and below that a shell of still greater density about 630 miles thick (BBB). Below the last-named shell there seems to be a marked change of physical condition—either the density is much less (which is hardly conceivable) or the centrosphere (CCC) is viscous. I have drawn hypothetically the possible paths of preliminary waves reaching the San Fernando Observatory from the origin: (a) They may have been transmitted along a path approximating to the chord 111, but with greatly reduced speed through the central portion; or (b) they may have been transmitted along, or nearly along, the path 222, as internal surface waves for the middle portion of the path—that is, along the surface of the centrosphere; or (c) they may have been transmitted along a path 3 r 3—that is, along the chords O r, r S.F., being reflected at r.

I put this forward as a mere trial hypothesis, based upon the examination of the records of one earthquake, and examined only partially by other records. It is, however, I think, worth careful examination in the light of all the available data of other earthquakes. I propose to make such an examination (which may last months, or even years), and hope to place the results, whether positive or negative, before you on a future occasion.

I should like to express my appreciation of the kindness of the observers in charge of the Milne seismographs at Sydney, Adelaide, Perth, and Christchurch in sending me copies of their records and seismograms. I regret that I have been unable to obtain any of the records of the instrument at the Melbourne Observatory.

ART. XIV. — Fluctuations in the Level of the Water in some Artesian Wells in the Christchurch Area.

By F. W. HILGENDORF, M.A., D.Sc.

[Read before the Philosophical Institute of Canterbury, 6th December, 1911.]

As part of the activities of the Artesian Wells Committee of the Canterbury Philosophical Institute, observations on fluctuations in the static height of the water in some flowing wells in the Christchurch artesian area were undertaken early in January, 1910. The records of the wells will be dealt with separately.

(I.) LINCOLN COLLEGE WELL.

This well is 341 ft. deep from the ground-level, which is 38 ft. above sea-level. It is a 2 in. pipe, and was sunk in 1893. The water rises to about 8 ft. above ground-level.

There are in the district four other wells of approximately the same depth. The nearest of these is about three-quarters of a mile away, and the next nearest over a mile away.

The observations were taken by means of a glass tube attached to a tap bored into the well-pipe, and the tube was backed by a wooden scale marked in centimetres. The hydraulic rams worked by the well were shut off for the purpose of taking the observations, and the water in the tube
allowed to come to rest. The oscillations ceased in about five minutes. A loose-fitting plug was placed in the top of both the well-pipe and glass tube to prevent the wind blowing down and agitating the level of the water. The readings were taken at 8 a.m. and 5 p.m., and only eleven readings were missed during the year.

The Monthly Fluctuation.

Disregarding the minor variations, the well sank gradually from January to June, during which time it fell 24 cm., or 10 in. On the 10th June and the following days, 6 in. of rain fell at Lincoln, and the well then started to rise, and continued to do so for four months, during which time it rose 66 cm., or 2 ft. 2½ in., on an average of the weekly readings. The lowest individual reading was 71.2 cm. on the 4th June, and the highest 141.5 cm. on the 25th September and the 17th October. This gives a maximum difference of 70.3 cm., or about 2 ft. 4 in.

The following graph shows the static level of the well for each month during the year, all the readings for the month being averaged to find the level for that month. Below the graph of the static levels there is shown the monthly rainfall at Lincoln in inches.

![Graph showing monthly averages of height of well and monthly totals of rainfall at Lincoln.](image-url)
A study of this graph shows that the rainfalls from January to May were not enough to balance the water drawn off from the reservoir supplying the well; that the rains in June and July were sufficient to replenish it; that the almost total absence of rain in August was accompanied by a still further rise in the level of the water, possibly indicating that the heavy rainfall of the previous months was still percolating to the reservoir; that the rains of September and October were accompanied by a slight rise, although they were almost exactly equal to the rainfall of January and February, which were accompanied by a fall in the level of the well; and that falls took place in November and December.

These last facts, and also, in part, the rise in August, are probably to be explained by the great amount of evaporation in November, December, January, and February, and its smaller amount in August, September, and October; that the evaporation might have an effect on the fluctuation of the well did not suggest itself to me early enough for me to install evaporation-gauges. It seems probable that the evaporation in the summer months would exceed the rainfall, and thus assist the lowering of the static level of the well; while in August, September, and October the evaporation would be very slight, and thus all the rainfall would be available for replenishment of the reservoir. The following table by Greaves, taken from Warrington's "Physical Properties of the Soil," p. 108, is instructive:—

**Evaporation from a Water Surface near London (Average of Fourteen Years).**

<table>
<thead>
<tr>
<th>Month</th>
<th>Rainfall</th>
<th>Evaporation</th>
<th>Month</th>
<th>Rainfall</th>
<th>Evaporation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan.</td>
<td>2.87</td>
<td>0.76</td>
<td>July</td>
<td>1.77</td>
<td>3.44</td>
</tr>
<tr>
<td>Feb.</td>
<td>1.60</td>
<td>0.60</td>
<td>Aug.</td>
<td>2.33</td>
<td>2.85</td>
</tr>
<tr>
<td>March</td>
<td>1.94</td>
<td>1.07</td>
<td>Sep.</td>
<td>2.35</td>
<td>1.61</td>
</tr>
<tr>
<td>April</td>
<td>1.43</td>
<td>2.10</td>
<td>Oct.</td>
<td>2.73</td>
<td>1.06</td>
</tr>
<tr>
<td>May</td>
<td>2.06</td>
<td>2.75</td>
<td>Nov.</td>
<td>2.02</td>
<td>0.71</td>
</tr>
<tr>
<td>June</td>
<td>2.21</td>
<td>3.14</td>
<td>Dec.</td>
<td>2.42</td>
<td>0.57</td>
</tr>
</tbody>
</table>

Total rain, 25.73 in.; total evaporation, 20.66 in.

I think it probable that a graph of the monthly rainfall minus evaporation would approximate the graph of the static level of the well, and I regret that the importance of the evaporation did not occur to me earlier.

This fluctuation of over 2 ft. during the course of the year is very much greater than that of 10 in. recorded by Captain Hutton, but is much less than one mentioned by Mr. Horne, of Leeston, who says that he had there a well which in a dry season was 3 ft. 6 in. below ground-level, and in a very wet season rose to 14 ft. above ground-level. A gravel-pit at Springston about 10 ft. deep is nearly always dry in February, and frequently is full to overflowing in August.
The following graph of the weekly averages of the readings of the well shows clearly the relation between the static level of the well and the rainfall.

![Graph showing weekly averages of well height and weekly totals of rainfall at Lincoln.]

It is clear from this graph that the well rises whenever rain falls, and that the rise in the well is approximately proportional to the rainfall. This result was anticipated from the work of Hutton* and Speight,† but it was considered impossible that the rainfall at Lincoln could be responsible for the rise in the well there, since, as before mentioned, the well draws its water from 341 ft. below ground-level.

Lincoln is situated on the Canterbury Plain, fourteen miles from the sea. The plain is about fifty miles wide, and slopes upwards from the sea to the mountains, at whose feet its level is about 1,300 ft. It is composed of a coarse gravel interstratified (especially in its coastal portions near Christchurch) with clay, peat, &c., as described by Speight (loc. cit.). On the supposition that the lower strata have been laid down at a steeper angle than those now on the surface, the water-bearing stratum tapped by the Lincoln College well should outcrop on the surface of the plain some miles above Lincoln, and it would probably be the rain falling on this outcrop that would supply the well. This idea is embodied in the following diagrammatic sketch, where the heavy lines show the clay strata between

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the shingle. If this were a correct supposition, it was considered possible to locate the outcrop of the water-bearing stratum by means of observing the rainfall at a number of places between Lincoln and the mountains, and noting at which places the rainfall most nearly corresponded with the fluctuations in the level of the well. For this purpose rain-gauges were installed or existing installations were used to obtain records of the daily rainfall from the following places: Rolleston, Lawford, Kirwee, Darfield, Hororata, Glenroy, and Mount Torlesse. The positions of these places are shown on the following map, which also shows the two rivers of the district. The slope of the plain is from north-west to south-east.

**Fig. 3.—Diagram of the Structure of the Plain.**

**Fig. 4.—Map of Portion of Canterbury Plain, showing Positions of Rain-gauges.**

- 1, Lincoln; 2, Rolleston; 3, Lawford (half-way between Weddon's and West Melton); 4, Kirwee; 5, Darfield; 6, Hororata; 7, Glenroy; 8, Mount Torlesse (two miles above Springfield).
FIG. 5.—WEEKLY AVERAGES OF STATIC LEVEL OF WELL, WITH WEEKLY RAINFALLS FOR DIFFERENT STATIONS.
Unfortunately, all the records did not begin at the beginning of the year, those from Darfield not commencing till the 1st April, and those at Rolleston till the 1st June. Valuable information was thereby lost. The records are, however, complete and accurate for the periods they cover. In the accompanying graph (fig. 5) the averages of all the readings of the well for each week for five months are shown, and underneath them the total weekly rainfalls for each of seven stations, Rolleston readings not having been commenced. Zero for rainfall is made a sloping line, roughly corresponding to the graph of the well, for the purpose of bringing the rainfalls-graph near to that of the well, to facilitate comparison. To simplify the figure, rainfalls are shown for only those weeks from which conclusions may be drawn. The falls of Glenroy and Kirwee were identical for the weeks shown, and therefore these two stations are represented by only a single symbol—viz., dots and dashes.

Starting with the station nearest the mountains—viz., Springfield—if the rainfall at Springfield (squares) for the week ending the 15th January was responsible for the rise of the well shown for the week ending the 22nd January, then also the much heavier rainfall for the week ending the 26th February must have been responsible for the almost imperceptible rise for the week ending the 5th March. These two results are inconsistent, and therefore it may be stated that the rainfall on which the well depends does not fall at Springfield, nor does the water-bearing stratum tapped by the well outcrop there. Similar inconsistencies may be noted for other localities, as follows:—Hororata: In the week ending the 15th January a rainfall of 1 in. is followed by a rise in the well of 1.5 cm., and on the 23rd April a rainfall of 2½ in. is followed by a decline of 1 cm. Glenroy shows inconsistencies for the weeks ending the 15th January and the 23rd April; Darfield for the weeks ending the 2nd and the 23rd April; Kirwee for the weeks ending the 15th January and the 23rd April; and Lawford for the weeks ending the 15th January and the 23rd April. But when we come to examine the rainfall at Lincoln, and compare that with the subsequent rises, or arrests of the decline of the graph of the well, a remarkable degree of consistency is disclosed. The graph of the static level of the well is as nearly parallel to that of the Lincoln rainfall as could possibly be expected under the circumstances, and, being given the rise of the well due to the rainfall of the 15th January, the graph of the one could be constructed with reasonable accuracy from that of the other. From this it is evident that the stratum tapped by the well outcrops in a district with a rainfall during the months shown almost exactly equal to that of Lincoln. None of the stations recording for me shows such an equality, and so it seems evident that the water-bearing stratum under consideration outcrops nearer to Lincoln than to the nearest of the stations. That station is Lawford, nine miles away, and so one would probably be safe in saying that the stratum of shingle 341 ft. under the surface at Lincoln reaches the surface seven miles or less up the plains. This would place the outcrop somewhere about Rolleston—a district noted for its loose shingly soil, directly underlaid by coarse gravels, with no interposing layer of clay. Such country is absorptive of water in the highest degree, and an ideal catching-area for an underground water-supply.

The surface of the land at Rolleston is 134 ft. above that at Lincoln. The water-bearing stratum then rises 475 ft. in seven miles, or about 68 ft. to the mile. The surface of the plains near their upper limit has a fall of about 60 ft. to the mile, while between Rolleston and Lincoln it is only
20 ft. to the mile. At the time that the fall on the surface of the plains between Rolleston and Lincoln was 68 ft. to the mile—that is, when our water-bearing stratum was deposited—the whole plain must have had a much steeper gradient than at present. This would probably be due to the much greater supply of waste to the above-gorge waters of the rivers, so that in those times the present plains would have been much more like the present-day shingle fans than like plains. That the gradient of the plains was once much steeper than now is proved by the high terraces round Woodstock, and by Racecourse Hill, a residual shingle mound some 60 ft. high. The cutting into their beds of the present rivers is merely a continuation of the process of lessening the gradient of the plain, the bed of the Waimakariri being virtually level with the plains at their lower edge, and over 300 ft. below them at their upper limit. It is therefore in accord with what I suppose would be the expectations of geologists that at one time the surface of the plains should be much more steeply inclined than now, but that the supply of waste should be so great as to form a deposit sloping nearly 70 ft. to the mile forty miles away from the gorge is perhaps noteworthy.*

It was stated above as evident that the collecting-ground for the well is nearer Lincoln than the nearest rainfall-station is. On the part of one unacquainted with the country, a possible objection to this is that the collecting-ground might equally well be more distant from Lincoln than the farthest station is. The country between Springfield and the West Coast, however, consists of mountains of greywackes and slates quite impervious to water in large quantities, and, in any case, this water would percolate out into the rivers flowing at the base of the mountains. The amount of water in the Waimakariri is, moreover, a gauge of the amount of rain falling on these mountains, and I have been so fortunate as to be supplied with daily readings of the height of the river during several months. Most of the floods that my records show occurred nearly contemporaneously with considerable rainfalls on the plains, and the subsequent rises of the well could not, therefore, be stated as dependent on, or independent of, the rises in the river. On the 23rd March, however (see the arrow-head in fig. 5), there was a heavy flood, sufficient to stop the mails at the Bealey, but, as fig. 5 shows, there was no sign of any rise or arrest of the decline of the well until rain fell in the second week after the flood.

Although it is impossible that the rain falling on the mountains should directly find its way into the water-bearing stratum tapped by the well, it seemed quite possible that after reaching the river the water might percolate into such a stratum where the river runs across its outcrop. This, indeed, is probably the common opinion held; but the observations made do not support the supposition, as far as the well at Lincoln goes. The observations on

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*At the meeting at which this paper was read Mr. Speight pointed out that the conclusion reached here is probably incorrect. His observations on the strata pierced by wells near Christchurch shows that the deep-lying strata are at practically the same slope as the present surface of the plain. It is a matter of common observation that clay strata, though common near Christchurch, disappear farther up the plains, and it is probable that Rolleston marks the distance from Lincoln at which the clay stratum over the water-bearing stratum fades away, rather than the outcrop of a series of strata regular in thickness from the base of the well to the outcrop. This idea is shown in the accompanying diagrammatic sketch, where the arrow-head shows the position of Rolleston. Mr. Speight's interpretation of the facts seems to me correct, and invalidates the conclusions above drawn as to the former slope of the surface of the plains.
the height of the river were made with great care, readings being taken each day to the nearest inch. On comparison with the graph of the static level of the well no agreement could be observed in any case, and the perfect indifference of the well to the flood on the 23rd March is typical of this.

Another possible objection to the placing of the outcrop at Rolleston is that this has been done almost entirely on the slight rainfall at Lincoln and the heavier rainfall at all other stations for the week ending the 23rd April. This is quite true; but occasions on which the rainfall is markedly different at different points on the plains are rare, and some years of observations may be needed to secure a confirmation, by this method, of the conclusion drawn. In the meantime, the accuracy of the rainfall recorded at the various up-plain stations is sufficiently substantiated by their mutual agreement, and the accuracy of the record at Lincoln by comparison with that made by three other observers in the neighbourhood.

**The Daily Fluctuation.**

Even during long periods of steady decline or rise of the well its static level showed comparatively large daily variations. On some occasions it would rise 3 in. in twenty-four hours (without rain), and would fall by the same or a greater amount by the succeeding morning. Variations of 2 in. on successive mornings were common, and usually the morning readings showed variations of over 1 in. The irregularities of the static level within short periods of time during which no rain fell led to an attempt to correlate the variations in the well with those of the barometric pressure of the air. At length it was found that by turning the barometer-readings upside down and multiplying them by four a marked degree of harmony between the graph of the well and that of the barometer was displayed—a harmony so consistent as to establish the fact that the level of the water in the well and that of the mercury in the barometer are influenced by the same causes. The accompanying graph (fig. 6) shows this clearly.

![Fig. 6.—Daily Readings of Well, Barometer, and Rainfall at Lincoln.](image-url)
The graph of the well is shown by the full line, and its variations in centimetres; that of the barometer by a dotted line, and its variations in inches. It will be observed that the scale for the well increases upwards, and that for the barometer downwards; further, the space between 29.82 in. and 30.30 in. on the barometer scale (virtually 1 in.) is the same as the space between 86 and 82 on the well scale—that is, 4 centimetres (virtually 2 in.). This means that the close agreement of the two graphs seen in fig. 6 has been obtained by turning the barometer-readings upside down and multiplying by four, as above stated. Figure 6 is a portion of a graph that was constructed for the whole year for the purpose of establishing the agreement between the fluctuations of the well and the barometer.

The section 22nd March to 8th April was chosen for illustration because it is fairly typical of the whole graph, and because there is no complication due to rainfall. There were showers on the 29th, 30th, and 31st March, and on the 1st, 3rd, 4th, and 6th April, but the three heaviest of these were only 0.07 in., 0.08 in., and 0.09 in., and the remaining were 0.01 in. each. These numerous rains, the greatest of which did not reach 0.1 in., cannot be suspected of influencing the graph of the well, since in any case the well does not always rise after the rainfalls shown.

That a low barometer is accompanied by a rise in the static level of shallow wells has been excellently demonstrated by F. H. King, and for artesians is recorded in the following sentence occurring in an article by Professor J. W. Gregory in the "Journal of the Royal Geographical Society" for August, 1911, p. 171: "The Hon. E. W. Lamb kindly tells me that an increased flow has been observed in some of the wells of New South Wales at times of low barometric pressure. The increased flow from springs when the barometer is low is a well-known phenomenon which has been established, for example, by the work of Mr. Baldwin Latham near Croydon. The increase is no doubt due to gas-pressure, the gases dissolved in the water expanding when the atmospheric pressure is reduced. Mr. Latham's evidence therefore shows that gas-pressure acts even on wells of which the flow is mainly determined by ordinary water-pressure."

I have examined this theory of the rise of wells under diminished atmospheric pressure. It appears to assume that water is compressible, or, at least, that the gases within the water are compressible. This, of course, is not so. If the pressure is diminished the gases will remain dissolved if the water is not already saturated with them, and if the water is saturated the gases will come out of solution and form bubbles. The water in the College well is saturated, containing 26-50 c.c. of gases per litre at N.T.P., made up as follows: Carbon-dioxide, 1.07 c.c. per litre; oxygen, 4.29 c.c. per litre; nitrogen, 21.14 c.c. per litre.

It must be further remembered that the volume of a gas absorbed by water is independent of the pressure, since, although doubling the pressure doubles the mass of the gas absorbed, the same doubling of the pressure halves its volume. If, then, the pressure were suddenly diminished the volume of gases liberated would be proportional to the diminution of pressure, and if the gases remained in suspension in the water the volume of the water would be increased.

Calculation shows that with a diminution of atmospheric pressure from 30 in. to 28 in. of mercury—that is, from 15 lb. to 14 lb. per square inch—the bubbles of gas liberated in this well 340 ft. deep would raise its level by 1.8 in. By observation, the rise of the well under such a barometric fall amounts to 8 in., and therefore the liberation of gases
theory is insufficient to explain the fluctuations of the well with the fluctuations of the barometer as observed at Lincoln.

In the above calculation it was assumed that the gas-bubbles formed remained in the water, but since the changes in pressure are very gradual, since the water is always flowing upward, and since one-third of the total liberation of gases takes place in the top 30 ft., it is evident that the bubbles of gas must escape, and therefore cannot raise the level of the water anything like the 1-8 in. calculated above, much less raise it the 8 in. recorded by the observations.

An explanation of the rise of the well with decrease of barometric pressure more in accordance with the observed facts is as follows: Water must continually be drawn away from the water-table at the outcrop by the flow of water from the well, and more particularly the flow at the lower outcrop of the stratum under the sea. Well-sinkers find that the water runs in certain fairly defined streams in the water-bearing strata, and at Islington is to be seen a very large and freely moving underground stream running through the shingle at the bottom of an open well 42 ft. deep. Small particles of sand have therefore been removed from these strata, and the water can move freely; but the land over the water-table at the outcrop is not thus freed from small particles, and, as the water is removed, the air has a difficulty in following the water downwards, and so a partial vacuum is set up over the water at the outcrop, after the manner of the production of a Sprengel's vacuum. The water in the water-bearing stratum and the water in the well-pipe now form the two arms of a water-barometer, at the open end of which the observations are being taken. Since the open end is being observed, the water goes up when the mercurial barometer goes down; since it is a water-barometer, it should go up thirteen times as much as a mercurial barometer falls, but since the vacuum at its closed end is not perfect its motion is not so great as this. It goes up four times as much as the barometer goes down, thus indicating that the vacuum over the water-table at the outcrop is about one-third of a true vacuum—i.e., that the air-pressure amounts to about 10 lb. instead of 15 lb. to the square inch.*

The Evening Rise.

That the well at the Museum in Christchurch is usually higher in the evening than in the morning is noted both by Captain Hutton (loc. cit.) and by Mr. Speight (loc. cit.). By both these writers it was thought possible that this evening rise might be caused by the shutting-off of other wells of the same stratum in the near neighbourhood in the afternoon, although Mr. Speight is not inclined to accept this explanation. That the shutting-off of adjacent wells causes any particular well to rise is proved by Captain Hutton's observation that the Museum well

* This explanation met with a great deal of adverse criticism at the meeting at which the paper was read. Mr. Hogg and Mr. Page suggested that changes of aerial pressure would be felt directly by the water in the open pipe, but only slowly by the water at the outcrop, owing to the fact that the air superincumbent on the water there is entangled among particles of soil. This, I find, is also King's explanation ("The Soil," p. 180). Warrington ("The Physics of the Soil," p. 128) appears to prefer the explanation attributed to King in the present paper in the section on "The Evening Rise"—viz., with a failing barometer the air in the soil expands, and the water filling the intensions above the water-level is expelled, and causes a rise in the water-level of the soil. Either of these explanations is perhaps sufficient to account for the fluctuations observed, but I still regard my explanation as a possible, and even a probable, one.
was constantly higher on Sundays than on Saturdays and Mondays, and that even a public holiday was accompanied by a decisive rise in the well under observation. Mr. Dobson, Christchurch City Engineer, has informed me that the installation of a city water-supply has been followed by the breaking-out of springs in numerous places about the city, and he explains this as follows: In the early days of the city's life wells sunk on some of the higher ground had a static level of 1 ft or 2 ft. above the ground. As more and more wells were sunk to the same stratum, the static level was lowered; those on ground a foot or two lower continued to flow, but those on higher ground had their static level reduced to below that of the ground, ceased to flow, were abandoned and forgotten, and their mouths covered up. On the installation of the city supply many users of artesian water stopped their flowing wells, the static level recovered itself, and the old abandoned wells recommenced their flow, sometimes in such inconvenient places as cellars, public parks, and important streets. The explanation seems very probable, and emphasizes the interdependence of wells sunk to the same stratum. Mr. Dobson further informs me that he on one occasion fitted a pump to a particular flowing well, and started to work the pump with a steam-engine, with the result that as long as the pump was at work all the wells in the neighbourhood ceased to flow. It was primarily to escape this interference of one well with others in its neighbourhood that I commenced observations on the comparatively isolated well at Lincoln, and it was the evening rise that was the original object of the inquiry. As stated before, there are only four other wells of the same depth as the College well within a radius of two miles; the nearest of these is three-quarters of a mile away, and I felt that I could secure from the owners of all these wells any co-operation necessary for my observations. The object for which the investigation was undertaken has, however, not been accomplished, since no light has been thrown on the evening rise, except that it does exist, and that it is not caused by the shutting-off of neighbouring wells. Out of the fifty-one weeks during which the observations have been made, the weekly averages of the evening readings have been higher than those of the morning readings on thirty-six weeks, equal on four weeks, and lower on eleven weeks. The following table shows the averages of all the readings of each month, with the evening rise:—

<table>
<thead>
<tr>
<th>Month</th>
<th>Morning Reading</th>
<th>Evening Reading</th>
<th>Evening Rise</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>101-21</td>
<td>101-60</td>
<td>0-39 cm.</td>
</tr>
<tr>
<td>February</td>
<td>95-08</td>
<td>95-20</td>
<td>0-12 cm.</td>
</tr>
<tr>
<td>March</td>
<td>88-47</td>
<td>88-66</td>
<td>0-19 cm.</td>
</tr>
<tr>
<td>April</td>
<td>82-10</td>
<td>82-40</td>
<td>0-30 cm.</td>
</tr>
<tr>
<td>May</td>
<td>75-60</td>
<td>75-80</td>
<td>0-20 cm.</td>
</tr>
<tr>
<td>June</td>
<td>95-10</td>
<td>95-30</td>
<td>0-20 cm.</td>
</tr>
<tr>
<td>July</td>
<td>104-30</td>
<td>105-20</td>
<td>0-90 cm.</td>
</tr>
<tr>
<td>August</td>
<td>130-16</td>
<td>131-36</td>
<td>1-20 cm.</td>
</tr>
<tr>
<td>September</td>
<td>136-84</td>
<td>137-11</td>
<td>0-27 cm.</td>
</tr>
<tr>
<td>October</td>
<td>137-97</td>
<td>137-92</td>
<td>-0-05 cm.</td>
</tr>
<tr>
<td>November</td>
<td>134-38</td>
<td>134-80</td>
<td>0-42 cm.</td>
</tr>
<tr>
<td>Average</td>
<td>107-38</td>
<td>107-76</td>
<td>0-38 cm.</td>
</tr>
</tbody>
</table>
The evening rise is thus fairly well marked. During the months of October and November I personally secured that all the wells in the neighbourhood were running continuously, with the exception of one (three-quarters of a mile away) which its owner was good enough to shut off from 7 to 9 a.m. and 4 to 6 p.m. every day. The readings during these two months were taken exactly at 8.30 a.m. and 5.30 p.m., so that the well had an hour and a half to recover any disturbance that might have been set up by the well whose flow was intermittent. That this intermittently flowing well could have any effect on the College well, so far away, is questionable, and, in any case, it was not (even during the months I did not keep special control of it) usually running in the morning or usually shut off in the afternoon. The interference of neighbouring wells may therefore be rejected as a cause of the evening rise.

Any constant variations in temperature are similarly to be rejected. I kept a record of the temperature of the flowing water just as it emerged from the ground from the 10th to the 30th October. The temperature varied from 12.81°C. to 12.90°C., and this variation was more probably due to the effect of the air on the stem of the thermometer than that of the water on its bulb. In any case, the temperature never showed any disposition to be regularly higher in the evening than in the morning, and, if it had, a much greater rise of temperature would have been needed to cause sufficient expansion of the water (inside an iron pipe, on which the scale was carried) to account for the observed rise in the static level. The water in the gauge-glass is, however, practically the same water all the time, and therefore takes on to a considerable degree the temperature of the atmosphere. It varied from 10.0°C. to 23.9°C. during the month of October. The higher readings were, however, on all but three occasions obtained in the morning, owing to the sun shining on the gauge-glass and above-ground portion of the well-tube in the morning and not in the evening; indeed, the highest reading (23.9°C.) was obtained in the morning, and on the same evening the temperature was 12.0°C. In any case, an average evening rise of temperature of about 25°C. would be needed to cause a 4 ft. column of water (in a glass tube with an independent scale) to expand sufficiently to account for the observed rise in the static level. A shrinkage of the wooden scale in the evening would also explain the rise; but means to detect and measure this, if it occurred, were not at hand, and the line of investigation held little promise. During the months of October and November, also, records were kept of the barometric pressure in the mornings and evenings, and it was found that the readings were, on the average, lower in the evenings than the mornings. The amount of the decrease in the barometric height in the evenings was 0.07 in., sufficient to account for a rise in the well of 0.56 cm., or more than the actually observed rise. The barometric observations were, however, taken on an aneroid barograph, the mercurial barometer unfortunately being out of repair. There is, I suppose, no question that the temperature of a living-room is higher in the evenings than the mornings. The apparent fall of the barometer each evening is, therefore, only a temperature effect, and
cannot be used to explain the rise of the well. This fact is emphasized by the following graph (fig. 7), obtained in Invercargill in 1903: it is perhaps sufficiently striking to merit publication.

![Barogram showing depressions due to rise in temperature at noon.](image)

During a temporary absence from home I placed the barograph in a window, so that an observer could read its records without entering the house. The window happened to face north-north-west, and the sun fell on the instrument just after midday. On each day the graph falls nearly 0.25 in. as soon as the sun strikes the instrument, and it rises again about 5 o'clock, when the sun passes off. The small fall of the barometric pressure recorded for the evenings during the present observation is therefore not reliable, and cannot be used to explain the evening rise of the well.

No explanation of this phenomenon can, therefore, be offered as the result of these observations. Mr. Speight has suggested to me that it might possibly be correlated with the expansion of the earth by the heating effect of the sun, and the passing of an earth-wave or earth-heave towards the sun as it sets, as explained by Milne. No observations or calculations have been made to test the probability of this suggestion.

F. H. King (vide "The Soil," p. 162, &c.) found a morning rise in his shallow wells, and this is explained by the fact that the soil-temperature is highest in the morning, and that the expansion of the soil-air expels some of the soil-water so that it reaches and raises the water-table and thus the well. It is possible that observations might show that at the outcrop of our water-bearing stratum the soil-temperature is higher in the evening, and this would explain the evening rise. This is another of the numerous points on which no observations were made.

(2.) The Museum Well.

This is a flowing well, 190 ft. deep, situated at the Canterbury Museum, Christchurch. It is the deep well whose behaviour was recorded by Captain Hutton (loc. cit.), and Mr. Speight made further observations on it during 1910 and 1911. I have worked up both Hutton's and Speight's observations in the same way as I have my own, comparing them with the barometer-readings, taking out weekly and monthly averages, &c., and have found the following facts: (1.) The major fluctuations in the static level of the well are small, the greatest annual variation recorded during the two series of observations being 10.5 in., as compared with 2 ft. 4 in. in the Lincoln College well. (2.) Its level is changed by rain in the same
manner and to the same degree as in the Lincoln well, but there is a much less decline in its static level during a similar period of almost similar rain. (3.) There is no sign of floods in the Waimakariri influencing the well. (4.) There is no sign of agreement between the graph of the well and that of the barometer, however the latter is manipulated. (5.) There is an evening rise. Points (2) and (3) are illustrated by the following graph (fig. 8), which is comparable to fig. 2, both graphs being on the same scale.

The want of agreement between the graph of the well and that of the barometer may be explained either as the result of the Waimakariri assisting the rainfall to supply the well, or as the result of the interference of neighbouring wells. That such interference does take place has been shown in a previous section.

The lack of pronounced decline during a comparatively rainless period, and the smallness of the annual variation (10\% in.), opens up seriously the question as to whether the Waimakariri does assist the supply of the flowing wells in Christchurch. In favour of the rainfall being the sole source of supply are the following facts: (1) The rise of the well after rain; (2) the absence of effect of even the greatest floods on the river (see fig. 8, 1st December); (3) the diminution of the static level of the wells as each additional well is put down. The Museum well has fallen 4\% ft. in fifteen years, and there is a generally expressed opinion that all the wells in the town are similarly affected. This would be the natural effect if there were a restricted supply of water, such as a rainfall of 25 in. affords. If the lowering of the static level of the wells is an indication of the lowering of the water in the water-table at the outcrop (and it is difficult to suppose otherwise), then the wells in the town are robbing the crops in the country of the supply of water that they should receive by capillary rise, a matter of some importance on light shingly ground.
Hilgendorf.—Artesian Wells in the Christchurch Area.

It has been often asserted by myself, along with others, that it is inconceivable that the rainfall should supply all the water outflowing at the Christchurch wells, but I have made a calculation that, whatever its faults, makes the case at least not inconceivable.

Population of Christchurch suburbs within the artesian areas—i.e., from Sockburn to New Brighton and from Papanui to the Port Hills—86,661 (say) ... 90,000

Gallons of water used per capita per day, including hydraulic lifts and cranes, street- and garden-watering—

Auckland (1910) ... 58
Wellington (maximum) ... 60
Dunedin (maximum) ... 61½
Say, average for Christchurch (where street-watering comes from river) ... 60

Two rams at College lift water an average of 22½ ft., and waste water is seven times that pumped. As this is above average height, we may say proportion of water used to that wasted ... One-tenth.

Then, total water drawn from artesians in Christchurch area per year = \(90,000 \times 60 \times 11 \times 365 \times 10 \div 2,240\) ... 96,251,760 tons.

Again—

Population having been taken as from Sockburn to New Brighton—

Length of catchment-area ... 10 miles.
First-stratum wells outcrop two miles up plain (Speight); deep wells (450 ft.) outcrop about eight miles away;
... width of catchment-area (about) ... 6 miles.
Average rainfall ... 25 inches.
1 in. of rain = in tons per acre ... 101

Then rain falling on catchment-area per year = 10 \times 6 \times 640 \times 101 \times 25 ... 96,960,000 tons.

If there is any approximation to accuracy in this calculation, then each additional well put down to any of the strata at present in use can receive its water only by robbing its neighbours, a condition of affairs that, in the upper strata has long ago been reached. As for the lower strata they have probably not been largely drawn on so far, and there is every reason to suppose that there are still lower strata available but still untouched.

In favour of the Waimakariri assisting the water-supply are these facts: (1) Water does undoubtedly percolate from the beds of some of the rivers, as stated by Speight (loc. cit.), and I am able to add that near Bealey a considerable amount of the Waimakariri flows underground. This water is almost certain to leak into every porous bed, especially where the thin deposit of silt that forms on the river’s bed has been removed by scour. (2) The great degree of constancy of the Christchurch supply, and the smallness of the annual variation in the Museum well during the three periods it has been under observation. I should be inclined to think that water from the river does assist the Christchurch wells in some degree, but the Lincoln well in no degree; but a longer period of observations would be necessary to establish any opinion on the matter.
(3.) THE BELFAST WELL.

This well is situated at the Canterbury Frozen Meat Company's works at Belfast, ten miles north of Christchurch, and within a mile of the Waimakariri. The well was sunk in 1896, and is 96 ft. deep. It is not a flowing well, but opens into a concrete sump, in which the water stands about 4 ft. below the surface. Its construction seems to preclude any surface drainage. Observations were made on it by Mr. L. P. Symes from the 14th October to the 1st December, 1911. The controlling factor influencing its fluctuations seems to be the level of the Waimakariri, as the following graph shows. The heights of the river are those noted at Bealey on the day before they are entered on the graph, as the water in the river takes eighteen hours to flow from Bealey to Belfast.

![Graph of Well at Belfast (Full Line) in Centimetres, and of Waimakariri (Dotted Line) in Feet](image)

**Fig. 9.** — Graph of Well at Belfast (Full Line) in Centimetres, and of Waimakariri (Dotted Line) in Feet.

**Conclusions.**

The well at Lincoln depends for its supply almost entirely on rainfall. The wells in Christchurch depend on rainfall, probably assisted by percolation from the Waimakariri. The wells at Belfast depend chiefly or entirely on the Waimakariri. The rain supplying the wells of present depth falls on the plains comparatively close at hand — say, within ten miles of the town. The discharge from the wells probably lowers the water-table in the country. The barometric pressure influences the wells.

At the close of a paper that is largely a compilation of the work of others I have a long list of helpers to whom to offer thanks. Mr. Speight and Mr. Symes have been good enough to offer valuable suggestions during the course of the work. The Council of the Canterbury Philosophical Institute has voted money for apparatus. Many of the students at Lincoln College, Mr. Speight, Mr. Symes, His Lordship Bishop Grimes, Mr. Crump, and the verger of the Presbytery at Lincoln, have either taken well-
observations for me of definitely placed wells at my disposal. Mr. Gray has supplied analyses of the gaseous contents of well-waters. Mr. W. Paine, telegraphist at the Bealey, has made for me very careful measurements of the height of the Waimakariri. The following have supplied me with rainfall records either for short periods or for the whole year: Messrs. G. Gray and G. Rennie at Lincoln, J. Brunton and R. Ellis at Rolleston, Griffith Smith at Lawford, J. Wilson at Kirwee, J. Reid Wilson at Darfield, G. Hall at Hororata, W. Hall and G. C. Hunt at Glenroy, P. H. Johnson at Mount Torlesse, and, finally, the Government Meteorologist for several stations. Mr. Hogg was kind enough to make the calculation concerning the alteration in the volumes of the dissolved gases under changes of pressure, and Dr. Evans and Mr. McLeod to provide material for apparatus. To all these I beg to offer my thanks, as without their co-operation this paper could not have been written in its present form. I have also to acknowledge the assistance given by the observations made by the late Captain Hutton.

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ART. XV.—A New Genus and some New Species of Plants.


[Read before the Auckland Institute, 28th November, 1911.]

1. Alectryon grandis Cheesem. sp. nov.

Arbor 15-pedalis et ultra; ramulis sericeo- et ferrugineo-pubescentibus. Folia pinnata, alterna, breviter petiolata, 22-30 cm. longa; foliola 2-3-juga, breviissime petiolata, late oblonga vel ovato-oblonga, obtusa vel subacuta, 10-18 cm. longa, 5-9 cm. lata, praeter costam venasque primarias plus minusve sericeo-pubescentia; venis ultimis conspicue reticulatis, subtus elevatis. Flores ignoti.

Hab.—Cliffs on the north side of the Three Kings Islands; a single small clump alone seen. T. F. C.

This is the plant referred to at page 103 of the Manual under the name of Alectryon excelsum var. grandis. Although no doubt existed as to its being a distinct species, I have deferred describing it as such, in the hope that some visitor to the Three Kings Islands might return with flowering specimens. But, as twenty-two years have elapsed since its original discovery without producing any additional information, it seems advisable to publish it without further delay. As the islands are now visited at least once every year, I trust that the publicity drawn to the plant may result in its rediscovery.

A. grandis can be distinguished from A. excelsum without the slightest difficulty by the small number of leaflets to each leaf, and by their shape and much greater size. In A. excelsum the leaflets are 2-4 in. long, and are ovate-lanceolate in shape; whereas in A. grandis they are 4-7 in. in length, and are broadly oblong or ovate-oblong. They are also firmer in texture, and much more obtuse.