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MANGERE WATER SUPPLY—MANUKAU COUNTY.

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The water supply system herein described, though comparatively small, is the most recent in the vicinity of Auckland, and is of additional interest because of its many-sided aspects and the unusual difficulties encountered and overcome in the course of its establishment.

All preliminary work in connection with the system was carried out by Mr. Page, and all subsequent operations were performed under his direction. The Author was appointed technical assistant on the County staff during 1929 and thereby became responsible for the detailed design of all subsequent works, the execution of these designs, and the placing of the system on a working basis.

Introductory:

The district of Mangere consists of a broad peninsula containing an area of approximately 14 to 15 square miles and forms one of the six Ridings which constitute the County of Manukau administered by the Manukau County Council.

While all virtually rural, considerable portions of the area are closely occupied for residential purposes, there are many small holdings used as market-gardens, etc., some larger dairy-farms, one aerodrome property, a large holding occupied by the Railway Department workshops, a small holding occupied by the Challenge Phosphate Works, and the usual proportion of public roads, public reserves, recreation grounds, etc.

At the Western end of the peninsula the soil is volcanic and at the Eastern end clay.

Prior to the establishing of the scheme which is the subject of this paper three comparatively small portions of the district only were supplied with water. At the Western or "Bridge" end a small area had been reticulated by the controlling authority, the Mangere Road Board, in 1918, and a small special area loan raised for the purpose; water was purchased from the Onehunga Borough and conveyed through the hand-rail pipes of the Mangere Bridge, thence distributed around and about Mangere Mountain. This arrangement served a useful purpose but by 1925 had become hopelessly inadequate and incapable of further development.

At the Eastern end a special loan area was created in 1921 adjacent to the Otahuhu Borough, and a small area reticulated. Water was purchased from the Borough of Otahuhu and retailed over the small area; this was a successful arrangement but by 1928 the scheme was becoming over-taxed, and its limits were in view.

In the third case a small number of residents near the Otahuhu Railway Station were being supplied direct by the Otahuhu Borough Council.

Many of the farmers and market-gardeners were lifting water from private bores by means of wind and other engines.

The district as a whole was not catered for, and from 1925 onwards the need for a comprehensive scheme made itself increasingly felt.

At that time it seemed possible that a large scheme involving the whole of the Auckland district, and in which the Manukau County could participate, for a Waikato River or Lake Taupo supply, might materialise and in view of that the County Council did not hasten local operations.

Early in 1928 the County Engineer was instructed to report, and as a result of that report was further instructed to ascertain if a local supply of water in sufficient quantity could be obtained.

Investigations were immediately undertaken; all available data with reference to local bores was assembled and all obtainable local information bearing upon the subject was rigorously sifted; this did not yield definite results; it was established, however, that from a strata of shell-sand at approximately 100 feet below sea level in various parts of the district water was being drawn through bores sunk by private people; in few cases, however, had large quantities been sought; in most instances hundreds of gallons per hour sufficed; in no case did the water rise to the surface on being tapped.

Investigation therefore became largely a matter of trial.

At a site in the old floor of a scoria pit, near the main road and electric power line, also near the foot of Mangere Mountain a shaft was sunk with dimensions of 8 ft. x 4 ft.; this was carried through scoria and basalt to a depth of 72 ft. 6 in.; after 40 ft. a pump was rigged to clear the working; when sinking was stopped at 72 ft. 6 in. no copious supply of water had been encountered.

A 6 in. bore was then drilled from the bottom of the shaft for a depth of 113 ft. and cased into a water-bearing layer of shell-sand at 60 ft., thereby carrying working operations to a total depth of 132 ft., approximately 77 ft. below sea-level.

This greatly increased the quantity of water available; a copious and steady flow from the bore quickly filled the shaft to a point 30 ft. from the bottom, the static level thus becoming established.

Subsequently two other 6 in. bores were sunk in the bottom of this shaft and similarly cased; this, however, did not increase the total flow of water but only served to provide alternatives in event of obstructions developing.

Tests for quantity and quality of water were then carried out under varying conditions over a long period.

A two-stage centrifugal pump and 14 h.p. motor were fastened on a wooden frame with a short direct chain-drive, a 4 in. delivery-pipe was rigged and the whole introduced into the shaft; an endless chain hoisting gear was arranged to facilitate raising and lowering without stopping the pump, and a length of flexible hose coupled to the delivery pipe near the surface.

The water was discharged into a wooden flume at a sufficient height to carry it ultimately clear of the scoria pit, and passed over a weir where measurement was taken.

As a result of these tests the quantity was found to closely approach 8,000 gallons per hour, and was definitely conservatively estimated at 7,000 gallons per hour.

As a test of quality the Public Health Dept., by request made frequent bacteriological and chemical analyses of the water; results showed that at times Bacillus Coli and other impurities were present in minute quantities, and that the water should not be used for potable purposes without chlorination.

At about this stage investigation was made for a further or auxiliary supply; a 2½ inch bore was driven at a point some 33 chains distant from the shaft or well in a disused quarry near the banks of the Ararata Creek; in this locality the shell-sand layer when reached at 123 ft. from the surface proved to be thicker and abundantly water-bearing.

An air compressor was temporarily brought into use and sufficient water brought to the surface and measured to show that a large quantity was available when required.

During 1929-30 a tentative scheme was prepared for consideration of the Council; this showed a proposed special area as the subject of loan and reticulation comprising the greater part of the Riding but excluding the purely farming lands in the south and south western portions of the peninsula. The gross area was approximately 5,800 acres and the nett area (less roads, quarries, reserves, etc.) 5,200 acres, made up in round figures as follows:—

Probable permanent	grazing lands	2,500 acres
,, ,,	market gardens	300 ,,
,, ,,	residential area	2,400 ,,

The existing number of houses in the area was 700, and the existing population approximately 3,000 persons.

Immediate requirements were summed up thus:—

	Gals.
3,000 people at 15 gals. per day per head	45,000
Market gardens, 300 acres at 200 gals. per acre per day	60,000
Grazing lands, 2,500 acres at 7 gals. per acre per day	17,000
Special items, trotting club, sports bodies, etc. (per day)	4,000
Totals gals. per day	126,000

This indicated an existing requirement of 5,200 gallons per hour.

Possible future requirements, say, as at 1950, were summed up thus:—

	Gals.
16,000 persons at 30 gals. per day per head	480,000
Market gardens, 300 acres at 200 gals. per acre per day	60,000
Grazing lands, 2,500 acres at 7 gals. per acre per day	17,000
Special services, say	6,000
Total per day	563,000

This indicated 23,500 gallons per hour as a possible future requirement.

It will be noted that for immediate requirements 15 gallons per head per day was the figure used and that this was doubled in estimating future requirements. This is explained by the fact that at the present time tanks are still in fairly general use in the district and that no drainage system is as yet in operation.

Figures for grazing and market gardening demand were estimated from data obtained from existing small supplies.

It was proposed to line the well with concrete, to establish suitable pumps with motors at the well and the necessary buildings, to construct a reservoir on the summit of Mount Mangere with a capacity of 500,000 gallons, to lay rising and delivery mains between well and reservoir, to lay approximately 30 miles of pipes throughout the area varying in size from 10 inches to 4 inches, provide all necessary fittings, service connections and meters, to establish a chlorinating plant at the well, and generally to carry out and provide all things necessary for the establishment and future development of the scheme.

The total estimated cost was £65,000, including £9,600 for redemption of existing small loans, £1,300 to cover costs of original investigation, £8,000 for future development and £46,100 for works and materials already briefly outlined.

The scheme was adopted by the Council without material amendment, and the necessary formalities prior to commencement of the work were duly and successfully completed; these included the explaining of the scheme at ratepayers' meetings, the holding of a Loan poll, the raising of the money, obtaining authority from the local Domain Board and the Crown with reference to establishing reservoir and mains upon Mount Mangere, and the conversion of portions of quarry reserves to water reserves.

Permanent work in connection with the scheme was commenced during the latter part of 1931. By April, 1932, the pumping station, duplicate pumps, reservoir and rising and delivery mains were complete in every detail; pipes and fittings were on hand and a start was made with the reticulation. The new system came into use in the "Bridge" area during September, 1932, and into full operation, with the discontinuance of the supply from Otahuhu to Mangere East, during January, 1933.

In the meantime, a serious position had arisen at the main well. Shortly after the changeover of the "Bridge" area to the new system the output from this source fell suddenly to a bare 3,500 gallons per hour. At the same time the demand, which under the old system had been limited to a maximum of 2,000 gallons per hour, rose almost immediately to 6,000 gallons per hour, as a result of a prevailing spell of dry weather, the great increase in pressure, and the consequent advent of sprinklers in market gardens. The position was met by installing a temporary air lift in one of the bores. This brought the capacity of the well back to its original 7,000 gallons per hour and enabled the system to carry on without the necessity of imposing restrictions. Arrangements were also made, however, for the immediate development of the auxiliary supply. This work was commenced in October, 1932, and was in full operation by March, 1933.

The final stage in the present development of the system was the installation of a filter plant at the Auxiliary supply during the 1933-34 summer season. Filtration of this supply became imperative because of its high iron content, and the detrimental effect of this on mains, meters and hot water systems.

Technical Details of the System.

Geology of the District:

Mangere is an extremely fertile, low-lying district, the plain-like surface of which is broken in several places by scoria cones and tuff craters. As a matter of fact, all elevations which are in excess of 40 or 50 feet above sea-level are of volcanic origin. This flat is part of what is known as the " 50 ft. terrace formation " of Auckland Pleistocene Geology. The beds of this formation are typically estuarine. They consist for the most part of partly consolidated sandy silts and fine pumice-derived quartz sands, with occasional interbedded seams of lignite and shell deposits. It is apparent that these beds were rapidly deposited in an extensive shallow estuary at a time when the land was slowly sinking. The silts and sands were largely derived from a juvenile Waikato River; the lignite and shell deposits represent ancient swamps and beaches or banks respectively of this old estuary.

Volcanic activity broke out in Late Pleistocene times and continued into Recent times in Mangere as in neighbouring parts of Auckland Isthmus. This activity almost invariably developed in the following sequential stages:—(a) the formation of an explosion crater surrounded by a low tuff ring; (b) outpouring of basaltic lava; (c) building of scoria cones with subsidiary flows of lava.

All three stages are well represented in many volcanic centres, but in others, activity concluded with stage (a). Mt. Mangere, the largest volcano of the Mangere district, is an example of the former type. Its scoria cone, which rises to + 351 feet, rests on a shelf of basalt approximately 1 mile in diameter which in its turn has filled and overflowed and all but obliterated all sign of the original tuff crater. A remnant of the latter is now exposed in the quarry in which the main well is located.

Sources of Water Supply:

The value of scoria cones in conserving rain water by means of the porosity and capillarity effects of their constituent materials is well-known, and has been exploited on many occasions in the vicinity of Auckland. The structure of Mt. Mangere, however, is such that the outflow of the water collected by its comparatively small catchment is not concentrated into such strong streams as are to be seen at Western Springs or at Onehunga, but is dissipated through innumerable springs round the periphery of the mountain. Nor is there any ponding

s

action created by its original tuff crater, as is the case of Mt. Richmond, Otahuhu, for the tuff crater of Mangere is completely filled with basalt.

It was discovered on investigating the logs of private bores, however, that a considerable water-bearing shell stratum occurred in the Pleistocene beds of central and west Mangere at an approximate level of RL–100, and this, on being proved, was found to be capable of yielding an ample supply for the district. This bed apparently varies from a few feet to 40 feet in thickness, and is at least 2 square miles in extent. 120 to 150 ft. of typical Pleistocene sandy silts overlie the shell and form an excellent natural filter. Thin bands of pug or lignite occur irregularly in these overlying beds but are not of sufficient extent to impair the efficiency of the main shell bed as a medium for collecting and storing water.

These shell beds in the Pleistocene series form the main source of supply for the Mangere System.

Both the main well and the auxiliary bores are in Quarry Reserves vested in the Council—a factor of some importance in the choice of sites. The main well was sunk originally in the hope of tapping some of the water held by Mt. Mangere, but was disappointing in this respect. Little uncertainty existed with regard to the auxiliary bores, however, for evidence revealed in the main well bores and elsewhere indicated that the site of the auxiliary supply was well within the zone of the main shell bed. Further, at this site an extensive portion of the sheet of basalt which occupies this particular locality had been quarried away, thus exposing the underlying Pleistocene strata and thereby rendering well drilling a comparatively simple matter.

Nature of the Waters:

Mangere waters are typical of those of deep wells. They are subject to surface contamination, mainly in consequence of the large amount of highly cultivated land within their catchment, and have therefore to be moderately heavily chlorinated for safety.

The immediate catchment of the main well is largely uninhabited scoria country, and therefore water from this source is definitely superior to that from the auxiliary bores. Though moderately hard according to local standards, it requires no treatment other than chlorination to render it highly satisfactory for domestic purposes.

Water from the auxiliary bores is harder, and in addition contains a disagreeably high amount of iron in solution in the form of ferrous bi-carbonate. On exposure to the air the latter is oxidised and precipitated as an insoluble iron oxide, thereby quickly imparting a brownish turbidity to what on being first drawn is a perfectly bright and clear water. This process led to such serious deposition of reddish sludge in mains and hot water systems that filtration of this supply soon became imperative.

Bacteriologically, raw waters from both sources vary considerably—from almost complete purity during the summer months to maxima of B. Coli present in 1 c.c. and Agar counts at 37°C of 700 colonies per c.c. Chlorination with 0.3 parts chlorine per million gallons, however, suffices to keep B. Coli negative in 100 c.c. and Agar count to an average of 5 colonies per c.c. in the distribution system.

As is to be expected, maximum pollution, both chemical and bacteriological, tends to occur in the early part of the winter or after any particularly heavy rainfall during a generally dry period.

Average analyses of these waters are appended and clearly show the general characteristics of the supply.

Supply and Demand:

During the winter months from at least June to September inclusive, the auxiliary plant and filters are idle. At this period of the year, the weekly demand rarely exceeds 500,000 gallons, whereas inflow into the well, mainly as a result of the interception of surface water by the auxiliary supply delivery tunnel, rises to as much as 20,000 gallons per hour. During the summer months, however, the capacity of the main well has now fallen as low as only 3,000 gallons per hour, whereas the demand rises to as much as 2,000,000 gallons a week, or an average of 12,000 gallons per hour. This necessitates the operation of both pumps, and the auxiliary bores become the main source of supply.

The demand during 1934 averaged approximately 770,000 gallons per week, but varied from 50 per cent. under to 250 per cent. over this mean—a range of more than 500 per cent. This highly variable and seasonal demand is due almost entirely to the extensive market gardens within the district. These and their requirements have expanded to an unexpected extent with the provision of water facilities and are mainly responsible for the difference between estimated and actual demand on the system. The gardening interests create a marked peak demand immediately prior to Christmas each year. On two week-ends during December, 1934, for example, draw-off exceeded 20,000 gallons per hour for short periods, but did not embarrass storage to a serious extent.

During the summer of 1933-34 the Mangere system was called upon to assist a neighbouring borough whose own supply had partially failed at the time—this only eight months after portion of Mangere had been dependent on this source for water. This exceptional demand has not been repeated during the 1934-35 season, but yet the internal demand has so increased that the same average rate has been maintained within the district itself.

As far as the plant is concerned, the present rated capacity of the pumping station is 16,000 gallons per hour (8,000 gallons per unit), but this can be increased when required to approximately 24,000 gallons per hour by installing heavier motors.

The capacity of the present plant at the auxiliary supply has been reduced by almost 25 per cent. in consequence of the higher lift introduced with the installation of the filters. This source of supply is, however, far from fully exploited. Further development is under consideration, and can be economically effected by duplicating the compressor plant and bores, and by carrying out certain adjustments to the existing bores. The capacity of the filters is 21,000 gallons per hour.

General Layout of Plant and of the Supply System Generally:

Briefly, the layout of the supply system at the present time is as follows: Water is obtained from two sources—(a) from a well at the base of Mt. Mangere, fed partly by surface water and partly by the artesian flow of three 6 in. bores driven through its floor, and (b) from an auxiliary supply drawn by air lift from two bores, one 4 in. and one 6 in., in a reserve 33 chains from the main well. Water from these auxiliary bores contains an abnormal amount of iron in solution. It is therefore delivered first to special Candy gravity iron removing rapid sand filters. From these it passes over a measuring weir into a control tank, and thence by gravity through a 9 in. reinforced concrete delivery main, partly in tunnel, to the main well. Water is lifted from the well by means of two electrically driven six stage borehole pumps, and pumped through 29½ chains of 6 in. rising main to a two chambered, 500,000 gallon service reservoir on the crest of Mt. Mangere. A pump house over the well houses the motors and control gear, an automatically controlled chlorinator, a Venturi tube and 7-day recording and integrating meter on the rising main, and two level indicators, one for each chamber of the reservoir. These indicators are operated by potentiometers housed on the reservoir roof, per medium of an underground armoured cable. A mercury tube float switch in the well prevents pumping to a dangerously low level, and similar switches housed on the reservoir roof, one over each chamber, control the operation of the plant between adjustable ranges of level in the reservoir. Both rising and delivery mains pass through the pump house, so that control of the system is almost completely centralised.

The operation of the plant is entirely automatic, the only supervision required being occasional attention to lubrication details and periodic cleaning of the filters. The sequence of operations is as follows: The reservoir falls to a pre-determined level and the pumps are started by the reservoir float switches. When the well is pumped down to a certain level a float valve on the delivery end of the auxiliary delivery main opens, and water is drawn from the auxiliary supply control tank. The level in the latter falls a predetermined amount and then trips a float switch to start up the air lift plant. Simultaneously, a float-operated 4-way cock opens a hydraulic valve on the filter outlets and brings the filters into operation.

When the reservoir is filled its float switches stop the pumps, the well level builds up and closes the auxiliary delivery float valve, the auxiliary control tank level builds up and stops the air lift plant by means of its float switch, and at the same time the filter outlet hydraulic valve closes and prevents the filters from draining out.

Time switches are included in the pump controls. These automatically close the plant down during evening periods of high peak power charges.

Main Well:

This is sunk 72 ft. 6 in. through basaltic rock of varying density to R.L.–17 (datum being mean sea-level) and is concrete lined throughout. During the summer it is fed entirely by artesian flow from three 6 in. bores driven through its floor. Average T.W.L. in the well is R.L. + 14.

The first bore was of the nature of a trial. It was driven to R.L.–130, first through 4 ft. of rock, and then for the most part through normal Pleistocene sandy silts. Two beds of shell were encountered, one 12 ft. thick at R.L.–72, and another 2 ft. thick at R.L.–95. The former is sealed below with a band of pug and gave a good yield; the latter did not warrant exploitation. This bore was cased to the main shell bed, but left open below. Unfortunately, considerable time elapsed before work of a permanent nature was authorised, and during this period the walls of the bore disintegrated to such an extent that the slight disturbance caused later when screens were being placed produced such insilting that the bore had ultimately to be abandoned. The breaking of the pug seal at this point in exploring the underlying strata also contributed largely to this failure.

The two remaining bores were driven in opposite corners of the well and cased to the shell. Five inch slotted screens were then placed through them and the shell, and were sealed into the underlying pug. These bores are canted to spread their bases as much as possible.

The yield of this source was 8,000 gallons per hour consistently during early test stages, but has now fallen to as low as 3,000 gallons per hour. The probable explanation of this is that the shell bed exploited at this point is merely of local extent, and in any case may well be within the zone disturbed by the eruptions of Mt. Mangere. The band of shell at R.L.–95 may represent the thinned edge of the more extensive shell bank encountered by the auxiliary bores.

Pumps:

Each pumping unit consists of a 6 stage turbine type vertical spindle borehole pump, suspended by a $4\frac{7}{8}$ in. diameter rising main and direct coupled to a vertical spindle squirrel-cage motor of 27 B.H.P. at 1470 R.P.M. on 400 V, 3 phase, 50 cycle current. The spindle between pump and motor is coaxial with the rising main and is supported at 4 ft. $4\frac{1}{2}$ in. centres by water-lubricated white metal-bushed spider bearing housings. Renewable bronze sleeves encircle the spindle at each bearing. Pump impellers and guides are of phosphor-bronze. Guides are fitted with renewable eye rings. Impellers are adjusted in position by means of a distance piece in the spindle head. The weight and thrust of the pump is taken by a Hoffman ball suspension bearing housed in the motor pedestal. Each motor is controlled by means of an automatic contractor-type auto-transformer starter. This supplies reduced voltage to give initial acceleration and enables the machine to start under load. No-volt and two overload relays are incorporated and push-button control is also allowed for.

Pump motors and starters are housed in a brick pump house over the well (floor level R.L. + 55.5); the bases of the pumps are at R.L.–8; No. 1 footvalve is at R.L.–15 and No. 2 at R.L.–14. Suctions and deliveries are 3 in. diameter, and 3 in. reflux valves and regulating sluice valves are fitted to each delivery.

The normal duty of each of these units is 8,000 gallons per hour against a total head of 400 ft., but they are capable of dealing with as much as 12,000 gallons per hour for short periods.

The overall efficiency claimed by the manufacturers for each pumping unit was 59 per cent. with motors 91 per cent. efficient, and this has been well maintained. Power consumed at normal pumping rates averages 2.7 units, approximately, per 1,000 gallons lifted to the reservoir.

Some initial difficulties were experienced before the pumps settled down, but with these overcome, they have functioned excellently. The original foot-valves, for example, were of the ball type with phosphor-bronze balls and seatings, but these quickly became so bruised with constant chattering that ultimately they had to be replaced with standard leather faced flap valves. The pump impellers, also, had to be lifted almost 3/32nd in. before efficient running was achieved—apparently to overcome " stretch " of the long spindle under load. The most serious trouble encountered, however, was overheating of the main ball suspension bearings, and considerable experimenting with lubricants and spare races and balls was entailed before the trouble was located. The outer margins of the main races had been turned, but not ground, after having been slotted for lubrication purposes. The tool had apparently "jumped" at each slot, for across the horns of opposite slots the race diameter was 3/1000th in. greater than elsewhere. This was sufficient to cause the race to bind on the housing with the slightest expansion, and by interfering with the flexible action of bearing prevented its seating evenly.

Auxiliary Supply:

As previously indicated, this supply is obtained by air lift from two bores, is then filtered and discharged over a measuring weir into a control tank, and is finally delivered by gravity feed into the main well per medium of a 9 in. reinforced concrete pipe delivery line.

The quantity drawn from auxiliary supply is recorded on a weekly chart by means of a weir recorder mechanism.

The control tank was designed originally as a settling tank. This accounts for its comparatively large size and its deep sump.

Delivery:

The intake of the delivery line is at R.L. + 20, 5 ft. below control tank T.W.L.; it enters the main well at R.L. + 12.6, and discharges through a float-valve at R.L.–9. For 11 chains adjacent to the well this line is laid, cushioned, in an open tunnel; over the remaining 22 chains of its length it was laid in short drives or open cuts 5 ft. to 18 ft. deep. Rock was encountered throughout the whole length.

Auxiliary Bores:

The water bearing shell at this point is at R.L.—98, and is 25 ft. thick. It is immediately overlain with a 2 ft. band of coarse quartz sand, but is otherwise enclosed in normal Pleistocene silts. Occasional pug bands occur in the overlying beds. Ground water level in these bores rises to R.L. + 10 approximately.

At No. 1 bore a 4 in. casing was sunk by widening out a $2\frac{1}{2}$ in. trial bore driven some months previously. Once again trouble ensued through rotting of the old bore walls, with the result that by the time the casing was placed it was resting loose in a hole some 9 in. in diameter. The annular space outside the casing was filled with $\frac{1}{2}$ in. and $\frac{3}{4}$ in. crushed basalt, but under test the rush of water broke the seal under the bore and brought large quantities of sand and this metal to the surface. Casing and screens had to be driven home periodically for some time before this scouring action was finally controlled.

No. 2 bore was driven for experimental purposes and as a standby in this obviously tricky country. Profiting by previous experience, casing and screens were placed as soon as possible after drilling, with the result that this bore has lifted practically no sand and has remained perfectly tight during two seasons of heavy draw-off.

The screens to the auxiliary bores consist of 20 ft. lengths of 4 in. G.I. piping, pierced with four rows of $\frac{1}{2}$ in. holes at 3 in. centres, spirally wound with $\frac{1}{8}$ in. gauge G.I. wire and wrapped with 30 mesh brass gauze. In the case of No. 1 bore, the screen forms the lower length of the 4 in. casing—a system possible only because of the enlarged bore hole. In No. 2 bore, a 6 in. casing was carried down to shell level, and the screen placed through this and sealed into it with a steadying length of 5 in. piping; the sockets of the latter were turned to a neat fit in the casing.

No. 2 bore was drilled, cased and screened in two working days. Drilling alone through 110 ft. of sandy silts took only three hours.

Experience at Mangere indicates that bores driven in Pleistocene or other beds of the type there encountered can be left several days uncased without fear of trouble. If untouched, they will stand for months, but any disturbance then causes disintegration of the walls and the formation of what is virtually a quicksand in the bore. Unless high pressure water is available

this can be removed only with the greatest difficulty. Disintegration under an open bore is equally dangerous, because of the difficulty in sealing the casing. It is impossible to drive a casing into this quicksand, yet the latter will pass water so freely as to cause extensive undermining before a bore can be considered to have become stabilised.

The Air Lift Plant:

The air lift plant comprises a vertical single stage twin cylinder compressor driven by a squirrel-cage motor of $17\frac{1}{2}$ B.H.P. at 1420 R.P.M. on 400 volt 3 phase 50 cycle current. A short centre jockey pulley belt drive is used. This gives the plant a degree of flexibility, for by using various sizes of motor pulleys the quantity of air delivered and therefore, within limits, the amount of water raised can be adjusted in accordance with the pumping rate of the main pumps. The present maximum speed of the compressor is 715 R.P.M. At this, piston displacement is 105.5 cu. ft./min. and the free air delivered is 81 cu. ft. per minute. Its maximum catalogue speed is 800 R.P.M., but this would seriously overload the motor.

The motor is controlled by means of an automatic star-delta type starter operated by a float switch in the control tank. Two overload relays, no-volt release, and push button controls are incorporated.

Ability to start even against full receiver pressure is achieved by means of a solenoid-operated unloading valve. This is opened by the closing of the starting contactors and is closed by the closing of the running contactors of the starter. When open, it allows air under pressure to pass from the receiver and depress the suction valves of the compressor, and thereby removes all load from the machine during its starting period.

Ample provision is made for the elimination of oil from the air delivered to the bores. Oil scraper rings are fitted to the compressor pistons and the little oil that passes these is precipitated in the receiver. The latter has a water-cooled double bottom and a wood-wool packed head. Air is caused to impinge on the former on entry and is filtered through the latter on delivery.

Air Lift Operation:

The principles and main factors affecting the operation of air lift pumps has already been dealt with before the Society (Corkill, on "Invercargill Water Supply"; *Proc.*, N.Z.Soc.C.E., Vol. XVIII, pp. 230-262), and need not therefore be recapitulated in full here.

The driving force in such pumping systems is the unbalanced hydrostatic pressure between an intimate mixture of air and water in a discharge pipe on one hand, and a surrounding column of water only on the other. The air-water mixture is created by introducing fine streams of air into the water near the base of the discharge pipe by means of an air pipe terminating in a special nozzle. The water surrounding the air pipe is usually retained in a well or bore.

The relationship of the various factors concerned in air lift pumping is given by the following formulae:—

$$\text{Within the limits of the well, } Q = \frac{A.C. \log \dfrac{H + 34}{34}}{h}$$

Where Q = quantity of water delivered, in gallons per minute.
A = free air supplied, in cubic feet per minute.
H = working submergence, i.e., depth of air nozzle below well pumping level, in feet.
h = total lift, from well pumping level to discharge level, in feet.
C = a constant which varies with the percentage of submergence to the whole air-water column.

Lack of precedent in the Mangere district meant that none of the above factors were known with any degree of certainty. The original layout was therefore largely of the nature of a trial for the determination of the data required for that correct proportioning of the various parts which is so essential to the successful operation of an air lift. For the purpose of tests No. 1 bore was cased 4 in., but No. 2, 6 in. These casings act as discharge pipes; the surrounding water is ground water in the "country."

One inch air pipes are used, with their nozzles at R.L.–90, 8 ft. above shell level. A greater submergence than this gave a greater yield, but was considered to be too low for absolute safety from scour at such an early stage in the life of the bores.

The drop of ground water level with pumping is not directly observable with the layout adopted, and has therefore had to be calculated from the readings of pressure gauges on the air lines. (Air pressure depends on "Well" level only, and not on the lift). This method is too coarse for the determination of differences in pumping level with different pumping rates, but has now yielded reliable average results. Thus winter static level approximates to R.L. + 10 and winter pumping level to R.L.–2; summer static level to R.L. + 4 and summer pumping level to R.L.–12.

The original summer yield of these bores when discharging at R.L. + 25.5 and using 81.5 cu. ft. air per minute between them was 14,000 gallons per hour. This subsequently dropped to and remained steady at 12,000 gallons per hour. Percentage submergence was 67½ per cent.

The installation of filters has so affected the factors concerned that original proposals based on early tests have had to be wholly revised. Discharge level is now R.L. + 42; percentage submergence is 59 per cent.; the yield with 81.5 cu. ft. air per minute between the bores is only 9,000 gallons per hour.

When required, the present yield is increased by bringing a portable standby compressor into use on one bore and confining all the air from the permanent machine to the other. It has been proved that within wide limits the bores, though only 72 ft. apart, do not interfere with each other to any great extent when operated independently in this manner. The combined yield is never lower than 80 per cent, of the summation of the yields from each bore acting alone.

Since the installation of the filters the yield of No. 2 bore alone has been considerably lower than that of No. 1 bore under identical conditions, in spite of the fact that it is a larger and in other ways generally a more satisfactory bore. This is due to the fact that with the reduction in yield consequent upon the imposition of extra lift, the velocity of the discharging air-water column has dropped below the critical velocity required to maintain an intimate mixture of air and water. The resultant separation out or "slippage of air gives a very erratic discharge and a heavy loss of efficiency. The practical limits of discharge pipe velocities to retain the air-water mixture and yet keep friction losses within reasonable bounds are 6 ft. to 12 ft. per second at the base and 12 ft. to 25 ft. at the discharge end. The velocity at the base of No. 2 bore when delivering 6000 gallons per hour with 70 cu. ft. air per minute under 4 atmospheres pressure is only 3.2 ft. per second; discharge velocity, by reason of expansion of the air with reduction of pressure, is approximately 7 ft. per second.

The flow from No. 1 bore (4 in.) is steady and its operation efficient. Under comparable conditions to the above its base velocity is 7.7 ft. per second and its discharge velocity 16 ft. per second.

The overall efficiency of the Mangere air lift plant as it stands at present ranges between 15 per cent. and 20 per cent. depending on the pumping rate. Under average conditions, power consumed is approximately 1.5 units per 1000 gallons lifted and filtered. This is not excessive under the circumstances, for even correctly proportioned air lifts rarely display efficiencies greater than one-third that of high-class modern pumping units for the same lift and discharge. Air lifts are not efficient, but are expedient under conditions such as those obtaining at Mangere. They are flexible in operation, are easily duplicated or extended, and in small bores usually give a much greater yield than that obtainable by any other type of pump.

The main sources of loss of efficiency with the Mangere bores are the "slippage" of air in No. 2 bore, and the system of using casings as discharge pipes. The extent of these losses is indicated by the low and variable values obtained from test results for the constant "C" of the air lift formulae. "C" is in any case an indefinite "constant." Its value for 60 per cent. submergence, for example, varies in different published tables from 240 to 335. Under similar conditions at Mangere, however, its value was found on the average to be as low as 180 for No. 1 bore only, and 200 with both bores in operation.

Adjustments in view to give effect to test results are simple, and are expected to definitely increase both efficiency and yield. A 4 in. discharge pipe is proposed for No. 2 bore. This will be coupled into the head of the screens, and will in itself overcome both sources of loss. A separate discharge pipe in the smaller No. 1 bore would, however, probably defeat its own ends because of the high discharge velocities which would be attained. The screens in both bores appear to have now sealed themselves against the passage of fine sand; air nozzles can therefore now be lowered probably 10 ft. without introducing undue risk of scour. The present 1 in. air pipes involve high air velocities, and could therefore be profitably replaced with 1¼ in. piping.

Extensions under consideration are the duplication of the compressor plant and the driving of a third bore. Future bores will be cased 6″, and will be fitted with 4″ discharge pipes and 1¼″ air pipes. This layout should give them a yield of from 9,000 to 10,000 gals. per hour each with the present compressor plant.

The Filters:

This plant consists of two Candy Gravity iron removing filters, each with a filtering area of 105 sq. ft. and a capacity of 10,500 gallons per hour. Filter chambers are of reinforced concrete; the control chamber is of brick.

Water from the bores is discharged at R.L. + 42 into a dividing tank. From this it is fed to spray pipes, one over the centre of each filter, and is discharged in the form of a fine spray through a series of special spray nozzles. This ensures fairly complete preliminary aeration and oxidation of the iron in the water, and facilitates its later removal.

The filter beds consist of the following media:—

12″	20/30 grade fine sand.
6″	" Polarite."
12″	20/30 grade fine sand.
4″	10/20 "coarse."
4″	¼″ to 1/10th.″ grade fine gravel.
4″	½″ to ¼″ grade coarse gravel.

The medium " Polarite " is provided to deal with any iron not oxidised by the sprays. It consists of 50% magnetic oxide of iron, 25% silica, and small percentages of lime, alumina, and magnesia; it is very porous, and occludes large volumes of oxygen which by a process of wet combustion when in contact with water destroys organic matter and breaks up ammonical compounds.

Uniform collection of filtered water and even distribution of air and washwater for cleaning purposes is achieved by means of a Patent floor system. This contains four collecting nozzles per square foot, which discharge into a system of 3″ field tiles and thence to the outlet mains.

The outflow of filtered water is controlled at the outlets by means of wing valves operated by a float in each chamber.

The filters are cleared by air scour followed by upwash of water from the reticulation mains. Air is obtained from the air lift plant. Pressure reducing valves reduce air pressure to 5 lbs. per sq. inch and wash water pressure to 15 lbs. per sq. inch, for cleaning purposes. When operating continuously each filter has to be cleaned once in 24 hours. Wash water amounts to a little over 1 % of the water filtered. Loss of head gauges in the control room indicate when cleaning is necessary.

These filters have fully achieved their purpose, and are delivering an excellent water. Before their installation considerable complaints were made with regard to the hardness of the water—so much so that the advisability of installing a softening plant in conjunction with the filters was at one time under consideration. This is not now a pressing matter, for much of the trouble lay in the way in which hardness effects were simulated by the iron in the water, mainly in the formation of a flocculent scum with soap. The removal of iron from the water has achieved a considerable reduction in "apparent" hardness.

Appended analyses illustrate the degree of improvement, both chemically and bacteriologically, achieved by filtration.

It will be readily understood that had the necessity for filtering been apparent from the outset several advantageous alterations to the present layout of the auxiliary supply could have been effected.

The Service Reservoir on the summit ridge of Mt. Mangere is a circular, double chambered, monolithic reinforced concrete structure, with an average internal diameter of 72′ 7″, a depth of water of 20′, and a total capacity of 500,000 gallons. Top water level is at R.L. + 340.

The outer wall of the reservoir is 21″ thick at the base and 9″ at the roof; it is reinforced with circumferential rods ranging from a triple row of $\frac{7}{8}$″ round bars to $7\frac{1}{2}$″ centres at the base to a double row of $\frac{1}{2}$″ round bars at 12″ centres at roof level. The partition wall is designed as a vertical slab supported by roof and floor. It is 20″ thick from its base to mid height and then tapers to 12″ at roof level, and is reinforced with 1″ round bars at $7\frac{1}{2}$″ centres both faces. The floor is 9″ thick, with light reinforcement. All walls are bonded into the floor with reinforced haunches of 12″ side. A 6″ slab roof is carried on beams and columns supported on footings incorporated with the floor.

"Underwater" concrete is of 1 : $1\frac{1}{2}$: 3 mix, but a 1 : 2 : 4 mix was used for the roof and other details. Coarse aggregate used throughout was crushed basalt 1″ to $\frac{1}{8}$″, 70% to be over $\frac{1}{2}$″.

Shutters for the walls were constructed in 8 ft. lengths. At each lift they were bolted to stout guide posts, the sides of which were tapered to take up differences in circumference due to varying wall section.

Plastering was specified only as an indemnity, it being the Engineer's desire to prove such treatment unnecessary with properly executed work. The results achieved have fully justified this, for loss of water from the reservoir is scarcely measurable even after weeks of standing. The only leakage trouble experienced was in a short section of one construction joint, the lower surface of which had been unavoidably subjected to a torrential downpour of rain while still green. Extra chipping had been done along this section in view of this, but apparently did not go deep enough. The fault was ultimately overcome by cutting out the faulty seam and filling it with mastic plastered over. This is the only plaster on the structure.

Naturally such results called for the exercise of great care in the placing of concrete and the location of joints. Each section of the work was poured continuously, the floor in two halves and the walls in 2 ft. lifts. The following procedure was adopted for all joints. The top 1″ of concrete of each lift was carefully chipped away the day after it had been poured; chippings were left in place saturated with water until the following day when, if possible, shutters were lifted and reset and the next ring poured; the chipped surface was hosed and brushed clean and grouted immediately ahead of shutters and concrete respectively.

Placing of concrete was carried out expeditiously considering the degree of care called for. Each half of the floor (60 cu. yds.) was poured by 8 men in $12\frac{1}{2}$ hours; the heaviest lift of the walls (38 cu. yds.) was poured by 9 men in 9 hours.

Reticulation—Pipework generally:

The reticulation system has been designed to give a minimum working pressure of 60 lbs. per sq. in. at maximum development, on the basis of 10% of maximum daily consumption in one hour ($2\frac{1}{2}$ times average hourly consumption). The average static pressure over the district is 130 lbs. per sq. in.

At the present time the system includes approximately $\frac{3}{4}$ mile of 10″ pipe, $\frac{3}{4}$ mile of 9″, 2 miles of 8″, 14 miles of 6″, and $16\frac{1}{2}$ miles of 4″—a total of some 34 miles of mains. The great majority of these are of spun cast iron, the only exceptions being 3,000 ft. of recently installed, locally manufactured concrete lined steel pipe in a 6″ connecting main along the railway between Otahuhu and Mangere Crossing, and some old, small cast iron mains incorporated from the original system at Mangere east. Several long dead ends exist at the present time. These, and the high proportion of mains over 4″ in diameter, are merely reflections of the present distinctly rural nature of large portions of the district.

The rising main (6″) and delivery main (10″) parallel each other up the steep slopes of Mt. Mangere, and are heavily anchored at frequent intervals. By-passes between them are provided both in the pumping station and at the reservoir, and spring loaded concussion valves are fitted to both in case the delivery main should be required to be used as a rising main. Flange-jointed pipes and fittings are used in particularly steep country near the pumping station.

The main feeder from the delivery main runs as direct as possible to the centre of population at Mangere East, and comprises 10 in., 9 in. and 8 in. pipes. It is assisted by 6 in. loops through the smaller segregations of population at Mangere Central and Eccleston Settlement.

All special pipe fittings are of cast iron to British Standard Specification, locally manufactured. This was insisted upon in the first case because of the admitted excellence of these standards and the desirability for their general adoption, particularly in new systems, and secondly because of the considerable variations in the dimensions upon which the several local foundries have been standardising. In all cases, these local fittings are considerably shorter than British Standard. It is true that in adopting this procedure the choice of fittings in Auckland has been still further complicated, but this has merely introduced a recognised standard where no standard at all has previously existed. The large numbers of fittings required for Mangere justified the making of new patterns.

A new type of ball hydrant was also evolved for Mangere, based on the clearances in general use in British practice. This hydrant has standard 3 in. lugs, a full 3 in. outlet and a comparatively unobstructed inlet. It uses a 3⅞ in. ball—the standard in England—with ½ in. clearance all round in the body. The so-called 3 in. ball hydrant in general use in Auckland has standard lugs, but only a 2¾ in. outlet, and its inlet is greatly restricted by heavy ball rests. It uses a 3⅝ in. ball with a bare ¼ in. clearance in the body. The comparative efficiency of the new type has been demonstrated under test. On a 6 in. main it delivered 250 gallons per minute; an old type hydrant on the same tee delivered only 210 gallons per minute.

Approximately 600 of these hydrants are in use in the Mangere system. They are spaced from 3½ chains to 5 chains apart, depending on the size and location of the main.

The efficiency of the system generally for fire-fighting purposes is best illustrated by the following figures obtained during fire underwriters' tests:—

Location of Hydrant Tested.	Distance from Reservoir.	Static Pressure	Through 1 in. Nozzle direct on Stand Pipe.	
			Flow Gals./min.	Running Pressure
Taylor Rd. — highest point in district—on 4 in. circuit	¾ mile	115lbs.	300	90lbs./sq.in.
Mona Avenue — lowest point in district — end of 4 in. dead end 35 chains long.	1 mile	150lbs.	280	75lbs./sq.in.
Rosella Rd. — furthest point from reservoir—end of temporary 4 in. dead end 30 chs. long.	5 miles	140lbs.	200	45lbs./sq.in.
Henwood Rd. — end of 6 in. dead end 50 chs. long.	4 miles	140lbs.	340	93lbs./sq.in.
Entrance to Railway Workshops — 6 in. circuit.	3¼ miles	145lbs.	400	100lbs./sq.in.

Pipe Laying:

Of the 2,400 chains of pipe laying in the main reticulation contract, 800 chains were in the rock area surrounding Mt. Mangere, and the remaining 1,600 chains in flat clay and loam country. One thousand chains of trenching in the latter zone was performed by local labour on a party piecework basis, but all other trenching and the whole of the backfilling was carried out almost exclusively by means of a petrol-driven navvy. In the "clay" area this machine consistently opened up 15 chains of trench per day, and could backfill and ram 40 chains per day quite comfortably. In the rock area it dealt with all but a comparatively few patches of tough flow rock, at the expense, however, of fairly frequent breakdowns. The cost of running this machine, including driver, assistant, and normal maintenance, was in the vicinity of £2 per working day.

Pipe laying was carried out at an average rate of approximately 120 chains per week. The pipe laying gang usually consisted of three men on the smaller sizes of mains and four or five men on larger sizes, with an additional three men at least opening up caulk-holes. Under good conditions a three-man gang had no difficulty in laying and caulking 16 chains of 6 in. pipe per day or 27 chains of 4 in. pipe.

All pipes were jointed separately in place. The total amount of lead used for jointing purposes was approximately 5 per cent. over the theoretical quantity required on the basis of lead for half the depth of sockets. Details of costs for this section of the works are appended to this paper.

Testing of Mains—Bursts:

In view of the peculiarities attached to spun-cast-iron pipes, all mains were subjected to slight water hammer whilst under test. As a general rule this was applied progressively along each length by simutlaneously closing two fully opened 3 in. stand pipes located on adjacent fire hydrants. This test, which may be considered to impose upon a main the maximum stress to which it can be subjected in normal practice, was proved to be fully justified.

During the course of the reticulation contract some 90 bursts or cracked pipes were dealt with, out of a total of some 9,250 lengths of pipe laid. In addition, several lengths were broken at the ship's side or in transit, in spite of the fact that considerable care in handling was exercised at all stages.

In many cases, bursts were simply the opening out of undetected hair cracks as soon as the pressure was felt—a common enough experience with spun pipes. In many other cases, however, a more disturbing source of failure was revealed, and then usually only under hammer. At times, such bursts revealed old hair-cracks from the inside which had not broken the outer, chilled skin peculiar to these pipes. More frequently, however, the break was of an extremely jagged kind revealing metal of a distinctly stressed nature. Such breaks always occurred near the sling points and were attributed to nipping of pipes due to overloading in the slings. Eight in. pipes in 18 ft. lengths were particularly susceptible to this type of failure. These pipes were an experiment on the part of the manufacturers as far as New Zealand was concerned, 12 ft. having been the previous standard export length for this size. They were not difficult to handle on the ground, but obviously required careful treatment at all stages. Another outstanding feature in this question of bursts was that a considerable proportion of the total failures occurred in pipes from one particular shipment. This fact is brought out in the following table illustrating the position:

	10in. x 12ft.	9in. x 12ft.	8in. x 18ft.	6in. x 18ft.	4in. x 18ft.
Total pipe lengths delivered	374	285	594	3707	4280
Lengths broken or burst	3	3	26	44	14
Percentage broken or burst	0.8%	1.05%	4.4%	1.2%	0.33%
Pipes delivered ex "Ruahine"			261	475	905
Lengths broken or burst			21	9	10
Percentage broken or burst			8.1%	1.9%	1.1%

The position created by the abnormally high percentage of failures was the subject of investigation at the conclusion of contract, and in view of the facts brought to light, was unhesitatingly met to an appreciable extent by the manufacturers.

No further trouble has been experienced since the system has been in full operation.

Metering:

The original systems at Mangere were in the first case metered with American Keystone meters. Later, and in the early stages of the new system, the British positive type Measurement S.T. meter was adopted.

During the first year's operation of the new system a discrepancy of 15 per cent. was found between the main meter and the total recorded by the service meters. Investigation soon found the trouble to lie in the fact that many of the old American meters were hopelessly inaccurate at rates of flow of 100 gallons per hour and under, and it was therefore decided to test all of the 400 odd meters of this make in service and replace any which failed to come up to a reasonable standard of accuracy.

The British meters in use were also giving a certain amount of trouble on account of certain unfortunate mechanical features in their construction. Service tests were therefore carried out on all the better known makes of modern positive meters with a view to determining that best suited to the rather severe Mangere water.

All meters are placed adjacent to the service stop cocks and are enclosed with them and protected by means of light cast iron boxes.

Résumé of Principal Costs of the Work.

	£
Sinking and Testing main well	1,300
Well bores (3) cased and screened	240
Auxiliary bores (2) cased and screened......	150
Pumps, motors and controls (2)	1,234
Automatically controlled Chlorinator	220
Venturi tube and recorder	151
Level indicators (2), including cable	183
Lining well, brick pump and compressor houses, etc.	770
500,000 gal. reservoir (including 470 c. yds. 1 :1½ :3 concrete, reinforced and boxed, at £6 per cu. yd.	3,002
Pipes—30 miles, 10 in. to 4 in.—Class C spun C.I	22,380
Valves	700
Special castings and hydrants (600 at 11/-)	1,870
Pipe laying and trenching	5,470
Air lift plant	300
Auxiliary supply delivery line, including: Trenching, etc., 1400 cu. yds. at 15/6; Tunnelling, 750 ft. at 37/6; 9 in. R.C. Pipe, 2,200 ft. at 4/-	3,160
Filter Plant—21,000 gals. per hour capacity	1,750

Detailed Cost of Mains.

Size	Pipes.		Specials, Valves, Hydrants, complete—per chain	Laying and Jointing.		Total per chain.
	per ft.	per chain		Joint	Chain	
10" x 12'	7/1	£23 7 6	£2 1 9	6/-	£1 14 9	£27 4 0
9" x 12'	5/7	18 8 6	1 17 8	5/7	1 13 0	21 19 2
8" x 18'	4/7¼	15 3 11	1 7 10	5/-	1 0 0	17 11 9
6" x 18'	3/1½	10 6 3	1 2 4	4/-	0 16 1	12 4 8
4" x 18'	1/9	5 15 6	1 2 8	3/-	0 12 9	7 10 11

Trenching and Backfilling "Clay" area—17/8 per chain;
"Rock" area—27/- per chain.

N.B.—Costs of all imported goods were subjected to an adverse exchange rate of 10% at time of contracts.

Analyses of Mangere Waters.
(Unchlorinated)

	A	B	C	D	E	F
	Parts per 100,000.					
Chlorine in Chlorides......	3.6	4.2	4.50	4.45		
Nitrogen in nitrates	0.60	nil	nil	0.046		
Nitrogen in nitrites	0.0112	nil	nil	nil		
Ammoniacal nitrogen from free and salina ammonia	0.0115	0.0517	0.0520	0.0005	0.0068	0.0010
Albuminoid ammonia	0.0031	0.0009	0.0048	0.0022	0.0155	0.0100
Oxygen absorbed in 4 hrs. at 80°F.	0.082	0.192	0.187	0.161	0.209	0.100
Total Solids	27.0	45.0	44.0	45.0		
Iron, as Fe	0.03	0.35	0.34	0.025		
pH. Value	7.2	7.6	8.1	8.0		
	°Clark—Grains per Gallon.					
Hardness—Temporary......	1.7	8	8.2	8.2	11.9	
Permanent......	6.3	6	1.4	1.0	4.1	
Total	8	14	9.6	9.2	16.0	
Agar Count-colonies/C.C.	200	60	1	4	248	5
B. Coli	+1cc	+10cc	-100cc	-100cc	50% +0.1cc	50% +100cc

A—Main Well—Average Health Dept. analyses, 1929-1934.
B—Auxiliary Supply—Average Health Dept. analyses, 1929-1934.
C—Raw Auxiliary water-filter efficiency test, January, 1935.
D—Filtered Auxiliary water-filter efficiency test, January, 1935.
E—London—Raw Thames water, for comparison.

F—Houston's "Standards"—safe maxima for potable water. (London's filtered water comes well within these standards).

Nitrite in the main well is probably due to deoxidation of nitrate by iron, and does not necessarily indicate recent pollution. Amoniacal nitrogen as high as 0.0660 parts has been recorded from Auxiliary supply. Albuminoid ammonia is highly variable.

Notice that in the course of filtration (C and D) nitrogen is converted from the form of ammonia to the form of nitrate. The effectiveness of iron removal treatment is also demonstrated.

Bacteriological counts vary over wide ranges. Note the purity of auxiliary water in this respect during the present exceptionally dry period. (C and D).

Hardness of both waters is also very variable.

Mr. Firth, in introducing this paper, said that he desired to apologise for the absence of Mr. Page, who had found it impossible to attend the meeting. This was rather unfortunate, as after the paper was written, he himself had been transferred to another county, and was therefore not in direct touch with developments at Mangere during the past year. However, he had made it his business to keep himself fully acquainted with the results that had been achieved. During 1935, the compressor plant had been duplicated and a third bore had been installed. In conformity with test results the latter was put down with 6″ casing, coaxial 4″ delivery, and $1\frac{1}{4}$″ air line. This new bore had given a steady flow, as had been anticipated, but the yield of 6000 to 7000 gallons per hour under normal running conditions was little better than that obtained from the old bores. This indicated that the low values obtained for the "constant" in the air lift formula as applied to the Mangere bores was due more to the nature of the water bearing strata than to inefficient layout. The science of underground water supply had been developed to a considerable extent in Africa and Australia by specially trained engineer-geologists. A useful terminology, which might be of interest to members, was now in general use in these countries. The water content of saturated rock was given by its porosity, and consisted of two parts: first, "gravity ground water" which was readily available to wells; and secondly, "ground moisture" or water held by capillarity and molecular attraction. "Specific yield" was the percentage of gravity water present to the total volume of

the rock concerned; "specific retention" was the percentage of ground moisture present. There was no connection between porosity, and permeability or yield. Thus, clay had a high porosity of up to 52 per cent., a high specific retention, and a negligible specific yield, and was therefore useless for water supply purposes; clean gravel, with a porosity of from 32 to 36 per cent., had a high specific yield and a negligible specific retention and was ideal for water supply. The water bearing shell beds of Mangere contained a considerable admixture of fine shell debris and sand, with the result that their specific yield, though still relatively high (roughly 25 per cent.), was too low for high air-lift pumping efficiency. However, the total yield of the auxiliary supply was now from 14,000 to 15,000 gallons per hour. This, plus about 3,000 gallons per hour from the main well, enabled the pumping plant to operate well up to its rated capacity without difficulty. The paper contained some notes on the geology of the Mangere district, and he thought they would all agree that in underground water supply questions, the geology of the area was such a fundamental matter that a few more remarks on the subject would be of interest. For those who were not well acquainted with the Auckland district he might explain that the western part of South Auckland, from the Waikato River near Mercer to Manukau Harbour, was portion of an area down-faulted to the west along a pronounced fault, the scarp of which was now marked, particularly from Bombay to Papakura, by a sharply rising line of hills immediately east of the Great South Road. This downthrow to the west at one time formed a large estuary. During Pleistocene times, the Waikato River entered the sea by means of this estuary, and built up therein an extensive delta which orginally must have been over 30 miles long and at least 15 miles wide. To the west it provided its own margin, with the assistance of wind and wave action, in a long spit-like line of sandhills. These now formed Awhitu Peninsula. The deltaic-estuarine deposits were several hundred feet thick in places, and were typically pumice-derived silts and sands. Conclusive evidence showed that the floor of the estuary was still slowly sinking while they were being accumulated. Banks of shell occurred throughout the formation in several localities. They represented barrier beaches thrown up by selective wave action at times when the rate of accumulation of sediments exceeded the rate of subsidence of the estuary floor for periods sufficiently long to produce the reduction in off-shore profiles necessary for the institution of this action. On the landward sides of these barriers, swamps and lagoons tended to form and these, when buried, gave rise to bands of pug and lignite. Intense volcanic action broke out in late Pleistocene times. A great flood of basalt swept across the head of the delta from Bombay to Waiuku, and diverted the Waikato to its present mouth. Lesser vents broke through the floor of the old estuary at many places, particularly in the Mangere and Pukekohe districts, and formed numerous tuff and scoria cones. Later, after many fluctuations of level, the old delta established itself as an extensive lowland with a surface level roughly 50 feet above present sea level. The greater part of Manukau Harbour had been formed by the cutting back of the relatively uncompacted deltaic deposits by subsequent wave action. Material thus eroded had accumulated over the floor of the harbour as a thick veneer of highly impervious mud, and thereby formed an effective seal against the infiltration of salt water into underlying strata. Mangere was the northernmost remnant of the old delta; its salient position in Manukau Harbour was due to the protection from erosion given by its volcanoes; its shell bed was the largest recorded from the formation. To the east, at Otahuhu, there were extensive lignite and pug deposits which probably represented a lagoon or swamp associated with the shell bank. These deposits were undoubtedly the source of the iron in Mangere waters. Swampy waters precipitated iron in the form of bog iron ore, so that the presence of the latter in swamp accumulations was not unusual. One disadvantage of working on a down-faulted lowland was that there was no possibility of obtaining artesian water. In any case, the highlands to the east were of greywacke and Waitemata sandstone, and were incompetent to transmit artesian pressure. The question of water supply was concerned almost entirely with the characteristics of the Pleistocene formation of the district. The scoria cone of Mt. Mangere really affected the position only in connection with the tunnel section of the auxiliary supply delivery line. The tunnel passed under the flank of the mountain reserve. Water from this source was, therefore, almost entirely free from contamination and in winter time was a valuable asset. The question of demand provided a most interesting source of investigation at Mangere. During 1934-35, the total quantity of water pumped was 44,110,000, and the average weekly demand 850,000 gallons, an increase over 1933-34 of 10 per cent. The summer of 1934-35 had been particularly dry at the most critical period for market gardeners, and had resulted in a maximum weekly demand of 2,000,000 gallons. The range of weekly demand throughout this year was 600 per cent. The summer of 1935-36 had been relatively

wet and had appreciably eased peak demand. The original estimates for pumping were largely nullified by two factors. In the first place a particularly high and unexpected commercial demand had developed, which during 1934-35, had reached 11,000,000 gallons, or 25 per cent. of the quantity pumped. In the second place, they had thought that a deterrent to the liberal use of water would be placed on market gardeners by the price, but that had not been the case. Ever since the scheme was initiated the market gardeners had been using as much water as the system could give them and had paid for it quite willingly. The question of market gardening demand in the future was a vital one. There was, however, considerable justification for the assumption that the acreage under garden would remain appreciably constant. Mangere tended to become more and more urban and increasing ground rentals were therefore to be expected. Gardeners had the choice of cheaper land further out without water facilities or dear land capable of a more constant yield because of water. In view of their experience of gardening at Mangere it might be of some interest to members to have some details of the actual demand which they had experienced from the gardeners. Recently he had had a test undertaken in regard to a typical efficiently reticulated property of $4\frac{1}{2}$ acres. A 6-inch main passed along the front of this property, with meter, feeder lines and hoses, all of $\frac{3}{4}$ inch. The maximum length of feeder was 350 ft., with sprinkler points at every 50 ft. Hose lengths varied from 50 ft. to 250 ft. The consumption with one sprinkler only was 440 to 500 gallons per hour, with two sprinklers 670 to 720 gallons per hour, and with three sprinklers 1,000 gallons per hour. That particular property in dry weather normally worked with two sprinklers, but at times it used three. The dry weather operating time ranged from ten to sixteen hours per day. The dry weather consumption on this basis ranged from 1,500 to 3,500 gallons per day. Two thousand five hundred gallons per acre per day was quite a usual demand. The maximum daily demand on the whole system for the summer of 1934-35 was 400,000 gallons a day, and this had been attained on several occasions. During one or two short periods there had been draw-offs of 30,000 gallons per hour. It was estimated that of the maximum demand, commercial concerns would account for 60,000 gallons per day, domestic supply 60,000 gallons, leaving a balance of roughly 300,000 gallons per day for the market gardeners. This was an average of 1000 gallons per acre per day over the 300 acres of gardens in the district. It therefore appeared that a demand of 2000 gallons per acre per day would be a reasonable figure to adopt for a group of efficiently reticulated gardens. The auxiliary supply continued to do its work thoroughly, except, of course, that the yield was not as high as was expected. Air-lift pumping was not efficient, but was the best system available under the circumstances. During the past year the discrepancy between water pumped and water accounted for, had been reduced from 15 to 11.5 per cent., due to the replacement of faulty meters. To date, 200 old meters had been condemned after test and replaced. The new type of meter that had been installed was chosen as a result of extensive tests, and was giving very satisfactory results. These tests had been carefuly controlled to ensure that the meters would not be driven beyond the working rates recommended by the makers, and the test layout had been designed to emulate actual service conditions as closely as possible. The results obtained had been conclusive. (Slides exhibited and explained). The Mangere system was relatively small, but provided a number of unusually interesting features. Cheap water was never expected at Mangere. The position had, however, become acute, and the system adopted had given the most economical relief available. In their first season the demand was three times that experienced under the old system, although the number of consumers was the same. During the second season, it had been necessary to work the pumping plant to capacity on several occasions, to meet the demand. The cost of production was higher than expected, mainly because of unexpected developments. In the first place the partial failure of the main well and the accompanying rising demand meant that they had had to develop the auxiliary plant much sooner than they had expected. That had involved double pumping and more capital outlay. Then it had become necessary to install iron-removing filters. That had not only added considerably to the charges but had also reduced the yield of the auxiliary plant because of the extra lift entailed. The making of chemical as well as bacteriological analyses of the water had been entrusted to the Health Department, but their chemical analysis was strictly really only a sanitary analysis, and therefore the presence of iron had not been detected. Troubles with old galvanised feeders and the work involved in dealing with faulty meters had resulted in heavy supervision charges. The total cost of producing water was 5.7d. per 1000 gallons. Of this, the main pumping costs amounted to 2.1d. per 1000 gallons, the auxiliary plant 0.97d. per 1000 gallons, supervision and maintenance 1.80d., and sundries .78d., which included a certain proportion for depreciation. The installation

of filters was responsible for approximately 0.5d. per 1000 gallons. Water was charged for at 1/9d. per 1000 gallons. Annual revenue was roughly £3,000 a year and the charges £1000, leaving a balance of £2000 transferable to interest account. Under the circumstances, the position of the whole scheme was considered to be very satisfactory. In spite of unexpectedly heavy demands on plant and supply, they had not had to impose any restrictions on the use of water, not even during a very severe summer which had resulted in the application of restrictions in several neighbouring systems. As was well-known, the whole question of water supply in the immediate neighbourhood of Auckland had been subject to enquiry, and it would probably be only a matter of years before a metropolitan water board was established. With that in view, they would not have been justified in providing heavy and expensive pumping units, but had adopted instead a policy of meeting demand in this respect as called for. Reticulation however, had been designed to cover all future needs.

Mr. Corkill thanked the authors of this paper, describing an interesting water-supply scheme which presented all sorts of unusual features. It well illustrated the trend towards the utilisation of local underground sources of water by pumping instead of going further afield for upland supplies which is particularly noticeable in the Old Country. In New Zealand there were a number of towns which depended upon pumping for their supplies, and in the South Island it was rather curious to note how many of these schemes were troubled with iron. The author had explained the reason for the occurrence of iron, and it would appear that iron troubles were to be expected in such supplies. In Invercargill there was difficulty with iron, as also in Gore, which drew its water from wells about 18 feet deep. Iron trouble was scarcely to be expected there since the wells were very close to the Mataura River. In Balclutha it was even worse, where the water was drawn from a well in which it stood only 22 feet from the surface, and about 60 feet from the Clutha River. Here it was difficult to understand why iron-bearing water should be yielded rather than clear water from the Clutha, particularly when the topography of the country was seen, with the river running right round the town in a loop. At Mangere they used a Polarite filter. It was interesting to know that there had recently been developed simple methods of dealing with iron. It had formerly been considered that the zeolite process was not applicable to waters containing iron, but now, provided that the iron existed in the ferrous state, it could be treated by special zeolites.

The authors of the paper commented upon the hardness of iron-bearing water. In his own city, Invercargill, it was common to talk of the "hardness" of the water, which actually showed a hardness of only about 4 degrees. It was easy to show by the soap test that the water was not hard, but certainly the results in use were similar to hardness.

The results of the bacteriological tests at Mangere were rather disappointing. Could Mr. Firth suggest any reason for the high figures of B. Coli present? One would expect that waters coming from remote sources would be better than indicated.

In dealing with any well supply such as this the variability of the flow of the wells was extraordinary. One of his best wells, of 22-inch diameter, was at one time supplying 10,000 gallons per hour, and when a new pump was installed the output rose to 35,000 to 36,000 gallons per hour, and continued at this rate for some years. It then dwindled to 20,000 gallons, and suddenly dropped last year to 13,000 g.p.h. No amount of investigation had yet been able to explain this drop. He had made a tool like a large chimney-sweep's brush and brushed the interior of the borehole and slots clean, and he had removed large quantities of gravel, but there was no difference in the flow. His experience with 6-inch wells had been the same—after giving a good flow for some years the flow had dwindled to nothing, while new wells close by gave a good flow. The results at Mangere seemed to show that they had at first been drawing from an accumulation of water which had not been replenished. That sometimes seemed to happen.

The variability in the output of the wells had also a considerable bearing on the utility of the air-lift.

Mr. Firth had referred to his tests of meters. He (Mr. Corkill) had had the good fortune to see the results of these tests, and they were very informative. They made it clear that many of the meters were very unreliable. The main thing about a good meter for domestic use was its reliability at low flows. It was useless to have a meter which registered accurately at moderate flows but passed low flows without registering. People soon learned this and operated accordingly.

Referring to the quality of the water, the metals used in the construction of the meters were often very important. Meters built with usual metals were often useless in water such as that described.

The experience at Mangere, where no restrictions were required to be put on the use of water in a dry season, was typical, it being frequently the case that towns having pumped supplies were better off at such times than those having supplies from upland sources. At the same time pumped supplies, being dependent upon machinery, were at all times liable to breakdown.

The question of pipe breakages had been dealt with very interestingly. Statements as to the lack of strength of spun cast iron pipes were frequently heard, but Mr. Firth had given some interesting information on this point. He (Mr. Corkill) gave some figures dealing with large quantities of spun pipes, 12 inches to 4 inch, laid about 7 years ago, when the process of manufacture was not as good as it is to-day. Even then the total number of breakages was very small. Actually his impression was that all damage had occurred in the unloading, when, for instance, three or four 12-inch pipes were lowered into the trucks on the wharf in one rope sling, after which the ship's hook was hooked to one end of the sling and pulled, while the pipes rolled over one another and were cracked or broken in the process.

The 12-inch pipes were damaged more than were the smaller sizes; the amount of damage decreasing with the pipe size. Actually, on a consignment of 11 miles of pipes, only 131 feet were lost, other damaged pipes being salvaged by cutting off. This was very small, considering the sea journey from England, unloading, and transport by rail and then by lorry. As far as service was concerned, his experience was the same. Cracking of pipes had not been heavy. For the information of those who advocated steel pipes, he said that, in 5 years, 1½ miles of these had produced 14 failures—more than in the balance of about 60 miles of cast iron mains.

In conclusion, he wished to say that he had been very much interested in this paper, which warranted a good deal more study than had been given to it.

Mr. Furkert said that with regard to the shell banks, which apparently were not connected with Westfield district, it seemed to him that the shell banks would not be over a very considerable area, but rather in long stretches. He would like to know whether there was anything to mark the shell banks because that would give you an idea as to where to put down your boreholes. With regard to the water used by the market gardeners, he had been trying to arrive at how much per annum, at 1/9d. per 1000 gallons, the market gardeners paid. Mr. Firth had not given the time during which they used the water, how many days in the year, but he had tried to make an assumption, and had arrived at the figure of £2/5/- per acre per annum. That might sound a lot of money but really, judging by the value of the crop raised, it was probably not excessive. Apparently the gardeners themselves did not regard it as excessive. In Central Otago, when the Government charged the farmers one-quarter of that, they said they would be bankrupt, but of course they were not market-gardening but using the water for other crops. This evidence showing that the Mangere men were paying £2/5/- per acre should be valuable to Mr. Ball in his negotiations with the men in Central Otago. He had been taken over this Mangere scheme, which had struck him as being a very well considered scheme. He trusted that the authors would be able to produce duplicates of the illustrations for the *Proceedings*.

Mr. Slocombe said that in the estimates of consumption of water given the domestic consumption was set down at from 15 to 30 gallons per head per day. In most of the water-supply systems in New Zealand it had been found that the consumption was generally about 50 gallons, and even up to 80 gallons in dry spells when gardens were being hosed continuously, in spite of by-laws, which appeared to be almost unenforceable.

He presumed that the low figure adopted by Mr. Firth was based on the supplies being all metered, and there was no doubt, that if metering were universal, the very high consumption which was at present provided for in most towns, involving heavy capital expenditure on mains and headworks or pumping stations, would be very considerably reduced.

Discussion by Correspondence:

Mr. F. E. Powell wrote:—The paper by Mr. C. W. Firth, describing his water-supply scheme for the district of Mangere in the Manukau County, contains much useful information in respect of the geological structure of the locality, particularly as to its bearing on water supply, but I do not think his conclusions are borne out by the facts. Broadly speaking, the conditions are as follows: The Mangere Hill is a scoria cone of very porous nature resting upon a thick bed of Pleistocene silt of such fineness that it acts as a very slow filter. The upper surface of this bed is approximately at sea level, and forms the sea bed in the vicinity. Under the silt is the water-bearing stratum described in the paper as shell-sand. Mr. Firth correctly points out that no defined flow of water occurs as in other volcanic areas in Auckland, but that the shell-sand stratum forms a collecting basin, any surplus water escaping over the surface of the silt into the sea. He has assumed that the large amount of water undoubtedly stored in the shell-sand layer is available for a water supply on a fairly large scale. The figures given do not, as far as I can see, bear this out. The conditions are admirable for a large number of small individual supplies, such as would be suitable for small farms and market-gardens, but much too risky for a single large-scale undertaking. It is highly probable that this would have been recognised if investigations had been carried out long enough at the first well. The author points out that the tests showed that the quantity could be "conservatively estimated" at 7000 gallons per hour, yet, later we are informed that this supply has fallen as low as 3000 gallons per hour. It is well-known that in Auckland districts underground water supplies must be viewed with suspicion from the point of view of sufficiency, and a prolonged maximum trial pumping at this source would have been warranted.

The reason for the observed diminution of flow is not far to seek, and this dimunition must be viewed with anxiety on another score than insufficiency. Salt water overlies the silt layer everywhere in the vicinity and is only prevented from penetrating the silt "filter" by the static head of the fresh water constantly maintained in the scoria, which may be compared to a sponge. Should this "head" be disturbed, say, by abstraction of water from the shell-sand at any point adjacent to the tide—at the Ararata Creek well, for instance—in such quantity as to be beyond the capacity of the filtering medium to replace, it is only reasonable to suppose that salt water can be drawn in. Owing to the comparative imperviousness of the Pleistocene layer it would be a long time before such percolation became detrimentally effective, but its danger must be recognised.

Yeld and Demand.—I cannot reconcile the estimates given for present and future requirements with the statements for supply and demand. It appears that the present maximum demand exceeds the average by four times. It seems likely that the area will develop as a market-gardening district, for which it is naturally adapted, and the discrepancy between normal and maximum demand is not likely to decrease. Obviously, such extra demand will occur when the wells are least able to meet it. Consequently, maximum demand is the controlling feature. The maximum *yield,* as far as I can gather, from the original well, the two auxiliary bores, and the proposed third bore, will be only 480,000 gallons per day in dry seasons, equal to 3,360,000 gallons per week. But it would be extremely risky, not to say bad engineering, to assume this to be a safe estimate, more especially when the supply is dependant on continuity of flow. In any case it is only about fifty per cent. increase over what has already been experienced, and—arguing backwards—it means that at the best the supply is only good for a population one-and-a-half times the present figure, say 4500—a long way from the 16,000 suggested.

It may, however, be argued that such a small increase in population may accompany a large increase in the market-gardening business, and that the number of people concerned is immaterial as long as the supply suits the conditions. This is true, but in this case one of the conditions is cost, because water can easily be too expensive for market-gardening purposes. A thousand gallons will only give about one inch of water over a plot, say 40 ft. x 50 ft., which many of us would not regard as a large garden, and this amount is needed at least once a week in the volcanic soil at Mangere for vegetable growing. The allowance of 200 gallons per acre per day only amounts to one-twentieth inch per week, which is negligible.

Costs.—The total amount of expenditure is stated to be £65,000, and I understand that the rate of interest plus sinking fund equals 7½ per cent., which means an annual bill of £4,875 for these items. I gather that under a recent Act the ratepayers are relieved to the extent of 20 per cent. of the interest, which simply means that the unfortunate people who provided the funds have to find the difference. The working costs and the total consumption per annum are not given, but as far as I can judge the former must be about £1,000, and the consumption somewhere between forty and fifty million gallons per year. (I believe these figures are admitted). At the fifty million rate the cost per thousand works out at about 28 pence, and at the forty million rate, about 35 pence per thousand. It does not seem possible that the rate can ever become less than two shillings. A high price for water under the scattered conditions obtaining in the district is inevitable, but such figures are surely too high for practical use in market-gardening. Another way of looking at it is that as there are 700 houses (and presumably 700 ratepayers) their average water bill must be between £8 and £9 per annum, apparently for a consumption of about 15 gallons per head per day. The provision of plant seems to have been well thought out to suit the yield conditions, though the double pumping made necessary by the positions of the sources is objectionable and will be worse if it is found necessary to go further afield.

Pollution.—I understand that the Health Department when dealing with new sources of water supply is much less concerned, if at all, with chemical analyses than with the bacteriological aspect, so that it must have come as a surprise to find the pollution by iron. This seems a very undesirable state of things. Final approval of a scheme is also given by the Loans Board, and although this is not strictly an engineering matter, it does

seem that when a scheme is put before ratepayers, with the assurance that it has been authorised by responsible Government Boards, they would have the right to assume that all practical matters have been studied. This is not, of course, any reflection on the author, who very likely had to suffer as a result of a flaw in the system of Government control. On the other hand, it is to be noted that in the winter, some 20,000 gallons of water per hour come from intercepted surface water, via the supply tunnel, which crosses under a main highway at no great depth. It seems incredible that the Health Department has not objected to this.

Mr. Firth, in replying to the discussion, said, in reference to Mr. Corkill's remarks, there was a tendency for gravels to become iron-cemented with age, and therefore for waters, therefrom to be iron-bearing. With regard to apparent hardness of water due to iron, it was noticeable that there had been few complaints as to hardness in connection with the Mangere water since they had installed filters for the removal of iron. The average hardness of Mangere water was about 9 degrees, and was therefore not excessive. With regard to the presence of Bacillus Coli, this was due to the fact that the catchment for the supply was an extensive, intensely cultivated, heavily manured flat of low run-off. Bacilli counts in supply water had, however, never been dangerously high. The 100 ft. of fine sands over the water bearing shell bed had proved a reliable filter in this respect. Fluctuations in yield appeared to be almost inseparable from bore-derived supplies. Actually, the Mangere bores had been remarkably constant once they had settled down. The serious diminution of yield from the main well-bores was probably largely due to the drawing of fine sand into the shell bed. In the case of the auxiliary bores, the falls in yield experienced had been comparatively small and had been confined to early stages. Initial pumping drew off a certain amount of fine sand before the screens sealed themselves, and this would involve adjustments of the materials in the shell bed. Clogging of the screens in the sealing process was considered to be the chief cause of initial fall off of yield in these bores. With regard to spun cast iron pipes; on the whole, these had given remarkably good results. It was with one shipment only, and mainly with only one size of pipe—8-inch—that any great trouble had been experienced. Apart from that, there had been only about 1 per cent. of breakages, which was not unreasonable.

Several breaks had occurred since the completion of the contract but had not caused any great alarm—a little of that sort of trouble was to be expected. Regarding Mr. Furkert's question as to the nature of the shell banks; these were typically elongated and tapered off almost insensibly into the normal silts on all sides. Exploration by boring was the only way of locating such banks as those of Mangere, and it was here that private bores gave invaluable information. The very nature of the formation of these banks rendered them subject to changes in texture. The third auxiliary bore, for example, had apparently encountered a finer grade of material than that in the two previous bores, and this undoubtedly had an effect on yield. In regard to the cost of the water to the market gardeners, he had not the details at hand at the moment, but in most cases the water cost ran out at between £2 and £4 per annum per acre. Most of the gardeners were Chinese, and were good "payers." They apparently found it a payable proposition to carry on at Mangere in spite of high ground rentals and water charges. At Pukekohe, gardeners paid as much as 2/6 per thousand gallons for their water, but naturally there was not much of it used at that rate. Mr. Slocombe had brought up the question of domestic consumption. At Mangere, purely domestic demand rarely exceeded 15 gallons per head per day, and in a large number of cases was only about 7 gallons per head per day. Such low figures were due to the continued use of tanks by many householders, the absence of a drainage system, and to universal metering. Where water had to be pumped, the installation of meters on all supplies was usually a first essential. It was equally important, however, that meters should be carefully chosen with respect to the duties and the water with which they had to deal, and as Mr. Corkill had pointed out, particular attention should be given to the matter of accuracy at low rates of flow.

The President said that this paper was written in a racy style, and had been made very interesting by the authors. The scheme bristled with difficulties and gave one much food for thought. He was sure that members felt that they owed their thanks to Mr. Firth, and he would ask Mr. Firth to convey the Society's thanks to Mr. Page. He would like members to pass a hearty vote of thanks to the authors of the paper. (Carried by acclamation.)

In reply to correspondence the author wrote:—

Many of Mr. Powell's criticisms have been replied to during discussion, but the following amplification may be of value.

Conditions at Mangere are undoubtedly more suitable for numerous small individual supplies than for a single large undertaking, but this is generally true for all underground water supplies.

Mr. Powell's remarks with regard to such supplies in the vicinity of Auckland are in general correct. Unsatisfactoriness in this respect is to be expected from the nature of the strata encountered. The widespread Waitemata (Tertiary) sandstone formation, for example, consists of fine-grained sandstone of low specific yield, regularly interbedded with bands of impervious mudstone. It is water bearing only in fractured zones and in disconnected, irregularly disposed lenses or pockets of interbedded material of volcanic origin known as the " Parnell Grit." Wells in the "Grit" may give copious yields when first tapped, but invariably fall away rapidly.

In another category are Auckland's volcanoes. Several of these are yielding excellent supplies as a result of the concentration of water collected and stored in scoria cones into well defined drainage channels in lava tunnels or scoria "lanes," but more usually, flow basalts and scoria belts are so confusedly intermingled that innumerable small " pocket " supplies or general dispersions of water are the general rule.

Pleistocene strata form extensive lowlands near Auckland and present a third distinct case. In the east, at Otahuhu and Tamaki, and at New Lynn, they comprise fine grained, partly consolidated sands interbedded with considerable clays and pugs. To the west, towards the centre of the ancient estuary in which they were deposited, the former increase in importance and in size of grain, the latter become unimportant or may be absent altogether, and belts of shell sand—old barrier beaches—occur locally. The explanation of this is that in the east, the formation incudes typical marginal estuarine material; to the west, it is built up almost entirely of relatively clean, well sorted material from the juvenile Waikato. The central and western portions of Mangere are typical of the latter zone. Good yields of water are to be expected from the Pleistocene formation only if one of the shell banks is encountered. Mangere is unique in that the shell bank there developed is of considerable extent. Also, the beds overlying this bank are uncemented and remarkably uniform, and are admirably suited to the absorption of rain water, its storage, and its delivery to the underlying shell.

These conclusions are based on prolonged pumping tests and the results of several seasons of heavy drawoff, and on actual tests carried out on the strata concerned. Thus the normal Pleistocene sands of Central Mangere (in the vicinity of the bores) have a porosity of 40%—an indication of remarkable evenness of grain—and a specific yield of 5%. Dominant grain size is roughly 1/200″, but belts of much coarser, almost pure quartz sands were encountered in the bores. On the other hand, typical barrier beach shell sands, as given by samples from modern Manukau banks, have a porosity of 52% and a specific yield of 25%—this from a sample with 50% sand passing a ⅛″ square mesh, 30% passing 1/16″ mesh, the balance retained on an ⅛″ mesh and consisting of broken to complete shells (cockle). As far as can be ascertained, the Mangere shell bed agrees reasonably closely with this analysis.

The relative openness of the Mangere Pleistocenes ensures their complete saturation below ground water level. From the above figures, their yield would be 13,600 galls. per acre foot, and it therefore appears that a drawoff of 2,000,000 galls, per week maintained over a period of drought of as long as three months, would entail a lowering of ground water level of 6 feet over an area of only 300 acres—yet the shell bank is roughly 2 square miles in extent. This presupposes the shell bed to be not so much a reservoir as a means of providing easy passage to the bores for water drawn down from the overlying beds. The high specific yield of the shell ensures this. On the basis of a 300 acre circle of influence, the rate of draw down called for from the overlying beds at present maximum pumping rates is only 0.03 galls, per sq. ft. per day; this is only a fraction of the possible rate of yield from these beds as revealed by actual tests. Quite apart from this replenishment from above, the shell bed alone is capable of yielding of itself at least 68,000 galls. per acre foot, or on a conservative average thickness of 20 feet, 1,360,000 galls. per acre.

It would, of course, be extremely dangerous under the known circumstances to rely entirely on the result of research such as the above. Working operations over three summer seasons, including one of exceptional severity, have, however, resulted in a much smaller lowering of ground water level than that indicated above. A much larger circle of influence than 300 acres or a higher specific yield than 5% in the cover beds is therefore indicated, and in either case the conclusions reached are completely vindicated. (The drop in T.W.L. in the bores during pumping, recorded in the paper under "Air lift operations" is purely local, and is concerned merely with pumping efficiency. Beyond this restricted draw down, even within a few chains of the bores, ground water level has as yet not entered the wide tidal range of Manukau Harbour.)

One point to be remembered is that in a uniform formation such as that of Mangere, as ground water level is lowered at any point, surrounding ground water gradients will increase and the circle of influence must therefore progressively widen. Also, provided that drawoff is not out of all reason with reference to ultimate source of supply, lowering of ground water level must become progressively slower and slower.

Supply to the shell bed is undoubtedly assisted by the fact that the whole Pleistocene formation of the area, though essentially undisturbed, appears to have a slight dip to the N.W., imposed, probably, by tilting accompanying block fault movements. There is therefore a tendency for water to the east to seep down to the extensive pugs and lignites of the Otahuhu locality, and thence gravitate down this gentle slope towards Mangere Central and the shell bed. This would considerably widen the scope of supply, but is also probably the cause of the high iron content of Mangere waters.

The ultimate source of supply at Mangere is, of course, rainfall. Assuming again a catchment of only 300 acres, 8″ only of the average annual rainfall of roughly 50″ suffices to provide present annual requirements. Surplus water seeps into Manukau Harbour along the ground water table. Surface run-off is so light that few permanent streams exist in Mangere.

From the foregoing it will be seen that there is every reason for optimism as far as sufficiency of supply is concerned. The practical impossibility of contamination by entry of salt water is also demonstrated, quite apart from the effective seal to such action provided by the thick layer of impervious marine muds which is so characteristic of the bed of Manukau Harbour. Even if salt water did penetrate this seal, it would take between three and four years of continuous drought for it to follow the lowering fresh water T.W.L. down into the shell bed—again on the basis of only 300 acres catchment.

Diffusion of salt into fresh water would undoubtedly reduce this estimate somewhat, but it is difficult to imagine any source of real danger in this respect with our present rainfall. Mr. Powell's statement in this respect of disturbance of retaining "head" by abstraction of water from the shell sand "in such quantities as to be beyond the capacity of the filtering medium to replace" is surely unconsidered. If this medium were so impervious to its own contained water, it would be equally so to salt water, and in any case this contained water would have to be removed—from 100 feet of strata—before salt water could reach the shell bed.

Mr. Powell omits to mention the existence of the basal basaltic shelf under Mt. Mangere, and therefore places undue importance on the effect of the Mountain in restraining salt water and in supply matters generally. The material of the

Mountain is so pervious that it is better compared with a colander than a sponge. (The unqualified use of the term "porous" is to be deprecated; there is no connection between porosity and permeability.) The main well penetrates both the scoria levels of the Mountain and the underlying basalt sheet, but run-off is so rapid—along the scoria-basalt contact into the sea—that there is surprisingly little difference between summer and winter T.W.L. Confidence in the scheme has been developed entirely upon a knowledge of conditions in the Pleistocene formation; any assistance derived from the Mountain is considered only in the light of a useful additional "factor of safety." With regard to the interception of surface water by the auxiliary supply delivery tunnel; this tunnel section of the delivery line is adjacent to the main well and is entirely under a public reserve—the whole Mountain is an unoccupied reserve. It is sealed from the more remote shallow cut and cover section along the Main Highway by a manhole at the tunnel entrance, and is therefore effectively protected from pollution. The tunnel crosses the basalt-scoria contact.

It is obvious that Mr. Powell considers the diminution of flow from the bores to be insufficiency or partial exhaustion of supply. This is not so. The fall from 7,000 galls./hr. to only 3,000 at the main well, as pointed out in the paper, may be partly due to this cause, but is now considered to be primarily due to disturbance of the strata, known to have taken place during experimental stages, causing inflow of fine sand from the overlying beds into the shell bed, and thereby decreasing its specific yield. Unfortunately, the fact that bores at this point have to be drilled through the limited area of the base of the well does not permit of the installation of new bores sufficiently clear of the disturbed zone to remedy this condition. Mention is made in the paper of the bringing back of the yield of the well bores by the use of an air lift plant. This plant was in almost continuous operation for about two months during the first season of supply, and the fact that no difficulty was experienced in maintaining an output equal to the original test yield, indicates that this quantity is still available if assisted in overcoming the increased resistance to flow of the sand affected shell bed. The cost of providing this assistance is, however, uneconomical.

In the case of the auxiliary bores, the relatively small initial fall in yield experienced, apart from that caused directly by the additional lift entailed by the introduction of filters, is entirety due to partial clogging of the fine mesh screens by fine sand in the course of their sealing themselves against inflow of such material. This action is to be expected and is unavoidable. Relief may be and has been obtained by driving the screens slightly, but the advantages derived are usually temporary only and are offset by the danger of damaging the screens. It is possible that it would have been expedient to use coarser screens than the 30 mesh to the inch adopted. This, however, would have entailed the withdrawal of considerable fine sand before the screens could be considered to be sealed, and would have introduced the danger of drawing into the shell bed still finer material from the overlying strata. It will be remembered that ⅛" slotted screens were used in the main well bores, and that the results obtained therefrom had been far from encouraging.

No further drop in yield has occurred in the auxiliary bores after three seasons of heavy drawoff. As at the main well, yield may be increased merely by providing additional power to overcome the resistance introduced by this very necessary sealing of the screens against sand inflow. In any case, should a bore fail, there is ample room at the auxiliary supply site to clear disturbed ground. In an emergency, a new bore could be drilled and put into commission within 48 hours.

It has been the policy of the Council to develop supply as warranted by the demand, partly because it is economical to do so, and partly because it can only be a matter of time before a desirable consolidation of water supply interests in the vicinity of Auckland is effected. Capital expenditure on plant has therefore been kept down as low as possible to safely meet ruling conditions. It is true that wholly unexpected summer demand has considerably reduced the margin anticipated at this stage in the life of the system, but this can be economically remedied when warranted. As far as sources of supply are concerned, under the admittedly tricky conditions obtaining at Mangere, it is safer to develop a series of interconnected small bores as required, than to rely entirely on one or two large bores or wells.

The trend of development in the matter of demand is difficult to forecast, and is dependent entirely upon the future of market gardening operations. Under the old system installed by Mr. Powell, the maximum delivery obtainable on a property of any extent was only in the vicinity of 100 galls. per acre per day, even in the most favourably situated gardens—the system had been intended for domestic supply only. As a result, there was a definite drift of gardening interests to localities further afield, where lack of water facilities were offset by cheaper ground rentals. It was in the interests of the district to halt this drift, and this has been accomplished by providing a water supply the advantages of which adequately offset relatively high rentals. The acreage under garden has been remarkably constant over a number of years, and there appears to be considerable justification for the assumption that it will remain so. By the time the population in the water supply area reaches the, anticipated, future 16,000, land will be definitely too valuable for market gardening on a large scale. A state of balance may reasonably be expected.

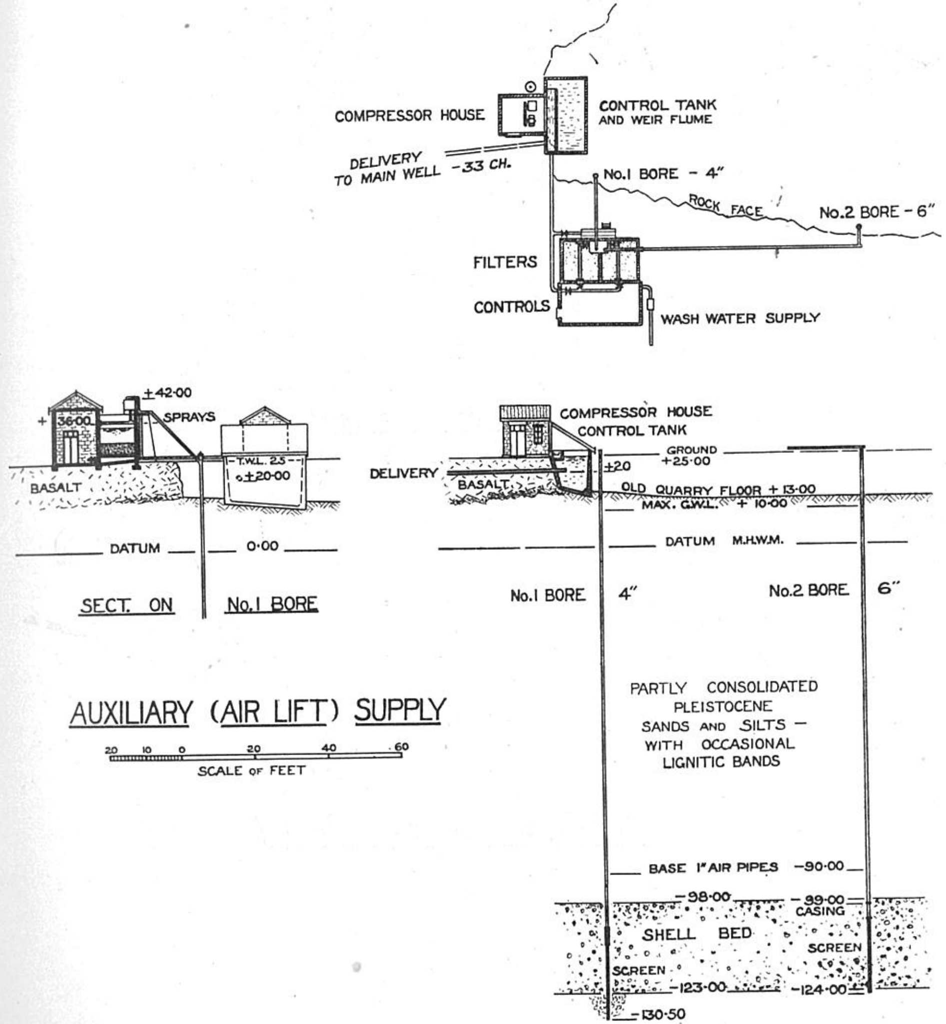
The questions of costs and rate of gardening demand have been dealt with under discussion. To recapitulate—it has been found that the average maximum demand is in the neighbourhood of 1,000 gallons per acre per day, but that this is greatly exceeded in some properties. There is as yet no question of water being too expensive for this purpose. The original estimate of 200 gallons per acre per day had been adopted in the belief that at 1/9 per 1,000 gallons, the use of much larger quantities would be prohibitive, and that there would be a strong incentive to retain the private supplies then in use. The present cry of the gardener, however, is for still more high pressure water. Although this high seasonal demand has involved wholly unexpected development of the supply system and has greatly reduced the anticipated margin of the plant, these disadvantages have been more than offset by resultant additional accrued revenue.

At the present time some 770 services are in operation, but 57% of the total consumption is accounted for by 90 services on non-domestic supplies. For this reason the average annual charge for domestic supply, including water rate, is only about half the averages arrived at by Mr. Powell. During the past season production costs on the 44,000,000 gallons pumped amounted, roughly, to £1,050, and revenue to £3,000. Cheap water was never anticipated at Mangere. The position had, however, become critical, and has been met in the most economical manner possible.

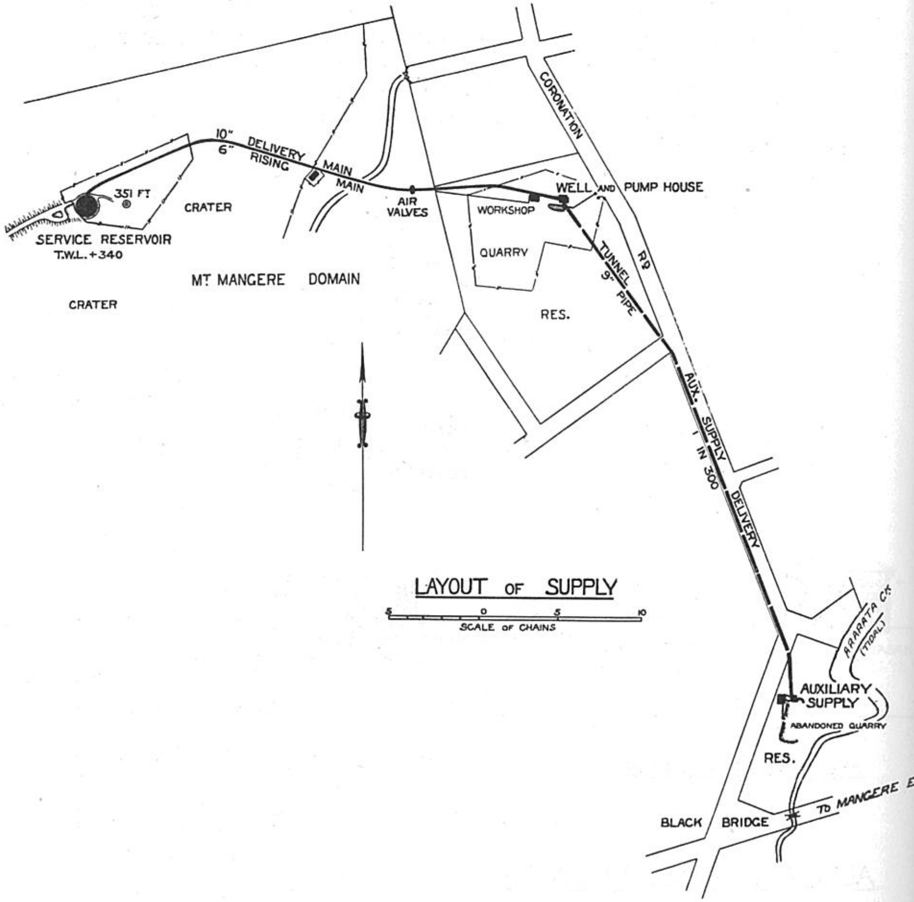
From the foregoing, it will be seen that right from the inception of the scheme, nothing has been left to chance. Mr. Powell's suggestion that investigations were too limited and that therefore the difficulties and risks involved were not recognised, is erroneous. It was because the difficulties were so fully appreciated—as a result of special knowledge of the district—that investigations, including several periods of prolonged pumping at maximum rates, were extended over several years before permanent work was attempted. The only serious omission in the matter of investigations resulted from the failure on the part of the Health Department analysts to detect iron in

auxiliary supply water. Complete chemical analysis had been requested, and the results obtained were thus described. It ultimately transpired, however, that this was a case of loose terminology, and that sanitary analysis only had been undertaken.

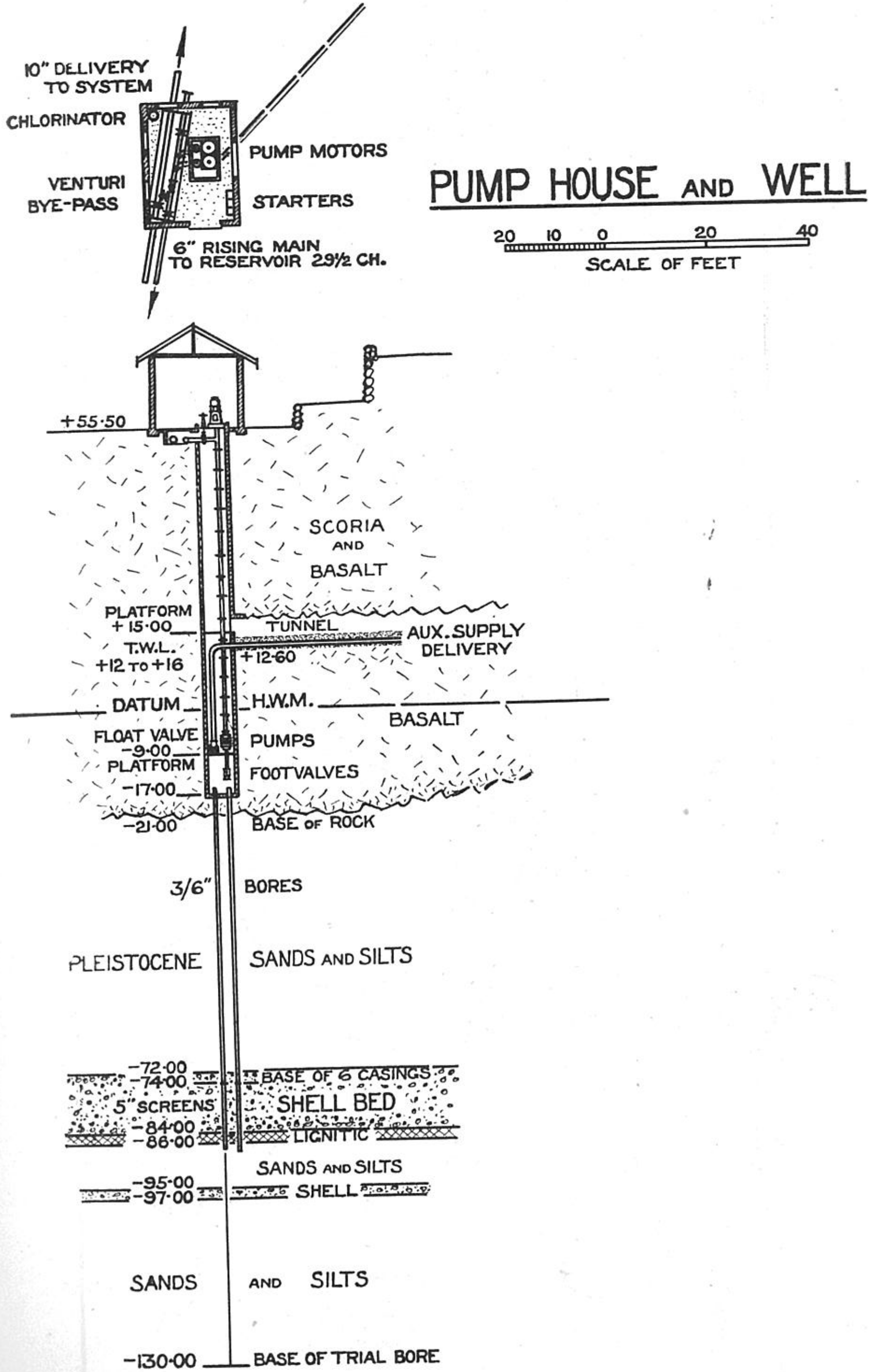
In verification of replies given to Mr. Furkert's enquiry as to the annual charges for supply to market gardens; the average figure over 300 acres for the 1934-35 season was roughly £3 per acre, and the maximum for any one property, £4/10/- per acre over 17 acres. Private bores are still in use on several properties.

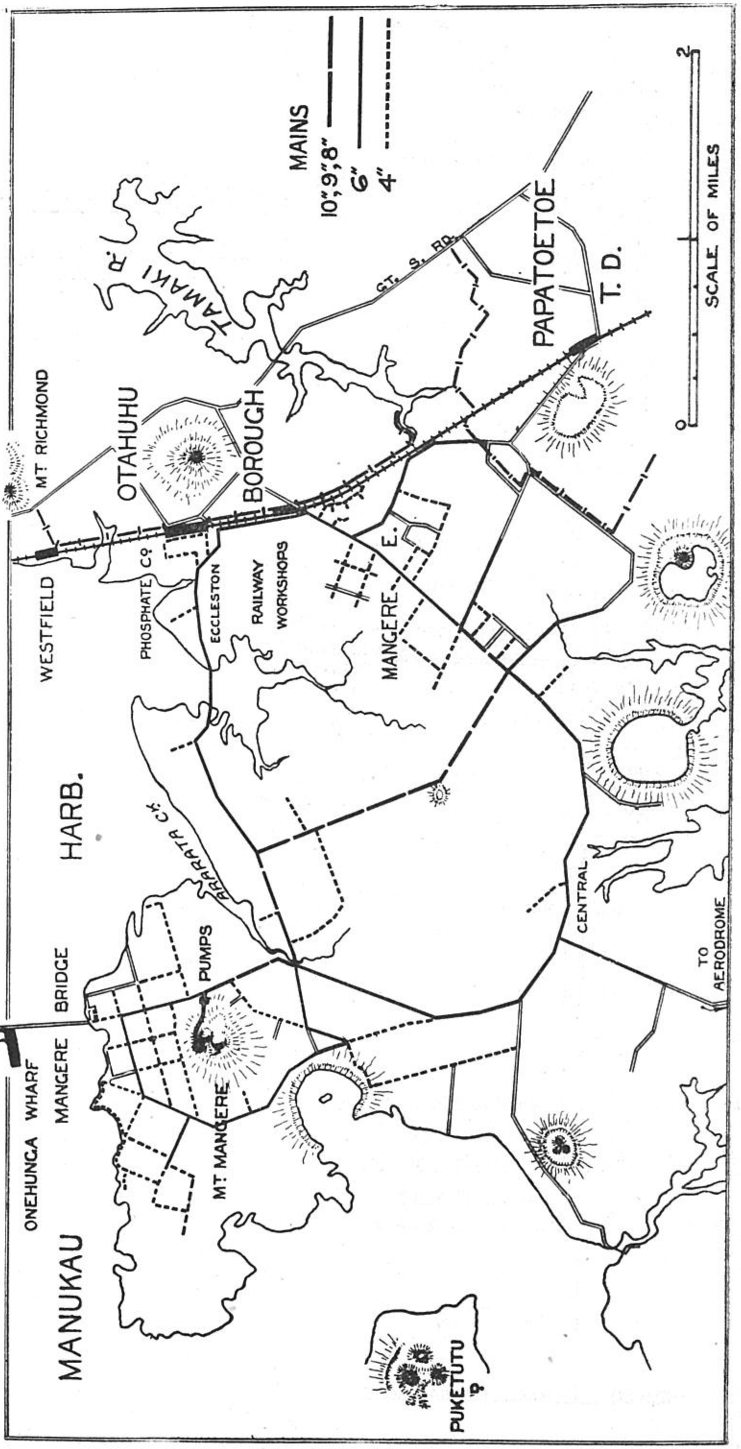


AUXILIARY (AIR LIFT) SUPPLY



MANGERE WATER SUPPLY





THE OMAKAU IRRIGATION SCHEME.

With Special Reference to Concrete Pressure Lines.

By DONALD F. HULSE.
(Associate Member).

Introduction:

The Omakau Irrigation Scheme, which came into action in November, 1935, will irrigate 16,000 acres in the upper portion of the Manuherika Valley in Central Otago. (See Fig. 1.)

An annual rainfall of 12—18 inches, coupled with high summer temperatures, places Central Otago at a decided disadvantage compared with more humid portions of the Dominion.

The valley floors are sparsely covered, with the hills in a denuded state. Fortunately, however, the soil in the valleys is quite good, composed of mica schist silt overlying gravels, thus affording almost ideal conditions for irrigation.

The area covered by the Omakau Scheme is typical of the semi-arid Central Otago region, with the exception of about 4,000 acres which was partially irrigated by private concerns. The Scheme provided for the consolidation of these private rights with a resultant economy in distribution and maintenance, and also included the expenditure of £15,500 on the purchase, rehabilitation, and extension of the Matakanui Scheme (out of Thompsons Creek), which was controlled by the Vincent County, and which through shortage of water was serving a large area inefficiently. (Fig. 2.)

The Main Scheme commands a large portion of this area, thus making part of the Matakanui water available, through the extended system, for additional good land above the main scheme.

The total area to be irrigated is made as follows:—

	Acres.
From Main Race:	
Omakau Basin and Chatto Creek Section	10,500
From Thompsons Creek:	
Matakanui Section	3,500
From Lauder Creek:	
Lauder Section	2,000
Grand Total .... Acres	16,000

The Lauder section covered the purchase of a large private right out of Lauder Creek and the construction of a new race system at a total cost of £19,500.