

# THE AUCKLAND WATER SUPPLY SYSTEM

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(Member)

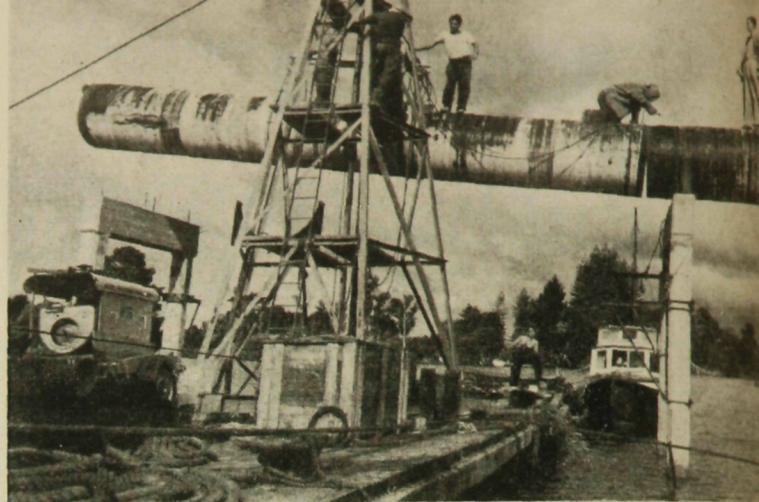
## I. INTRODUCTION

THE Auckland City water supply system is essentially a metropolitan service. The city administers direct supply, not only to itself, but also to parts of two adjacent counties and to a heavy industrial centre outside its boundaries, and, in addition, gives bulk supply to eighteen boroughs within the metropolitan district in and adjoining the Auckland isthmus. Supply is derived from city-owned water supply reserves in two upland areas—the Waitakere ranges 10 to 16 miles west of the city and the Hunua-Wharekawa ranges, 23 to 30 miles south-east of the city. Combined potential safe mean yield from these reserves is of the order of 100 million gal./day. Present average daily demand on the system is 22 million gal./day. Peak demands run close to 32 million gal./day.

Auckland, founded in 1840, now has a population of 380,000 in the metropolitan area within a radius of 8 miles from the city centre. The greater part of this population is concentrated in the Auckland isthmus—a sharply defined area of 35,770 acres, 6 miles wide, between the Waitemata Harbour to the north and the Manukau Harbour to the south, and 10 miles long, between Whau River to the west and Tamaki River to the east—but considerable development has also taken place on the North Shore of Waitemata Harbour and in areas immediately west and south of the isthmus.

Auckland has a tradition of space. Urban sprawl is marked, and population densities are low, ranging from 10 to 14 persons per acre in the older urban districts to an average of 6 per acre over all urban districts in the metropolitan area. The area covered by reticulation is therefore correspondingly high. Urban districts now served total 50,837 acres (including the 18,253 acres of the city), and, in addition, rural or semi-urban service is given to 31,000 acres in adjoining county areas.

The Auckland isthmus is dominated by numerous Recent basalt-scoria cones and associated lava flows, superimposed upon a deeply gullied terrain cut in sandstones and mudstones of the Tertiary



Construction of the 600 ft. pipeline across the Pakuranga Creek. The 3 ft. 6 in. pipes are part of the link with the Hunua dam.

Waitemata formation. The resultant broken topography led initially to scattered local settlement, and to the consequent establishment of numerous independent local authorities. Subsequent amalgamations have resulted in the city now comprising approximately half of the isthmus area, with eight boroughs sharing the balance. The artificial boundaries thus created are tortuous, and, from the point of view of water supply, are an unfortunate anacronism.

Original piped water supplies for the city and for the several adjoining independent local bodies were almost all from springs associated with the scoria cones and lava-filled valleys of the isthmus. At about the turn of the century, however, these local sources of supply were becoming overtaxed; the city embarked upon a policy of development of more remote upland catchments; the outside authorities progressively abandoned their independent spring supply in favour of bulk supply from the city system. The Borough of Onehunga, on Manukau Harbour, is now the sole remaining authority in the district with a water supply independent of the city, and even in this case a cross-connection to the city is available for use in emergency.

## 2. HISTORICAL REVIEW

### 2.1. Government

Auckland was founded in 1840 as the seat of the N.Z. Colonial Government and the headquarters of Auckland Province. The central government was transferred to Wellington in 1865, but the provincial legislature remained until the provincial system of government was abandoned in 1876.

In 1851 Auckland was created a borough, initially, interestingly enough, with jurisdiction over the greater part of the Auckland isthmus from Waitemata Harbour to Manukau Harbour—over an area of about 28,000 acres. To meet local needs, the borough was subdivided into a number of “highway” or “road” districts. Responsibility for major works in the area remained, however, with the Government or the Provincial Council.

In 1871 the City of Auckland was constituted with complete autonomy in matters of local government, unfortunately, however, over a very limited area of 623 acres adjacent to the port and to Queen

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Street, the settlement's main thoroughfare. Boundaries were extended in 1882 by inclusion of three adjoining highway districts and the city's area was thereby increased to 1,605 acres. No further changes eventuated until 1913, but between 1913 and 1928 eleven boroughs and road districts joined the city and raised its area to its present figure of 18,253 acres.

Until quite recently, natural boundaries made it appropriate to apply the term "Metropolitan Auckland" to the isthmus area alone. Four boroughs on the North Shore formed another distinct geographical unit. In recent years, however, expansion has been so rapid and community of interest has been so strongly developed by modern public services that the term now has a much wider coverage. Power, transport and drainage have long been administered by *ad hoc* bodies. Water, however, remains under city control. A Metropolitan (Town) Planning Organization is now established, with jurisdiction over the extended area, but the authority of this body is limited. The need for an effectively empowered co-ordinating authority for administering metropolitan services has long been recognized, and is at present being closely investigated.

### 2.2. Early Supplies

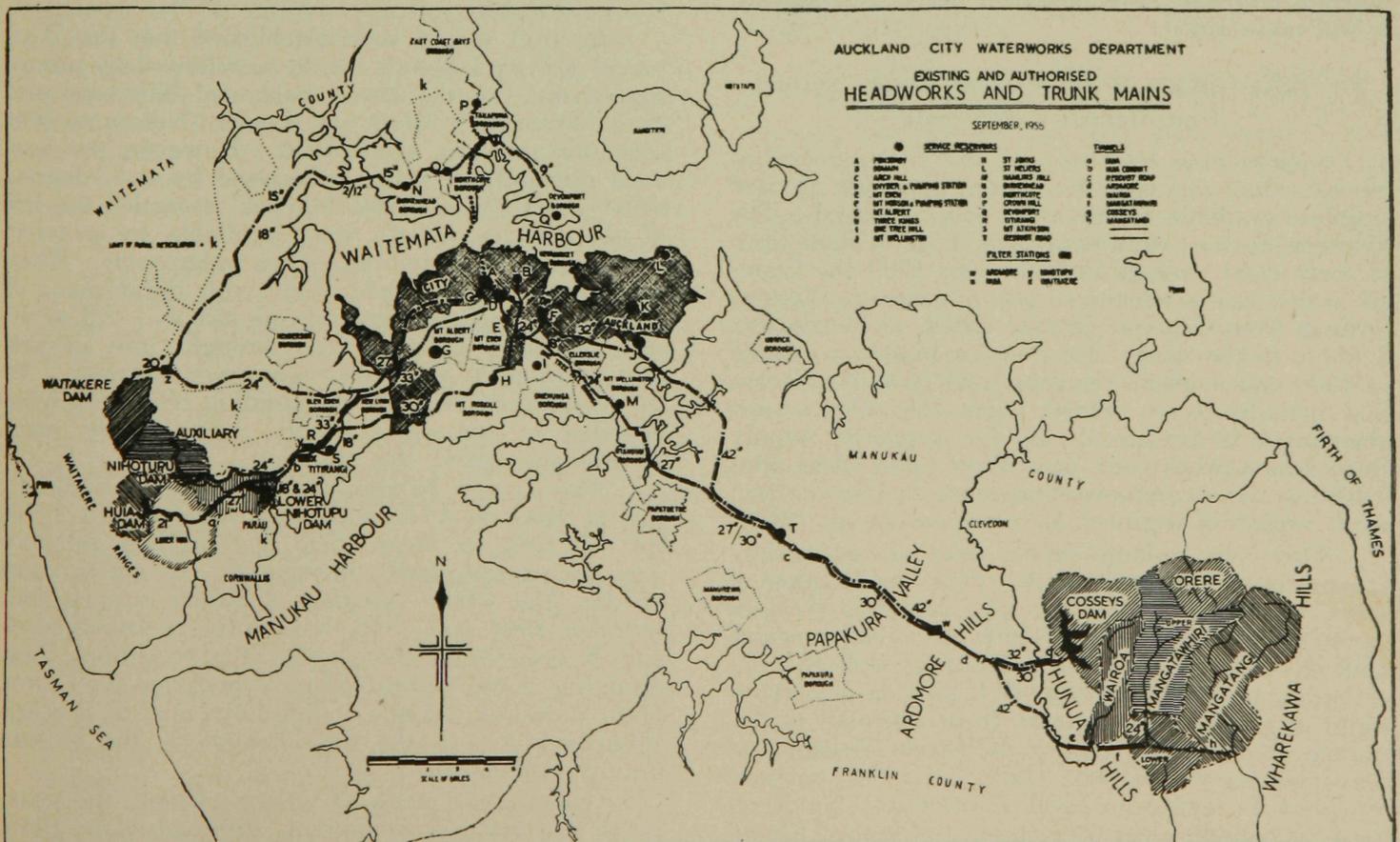
Auckland developed rapidly by reason of its favourable location on Waitemata Harbour and the natural resources of the province which it serves so admirably, yet for 29 years its only source of water supply was rain water from house tanks, supplemented in downtown areas by four wells "with

pumps attached" and by a small spring nearby. There were no reliable streams in the immediate vicinity of the growing settlement.

In 1859-60, with urban population at 8,000, and again in 1864, public pressure inspired the authorities to obtain reports on the provision of a public water supply system for the city, but in neither case was anything done about the matter. The 1859-60 reports dealt mainly with schemes for development of supply from appreciable springs associated with some of the volcanic centres at various places in the Auckland isthmus. The 1864 report is of interest in that the reporting engineer, with admirable foresight and faith in the future of the city, recommended a gravitation scheme from Nihotupu stream, 10 miles west of the city, in the Waitakere Ranges. Thirty-six years later this scheme, appropriately modified, was actually put in hand as the first stage of development of the Waitakere upland catchments.

In 1869 the Government installed the first piped supply to the city—a 6 in. gravity line from spring-fed ponds in the shallow crater of Auckland Domain, one mile from Queen Street. By 1872 this supply was completely overtaxed and the newly-formed City Council obtained temporary relief by supplementing the ponds, via a small reservoir on Domain Hill, with up to 30,000 gal. of water daily pumped from the nearby privately owned Secombes well in Khyber Pass Road.

In 1875, following a close re-investigation of available sources of supply, the Council purchased the Low & Motion property surrounding Western



Springs,  $2\frac{1}{2}$  miles west of the city centre, and proceeded immediately to develop the Springs as the main city supply. The scheme adopted involved the installation of a massive steam-driven beam-engined pump to lift water 230 ft. through 140 ch. of 21 in. C.I. pipe to a reservoir at Ponsonby Road, on the first major ridge behind the city; a pumping plant at Ponsonby to serve a reservoir 90 ft. higher at the top of Khyber Pass Road; and, later, a pumping plant at Khyber Pass to lift water a further 170 ft.—to R.L. 490—to a reservoir on Mt. Eden, the highest scoria hill on the isthmus, to serve the higher levels of the city and suburbs.

Western Springs discharge a steady flow of 1.4 million gal./day, near sea level, from beneath an extensive flow of porous basalt. Their catchment includes several of the larger scoria cones of the isthmus. The Springs were brought into service in 1877, served the city continuously for the next 22 years (during this period the population supplied rose from approximately 18,000 to 50,000), and are still retained as an emergency supply. The old engine and pump with its 24 ft. beam and 20 ft. 6 in. diameter flywheel is still retained in its original brick building as a "museum piece", and the original 21 in. pumping column to Ponsonby reservoir is still in use, incorporated as part of the present trunk main system. The old steam pumping stations at Ponsonby and Khyber Pass have long since gone, but the original reservoirs at these localities have only in recent years been demolished to make way for larger, modern structures. The original triple pressure zoning of reticulation based on Ponsonby, Khyber and Mt. Eden reservoir levels respectively is still maintained.

### 2.3. Development of the Present Supply System from Upland Catchments

Approaching the turn of the century it was obvious that the city was outgrowing the limited supplies available from sources close at hand. The Western Springs were being drawn on to their limit to meet even average demand. In 1899 the Council authorized a scheme to pump water to Western Springs from Canty's (Oratia) Creek, at Henderson, 6 miles to the west. Tenders for pipe were called in 1900 and work on the pipe track near Henderson had actually been started when the scheme was abandoned in favour of one for a gravity supply from Nihotupu Stream, near West Coast Road, thus fulfilling the recommendation made by the Government reporting engineer 36 years earlier, in 1864.

This first upland supply was an emergency scheme to yield 1 million gal./day, via  $7\frac{3}{4}$  miles of 9 in., 10 in. and 12 in. C.I. pipe between Western Springs and Titirangi, a 570,000 gal. break pressure tank at "Smythe's Saddle", Titirangi, and 8 miles of light-gauge riveted 12 in. W.I. pipe on a tortuous route in rugged bush country from Titirangi to two timber dam intakes, one on Nihotupu Stream and the other on a tributary, Quinn's Creek. Sections of the C.I. mains are still in service: "Smythe's tank" is now the clear water tank of Nihotupu filters; the W.I. pipeline was abandoned in 1920; the 30 ft.

high Nihotupu timber dam was demolished in 1914 to make way for construction of the present dam.

The Nihotupu emergency main was brought into service in February, 1902. In the meantime, supply had been precariously maintained by auxiliary pumping from Edgcombe's (Motion's) Creek and the "Avondale" springs near Oakley Creek.

The city now entered into a period of definite policy with respect to water supply. In 1902 and 1904, and again between 1916 and 1921, detailed investigations led to the adoption and reassertion by the Council of a long-term policy which envisaged, first, the development, in succession, of the several catchments in the Waitakere ranges west of the city, and the following-up of this with similar development of the more extensive but more distant catchments of the Hunua-Wharekawa ranges to the south-east. Consideration was also given on all occasions to the merits of a pumped supply from the Waikato River, 35 miles south of the city, but this has always been shown to be less economic than the upland schemes.

This policy has been criticized from time to time, particularly by proponents of the Waikato scheme, but has been vindicated by overseas advice and by a Royal Commission.

The 1902 and 1904 reports initiated the development of three major gravitational headworks in the Waitakere ranges, on the Waitakere, Nihotupu and Huia Streams respectively, in succession and in that order. This phase was completed in 1929, and made available a safe mean yield of  $12\frac{1}{2}$  million gal./day. Population served had by then risen to 140,000.

In 1921 it had been established that the Waitakere gravity schemes should be followed by unimpounding schemes on the lower reaches of Nihotupu and Huia Streams. Work at Lower Nihotupu was scheduled to start about 1936. However, the lessened demand for water occasioned by the "depression" years of the early "thirties" extended the life of the surplus supply then available by gravity, and caused postponement of this programme. Then came the Second World War, with curtailment of civil works. Water demand rose steeply. All available auxiliary supplies were brought into service, and restrictions were imposed every summer. In the autumn of 1943 all impounding reservoirs were depleted to one day's supply, when heavy rains fortuitously saved the situation.

The Lower Nihotupu scheme was ultimately put in hand in 1943, and was completed in 1948. By this time its mean yield of 6 million gal./day was almost completely mortgaged. In anticipation of this, the whole question of future supply had, between 1944 and 1946, been fully re-investigated, and it was found that, under the conditions then applying, it was advantageous to postpone the Lower Huia pumping scheme indefinitely and to proceed immediately with the development of the Hunua gravity catchments.

Construction work at Cossey's Creek, the nearest of the Hunua catchments, commenced in 1946, but, owing to shortages of staff, material and labour

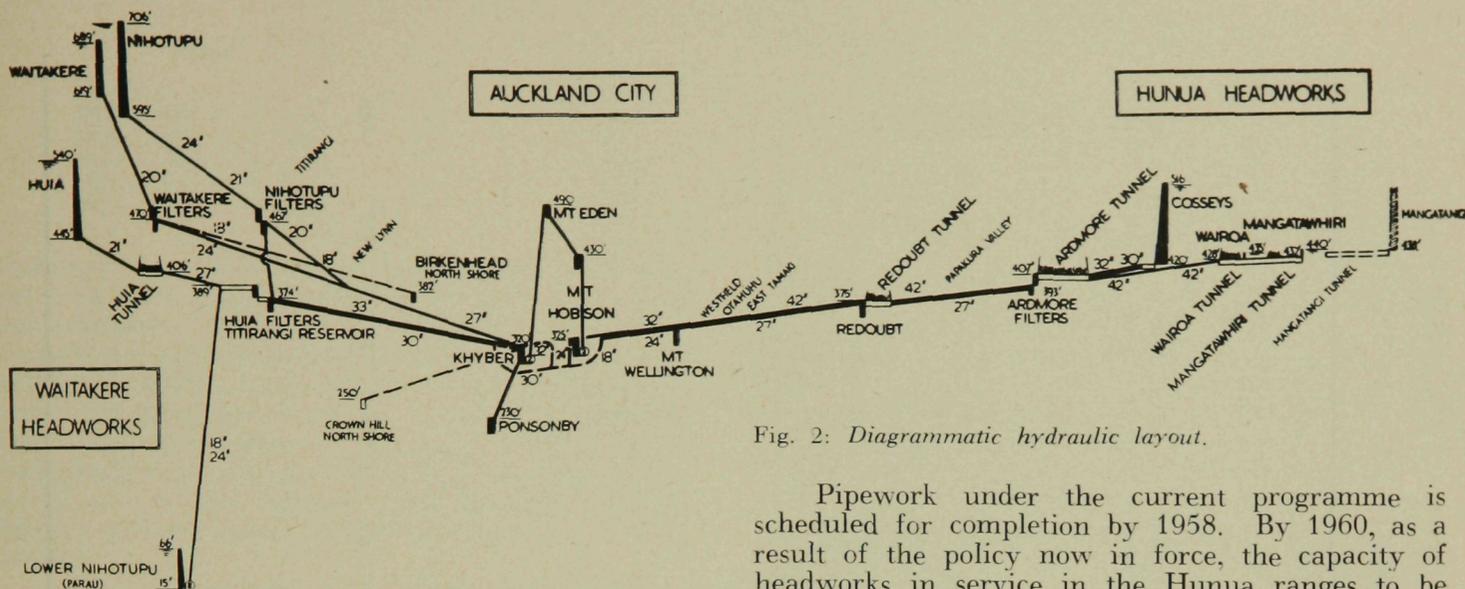


Fig. 2: Diagrammatic hydraulic layout.

in the post-war years, it was 1953 before the first stage of the scheme—the tapping of stream flow only—came into service. This stage, however, was in itself a major work, involving, as it did, the driving of  $3\frac{1}{2}$  miles of tunnel aqueduct of 54 million gal./day capacity—sufficient to handle the whole “high-level” Hunua supply—and the laying, initially, of 15 miles of 30 in. and 27 in. pipe for the No. 1 Hunua trunk main.

The second stage of the Cossey’s scheme, the building of Cossey’s impounding dam, was put in hand late in 1951 and completed early in 1955. This enables the No. 1 Hunua main to operate at its full capacity of  $6\frac{1}{2}$  million gal./day, and corrects the storage deficiency which has dogged the supply system since pre-war years. It is a fact that over the greater part of the last fifteen years demand has been generally in excess of available rated supply, and has been met only by the incidence of a succession of years with appreciably higher than normal rainfall and by the periodic imposing of restrictions.

In recent years it has become increasingly obvious that the headworks programme would have to be accelerated if supply was to be kept adequately ahead of the demand being created by the phenomenal growth of the metropolitan area. Population supplied has doubled in the last fifteen years, and now stands at 330,000. Early in 1954, therefore, the Council authorized works to be commenced to tap the next two catchments in the Hunua area—*i.e.*, those of the Wairoa and Mangatawhiri Streams—at the earliest possible date. The original Hunua development programme had envisaged a No. 2 Hunua trunk main of  $7\frac{1}{2}$  million gal./day capacity—sufficient to deliver, with the No. 1 main, the peak draw-off of 14 million gal./day available from the completed Cossey’s scheme. Under the revised programme now in hand the No. 2 main is being increased to 15 million gal./day capacity—sufficient to handle the balance of Cossey’s water and the first stages of yield from the new catchments. This involves the laying of 27 miles of 32 in. and 42 in. pipe-lines and the driving of a further  $2\frac{1}{2}$  miles of tunnel aqueduct.

Pipework under the current programme is scheduled for completion by 1958. By 1960, as a result of the policy now in force, the capacity of headworks in service in the Hunua ranges to be achieved over the fourteen years since 1946 will be equal to that of the yield from all the Waitakere headworks developed between 1900 and 1947. Capital expenditure on the latter and their ancillary works was of the order of £.5 million. Expenditure to date and authorized to complete the current Hunua programme is £4 million.

### 3. DETAILS OF THE PRESENT SYSTEM

Data concerning headworks and catchments are tabulated in Table I.

Figure 1 shows location of headworks and trunk mains. Fig. 2, the schematic hydraulic layout of the system, and Fig. 3 graphs of population, rainfall, supply and demand.

#### 3.1. Nature of the Water Supply Reserves

Both the Waitakere and the Hunua-Wharekawa ranges comprise for the most part rugged, heavily-bushed country, well elevated and well watered. Land for water supply reserves has, under the city’s long-standing policy, been acquired and alienated well in advance of needs, so that reversion to scrub and bush of areas that have been cleared will be well advanced by the time catchments are brought into service. The reserves include ample protective fringe lands outside actual catchments.

The Waitakere water supply reserves, located 10 to 16 miles west of the city, now total 17,000 acres, of which 9,550 acres are actual catchments in service. The Waitakere hills rise to an elevation of 1,500 ft., and are composed of dense andesitic conglomerates of submarine volcanic origin, formed in Miocene times following deposition of the Waitemata mudstone and sandstone formation of the Auckland area. Their general configuration favours two-stage development—by gravity schemes in headwater sections of main streams, and by pumping schemes in downstream sections.

The Hunua-Wharekawa ranges, 23 to 30 miles south-east of the city, rise to over 2,200 ft., and comprise a group of deeply dissected upfaulted blocks of Mesozoic greywacke—the “basement” rock of the North Island of New Zealand. The greywacke is completely shattered and deeply weathered, and



TABLE 2: PERIODS OF "DEFICIENT" RAINFALL, AUCKLAND CITY.

Period	Average Annual Rainfall (in.)		
	Over Period	Worst 3 Consecutive Years	Worst Year
1863—1866 = 4 years	40.7	1864—1866 = 39.6	1864 = 37.5
1876—1882 = 7 years	40.9	1880—1882 = 39.6	1881 = 34.2
1884—1888 = 5 years	40.0	1885—1887 = 37.4	1885 = 32.3
1911—1914 = 4 years	38.7	1912—1914 = 36.6	1914 = 28.5
1932—1934 = 3 years	41.7	1932—1934 = 41.7	1932 = 40.6

therefore the several strong streams which traverse the area have much steadier flows than do those of the relatively impermeable Waitakere area. The Council commenced acquisition of land in these hills during the 1920's, and now holds most of the 40,000 acres required for reserves. Actual catchments listed for development comprise 30,760 acres. Topography favours development by gravity to two levels—one to the "Khyber" pressure area (T.W.L. 320 ft.) and the other to the Ponsonby level (T.W.L. 230 ft.).

All catchments in service are completely alienated for water supply purposes, and use of reserves in general is strictly controlled. The eastern front of the Waitakere ranges overlooks the city, and the southern and western fronts abut on to Manukau Harbour and the West Coast respectively. These marginal areas are therefore used extensively locally for residential and recreational purposes. The highway to the West Coast surf beaches crosses the Nihotupu catchment and a scenic highway along the eastern hills skirts the Nihotupu watershed locally, but elsewhere protection is afforded by ample fringe lands in the reserves and by wide tracts of public parkland which partially surround the reserves and afford ample scope for public use. In the case of the Hunua-Wharekawa ranges the reserves are remote from settlement, and what little internal roading does exist is little used and is in process of being closed to public use.

Wild pig and the introduced Australian opossum are a decided nuisance in all the reserves. They are controlled by the Council's rangers and by authorized hunters.

### 3.2. Rainfall and Catchment Potentials

Rainfall records have been kept in Auckland City since 1853, in the Waitakere ranges since 1910, and in the Hunua ranges since 1928. Gauging

stations in the water reserves have been added to progressively, and now total 32. Present coverage is of the order of one gauge per 1,200 acres in the Waitakere reserves, and one per 2,000 acres in the Hunua reserves. With the exception of two "monthly" gauges in remote parts of the latter, all gauges are read daily or weekly. A proportion of recording gauges are installed in both areas.

Rainfall in Auckland is spread very evenly through the year. In the city, for example, long-term monthly averages range from a maximum of 5.5 in. for July to a minimum of 3.0 in. for December. Annual rainfall in the city over the 92 years since 1863 (there is some doubt as to the reliability of the records prior to 1863) has varied between 74.5 in. (1917) and 28.5 (1914), and averages 47.2 in.

Rainfall distribution in the district has been found to be sufficiently consistent to justify the use of Auckland City rainfall records as a basis for long-term rainfall data for both water reserve areas. Average rainfall over both the Waitakere and the Hunua-Wharekawa reserves at any time is very close to the corresponding city figure plus 50%. Average total run-off in both cases ranges between 60% and 70% in different catchments. It is therefore convenient and appropriate to use city rainfall figures for preliminary assessment of catchment yield potentials.

Estimated long-term average rainfalls range from 65 in. to 85 in. at various gauging stations in the Waitakere reserves, and from 50 in. to 85 in. in the Hunua-Wharekawa reserves. Maximum annual rainfall in both cases is of the order of 112 in.

Since 1863 the city has experienced five periods in which rainfall in each of at least three consecutive years has been less than average. These are as shown in Table II.

TABLE III: CATCHMENT RAINFALLS AND YIELD DATA (inches of rain annually)

	Mean Annual Rainfall		Storage as Inches of Rainfall	Safe Mean Yield: Inches of Rainfall
	Long Term	Driest 3 Consecutive Years (est.)		
<i>Waitakere Catchments:</i>				
Waitakere	68.3	53.0	8.6	27.6
Nihotupu	78.2	60.5	10.8	30.2
Lower Nihotupu	74.6	58.0	15.0	31.2
Huia	72.8	56.5	12.1	33.0
Lower Huia	77.2	60.0	*15.5	*37.6
<i>Hunua-Wharekawa Catchments:</i>				
Cossey's	61.3	47.5	26.6	30.6
Wairoa	63.5	49.0	*12.4	*30.2
Upper Mangatawhiri	76.0	59.0	*16.5	*33.1
Lower Mangatawhiri	64.8	50.0	*17.2	*37.6
Mangatangi	73.3	56.5		

\* Estimates only; schemes in prospect

The safe mean yields of catchments as listed in Table I have been determined from mass curve analyses of these "deficient" periods in conjunction with available storage. Run-off is taken to be equivalent to actual city rainfall in the first case, and is later adjusted as catchment data become available.

In the case of the Waitakere gravity headworks, topography and site conditions have set very definite limits to economic storage. In the Hunua-Wharekawa catchments, however, valleys above dam sites are in general much more open, and it is therefore possible to work to much higher storage factors and to assess yield accordingly over the longer "deficient" rainfall periods. Table III illustrates rainfall, yield and storage relationships in the main catchments in service or in prospect.

### 3.3. The Waitakere Headworks System

#### 3.3.1. *Waitakere Gravity Headworks*

The Waitakere ranges are essentially an uplifted, dissected plateau. Multicycle topographic development is marked. In all main stream valleys adjustment to recent uplift is incomplete, so that lower reaches, well graded with respect to present sea level, are separated from headwater reaches, still roughly graded with respect to an earlier cycle, by short steep sections of spectacular cascades and falls.

The dams for the three gravity headworks, Waitakere, Nihotupu and Huia, are located adjacent to the tops of these "steps" in their respective valleys. Waitakere dam overlooks a 330 ft. fall; Nihotupu, one of 150 ft. All three are mass concrete gravity structures, with spillways over the dams themselves. Country rock is dense Miocene andesitic conglomerate of submarine origin. Concrete coarse aggregates were in each case obtained by quarrying andesite flows which occur locally within the conglomerate.

The original Waitakere dam was a relatively small structure fitted to the topography. In 1926 it was raised 16 ft. to double its storage to a figure more commensurate with the safe mean yield of its catchment, and to this end it was necessary to raise a low saddle on the reservoir perimeter by means of an embankment 400 ft. long by 22 ft. high.

The Nihotupu auxiliary dam is a small reinforced concrete slab and buttress structure erected as an emergency measure to meet demand pending completion of the main Nihotupu dam.

#### 3.3.2. *Lower Nihotupu Pumping Headworks*

Lower Nihotupu dam is located at tidal limits at Parau at the mouth of Nihotupu Stream. At the time of its construction it created considerable interest as the first controlled rolled-fill structure in the Dominion. The fill materials available and the vagaries of Auckland weather called for very close supervision of material selection, moisture control and compaction techniques, and to this end a fully equipped soil mechanics laboratory was established and used continuously.

The embankment is founded on Waitemata series (Miocene) sandstones and mudstones which

conformably underlie the Waitakere andesitic conglomerates. It is keyed into this country rock by means of a low concrete cut-off wall and by a grout curtain on centre line. The bank itself comprises a clay-silt core section flanked by increasingly coarsening fill to silty gravels at both faces. The upstream face is finished to a slope of 1 in 3 and is faced with hand-packed basalt stonework. The downstream face is sloped  $2\frac{1}{2}$  to 1, bermed and grassed.

Waitemata strata weather readily to a very cohesive residual clay. This material dominates the vicinity of the dam, and was in surplus supply. Silts and gravels, however, were confined to flood plain terrace deposits in the valley floor and were in limited supply. Core design in particular, therefore, called for development of clay mixes stabilized with closely husbanded silts and grits.

Construction problems largely revolved around techniques for working, mixing and drying this cohesive fill to optimum moisture content appropriate to compaction with tractor-drawn equipment and sheepsfoot rollers.

Auckland's well-spread rainfall gives rise to short working seasons for this type of work, and called for very concentrated effort whenever favourable weather eventuated. The bank was completed in 180 working days spread over three seasons.

The spillway at Lower Nihotupu is a double-sided trough type of 17,000 cusec capacity, located in the eastern abutment. The valve tower adjoins the spillway and seals the original diversion tunnel.

Water from Lower Nihotupu is lifted 374 ft. through twin 18 in. and 12 in. rising mains,  $1\frac{1}{4}$  miles long, to discharge into the "Huia conduit". The pumping station incorporates five Thompson two-stage pumps each of 2 million gal./day capacity, driven by 220 h.p. direct-coupled English Electric motors.

### 3.4. Trunk Mains from Waitakere Headworks

Trunk mains to the city from headworks in the Waitakere ranges are based on delivery to "Khyber" reservoir level at R.L. 320 ft., via filter stations and clear water break pressure tanks located on the eastern fringes of the hills. Four main lines are now in service, totalling  $\frac{3}{4}$  mile of tunnel aqueduct, 2 miles of conduit, and 53 miles of pipe ranging from 18 in. to 33 in. in diameter.

#### 3.4.1. *Waitakere Trunk Mains*

Waitakere dam discharges from R.L. 618 ft. to the Waitakere filters via 2 miles of 20 in. C.I. main. Two mains feed from the clear water tank at the filters (T.W.L. 470 ft.)—an 18 in. main to the North Shore boroughs, and a  $7\frac{1}{2}$  mile x 24 in. x  $\frac{1}{4}$  in. steel main to New Lynn, near the western city boundary. At New Lynn the latter is joined by an 18 in. C.I. main from Nihotupu filters, and then carries on for  $6\frac{1}{4}$  miles to Ponsonby reservoir, mainly in 27 in. x  $\frac{1}{4}$  in. steel pipe, via the north-west suburbs and Western Springs. A further mile of 18 in. and 15 in. pipe carries on from Ponsonby to Khyber reservoir.

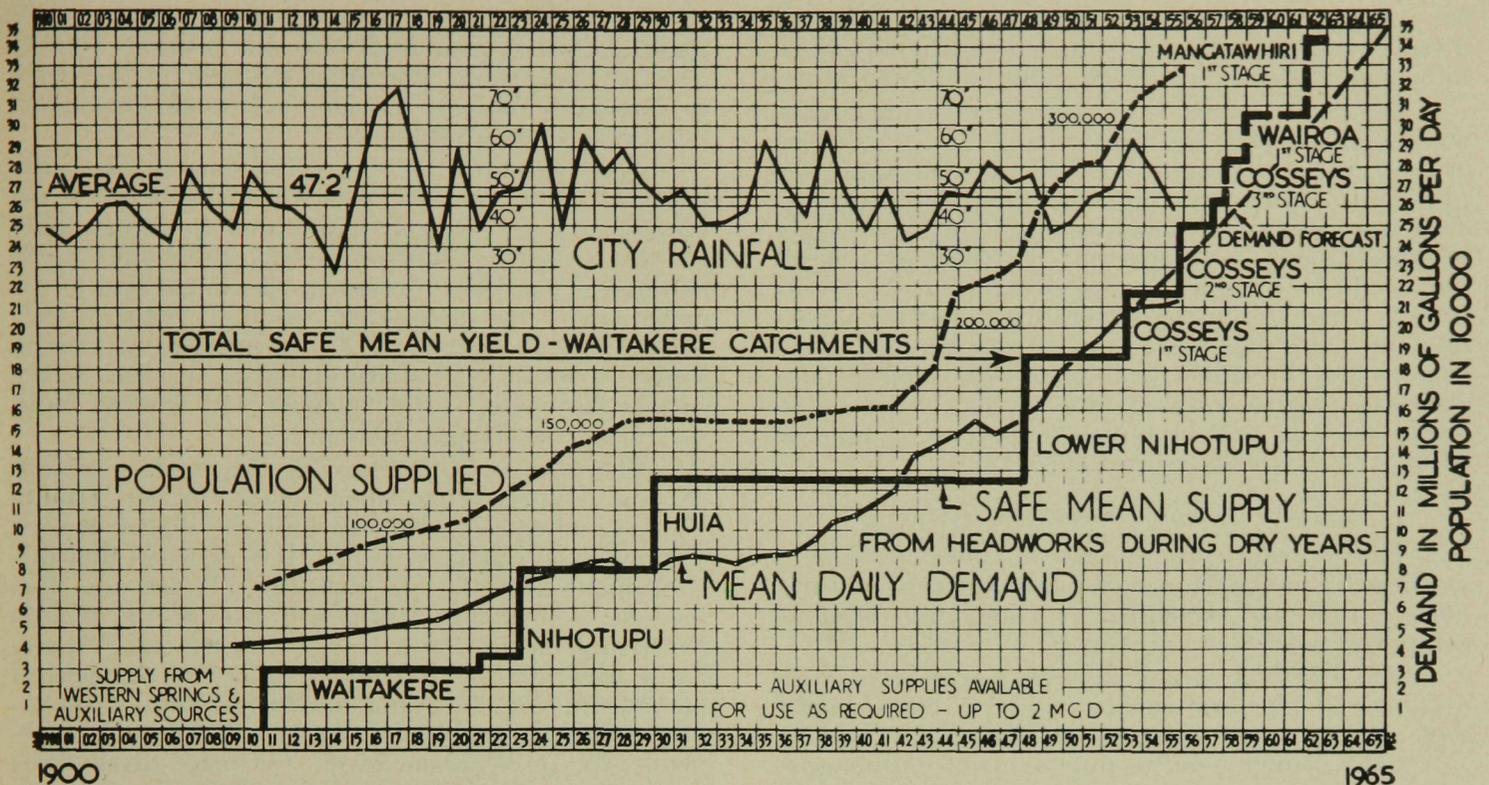


Fig. 3: Supply and demand, population and rainfall curves.

As was the case at Nihotupu, initial installation included construction of a 570,000 gal. break pressure tank on the line, used later as the clear-water tank for the filters.

The Waitakere main to the city came into service in March, 1907, handling run-of-the-stream water only from a timber-dam intake beyond the reservoir area until Waitakere dam was completed in 1910. In 1930-31 pinholing of the 24 in. and 27 in. steel pipes became apparent, and consequently during 1934-36 thirteen miles of the line was lifted, reconditioned and relaid. These pipes are of the locking-bar type, lead jointed, with simple bitumen-dipped coating and lining and outer hessian wrap.

### 3.4.2. Nihotupu Trunk Main

This main, laid between 1913 and 1920, comprises  $5\frac{1}{2}$  miles of 24 in. and 21 in. C.I. pipe-line between Nihotupu dam and Titirangi filters, and  $3\frac{1}{4}$  miles of 20 in. and 18 in. C.I. line between Titirangi and the Waitakere trunk main at New Lynn. Discharge level at the dam is R.L. 595 ft. and T.W.L. of the filters clear water tank is R.L. 467 ft.

Beyond Titirangi the pipe-line route follows in general that of the 1900-02 Nihotupu emergency main, but is shortened considerably by means of 24 tunnels totalling 10,800 ft. ranging up to 2,000 ft. in length. On the city side of Titirangi, two sections of the emergency main are still in service. One mile and a-quarter of 12 in. C.I. remains for local supply at Titirangi, and  $4\frac{1}{2}$  miles of 10 in. C.I. main is used in parallel with the 27 in. Waitakere main between New Lynn and Western Springs.

### 3.4.3. Huia and Lower Nihotupu Trunk Mains

Huia Dam discharges from R.L. 540 ft. via  $2\frac{1}{2}$  miles of 21 in. x  $\frac{1}{4}$  in. steel pipe to a 4,000 ft. long

tunnel aqueduct of 25 million gal./day capacity between the Huia and Nihotupu valleys, and thence by  $2\frac{1}{4}$  miles x 27 in. x  $\frac{1}{4}$  in. steel pipe across Nihotupu valley to the 1.5 mile long "Huia conduit"—a reinforced concrete box structure of 32 million gal./day capacity which feeds into the Huia filters at Titirangi. Both the "Huia conduit" and the Huia tunnel are designed with capacity sufficient to handle all present and possible future development of the western Waitakere catchments.

Lower Nihotupu dam discharges by pumping from R.L. 15 ft. into the head of the "Huia conduit" at "Mackie's Rest" at R.L. 389 ft., via twin 18 in. and 24 in. steel and R.C. rising mains, each  $1\frac{1}{4}$  miles long.

The Huia filters discharge at R.L. 374 ft., 93 ft. lower than the adjacent Nihotupu filters, via a further 1,840 ft. of conduit and tunnel to Titirangi reservoir. From the latter, two mains feed to Khyber reservoir—an  $8\frac{3}{4}$  mile x 33 in. x  $5/16$  in. steel main of 11 million gal./day capacity on a direct route via the northern railway, and a 9 mile x 30 in. x  $\frac{1}{4}$  in. and  $5/16$  in. steel main of 8 million gal./day capacity, via the southern districts of the isthmus into the Khyber feeder main system at Epsom.

The 33 in. main, authorized as part of the Huia development, was in fact brought into service in 1925, four years before completion of Huia dam, to meet a demand which by this time was at times taxing the capacity of the old 27 in. Waitakere-Nihotupu main. As an interim measure, the new main was fed with peak-load yield from Nihotupu dam via a 24 in. C.I. by-pass from the Nihotupu break-pressure tank. This by-pass now feeds into Titirangi reservoir. The 33 in. main is of locking-

bar pipe with bolted joints, bitumen-dipped and hessian-wrapped. It is anticipated that it will have to be reconditioned within the next five to ten years.

The 30 in. main is of spiral lap welded pipes with welded joints, installed during 1945-47 as part of the Lower Nihotupu development. Owing to war conditions at the time, it was not possible to concrete-line pipes as had been intended. Simple bitumen-dipped, hessian-wrapped treatment was all that could be obtained in the circumstances. At its present terminus in the Epsom district it is coupled into the south-east feeder main from Khyber reservoir to the Westfield industrial area, and is also extended to give a direct feed to Mt. Hobson low-level reservoir and pumping station via 1 mile of 24 in. x  $\frac{1}{4}$  in. concrete-lined steel main.

### 3.5. The Hunua Headworks System

The current programme of development of catchments in the Hunua-Wharekawa ranges, initiated in 1946 and scheduled for completion in 1960, comprises the following works:

(1) The Nos. 1 and 2 Hunua aqueducts, with a combined pipe-line capacity of 21.5 million gal./day.

(2) Cossey's dam, to provide 3,180 million gal. storage.

(3) Intake works for run-of-the-stream development of the Wairoa River and Mangatawhiri Stream.

(4) Ardmore filter station, to an initial capacity of 20 million gal./day.

(5) Service reservoirs of a total capacity of 18 million gal.

This programme will involve a total expenditure of £4 million.

#### 3.5.1. General Geology of the Hunua-Wharekawa District

Geological considerations are of such importance in this area and to the works in hand that the following outline is of interest.

The Hunua-Wharekawa ranges are the eastern and highest of a group of rectilinear fault-block uplands immediately north of the Mangatangi-Pokeno section of the Lower Waikato basin. The group faces these lowlands along an abrupt hill front, the scarp of the ENE, trending Pokeno Valley fault. The several blocks of the group are defined by a series of NNW, trending faults, are all tilted to a greater or lesser degree to the NE., and rise in a series of back sloping steps from west to east. Displacements along the faults are up to the order of 1,000 ft.

The two major blocks of the group, the Bombay-Hunua and the Hunua-Wharekawa blocks, are on the downthrow (west) and upthrow (east) sides respectively of the Wairoa fault. In the former, Tertiary strata overlie "basement" Mesozoic greywackes and argillite and are extensively preserved. In the latter, the Tertiary cover has been completely eroded except in one limited locality.

The northern margin of the Bombay-Hunua block is upraised to form the Ardmore Hills, along

an ENE, splint fault system, the Hunua fault, which abuts against Wairoa fault one mile north of Hunua. The Ardmore Hills are tilted strongly to the north to Papakura Valley, a wide fault-angle depression now infilled with alluvium.

The remainder of the block has a very pronounced tilt to the NE, into the angle between the Hunua and the Wairoa faults, and in consequence of this a sharply defined intermontane fault-angle depression has been formed in this angle and to the south along the steep scarp front of Wairoa fault. The northern section of this depression is Hunua Valley. South of Paparimu, offset  $\frac{1}{4}$  mile to the east by an en-echelon development of Wairoa fault, it is known as Happy Valley.

The Hunua Hills comprise the western section of the Hunua-Wharekawa block facing Hunua Valley, and the Wharekawa hills the higher eastern section facing Hauraki Gulf. It is possible that discontinuous faulting or warping divides the two sections. The Hunua hills are drained by Wairoa River and its tributary, Cossey's Creek, the Wharekawa hills by Mangatangi Stream, and the central part of the block by Mangatawhiri Stream. Mangatangi and Mangatawhiri Streams flow south independently to Waikato River. Wairoa River flows south in its headwaters, leaves the hills and cuts across Wairoa fault at Paparimu, and then swings north and flows along the front of the fault to tidal water at Clevedon. It traverses Hunua Valley in a series of graded reaches between barriers of either volcanic or "basement" rocks, and leaves the valley through a spectacular gorge, the Wairoa Gorge, cut along the line of Wairoa fault across the end of Ardmore Hills.

It appears that, prior to the cutting of Wairoa Gorge, Wairoa River flowed to the south to join the Mangatawhiri, and the Hunua fault-angle depression was occupied by a lake. This lake was infilled to at least R.L. 460 ft. with lacustrine pumiceous silts, sands, gravels and peaty beds, and was in time drained by breaching of Ardmore hills at the fault angle. As the breach deepened to form Wairoa Gorge, Wairoa River was "captured" at Paparimu and turned north, and the lacustrine beds were extensively eroded.

Between the gorge and Hunua Falls, where grade is interrupted by a 100 ft. high basalt intrusion, the river has cut through 330 ft. of alluvium to the original lake floor, 130 ft. above sea level.

#### 3.5.2. Cossey's Creek and its Headworks

Cossey's Creek enters Wairoa River immediately below Hunua Falls, approximately 5 miles from tidal water at Clevedon. It was originally maturely graded, probably in part with respect to the Hunua lake and in part due to back-tilting of the Hunua block, but in its lower reaches has since been rejuvenated in keeping with the downcutting of Wairoa River through the Wairoa Gorge. The fall-line of this rejuvenation is now 1 mile back into the hills, and has provided a good dam site at a level appropriate for gravity supply to the city. At and below this point the stream is sharply and

deeply incised in a youthful gorge valley. Above it, the original open, mature valley persists and provides very favourable storage conditions.

At Cossey's dam site the stream is incised almost 200 ft. to R.L. 380 ft. in a narrow, youthful gorge. At the south abutment weathered country rock is capped with pumiceous alluvium similar to the Hunua lake beds up to R.L. 565 ft., and, in a shallow saddle 600 ft. south of the stream, investigations revealed the same beds filling an old stream valley down to R.L. 490 ft., 26 ft. below reservoir T.W.L. These features can be in part related to the history of the old Hunua lake, but the superior elevation of the alluvium at the dam site and the nature of the mature valley upstream suggests that uplift and back-tilting of the Hunua hills along Wairoa fault was still active at the time, and may have caused ponding back of the creek. Subsequent rejuvenation resulted in superposition of the stream in its present position to the north of its original course.

These conditions greatly affected design of the Cossey's headworks. They led to the adoption of rolled-fill construction for the dam itself, and determined the location of the spillway at the northern abutment instead of in the shallow saddle to the south as had been originally intended.

Cossey's dam is constructed entirely of residual clays and rubbles from greywacke-argillite country rock. This formation is hard and indurated, is close-jointed or shattered, and dips at very high angles. Weathering is deep, and the soil profile a regular transition from sandy clay suitable for core gradings near the surface, through clay rubbles and rock rubbles to unweathered rock at depths ranging from 10 ft. to 80 ft. in the several borrow pit areas. All materials were obtained from within a haul distance of 1,600 ft.

The dam has no concrete key wall, the core section being simply chased into sound *in situ* country over a width of from 20 ft. to 30 ft., and the country below sealed with a grout curtain. The embankment has a regular transition from clay and clay-rubble "core" over the central third to rock rubbles at each face. This follows the soil profile gradings in the borrow pits, and therefore selection of materials presented no real problem. Control of fill with such satisfactory material was almost entirely simply a matter of checking moisture content and compaction densities.

The upstream face of the bank is stone-faced on a 1-in-3 slope, and the downstream face grassed on a 1-in-2½ slope with five berms. Placement of the 537,900 cu. yd. involved followed normal techniques with heavy earthmoving plant, and was completed in 190 placing days spread over three seasons. Compaction was by sheepfoot rollers and by pneumatic-tyred rollers up to 50 tons in weight.

During construction, the stream was carried through a 14 ft. diameter x 760 ft. diversion tunnel, now sealed with a 20 ft. diameter x 138 ft. valve tower housing five intakes.

The spillway is of the bellmouth type, designed to discharge 15,000 cusecs over a 130 ft. diameter

weir with 6 ft. surcharge. The throat section is 20 ft. diameter with a drop of 96 ft. from weir level to invert of a 17 ft. 9 in. diameter x 725 ft. long spillway tunnel which discharges to a lined channel clear of the downstream toe.

Filling of the 3,180 million gallon reservoir behind Cossey's dam commenced on May 13, 1955, and, as a result of a season of much heavier than normal rainfall, was completed by July 12, 1956.

### 3.5.3. Wairoa Headworks

The headwaters section of Wairoa River displays similar features to those of Cossey's Creek, but to a less marked degree. Back-tilting of the Hunua block has resulted in upper reaches of the valley being graded and moderately flaring, and in youthful valley forms in the lower reaches across the hill front, but there is no sharply defined fall-line. The degree of rejuvenation of the river at this point has been limited by the presence of the graded reaches throughout Hunua Valley.

A satisfactory dam site has been selected in the lower reaches approximately  $\frac{3}{4}$  mile into the hills. The storage factor of the site is reasonably good, but is limited in that only partial use can be made of the storage potential of the flaring, mature valley further upstream. Under the current programme, however, run-of-the-stream water only is to be developed, from a temporary intake immediately upstream of the dam site. This course was adopted when it was determined that a tunnel aqueduct could be driven to intercept Mangatawhiri Stream for roughly the same cost as that of a dam on the Wairoa, and that this would make available a greater mean yield than that obtainable from storage at Wairoa. The driving of the Mangatawhiri tunnel is also a stage towards the development of Mangatangi Stream, which, with a minimum gauged flow of 10 million gal./day, is attractive for consideration as the next source of supply to be developed.

### 3.5.4. Mangatawhiri Headworks

Mangatawhiri Stream traverses almost the entire length of the interior of the Hunua-Wharekawa block, flowing south against the general northerly tilt to leave the uplands across the Pokeno Valley fault in a spectacular youthful gorge from a well-defined fall-line 2 miles in from the hill front. Upstream from the gorge the stream traverses a deep but mature 6-mile long gravel-floored valley nestled unexpectedly in the heart of the hills. This is Moumoukai Valley, an intermontane valley which has been extensively aggraded as a result of upstream down-tilt and by back-ponding of the stream consequent upon such tilt.

This geology is unfortunate. Excellent dam sites are available at the fall-line at the head of the outlet gorge at the southern end of the valley, at a level of R.L. 330 ft., far too low for supply to Khyber reservoir level. They are, however, suitable for low-level development to feed to Ponsonby reservoir level in the future. Stream level appropriate for supply into the present Hunua aqueducts occurs about midway in Moumoukai Valley. Dam site conditions are not favourable at this point. Storage potential is

excellent, but the valley is wide and the depth of gravel aggradation considerable. The current programme is therefore limited to construction of an intake weir and development of run-of-the-stream water only. This will be fed into the Mangatawhiri tunnel  $1\frac{1}{4}$  miles downstream from the intake, in 24 in. pipe. Mangatawhiri tunnel is aligned to suit future extensions to Mangatangi.

### 3.5.5. *Mangatangi and Orere Catchments*

These are not involved in the current construction programme, but are described to complete the picture.

The Wharekawa hills appear to be tilted to the east, not to the north or north-east as are the Hunua hills, and therefore Mangatangi Stream does not display the two-cycle profile which is so characteristic of the other streams considered in the foregoing. It is a strong, youthful stream throughout its 9-mile course in the hills, approaching general grade with respect to the lowlands to the south. An excellent dam site at R.L. 430 ft. is available  $1\frac{1}{4}$  miles in from its debouchure from the hills, so that the greater part of its well-watered catchment is available for high-level development.

Orere Stream drains a limited catchment at the north end of the Wharekawa hills. It is roughly graded on a very steep parabolic profile. The most favourable dam site on its course is at R.L. 360 ft., and is therefore suitable for low-level development only.

### *No. 1 (Cossey's) Aqueduct*

This work comprised the first stage of the Hunua development, and included 3.54 miles of concrete-lined tunnel aqueduct and 15.2 miles of 30 in. and 27 in. pipe-line for supply, initially, of run-of-the-stream water from Cossey's Creek to the city's then southernmost feeder main at the Westfield industrial area, 6 miles, direct, south-east of Khyber reservoir.

Tunnelling commenced in late 1948 and was completed early in 1953. It involved Cossey's tunnel, 5 ft. 2 in. x 3 ft. 6 in. x 3,390 ft. in greywacke from Cossey's dam site to Hunua Valley; Ardmore tunnel through Ardmore Hills from Hunua Valley to Papakura Valley, 6 ft. 4 in. horseshoe x 11,040 ft., mainly in greywacke; and Redoubt tunnel, 8 ft. horseshoe x 4,240 ft., north of Papakura Valley, in Tertiary Waitemata formation sandstones and mudstones. The Ardmore and Redoubt Road tunnels are of 54 million gal./day capacity, and are capable of dealing with total high-level mean rated yield of the Cossey's, Wairoa, Mangatawhiri and Mangatangi catchments, plus 30% peak load factor.

First-stage pipe-line design was conditioned by economic considerations and by severe shortage of steel plate at the time. Because of these factors, initial pipe capacity was limited to  $6\frac{1}{2}$  million gal./day (approximately 50% of ultimate peak load demand on the Cossey's headworks); 1.7 miles of 30 in. concrete pressure pipe was used in low-pressure sections of the line; pipe sizes were reduced from 30 in. to 27 in. north of Redoubt Road tunnel, to take advantage of draw-down in gradient due to

the Westfield load; extension of the line north of Westfield was postponed. The first pipe-line, therefore, comprises 2 miles x 30 in. pipe in Hunua Valley between Cossey's and Ardmore tunnels, 5.7 miles x 30 in. pipe across Papakura Valley between Ardmore and Redoubt tunnels, and 1 mile x 30 in. plus 6.3 miles x 27 in. between Redoubt tunnel and Westfield. All steel pipe is  $\frac{1}{4}$  in. or  $\frac{5}{16}$  in. spiral lap-welded, concrete-lined, bitumen dip-coated and hessian-wrapped, with welded joints on 30 in. line and Johnston bolted joints on 27 in. pipe.

The No. 1 pipe-line has since been extended from Westfield, and is now linked into the 30 in. main from Titirangi at Epsom via a further 5.6 miles of 27 in., 24 in. and 18 in. main. A final extension of 2 miles x 32 in. main from Epsom to Khyber is in hand.

### 3.5.7. *No. 2 Hunua Aqueduct*

As mentioned earlier, in 1954 the City Council decided to accelerate development of the Hunua catchments, and to this end authorized work to proceed with the installation of a second line of not less than 15 million gal./day capacity, sufficient to handle, not only the balance of Cossey's water, but also run-of-the-stream water from the Wairoa and Mangatawhiri catchments as well.

The aqueduct for this purpose includes two further tunnels—the 4,640 ft.-long Wairoa tunnel from Hunua Valley to Wairoa dam site in Otau Valley and the 9,000 ft.-long Mangatawhiri tunnel from Otau Valley to Moumoukai Valley. Both these tunnels are in greywacke and are being finished concrete-lined 6 ft. 4 in. horseshoe to suit equipment available from previous tunnelling work. They therefore have ample capacity for yield from all high-level catchments beyond them. Wairoa tunnel was completed in August, 1956. Work on Mangatawhiri tunnel is now proceeding, and is scheduled for completion by 1960.

Pipework in connection with the No. 2 aqueduct comprises 27 miles of 32 in. and 42 in. trunk mains, a short 18 in. intake line at Wairoa, and a  $1\frac{1}{4}$  mile long x 24 in. intake line at Mangatawhiri. Trunk main work in the Hunua district includes 2 miles x 32 in. pipe of  $7\frac{1}{2}$  million gal./day capacity between Cossey's and Ardmore tunnels, to handle the balance of the peak load draw-off of 14 million gal./day from Cossey's reservoir, and 4.7 miles of 42 in. pipe of 15 million gal./day capacity between Wairoa and Ardmore tunnels. Across Papakura Valley 5.7 miles of 42 in. pipe will parallel the 30 in. No. 1 line. North of Redoubt tunnel, 42 in. pipe will parallel the No. 1 line for 3.1 miles to East Tamaki, and will then deviate to the north and proceed to Mt. Wellington via a further 7.6 miles of 42 in. pipe-line. At Mt. Wellington the line feeds into the existing feeder main to eastern suburbs, and then continues in 3.2 miles x 32 in. pipe into the existing trunk and feeder system at Mt. Hobson.

Mt. Wellington is located adjacent to Tamaki River at the eastern limits of the Auckland isthmus, in the centre of an extensive and rapidly developing residential and industrial area. It rises to an appro-

priate height on the hydraulic gradient between Hunua and Khyber reservoir, and therefore has been chosen as the site for a 10 million gal. service reservoir to balance the trunk main and control supply to the eastern suburbs.

Pipelaying on the No. 2 pipe-line commenced early in 1956 and is scheduled for completion in 1958. In order to make initial progress while awaiting steel plate supplies, 0.5 miles of 33 in. and 0.5 miles of 42 in. concrete pressure pipes have been used in low-pressure sections of the main in the Hunua district, but, apart from this, all pipes are of Australian steel, locally fabricated in 6 ft. sections into 30 ft. lengths, butt-welded circumferentially and longitudinally by submerged arc welding. Steel pipe shells are tested and end-formed for semi-ball and socket jointing, primed, coated with three 1/16 in. layers of pitch enamel and wrapped with fibreglass fabric drawn into the enamel. They are then concrete-lined. In the field, joints are fillet-welded internally and externally, the annular space in the sleeve is pressure-tested, and the gap in linings at joints is then made good with mortar.

Because of the superior type of coating used on these pipes, corrosion allowances have been limited accordingly. Plate of  $\frac{1}{4}$  in. is used for all 32 in. pipe, and 5/16 in. and 3/8 in. plate for 42 in. pipe. Maximum static head is of the order of 360 ft.

#### 4. FILTRATION

Both Waitakere and Hunua waters are typical upland waters, differing in minor details in accordance with country rock in each case. Both raw waters are soft, but have the characteristic brown colour of bushland derivation.

In 1927, primarily to remove colour, rapid gravity filters comprising 6 beds and 7 beds respectively were installed alongside the break-pressure tanks on the Waitakere trunk main near Swanson and the Nihotupu trunk main at Titirangi. These original plants were so successful that, when the Huia scheme came into service in 1929, filtration was included and the Huia station of 8 beds was established at Titirangi. This station was extended to 14 beds in conjunction with the Lower Nihotupu development in 1947.

These three stations in the Waitakere area are all of Candy design, using alum coagulant and post-liming for pH correction. Nominal bed capacity is in each case 1 million gal./day, and, except at times of flood and high turbidity, this is normally satisfactorily maintained. Presettling is, however, under consideration to cover all ranges of conditions. Chlorinators are installed at all stations, but normally are required to be used only at times of high rainfall.

From the point of view of economical operation it is unfortunate that topography and location of headworks are such that filtration of Waitakere water has to be undertaken at three separate and relatively small stations. No such problem arises with regard to Hunua water. The current Hunua development programme provides for presettlement and filtration at Ardmore, at the city end of Ard-

more tunnel, in accordance with overall plans for ultimate development to handle full high-level peak demand of 54 million gal./day.

Installation of filtration plant at Ardmore has been delayed to enable the Council to take full advantage of post-war advances in filtration techniques. In the meantime, since supply began in 1953, water from Cossey's headworks has been treated by chlorination only, and this has at times led to "rusty sediment" problems due to oxidation and subsequent flocculation and settling-out of the small but significant amount of iron present in this water.

The Ardmore station will be a Candy plant, incorporating upward-flow presettlement and centralized, semi-automatic control of all stages of treatment. Settling tanks are of nominal 0.5 million gal./day capacity, and filter beds of 1.5 million gal./day each. The station is unorthodox in that, owing to site limitations, the clear-water tank is located under the control building and the filter beds.

Current contracts at Ardmore are for the control building and for sufficient settling tanks and filters for 12 million gal./day capacity, to be completed in 1958. Subsequent extensions to 20 million gal./day capacity are authorized. Treatment by settlement only is being introduced in the meantime as tanks become available. The first battery of settling tanks came into service early in September, 1956, and by the end of the year two batteries, comprising 15 tanks, were in operation.

#### 5. DISTRIBUTION

The configuration of the Auckland isthmus, with its gullied terrain surmounted by numerous volcanic cones, has simplified distribution in that sites for service reservoirs are well distributed, but has introduced complications in the matter of establishing pressure zones. Further difficulty arises from the fact that the boundaries between the many independent local authorities within the supply area are irregular, arbitrary and quite unrelated to topography.

Original distribution was well served by the establishment of three pressure zones—a low-level port and inner city area served by Ponsonby reservoir with T.W.L. at 230 ft., an intermediate zone surrounding the former and served by Khyber reservoir, with T.W.L. at 320 ft., and a high zone fed with water pumped from Khyber reservoir to a reservoir with T.W.L. of 490 ft., on Mount Eden, the 644 ft.-high scoria hill which forms the "centre-piece" of the isthmus. In the central city area these zones are still effectively maintained by series of shut valves in reticulation, but, as the city has expanded, outer areas have had to be controlled to an increasing extent with respect to Khyber level, or to levels of local service reservoirs. In a few instances in low-lying residential outer areas pressures are controlled with break-pressure valves.

Khyber pumping station comprises four units with total nominal capacity of 8 million gal./day. The city's only other permanent distribution pumping station is at Mt. Hobson, where a three-unit

installation with total nominal capacity of 3 million gal./day pumps from a low-level reservoir on the Khyber trunk main system to Mt. Hobson high-level reservoir at T.W.L. 433 ft. The latter, which is fed also by gravity from Mt. Eden reservoir and thereby indirectly from Khyber pumping station, controls the greater part of supply to the widespread eastern suburbs. It will be relieved of a considerable part of this load with the construction of Mt. Wellington (10 million gal. x 330 ft. T.W.L.) and St. Johns (4 million gal. x 275 ft. T.W.L.) service reservoirs under the current Hunua development programme.

Pressure zones in the central city area are interconnected with "fire" valves at Khyber reservoir and pumping station and at Ponsonby reservoir and depot—both continuously manned—and these are opened to lift pressures in lower zones as required for fire-fighting purposes.

The inner city area of the Ponsonby pressure zone is well served by a 27 in. to 12 in. ring main system. Elsewhere, topography and irregular arbitrary boundaries limit the provision of fully effective ring mains, and distribution is generally by feeder mains only. These range up to 24 in. diameter.

### 5.1. Service Reservoirs

The city at present owns and operates reservoirs at 19 points throughout the supply area. Aggregate capacity of these, including those under construction, but excluding the authorized 10 million gal. Mt. Wellington reservoir, is 59.6 million gal.—about two days' present peak supply, or  $2\frac{1}{2}$  days' present average supply. In addition, twelve of the eighteen authorities on bulk supply operate their own service reservoirs and provide a further 7 million gal. storage.

The original reservoirs at Ponsonby (2.5 million gal.) and Khyber (2.0 million gal.) were simple concrete-lined excavations with timber and iron roofs. They have only recently been demolished and replaced. All other reservoirs are completely enclosed and are of reinforced concrete or mass concrete design.

Of present storage available or under construction, 31 million gal., or 52% of the total, is concentrated at the four main distribution points. Storage at the Ponsonby and adjacent Arch Hill group of reservoirs totals 9.5 million gal.; the Khyber group 10.6 million gal.; Mt. Eden 5.1 million gal.; and Mt. Hobson (high-level), 4.9 million gal. It is also of interest that service reservoir capacity in 1946 totalled 28.5 million gal. Since then 4.5 million gal. of old reservoir capacity has been demolished, but new construction totalling 35.6 million gal. added—a net increase of 31.1 million gal., or 110%, in ten years.

### 5.2. Supply to Other Authorities

The city administers direct supply, by special arrangement, to the Westfield industrial area—mainly freezing works—and to large parts of Waitemata County to the west and north. Bulk supply is given to 19 independent authorities within the

supply area, comprising 18 boroughs and one county. Conditions of supply in Waitemata County, originally rural, are now rapidly changing to urban in many localities, and therefore arrangements are now in hand for this authority to take over bulk supply also.

Of the independent boroughs, seven lie south of and contiguous with the city within the isthmus area, three lie west of the isthmus in or contiguous with Waitemata County, four are to the east and south-east in or contiguous with Manukau County, and four form the group of North Shore boroughs on the northern side of Waitemata Harbour.

Bulk supply is given at local authority boundaries, as a general rule by feeder mains direct off trunk mains. In a few cases in the isthmus area supply is given from different city pressure zones to enable the local authority to establish pressure zones within its own territory.

Bulk supplies are arranged under a basic 21-year contract. New bulk custom is contracted for to be co-terminal with the basic contract. Most current contracts expire in June, 1958.

Charges for bulk supply have been established by agreement every 7th year, and purport to cover estimated average bulk costs for the ensuing seven-year period. Bulk costs cover headworks, filtration and trunk mains, and those feeder mains and city service reservoirs which give Metropolitan as distinct from purely city service. As a general rule, costs of feeder mains to supply points are pooled; the same charge applies to all authorities, irrespective of their location with respect to trunk mains or headworks.

It is probable that when new contracts are negotiated in 1958 modification of the seven-year charge period will be sought. Under present conditions of unprecedented expansion and unpredictable cost fluctuations more frequent review would appear to be equitable.

### 5.3. Supply to the North Shore

The four North Shore boroughs are supplied in bulk under the general bulk supply contract, although in their case the feeder main is abnormal. Water supply to the North Shore was originally derived by pumping from Lake Pupuke, a centrally located 270 acre x 198 ft. deep fresh-water lake occupying a low-lying volcanic caldera. In due course excessive draw-off resulted in such rapid lowering of the lake that this, in conjunction with periodic severe infestation of the lake water with the protozoa *Ceratium* led the Department of Health to requisition the city to take over the supply. The appropriate empowering Act came into force in 1941. Under this Act the city supplies the North Shore boroughs with water from the Waitakere headworks via a trans-harbour pipe-line, and also controls Lake Pupuke and maintains pumping plant thereat for emergency purposes.

Lake Pupuke has now returned to its original level, approximately 12 ft. 6 in. above high-water

mark, but the *Ceratium* problem persists. The Council therefore, in 1955, installed a single-unit Glenfield Kennedy 7 ft. 6 in. micro-strainer at the emergency pumping station, and has used this on several occasions to assist or take over supply. It has successfully handled demands of up to 1.5 million gal./day, with at least 98% removal of *Ceratium* counts ranging up to 1 million per litre. The strainer is fitted with 35 micron aperture Mark I fabric.

The North Shore main feeds from Waitakere filters to a service reservoir with T.W.L. 382 ft. at Birkenhead, via 11½ miles of 18 in., 16 in. and 15 in. pipe-line, and a ¾ mile long underwater crossing of the harbour at Hobsonville. From Birkenhead, a further 3 miles of feeder mains distribute to the individual boroughs.

The harbour crossing is by twin 12 in. pipe-lines, and includes a vulnerable 1,300 ft. wide and up to 39 ft. deep channel section subject to high tidal velocities. One of these lines was replaced in 1952-53 and replacement of the second and the laying of a third line was under consideration in 1954, when the decision was reached to proceed with construction of the harbour bridge between the city and Northcote point, on the North Shore. Authority was therefore obtained to revise completely the supply lines to the North Shore, at an estimated cost of £250,000, and to this end immediate arrangements were made to install two 21 in. mains on the bridge itself. The bridge is to be available in 1958/9. In the meantime the existing underwater mains are being maintained, and their present limited capacity of 1.5 million gal./day is being pump-boosted to meet the rapidly increasing North Shore demand.

The new North Shore main will feed from Khyber reservoir in 32 in. pipe, and will break down progressively to 15 in. to terminate at R.L. 250 ft. at Crown Hill reservoir, Takapuna, at the northern limits of the present supply area. From this point supply can be given to the new East Coast Bays Borough further north. The total length of main involved will be 8 miles exclusive of the ¾ mile long bridge section. It will have capacity to supply a population of at least 85,000, double the present North Shore figure. This, with the expansion anticipated consequent upon completion of the bridge, could be reached within the next twenty to twenty-five years.

#### 5.4. Statistics of Supply

At present, of the total population of 330,000 within the supply district, 42% is resident in the city, 52% in the independent boroughs, and the remaining 6% in the adjacent counties. On the demand side, the city accounts for 47% of all water supplied, the independent boroughs 38%, the counties 3% and the Westfield heavy industry area 12%.

*Per capita* consumption figures are only partially significant because, although a measure of decentralization of industry and commerce is now apparent, the boroughs are still to a substantial degree "dormitory" areas with respect to the city's industrial and commercial life. On a simple resi-

dential population basis, however, average *per capita* demand in recent years has averaged about 72 gal./day in the city, 48 gal. in the boroughs, and 30 gal. in the counties. Demand in the boroughs has ranged from over 200 gal. per head per day in the small, predominantly industrial and commercial "island" borough of Newmarket to an average of 35 gal. per head per day in the purely residential boroughs. Recent average daily demand over the whole supply area has ranged between 65 and 70 gal. per head of population.

In all areas on bulk supply, with the exception of the Borough of Newmarket, metering is universal. In the city, however, "extraordinary" supplies only are metered. Water charge on ordinary domestic demand is by rate on annual value. This rate is also the minimum charge with respect to metered supplies. Garden watering by sprinkler is classed as extraordinary supply, and is metered, but if by "held-in-the-hand" hosing only, is charged for by annual licence fee.

At present 3,300 of the 42,300 services in the city itself are metered. The city controls a further 6,000 metered services in the county and industrial areas directly administered.

Aqueduct and pipe work other than services installed and administered by the city now total 710 miles, and are increasing at a rate of about 15 miles per year. This total comprises 125 miles of trunk and feeder mains in service, 445 miles of reticulation fully equipped for fire service within the city, and 140 miles of semi-rural reticulation in Waitemata County.

Receipts and expenditure of the Department now amount to £600,000 per year. Loan charges account for approximately 60% of expenditure.

During 1956-7, expenditure on capital works financed by loans reached a record total of £1,057,000.

#### 6.4. ACKNOWLEDGMENTS

For the first 40 years of the 87 years which have elapsed since piped water supply for Auckland was initiated, consultant engineers were either responsible for, or closely associated with, all major works. Over the last 50 years, however, except for consultant advisory services early in the period, all works have been undertaken entirely by the Council's engineers. The waterworks undertaking has for the greater part of this latter period been operated as an essentially autonomous department, with the waterworks engineer as head of the department, under the City Engineer as the Council's engineer-in-chief.

Consultants vitally concerned in the earlier developments include E. O. Moriarty (Western Springs) and H. Munro Wilson (original Waitakere and Nihotupu schemes). R. L. Mestayer, M.I.C.E., reported in an advisory capacity on the Waitakere

scheme, and J. H. Metcalfe, M.I.C.E., and M. H. Morton, M.I.C.E., on the main Nihotpu scheme.

A. W. Blair, S.M., A. D. Dobson, M.I.C.E. (later Sir Arthur) and A. J. Baker, M.I.C.E., comprised the Royal Commsision set up in 1927 to enquire into and report upon the whole question of water supply for metropolitan Auckland, and in 1929 H. H. Dare, M.E., M.I.C.E., prominent Australian hydraulics engineer, reported upon and confirmed the Council's water supply development policy.

City Engineers who have held office since the turn of the century are the late W. R. Wrigg (1899—1906), W. E. Bush, M.I.C.E. (1906—1929) and J. Tylor (1929—1944). The present Director of Works and City Engineer, A. J. Dickson, B.E., M.I.C.E., has been in office since 1944. Over the same period Waterworks Engineers have been J. Carlaw until 1928, A. D. Mead, B.E., A.M.I.C.E., from 1929 to 1953, and the writer since Mr. Mead's retirement in 1953.

Of the many engineers who have been involved in the development of the present system, the con-

tribution of some is deserving of special mention. Mr. Munro Wilson will be remembered in connection with the initiation of the Waitakere headworks schemes; Mr. Bush, for the continuation of this work and the formulation of the general policy of upland development; Mr. Mead for the implementation and extension of this policy over a long and vital period; and Mr. Dickson for general oversight in the recent period of exceptional development.

Reference to Table I will show that total potential yield from the Council's water supply reserves in the Waitakere and Hunua-Wharekawa ranges amounts to at least 99.5 million gallons per day. This, on present usage trends, will probably suffice for a population of 1 million. The pattern of growth in Auckland is such that it is possible that this population may be obtained by the turn of the century, so that about this time consideration will have to be given to the drawing of supply by pumping from the Waikato River. In the meantime, progressive development of existing resources is fully bearing out the faith of past generations in the future of Auckland.

#### APPENDIX I Auckland Water Supply: Typical Analysis

*Waitakere water:* Averages from all headworks; treated by filtration and liming.

*Hunua water:* Averages of limited samples; treated water chlorinated, settled and limed; includes some ground water.

	Waitakere		Hunua (Cossey's)	
	Raw:	Treated:	Raw:	Treated:
pH	6.6	7.1	6.7	7.0
Colour: M.M. Burgess	95	25	100	22
Turbidity: A.P.H. usually	Nil	Nil	Nil	Nil
Plankton: Mainly diatoms: per litre	200 to 40,000	± 100	± 1,000,000	± 7,000
<i>B. coli</i> M.P.N. in 100 ml.	0 to 1,400	Nil	± 50	Nil
Agar Count: Per ml. at 37° c.	5 to 500	± 25	50 to 800	± 50
	Parts per Million			
Total alkalinity as CaCO <sub>3</sub>	15.0	17.0	18.0	20.0
Total hardness as CaCO <sub>3</sub>	16.0	25.0	15.0	24.0
Oxygen consumed: 30 min. at 100° c.	6.2	3.3	5.0	2.5
Free CO <sub>2</sub>	1.8	0.8	2.0	1.0
Nitrites and nitrates	Nil	Nil	Nil	Nil
Free ammonia	0.02	0.02	0.01	—
Albuminoid ammonia	0.13	0.10	0.26	—
Total solids	93.0	90.0	90.0	—
Volatile solids	22.0	10.0	11.0	—
Phosphate	Nil	Nil	Nil	Nil
Chloride ion (Cl)	22.0	22.0	14.0	16.0
Sulphate ion (SO <sub>4</sub> )	4.5	12.0	4.0	15.0
Bicarbonate ion (HCO <sub>3</sub> )	17.0	17.0	18.0	23.0
Alkalis as Na	13.0	12.0	8.0	11.0
Zn: Cu: Pb: Mn: As	Nil	Nil	Nil	Nil
Calcium as Ca	3.3	7.5	3.5	9.0
Magnesium as Mg	1.5	2.6	1.9	1.3
Aluminium as Al	0.7	0.8	1.0	1.5
Iron as Fe	0.7	0.3	1.1	0.3
Silica as SiO <sub>2</sub>	16.0	10.0	16.0	17.0
Fluorine as Fl	0.2	0.2	0.2	0.2