Reconstructing Rotomahana Basin topography to disclose the lost White Terraces, New Zealand's Eighth Wonder of the World

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"Ye cannot see the wood for the trees"
−John Heywood, 1546.

Abstract

The greatest geoscience and tourist attractions in the southern hemisphere were the *Pink and White Terraces*, the lost *Eighth Wonder of the World*. British, American and European tourists bypassed local calcareous terraces, for the sea voyage to New Zealand where the siliceous terraces astonished a global audience. Their allure remains. In 1886, the Mount Tarawera eruption buried the terraces. They were not officially surveyed, hence no one knew for certain, where they lay. Debate over their survival continued until the 1940s.

In 2011, a *joint New Zealand-American project* claimed to have found the Pink and White Terraces underwater. Recently their claims were refuted. In Europe, terrestrial survey documents were unearthed, including the only compass bearings to the terraces. Ferdinand Hochstetter's survey records were repatriated and his 1859 survey reconstructed.

This spatial analysis reports the White Terraces could have been located after the 1886 eruption, by a competent examination of the Rotomahana Basin. By studying its topography, eruption crater, lakes and river systems; by georeferencing and from indigenous Māori knowledge; the early search and rescue, government and university survey teams; had sufficient topographic evidence for a *Chain of Evidence*, locating the White Terraces.

They also failed to consider water flows into and around the crater. Herein, I trace water flows from the terrace springs. These continued pumping during and after the eruption, creating watercourse evidence from the three terrace springs. These findings are compared with Hochstetter's survey locations for the Pink, Black and White Terraces. The methodologies agree.

This validation, together with a new published altimetry and Black Terraces spatial research, provides layers of evidence for the coordinates of the three terrace springs today. This new body of empirical evidence, together with Hochstetter's survey reconstruction; revises the historical record for the Rotomahana Basin eruption of 1886.

Keywords: Rotomahana Basin, Rotomakariri, Ferdinand von Hochstetter, spatial, topography, historical survey data, reverse engineering, Mount Tarawera eruption, Pink, Black and White Terraces, Lake Rotomahana.

1.0 Introduction

The Pink and White Terraces, New Zealand's *Eighth Wonder of the World*, were presumed by colonists to be lost in the 1886 Mount Tarawera eruption. Local Māori experts believed they survived, buried in mud (Warbrick, 1934).The media debate continued until local eyewitnesses and survivors passed on by the 1940s. The terraces passed into legend until 2011, when claims to have found the *in situ* terraces were made by a *joint New Zealand-American project,* garnering global attention (de Ronde, 2011). Due partly to an 1886 presumption the terraces were lost: their 2011 claims were accepted. Only one challenge was made (Keir, 2012). Recently their 2011− claims, based on photo-interpretation and an unfinished map, have been refuted (Bunn, 2020b, c; 2021; 2022a, b).

In 2014, I was drawn into the field after accepting the joint New Zealand-American project claims. It was several months before I noted flaws in evidence they published in institutional and lay media. My 2014 PAWTL Project (Pink and White Terraces Limited) to drain Lake Rotomahana and reveal the supposedly drowned terraces, was suspended after a warning from the New Zealand-American project, that it risked a further geothermal eruption (Bunn, 2014). In following years, the New Zealand-American project moved their Pink Terrace location to a second and a third deeper location; beyond our scuba reach. The new locations were unsupported by their original evidence (de Ronde et al, 2016; 2018). I left the research, to write a book on the subject.

In 2016, I re-entered the field with Dr Sascha Nolden's digitally repatriated documentary heritage material from the estate of Ferdinand von Hochstetter (1829-1884), known as the *Hochstetter Collection Basel*. From this time, we were not reliant on joint New Zealand-American evidence. Instead, Nolden and I began working with Hochstetter's 1859 survey notebooks, from the only terrestrial survey conducted over the Pink, Black and White Terraces, in the Rotomahana Basin. After transcribing, translating, interpreting and locating his bearings and landmarks; and auditing with leading surveyors: we began reverse engineering the survey and publishing the research (Bunn & Nolden, 2016, 2018).

Our third 2016 survey iteration, reverse engineering of Hochstetter's survey contained uncertain landmarks; given a landscape devastated by the 1886 eruption. In 2017, our fourth survey iteration published to global fascination (Bunn & Nolden, 2018). We were inundated with media and volunteer requests to join site work and I floated the *citizen science* PAWTL2 Project (Pink and White Terraces 2). In 2018 Bunn et al published the fifth survey Iteration, after auditing revealed a misidentified landmark (Bunn et al, 2018). In 2019, I published the final, sixth Iteration (Bunn, 2019). In 2020, further 1860 survey data came over my desk, supporting our 2016-2019 Hochstetter survey findings.

Now, we apply the survey dataset to unanswered questions about the 1886 Rotomahana-Rotomakariri Basin eruptions. We have published survey extrapolations on lands to the south,

west and north of Lake Rotomahana. We resolved surviving pre-eruption proximal landmarks e.g. Rangipakaru Hill and the Steaming Ranges, named by Daniel Mundy (1826−1881), (Mundy, 1875). The remaining lands lie east of Lake Rotomahana in the Rotomahana Basin. These include Lakes Rotomakariri and Rangarua and the Kaiwaka and Awaporohe Streams; which I attempted to locate in 2017. Figure 1 shows the post-eruption Rotomahana Basin topography.

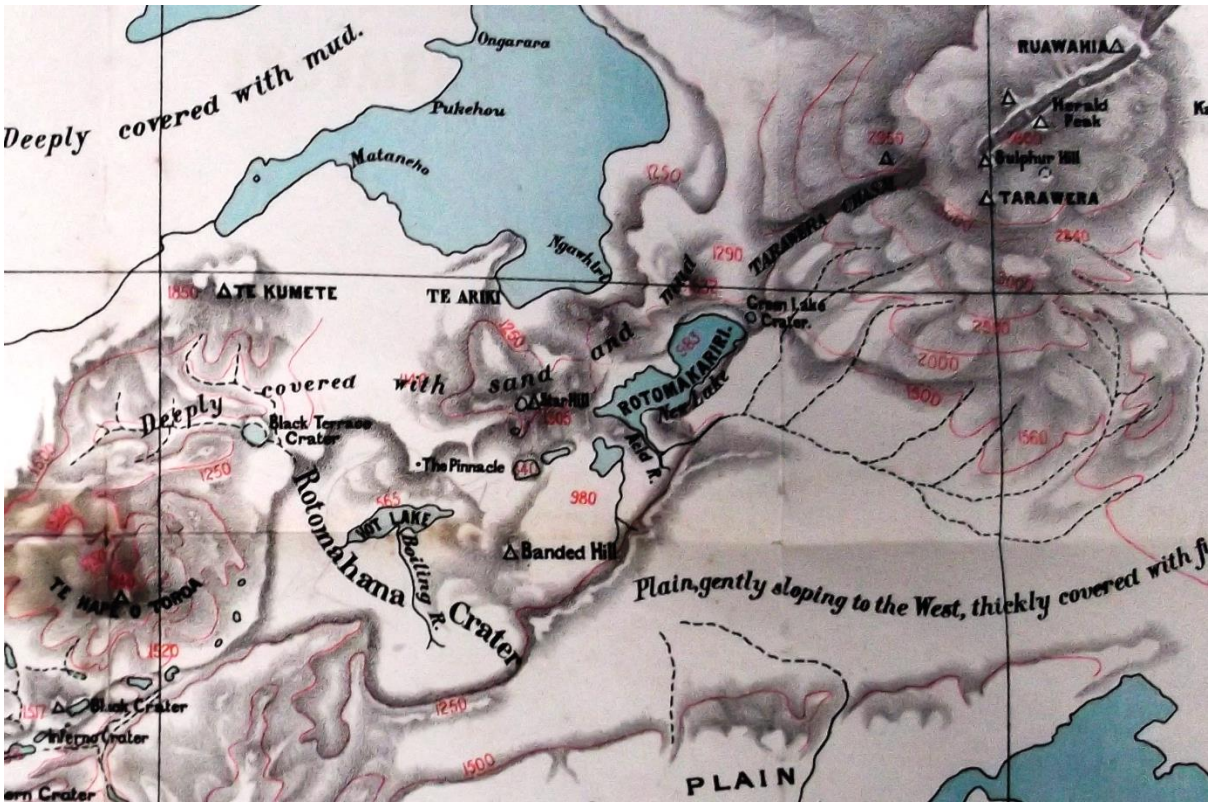

Fig. 1. The Rotomahana Basin in July-August 1886 (Smith, 1887).

This paper examines the lands east of Lake Rotomahana and the Steaming Ranges, with emphasis on adjacent water bodies and streams. Once the pre/post-eruption topography is resolved, these features lost in today's landscape provide further layers of evidence. Such features furnish control points to further triangulate the Pink, Black and White Terraces─ which since 1886 remain the ultimate research focus at Lake Rotomahana.

2.0 The Steaming Ranges

Hochstetter first described the Steaming Ranges (or Pinnacle Ridge), containing the White Terraces as: "a hill -- rising about 200 feet about the level of the lake, overgrown with fern and Manuka -- which steams on more than a hundred other places" (Hochstetter, 1867).

With hindsight─ even without Hochstetter's survey there was sufficient cartographic, topographic and historical record evidence as the sun rose that 10 June 1886; for the White

Terraces location to be found in the altered landscape. It is trenchant criticism of the three government teams which arrived over coming weeks; that they failed to recognise the evidence, even while including it in their reports. They were looking for a lake on a map and disregarded the evidence around them in the new landscape. The Tarawera eruption was witnessed on the night, with the rift starting on the eastern peak Wahanga and proceeding south-west along the Ruawahia and Tarawera peaks before creating the chasm in the side of Tarawera; then continuing under Lakes Rotomakariri and Rotomahana and into the Okaro area, along the Haumi Stream valley. This valley later became the Waimangu Valley. The eruption possibly carried on further into Okaro. It followed an azimuth of 57° all this way. The rift was in a state of chaos and later compared to a zipper opening. While zippers were not invented in 1886, commonsense suggests that 1886 observers wishing to grasp the topography, would look either side of the rift for prior features, perhaps forced apart by the rift: to orient themselves in the landscape and answer the question that stopped the nation i.e. did the Pink and White Terraces survive?

The Arawa Māori tribal elders, with different mapping and navigation approaches, observed that the Pink and White Terraces lay buried in mud. The government surveyors and geoscientists either did not ask or did not listen (Warbrick, 1934).

Signposts lay in the crater. It was common knowledge in 1886, that a hill (really an isolated ridge) lay along the east shore of Lake Rotomahana and this hill was ~1.4 km long, ~60 m high and ~600 m wide. Its axis lay north-south. The Waikanapanapa Valley divided it into north and south sections. It was known the White Terrace lay on the northwestern tip of that hill. Thousands of tourists had seen it there. Stephenson Percy Smith (1840-1922), the Assistant Surveyor General refers to this hill in his field report: “immediately to the north of the central lake there are some rugged pinnacles of black rock, rising to the height of the crater rim. These have a special interest as marking the site of some of the hills which formerly stood close to the White Terraces. The exact position of the [White] terraces cannot be identified, as the ground around where they formerly stood has been blown away; [sic] but they were evidently close to, and to the north-west of, the pinnacles” (Smith, 1887).

There were two sets of steaming pinnacles: one to the north of the main crater and one to the south. The latter abutted an eminence in the crater which was named Banded Hill. These steaming pinnacles, joined by a shallow, curved ridge over the crater floor, connected Banded Hill (later christened Patiti Island to honour Alfred Warbrick and now recognised as Rangipakaru Hill), with the main ridge to the north of the crater (Bunn, 2020c). These formed an obvious pairing – the two sets of steaming pinnacles on each side of the rift, witnessing their connection. No one recorded this connection prior to this paper.

Our reconstruction of Hochstetter’s survey bearings and our georeferencing of his cartography, confirm Smith’s 1887 report i.e. this northern hill was the surviving northern stump of the Steaming Ranges (Smith, 1887). Separating the two sets of pinnacles lay the volcanic rift, stretching down from Mount Tarawera at an azimuth of 57°.

This is shown on Smith’s 1886 manuscript and published maps, in period photography by e.g. George Valentine (1852–1890), and in paintings by Charles Blomfield (1848–1926), (which provide a better perspective from the crater floor, versus the photographers along the northwest crater rim). The highest section of the northern pinnacles (which was named *The Pinnacle),* is

surrounded by steam and ejecta joining it with the land on the north crater rim in Figures 1 and 2.

Fig. 2: Tarata Peninsula, abutting the northern pinnacles and Banded Hill abutting the southern pinnacles (and extending out of shot). Burton, MA_1323002. (Te Papa).

Smith's opinion the northern pinnacles were located on the Steaming Ranges is confirmed by our surveying, which in turn supports Ron Keam's observation (1932−2019): "…almost at its northern extremity, hosted Te Tarata …" (Keam, 2015).

2.1 Overlooked Crater Signposts

I submit there were at least four visible crater signposts in Figure 1.

2.1.1 Tarata Peninsula─The first topographic signpost missed by Smith and other 1886-1887 government and university survey teams was the promontory they observed above the northern pinnacles in Figures 1 and 2. This extended from the northern crater rim (and was later termed Tarata Point, then Tarata Peninsula). Smith et al correctly associated it with the Steaming Ranges. However, no one from 1886−2022 made the elementary deduction i.e. that as Tarata Peninsula was the northern stump of the Steaming Ranges, then regardless of the missing lakes or the enormous crater; the White Terraces must be on the northern end of that stump, not the south end. Harding in 1887 mistook this topography and placed the old lake and terraces in the crater, south of the peninsula. This became conventional wisdom until 2011, when the New Zealand-American project placed them even further south in the crater; relying on sonar imagery, which I have suggested was misinterpreted (de Ronde et al, 2016; 2018. Bunn, 2020b). The Rotomahana Basin topography was not corrected until we began reconstructing Hochstetter's survey in 2016.

2.1.2 Banded Hill—The second missed topographic signpost in the 1886 crater was Banded Hill. To observers on the crater rim or to those with an aerial oblique view from Oruakorako or Hapeotoroa Hills; this hill lay half a mile from the Peninsula, to the south-east. It was common knowledge and from Hochstetter's published map and book, that (before the eruption), south-east of the Steaming Ranges lay an isolated hill called Te Rangipakaru (or Broken Sky), and see Figure 3. This contained a tourist attraction, a large solfatara. This hill lay ~150 m away across the flats and was elevated ~80−100 m. The distance from the nearest Steaming Ranges peak to its peak was ~ 400 m. It is inconceivable the first mention of this coincidence in the historical record came only in 2015 and even then, its significance went unrecognised (Keam, 2015).

Rangipakaru Hill in 1885 and in 2016 as Patiti Island, is photographed in Figure 3. The photographs are taken along azimuths 125° (top) and 135° (bottom). The western side of Rangipakaru Hill was lost in the eruption. Patiti Island is the eastern hill, extending (approximately) from the parados of the solfatara crater. This first close-up view of Rangipakaru Hill is only possible, thanks to the large-format camera and fine-grain emulsion used on its dry-plate. These allow us to crop and magnify, to distinguish smaller features. The large solfatara of Rangipakaru Hill is shown (probably for the only time); stretching diagonally from left to right across the top shot; just as Hochstetter recorded it on his April 30 map. The crater scale and the steaming-fog from the solfatara confirms geothermal activity predated the 1886 Tarawera eruption. This helps answer the question which puzzled Tontini in 2015— *the abscence of well-defined demagnetization anomaly at the Patiti hydrothermal system* (Tontini et al, 2015). Hochstetter's observation station on Puai Island is in the foreground.

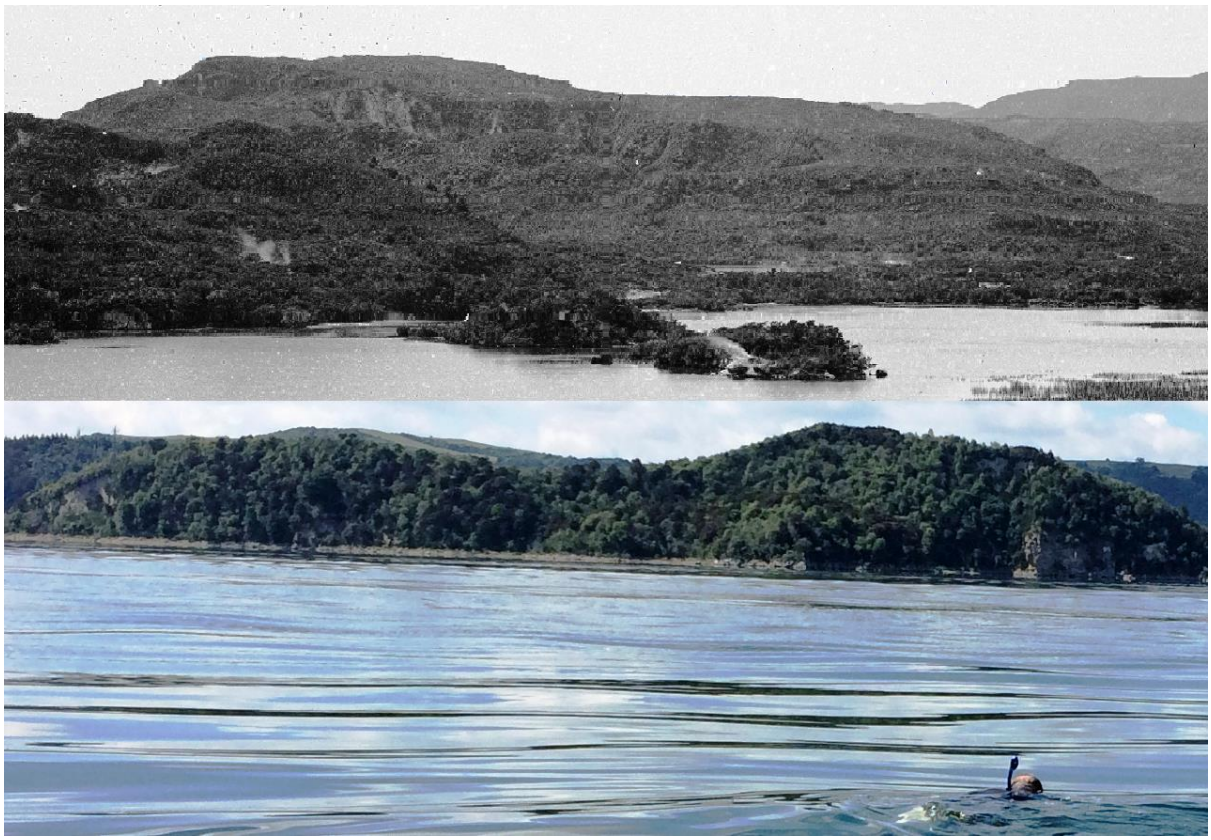

Fig. 3, Rangipakaru Hill in 1885 (inset top) Burton Bros. Patiti Island in 2016 (bottom). (Ingrid Fisher). The author is scoping our first scuba dive off Tarata Peninsula.

To any observer noting this coincidence between Banded and Rangipakaru Hills in 1886, on Smith's 1886 map the Peninsula−Banded Hill distance is ~800 m. This distance on Hochstetter's published 1864 map would disclose the Peninsula ended halfway up the Steaming Ranges─ more evidence the White Terrace lay buried north of the crater rim.

The northern Steaming Ranges are in Figure 4 as Tarata Peninsula, beyond the rim of Star Hill crater (marking Lake Makariri) in foreground. Rangipakaru Hill (Patiti Island) is to the left. In 1921, the land was still unvegetated, providing a Lidar-like perspective.

Fig. 4: Lake Rotomahana, Rangipakaru Hill (now Patiti Island) and Tarata Peninsula c. 1921. (Cotton, 1921, Te Papa).

It follows that as Tarata Point (Tarata Peninsula as Ron Keam later named it), continues north under the 1886 ejecta; the White Terrace spring must lie buried on land, close to but outside the crater as in Figure 5 (Keam, 2015).

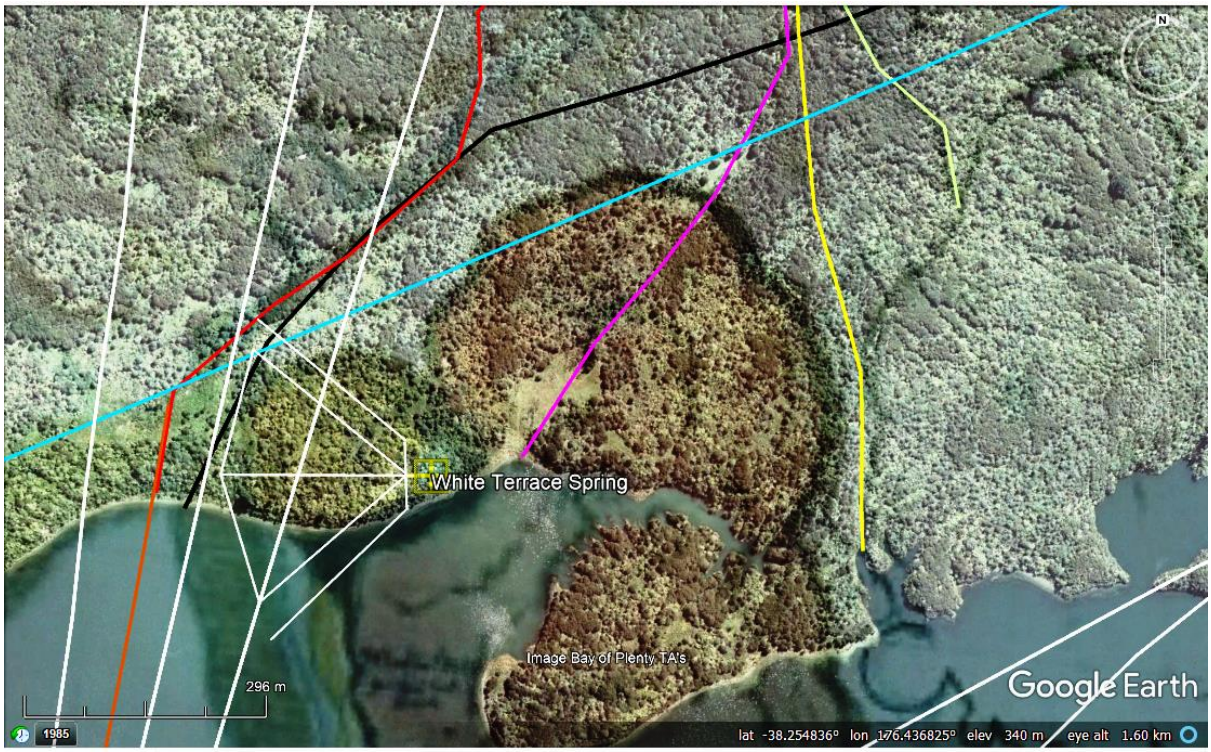

Fig. 5: Georeferenced Steaming Ranges (in burnt umber), over Tarata Peninsula on Google Earth™, with Lake Rotomahana and White Terrace on left and Lake Rotomakariri on right. River entry paths are shown and discussed below. (Hochstetter's 30 April, 1859 map).

In other words, White Terrace is *ipso facto* located on land, not in the crater which later became the new Lake Rotomahana; for the Tarata Peninsula traversed the shoreline and continued on buried land to the north as in Figures 5 and 6. Rangipakaru Hill, the Pinnacles and Tarata Peninsula form a north-south *Chain of Evidence*: that should have lead geoscience investigators to the White Terrace location, using the maps available from 1864 and 1887. Investigators since 1886 have all been oblivious to the obvious.

Fig. 6: Southern end of Tarata Peninsula (Bunn, 2016).

In Figure 5, the area between of the White Terrace and Tarata Peninsula, is now a shallow lake inlet. Pre-eruption photography and georeferencing show this was an overlooked valley. This valley opened west and wound behind the Tarata embankment. It hosted the first two great boiling springs on the tourist path i.e. Ngahutu and Ngahapu. For these, refer to the inset photograph in Figure 15. Ngahutu Spring disappeared from the historical record but this valley and its springs reenter the narrative for two reasons discussed herein. First, it contributed a low point to the post-eruption crater rim. Second, its springs each contained ~1.5 ML water.

2.1.3 Crater Watercourses─ The third topographical signpost, overlooked by all researchers from 1886-2022, were the watercourses in the Rotomahana basin crater. These, together with Tarata Peninsula and Rangipakaru Hill; enabled spatial location of Lakes Rotomahana and Rotomakariri and the White Terraces after the 1886 eruption.

2.1.4 Mātauranga Māori─ A fourth potential signpost was *mātauranga Māori*: the Māori topographic knowledge of the Rotomahana Basin. The extensive topographic nomenclature throughout the basin and evidenced in Hochstetter's survey; indicates a developed Māori spatial *mental map* existed for the region, as for the North Island generally.

The leading published proponent of Mātauranga Māori for the period was Alfred Warbrick (1860−1940). He was a first Ngāti Rangitihi guide on the Terraces from 1885 and organised the first rescue teams in June 1886. After the eruption he became the government Chief Guide at the new Waimangu Valley tourism site for a further 25 years. In his 33 years at the old and new Lakes' Rotomahana, he reported finding no terrace fragments either on the surface or exposed by the extreme erosion throughout that time. In 1936, on the fiftieth anniversary of the 1886 eruption he gave his last interview (Warbrick, 1936).

"I am certain they are there to be rescued," said Mr. Warbrick last week. "I use the word 'rescued' deliberately. I admit that some men of my generation who were familiar with the Terraces and the general terrain of the region were as certain of their destruction as I am of their survival. It is an old controversy."

"For the benefit of people of the younger generations it is necessary to explain that prior to the eruption there had never been a survey of the lake which would have fixed points from which the sites of the Terraces could have been accurately determined." I realise that in the absence of preexisting Survey maps theories as to the survival of the Terraces run the risk of being dismissed as personal opinion but there is nothing new to be threshed out in that regard."

"Had they been shattered in that vast upheaval, a convulsion which threw debris thousands of feet into the air, is it not reasonable to assume that some fragments of the easily identified material which formed them, would have been found? Not a piece of it has ever been picked up over the area." (Warbrick, 1936).

Had Warbrick known that a terrestrial survey did exist, he would doubtless have prosecuted his campaign to recover the terraces more forcefully in 1886. In this last 1936 interview he reprised his plan to recover the Terraces:

" … The scheme I suggest is the one I have advocated for years—that the waters of Lake Rotomahana should be lowered by 50 feet or 60 feet, a simple task requiring only the reopening of the old Kaiwaka channel into Lake Tarawera; and that then the steep shores at places I have marked should be excavated by means of sluices. A strong nozzle at each point would speedily remove the mud and ash deposit and prove, once and for ever, whether the Terraces exist. I have been advised that the whole job would not cost more than a few thousands of pounds."

Ironically and not having read Warbrick, I proposed a similar engineering method in 2014 for the PAWTL Project, using siphons and Hero's Fountains.

In Figure 7, Warbrick inserted black arrows pointing to the lake shores where he judged the buried Pink and White Terraces lay. His Pink Terraces lie in the second small bay below Boat Launch Bay and the White Terraces are a little west of Tarata Peninsula. The white arrows point to our Terrace locations in 2022, based upon the fifth and sixth iterations of Hochstetter's survey and this spatial paper. The 1936 and 2022 arrows point to the same shoreline locations. This vindicates Warbrick's claims from Mātauranga Māori after 136 years, while validating Hochstetter's survey and this revised topography.

Fig. 7. A c. 1936 aerial photograph of Lake Rotomahana, taken from the southwest. Warbrick's 1936 black arrows point to his shoreline locations of the Terraces: the Pink Terraces in the second small bay below Boat Launch Bay and the White Terraces a little west of Tarata Peninsula. The white arrows point to our 2022 Terrace locations, based on Hochstetter's survey. The 1936 and 2022 arrows point to the same locations (New Zealand Herald, 16 May 1936, by permission).

3.0 Rotomahana Basin Streams exiting into Lake Rotomahana before and after 1886

Apart from Hochstetter in 1859, no survey or large-scale mapping of the Rotomahana Basin was completed before the 1886 eruptions. Hochstetter's 30 April 1859 map, showing Lakes Rotomahana and Rotomakariri, and associated streams is in Figure 8.

Fig. 8: Hochstetter's 30 April, 1859 map of Lake Rotomahana showing streams entering and leaving the lakes. Kumete Ridge lies from 9 to 12 o'clock (Nolden & Nolden 2013: 78).

Hochstetter mapped streams entering Lake Rotomahana from the south and east; one (Black Terrace Stream) from the west and none from the north where the lake drained to Lake Tarawera down the Kaiwaka Stream (or Channel). No other pre-eruption watercourses west of Rotomahana are documented prior to 1886, (though the topography suggests they existed). The flow of surface water was west-to-northwest across country to Lakes Rotomahana and Tarawera and thence down Tarawera River to the Pacific Ocean.

3.1 Western Streams from Te Kumete ridge

Today, there are five Strahler first-order streams draining Te Kumete Ridge to the east; one, the Wairua draining its western side and one to the north. Three of the eastern streams drain the peaks along the ridge, entering the lake at Boat Launch Bay via Strahler fourth and second-order streams. Two of these descend from Hochstetter's landmark peaks "c" and "d" along the ridge (Bunn & Nolden, 2018). The "d" stream drains from Te Kumete trig. The main branch tracks over Black Terrace Stream, beneath today's forest road, to Black Terrace and Black Terrace Crater; in its Strahler third-order stretch. The *River Pilot* lists Black Terrace Stream here as Drain 1019568 (Land Information New Zealand, 2022).

These streams were noted by Smith in 1886 and therefore are probably on similar courses to their pre-1886 courses. Two more drain the eastern ridge and 1755276 is of pivotal interest to researchers, for it connects into the old and new Kaiwaka Streams in lower reaches. The other short, northerly stream 1755688 now empties above Te Rata Bay. After studying contour lines, I consider this stream on its pre-eruption course, joined 1102173 and drained the eastern portion of Kumete north into Lake Tarawera. Today (like others) it is deflected, southeast to join the Kaiwaka above its pre-eruption exit into Lake Tarawera. There are to my knowledge, no reports of any stream entering the pre-eruption Kaiwaka from the west, only the Awaporohe from the east.

The absence of visible streams is partly due to the astonishing absorption speed of the soils around Rotorua, as Smith and today's residents note: "It is one of the remarkable features of the whole of the volcanic zone that, whilst there are on every side the evident signs of a surface deeply scored by the action of water, the water itself, even after the heaviest rains, is rarely seen and then only for an hour or so, standing in little pools…" (Smith, 1887).

This is significant for the later government surveyor reporting herein of the Kaiwaka Stream.

3.2 Eastern Streams

In his 1886 map Smith showed two streams debouching from the second and third gullies east of Rangipakaru Hill and tending towards the crater and Banded Hill (Smith, 1887). The three streams and their gullies, lying between Waimangu and Lake Rerewhakaaitu are easily checked on today's mapping and the River Pilot, for they exit into the new Lake Rotomahana in Figure 9.

3.2.1 Hangapoua Stream and Boiling River

There was evidence of the pre-eruption topography in the Rotomahana-Rotomakariri crater, from the first-responder visits in 1886, and for a decade while the crater lake filled. The first overlooked evidence was a hot stream flowing into the crater from south of the southern Pinnacles and west of Banded Hill. The government investigators elected to name this stream Boiling River, though its branches entered the crater through the southern and southeastern walls, marking it as a pre-eruption feature. This was an enduring oversight (Smith, 1887).

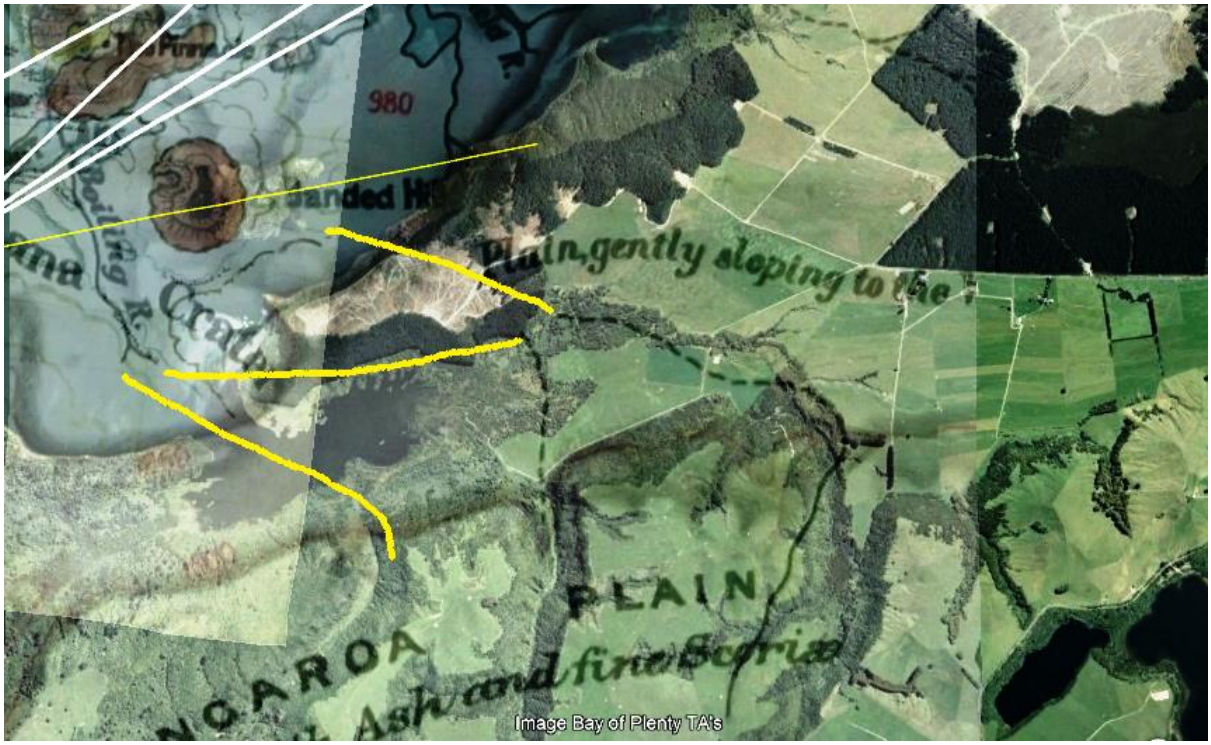

Fig. 9: Georeferencing showing Boiling River branches superimposed over Hangapoua Stream on Hochstetter's manuscript map. It connects with streams 1283784 and 1283810. The Waiahinekahu connects to the existing stream 1102186. Note the three eastern gullies, issuing these streams then and now.

When georeferencing Smith's 1886 and Alpha Harding's (1856-1945) 1887 crater maps on Google Earth, (using Banded Hill and the southern embayment wall as control points); the Boiling River lies beneath the Hangapoua Stream course (Thomas, 1887). This Stream entered the old lake at its south-eastern corner, below Lakes Ruahoata and Wairake. It is marked on August Petermann's (1822–1878) published 1864 map, which was commissioned by Hochstetter and familiar to the government's General Survey Office delineators (Petermann, 1864). Today, the Boiling River−Hangapoua upper reaches are found on the River Pilot as streams 1283784 and 1283810.

Up to the 1970's the area where these streams would enter new Lake Rotomahana was periodic dry land. These Strahler second-order streams arise from the first and second gullies east of Waimangu on topographic mapping, in Figure 9 and on Hochstetter's maps (see Figure 8).

3.2.2 Waiahinekahu Stream

More obvious was the second, unnamed stream marked by Smith entering the crater from the southeastern crater wall, east of Banded Hill. This Strahler second-order stream fed a pond in the crater floor. Its crater entry east of Banded Hill was another navigation aid; for the Waiahinekahu Stream is marked on Hochstetter's manuscript map and on Hochstetter's published map (i.e. that by Petermann in 1861), at that location. Formerly, it wound around

Rangipakaru Hill and fed Lake Rangipakaru. Smith marked its characteristic, sickle course toward the crater on his map, pointing at Banded Hill (the pre-eruption Rangipakaru Hill). This evidence has been in sight since 1886. The upper reaches of the Waiahinekahu can be seen today in stream 1102186 arising in the third easterly gully, on Smith's and today's maps.

3.2.3 Station 21 Stream

A third, (unnamed) first-order stream entered old Lake Rotomahana between the Haumi and Hangapoua Streams, below Hochstetter's observation Station 21. It is marked on his 30 April, 1859 map and his map produced by Petermann at Gotha. This can be seen on the River Pilot and topographic mapping as Stream 1283776. Its lower course has, like others been altered by the eruption.

3.2.4 Acid River

On Smith's map, a fourth stream entered the northeast crater, joining a fifth stream on the crater floor. The government surveyors labeled the fourth as a new stream i.e. Acid River; exiting into ponding on the crater floor which they named New Lake Rotomakariri. Such a stream is mapped only on Hochstetter's 29 April map and may have drained Lake Rangarua. It is today stream 1050539, a Strahler first-order stream entering the lake in the northeast corner. The northern branch would be stream 1102189, today draining Mount Tarawera.

A sixth, first-order stream entered the crater east of Banded Hill, draining into a small pond. It is unclear where its pre-eruption course lay, but it may have drained Lake Rangarua. A branch of the Waiahinekahu Stream is also likely.

In summary, the three southeastern pre-eruption streams entering the old lake below Rangipakaru Hill are found on Hochstetter's 1859 map, his 1864 published map and Smith's 1886 maps. They can be traced on today's River Pilot and topographic mapping. The question arises: why didn't Smith or generations of geoscience researchers since, join the dots which connect the streams to old Lake Rotomahana and its terraces?

Given the bases of Māori mental mapping, these watercourses in and around the 1886 crater would have been interpreted by Ngāti Rangitihi and Tūhourangi elders, as they assessed where the old lakes and terraces lay.

3.3 Southern Streams

3.3.1 Haumi Stream

This stream 1502345 is marked on Hochstetter's and Peterman's mapping. It drained Lake Okaro as it does again after a hiatus of ~76 years. The lower reaches are renamed Waimangu Stream. This stream was blocked below Lake Okaro by the 1886 eruptions and did not run freely until the late 1960's (Cross, 1963). For this reason, it is another instance of misleading mapping where Harding drew in the Haumi as if it entered the crater: even as he showed it blocked on the same map. He made a similar mistake with the Hangapoua; suggesting more geospatial credibility to his mapping than it deserves. These aspects were artistic licence.

The pre-eruption Haumi stream is shown on our latest georeferencing to coincide with today's Waimangu Stream exit into the new lake, allowing for >12 eruptions which carved the valley into its present configuration and erosion.

3.4 Northern Streams

No streams entered old Lake Rotomahana from the north. Today, only three short streams drain Mount Tarawera into the new lake from the north.

3.4.1 Kaiwaka Channel− Pre-eruption

Note: In view of its forensic importance, I divide the Kaiwaka analysis into pre and post-eruption sections.

Only one stream exited old Lake Rotomahana and this has pivotal significance for the locations of the White Terraces and the old lake. The Kaiwaka Channel (or Stream) was the only waterborne tourist access to the terraces. Tourists transhipped from dugout lake canoes at the Kaiwaka exit into Lake Tarawera. In another common, enduring error from the period; this was not at a village called Te Ariki. The nearest Tūhourangi village was Kokotaia (Bunn, 2017b). Guests were poled or pushed up the steep, strong-flowing Kaiwaka, which drained Lake Rotomahana beside the White Terraces. Many tourists wrote about their alarming transits down the Kaiwaka. Hochstetter described his: "The Kaiwaka, the outlet of the Rotomahana, is the water-route into Lake Tarawera … The word signifies canoe-eater or canoe-destroyer, probably from the rapids which are to be passed in the river, as canoes there strike the ground and are easily damaged" (Hochstetter, 1867).

In his 1887 eruption report, Smith noted: "… a strong stream of hot water formed the Kaiwaka river, which after a course of a mile, and a descent of 40ft., fell into Tarawera Lake …the powerful stream which drained the lake …" (Smith, 1887).

After the eruption, the first government survey report was unsatisfactory and a second team sent, led by S. P. Smith. His report to parliament was flawed and hedged. It contributed to mistakes on the public record concerning the Pink and White Terraces. Smith's 1887 report on the Terraces concluded: "The exact position of the [White] terraces cannot be identified, as the ground around where they formerly stood, has been blown away; but they evidently were close to, and to the north-west of the pinnacles … The site of the Pink Terraces cannot be identified with more certainty than that of the White Terrace" (Smith, 1887). Smith mentions sinter had been found nearby, but apparently unseen by him. Sinter occurred at many sites around this lake, not just at the terraces.

The likely reason for Smith's inability to be more open on the locations and status of the terraces was that, as Assistant Surveyor-General he was aware of his department's failure to complete a survey of the terraces, the greatest tourism asset in the country. His inability to accurately locate the terraces left the question open for 130 years, until Hochstetter's 1859 Terrace survey material arrived back in New Zealand. His advice they appeared destroyed sent the public into mourning (Warbrick, 1934).

Smith's 1887 report on the Kaiwaka concluded: "It was at a point due north from the centre of the lake that Kaiwaka River flowed out of Rotomahana. The valley has been completely filled up with sand and mud to a depth of 80ft. [24 m], forming as it were a great dam … though within a quarter of a mile of the crater rim, the hollow, deepening into a valley now occupied by a watercourse, can be seen and followed out to its junction with Lake Tarawera" (Smith, 1887).

Smith drew the large scale map for his 1887 report but did not publish his thoughts on the Kaiwaka, valley detail, watercourse, old lake coordinates or the Awaporohe River. His 1886 manuscript map sketched the entry in a reentrant in the crater rim, at an azimuth of 17°.

In 1887, Harding first sketched locations for the old lake, the Kaiwaka, Awaporohe and Hangapoua streams. These may have been suggested by Algernon P. W. Thomas (1857-1937) for whose report Harding drew this map (Thomas, 1887). He may have attempted to use control points of the White Spring, Haumi and Hangapoua to orient his old lake map in the crater. His lake is ~6% larger than the published Hochstetter map he would have had to hand. It is closer to our surveyed lake size. His positioning of the White spring does not follow his superior, Smith's report i.e. Harding has the spring and terrace due north of the Pinnacle, whereas Smith says it lay to the northwest; where we locate it today. His Boiling River is superimposed on the Hangapoua. His Kaiwaka entry and Kaiwaka−Awaporohe entries gap is displaced eastward but at ~1,070 m his gap is consistent with our georeferenced gap. His entry lies at an azimuth of 25° and differs from Smith in its position. Harding placed his entry in the rim cleft which we report herein, was formed above the Ngahutu Valley. This appears a desk-mistake by General Survey Office staff. Given the chaos along the crater rim in 1886, from eyewitness accounts, photographs and artwork; no other landmark existed for this Kaiwaka−Awaporohe depiction by Harding: it was an invention. In 1894 Smith published a large-scale map of the Rotomahana crater, including Harding's depiction of the old lake inside the new (Smith, 1894). Smith's Kaiwaka entry position differs from Harding's and his own earlier efforts, lying now at an azimuth of 57°. These portrayals underline the artistic licence applied to the Kaiwaka.

Harding's speculation was adopted, in the absence of other mapping and persists to this day. It helped that nearby on the crater rim, a low point developed; providing a convenient point to relate to Harding's map. The Rotorua District Council installed an overflow pipe there in 1974 (Paterson, 2003). Generations of geologists uncritically followed Harding and adopted this overflow as the site of the *New Kaiwaka*.

3.4.2 Awaporohe Stream

This short stream drained Lake Rotomakariri to the north and joined the Kaiwaka before it emptied into Lake Tarawera, beside Pukekiore Hill. Their junction lay north of the fourth silica terrace at Tamariwi. Little was documented about this stream. It was sufficiently large to warrant a canoe moored where it crossed the tourist path. Hochstetter included it on his maps, though he never reached the stream or Lake Rotomakariri. It lay beside the Steaming Ranges, as the Kaiwaka lay on its west side. The stream entries were separated ~1,000 m by the Steaming Ranges.

We georeferenced the junction of the two streams and in 2018, I planned to take a metal detector there, given the likelihood of tourists losing items from dugout canoes.

3.5 Percolating Streams

The phenomenon Smith noted of surface water dissipating is well-known to residents of Rotorua and the surrounding lakes. Surface flooding is rare there today. Volumetric flow analysis at Lake Rotomahana in 2014 showed 62,200 m^3 (62.2 ML) of water percolates through the isthmus daily to Lake Tarawera (Bunn, 2014). The new Rotomahana has no natural outlet. This is another signpost missed by reports from the time and by geologists up to the present. The percolation was well known after the eruption, as attested by Gilbert Mair (1843–1923), on a 1918 photo. His legend states: “surplus waters of Rotomahana Lake rushing into the end of big rift at west end of Tarawera Mountain 100 feet below … This is where the waters pour into the rift and [can?] be heard roaring and gurgling far below. Gilbert Mair 18/11/18” (Mair, 1918).

It is clear from the discussion of streams percolating into the crater that water flowed easily beneath the ejecta, finding paths during and after the eruption.

3.5.1 Kaiwaka Channel− Post-eruption

After the eruption, a great watercourse was seen on the Rotomahana isthmus i.e. between Lakes Rotomahana and Tarawera, beginning ≤1,200 m below the crater. Smith recalled the Kaiwaka exited the old lake at its northern end, but was unable to position the old lake, the Kaiwaka or the terraces relative to the crater; beyond a guess. He recalled the Kaiwaka was a mile long and was able to walk the lower third of its length, for water flow had carved through the ejecta when the first rescue teams arrived days later as in Figure 10.

Fig. 10: Kaiwaka Lower section, probably by Charles Spencer (1854-1933), for Burton Brothers, Dunedin over 13−18/6/1886. (MA_1043612 Te Papa).

In Figure 10, the erect man (~1.7 m height from WWI army biometrics), enables measurement of the watercourse at ~11 m wide and ~9 m high. This is a section of the pre (and post) eruption Kaiwaka, in the lower third before Pukekiore Hill. It is almost as wide as the Tarawera River entry, and aligned on Koa Peak. Runnels inside the watercourse, indicate it was antecedent. The size disparity shows the course carried a major water flow, during and after the eruption, which lasted two hours, as F. W. Hutton (1836−1905) reported: “At about 0330 hr the activity on Wahanga and Ruawahia became more explosive … At the same time Rotomahana burst into eruption, throwing out a column of steam higher than that from Tarawera” (Hutton, 1887). Jim W Cole, states that “It was an explosive eruption, charged with the soft lake sediments of the old Lakes Rotomahana and Rotomakariri, as well as volcanic rock intensively altered by earlier thermal activity, to form the Rotomahana Mud. The eruption was largely over by 0530 hr. “(Cole, 1970).

Nearly all the eruption surges carried to the west, hence much airborne Rotomahana water, was dumped over and beyond Kumete Ridge, rather than over the isthmus. Ian Nairn records one base surge passing over the Steaming Ranges position (Nairn, 1979). The Rotomahana eruption column was carried away by south-southeast winds, as it cooled and lake water vapour

condensed. The 10-13 km column entered the stratosphere, where water would not have condensed and fallen. The deposits near the lake itself were hot and dry (Nairn, 1979).

As the eruptions that night progressed southwest from Wahanga peak, the chasm eruption and that under Lake Rotomakariri would precede those under Lake Rotomahana. Cole suggested: “the explosions from The Chasm could have been caused by cold water draining from Lake Rotomahana into the eruptive fissure” (Cole, 1970). The chasm water would have come from Lake Rotomakariri to both cause the chasm to erupt and then to drain into the Chasm-Rotomakariri eruption fissure. Once the fissure extended under the Steaming Ranges, Rotomahana lake water would have drained into the growing fissural excavation.

Fig. 11: Georeferenced Hochstetter 30 April 1859 manuscript map over Smith 1886 on Google Earth. Note Smith’s Pinnacle marked over the Waikanapanapa Valley (in yellow ochre).

In Figure 11, Smith’s Pinnacle is over the Waikanapanapa Valley, consistent with Keam’s suggestion the Rotomahana eruption began here (Keam, 2015). Keam with Figure 11, suggests the Pinnacle may have had a role in the eruption. Our georeferenced location (from Smith’s map) is near the GNS-reported pinnacle in 2011 (de Ronde et al, 2016). Both the Waikanapanapa Valley and the southern stump of the Steaming Ranges orient at 57°, the same azimuth as the Tarawera eruption rift, reflecting a rift event.

Cole states: “at the time of the eruption, superheated water, water vapour and liquid water would have boiled violently into the atmosphere” (Cole, 1970). Once this happened, natural water flow at the Kaiwaka entrance ceased. However, there was clearly a large water flow down the lower Kaiwaka watercourse in Figure 10. This occurred after the fall of ~9 m of ash there on the night of June 9 and before the rivulets formed over the floor. It was evident by 13−15 June when rescue teams arrived and a warm stream of water still issued from it (Paterson, 2003). As no rain had fallen since the eruption, the rescue teams were at a loss to explain it. Some negotiated ~300 m up this watercourse. They attributed the water to the Kaiwaka Valley and thus the misconception was borne. None considered Tarata still pumping above them. A 2014 Tarawera River volumetric study indicates natural Kaiwaka flow ended about an hour from the Rotomahana eruption (Bunn, 2014).

Once the lake level dropped at the Kaiwaka entry, due to inter-lake and fissural drainage, and the eruption column; there was no lake water to account for this 100 m^2 watercourse. The channel formed after Nairn’s northern base surge (Nairn, 1979). There was no rain. Nor can redeposited lake water alone account for the large watercourse. Yet the evidence lies in Figure 10. There was one source to carve out the great Kaiwaka watercourse both during and after the eruption. This was Te Tarata, the immense White Terrace spring.

Our georeferencing of Hochstetter’s 30 April map shows the Tarata Spring is <100 m from Harding’s sketched Kaiwaka entry, which is itself ~100 m from the rim saddle which formed. The two may be causally related. It lies close to the crater rim. As with Black Terrace spring, it would continue pumping during the eruption, until its supply pressure fell, or its plumbing fractured. The rescue teams’ reports are consistent with a disturbance to the Tarata plumbing, and significant water flow exiting the spring and finding a path through the ejecta to its pre-eruption course down the isthmus (Warbrick, 1934). How the Terraces’ springs continued pumping through the eruption was explained by Keam: “a geothermal system is robust … it can survive major disruptions – even quite large volcanic eruptions through part of the same three-dimensional region it occupies” (Keam & Lloyd, 2016).

The basin volume and flow from the great spring were sufficient to carve out piping within hours or days and connect with the original Kaiwaka course, whose entry Hochstetter’s survey shows, lay west of the saddle. This is another *chain of evidence*.

This evidence poses a question, why did Harding pick that spot on the crater rim for his Kaiwaka entry? There is no sign of a stream entry draining north from the rim. In any case, the rim was ~40 m above the Kaiwaka entry. The rescue teams never approached the rim here. It was too hazardous. In any event, the new surface there did not reflect the underlying topography and provided no guide (Nairn, 1979). Smith had a general idea of where the Kaiwaka entry lay and did not map it in 1886. It can only have been a guess by Harding.

In Harding’s 1887 map and in Smith’s 1893 map, the new Kaiwaka is first shown (Bunn, 2017a). On these maps, the watercourse is labeled as the start of the Kaiwaka Stream, but the historical record and Smith’s own report shows there was no water flowing down the watercourse from the crater rim when he visited after the event. The new lake took 126 years to reach a height where flow down this overflow channel could occur. The installed pipe has carried water only when the lake occasionally overtopped. The 1886 crater rim there was slightly lower, forming a natural saddle as Keam describes: “in April 1974 an outlet culvert was

constructed at the saddle where natural overflow would have commenced had the lake ever risen sufficiently" (Keam & Lloyd, 2016).

The most likely reason for the saddle is shown in Figures 12 and 13. These show it lies over the Ngahutu Valley, the valley between the White Terrace and the Steaming Ranges. The saddle has nothing to do with the Kaiwaka Channel. Harding's artistic licence with the Kaiwaka was accepted as an aspect of the catastrophe. Since then, geologists in the 20th and 21st centuries adopted it without question. The rim saddle became the old Kaiwaka entry. The evidence herein shows it was not.

3.5.2 Black Terrace Stream

This stream fed by the Black Terrace spring, emptied into Lake Rotomahana north of the Pink Terrace, between Te Whakataratara and Te Waiti. It was mapped by Hochstetter and his map publisher Petermann. The seminal research on the Black Terrace was published by Bunn in 2017 and recognised post-eruption spring flow occurred there (Bunn, 2017a; 2022a). Recently, I extended this spatial research, triangulating the locations of the Black Terrace spring, Black Terrace Stream and Black Terrace Crater (Bunn, 2022b). These sites are circled in Figure 15.

3.5.3 Post-eruption Pink Terrace flow

Given the evidence of post-eruption water flow from the White and Black Terraces; I reexamined hundreds of photographs for evidence of water flow from the third, Pink Terrace. This was done without great expectation, for this spring was smaller and cartography showed it lay close to the rim. Given the chaotic landform at the crater rim, few apart from bold Alfred Warbrick ventured there. He explored this part of the crater about 8 July, descending on a one-inch Manila rope to look for the Pink Terrace. He reported hot mud rivers flowing near a mound he associated with the Pink Terrace, but was forced to evacuate by a fresh eruption (Warbrick, 1934).

Figure 12 is a photograph of the rim where this occurred, taken by Frederick Muir (1852-1945), weeks later from Hapeotoroa Hill. We navigate this print from right to left. The northern pinnacles are on the right, with the buried Steaming Ranges to their left. Next is the Ngahutu Valley cleft (the saddle), and the buried White Terraces. On the left is Black Terrace Stream emptying into what is now Boat Launch Bay. Next, are two small bays and a third larger (sometimes termed Otukapuarangi Bay). The second small bay is where our 2016 georeferencing first placed the Pink Terrace. Three survey iterations later, we again fix it close to this bay. These crater bays remain on topographic mapping. Note the ponding between the second and third bays.

Fig. 12. Muir's photograph (cropped) of the northwest crater in late July-early August 1886. Surface water is seen beside the near embayments. (Te Papa MA_1023507)

Figure 13 is a cropped photograph of this same area by Spencer, taken earlier that month. Water flows in Black Terrace Stream. South of this, between the second small bay and Otukapuarangi Bay are collections of surface water. There are ~20 small ponds. On magnifying this photograph, one of these ponds (up-arrowed) appears right-sloping at 6°. This is unlikely to be lens barrel distortion, given the section is not central in the negative. The camera is level and the print seems within normal limits. Rectilinear lenses were widely used by this time. Still-water has a fluid level and does not slope. The distal portion of Black Terrace Stream shares the 6° slope. These waters are running and the outline of a possible runnel connecting with the ponds is seen, on maximum magnification.

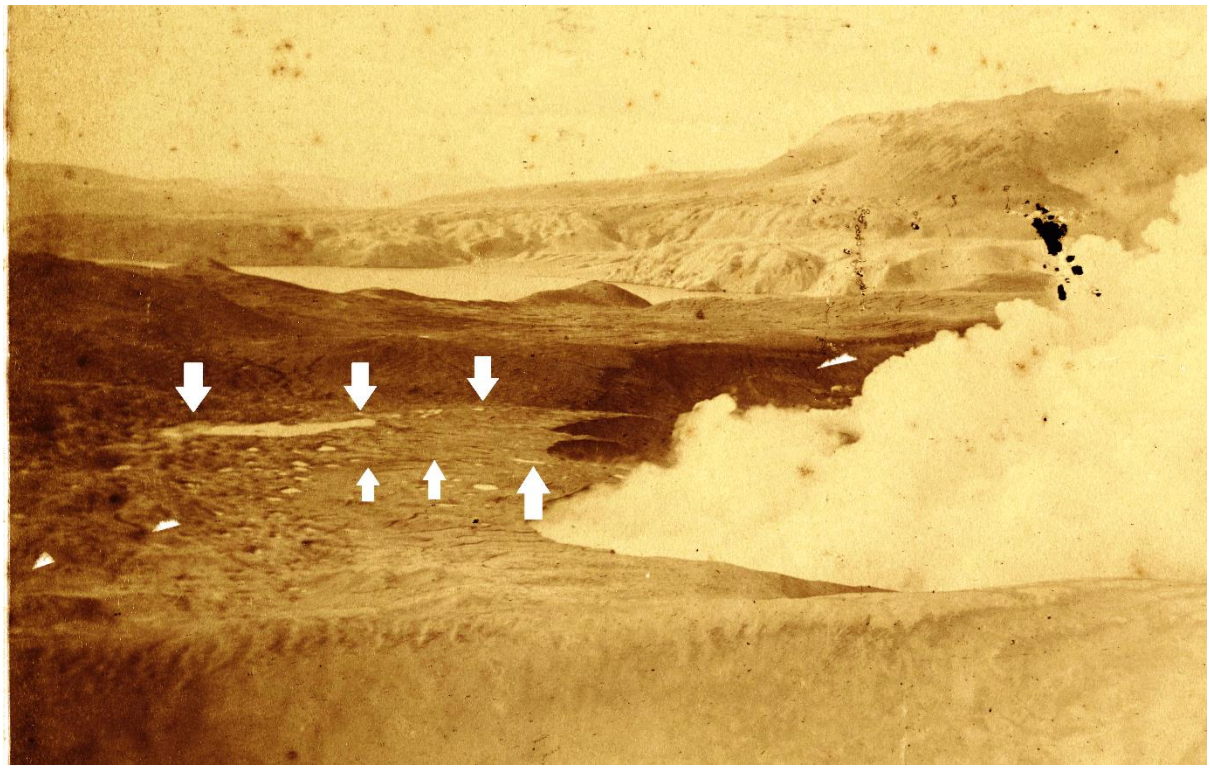

Fig. 13. Spencer's photograph (cropped) of the northwest crater in July 1886. Black Terrace Stream, surface water and the runnel are arrowed (Te Papa MA_1396152). (Image deterioration probably from poor print fixing).

When we compare this section of crater rim with our published fifth iteration Pink Terrace location in Figure 14; the ponding, runnel and terrace share the location i.e. between Boat Launch Bay and Otukapuarangi Bay, close to the 1886 rim and the 2022 shore. This is also Warbrick's location.

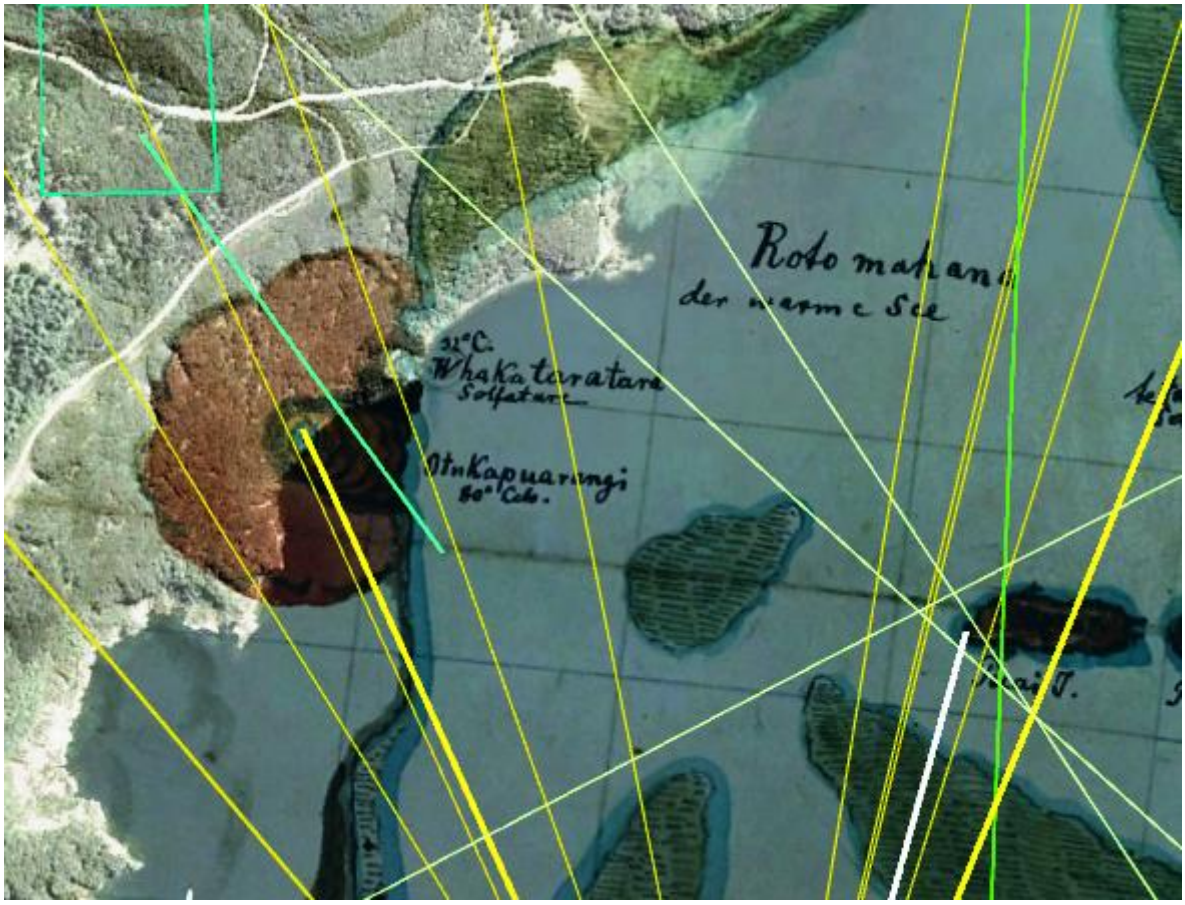

Fig. 14: Our published Iteration V-VI Pink Terrace spring location, lying along the same section of rim in Figures 12 and 13. (Bunn, 2019). Hochstetter's Pink Terrace bearing also strikes this spot, confirming Warbrick's location.

Previous researchers noticed surface water in this area and assumed it was rainwater or lake water from the eruption weeks before. The percolation evidence herein, provides a more credible explanation. We now have evidence of water flow from the White, Black and Pink Terrace springs.

3.5.4 Post Eruption Tarata Spring Flow

Unlike the topography about the Pink and Black Terraces; that around the White Terrace is complex. Cartography is of limited value and photography from Mount Tarawera requires enlargement to discern surface detail. In Figure 15, I show the Tarata Peninsula on the left and the White Terrace; separated by the Ngahutu Valley (so referenced for this paper as it is overlooked in historical records); and now underwater. A frontal view of this valley is inset. The Kaiwaka Channel is red, curving around to join the Awaporohe before its exit, as Hochstetter and Smith observed. The Awaporohe Stream is yellow; its entry a kilometer east of the Kaiwaka. Of Lake Rotomakariri, a surviving trace is Star Hill Crater in the foreground. This appears to have erupted through one of the eastern tuff-crater basins in Figure 18. The new Lake Rotomahana overflow at the saddle is in mauve. Its watercourse merges with the

Awaporohe, further explaining the early confusion. The main stream draining the Kumete Ridge is 1755276, is blue. Given it follows the Kaiwaka course, it deserves the name.

There was little surface water over the isthmus apart from these watercourses and springs. This is negative evidence for the thesis that spring flows continued after the eruption and left evidence. There was little rain between the eruption on June 10 and the photograph in Figure 10. Hence, part of the flow which carved out the enlarged lower Kaiwaka had to come from other sources. The possible water sources were Tarata, Ngahutu and Ngahapu springs. These three springs contained ~ 6 ML, sufficient to carve out the Kaiwaka below their junction. The Awaporohe might also have contributed. Stream 1755276 would not have contributed until after appreciable rainfall.

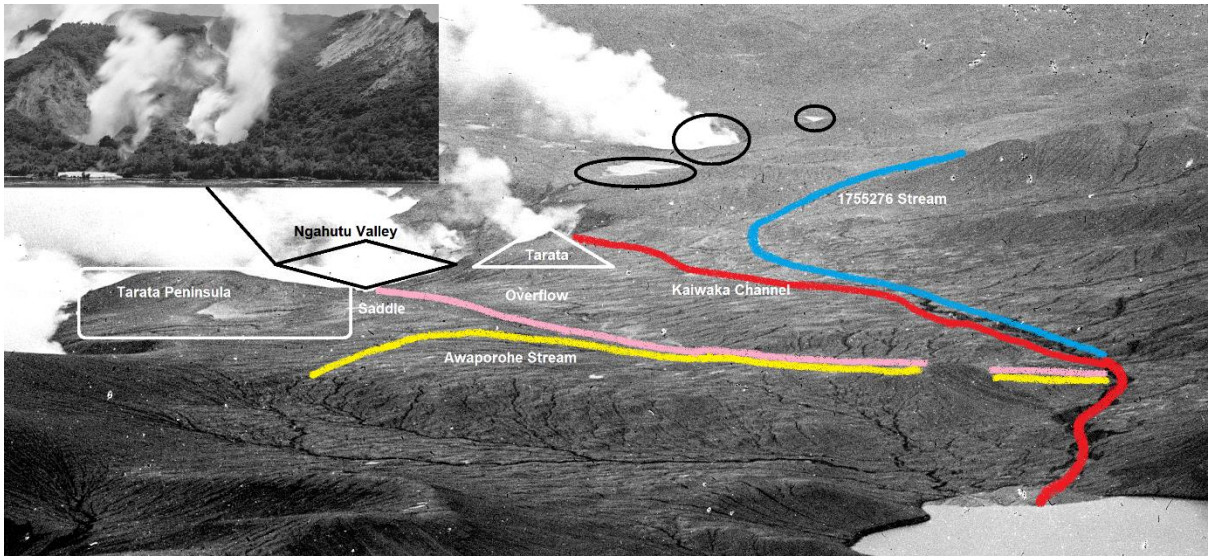

Fig. 15: The post-eruption isthmus landmarks and streams (MA_1269460, Te Papa). Note: this Muir image is cropped and enhanced to improve watercourse visibility. The main Kumete watercourse is Blue. The Kaiwaka is red. The Awaporohe is yellow. The saddle overflow is mauve. The Black Terrace, Black Terrace Crater and Black Terrace stream are circled in black. The Ngahutu Valley is inset. The Tarata (White Terrace) location is the same as Warbrick's.

In summary, there is evidence of surface water and flows from the Terrace springs during and after the eruption. We know new Lake Rotomahana passes ~ 2.6 ML per hour into Lake Tarawera and, given the same catchment areas for the old and new lakes, this must be similar to pre-eruption Kaiwaka flow. For example, had the Tarata, Ngahutu and Ngahapu springs emptied on the night, their combined flow was sufficient to fill the Kaiwaka for about two hours: coincidentally the period of the Rotomahana−Rotomakariri eruption.

4.0 Rotomahana Basin Lakes

The total pondage in the Rotomahana basin was small: far less than geologists guessed. Figure 16 shows a volumetric analysis of the basin lakes from Hochstetter's cartography, Smith's report and from Alfred Warbrick's and my field bathymetries. I estimate the basin contained ≤6,000 ML (0.006 $km^{3)}$ impounded water.

Pre-eruption Rotomahana Basin Lakes as of 9/6/1886*

Lake	Major Axis	Minor Axis	Max. Depth	Area m^2	Volume ML
Rotomahana	800	500	9	1,256,000	4,522
Rotomakariri	400	250	10	314,000	1,256
Rotomakariri 2	200	100	3	62,800	75
Rangarua tapu	150	50	3	23,550	28
Rotomahana Basin				1,656,350	5,881
				(or 0.005881km^3)	

* Lakes are treated as battered ellipses for volumetric calculation
Note: Lakes Rangipakaru, Wairake and Ruahoata are included under Lake Rotomahana.
Some of the smallest ponds are excluded.

Fig. 16: Estimated Rotomahana Basin water volume in 1886.

This contrasts with Andrews' estimate: "The volume of the environmental pre-eruptive total water volume is approximately 0.1 km^3 (100,000 ML), with the assumption that the entire volume was catastrophically removed or converted to steam during the eruption …" (Andrews, 2014). His provision is 17 times the actual basin pondage. Groundwater does not explain the variance.

The government survey teams noted water in the crater and some was redeposited lake-water. In Figure 17, I estimate the post-eruption crater water, from Smith's and Harding's mapping and reports.

Post-eruption Rotomahana Crater Lakes as of 7-8/1886*

Lake	Major Axis m	Minor Axis m	Max. Depth	Area m^2	Volume ML
Hot Lake	470	94	5	138,977	278
Rotomakariri New	641	250	5	503,569	1,007
Unnamed west	154	100	3	48,343	58
Unnamed east	128	50	3	20,143	24

Green Lake	43	50	3	6,714	8
Rotomahana Crater				711,031	1,367

* Lakes are treated as battered ellipses for volumetric calculation

Fig. 17: Estimated water volumes in the Rotomahana-Rotomakariri crater by July-August, 1886.

In Figure 17, a quarter of the pre-eruption Rotomahana Basin water volume collected in the crater, in the weeks following the eruption. This is consistent with my 2014 inflow to Lake Rotomahana of 62.2 ML per diem.

As in Figure 18, Hochstetter described the *Rotomahana Basin* between Lake Rotomahana and Mt Tarawera thus: “Before leaving lake [sic] Rotomahana, the warm lake, however, I must also make mention of the Rotomakariri, or the cold lake, situated East of the Rotomahana at the foot of the Tarawera mountain” (Hochstetter, 1867).

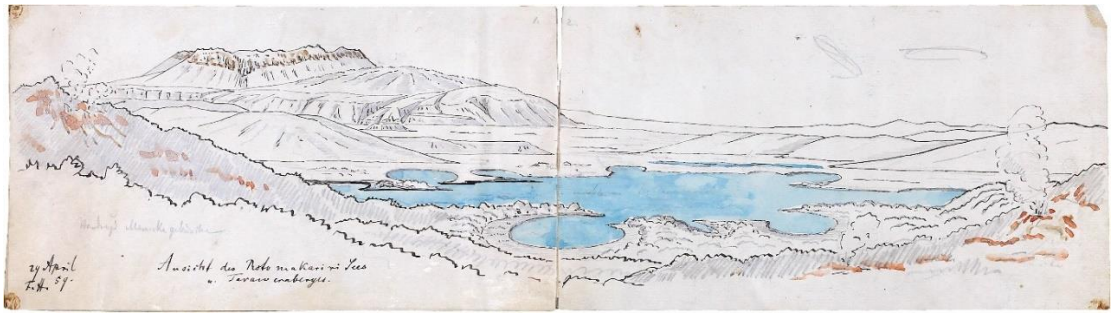

Fig. 18: View of the Rotomakariri (cold lake) with the Tarawera mountain, looking southeast, by Ferdinand Hochstetter, 29 April 1859. (Nolden & Nolden, 2013: 82).

He continues: “It is smaller than the Rotomahana and shows very remarkable circular coves reminding me of the circular tuff-crater basins in the vicinity of Auckland. However, having seen the lake only from the heights above the Rotomahana, I am not able to say, how that phenomenon is to be explained. East of the Rotomakariri, there is another little water-basin, surrounded by swamps, and the joint outlet of both is the Awaporohe, which unites with the Kaiwaka river [sic] between the Rotomahana and Tarawera.” (Hochstetter, 1867).

Cole described it: “There were two main lakes in the basin, the warm Lake Rotomahana and the cold Lake Rotomakariri. Lake Rotomahana was shallow and flowed out through Kaiwaka Stream into Lake Tarawera. Lake Rotomakariri was surrounded by numerous small sinter cones and flowed out through the Awaporohe Stream. Te Waingongongongo, the area between Lake Rotomakariri and Mount Tarawera, was swampy” (Cole, 1970).

4.1 The Old and New Lakes Rotomahana

As old and new Lake Rotomahana are documented in our past papers, here I focus on those poorly documented lakes of the Rotomahana Basin (Bunn & Nolden, 2016; 2018: Bunn et al, 2018; Bunn, 2019).

4.2 Lake Rotomakariri

This unusually shaped, lake translates as the *Cold Lake*, versus Rotomahana the *Warm Lake* (a misnomer for the mean temperature was ~26°C). It was described by Smith as:

"Lying between Rotomahana and the base of Tarawera Mountain, and about a quarter of a mile from the White terraces, was Rotomakariri, the cold-water lake, with an area of about twenty or twenty five acres, between which and the mountain was a swampy valley called Waingongongongo, in which were two or three swampy ponds …" (Smith, 1887).

A later description (paraphrasing Hochstetter and Smith), published by Sir Robert Stout (1844−1930), provides some idea of the lake dimensions and area.

"About a quarter of a mile to the east of the White Terrace was Rotomakariri, a lake of cold water, as the Maori name indicates, This was only one-third of a mile in length from west to east, and about half as much in width. Its shores showed numerous circular cones, which, Hochstetter states, reminded him of the volcanic tuff-craters of the neighbourhood of Auckland ... Around Rotomakariri the ground was swampy, and several smaller pools of water occurred here" (Stout, 2016).

Stout's paper describes Rotomakariri as ~536 m by ~270 m. Given its generally elliptical shape, the lake area would be ~ 28 acres. This compares with Smith's estimate of 20-25 acres. Based on our georeferencing of the three maps showing Rotomakariri i.e. Hochstetter 29 and 30 April and his published 1961 map; the areas are 47 acres by Hochstetter 29 April, 56 by his published map, and 79 acres by Hochstetter on 30 April. Estimating distances over water is judgmental and variance is expected.

East from Lake Rotomakariri lay a small unnamed lake of ~10 acres which drained into Rotomakariri. I reference this as *Lake Rotomakariri 2*. Under Mount Tarawera was the last named lake in the basin; the small *Green Lake*.

Smith estimated Lake Rotomakariri was *about a quarter of a mile* from the White Terraces. He does not give his location on the terrace and I adopt the observation station on *Lucy's Isle* as his most likely datum. This is the correct name of the small island in the centre of the White Terrace spring. The western shore of Lake Rotomakariri lies ~500 m east of Lucy's Isle, consistent with Smith.

Hochstetter's maps developed over his weekend visit. On April 29, he drew Lake Rotomakariri for his diary, based on aerial-oblique glimpses the day before from Kumete Ridge. His second draft was from the south, probably *en route* to Rangipakaru Hill and with a poor perspective from the flats. He first sketched a smaller lake lying perpendicular to the hill, and with the tuff craters. He labelled it *Kreis See* (Circle Lake). His Awaporohe tracked out of sight, north along the hillside. This draft was corrected to capture the size and orientation of the lake, parallel with the Steaming Ranges and with the Awaporohe and Kaiwaka junction included. See Figures 5, 9 and 19 for both draft and 30 April, river courses.

This correction may have taken place later at Te Mu where he relates: "…the constant heavy rain preventing our departure, we spent two more days with that amiable, hospitable family. This delay was quite welcome to me, because by it I found time to finish the topographical sketches, deriving great benefits for my purpose from the excellent local knowledge of Mr. Spencer" (Hochstetter, 1867).

His third lakes map of 30 April, reproduced the size and orientation of his second draft, in Figure 8. He did not reach the Rotomakariri shores and on his defining Rotomahana map, it remains an outline.

This correction to the maps of Rotomakariri may have been the cause of Petermann's mistaken depiction of Rotomakariri in his 1864 map. He showed Rotomakariri perpendicular to the hill rather than parallel and displaced it south; perhaps as a larger Circle Lake. His mistake was accepted from 1861 until Hochstetter's 30 April lake map was published in 2011.

4.3 Lake Rangarua Tapu

Below Lake Rotomakariri 2 and east of Waikanapanapa Valley lay another lake of ~ 10 acres, one Hochstetter named Lake Rangarua Tapu. This kidney-shaped lake does not appear further in the literature. Hochstetter was given the name by guide Akutina Rangiheuea. It connotes a spiritual significance for the Tūhourangi (or perhaps the Ngāti Rangitihi) as a literal translation indicates a sacred crater involving a group of people.

5.0 A New Paradigm for the Rotomahana Basin.

The key findings from this lake and river analysis are in Figure 19.

a) The Tarata Spring and scaled outline of White Terrace are shown in Yellow.

b) The Brown bearing ray from Hochstetter's Observation Station 21, strikes the georeferenced location of the old Kaiwaka entry.

c) The Kaiwaka is in Red, from Hochstetter's survey, maps and photography; together with today's topography, contours and vegetation.

d) The Purple ray is best called *Harding's Mistake*, and follows the Awaporohe course down the isthmus, connecting with the Kaiwaka.

e) The Yellow path is the initial course of the Awaporohe, based on Hochstetter's 29 April map.

f) The White path is the final course of the Awaporohe, based on Hochstetter's 30 April map.

g) The Black path follows the Haroharo caldera in a series of coincidences with the Kaiwaka. These include superimposed crossings at the rim, parallel courses in the lower Kaiwaka, their second superimposition at the Kaiwaka exit and their paths curving around Pukekiore (Tontini et al, 2015).

Note: paths d−f join the Kaiwaka as it passes under Pukekiore Hill, consistent with historical records.

Other key Hochstetter survey findings in Figure 19 include:

h) Patiti Island overlaps Rangipakaru Hill.

i) The Black Terraces location

j) The Steaming Ranges

k) The Pink Terraces location

l) Hochstetter's observation stations: his White rays leading to distal landmarks.

m) Red and Green triangulation rays for Black Terrace Crater.

n) The shore between the Pink and White Terraces, where old and new lake shores coincide.

o) The Ngahutu Valley between White Terrace spring and Waikanapanapa Valley, shown in inset in Figure 15.

p) The basin lakes now have an evidence-based altimetry (Bunn, 2022a).

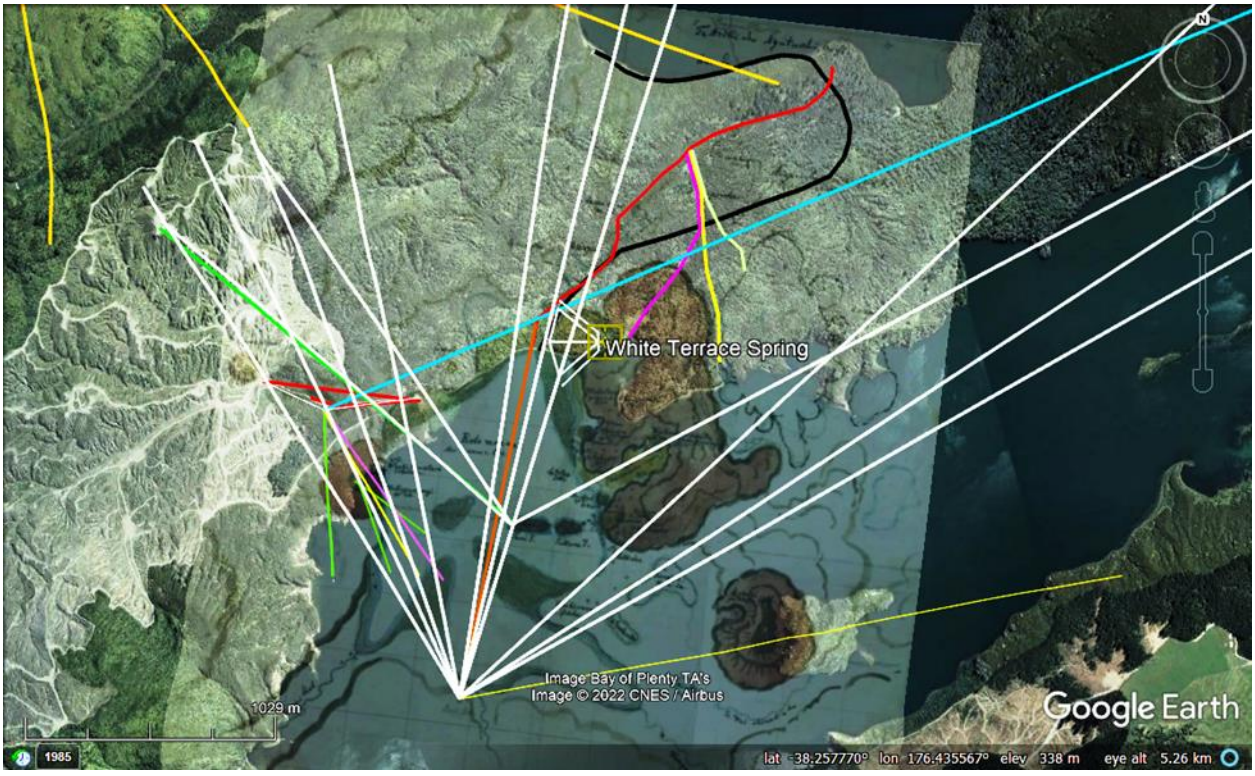

Fig. 19: Hochstetter's 30 April 1859 map georeferenced on Station 21 and Puai Island, over Google Earth. White rays are Hochstetter's survey bearings. The Steaming Ranges are in burnt umber. Lake Rotomakariri is sketched in outline to the right of the Ranges. See text for river courses.

6.0 Conclusions and Discussion

The topographic and riverine evidence in this paper has been available for 136 years. My examination integrates the historical record, cartography, photography, topography and altimetry. Much of this would have been common Māori and public knowledge in 1886. While a few visitors e.g. Edward Payton (1859–1944) and all Māori tribal elders together with Chief Guide Alfred Warbrick reportedly recognised it; the powerful government General Survey Office staff wrote the official eruption account and for whatever reasons, disregarded the evidence.

With interdisciplinary hindsight and Hochstetter's Rotomahana survey, this spatial paper assembles and revises the historical record on the Rotomahana-Rotomakariri eruptions of 1886, across the Rotomahana Basin. There was sufficient, even abundant evidence in the days after the eruption, for rescue teams, General Survey Office and academic survey teams; to better locate the shoreline of the old Lake Rotomahana and the Pink, Black and White Terraces, in the absence of a survey. The central government overlooked the existence of Hochstetter's survey.

Banded Hill (Rangipakaru Hill) and the Tarata Peninsula lay in plain sight of the first-responders, and the peninsula was associated in the government reports with the Steaming Ranges and the White Terraces. It remains clear the White Terraces lay on the northern tip of this buried hill, and must therefore lie outside the 1886 crater and the new Lake Rotomahana. However, this realisation did not appear in the two key General Survey Office maps published in 1886 and 1887, or a third in 1894 (Smith, 1894). The Hill, the Pinnacles and the Peninsula formed a topographic *Chain of Evidence*, which was overlooked by colonial and all later investigators.

Equally, there was no effort made to associate the rivers observed and named in the crater; with known rivers which percolated into the crater after the eruption. These streams provided researchers a means (as they do today), of positioning old Lake Rotomahana with reference to the crater. These enabled accurate navigation to the Pink and White Terraces in 1886. Instead, the government's General Survey Office left this task to Thomas and Harding; who in 1887 attempted to position the old lake and Terraces by sketching imaginary paths for the Haumi and Hangapoua streams in the crater. Ironically, the only stream they connected with an extra-crater, pre-eruption path was the Haumi. This was blocked by the eruption, so their sketched course was confected. The Haumi never flowed into the crater. They superimposed the Hangapoua over a crater feature named Boiling River, but made no attempt to follow this outside the crater. Had they done so, the pre-eruption topography would have been revealed.

Instead, the General Survey Office effort was placed on the streams exiting the old lake i.e. the Kaiwaka and Awaporohe. The early field reports were conjectural and accepted by the General Survey Office into their government mapping. The amalgam of official, local Rotorua (excluding Māori) and academic field reports were constructed into an official eruption record, which put the public into a state of grief over the lost terraces. Given the lack of evidence in the General Survey Office reports, public debate erupted and continued until the 1940s when the eruption generation passed on.

It is only now, with the advent of Hochstetter's terrestrial survey reports; that we can fully reconstruct the events impacting the Pink, White (and the Black) Terraces on that winter's night in 1886. The layers of evidence published by Nolden and I from Hochstetter's survey diaries, notebooks, maps and ephemerae; together with the spatial, topographic, Mātauranga Māori and altimetric research herein: finally corrects the historical record for the Rotomahana Basin eruption of 1886. I trust this research will aid more accurate field investigations and that one

day, New Zealand's lost *Eighth Wonder of the World* may again be revealed to public gaze, as Alfred Warbrick long sought.

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Conflict of Interest

The author has no conflicts of interest to declare and there is no financial interest to report. I certify that the submission is original work.

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