation issue between the 'Old Bessel' and HGRS1987 causes significant problems. To accomplish this he/she often uses in-situ/ad hoc techniques, focusing only on a limited area of interest (e.g., one or two city/town blocks). The GR-Datum's fundamental point (Central Pillar) is located in the National Observatory of Athens (NOA). The initial latitude and longitude of the Observatory are 37° 58' 18.68' N, 23° 42' 58.815' E. By convention, the NOA longitude value is set to 0° 00' 00.000' E (null GR-Datum meridian) for the GR-Datum, and the geodetic longitude of any point in the system is always estimated with respect to the NOA's conventional meridian. This is true for both 30' x 30' and 6'x 6' map sheet distributions. As previously mentioned, the GR-Datum uses Hatt's projection. Hatt's is not a commonly used projection (its application is limited to some French colonies, Mugnier 2002). The Hatt projection could not be used over large areas due to significantly increasing distortions for ellipsoidal trapezoids with sides greater than 55-60 km. The reason for adopting Hatt's projection was its simplicity which was appropriate to the modest skills and computational abilities of rural Greece at the beginning of the 20th Century. At that time the need for quick land surveys was great. Following the Greek-Turkish war and the resulting 1923 Treaty of Lausanne, hundreds of thousands of refugees from Pontus and Asia Minor were in need of accommodation.

We should underline that the 'Old Bessel' is used by the surveying agency of the Greek Ministry of Agriculture. It was the Ministry of Agriculture that decided that map sheets would be divided into trapezoids of 6' x 6'. Each map sheet defines its own coordinate system, with its own latitude and longitude of origin called the *centroid* (e.g., Fotiou 2007). The *centroid's* longitude, λ_0, is defined with respect to the conventional null meridian of the GR-Datum. The *centroid's* spherical coordinates play a crucial role in the Hatt projection. The projection coordinates of a specific point are estimated from the differences between the measured geodetic latitude and longitude of the point, and the latitude and longitude (φ_0, λ_0) of the centroid. In Section 3.1 we will give a description of the procedure. All 'Old Bessel' map sheets refer to the same geodetic datum, but at the same time, they define their own coordinate system. A rough parallel example is that of the UTM system, which allow a number of different zones, with a common geodetic datum. The only difference for the GR-Datum case is that we have hundreds (or even thousands) of different coordinate systems. The irony of a system created for its ease of application at the local level, lies in the complications of this diverse cartographic heritage for modern surveyors working within the unifying and generalising trends of geocentric coordinate systems. In the present study we test the transformation between the 'Old Bessel' and HGRS1987 for an area located in Serres, in Northern Greece. We shall apply two different models: the similarity and polynomial transformations.[2]

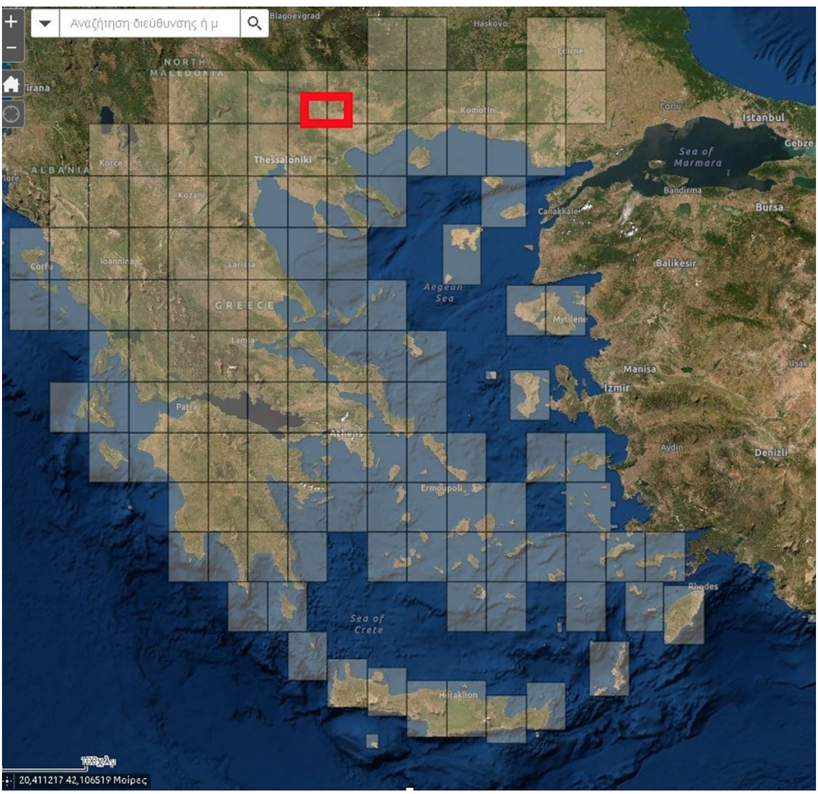

Figure 1: Distribution of the 1:100000 map sheets in Greece (www.gys.gr). The red box shows the area of our study.

Methodology

More background

As discussed above, the 'Old Bessel' is realized by the choice of 6'x 6' map sheets. Thus, for relatively large areas covered by many map sheets, there are many different coordinate systems! For our case study, we began by identifying a number of common points (control stations) between the 'Old Bessel' and HGRS1987 datums. One might keep in mind that for each map sheet, the projection coordinates (x,y) of the common points are determined—this would be the same process whether dealing with 30' x 30', or the 6'x 6' map sheets—with respect to a specified centroid (see Section 2 above for more information on the map *centroid*). The *centroid* defines the origin of the map sheet, i.e. the (φ_0, λ_0) coordinate. The projection coordinates (x,y) are determined using the so-called direct mapping equations to calculate projection coordinates from the geodetic curvilinear coordinates. The input of the direct mapping equations are the geodetic latitude and longitude difference $(\Delta\varphi', \Delta\lambda')$ between the geodetic latitude φ and longitude λ and the latitude and longitude of the *centroid*: $\Delta\varphi = \varphi - \varphi_0$, $\Delta\lambda = \lambda - \lambda_0$. It so happens that the *centroid*'s geodetic curvilinear coordinates are chosen to be placed at the 15th and 45th minutes of a degree (both for latitudes and longitudes) for the case of the 30' X 30' map sheets, and every even 6th minute for the 6' x 6', map sheets.[3]

We begin the transformation process by re-computing geodetic latitude and longitude (i.e. removing the effect of the *centroid* on geodetic latitude and longitude). Using the inverse mapping equations and with respect to the map's sheet centroid, projection coordinates (x, y) can be converted to the associated $\Delta\varphi$ and $\Delta\lambda$ geodetic latitude and longitude differences, respectively. Then it is straightforward to estimate the geodetic coordinates: $\varphi = \Delta\varphi + \varphi_0$, $\lambda = \Delta\lambda + \lambda_0$. Note that the longitude still refers to the conventional null meridian (see Section 1).

Change of Map Sheet's Centroid (CMSC)

Though the control points used in this study are common to both Old Bessel and HGRS1987 datums, the Old Bessel points are on multiple map sheets, and so it is necessary to unify all the different control points of the different 6' x 6' map sheets to a common coordinate system. This is accomplished through a change of a map sheet's centroid (CMSC, Fotiou 2007). The procedure can be summarized as follows:

a. We choose a new reference centroid as φ'_0, λ'_0. We easily compute the new differences: $\Delta\varphi' = \varphi - \varphi'_0, \Delta\lambda' = \lambda - \lambda'_0$. This centroid is used for locating all the control points on a common map sheet. The *centroid's* choice is arbitrary, or one might decide to locate the *centroid* in the middle of the area of interest which is a common choice for studies over large areas.

b. Finally, we determine the new projection coordinates (x', y') through the direct mapping equations, using as inputs the geodetic differences $(\Delta\varphi', \Delta\lambda')$.

Now, all the new projection coordinates (x', y') previously belonging to different 6' x 6' map sheets, refer to a common centroid and a common coordinate system. With this object achieved we are ready to apply the first of our coordinate transformation techniques.

Coordinate Transformation

The model of similarity transformation:

The general model is defined (point wise):

$$X_i = \mu cos\theta x_i + \mu sin\theta y_i + t_x$$

(1a)

$$Y_i = -\mu sin\theta y_i + \mu cos\theta x_i + t_y$$

(1b)

where X_i, Y_i are the coordinates with respect to the HGRS1987 (final system), x_i, y_i are the projection coordinates with respect to the 'Old Bessel' and μ, θ, t_x, t_y are the four unknow parameters of the 2D similarity transformation (uniform scale, rotation and two translations of the axes, respectively), which will be estimated through least squares adjustment (e.g. Dermanis and Fotiou 1992, Kalamakis 2020). The 2D similarity model is widely used for datum transformations (DMA 1987, Hoffmann-Welhenchof et al. 1993, Yang et al. 1999). The main limitation of the 2D similarity transformation is that it is best applied locally, and should not be applied over extended areas. The main advantage of the 2D similarity transformation (in contrast to e.g. 3D Helmert transformation) is that it works without any knowledge of station heights. In the past this has been a crucial issue since height information was either non-available or weak (Torge and Müller 2012).

The model of the polynomial transformation

We choose the 2nd degree polynomials as follows. The equation yields, pointwise:

$$X_i = a_0 + a_1 x_i^2 + a_2 y_i^2 + a_3 x_i y_i + a_4 x_i + a_5 y_i$$

(2a)

$$Y_i = b_0 + b_1 x_i^2 + b_2 y_i^2 + b_3 x_i y_i + b_4 x_i + b_5 y_i$$

(2b)

where X_i, Y_i are the coordinates with respect to the HGRS1987, x_i, y_i are the coordinates with respect to the 'Old Bessel' and $a_0, a_1, a_2, a_3, a_4, a_5, b_0, b_1, b_2, b_3,$ b_4, b_5 the coefficients of the 2nd degree polynomials, estimated through least squares adjustment.

Transformation of coordinates by second-degree polynomial methods is a recognised method (HEMCO 1995, Junkins 1998, Alashaikh 2017, Ampatzidis and Melachroinos 2017). The research shows that 2nd degree polynomials can absorb more systematic effects than can a similarity transformation. However, the main drawback of the the application of the polynomial method is that it can distort shapes: E.g. a square might lose its perpendicularities in the process.

Application

We test the two aforementioned mathematical transformations in the area of Serres in northern Greece. We identified 37 common points (Figures 2 and 3) between the, Old Bessel' and HGRS1987. The common control stations have officially published coordinates for the 'Old Bessel' and the HGRS1987 geodetic systems, respectively. These control stations are located in 14 different 6' x 6' map's sheets. Implementing the CMSC (see section 2.1) we refer all the different map sheets to a common one. After in situ search, we found 23 existing control stations (the other 14 had either been destroyed or severely damaged). For the the purpose of a dataset that might be used in the future for further studies, we obtained GNSS measurements at all existing control stations, using the RTK mode. This last exercise aligned the control stations to the International Terrestrial Reference Frame 2014 (ITRF2014, Altamimi et al. 2014). The RTK survey furthermore provided height information that will undoubtedly be useful in future.

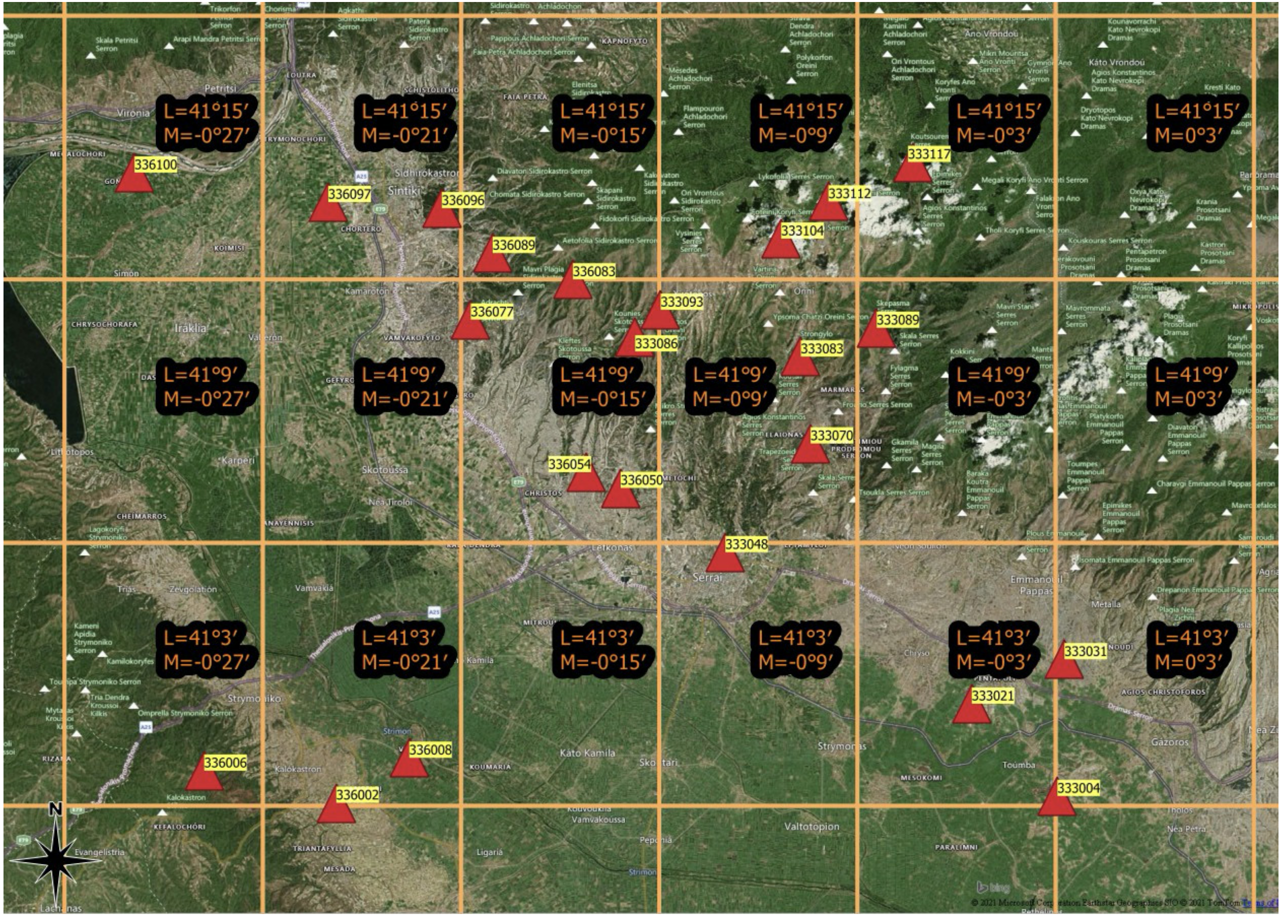

Figure 2: The initial set of the 37 common points between Old Bessel an HGRS87. The Figure comprises all fourteen 6' x 6' map sheets used in the present study. L corresponds to each centroid's latitude (φ_0) while M to each centroid's longitude $(\lambda_0,)$ —with respect to the conventional NOA's meridian. The letters L and M are traditionally used for the 6' x 6' map sheets' centroid's curvilinear coordinates.

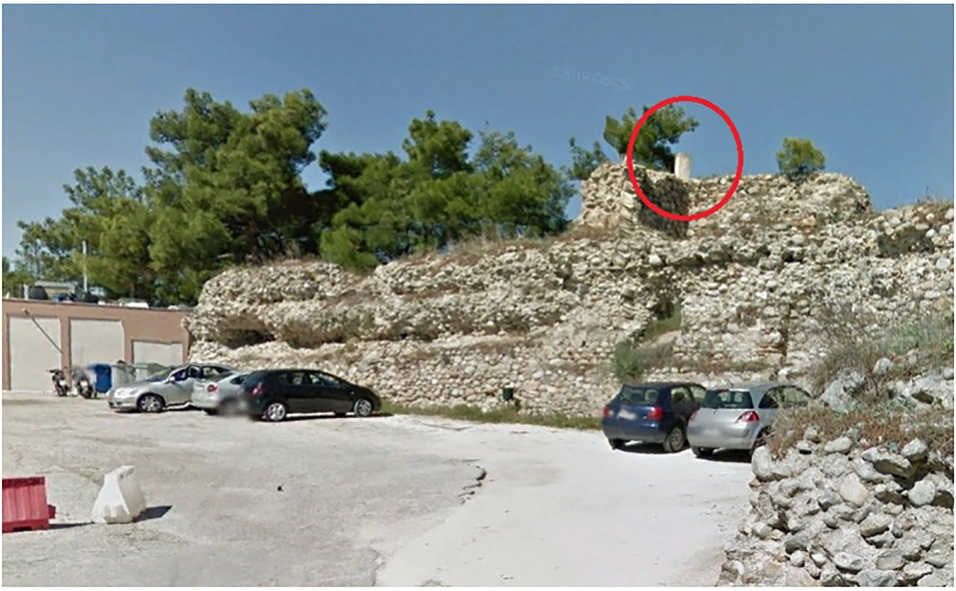

Figure 3: A benchmark (inside the red circle) located in Serres area.

Application of the 2D similarity transformation

We performed the 2D similarity transformation on the 'Old Bessel' (initial geodetic reference system) and the HGRS1987 (final geodetic reference system) datums at the common points. The application of the 2D similarity transformation leads to the estimation of the least squares adjustment's residuals. The residuals' behaviour gives a sense of the consistency between these two geodetic reference systems. The possible outliers are excluded using the 3-sigma criterion (removing points which their residuals are found 3 times larger than the standard deviation of the residuals). We repeat the least squares adjustment till no outlier is identified. In the present case, we had no need to remove any control stations, since the 3-sigma criterion control was successful. Table 1 shows the transformation parameters from 'Old Bessel' to HGRS1987 and Table 2 summarizes the statistical performance of the 2D similarity transformation. Figures 4 and 5 show the residuals per component and their associated horizontal residuals.

Table 1: The similarity transformation parameters (from 'Old Bessel' to HGRS1987)

parameter	value
$t_x (m)$	455303.161
$t_y (m)$	4566439.332
θ *(deg)*	-0.3478680055
μ	0.9996063239

Table 2: The statistical performance of the 2D similarity transformation

statistical quantity	x-residual (in m)	y-residual (in m)
minimum	-2.24	-2.95
maximum	1.68	2.83
mean average	0.00	0.00
standard deviation	1.05	1.24

Application of the 2nd degree polynomial transformation

The mathematical model described in equations *2a* and *2b* above is applied. The 3-sigma criterion was again successful, without any removal of stations (following the same concept as described in Section 3.3). Table 3 refers to the estimated polynomials, while Table 4 shows the statistical quantities of the 2nd degree transformation. Figures 6 and 7 show the residuals per component and their associated horizontal residuals representations, respectively.

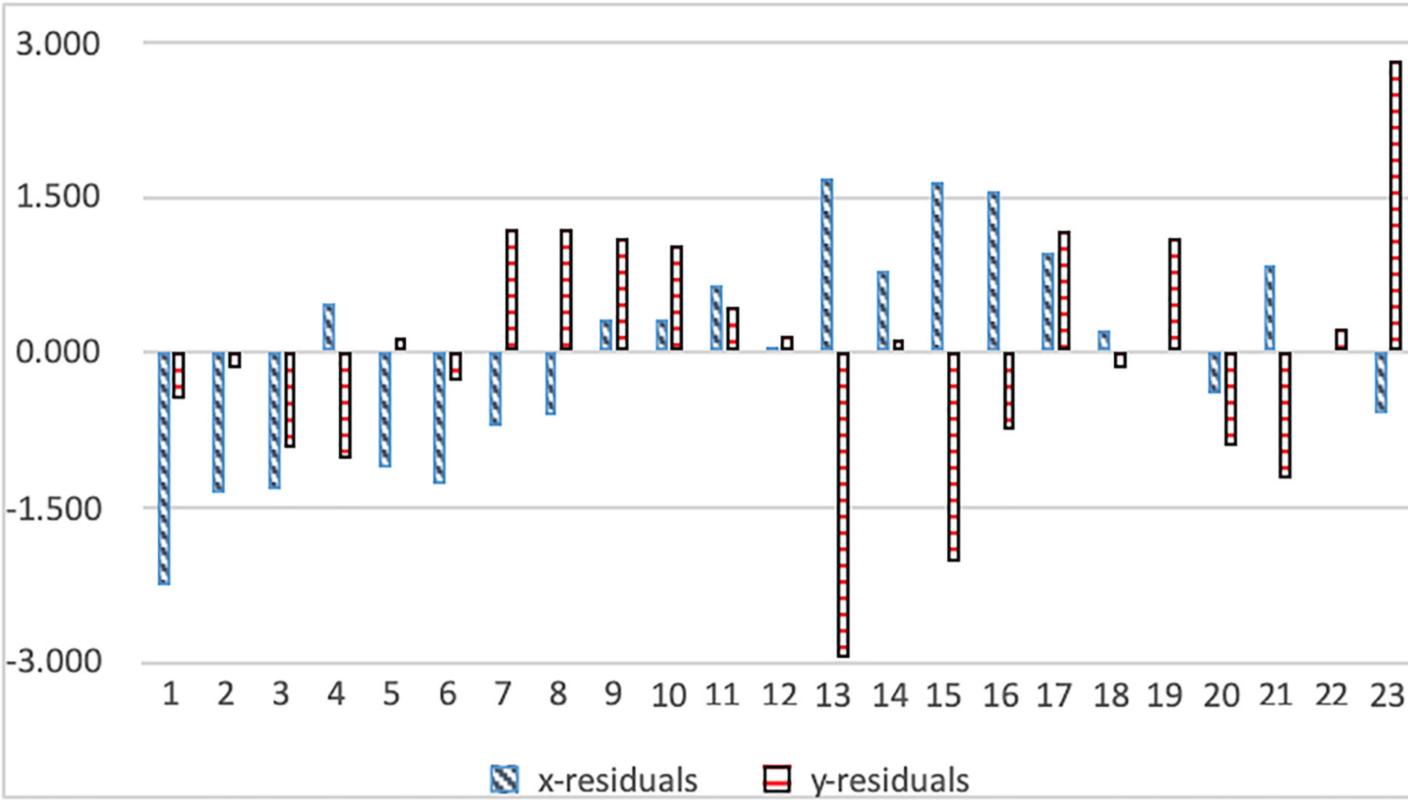

Figure 4: The residuals of the 2D similarity transformation per component.

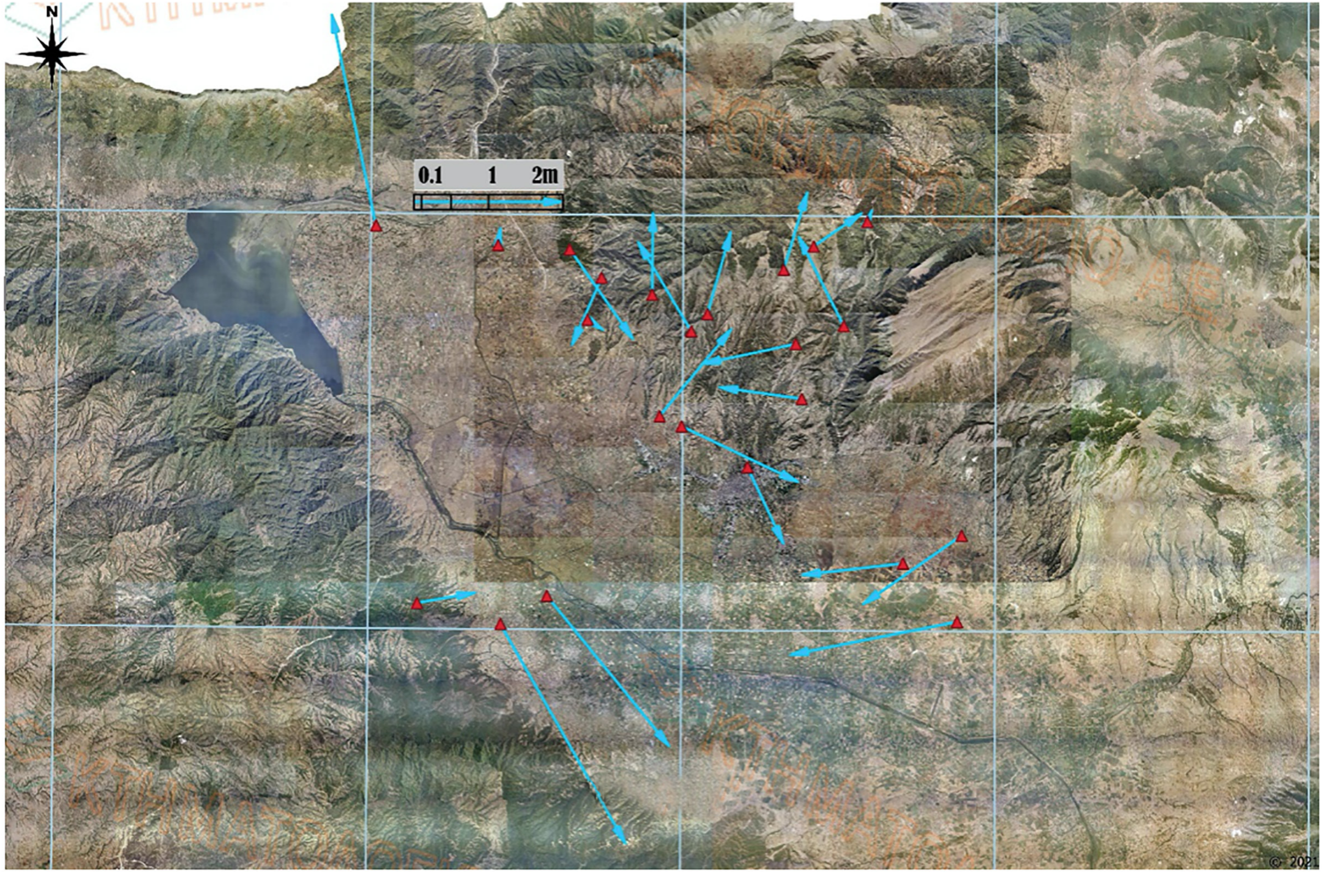

Figure 5: The horizontal residuals of the 2D similarity transformation for the examined area.

Table 3: The polynomial transformation parameters (from 'Old Bessel' to HGRS1987)

parameter	value
$a_0(m)$	455303.7852
a_1	0.9995969128
a_2	0.006132481192
a_3	-3.91E-09
a_4	3.28E-09
a_5	2.66E-09
$b_0(m)$	4566438.744
b_1	-0.006095481756
b_2	0.9994124097
b_3	6.54E-09
b_4	-9.84E-09
b_5	9.66E-10

Table 4: The statistical performance of the 2nd degree similarity transformation

statistical quantity	x-residual (in m)	y-residual (in m)
minimum	-1.03	-1.54
maximum	1.28	1.23
mean average	0.00	0.00
standard deviation	0.58	0.83

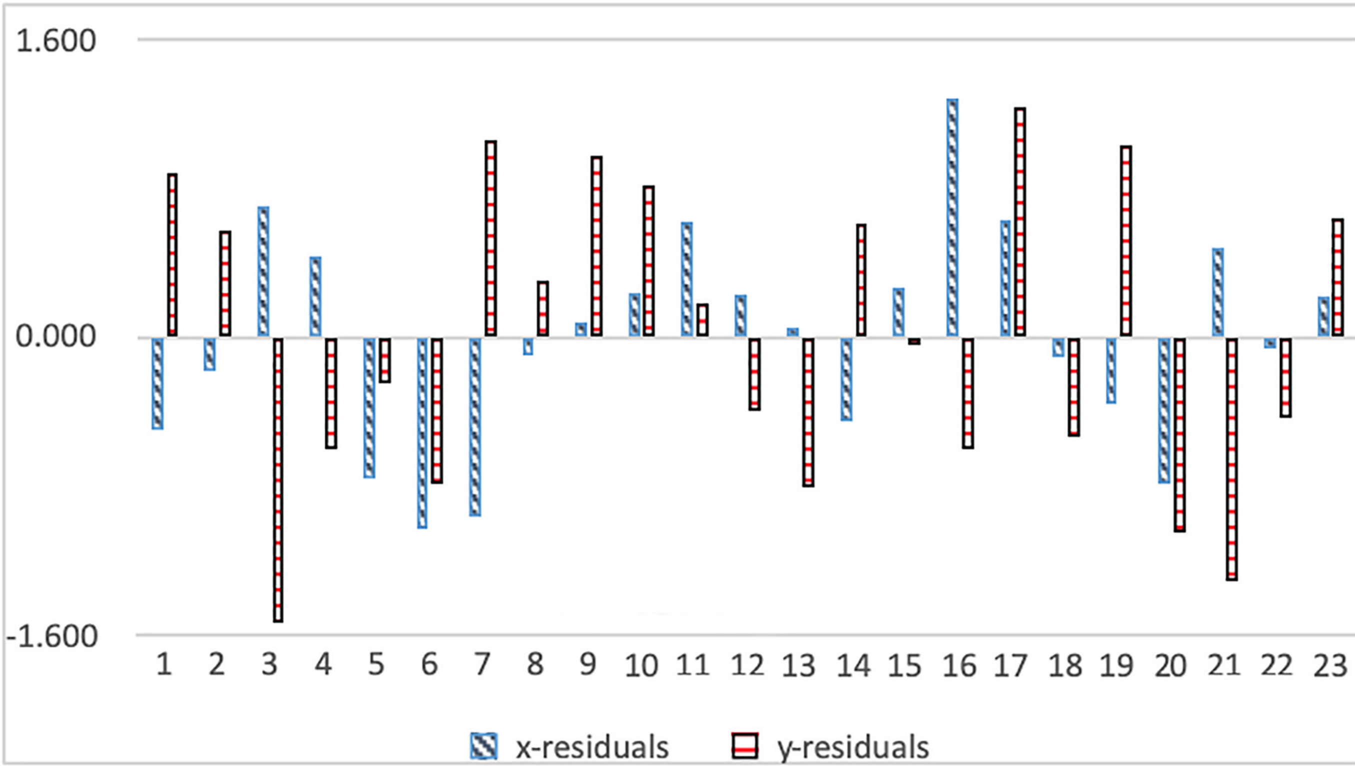

Figure 6: The residuals of the 2nd degree polynomial transformation per component.

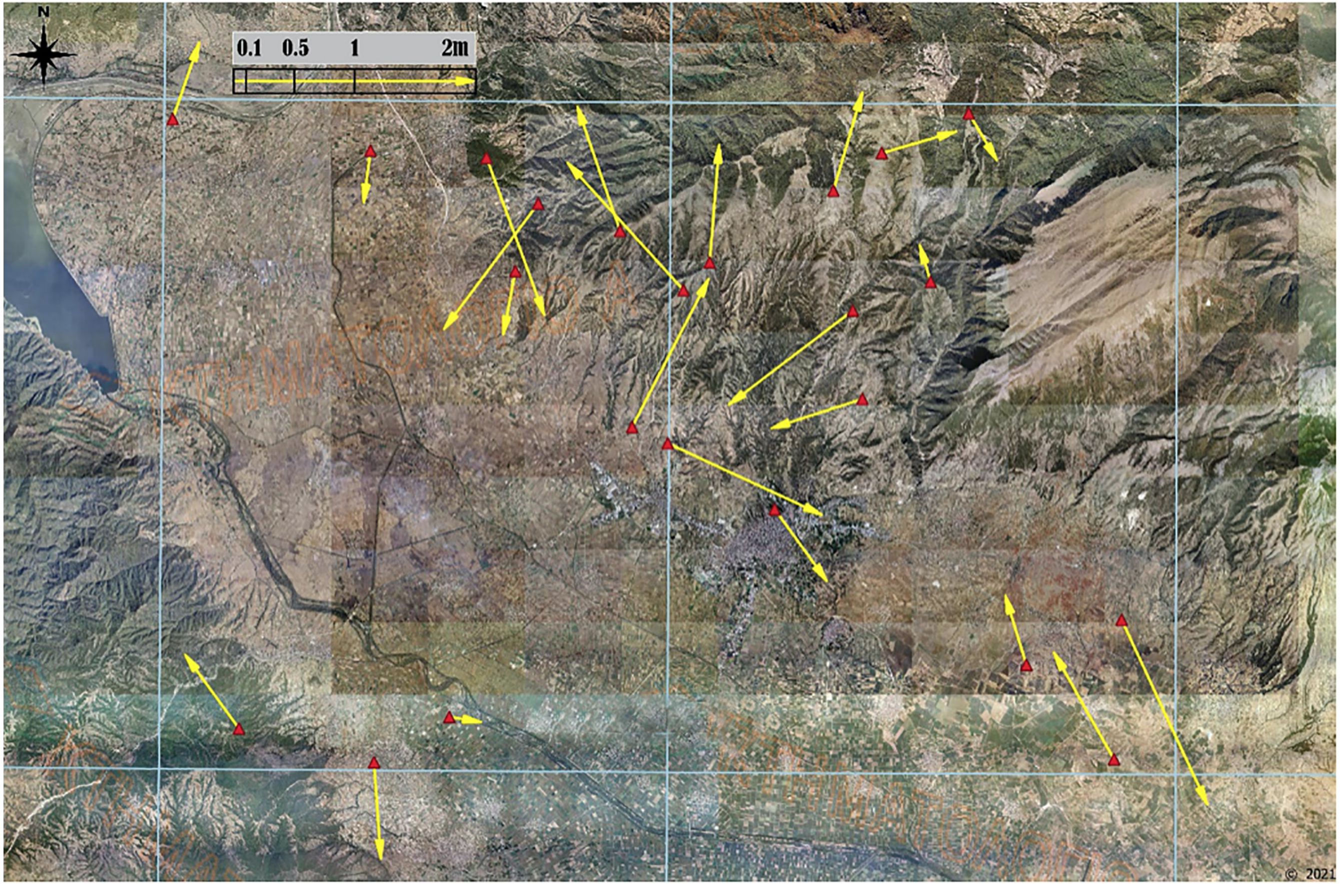

Figure 7: The horizontal residuals of the polynomial transformation for the examined area.

The residuals of both transformation types (2D similarity and polynomial, Figures 5 and 7, respectively) do not indicate any systematic influence (e.g. homogeneous orientation or scale). On the contrary, the arrows representing the residuals appear to behave randomly. This fact leads us to the conclusion that the 'Old Bessel' geodetic networks were solved independently, and were not part of a common adjustment scheme. Therefore, there is little that can be done with the associated residuals.[4] Nevertheless, this is only a local case and there definitely could be cases where the results of the transformations will be more homogeneous and suitable for further consideration. One may also reduce the examined area in order to improve the results of the initial transformations. However, this could not be done in our study of the Serres region because we did not find many benchmarks and were hence unable to limit our area of interest.

As a final comment on the transformation procedure, we would like to emphasize that the estimated parameters (both for similarity and polynomial transformation) refer to a specific common centroid. The transformation parameters are dependent on the choice of centroid and therefore, each map sheet can only be transformed (by these sets of parameters) once it has been aligned to this particular centroid.

Conclusions

The aim of the present study is to present a practical and straightforward method, using well-known mathematical tools, to perform consistent transformations between the 'Old Bessel' (the Oldest version of the GR-Datum) and the HGRS1987 datums. We hope to offer a practical means of overcoming the transformation problems experienced by surveyors and others working with these systems in Greece.

We have found that the consistency between the official HGRS1987 datum and the 'Old Bessel' is at the level of 1.2M for the case of the 2D similarity transformation and that it is significantly improved for the 2nd degree polynomial transformation case—i.e. 0.83M for the y-component. This is a clear indication that the two aforementioned datums (and especially the 'Old Bessel') carry both systematic biases and random errors.[5] Our transformation cannot be used over large areas (e.g., more than 10 x 10 km). A possible enhancement of the method would be either using a smaller area or applying further gridding of the residuals. However, on the one hand it is not easy to find common points—the 'Old Bessel's' Benchmarks were mainly established in the 1950s or even earlier—and the distribution of found points is rarely such that it might not cause distortions. Our test could be applied in other areas of the country to assess differences in the quality of the transformation. In the hope that this might eventuate, we are developing a new software package (written in Matlab) for the implementation of the algorithms presented in this article. We are ready to communicate with any agency, individual or government organisation in order to facilitate efforts to solve the transformation problem between these two geodetic reference systems.

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Notes

[1] While not a part of the coordinate transformation exercise, the control stations were surveyed in the 2014 International Terrestrial Reference Frame ITRF2014 in order to provide information for potential future studies, as well as contributing to available survey information, in particular elevations, for the stations in question.

[2] We should also underline that in Greece there are no officially implemented dynamic or semi-dynamic datum realizations as there are in New Zealand and Australia (see e.g., Donelly et al. 2014, Blick and Donelly 2016). The merit of the semi- or pure dynamical datums, respectively, is based on the exploitation of 2D and 3D velocities (derived from a velocity model) in order to relate the geodetic coordinates of a point to a specified reference epoch (e.g. Chatznikos and Kotsakis 2017). This is a crucial issue for geo-dynamically active areas like Greece, since points move with an average velocity of 2 cm/yr with respect to the Eurasian plate (Ampatzidis 2011). We believe that the tectonic deformation is one of the major bias sources causing inconsistencies among the Greek datums. However, the issue of the tectonic deformation is beyond the scope of the current paper.

[3] The 30'x 30' map sheets are called the 'Big Sheets' while the 6' x 6' sheets are called the 'Small Sheets' in Greek geodetic jargon.

[4] E.g. application of a gridding method. The gridding concept is based on an interpolation of residuals using such mathematic tools as variograms, least squares collocations, splines etc.

[5] Sources of these errors include: tectonics; historical measurements biases; network adjustment failures and random errors which cannot be identified or removed.

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Post-earthquake accuracy and precision assessment of NZGD2000

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Introduction

This paper assesses the accuracy and precision of the Land Information New Zealand (LINZ) PositioNZ sites, which underlie New Zealand's geodetic infrastructure and have, over the last decade, been affected by several significant earthquakes. We do this by estimating the coordinate precision (standard deviation) and accuracy (root mean square error (rms)) at approximately one year intervals from 2014 to 2020. The coordinates for all (mainland) PositioNZ sites have been computed as part of a student assignment (Paper SURV301, Survey Methods 2, School of Surveying) using the LINZ online post processing service, PositioNZ-PP (see below). Over this period of time, and taking into account the disruptive effects of both the Christchurch and Kaikōura earthquake events, we find that there is a general improvement in both the coordinate precision and accuracy. However, the largest sources of coordinate error are from uplift and subsidence which are currently assumed, by the deformation model, to be zero; slow slip events (SSEs), and post-seismic deformation. The deformation model itself implicitly assumes zero vertical motion, the model only has horizontal motions. Assuming that there is no vertical land motion will result in accumulated coordinate error. This has implications for our understanding of sea level rise, coastal communities and local authority planning. Ignoring SSEs will result in small, but not necessarily insignificant positioning bias while the post-seismic deformation following the Kaikōura 2016 event (and potentially future events), will result in accumulated coordinate error at the decimetre level over time periods of years to decades.

This paper briefly describes the background of the New Zealand Geodetic Datum 2000 (NZGD2000), including crustal deformation; the online positioning service; PositioNZ-PP, provided by LINZ, and the NZGD2000 Deformation Model (NDM). We describe the precision and accuracy assessment of the PositioNZ sites and show that the horizontal and vertical repeatability (precision) is consistently better than ±10 mm. The horizontal accuracy is now better than ±10 mm (range ±3–388 mm) and the vertical accuracy is at the ±10 mm (range ±2–289 mm) level. The LINZ coordinate accuracy standard (LINZG25706, LINZ (2010)) specifies the horizontal and vertical network accuracy for Order 0 (National Reference Frame) sites is better than 0.05 m (95% confidence level). On average, a total of 2 and 11 sites in the horizontal and vertical components respectively have calculated accuracies that are greater than (i.e. do not conform), to the LINZ coordinate accuracy specification each year.

A Brief History of NZGD2000

The current geodetic datum, New Zealand Geodetic Datum 2000 (NZGD2000), was implemented over 20 years ago. Although an understanding of earth deformation in New Zealand at the plate tectonic level was well documented (e.g. Bevin et al., 1984), the first static GPS data observed in 1989 showed that deformation and distortion of the previous horizontal datum, NZGD1949 (Lee 1978), had resulted in the accumulation of over five metres of movement (Bevin and Hall, 1995). Grant (1995) promoted the idea that earth deformation needed to be modelled and incorporated into the geodetic infrastructure in order to manage the cadastral and topographic datasets (Blick et al., 2003). Subsequently, the limitations and requirements of the new datum were recognised (Blick and Rowe, 1997) and options for managing crustal dynamics were developed (Grant and Blick, 1998). The complexities of crustal deformation, largely due to plate tectonic motion and seismic events, but to a lesser extent volcanic and large-scale landslide activity, also needed to be addressed in order to maintain datum accuracy for a wide variety of national spatial data applications. From a technical and geodetic perspective, the implementation of NZGD2000 was straightforward, but Blick and Grant (2010) outlined the need to manage both horizontal and vertical deformation on an ongoing basis. Today, using GNSS technologies and continuous GNSS sites (e.g. PositioNZ and cGNSS (Continuously Operating GNSS) services), it is a straightforward process to generate accurate, three dimensional positions, anywhere in New Zealand. What is more challenging is accommodating—and thereby maintaining the accuracy of the deformation model—of periodic and transient effects that result from seismic, volcanic, and landslide deformation.

Crustal Deformation

In contrast to NZGD1949, where the coordinates of the 1st Order trigonometric stations remained unchanged for nearly five decades, it was clear that relative deformation across the country would need to be accounted for in a new datum (Blick, 2003). Beavan and Haines (2001) developed the first nationwide velocity field for New Zealand that implemented the concepts of dynamic and semi-dynamic datums. In principle, this allows the position of any point in the country to be determined for any time if one knows the point's reference coordinate and its velocity:

$$X(t) = X(t_0) + V_X (t - t_0) \tag{1}$$

where $X(t)$ is the position at time t, V_X is the secular velocity and $X(t_0)$ is the position at a reference epoch t_0 e.g. 2000.0. This allows sites with different long term linear (otherwise referred to as, secular) motion to move at different rates thereby allowing for crustal deformation across the Australian/Pacific plate boundary. For most day-to-day survey operations that tend to be localised (e.g. topographical, engineering, cadastral), large scale nationwide deformation is not critical. However, with modern survey technology e.g. GNSS and the ability to measure to distant trigs (albeit GNSS base stations) over 100 kms away, it has become necessary to correct for the effects of ongoing deformation. Examples of applications include NetworkRTK (Denys 2017; Denys et al. 2017), online processing engines e.g. PositioNZ-PP, Precise Point Positioning (PPP) as well as any global or national geospatial datasets where positioning data has been recorded in terms of a geocentric datum.

Over time, a number of limitations of NZGD2000 have been identified (Beavan and Blick, 2007; Blick et al, 2009). In the New Zealand context, in addition to ongoing secular plate tectonic motion, earth deformation also results from earthquakes, slow slip events, and volcanic activity. It becomes necessary to have the ability to survey, record and account for the deformation in order to maintain the accuracy of the geodetic infrastructure (Blick, 2005). Because of the complex deformation experienced in New Zealand, the deformation cannot adequately be modelled as a simple velocity field (Equation 1), and additional short term deformation (e.g. earthquakes, slow slip events), and longer term deformation (post-seismic deformation) need to also be accounted for e.g. Denys and Pearson (2015, 2016).

PositioNZ-PP Positioning

PositioNZ-PP generates the three-dimensional coordinate of a point in a specific realisation of the International Terrestrial Reference Frame (ITRF—e.g. ITRF2008). Since the ITRF is a dynamic coordinate frame, the coordinate epoch is the current date of the observational data, referred to the instantaneous or observational epoch. The coordinate transformation from ITRF2008 to NZGD2000 is a two-step process; namely

(1) a 14 parameter Helmert coordinate frame transformation from ITRF2008 to ITRF1996 (the coordinate frame upon which NZGD2000 is aligned) at the epoch of observation (Donnelly et al., 2014);
(2) followed by the application of the National Deformation Model (NDM) from the current date to the reference epoch 2000.0 (i.e. 1/1/2000) that accounts for plate motion and other deformation effects since 2000.0.

The transformation is summarised as a Helmert 14 parameter transformation for the epoch of observation:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}^{ITRF1996} = \begin{bmatrix} T_X \\ T_Y \\ T_Z \end{bmatrix} + \left(1 + \Delta\mu\right) \begin{bmatrix} 1 & +\theta_Z & -\theta_Y \\ -\theta_Z & 1 & +\theta_X \\ +\theta_Y & -\theta_X & 1 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}^{ITRF2008} \tag{2}$$

where the transformation parameters for epoch, t, and reference epoch, t_0 = 2000.0, are given by

$$x(t) = x(t_0) + \dot{x}(t - t_0) \tag{3}$$

The ITRF1996 cartesian coordinates given by Equation (2) are transformed to topocentric (projection) coordinates and the NDM applied using Equation (1) (LINZ 2017).[1]

NZGD2000 Deformation Model

Integral to the PositioNZ-PP coordinate calculation, is the NZGD2000 Deformation Model (NDM) that transforms the calculated position from the epoch of observation to the NZGD2000 (epoch 2000.0). The model is based on the long term secular velocity as originally computed by Beavan and Haines (2001) and updated in 2013 (Crook and Donnelly, 2013; Crook et al., 2016). The concept of dynamic or semi-dynamic datums, proposed by Grant (1995), Grant and Blick (1998), is a practical approach for dealing with a continuously deforming plate boundary margin. However, from time to time the plate boundary undergoes seismic events that can potentially cause three effects: (1) abrupt, up to ~10 metre position changes due to an earthquake event (coseismic displacement), (2) slowly evolving post-earthquake relaxation that results in transient position changes on time scales of days to decades (postseismic deformation) and (3) small centimetre level periodic displacements that occur semi-regularly at multi-year intervals (Slow Slip Events—SSE).

To maintain the integrity of the geodetic infrastructure, LINZ recognised the complex nature of the deformation caused by earthquakes and other seismic events needed to be taken into account (Blick et al., 2009). Jordan (2006) introduced the concept of a Localised Deformation Model (LDM) or deformation patch that models a deformation event for a given time period and with defined spatial limits. The LDM is then incorporated into the NDM to refine the deformation spatially and temporally. A first attempt to create a LDM used a dislocation model of the 2003 Secretary Island Mw 7.2 earthquake (Jordan et al., 2007). While the effect of the earthquake was limited to the Fiordland region, the LDM demonstrated that the spatial distribution of the deformation caused by a large earthquake could be accurately modelled based on a relatively small number of survey marks.

Deformation patches have subsequently been developed by LINZ following major earthquake events (see Table 2). For example, the Dusky Sound 2009 earthquake (Winefield et al., 2010), the Christchurch 2010-2011 sequence (Crook et al., 2013), Cook Straight 2013 and Kaikōura 2016 events. In practice, the concept of a reverse patch (Crook et al., 2013) is nearly always applied. The modelled coseimsic displacements are applied to all affected NZGD2000 coordinates at epoch 2000 to correct for the earthquake (coseismic) deformation. The long term secular motion (Equation 1) is then applied in "reverse" to recompute the NZGD2000 (epoch 2000.0) coordinate from the current date back in time to the NZGD2000 reference epoch, 2000.0. In other words, a new NZGD2000 (epoch 2000.0) coordinate is determined as *if the earthquake event did not occur!*

Assessment of the PositioNZ Precision and Accuracy

As a School of Surveying class assignment,[2] PositioNZ rinex data has been downloaded each year since 2013 from the LINZ archive[3] and processed using the PositioNZ-PP online engine.[4] Each student was allocated a block of six days for 5-6 PositioNZ sites from the previous 12 month period. The Receiver Independent Exchange (RINEX) data files are uploaded (individually or in batches) to PositioNZ-PP plus an email address in order to receive and download the PositioNZ-PP processing results. Each year this generates a set of ~1300–1900 site positions (approximately 50 students x 6 sites x days) covering all mainland PositioNZ sites at arbitrary times over the previous 12 month period. In the initial years, the sheer quantity of data files would overload the LINZ processing server(s). Over time the LINZ systems have improved, and the failure rate reduced such that it is now not a significant issue.

Precision and accuracy estimates are determined for the sites and tracked over the seven year period. We tabulate the descriptive statistics for all years (2014 – 2020, Table 1), but exclude the 2017 data from the graphical plots (Figure 1 and Figure 2) since, at the time, LINZ had not updated the geodetic database coordinates or NDM to account for the Kaikōura 2016 earthquake event. As the earthquake significantly affected all PositioNZ sites in the upper South Island and lower North Island, the precision and accuracy estimates are adversely affected.

To determine the position repeatability or precision, we compute the circular horizontal[5] and linear vertical coordinate standard deviation, $\left(\sigma_{Hz}, \sigma_{Vt}\right)$, for each PositioNZ site for each block of ~6 days for which

$$\sigma_{Hz} = \sqrt{\frac{\sum\left[\left(E_i - \hat{E}\right)^2 + \left(N_i - \hat{N}\right)^2\right]}{n-1}} \, and \, \sigma_{Vt} = \sqrt{\frac{\sum\left(H_i - \hat{H}\right)^2}{n-1}} \qquad (4)$$

where E_i, N_i, H_i are the computed topocentric coordinates and $\hat{E}, \hat{N}, \hat{H}$ coordinates for each block of *site* positions (the mean of 6 daily positions). Table 1 reports the mean standard deviation, $\left(\hat{\sigma}_{Hz}, \hat{\sigma}_{Vt}\right)$ for each year. Note that the horizontal standard deviation is interpreted as the precision about the mean horizontal coordinate, $\hat{E}, \hat{N}$.

In a similar manner, the positional accuracy is determined with respect to each PositionNZ site's official coordinate by computing the circular horizontal and linear vertical root mean square error, (rms_{Hz}, rms_{Vt}), for which

$$rms_{Hz} = \sqrt{\frac{\sum\left[\left(E_i - E_{LINZ}\right)^2 + \left(N_i - N_{LINZ}\right)^2\right]}{n}} \, and \, rms_{Vt} = \sqrt{\frac{\sum\left(H_i - H_{LINZ}\right)^2}{n}} \qquad (5)$$

where E_{LINZ}, N_{LINZ}, H_{LINZ} are the LINZ official geodetic topocentric coordinates for each site and *n* is the total number of computed positions for each year and site. The root mean square error is normally used as a comparison against the true or known value of a higher accuracy quantity e.g. coordinate. In the case of the current study, the coordinates used by PositioNZ-PP for the PositioNZ sites are determined using position time series analyses as described in Pearson et al., (2013a, b, 2015a, b), and not the official LINZ values (i.e. E_{LINZ},N_{LINZ}, H_{LINZ}). Because the same GPS/GNSS data is used in in establishing official LINZ NZGD2000 coordinates as well as the position time series for each PositioNZ site, it is not strictly an independent assessment. However, ignoring that the same data is used for both the PositioNZ coordinates and PositioNZ-PP calculations, and since the LINZ coordinates are the authoritative values used in New Zealand, it is the sensible choice for the "known" coordinates to compare against. Table 1 reports the mean *rms* for each year together with the minimum and maximum *rms* values.

PositioNZ coordinates are periodically updated as a result of national geodetic adjustments that are required to maintain the geodetic infrastructure, but also in response to major seismic events e.g. the Christchurch 2010-2011 sequence (Kaiser et al., 2012) and Kaikōura 2016 (Hamling et al., 2017). Table 2 summarises key PositioNZ position changes and updates. The known coordinates used for the calculation given in Table 1 are therefore the most recent official coordinates for each year, downloaded from the geodetic database.

The network accuracy, for both the horizontal and vertical PositioNZ sites (Order 0, Tier A), is given in the LINZ (2010) fact sheet as ±0.05m at the 95% confidence level. Using the *rms* as an estimate of the network accuracy equates to the maximum horizontal error (HE) and vertical error (VE) for a position of HE_{68} = ± 29mm and VE_{68} = ± 26mm respectively (68% confidence level). Table 1 reports the number of sites that exceed these limits, (i.e.HE_{68} VE_{68}), out of the total of 32–37 sites used in each year's analysis.

For the majority of PositioNZ sites and excluding 2017, the horizontal accuracy is satisfactory with an average *rms* of approximately ±10 mm and only a few (<5) sites exceed the LINZ maximum HE. Clearly the 9 sites where HE_{68} > ± 29mm in 2017 is due to the Kaikōura 2016 earthquake. Compared to the horizontal accuracy, the average vertical *rms* is greater than ±10 mm, while the number of sites exceeding the maximum VE, with VE_{68} > ± 26mm is consistently over 7 (average >10) and does not appear to be improving.

***Table 1**: The horizontal and vertical mean standard deviation (precision) and the mean, minumum and maximum root mean square error (rms) (accuracy) for PositioNZ sites, 2014-2020. The number of sites that exceed the maximum horizontal error (HE_{68} = ±29 mm, 68% CI) and vertical error (VE_{68} = ±26 mm, 68% CI) are computed using the LINZG25706 standard (LINZ 2010). For each year, the total number of sites and observations (n) is given on the RHS.*

	Precision (mm)		Horizontal Accuracy (mm)		HE_{68}	Vertical Accuracy (mm)		VE_{68}	Total	
Year	$\hat{\sigma}_{Hz}$	$\hat{\sigma}_{Vt}$	$r\hat{m}s_{Hz}$	min / max	Sites >29 mm	$r\hat{m}s_{Vt}$	min / max	Sites >26 mm	Sites	n
2014	3	5	16	5 / 41	4	34	4 / 148	25	32	1276
2015	3	6	7	3 / 20	0	12	5 / 26	9	34	1438
2016	3	6	5	2 / 13	0	8	2 / 23	7	35	1697
2017	18	14	27	3 / 388	9	18	3 / 289	10	37	1822
2018	6	8	11	3 / 61	5	11	3 / 44	11	37	1592
2019	3	6	6	2 / 35	2	9	3 / 25	8	36	1841
2020	4	8	8	3 /42	1	10	5 / 35	10	36	1914
mean	6	8	11		3	15		11	total	11580
mean[1]	4	7	9		2	14		12	total	9758

[1] Mean value excluding 2017 due to the Kaikoura 2016 earthquake

Table 2: Sequence of PositioNZ coordinate upgrades (LINZ 2018)

Date	Description	NMD version
28-Jul-1999	NZGD2000 Development Project, secular velocity model	20000101
14-Dec-2013	Geodetic patch including signficant earthquakes 2003-2011	20130801
12-Dec-2014	Geodetic patch for the 2013 Cook Strait and Lake Grassmere earthquakes	20140201
17-Dec-2015	PositioNZ Coordinate update, includes Auckland and Antipodes Islands	20150101
30-Jun-2016	Geodetic patch for the February 2016 Christchurch earthquake,	20160701
14-Jan-2018	National Geodetic Adjustment NZGD2000 update. Geodetic patch for the 2016 Kaikoura earthquake	20171201
25-Oct-2018	Update geodetic patch for the Kaikoura earthquake	20180701

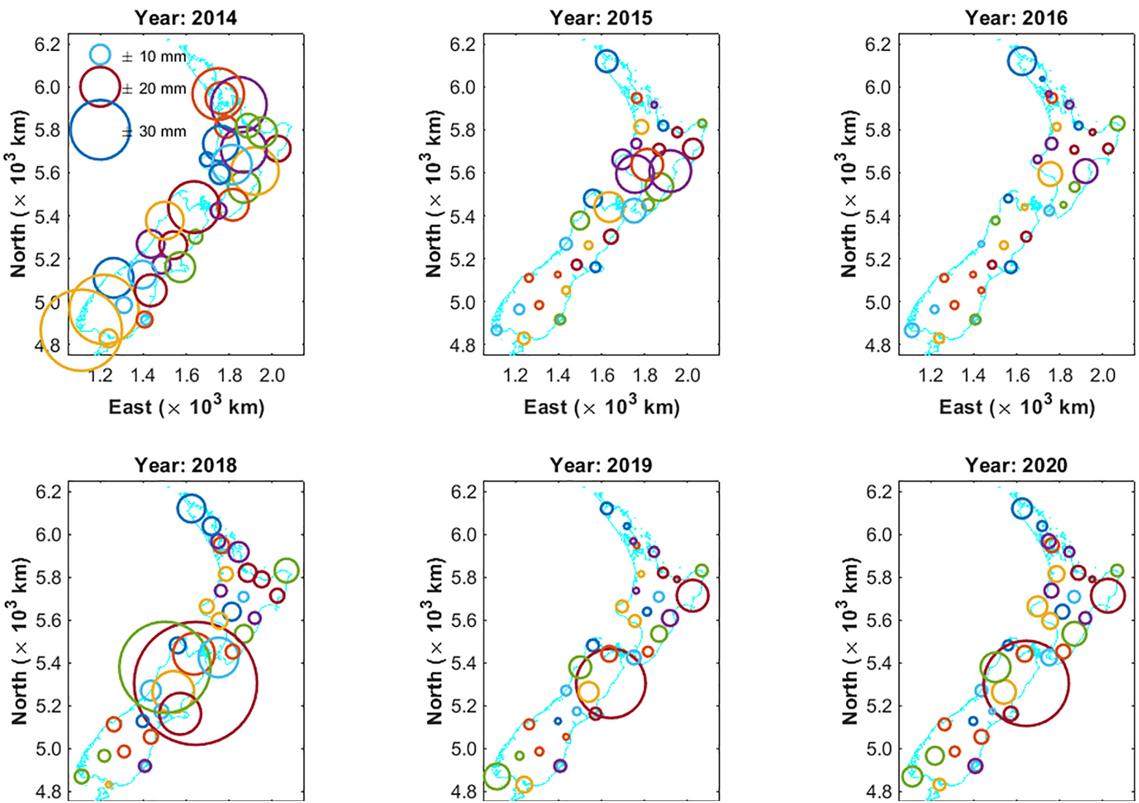

Figure 1: Mean horizontal accuracy (rms) for PositioNZ sites 2014-2016, 2018-2020. The plot for 2017, following the Kaikoura 2016 earthquake, is excluded since the coordinate error is unrepresentatively large (see 2017, Table 1). LINZ subsequently recomputed and updated the official coordinates, which have been used from 2018.

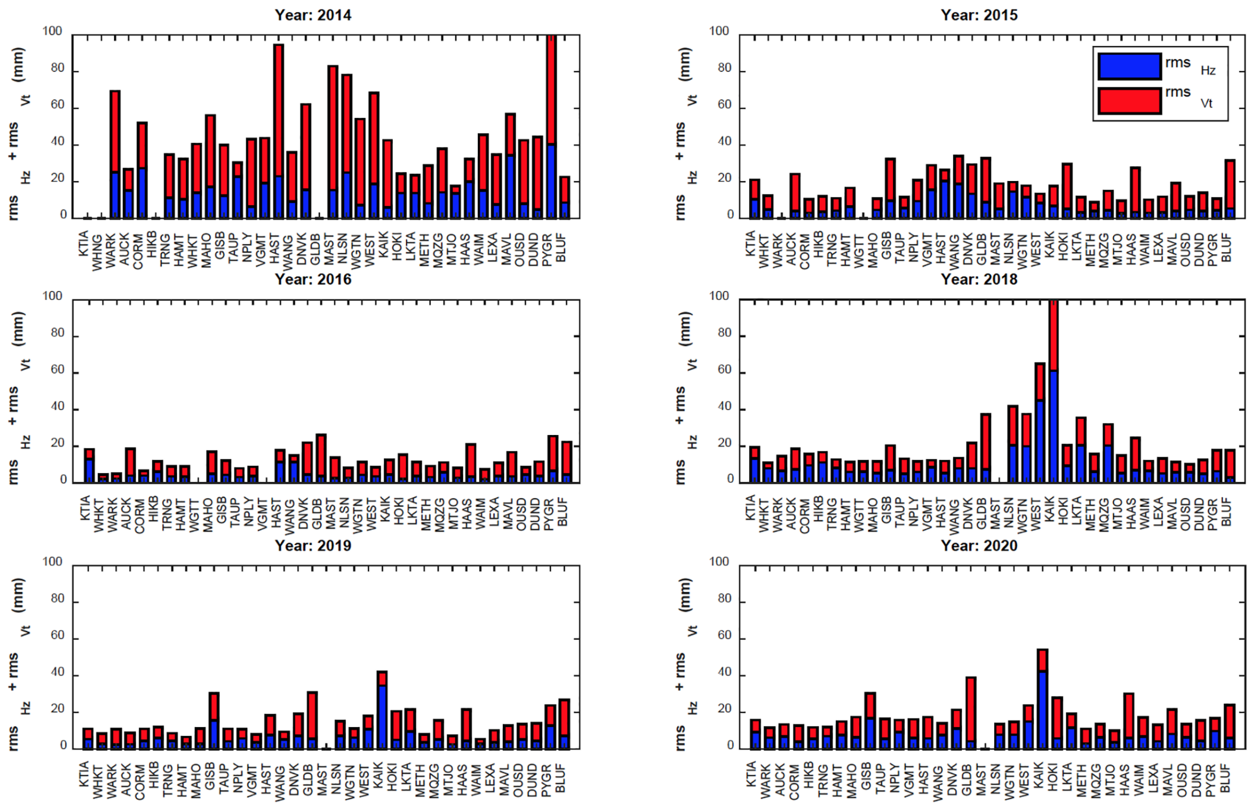

Figure 2: Combined rms_{HZ} and rms_{vt} for each PositioNZ sites 2014–2016, 2018–2020. The plot for 2017, following the Kaikoura 2016 earthquake, is excluded since the coordinate error is unrepresentatively large (see 2017, Table 1). The PositioNZ sites are order approximately by latitude from the North (left) to the South (right).

Interpretation

Except for 2017, the site repeatability estimates are largely consistent over the seven year period, 2014-2020 (Table 1). The elevated standard deviations in 2017 (× 2–5) is not unexpected since the Kaikōura earthquake impacted all sites throughout New Zealand. The upper South Island and lower North Island underwent both horizontal and vertical deformation of up to approximately the 10 metre level (Hamling et al., 2017). Clearly, the earthquake deformation created significant relative positional changes between PositioNZ sites, resulting in a decrease in precision for approximately one year following the earthquake event. As the PositionNZ sites had moved physically, compared to the authoritative coordinates, the PositioNZ-PP processing introduced bias to the baseline vectors used to determine the positions of the site(s) being processed.

In terms of accuracy, compared to 2014, the December 2014 PositioNZ coordinate update (Table 2) made a significant impact with an approximately 60% improvement in both the horizontal and vertical accuracy (Table 1, Figure 1 and Figure 2). In 2014, the vertical accuracy is particular poor with rms_{Vt} = ± 34mm, which is nearly double the 2017 rms value, and with more than 75% (25/32) sites exceeding the maximum vertical error specification of VE_{68} = ± 26mm. The most uniformly high accuracy across the whole of the geodetic network is achieved in 2016 (sub-centimetre level: rms_{Hz} = ± 5mm, rms_{Vt} = ± 8mm), as well as having the least number of PositionNZ sites that exceed the maximum horizontal and vertical error limits with 5 and 7 sites respectively (total 35 sites). This is clearly seen in Figure 1 and Figure 2.

The three years, 2018–2020, show consistently the ongoing elevated network error levels where the sites in the Kaikōura region continue to dominate. A horizontal accuracy improvement of 45% following the October 2018 PositioNZ update can be seen visually in Figure 1 , although there is no discernible improvement in the vertical accuracy (Table 1). Overall, the mean horizontal and vertical accuracy following the national geodetic adjustment and reverse patch update (January 2018) appears to be at the one centimetre level or slightly better.

The effects of the Kaikōura earthquake clearly continue to bias the sites, KAIK, LKTA, GLDB and WEST, where the horizontal *rms* > ± 10mm (Figure 2). In fact, the horizontal rms at these sites increased in 2020 suggesting that the effect of on-going Kaikōura postseismic deformation is significant and the error is likely to become larger in the future. Notably the vertical rms for these sites and others in the upper South Island tend to be at the rms_{Vt} ~ ± 10mm or larger and are generally less than the horizontal rms suggesting that vertical post earthquake deformation has stabilised while the horizontal deformation has not. The post-seismic deformation since January 2018 has not been included in the current NDM.

Two other sites on the east coast of the North Island, GISB and DNVK, also have horizontal and vertical rms values > ± 10mm, which is due to the slow slip events (SSE) caused by the East Coast subduction zone.

Discussion

Updating New Zealand's geodetic infrastructure, upon which all other spatial data sets are based (e.g. cadastral, topographic maps, hydrographic charts), has clearly been achieved following the major earthquake events that have occurred in the South Island over the last two decades. What has not been achieved is adequate modelling of non-linear deformation (Denys and Pearson, 2015, 2016) and ongoing post-seismic deformation e.g. Denys et al. (2019). The current NDM does not include deformation caused by subsidence and uplift (the vertical component) (Pearson and Denys, 2015), slow slip events (SSEs) and post-seismic deformation.

Vertical deformation: New Zealand's global position on the boundary between the Australian and Pacific plates means that there is significant vertical deformation as well as horizontal deformation. For example, the subduction of the Pacific plate under the Australian plate along the east coast of the North Island, Kāpiti Coast and upper South Island results in ongoing subsidence of up to 10 mm/yr (Fadil et al., 2013). Further south, Bevan et al. (2010) showed that the central Southern Alps are uplifting by 5–6 mm/yr. In addition, other geophysical processes also contribute to vertical instability. For example, modelling by Riva et al. (2017) shows that the loss of ice in the Southern Alps due to a warming climate has a small but consistent impact on the solid earth throughout the whole of New Zealand. The whole of the North Island is subsiding >0.35 mm/yr (35 mm/ century), the South Island slightly less at 0.3 mm/yr (Denys et al., 2020) while the central Southern Alps is uplifting at 0.8 mm/yr. The lack of vertical velocities in the (NDM) will cause a bias between (GNSS measured) ellipsoid heights measured at different epochs. The lack of vertical velocities is probably the most serious deficiency in the NDM as the bias will accumulate with time.

Slow Slip Events: New Zealand is subject to non-linear deformation associated with slow slip events (SSEs). These typically cause periodic 10-20 mm position changes along the central east coast of the North Island and up to 50 mm along the Kāpiti Coast. This level of regional deformation is not incorporated in the NZGD2000 deformation model. Since the NDM velocities are determined using a linear model, the effect is averaged across multiple SSEs, resulting in the true position of the point being systematically displaced from the SSEs, resulting in the true position of the point being systematically displaced from the modelled position by an amount dependent on where the SSE cycle happens to be at the time in question. This is similar to a cyclic error but does not have a regular sine curve periodicity.) As a result, coordinates determined at different times for points located in areas subject to SSEs will have a potential bias in both the horizontal and vertical directions. However, since the SSEs are quasi periodic, the bias is limited to plus or minus half the typical amplitude of the SSEs i.e. typically ~ 10 – 20 mm. For the PositioNZ site, HAST (Hasting, Figure 3), the SSE results in a significant eastward shift of ~100 mm, a small southward shift of 10 mm and 50 mm of vertical uplift over 18.5 years.

Post-seismic deformation: Unmodelled post-seismic relaxation is a third source of bias. The NDM does not currently include post-seismic relaxation models, instead, it includes a series of temporary velocity changes or ramps that approximates the post-seismic deformation. However, for the Kaikōura earthquake, the ramp functions terminate at 14 Feb 2017. As a result, the ongoing post-seismic deformation since this time is not corrected by the NDM and will bias the NZGD2000 coordinates when transformed to epoch 2000.0 (NZGD2000). As an example, we plot the position time series in Figure 4 (East, North, Height components) for the GeoNet station CMBL (Cape Campbell, located near the northern trace of the Kaikōura earthquake) with the date 14 Feb 2017 marked as a vertical line. Up until this date, the post-seismic displacements amounts to 0.03-0.05 m. Clearly the post-seismic deformation has continued and has now resulted in (May 2021) displacements of over 0.1 m and 0.15 m in the horizontal and vertical components respectively.

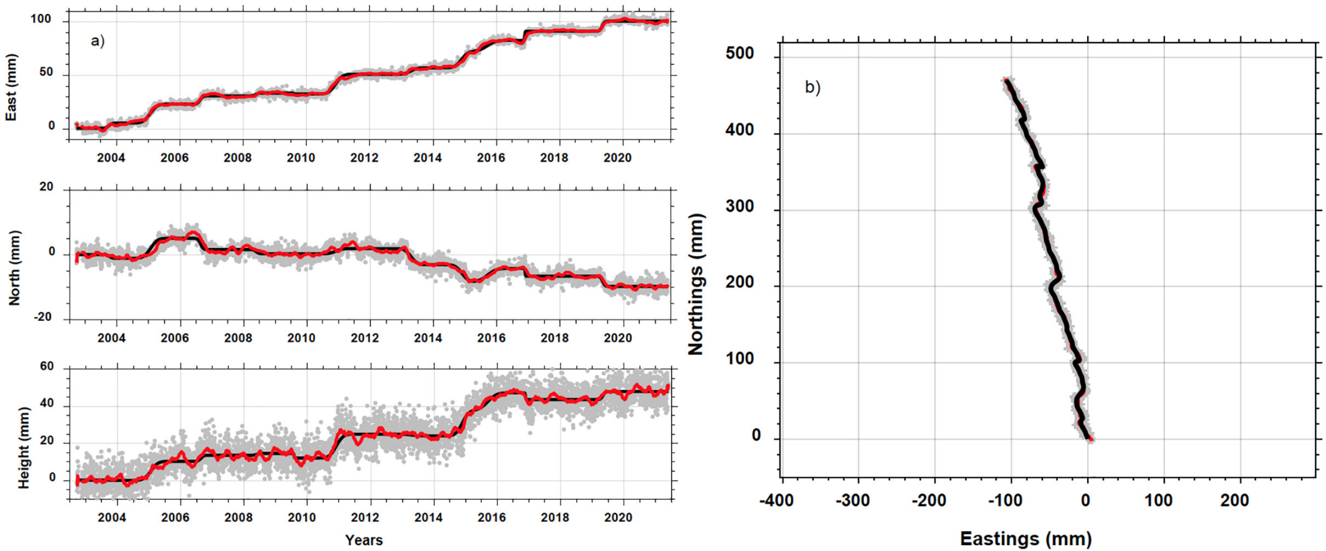

Figure 3: The PositioNZ station HAST (Hasting) showing the semi-regular SSEs for the East, North and Height time series components (a) and as a horizontal plot (b). The accumlated motion over 18.5 years is over 0.1 m east, 0.01 south and 0.05 m up.

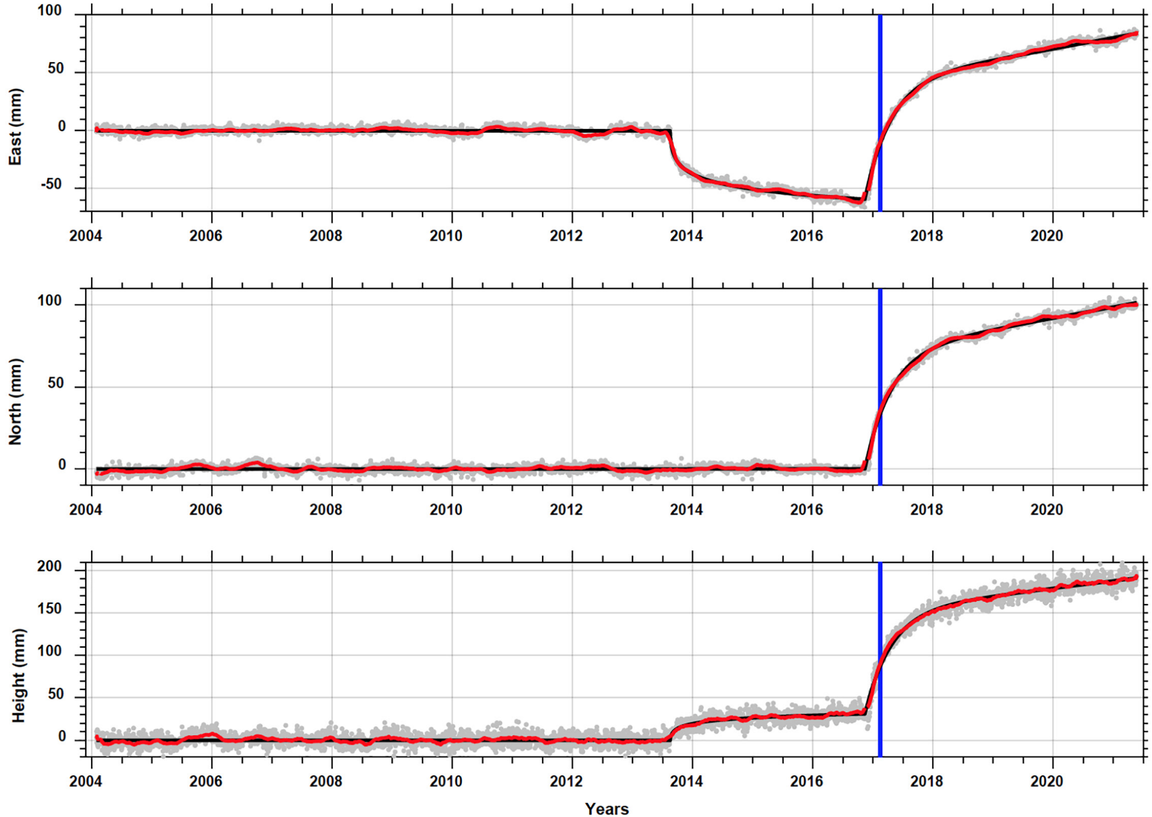

Figure 4 Position time series for GeoNet station CMBL (Cape Campbell) showing the combined post-seismic deformation from the Grassmere/Cook Strait earthquakes (2013.6) and the Kaikoura earthquake (2016.8). The coseismic displacements are not shown, (~1 – 2.5 m level). For the Kaikoura event, the ongoing post-seismic deformation exceeds 0.1 m in the horizontal components and 0.15 m in the vertical component. The date 14 Februray 2017 is shown as a vertical blue line.

Summary

Over the seven year period 2014 – 2020, and ignoring the immediate effect following the 2016 Kaikōura earthquake, the estimated PositioNZ site repeatability is a consistent ±4 mm and ±7 mm for the horizontal and vertical precision respectively. Site accuracy is approximately double the site precision at ±9 mm and ±14 mm for the horizontal and vertical components respectively. The least accurate sites are typically ±20 – 40 mm. The number of sites that exceed the LINZG25706 standard (LINZ 2010) for the maximum horizontal error is less than five (2018) and less than 11 (2018) for the maximum vertical error. For the seven year period the number of sites that exceeded the maximum horizontal error has been or is decreasing to zero while the maximum vertical error is consistently in the order of 10 sites.

New Zealand's tectonic setting means that the country is actively deforming as a result of plate boundary processes. While the relative deformation is regular and largely secular in nature, seismic activity results in significant displacements (coseismic deformation) as well as ongoing postseismic relaxation and SSEs. It is these three geophysical phenomena that degrade New Zealand's geodetic infrastructure and are currently impacting the overall geodetic accuracy of the network. Clearly, LINZ's geodetic network upgrades following significant earthquake events has improved the horizontal accuracy, although sites closest to the Kaikōura region are still affected by on-going post-seismic relaxation. Throughout the country, vertical accuracy remains consistently less accurate, which in part can be attributed to an assumed zero vertical land motion in the NDM.

It is imperative that the geodetic infrastructure is maintained to a regular standard in order to underpin the topographic, cadastral and bathymetric datasets as well as the most remote sensing technologies, which are based on a geocentric coordinate frame. While many of the geodetic biases are small, it is the incremental effects that gradually distorts the geodetic infrastructure over time. Vertical deformation; SSEs, and post seismic deformation should be included in the NDM in order to maintain the accuracy of the geodetic infrastructure.

Notes

[1] We note that the deformation model does not include vertical velocities which happen to be quite high especially along the east coast of the North Island. Other parts of LINZ do incorporate vertical change such as PositioNZ processing. Hence when we do a PositioNZ-PP solution the coordinates we assume for the PositioNZ stations are corrected for vertical motion to give an accurate current position but when we project these to epoch 2000.0 we ignore the vertical component.

[2] Paper SURV301 (Survey Methods 2), School of Surveying, University of Otago

[3] www.linz.govt.nz/data/geodetic-services/positionz/rinex-data-archive

[4]www.linz.govt.nz/data/geodetic-services/positionz/positionz-post-processing-service

[5] Circular horizontal standard deviation is a circle with a radius computed from the square root of the sum of east and north variances

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