THE GROUND WATERS OF THE HERETAUNGA PLAINS

I—The Ngaruroro River as a Major Recharge Source

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SUMMARY

For summer flow conditions, values of average water yields per sq. mile are given for sub-areas of the Ngaruroro River catchment. These indicate that the greatest water yields are from the Kaweka and northern Ruahine ranges — the regions of highest average rainfall.

At many sites on the Ngaruroro River it appears that a considerable part of the total water volume occurs as underflow.

Losses from the Ngaruroro River, between Maraekakaho and Fernhill, amount to not less than 182 cusecs, and it is suggested that this water recharges the ground water system of the Heretaunga Plains and constitutes its major source of recharge.

During summer, about 55% of the catchment water yield contributes to the ground waters of the Heretaunga Plains.

INTRODUCTION

The Heretaunga Plains, an area of about 85 sq. miles, abut Hawke Bay (Fig. 1) and are traversed by the Tutaekuri, Ngaruroro and Tukituki rivers. For domestic, agricultural and industrial purposes a population of about 75,000 draws its water supplies from the ground waters of the plains (Fig. 3).

The earliest published work concerning the origin of the ground waters of the plains was by Hill (1887) who asserted that the underground basin comprised a stream which moved slowly and steadily through a shingle bed between two impervious beds; and "the water has been discharged along the bed of the ocean far from the land." Commenting that increases in artesian flow had been noticed about Hastings at the time of flooded rivers, he stated: "the natural inference has been that the artesian supply comes directly from the rivers Ngaruroro, Tukituki, and Tutaekuri

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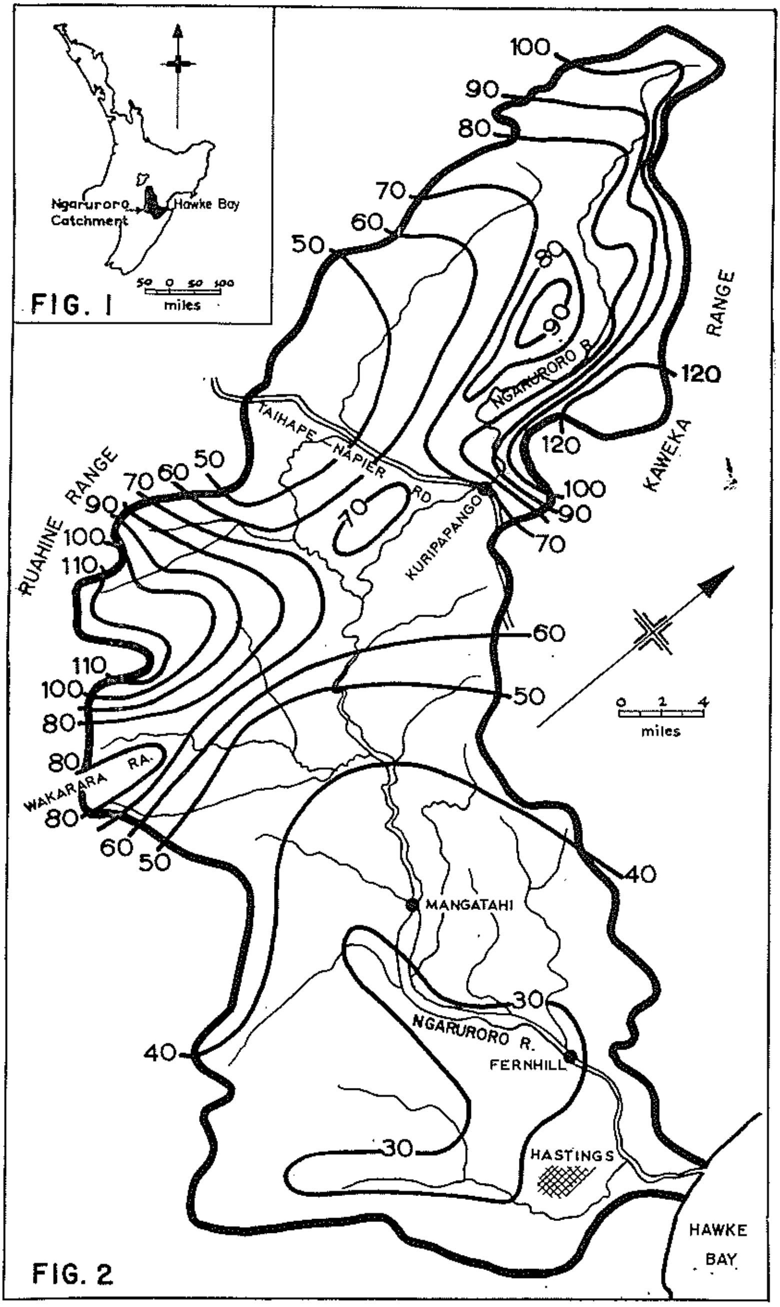

Fig. 1 — LOCATION of Ngaruroro Catchment.

Fig. 2 — AVERAGE ANNUAL RAINFALL, with values in inches.

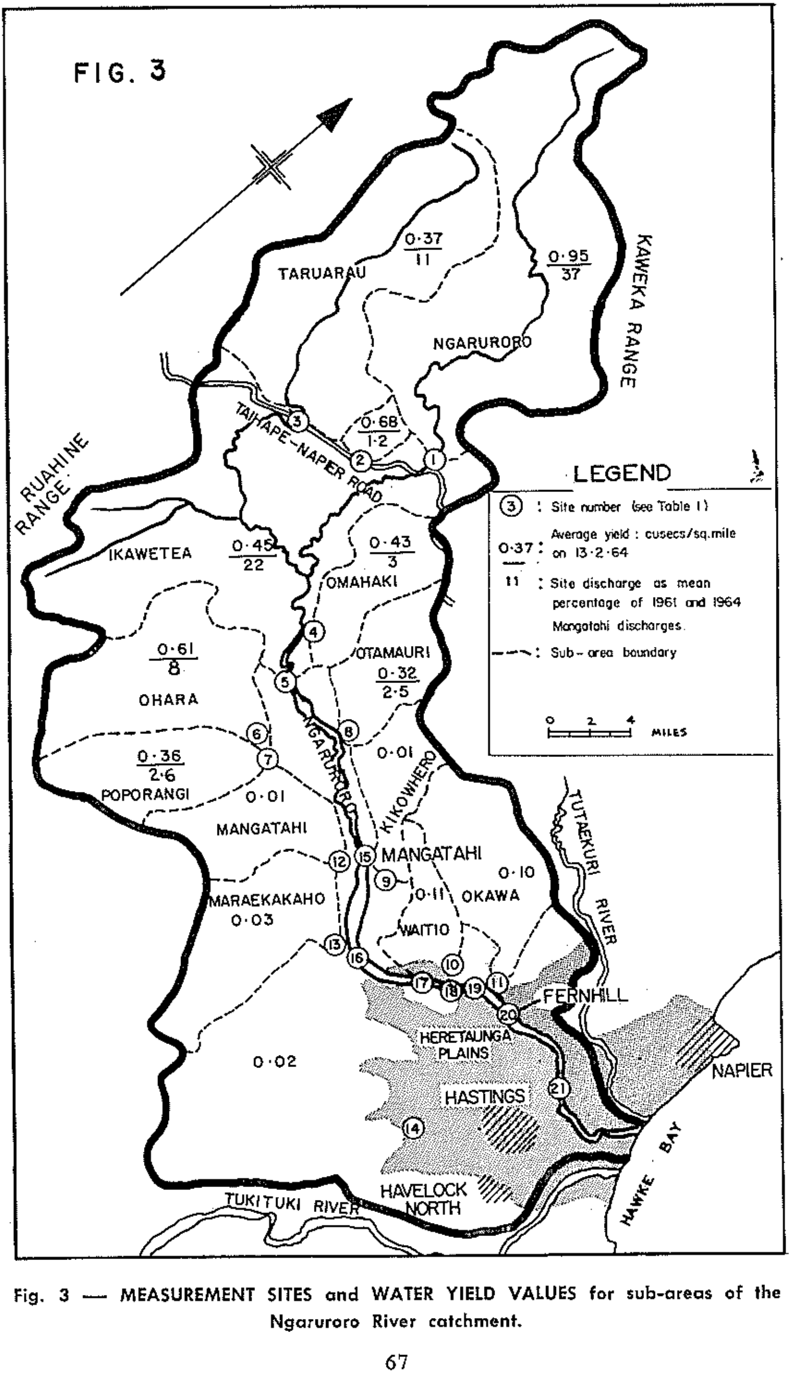

Fig. 3 — MEASUREMENT SITES and WATER YIELD VALUES for sub-areas of the Ngaruroro River catchment.

by percolation through the shingle . . . ." However, he added: "as for the origin of the water-supply, little can be stated with certainty." After eliminating rainfall on the Heretaunga Plains as a source of supply, Hill concluded that "the large quantity of water that is constantly passing underneath the plain, is to be accounted for by the presence of numerous underground springs at the junction of the limestones and the clays which underlie them, and by the percolation of river water through the shingle and sands at the outcrop of the beds."

In 1957 Grant-Taylor presented a guide to the geology and hydrology of the Heretaunga Plains ground water system. In his report (Grant-Taylor, 1957) reference was made to the positive influence of the Ngaruroro River, when in high flood, on artesian pressures.

In relation to ground water the first flow measurements were made on Ngaruroro River in 1957; and in 1960 those reaches of the Tutaekuri and Tukituki rivers likely to be related to ground water recharge were broadly studied by the author. The Ngaruroro River measurements indicated that a considerable discharge loss occurred above Fernhill; but no significant losses from the Tutaekuri and Tukituki rivers were detected. Subsequent work was therefore directed to the Ngaruroro River; and this paper is a summary of the water yield resources of the Ngaruroro River catchment, and of the relations between some lower reaches of the river and the Heretaunga Plains ground water system.

NGARURORO RIVER CATCHMENT

At its mouth the Ngaruroro River has a catchment area of approximately 970 sq. miles; but this study is concerned in the main with the catchment area above Fernhill (Fig. 3) of about 744 sq. miles.

River length above Fernhill is 85 miles. The upper 9 miles are graded and meandering, the central 50 miles are deeply incised, and the lower 26 miles constitute a wide gravel bed upon which the channel is often braided. The maximum altitude of the upper catchment just exceeds 5,500ft and much is above 3,000ft (Fig. 2).

Grindley (1960) has mapped the geology of the upper catchment which consists chiefly of complexly deformed Kaweka and Kaimanawa greywackes. Elder (1959, 1962, 1965) has described the vegetation types and patterns on and about Kaweka Range and on Ruahine Range.

A broad pattern of average annual rainfall appears on Figure 2. In the upper catchment the pattern has been determined by the author mostly from short-record storage raingauges.

INVESTIGATION BASIS

Throughout the Ngaruroro catchment, accessible measurement sites (Table 1) have been selected on Ngaruroro River and on tributary streams. A time was chosen to commence discharge measurements when run-off had passed from the catchment, flow was in a phase of steady recession representing catchment ground water depletion (Toebes & Morrissey, 1961), and the chances of rain falling during the study period were remote. Hydrographs from automatic water level recorders at sites 1, 3, 5 and 20 (Fig. 3) gave a ready check on the absence of effective rainfall during the measurement series. In the event of widespread run-off before the measurements are completed the series must be abandoned; but in the case of light local falls, field measurements can often be satisfactorily adjusted.

In November 1961, and again in April 1964, a series of discharge measurements was made throughout the catchment. The 1961 series extended over seven days, the 1964 series over four days. No effective rain fell during the periods, and the 1961 series of measurements was adjusted, using the flow recession rate at site 5, to 1200hrs on 28 November; the 1964 series was adjusted, using sites 1, 17 and 20, to 1200hrs on 13 February. The adjusted discharge values represent instantaneous discharges and these are the basis for the discussion that follows (Table 1).

TABLE 1— Measurement Sites and Instantaneous Discharges

Site No.	Waterway	Site Location and N.Z.M.S. 1 Map Ref.		Catchment Area (sq. mls.)	Discharge (cusecs)		Discharge as Percent of Mangatahi Amount		
					28 Nov 1961	13 Feb 1964	Nov 1961	Feb 1964	Mean
1	Ngaruroro	Kuripapango	N123:783533	143	179	136	33	40	37
2	Kakakino	Taihape Rd	N123:758503	5.9	—	4.0	—	1.2	1.2
3	Taruarau	Taihape Rd	N123:682467	96.7	58	36	11	11	11
4	Omahaki	above confluence	N133:824356	28.1	13	12	2.4	3.6	3.0
5	Ngaruroro	Whanawhana	N133:843320	422	396	252	74	75	74
6	O'Hara	Big Hill Rd	N133:874264	56.2	32	34	5.9	10	8
7	Poporangi	Big Hill Rd	N133:878264	27.6	12	10	2.2	3.0	2.6
8	Otamauri	ab. confluence	N134:912325	24.7	14	8.0	2.6	2.4	2.5
9	Kikowhero	Whanawhana Rd	N134:034279	20.6	1.2	0.2	NA	NA	
10	Waitio	Ohiti Rd	N134:138263	15.8	13	19	"	"	
10A	Waitio	Tirohia	N134:090233	9.0	—	1.0	"	"	
11	Okawa	Broughton's Bridge	N134:165284	42.2	8.1	7.0	"	"	
11A	Okawa	Kautuku	N134:151292	40.9	—	4.0	"	"	
12	Mangatahi	Aorangi Rd	N134:402254	29.3	2.6	0.3	"	"	
13	Maraekakaho	ab. confluence	N134:052203	47.3	9.0	1.6	"	"	
14	Kahumoko	Pakipaki	N134:211147	52.3	—	1.0	"	"	
15	Ngaruroro	Mangatahi	N134:972284	558	540	337	100	100	100
16	"	Maraekakaho	N134:055213	598	—	—	NA	NA	
17	"	Ohiti	N134:122243	678	455	285	"	"	
18	"	Rifle Range	N134:139253	680	—	—	"	"	
19	"	Glenside	N134:157272	701	—	215	"	"	
20	"	Fernhill	N134:185275	744	300	155	"	"	
21	"	Ormond Rd	N134:267267	746	—	—	"	"	

NA: Not applicable; site down stream of Mangatahi.

RELATIVE WATER YIELDS

Mangatahi (site 15) on Ngaruroro River is adopted as the main control site for the upper catchment.

Yields on an Areal Basis

On 28 November 1961 the flow at Mangatahi was about 540 cusecs*, on 13 February 1964 it was 337 cusecs. Because areal yield values are likely to be of greater significance for smaller discharges, the 1964 data have been used to derive yield areal averages. These are expressed as cusecs per sq. mile and are shown on Fig. 3. Although there is marked harmony quantitatively between average water yield values (Fig. 3) and average annual rainfall amounts (Fig. 2), it must be emphasized that water yield values are simply averages that result in many cases from great spatial variability of rainfall, rock, vegetation and physiography. Nevertheless such average water yield values can be used safely as indices of the relative water yield capacities of various areas of the catchment under extreme drought conditions.

Sub-discharges Related to Mangatahi Discharge

In November 1961 the flow at Mangatahi was 540 cusecs; in February 1964 it was 337 cusecs — about 62% of the former. Despite this difference there was good agreement at each site when discharges were expressed as a percentage of the respective Mangatahi discharge (Table 1). The mean percentages of subareal discharges in relation to discharge at Mangatahi are shown on Fig. 3. These values are not absolute, but they have sufficient reliability to permit a reasonable assessment of the water yields of sub-areas of the catchment under low flow conditions. Percentage values (Fig. 3) indicate that the upper Ngaruroro River basin, above Kuripapango (site 1), is the greatest contributor; it supplies 37% of the Mangatahi volume. On a unit-area basis this is also true, for the yield value of 0.95 cusecs/sq. mile is by far the highest. There is some justification, therefore, for considering the high Kaweka Range block as the greatest water contributing region in the catchment. Second in importance is the northern portion of Ruahine Range which drains into the Ikawetea and O'Hara streams.

In relation to the Mangatahi discharge, we find that of this volume — using mean percentage values — 74% originates above Whanawhana (site 5), 10.6% is supplied by the O'Hara and Poporangi (sites 6 & 7), and 2.5% is supplied by the Otamauri (site 8); a total of 87%. The area below these four sites which flanks Ngaruroro River to Mangatahi is 27 sq. miles and applying a generous yield factor of 0.10 cusecs/sq. mile produces a likely

*one cusec = one cubic ft per sec. or 6.24 galls per sec. or 374 galls per min.

maximum yield of about 3 cusecs which represents about 1% of the 1964 Mangatahi volume. Only 88% of the Mangatahi discharge has been accounted for in the 558 sq. mile catchment above Mangatahi; there is therefore an unmeasured volume representing 12% of that at Mangatahi. In 1961 this deficit was about 65 cusecs, and in 1964, 40 cusecs. In other words about 65 and 40 cusecs respectively have escaped measurement at sites 5, 6, 7 and 8; and after consideration of pertinent hydrological and site factors it appears that the bulk of the deficiency results at Whanawhana (site 5). Both in 1961 and 1964 assumed deficits at Whanawhana, representing 16% of measured discharges (1961:396 cusecs, 1964:252 cusecs), must have passed unmeasured through the gravel river bed which is 400ft wide, of coarsely graded materials to 12in. diameter and of considerable but unknown depth, and having a slope of 21ft per mile. At Fernhill (site 20), by discharge comparisons with site 21 (Table 2), suspected unmeasured water quantities in relation to measured amounts average 7.5%. The gravel bed at Fernhill is about 650ft wide, gravels seldom exceed 3-4in. diameter, and the channel slope is 14.8ft per mile. The relative losses at the two sites would appear to be adequately explained as underflow.

The same proposition applies, of course, in varying degrees to all comparable sites and it is reasonable to propose for Mangatahi (site 15) that measured discharge is deficient of real discharge by about 10%; the measured 337 cusecs on 13 February 1964 might then represent an actual quantity in the order of 370 cusecs. This means that at Whanawhana underflow would represent 29—30% of measured flow.

This somewhat involved assessment of the unseen underflows has shown that the surface water discharge measurements fall seriously short of the actual discharges; and this realisation is essential for a fuller appreciation of the discharge pattern in the Ngaruroro River reaches bordering the Heretaunga Plains.

DISCHARGE LOSSES FROM THE LOWER NGARURORO

Since 1957, discharges have been measured at various sites on Ngaruroro River below Mangatahi (Table 2). The earliest measurements demonstrated that from Maraekakaho (site 16) to Fernhill (Fig. 4) there was a loss of surface flow in the order of 150 - 200 cusecs. Subsequent measurements, concentrated on Ohiti (site 17) and Fernhill, have confirmed that such a phenomenon exists — probably continuously. Three series of measurements made in February and April 1964 were aimed at more closely defining the areas where major surface flow losses occur.

Before discussing river discharges it is necessary to consider discharge anomalies that have appeared on the Waitio and Okawa streams.

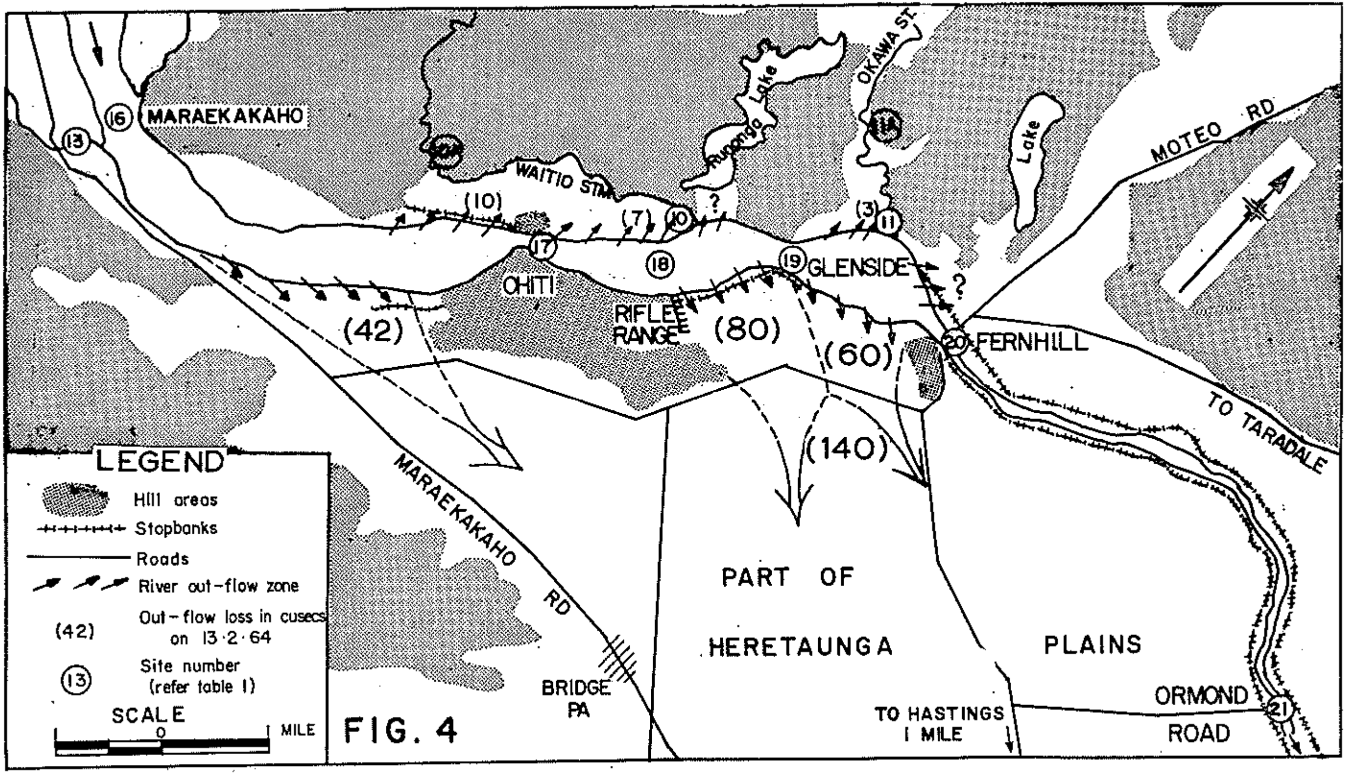

Fig. 4 — OUT-FLOW ZONES of the Ngaruroro River, in the vicinity of Heretaunga Plains, showing approximate out-flow quantities (cusecs) on 13 February 1964, based on surface discharges.

TABLE 2—Instantaneous Surface Water Discharges of Ngaruroro River (in cusecs)

Site: No.:	Mangatahi 15	Maraekakaho 16	Ohiti 17	Rifle Range 18	Glenside 19	Fernhill 20	Ormond Rd 21	Ohiti to Fernhill* % discharge loss
4. 3. 57	—	320	340	—	—	120	—	65
22. 7. 59	—	800	—	—	—	640	—	—
22. 1. 60	—	450	360	—	—	210	223	42
2. 3. 60	—	—	830	—	—	600	—	28
14. 4. 61	—	—	430	—	—	290	—	33
28. 11. 61	540	—	455	—	—	300	—	34
13. 12. 61	—	—	590	—	—	440	—	25
27. 2. 63	—	—	430	—	—	340	—	21
26. 3. 63	—	—	310	—	—	140	—	55
29. 5. 63	—	—	370	—	—	200	—	46
26. 11. 63	—	—	444	—	—	296	—	33
5. 2. 64	—	—	—	—	—	178	194	—
13. 2. 64	337	—	285	—	215	155	—	46
18. 2. 64	421	383	356	355	268	192	—	46
27. 4. 64	305	290	250	250	185	—	—	—
8. 10. 65	—	—	960	—	—	753	—	22
28. 10. 65	—	—	844	—	—	700	—	17

* Based on measured, not adjusted, Ohiti discharges.

Waitio and Okawa Discharges

Every measurement of Waitio Stream at site 10 (Fig. 4) has given a discharge which, in yield per sq. mile, is abnormally high in comparison with values for adjoining catchments. The discharge of 13 February 1964 of 19 cusecs (Table 1) represents a yield value of 1.20 cusecs per sq. mile whereas surrounding catchment yield values range from 0.01 to 0.10. Consequently, up stream from site 10 a series of discharge measurements was made and the Waitio channel was closely inspected. It was determined that the Waitio volume diminishes markedly and erratically along the 3-mile length to site 10A. For this length the Waitio is adjoined on its right bank by an alluvial flat which extends to, and is a former flood plain of, the Ngaruroro River. Inspection revealed that along most of the length of the right bank of the Waitio there exists a distinct seepage zone, usually several feet above the Waitio water level, and at many sites the in-flowing water is sufficient to comprise a small stream. The discharge at site 10A which is up stream of the alluvial flat was 1 cusec representing a yield of 0.11 cusecs per sq. mile. Comparisons and deductions from the Waitio for 13 February 1964 are more readily discernible from the following table:

	Catchment Area (sq. miles)	Discharge (cusecs)	Cusecs per sq. mile
Site 10	15.8	19	1.20
Site 10A	9.0	1.0	0.11
Derivation	15.8	1.7	0.11

When the yield factor of 0.11 is applied to the total catchment area of 15.8 sq. miles the expected discharge is 1.7 cusecs — not 19 cusecs. The Waitio at site 10 therefore carried a surplus of about 17 cusecs, and from field studies it was manifest that these 17 cusecs originated from the Ngaruroro River and passed as underflows through the alluvium bordering the right bank of the Waitio Stream. Discharge measurements indicated that above Ohiti (site 17) the Ngaruroro River lost about 10 cusecs to the Waitio, and between Ohiti and Rifle Range (site 18) it lost about 7 cusecs (Fig. 4).

In a similar manner the Okawa Stream was investigated and between sites 11 and 11A (Fig. 4) it was determined that about 3 cusecs accrue from the Ngaruroro River as underflows through alluvium between the river and Okawa Stream.

The above findings suggest that further discharge losses may take place from the river through left-bank alluvium along the 1-mile reach above Fernhill. However, as field studies in this region must incorporate investigations of likely discharge losses from Tutaekuri River to the north (Fig. 3), it must be assumed for the present that left-bank river losses immediately above Fernhill are of little consequence in relation to the discussion that follows.

In summary, Ngaruroro River out-flows to Okawa Stream return to the river on the same reach and no complication arises. But of the river out-flows to the Waitio, 10 cusecs (Feb. 1964) were lost above Ohiti and returned to the river below Rifle Range (site 18). This means that on 13 February 1964 the arithmetical difference of 130 cusecs between Ohiti and Fernhill discharges — 285 and 155 cusecs respectively — should more realistically be 140 cusecs (Fig. 4).

Ohiti-Fernhill Discharge Relations

The relation between measured discharges at Ohiti and Fernhill (Table 2) has been analysed and is shown in Figure 5. Naturally, discharges at the two sites are highly correlated, R* = 0.98; but the variability in the degree of relation, shown by the scatter of the plotted points, requires some explanation.

Using flow data from the Fernhill water level recorder charts two parameters were determined for the 15-week period antecedent to each discharge measurement set. These were:

(a) Number of river rises above 12.0ft (2,000-2,500 cusecs)
(b) Maximum water level attained.

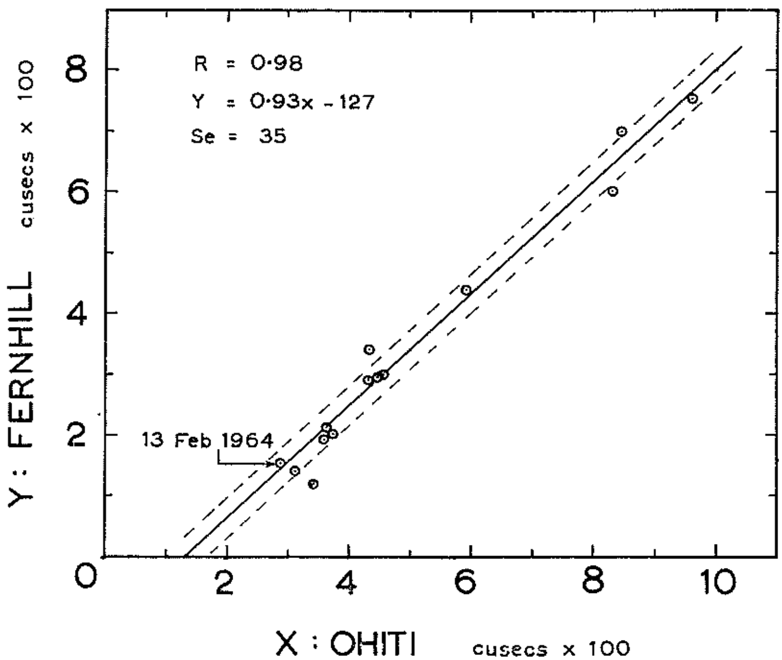

Fig. 5 — Relation between MEASURED DISCHARGES at Ohiti and Fernhill, 1957-65; R is coefficient of correlation and Se is standard error of estimate.

*R : Pearson's coefficient of correlation.

Each was correlated independently with the Ohiti-Fernhill percentage discharge difference (Table 2). No relation was found with the number of river rises; and the maximum water level was negatively but not significantly related: r**= -0.51, not significant at the 5% probability level.

The Ohiti-Fernhill percentage discharge difference was found to be negatively correlated with the discharge quantity at Ohiti: r = -0.83, which is significant at greater than the 1% level. However, as this relation accounts for only 69% (r^2) of the variability, it is possible that much of the scatter (Fig. 5) is attributable to variation, at each site, in the proportion of surface to sub-surface flow, consequent upon changed channel patterns.

It is possible to infer a curvilinear relation between Ohiti and Fernhill discharges (Fig. 5) but as this is not convincing with the limited data, a linear relationship has been calculated. The regression equation is

$$Y = 0.93X - 127$$

where Y represents Fernhill discharge, and X represents Ohiti discharge.

The computed standard error of estimate (Se) is 35 cusecs and, by definition, a vertical spread of 70 cusecs (=2Se) embraces 68% of the samples. This band is defined by control curves on Figure 5. In other words, for 68% of cases, $Y = 0.93X - 127 \pm 35$; and the indication is that when the surface discharge at Ohiti falls to around 127 cusecs, there will be no visible flow at Fernhill.

The regression coefficient, 0.93, indicates that X - Y increases as X increases, but when the standard error of estimate of 35 cusecs is taken into account, any residual variation in X - Y is not significant. However, it is clear that many more field measurements are required to clarify the relation between Ohiti and Fernhill discharges.

It is interesting to note that the Ohiti-Fernhill discharge relation of 13 February 1964 lies very close to the regression line (Fig. 5). Furthermore, when more realistic discharge differences between Ohiti and Fernhill are required it is necessary to increase the Ohiti measured value by 10 cusecs — this representing the out-flow loss, above Ohiti, to the Waitio Stream.

**r : Spearman's coefficient of correlation.

Mangatahi to Fernhill Discharge Losses

Discharge values (Table 2) indicate that river losses also occur between Mangatahi and Ohiti, and three series of measurements in 1964 make it possible to examine more closely the locations of river losses between Ohiti and Fernhill. The three discharge series have been adjusted to allow for out-flows to the Waitio Stream, and adjusted values with the respective percentage decreases from site to site are shown in Table 3.

TABLE 3—Instantaneous Discharges Adjusted to Allow for Left-bank Out-flows, and Percentage Differences Between Sites

	13 FEB. 1964		18 FEB. 1964		27 APR. 1964	
	Cusecs	% Diff	Cusecs	% Diff	Cusecs	% Diff
Mangatahi	337		421		305	
				9.0		5
Maraekakaho	—	12	383		290	
				4.4		10
Ohiti	295		366		260	
				0.8		1.1
Rifle Range	—	27	369		263	
				27		29
Glenside	215		268		185	
		28		28		
Fernhill	155		192		—	

Firstly, it should be pointed out that the high consistency in percentage losses between sites may not be applied to a wide range of discharges because a negative correlation ($r = -0.83$) was found between Ohiti discharge and Ohiti-Fernhill percentage discharge difference. However, the close percentage difference agreements of Table 3 do strengthen the validity of the discharge differences determined.

From Mangatahi to Ohiti a definite surface flow loss, averaging 13% took place, and this must have passed underground through the right-bank alluvium between Maraekakaho and Ohiti.

Between Ohiti and Rifle Range, where the right bank is bounded by high, solid country, discharges have remained constant — the slight differences being well within even the likely measurement error. Therefore no underground losses take place.

However, from Rifle Range to Glenside, losses again occurred and amounted to about 28%. And, equally as striking was the further loss of 28% from Glenside to Fernhill.

Between Mangatahi and Fernhill the Ngaruroro River lost about 54% of its surface water volume. Outstanding left-bank losses have been accounted for and balanced, and no measurable loss occurred from Ohiti to Rifle Range. Therefore it is completely reasonable to propose that the pattern of decreasing discharges, proceeding downstream from Mangatahi to Fernhill, is the consequence of considerable out-flow through portions of the right bank of the river.

In continuance of the catchment water yield pattern (Fig. 3) we will consider only the out-flow losses of 13 February 1964. Table 3 shows that 42 cusecs were lost from the river above Ohiti and this volume must have passed through the right-bank alluvium and travelled as ground water in a direction parallel with Maraekakaho Road (Fig. 4). In like manner, between Rifle Range and Glenside, 80 cusecs passed from the river, and from Glenside to Fernhill a further 60 cusecs were lost. These quantities would constitute a continuum of 140 cusecs which, as ground water, must follow the falling hydraulic gradient on a general SE to ESE trend (Figs 3 & 4).

At this point it should be remembered that the above out-flow losses to ground water are based on surface discharges. Therefore, as considerable underflow occurs at these river sites, as already indicated, we must regard the total loss to ground water of 182 cusecs, on 13 February 1964, as a minimum quantity. If previous reasoning concerning underflow volumes at Whanawhana, Mangatahi and Fernhill is correct, then underflow, on 13 February 1964, at Mangatahi was at least 34 cusecs, and at Fernhill about 12 cusecs. This means that on that day the total river loss to ground water could more closely be placed at around 204 cusecs.

Because discharges do not decrease from Fernhill to Ormond Road the zone can be regarded, at present, as one where out-flow losses do not occur — or if they do, they are balanced by in-flow accretion.

CONCLUSIONS

There is no doubt that the consistent surface discharge decreases of the Ngaruroro River, between Mangatahi and Fernhill, are the consequence of out-flows to the ground water system of the Heretaunga Plains; and the quantities involved are so large that the Ngaruroro River can rightly be classed as a major recharge source. All evidence indicates that this process is continuous.

During summer, about 55% of the catchment water yield contributes to the ground waters of the Heretaunga Plains, when large ground water demand coincides with small river flows. Diversion, for hydro-electric purposes, of the Taruarau River which supplies 11% of the total, therefore appears most undesirable.

ACKNOWLEDGMENTS

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