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Commissioning and Maintaining a Water Well in New Zealand: A Guide to Good Practice

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Commissioning and maintaining a water well in New Zealand: a guide to good practice.

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Abstract

This guide briefly covers all facets of well commissioning and maintenance, and provides a simple reference document which will assist a prospective well owner to follow a logical sequence of steps in commissioning a well and to be sure that construction is to a high standard. It also explains the responsibilities of the parties to a drilling contract and what can realistically be expected. Finally it outlines necessary well maintenance procedures and steps to follow when a well is permanently shut down.

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1. Introduction

1.1 Ground water use and development in New Zealand

About 25 percent of the urban population of New Zealand uses 200 000 cubic metres of ground water per day for domestic purposes, and much larger volumes are used by industry and for irrigation.

Use of ground water is expanding rapidly, especially for irrigation, and in some areas the resource is already fully committed or over-committed. In other areas, there are large ground water resources still available for development. But whatever the situation, ground water is an enormously valuable resource which must be developed and managed wisely to achieve maximum long-term benefit.

Large organisations commonly sink many wells to support increasing demand, and employ consultants who understand the ramifications of locating, exploring, abstracting and protecting ground water. Rural dwellers, farmers and small municipalities or industries may be interested only infrequently in acquiring ground water and may not normally be backed by professional advice. They may themselves need to exercise oversight of drilling and well construction. This guide is directed towards these latter groups of well owners and prospective well owners; individuals and small companies who once or twice in a lifetime invest considerable money in constructing a well. For the professionals in the ground water field there are existing overseas codes of good practice written in considerable detail (see bibliography), which can be adapted to differing New Zealand situations.

1.2 Ground water occurrence

Ground water is mostly derived directly from rainfall, and represents that fraction of rainfall which, instead of entering a river and flowing rapidly back to the sea, infiltrates into rocks that contain sufficient pores or crevices to absorb it, and slow its seaward flow. Ground water remains a transient resource, but much less so than is river water. Thus, it cannot be preserved simply by not using it, and conservation in a ground water sense simply means using it at the average rate at which it is replaced by natural or artificial processes.

Aquifers are geological formations containing ground water in economically useful quantities. Many subsurface rocks are completely saturated with water, but it is only when the material is sufficiently permeable to enable water to be easily extracted that the term aquifer is applied.

1.2.1 Ground water movement

Ground water flow obeys normal physical laws, inevitably flowing from areas of higher to lower elevation. It is true that ground water can flow 'uphill' under pressure, e.g., from flowing artesian wells (Fig. 1.1), but this is a special circumstance. Its ultimate destination is the sea, towards which it moves at speeds ranging from a few hundred metres per day to a few centimetres per year. It is, therefore, a dynamic resource with the level of the water table varying according to the amount of water entering the aquifer and the amount which is pumped out, or leaks out to a river or the sea.

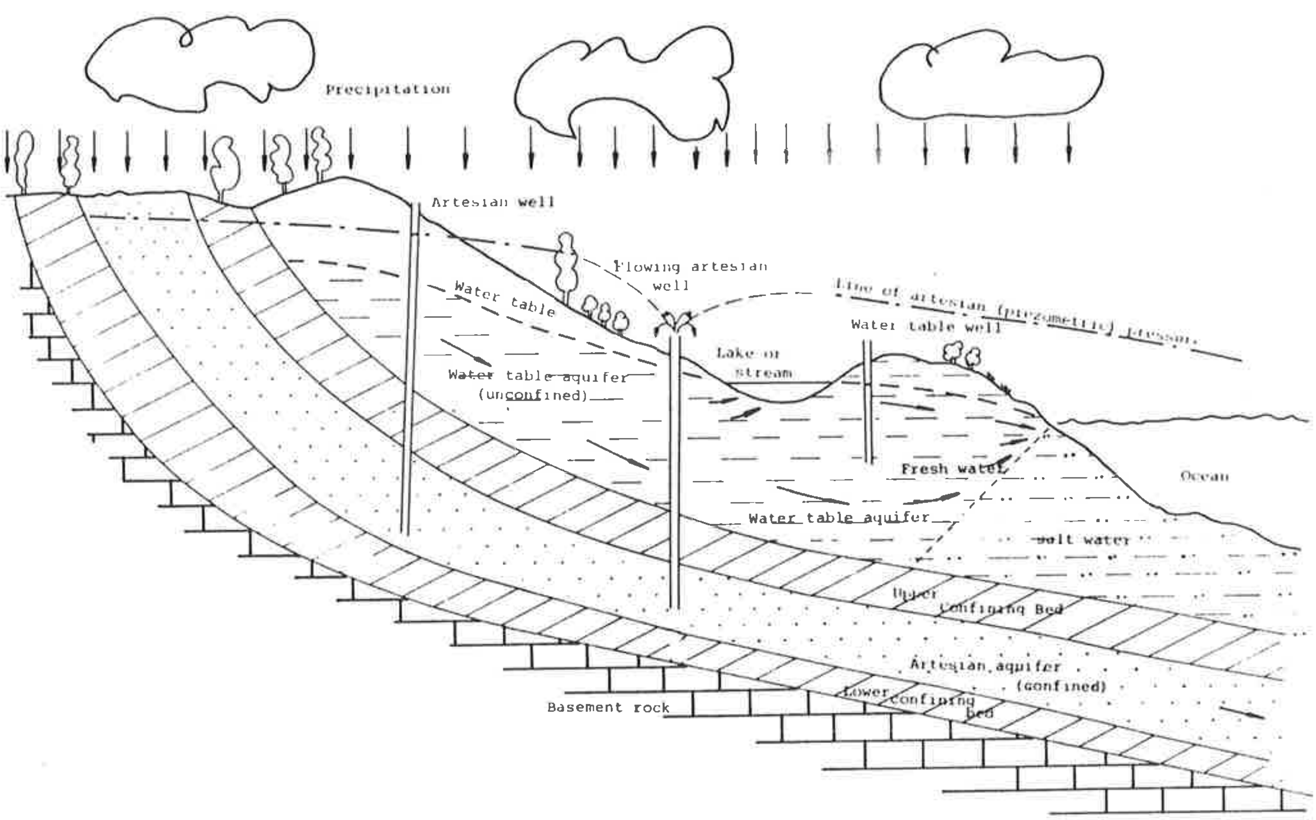


Figure 1.1 The ground water section of the hydrological cycle.

A marked advantage of ground water as a resource is that many aquifers store large volumes of water which can be drawn upon during an extended period of low rainfall and will be replenished when rainfall over the recharge zone exceeds drawoff and leakage.

The most prolific aquifers are those which are formed of coarse sediments, such as sands and gravels. Water can move freely through these materials (i.e., they are very permeable) and can be pumped out at high rates. Fine-grained sediments, such as silts and clays, clay-bound gravels, or solid rock (unless it is fractured), will not yield good water supplies, even if they are saturated. Younger sediments tend to provide higher yields than older sediments which are more compacted and cemented.

Rapid through-flow prevents the water picking up high concentrations of minerals from the aquifer rocks, resulting in excellent quality water. Conversely, where water has been in an aquifer for a long period, there is often a high content of dissolved minerals which may require treatment before the water can be used.

2. Preparation for Drilling

2.1 Deciding to drill and locating the well

The decision to construct a water well normally arises from a need for water, an awareness that ground water may be a viable supply and a belief that the costs are supportable. The questions that require consideration are as follows:

2.1.1 Will the ground water supply be adequate?

There can be no precise foreknowledge of what a well will produce, merely an assessment of prospects.

The first people to approach for information on ground water availability are the staff of the regional water board who can, if necessary, re-direct enquiries to the best source of geological or other advice.

A knowledge of the local geology is vital in assessing ground water prospects. The most common situation is where the would-be abstractor is within an area that has already been tapped by neighbouring wells. The success or failure of these is an important pointer to expected yields and aquifer depths.

Thus, information on both well yields and water quality should be sought from nearby well owners, local drillers or the regional water board. Advice on the applicability of that general knowledge to a particular site should be sought from a geologist, or from an organisation with an awareness of geological opinion, again most probably the regional water board. Such enquiries should enable a reasonable assessment of chances of success to be made, although it can never be assumed that aquifers persist laterally, even over short distances.

On occasion the would-be well owner breaks new ground by drilling in an unexplored area or by drilling to a greater depth than any local well. In such cases it is even more important to seek geological advice before drilling to give an indication of the presence or absence of possible aquifers and hence avoid wasting time and money.

2.1.2 How should wells be located?

Well location should be determined firstly by the management needs of the owner, secondly by the design requirements of the distribution system, if any, and thirdly by the cost of bringing power to the site. There is seldom any geological justification for insisting on a precise spot for drilling, although this is subject to the following qualifications:

- If the available area is terraced, it is normally preferable to site on the lowest surface.
- If the aquifer is bowl-shaped or dome-shaped (normally this occurs only in areas of Tertiary sediments*), drilling should be near the centre of the bowl or down the flanks of the dome.
- For volcanic aquifers, drilling should be near the lowest point of the aquifer.
- For all aquifers, well location should be as far as possible from, and preferably upstream of (in terms of ground water flow direction), any sources of contamination such as septic tanks, sites of intensive animal production, waste dumps or industrial sites.

If drilling in an area of irregular topography, for instance in dissected downland, do not select a site without consulting either a geologist or a ground water hydrologist who is familiar with the geological characteristics of the area. In areas where the choice of site is virtually unrestricted, there are many organisations which will be willing to help choose a suitable site. Among the most knowledgeable are drilling firms with long experience in the area.

2.1.3 Should a water diviner be employed?

Many prospective well owners choose to employ a water diviner to site a well. The authors are firmly of the opinion, based on long experience, that such mystical methods have led to a great deal of wasted time and money.

Ground water may indeed be found where indicated by a diviner but this by itself does not constitute proof of the effectiveness of the methods. In many areas ground water conditions are so favourable that water will be obtained by drilling virtually anywhere, so the success of a well on a divined site is almost inevitable.

To demonstrate their worth, diviners would have to show a success rate significantly better than that of a ground water geologist, an experienced driller or indeed random chance. This has never been done and in fact the opposite is true. There is no acceptable scientific evidence that water divining works; whenever controlled tests have been done, the claims of the diviners have been disproved.

2.2 Ground water administration and laws

The decision as to how ground water withdrawal should be related to ground water replenishment is extremely important. One effect of excessive pumpage, either seasonally or long term, will be a general lowering of the water table, which may increase pumpage costs and require lowering of pumps or

*The Tertiary period extends back from about 1.7 million years before the present to some 65 million years before the present.

deepening of wells. In addition, under some geological conditions, overdrawing may lead to subsidence of the land surface. It is therefore important that ground water abstraction be regulated; in New Zealand this is done by the National Water and Soil Conservation Authority which delegates the responsibility for all water resource management, including ground water, to regional water boards.

2.2.1 Water right legislation

The 1967 Water and Soil Conservation Act vests in the Crown the sole right to take natural water, whether from a stream or an aquifer, and management of the water resources of New Zealand is the responsibility of the regional water boards. Any prospective user of ground water (except for domestic, stock or firefighting) must apply to the regional water board for a water right or rights to authorise the taking of water. Any such right is normally for a defined period and details the source and quantity of water to be taken and the use to be made of it. Other conditions may also be specified by the regional water board.

2.2.2 Applying for a water right

Because of the legal requirements of the Act, the time involved in obtaining a water right can vary from two to six months or more depending on whether or not there are objections.

It is not necessary to have a water right in order to begin drilling but if there is a possibility of objections it is sensible to apply two or three months beforehand.

On receipt of an application the regional water board will advertise it in the local newspaper. Objections to the granting of the right may be submitted to the board concerned within 28 days of this public notification. A decision on the granting of a water right will be made by the board, or by a tribunal set up by it to hear evidence relating to the application and to the objections. The applicant and objectors will be advised of the decision and the reasons for it. Any appeal against the decision, either by the applicant or an objector, must be made within 28 days of that decision being posted. Such appeals are made to the Planning Tribunal whose decision is final (except on points of law).

The amount of water authorised by the right may be less than requested if this is considered necessary to ensure that other users will not be prevented from obtaining at least reasonable quantities of water for domestic, stock or firefighting purposes. A water right may also be declined.

2.2.3 Local bylaws

In addition to the administration of water rights a number of regional water boards have, pursuant to Section 4 of the Water and Soil Conservation Amendment Act 1973, adopted bylaws regulating the sinking of wells. One of the most common requirements of these bylaws is that a permit must be obtained before a well is sunk. Therefore, before any financial commitment is made, it is essential to check with the board whether a permit is required.

3. Drilling Contracts

Because of the variability of geological conditions, each drilling operation is to some degree exploratory, carrying with it the risk of failure to strike water. This risk is mainly borne by the prospective well owner. The driller is responsible for satisfactory construction of the well but cannot guarantee production of a specified amount of water.

3.1 Advantages of a contract

In a business transaction such as well drilling there are many opportunities for misunderstandings to arise. The use of a contract is the best way to ensure that the responsibilities of all parties are clearly defined and thus reduce misunderstandings to a minimum. A well prepared contract is also more likely to attract the more experienced and responsible contractors. When there is no contract or details are sketchy, vague or unduly restrictive, the bid of the less responsible contractor is likely to be lower than his more responsible competitor. The experienced contractor must include in his price an allowance for contingencies, must avoid unbalancing his quote and will refuse to take a chance that a major portion of his profit will result from claims for 'extras'.

The chances of securing a good contractor can be increased by using proposal forms that will protect him to the fullest possible extent against contingencies which could increase his costs without adequate compensation.

The New Zealand Drillers' Federation Inc., P.O. Box 1318, Hamilton, can provide a list of federation members active in any region. Selection hinges upon personal choice based upon interviewing the available drillers and perhaps also discussions with neighbouring well owners.

3.2 Specifications

The specification is the section of the contract which lays down the details of the drilling programme. The wording should be flexible to permit mutually beneficial variations where drilling conditions prove to be different from those anticipated. On the other hand it must clearly define:

- Method of drilling
- Method of well logging, water and rock sample collection and storage
- Standards of verticality and alignment
- Materials to be used in the well casing and screen
- Welding standards required
- Method of selecting screen slot size
- Method of well development
- Maximum sand content permissible
- Type of production test to be done on completion of drilling
- Details of well head completion and site restoration at the conclusion of the job
- Requirements for reporting construction details to the owner

The specification should also clearly specify who is responsible for arranging access to the site and any limitations on the activities of the driller.

In some cases the specification may be written by the client or his/her agent, but where technical knowledge is lacking the driller may write the specification so that the client knows what is being paid for and can have the specification checked if desired.

3.3 Types of contracts

There are two bases for securing quotes for water wells: lump sum contracts and unit rate contracts. Lump sum contracts are only considered when both the drilling conditions and well depth are predictable. These contracts are seldom used in New Zealand and are not considered further.

Where there is doubt concerning the extent of the work, which may require changes in estimated quantities, a unit rate contract is usual. Unit rates may be expressed either as hourly rates for each activity or item of equipment, or as rates for depth drilled plus supply of materials. Such contracts must be carefully prepared to ensure that all parties clearly understand what is included in the rate quoted.

3.3.1 Hourly rates

These are used where drilling and general operating conditions are unknown and cannot be predicted. Hourly rates are also normal for well maintenance and rehabilitation work (see section 8).

The rate is for hours actually spent drilling and includes an allowance for time spent on maintenance and repairs up to a certain maximum per month. All materials are extra, and may be purchased by the client or supplied by the contractor, at rates set under separate agreement. Separate rates may be used for non-drilling activities such as setting screens, developing and testing the well, or withdrawing casing. Positioning and removal of equipment are normally set as a lump sum.

Working to an hourly rate encourages a contractor to work a little more slowly and carefully. This may be the best form of contract where aquifer characteristics are unknown or water-bearing strata are thin and might be missed by a driller in a hurry.

3.3.2 Depth and materials rates

These are used where drilling conditions are generally known, but the depth of the well cannot be predicted.

The contract is priced on the basis of some small lump sum items plus a schedule of estimated quantities and rates. Thus, if the actual quantities prove to be different from those originally estimated, the overall cost can be easily altered. The following should be included as a minimum:

- Positioning and removal of equipment—lump sum. Includes all costs and profit margin for bringing and removing the drilling rig, accessory equipment and staff to and from the site. This excludes materials, but may include accommodation costs when working away from base.
- Depth rate (cost per metre drilled). This will take account of hole diameter, expected penetration rate and the method of drilling. The contractor's quote should include allowances for time spent "fishing" for gear lost down the hole, rig and equipment maintenance time, operating overheads, daily travelling, freight, wages and salaries.
- Supply of materials and delivery to site, i.e., rate per metre of casing or per bag of drilling mud, etc.
- Time rates for equipment. These include all work not covered by the drilling rate, such as standby, well development, pumping, withdrawing casing. The cost of stoppage through bad weather is carried by the contractor.
- The contractor and the client should agree that all unit rates are subject to variation by mutual agreement in writing, which is standard commercial practice. Contractors should allow for the risk involved in drilling, and the agreements should be finalised before the contract is signed.

3.4 Arbitration

Most contracts include an arbitration clause which sets out a procedure for resolving conflicts of contract interpretation without resort to law. Contracts which lack such a clause should be avoided; the nomination and acceptance of an arbitrator can avoid many serious conflicts.

4. Well Design

The overall economy of a well depends not so much on capital outlay as on the long-term operating and maintenance costs. In designing a well therefore, particular attention must be paid to minimising these costs.

Detailed design varies greatly according to the local geology but some general principles can be identified and are discussed below.

4.1 Single or multiple wells?

In aquifers of high permeability a choice may exist between pumping the required yield from one or a number of wells. If only one well is used it will need to be larger in diameter, with the pump set deeper, and fitted with a more powerful motor. The cost of a single larger pump and motor in a deeper well has then to be compared with the cost of drilling several shallower wells equipped with smaller pumps and motors. However, there is no doubt that a single, carefully designed and constructed well is more efficient than a series of wells pumping the same total amount.

On the other hand, standby and maintenance must also be considered. If the single well is shut down the user must depend on storage, whereas shut down within a multiple well system allows a continuous, although reduced, supply to be maintained.

4.2 Continuous or intermittent pumping?

In some situations it may be cheaper to use off-peak power to pump the whole requirement at a high rate for a short time compared to continuous pumping at a lower flow. The local power board should be consulted on this point. However, the delivery of the total requirement in a short period requires an aquifer of adequate permeability, and a bigger pump contained in a larger diameter, deeper well. Pipeline costs will also be greater and storage facilities may be required. These are all capital items and must be amortized over the expected life of the well to compare with the saving obtainable by using off-peak power.

From a well maintenance viewpoint, it is preferable to pump at a steady rate rather than intermittently.

4.3 Well diameter

Well diameter is usually governed by the dimensions of the pump (see section 7.4.4) and only indirectly by the pumping rate.

A key factor in improved long-term well performance is to keep water velocities to a minimum (see section 4.4) which can be done by increasing the diameter of the well and screen. This is also an effective way of increasing well yield in thin, but highly permeable aquifers. However, in aquifers of lower permeability, doubling the diameter will only increase the yield by 10–12 percent; this is not usually economic.

4.4 Well screens

The screen forms the interface between the aquifer and the well and is the critical component in ensuring maximum well efficiency.

A screen is designed to:

- Permit effective development of the aquifer (see section 5.7) thus improving the yield of the well for a given pumping lift.
- Avoid high water velocities at the entrance, which cause increased energy losses and can lead to accelerated corrosion and incrustation by minerals dissolved in the water.
- Provide a stable filter to permit the entry of water, free of sand.

In gravel aquifers the selection of a screen may be quite straightforward since the gravel is too coarse to pass through the screen, and after well development the gravel itself forms an additional filter. In sand aquifers where the sand size is such that it could be moved by the flowing water and could pass through a poorly chosen screen, careful selection is of vital importance (see section 5.5).

5. Well Construction and Development

5.1 Introduction

The components of a typical well are shown in Fig. 5.1. Well construction cannot be a routine process. The variability of geologic conditions and of ground water occurrence in any locality are so great as to make each drilling operation to some degree an exploratory undertaking. Thus the skill, local knowledge and experience of the well driller are factors basic to successful ground water development.

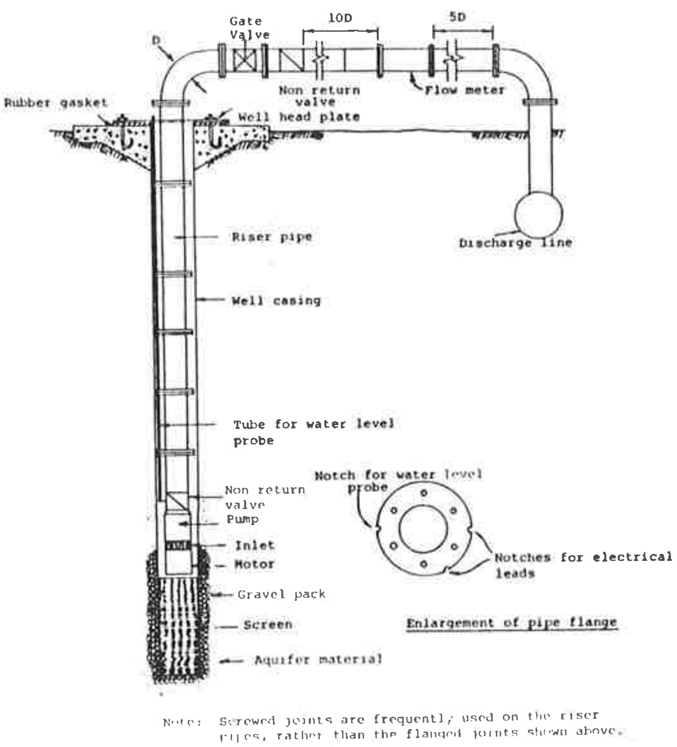


Figure 5.1 Components of a typical well.

5.1.1 General responsibility of the driller

Any arrangement by a drilling contractor to perform work for a well owner for payment constitutes a contract. Frequently, such arrangements are verbal, but whether the contract to drill a well is a simple verbal agreement or a detailed written arrangement including full specifications, the driller accepts responsibility to complete the work to an acceptable standard and to the customer's satisfaction.

When engineers are involved, there will be a written specification and the engineer assumes responsibility to see that the work is done to that specification and to the client's satisfaction.

If there is no specification and the desired results are not obtained, the question of where responsibility lies is often debated. It is generally accepted that the driller's obligation is to construct the well to a "proper" standard, select and install an "appropriate" screen and develop the well to produce "maximum" yield. However, without a written specification there is no objective definition of standards against which performance can be assessed.

When the yield achieved is less than expected, the driller can seldom be held responsible. However, he is responsible for a number of mechanical factors during the construction of the well, irrespective of whether or not they are included in a written specification. These factors are set out below.

5.2 Verticality

The driller must keep the well vertical and straight within practical limits by exercising proper care during construction. Wells are never perfectly straight, nor indeed do they need to be for the installation of submersible electric pumps. Plumbness and alignment become more important in deep wells or where vertical shaft drive pumps are used. These pumps have a surface-mounted motor connected by a long shaft to the pump impeller set down the well.

5.2.1 Standard of verticality

A reasonable standard of vertical deflection, which can be achieved using most well drilling equipment, is 1 percent. In other words, the maximum deflection in a well 100 metres deep would be 1 metre.

5.2.2 Testing of verticality and alignment

Testing for verticality and alignment involves the use of snug fitting 'dummies' suspended down the well casing. Displacement of the suspension wire from the centre of the casing at the surface is a measure of lack of verticality. The dummy used for testing alignment is straight and of a specified length and clearance inside the casing. This must be able to be passed up and down the casing without sticking.

5.3 Drilling in artesian conditions

When artesian conditions are anticipated particular care is required by the driller to ensure that uncontrolled leakage of water under pressure does not occur up the outside of the well casing. A number of standard techniques to prevent leakage have been developed by the drilling industry, usually involving the use of weighted fluids (i.e., drilling muds). The particular technique chosen by the driller will depend on the method of construction, relative pressure and depth, and a number of other factors. If proper precautions are taken the risk of leakage occurring is extremely small. If leakage from an artesian aquifer does occur, it is difficult and expensive to control. The cost and responsibility in this situation usually lies with the driller.

5.4 Mechanical defects

The driller is responsible for ensuring that all materials used in the construction of a water well are sound and of good quality. When a welded well casing is used the welding must be carried out to an acceptable industry specification. A broken well casing through failure of welded joints is always the result of poor quality welding, and/or workmanship. During well construction responsibility for broken casing joints, fractured drill pipe or collapsed screen column lies with the driller, except in special circumstances (e.g., in the event of being instructed to continue drilling in difficult conditions).

5.5 Well screen selection

Screen selection is frequently made by the driller, based on knowledge of the local aquifer and other successful wells in the area. When drilling in unfamiliar material, however, it is advisable to consult an experienced geologist or engineer, since sampling and testing of aquifer material is required before the best screen can be chosen.

Where wells are sunk in factured rock, screens may not be needed: most wells in New Zealand draw water from unconsolidated materials and therefore screening of some type is essential. Except in sandy aquifers, wells which take small quantities of water for stock or domestic purposes may function satisfactorily with simple slotted casing. This will be known from local experience. If larger volumes of water are to be pumped a manufactured screen is necessary.

Where the aquifer material consists of a range of sizes, the slot size is chosen so that 30-60 percent of the aquifer material cannot pass through the screen. The well development process will then remove the finer sizes from just outside the screen, and a natural filter will be formed (see section 5.7). The size range of an aquifer material can change markedly within a few metres vertically. Therefore it is advisable to take one sample for size analysis for each three metres of aquifer thickness so that the screen slot size can be accurately chosen. Slot size can be varied along the length of the screen if necessary.

5.5.1 Screen length

The rule of thumb is to make the screen long enough and wide enough to keep velocity through the slots less than 3 centimetres per second. To compute this, the discharge and total open area of the screen must be known. Low water velocities reduce energy losses and are less likely to dislodge sand sizes from the aquifer.

In thin aquifers it may not be possible to meet this velocity criterion, in which case careful selection of slot size to prevent sand entry is particularly important. When aquifer thickness permits, yield will be greater if a long thin screen is used rather than a short wide screen.

5.5.2 Gravel packing

Where the aquifer material is of fine sand of uniform size it may be difficult to extract enough water through screen slots which are fine enough to keep sand out. It is then necessary to introduce an artificial gravel pack (Fig. 5.1). This is a layer of coarser material which is carefully placed around the circumference of the screen and acts as a primary filter. Screens with larger slots can then be used. Gravel pack sizes must be carefully chosen in relation to the grain sizes of the aquifer material. Again, in such a case, it is wise to seek the advice of a geologist or engineer.

5.6 Installing well screens

Installing the well screen is one of the most important elements of well completion since inaccurate screen setting can permanently reduce the yield. Procedures for installing screens vary with the design of the well and with the method employed in well construction. The method of screen installation is at the driller's discretion, but most have developed standard procedures for particular areas.

5.6.1 Installation in cased holes

In New Zealand a high proportion of all water wells are screened, usually by lowering a screen into position inside the well casing. This is called 'telescoping'. With the screen held in position the casing is then lifted or 'pulled-back', leaving the screen exposed to the aquifer.

5.6.2 Installation in uncased holes

In uncased holes the screen is usually welded to the bottom end of the casing and the whole assembly is lowered into position.

5.6.3 Sealing screen with casing

After a telescoped screen is accurately positioned within the aquifer, it is necessary to seal the annular space between the screen and the well casing. This is usually done with some form of packer. Multiple neoprene rubber rings are widely used in the water well industry today.

5.7 Well development

After setting the screen in position the well must be developed. This procedure is critically important in bringing the well to maximum production of sand-free water. Development is energy intensive and takes time, therefore it is expensive. Nevertheless, the large increases in yield which are usually achieved, and the reduction in maintenance through pumping cleaner water, mean that the cost is certainly justified.

5.7.1 Benefits of development

Three beneficial effects are sought through development:

- The removal of finer material from immediately outside the screen increases the permeability of the natural formation, allowing water to flow more freely.
- The correction of any damage to, or clogging of, the aquifer which may have occurred as a side effect of drilling.
- The stabilisation of the sand fractions around the well to reduce or eliminate sand movement through the pump.

5.7.2 Development methods

There are numerous techniques for development, all of which are designed to create sharp pressure fluctuations and hence flow reversal in the vicinity of the screen. This flow reversal through the screen is essential to effective well development. Thus fine material is disturbed and drawn into the well from where it can be removed by bailing or otherwise.

Effective development methods are:

- Surging—A heavily weighted piston is worked sharply up and down inside the screen to displace water and create a washing effect.
- Air surging—Bursts of compressed air are released into the casing above the screen and then the well is conventionally air-lift pumped. Air lifting is a method of pumping for short periods whereby an air hose is lowered to near the bottom of the well and a steady air flow is used to aerate the water column and hence lift it to the surface.
- High velocity water jetting—A special high pressure pump and jetting tool are used to disturb the material. The tool is slowly rotated and worked up and down inside the screen to cover the entire surface.
- Chemical dispersal—Where clay fractions occur or drilling mud has been required, chemical dispersing agents are sometimes used to dislodge this material. In limestone aquifers, acid may be used to enlarge fissures.
- Overpumping—Pumping at a rate greater than will be required long term is not very effective in dislodging sand grains unless the pump is switched on and off frequently to provide pressure fluctuations.

Figure 5.2 New Zealand water well data form (NZGS).

SHEET No. M36 3 | GRID REF 730 271 11 | G.S. WELL No. W 945 15 | AREA TAITAPU

CATCHMENT HALSWELL RIVER H 16 | WATER AUTHORITY NCY C 17 | WATER USE IRR I 18 | PERMIT No. 810338 24

Well depth (m) 39.0 28 | Measured / Reported | Well diameter (mm) 150 L 29 | Wellhead altitude (m) a.m.s.l. 7.0 33

Yield ~~l/min~~ m³/day 2644 39 | Drawdown (m) 5.1 42 | Specific ~~l/min/metre~~ capacity m³/day 518

Driller McMillan Water Wells | Drilling date 810625 48 | Well status Driven E 49

Owner J. J. Ryan | Address Taitapu, No.2 R.D., CHCH

Pump Type Surface P 50 | Well Type Artesian B 51 | Type of development Surge

Screen Type PVC | Slot sizes 6mm ø | Set at 19·2 – 22·3m & 34·6 – 39·0m D 52

Source of information on well location, log, etc Driller / owner | Date July 1981

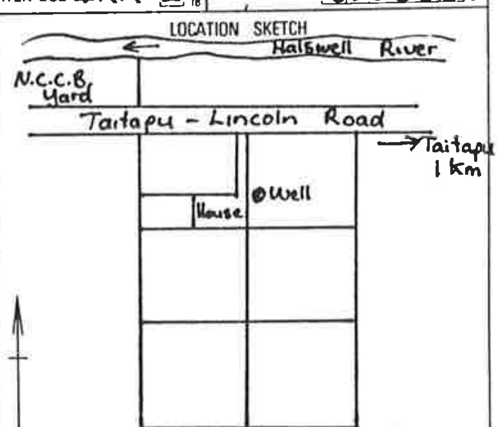
STATIC WATER LEVELS (m below surface)

HIGHEST	LOWEST	MEAN	RANGE	FREQUENCY OF MEASUREMENT Single I 53
		0·9 57		PERIOD OF MEASUREMENT 25/6/81 81 61

AQUIFER CHARACTERISTICS

Transmissivity (m²/day) 66 | Storage coefficient 72 | Water Temperature (°c) 73

Permeability (m/day) | Specific yield



TEST PUMPING		RECOVERY		REMARKS
Drawdown (metres)	After time (min)	Residual Drawdown (m)	After Time (mm)	

OTHER DATA

Pump Test	74
Chemical Analysis	75
Geophysical Data	76
Lithological Log	Y 77
Isotope Data	78
	79
Card Type	80

Compiled by N.C.C.B. Date July '81 Checked by Date

5.8 Driller's report

During construction of the well the driller must keep a daily log recording all relevant information and a comprehensive description of all materials penetrated. Upon completion of the well the customer should receive with his account for the work a "Well Log" showing all dimensions and depths, screen particulars, standing water levels, yield test figures and stratum information extracted from the driller's daily log. A copy of this "Well Log" is also permanently filed by the drilling contractor and another copy is normally held by the regional water board.

Figures 5.2 and 5.3 show the New Zealand Water Well Data Form, and the standard of 'logging' which should be expected. The collection of such well logs by the regional water board is of vital importance in furthering our understanding of ground water resources.

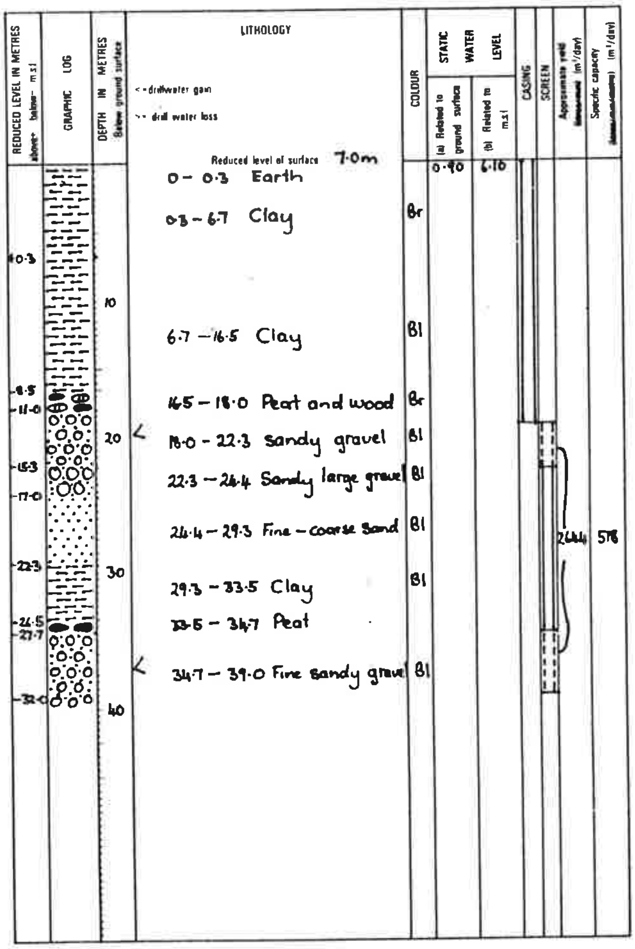


Figure 5.3 Well log (reverse of water well data form).

5.8.1 Depth data

The reference level for all depth measurements must be clearly stated and understood (ground level, mean sea level, etc.). The depth at which each stratum is encountered and its thickness must be recorded, and all materials described to a uniform standard defining colour, particle size, etc. A detailed soils description chart published by the New Zealand Geological Survey, DSIR, is available and all drillers are encouraged to use it.

5.8.2 Water level data

The water level in the well should be observed and recorded any time that the drilling process halts—say when welding on a new length of casing. A measurement before beginning to drill each day is especially important. The method of construction will determine, to some degree, how this is done, but the objective is to identify any significant changes in water level as drilling proceeds, as a clue to the location of different aquifers. Water level measurement during drilling may be impractical if drilling mud is used.

5.8.3 Lithologic data

Samples of all materials penetrated should be recovered, identified and stored. How the samples are taken should be the decision of the driller or the engineer, and will also depend upon the method of construction used and the type of materials drilled—whether consolidated or unconsolidated. In unconsolidated materials particular care is necessary with samples to be used for sieve analysis to determine grain size, which in turn determines the slot size of the screen (section 5.5).

6. Water Well Testing

When a well is structurally complete and fully developed, it is necessary to test it to determine how much water can be pumped under specified operating conditions. The limiting condition is usually the amount of drawdown* which is available in the well. At the same time water samples should be taken both for chemical analysis and to determine that the amount of sand being pumped is low enough to ensure satisfactory long-term pump performance.

6.1 Reasons for testing

- The productive capacity of a well must be known before a suitable pump can be chosen.
- Practical considerations may limit a test to a relatively short period of time and a discharge rate which is substantially less than the proposed long-term rate. A properly conducted test enables the prediction of long-term drawdown at a variety of discharges (i.e., a well performance curve will be produced—Fig. 6.1).
- The productive capacity of water wells may decrease with time. A performance test at the time of first commissioning provides a standard against which future well performance can be measured. Reduced performance can then be detected at an early stage allowing maintenance to be scheduled at a time of least disruption.
- Pumping tests of wells provide information about the aquifer itself which may be used in water right applications to demonstrate that nearby well

*'Drawdown' is the lowering of the water level from the rest position caused by pumping.

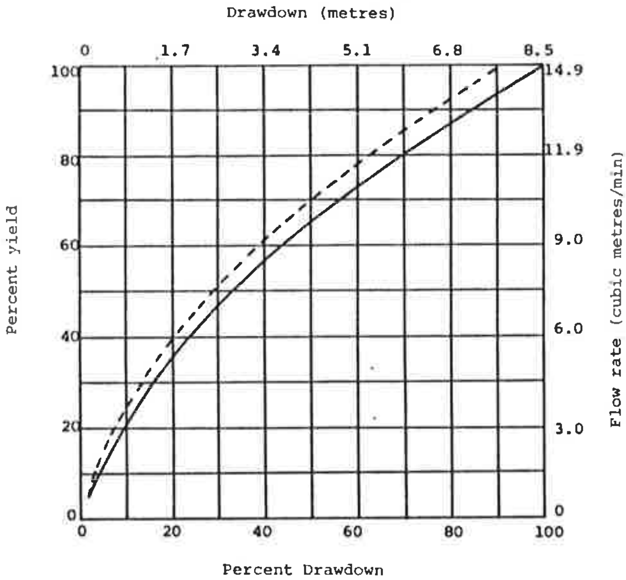


Figure 6.1 Performance curve of Well A, Dobson's Ferry Road. ----- After 300 minutes (5 hours) ____ After 144,000 minutes (3 months)

owners will not be affected. Important physical factors, such as permeability and aquifer storage† can be computed, which, when combined with data from other wells, will provide a better understanding of the ground water resource.

- Chemical analysis determines whether the water is fit for the desired use and whether it will be corrosive to pumps and fittings.
- A simple check on sand content is necessary to determine when to stop the development process.

6.2 Types of pumping test

There are two general types of test: those which use only the pumped well itself; and those in which drawdowns are measured in special observation wells at varying distances from the pumped well. Details of these tests are given in Appendix A.

6.2.1 Tests using the pumped well only

Such tests provide information about well performance and aquifer permeability but not about storage characteristics. They are simple to perform and relatively simple to analyse. They can be done in new wells as part of their commissioning or in old wells which have been re-developed.

Although permeabilities derived from such tests are not considered to be as accurate as those from tests with observation wells, there is far more opportunity to do them since they require only the pumped well. The volume of data possible from the aggregate of such tests is most useful in gaining an understanding of regional aquifer properties.

The simplest test, satisfactory for stock and domestic wells, is to pump at a constant flow rate for a period of 30–120 minutes while carefully measuring drawdown. The time of pumping is determined by the rapidity with which the water level settles down. (See Appendix A.2.1.)

†Storage of water within an aquifer is an important characteristic which affects seasonal and long-term changes of water level. Unconfined aquifers have high storage capability, confined aquifers generally have low storage capability.

A more accurate version of this test involves pumping at a sequence of different flow rates, and provides good information on well efficiency, long-term well performance and aquifer permeability. (See Appendix A.2.2.)

6.2.2 Tests using both pumped well and observation wells

For wells where efficiency is critical, such as for municipal supply, major industrial plants and where the ground water resource is limited, more elaborate testing may be warranted. In situations where there is continuous year round pumping the storage capability of the aquifer may be of great importance. The test to determine this requires observations to be made in special wells located near the pumped well, because the turbulence which exists in and around the pumped well and screen prevents accurate estimation of the aquifer storage. (See Appendix A.3.)

6.3 Duration of the test

The duration of a pumping test should be determined by the end use for which the well is intended. Wells intended for stockwater or domestic supply only, do not warrant complex tests of long duration. On the other hand, high producing wells intended for municipal supply over a period of many years should be tested exhaustively because significant pumping and maintenance costs can be saved by carefully matching the pump to the bore. Long-term tests will also determine aquifer characteristics which might adversely affect the test well and nearby wells during continuous pumping.

Suggested test durations for various types of well are shown in Table 6.1.

Table 6.1 Durations for pump testing

Well Use	Pumping Duration (hrs)	Recovery Duration (hrs)
Stock and domestic	0.5–2	0.5–1
Irrigation	6–24	6–24
Municipal or industrial	100+	24

The variability of each duration (e.g., 0.5–2 hrs) arises because aquifers respond differently to pumping. Water levels in confined aquifers stabilise more rapidly after a change in pumping rate than do water levels in unconfined aquifers. Good testing requires levels to be nearly stable at the end of the pumping period.

6.4 Testing for water quality

Sampling of well water in new areas or new aquifers is necessary to ensure that the screen, pump and distribution system will not corrode or incrust, and to determine if the water is up to, or requires treatment to meet, necessary standards. If water quality in the area is already well known, sampling and testing for these reasons may not be necessary.

Arrangements should be made well in advance for a laboratory to supply the sample bottles (which must be specially prepared) and do the tests. The laboratory or the regional water board may also advise on sampling techniques. It is desirable that some tests should be done at the well head; this requires an analyst to be in attendance with field testing equipment. These tests are:

- Temperature
- pH
- Dissolved oxygen
- Acidity (as CO_2)
- Carbonate alkalinity (only necessary if pH is above 6.5)
- Conductivity

However, where this is not practicable, each sample bottle should be filled to exclude air, tightly sealed and delivered to the laboratory within 24 hours of sampling.

When sending water for analysis it is important to label the sample bottles with basic information on the well: name and location, aquifer depth, sampling techniques and intended use of the water. This enables the laboratory to check that the tests are appropriate and to give the best advice on water suitability.

Testing for bacteriological contamination calls for particular care. The sample bottle must be sterile, and the sample must be chilled (not frozen), kept in the dark in an insulated chest (such as a chillibin) and delivered to the laboratory within six hours of sampling.

6.5 Testing for sand content

Small amounts of sand in the water quickly damage pumps and equipment and the importance of minimising this cannot be over-emphasised. During well development the discharge must be sampled frequently until the sand content is less than 5 g/m^3 (5 parts per million). Measurement is done by settling out the sand in a clean container (5 g/m^3 is equivalent to about 5 fine sand grains in a 5 litre bucket).

Copies of results should be forwarded to the regional water board.

6.6 Supply of test equipment and supervision of tests

It is the responsibility of the well owner or his/her agent to ensure that all well testing and water quality sampling is done competently.

The driller should supply the equipment for testing well yield but water quality testing requires specialised equipment and expertise which should be sought from either the regional water board or a private commercial laboratory. Analyses of samples should be done at a laboratory with TELARC* registration in the appropriate techniques.

*TELARC. Testing Laboratory Registration Council; a statutory body established to standardise and improve testing methods in many scientific and technical fields.

7. Pump Selection

Pump operating conditions are determined by the characteristics of the aquifer, the well, the distribution system and the pattern of water use. Thus, selection of a pump cannot be made until all these factors are known.

There are numerous types of pump available, each type designed to operate most efficiently under a given set of conditions. It is the responsibility of the well owner or his/her agent to specify to the pump supplier the particular set of conditions under which the pump is expected to function. These should include:

- Internal diameter of the casing
- Well depth to the top of the screen
- Details of well straightness
- The test pumping performance data
- Water quality information, especially sand content
- The name of the local power supply authority

The pump supplier can then offer a pump or a range of pumps which would satisfactorily meet these conditions.

7.1 Operating conditions

With the pumping test of the well completed, the distribution system will be designed and the pattern of water use established. At this stage the system-head* characteristics will be known (Fig. 7.1) and the pump can be selected with characteristics that best match the system. The water system-head characteristic curve is a graph of total pressure head against which the pump must deliver for various pumping rates (Fig. 7.1). The total head H_t consists of three parts—

$$H_t = h_\ell + h_f + h_v$$

where h_ℓ = the vertical lift from the water level in the well to the free water surface at the point of delivery, h_f = the frictional loss within the pipeline at bends, junctions, valves, etc., and h_v = the velocity head, the amount of energy needed to accelerate water from rest. h_ℓ, h_f and h_v all change with varying discharge and thus the range of discharges must be known in order to calculate the range of heads.

*'Head' is the pressure increase which the pump imparts to the water as it passes through the impeller.

7.2 Matching the pump with the system

Figure 7.1 illustrates how the head-discharge characteristic of the aquifer-well-distribution system is matched with the head-discharge characteristic of the pump. The intersection point of curves (a) and (b) gives the head-discharge condition at which the pump will operate, in this case a discharge of 62 ℓ/s at a head of 28.5 m. This is a good match because the pump will operate very close to maximum efficiency (intersection of vertical line with curve (c)). The power consumption for this duty will be 22 kW (intersection of vertical line with curve (d)). Several pump characteristics may have to be tried before a satisfactory match is achieved.

7.3 Corrosion or incrustation

Chemical analysis of a ground water sample will indicate whether corrosion or incrustation of the screen, casing or pump is likely.

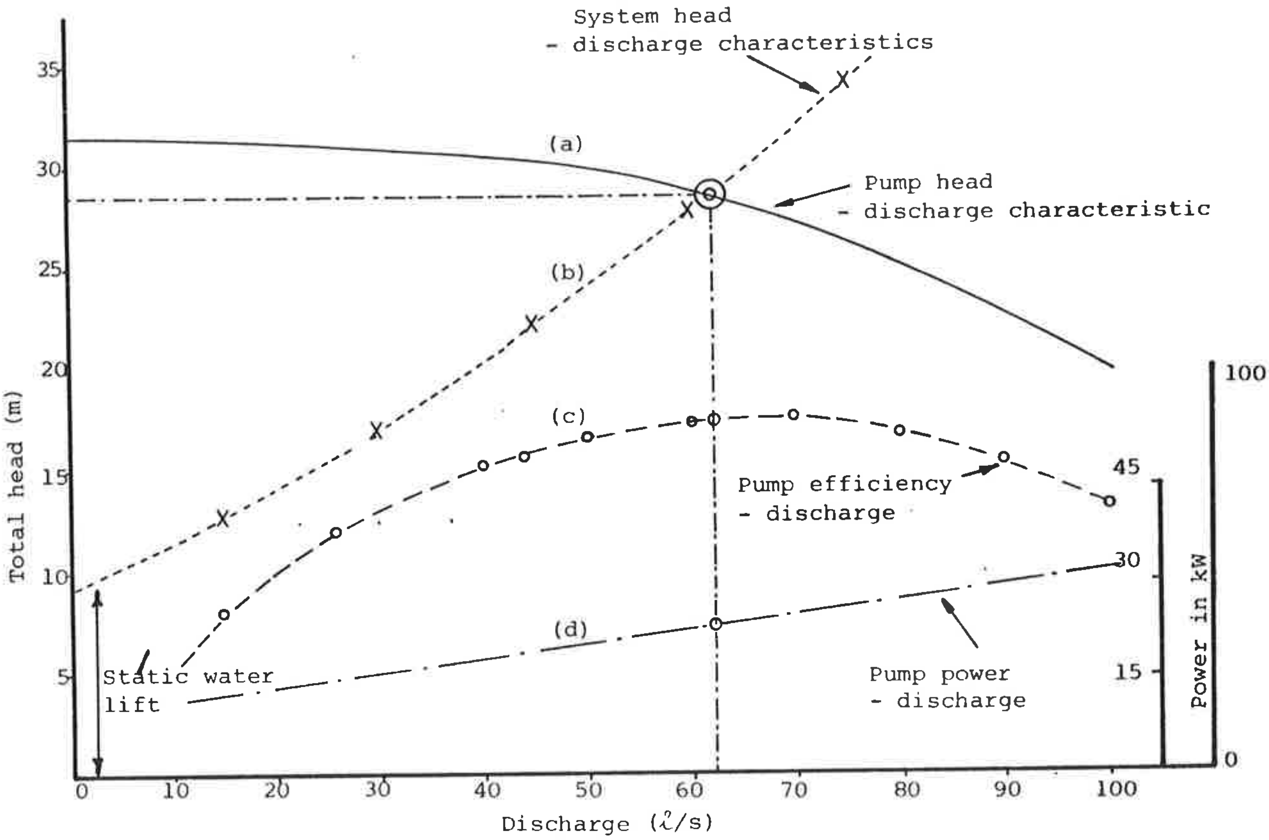


Figure 7.1 Matching the pump with the system.

If corrosion is predicted then corrosion resistant materials should be used whenever possible. For well casings this may be a non-metallic material such as polyvinyl chloride (PVC) or fibreglass reinforced epoxy resin. For well screens, galvanising, alloys or stainless steel are available. Manufacturers, given the water quality parameters, can supply pumps suitable for corrosive environments.

Conditions which indicate that corrosion may occur are as follows (see also section 8.2.3):

1. pH less than 7 indicates an acid water.
2. Dissolved oxygen exceeding 2 g/m^3. This might be found in shallow unconfined aquifers.
3. Hydrogen sulphide at concentrations exceeding 1 g/m^3. Even at this low concentration hydrogen sulphide (rotten egg gas) can be detected by smell.
4. Total dissolved solids exceeding 1000 g/m^3 may lead to electrolytic corrosion.
5. More than 50 g/m^3 of dissolved CO_2 causes low pH.
6. Chloride content exceeding 500 g/m^3.

In some areas incrustation may occur by precipitation of chemicals (usually carbonates) from the ground water. Deposits form on the screen or in the adjacent aquifer material, clogging and reducing well output. The remedy is to remove the incrustation periodically by acid treatment, thus the screens should be of corrosion resistant material. Indicators of likely incrusting conditions are:

1. pH above 7.5.
2. If carbonate hardness is above 300 g/m^3 incrustation of calcium carbonate (lime scale) is possible.
3. Iron content above 2 g/m^3 may lead to precipitation of iron compounds.
4. Manganese, above 1 g/m^3 in the presence of oxygen and coupled with high pH, will precipitate out.

Several water quality parameters are also combined to give an index number, the Langelier or Saturation Index, which expresses the tendency for corrosion or incrustation to occur. Negative values of the index indicate a tendency for corrosion, and positive values a tendency for incrustation.

Interpretation of water quality parameters should be sought from the laboratory analyst.

7.4 Pump installation

With a suction pump it is not possible to lift water from more than 6–8 m below the level at which the pump is set. When deciding whether to install a suction pump, on the basis of depth to the water table, allowance must be made for the seasonal or long-term variation of the water table and also the drawdown in the well caused by pumping. Surface pumps have advantages in ease of installation and maintenance, so to make their use possible in marginal situations they are sometimes set a few metres below ground level in lined pits.

For low volume pumping (i.e., domestic) simple reciprocating pumps are used. These are not discussed here, but details can be obtained from pump manufacturers.

Where the water table is more than 8 m from the surface the pumping unit must be set below the lowest expected water level. In some situations a line shaft pump is used whereby the pump is down the well and connected by a long shaft to a surface motor. In New Zealand the most commonly used water well pump is the electric-submersible, where the pump and motor are close-coupled and suspended down the well on the end of the delivery pipe (Fig. 5.1).

7.4.1 Pump accessories

Provision should be made on all wells to allow measurement of water levels with the pump either off or on. A screw plug of 25 mm diameter in the well cover plate is sufficient. For submersible pumps or where a flanged riser pipe is used, notches should be cut in the flanges to hold a guide tube, down which a water level probe can be dropped (Fig. 5.1).

All pumps should have a non-return valve to prevent backflow and possible well contamination. For ground level pumps this can be a foot valve on the end of the suction line. For submersible pumps a non-return valve at the well head is necessary and in deep wells (greater than 30 m) a second non-return valve should be located immediately above the pump. A pressure gauge on the pump delivery line is desirable for monitoring pump performance, and for ground-level pumps a vacuum gauge on the suction line should also be fitted.

Where a flow meter is to be fitted, it should be considered at the design stage so that the pipework will allow its installation. This normally requires a length of straight, unobstructed pipe from ten pipe diameters upstream of the meter to five pipe diameters downstream.

7.4.2 Electrical equipment

Virtually all permanent well pumping installations are electrically powered and have electrical control gear which must be carefully protected from weather, floods and intruders. Where installations are isolated, a walk-in shed at or near the well head is desirable.

All electrically powered pumps should be earthed at not more than 5 m from the well.

Malfunctions of various components of the pumping system can damage the pump unless provision is made for emergency shutdown. Therefore allowance must be made for:

- Low voltages which may lead to the motor overheating, especially in submersible pumps. A voltage cut-out or thermal overload switch is required.
- Low water levels in the well may lead to the pumping of air, resulting in lowered efficiency, cavitation* or lack of motor cooling. Water level limit switches are required.
- Failure of a pipe or valve in the delivery system or a blockage may lead to unacceptable pressure fluctuations. Pressure cut-out switches are required.
- For intermittent operation, timer switches or remote switches are convenient.

*Cavitation occurs where a reduction of water pressure induces bubbles of water vapour to form briefly within the flow. When these subsequently collapse high impact pressures occur which can erode pump components.

7.4.3 Surface pumps and motors

An adequate foundation should be provided to which the motor unit must be bolted. There must not be any relative movement between the pump and the well head.

To prevent air being pumped, the suction pipe should be centred within the well and should terminate with a foot valve at least 2 m below the lowest expected water level.

7.4.4 Submersible pumps

The base of the pump should normally be set just above the top of the screen. If the well has multiple screens and the pump is set between them, the water level should never be drawn down so that water cascades through the upper screen. This leads to air being entrained and possible damage to the pump by cavitation. The pump and the rising pipe should both be centred within the casing using spacers. The annular clearance between the pump and the casing should not be less than 4 percent of the internal diameter of the casing (i.e., 12 mm gap inside a 300 mm casing). This reduces the term h_v (section 7.1) in the total lift and reduces the likelihood of air entrainment. Where some water derives from a screen above the pump the annular clearance should be 8 percent, or adequate enough to keep velocity in the gap to less than 3 m/s. High velocities under these conditions may lead to excessive turbulence around the pump inlet. On the other hand, because motor cooling is dependent on the water flowing up the casing, the velocity in the annulus should not be less than 0.6 m/s.

7.5 Pump removal

Consideration must be given when constructing a well, that at some stage maintenance involving removal of the pump will be necessary. Therefore all fittings, machinery and pump housing must be removable to allow easy access for hoists and other equipment. Overhead power lines should be at least three horizontal metres from the well head to allow safe craneage.

8. Well Maintenance

It is often forgotten that a well is an engineering structure requiring regular maintenance. Frequently, inspection of the well is neglected until trouble develops, with the result that it is often beyond repair, or that costly treatment and redevelopment are required. Therefore it is good economics to check a well by running a yearly performance test (see Appendix A.2.1) and by removing the pump every two years for inspection. A drop of 30 percent efficiency can increase power consumption by as much as 100 percent. Operation outside the design capacity of the well will reduce its useful life.

8.1 Problems

In production wells there are three major problems: decline of yield, increase in pumped sand, and corrosion.

8.1.1 Decline in yield

Assuming the calibration of the flow measuring equipment has been checked, the cause may be any one, or a combination, of the following:

- A general decline in natural ground water level beyond that predicted in the design.

- Interference from new wells in the area.
- Excessive wear in pump, or motor.
- Mechanical clogging of the well or pump intake zones by silts and clays.
- Chemical clogging of the intake zones by corrosion products or precipitated compounds from the water.
- Biochemical clogging of the intake zones by slime produced by organisms such as iron bacteria.

8.1.2 An increase of sand in the discharge (See also section 6.5)

This may be caused by:

- Overpumping.
- Break or hole in the casing or screen.
- Incorrect positioning of the pump.
- Aquifer or gravel pack collapse (see section 5.5.2.).

8.1.3 Corrosion (See also section 7.3)

The correct selection of materials will retard corrosion and increase the economic life of the well. Corrosion occurs in three main forms:

- Direct chemical, where chemical and physical factors directly attack the metal surfaces reducing thickness and strength, or enlarging slot openings in the screen.
- Selective corrosion, where one metal of an alloy is removed.
- Electrolytic corrosion, where two different metals are connected electrically.

8.2 Identification of causes

8.2.1 Declining water table

The starting point of the search for the cause should be a study of the well's design, construction and testing records. It is most important, therefore, that these be obtained from the driller and pump supplier and kept by the well owner. A year-by-year record of standing water levels* in the well will show any excessive decline in the regional water table caused by drought conditions or interference from new wells.

If standing levels are normal, it will be necessary to carry out a pumping test to check 'well losses' (i.e., losses associated only with the screen or casing, see Appendix A.2.2).

The well records should include the test results of well losses at the time the well was first commissioned. A repeat of this test will indicate if well losses have increased during the operating life of the well. If no increases are observed then the pump or drive system is faulty. If, instead, there is a significant increase in well losses, then there must be some sort of clogging at the well intake zone, and cleaning and redevelopment will be necessary to bring the well back to its design yield.

8.2.2 Mechanical clogging

Mechanical clogging, which is infrequent if the well is properly designed and developed, is usually the result of the well being pumped above its design capacity. Over-pumping may cause aquifer material immediately outside the screen to be disturbed, thus reducing permeability. Alternatively, sand may enter the well and settle to the bottom, blocking a portion of the screen.

8.2.3 Chemical and biological clogging

If mechanical clogging is not considered likely, then the pump should be withdrawn from the well and closely inspected. Any incrusting material on the outer surface of the pump, or column, should be sampled and analysed. The action of pumping from a well reduces the pressure and allows dissolved carbon dioxide to escape from the water. This reduces the ability of the water to hold in solution iron compounds and carbonates, which then precipitate in the well. The treatment for chemical clogging will vary according to the deposits causing the clogging, which, commonly, will be a mixture of carbonates and sulphates of calcium, magnesium, hydroxides of iron and manganese, or perhaps aluminium silicate or organic slime material.

Analysis of the water should identify other potential problems based on the following indicators:

- Iron bacteria: their presence can be a problem particularly in combination with a high iron content, because the iron will become deposited on the walls of pipes and will block small apertures.
- Total iron: amounts greater than 0.3 parts per million could create a problem if iron staining is unacceptable or iron bacteria are present; again because of iron deposits accumulating throughout the system.
- Total manganese: amounts greater than 0.15 parts per million cause staining and deposits similar to iron, and for the same reasons.
- Total hardness: values in excess of 250 parts per million would indicate the probability of incrustation due to carbonates.
- pH: a high value measured at the well head would suggest incrustation problems, whilst a low value at the well head would suggest the presence of dissolved carbon dioxide and iron.

Slime-producing organisms, including iron bacteria, can live in ground water by feeding on carbon dioxide and other gases.

8.2.4 Increased pumpage of sand

The design should be checked against the operation. Has the pump been set too close to the inlet zone? Has the well been over-pumped or could the aquifer have collapsed due to some other problem in the well design? If corrections for the above features do not stop the pumping of sand then the well should be examined for holes in the casing or in the screens. This may require inspection by a downhole caliper or, in larger wells, by a television camera.

8.2.5 Corrosion

Corrosion will be detected during routine inspection of the pump.

8.3 Solutions

Once the problem has been identified, the solution will generally be obvious or straightforward. Special solutions will be required for clogging problems.

*Standing or rest water level is the level when not affected by pumping.

8.3.1 Clogging

A number of treatments are given in Table 8.1:

Table 8.1 Treatments for clogging

Method	Effect
Hydrochloric acid followed by chlorine	Removes iron, sulphur and carbonate deposits
Polyphosphate (i.e., sodium hexa-metaphosphate followed by chlorine)	Removes fine silt, clay, colloids, disseminated shale and soft iron deposits
Compressed air	Removes plugging deposits of silt and fine sand in areas adjacent to screens
Dry ice	Same as compressed air
Surging	Same as compressed air
Chlorine (50 ppm)	Removes iron and slime-forming bacteria
Caustic soda	Removes oil scum left by oil lubricated pumps

8.3.2 Corrosion

There are a number of treatments depending on the type of corrosion.

- The injection of chemicals to condition the corrosive fluid and treat the surface of the attacked metal, e.g., various alkaline substances for pH control, inhibitors, and preferential wetting agents.
- The use of corrosion-resistant alloys, either for replacement components or as platings and linings.
- The use of non-metallic coated and/or lined materials, such as plastic-coated tubing which has been widely adopted for corrosive environments.
- The use of cathodic protection, although not suitable for protecting internal surfaces (with a few exceptions), could be more widely used for the mitigation of external casing attack.

8.3.3 Increased pumping of sand

Downhole inspection may show damage to casing or screen. If the casing is damaged, the well may have to be re-drilled. If the screen is damaged, it will have to be replaced.

If downhole inspection is not possible, first try re-development and if unsuccessful the screen will have to be removed for inspection.

9. Sealing of Wells

The well owner should properly care for a well when it is not being used to supply water.

9.1 Temporary well shut-down

When a well is temporarily removed from service, it should be kept in a state of good repair. The top of the well should be sealed with a water-tight cap or seal to prevent the entrance of pollutants.

9.2 Permanent well shut-down

When a well, including any test or exploration well, is to be permanently removed from service it should be sealed to prevent it from being a channel down which water can flow and thus be a route for possible contamination of the ground water supply.

A cased well in unconsolidated formations should be sealed by filling completely with cement or concrete grout.

9.3 Shut-down of artesian wells

Artesian and non-artesian wells should be sealed in a similar manner, except that with artesian wells it may be necessary to pressure grout the aquifer layer to stop subsurface leakage. The remainder of the well should be filled with grout in the normal way.

10. Bibliography

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APPENDIX A—Conducting Pumping Tests

A brief guide to conducting pumping tests is given for those having the need to do, or supervise, such tests. Analysis of test data is complex and should only be attempted by experienced personnel. Regional water board staff may be prepared to undertake the task or nominate suitable consultants.

Further technical details can be found in the references listed in the Bibliography.

A.1 Measurements

The three factors which are measured during all pumping tests are time, flow rate and drawdown.

Time can be measured on a watch. Accuracy should be to within a minute over a period of 24 hours.

Flow rate can be measured by a variety of methods. When flow rates are less than 200 litres per minute, the rate can be measured by taking the time it takes to fill a container of known volume. For larger rates a flow meter of some type is required. The most reliable field instrument is the orifice flow meter. This can be readily made in an engineering workshop and should provide an accuracy of ± 5 percent if constructed according to Fig. A.1. (See also N.Z.S.S. 5103 : 1973). Accuracy of ± 2 percent can be attained with an orifice meter, provided it has been laboratory calibrated.

Drawdown is measured by sounding the well(s) and can be done in a number of ways. The simplest is listening for the splash using a tape measure with a plumbob attached. Greater accuracy can be achieved with various electric plumbobs which activate a light, buzzer, or ammeter when the bob touches the water. Automatic water level recorders may be used where the tests are done over several days. Measurement of drawdown should be to an accuracy of ± 2 percent or ± 5 mm, whichever is the smaller.

Drawdown occurs rapidly after changing the pumping rate and should at first be measured frequently. As the drawdown stabilises, the frequency of measurement is reduced. Thus take measurements as follows:

For the first 5 minutes	—	1 minute intervals
5 minutes to 60 minutes	—	5 minute intervals
60 to 120 minutes	—	15 minute intervals
Beyond 120 minutes	—	60 minute intervals

A.2 Tests using the pumped well only

The major advantage of these tests is that, since no observation wells are used, the test is much cheaper. Information is gained not only about aquifer permeability, but also about the performance of the well itself (Fig. 6.1).

A.2.1 Constant rate test

The constant rate test gives a rough measure of aquifer permeability and simple information about the short-term performance of the pumped well.

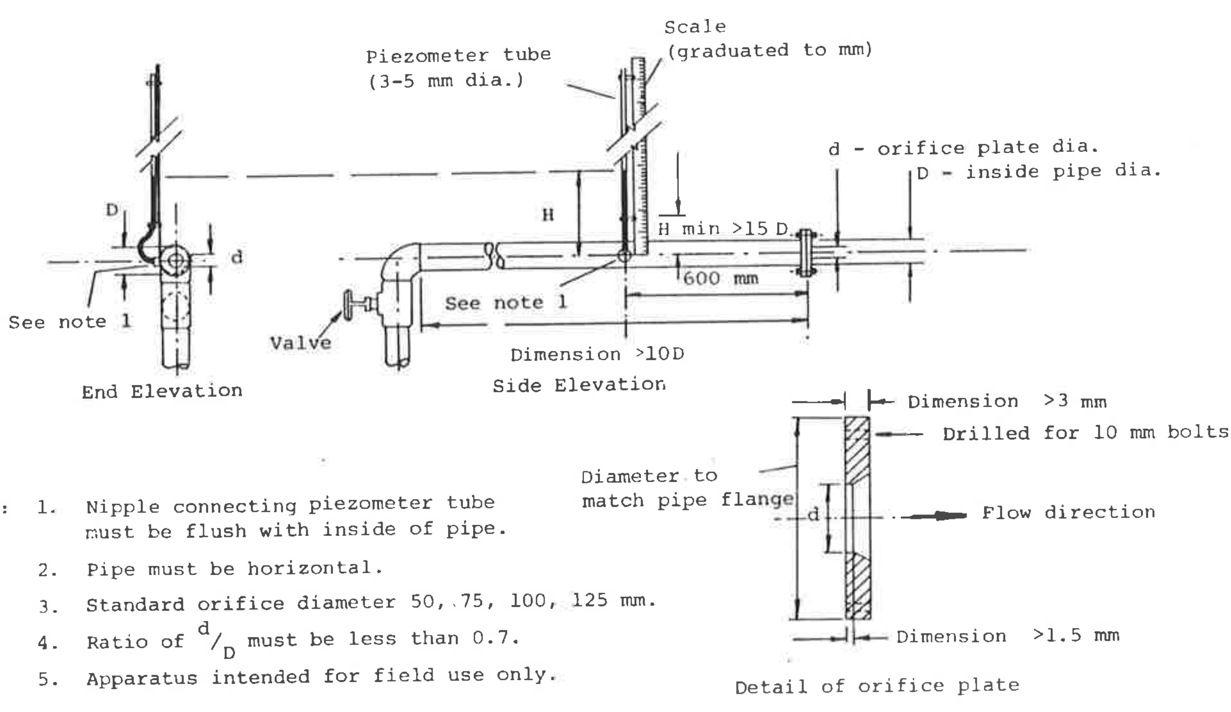
The well is pumped at a single rate for a period of 30-120 minutes while recording drawdown at intervals as given above. Flow rate must be checked repeatedly for constancy because flow reduces as drawdown increases. The test flow rate should be about the same as the planned production rate. After 30 minutes the pump may be switched off if drawdown rate is less than 1 mm per minute. After switching off, the residual drawdown is measured as the water level recovers toward the rest position. The same time intervals are used in both the drawdown and recovery phases.

A.2.2 Multi-rate (step drawdown) test

The multi-rate test gives a good measure of aquifer permeability and also allows estimation of well losses* and long-term well performance.

*Well losses are energy losses associated with flow through the screen and up the casing.

Figure A.1 Details of an orifice weir field arrangement (Adapted from N.Z.S.S.5103 : 1973).



Notes:
1. Nipple connecting piezometer tube must be flush with inside of pipe.
2. Pipe must be horizontal.
3. Standard orifice diameter 50, 75, 100, 125 mm.
4. Ratio of $^{d}/_{D}$ must be less than 0.7.
5. Apparatus intended for field use only.

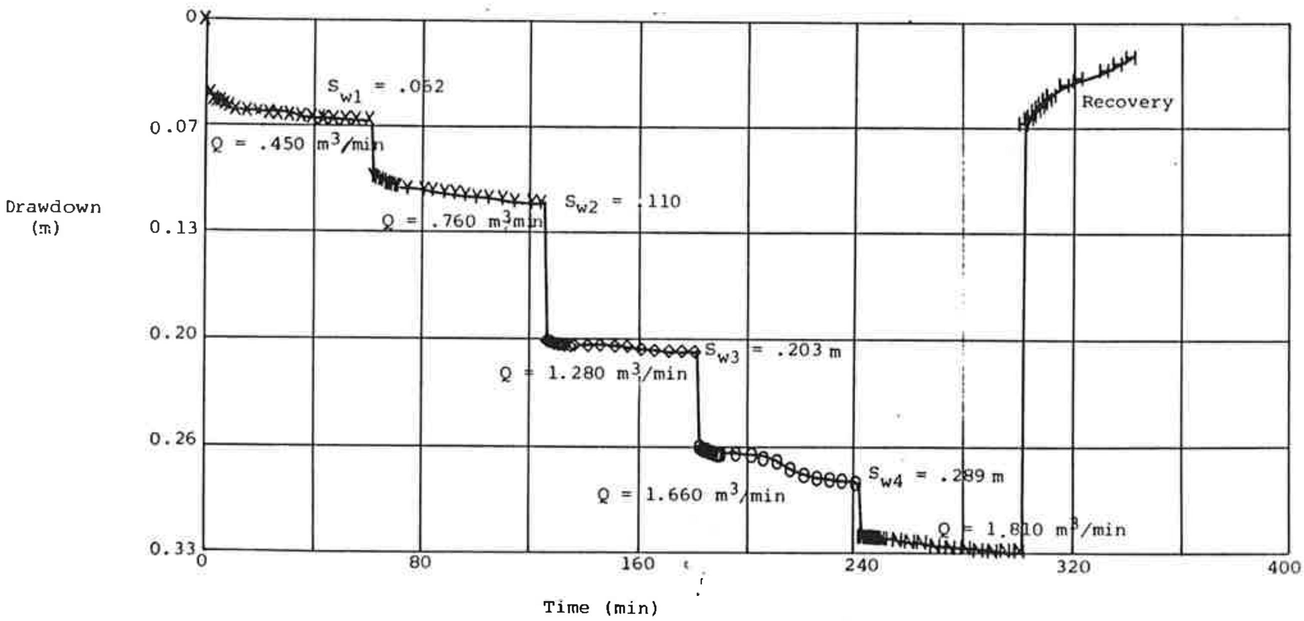


Figure A.2 Step drawdown test of Well A, Dobson's Ferry Road.

In a multi-rate test several discharge rates are set sequentially to cover the anticipated production capacity of the well. If Q is this capacity, the steps should be approximately 0.25Q, 0.5Q, 0.75Q, Q and 1.25Q. If the largest pump available has pumping capacity P, which is less than Q, then the test rates should be 0.2P, 0.4P, 0.6P, 0.8P and P.

When drawdown for each step has stabilised, or after 100 minutes, the discharge should be increased and a new set of drawdown measurements taken. A minimum of four steps is required. Finally, the pump is stopped and drawdowns are recorded as the water recovers to the original level.

When drawdown and time are plotted the graph appears as a series of steps (Fig. A.2) hence the name "step drawdown" test.

A variation on this method, which is suitable for testing irrigation wells, is to pump the well at rate 1.25Q for 23 hours and then reduce the flow in steps to Q, 0.75Q, 0.5Q and 0.25Q, holding each flow for 20-40 minutes until the water level is steady. Finally, the pump is switched off and the residual drawdown during the recovery period is measured.

The tabulated (Fig. A.3) and graphed data should be kept as a record by the well owner. This information should also be passed to the regional water board for full analysis and permanent recording.

A.3 Tests using both pumped well and observation wells

Tests using observation wells are regarded as more reliable than tests using only the pumped well because:

- The observation wells are free of the turbulence which exists in the pumped well.
- Measurements taken at several observation wells give an idea of the variability of the aquifer properties.
- A storage coefficient can be computed for the aquifer.

Such tests give no indication of well performance unless measurements are also made in the pumped well and analysed as a constant rate test (see A.2.1).

A.3.1 Number and location of observation wells

A minimum of two observation wells is desirable but three or more are an advantage. Where the thickness of the aquifer has been established the nearest observation well should be no closer than twice the aquifer thickness from the pumped well. Spacing of the other observation wells should enlarge with increasing distance from the pumped well. If they are too far from the pumped well, drawdown will be too small to measure accurately. If they are too close, the rate of drawdown in the early stages of the test may be too rapid to follow closely. Therefore, it is good practice to do a short step drawdown test first, from which the aquifer parameters can be estimated and used as a basis for spacing the observation wells.

A.3.2 Depth of observation wells

Initially the observation wells should be sunk to the depth of mid-screen of the pumped well and then tested by bailing or pouring water into the well to ensure that there is good hydraulic connection with the aquifer. Where wells have stood for a period of time they should be flushed by air lifting, or otherwise, to clear any accumulation of silt or fines. If an observation bore at the planned depth does not respond to the test well being pumped, or if the response of one observation well differs markedly from the others, then that well should either be drilled deeper to better material or pulled back, where this is indicated by the log.

A.3.3 Test procedure

The standard procedure for tests of this type is to pump at a single constant rate for the duration of the test. Drawdowns are measured in all observation wells at set time intervals. (See section A.1.)

Discharge must be monitored for constancy. Where drawdowns are very slow to stabilise, it may be necessary to extend the test beyond the recommended 100 hours. When the pump is stopped the rate of recovery of water levels should be recorded.

A.3.4 Corrections to drawdowns

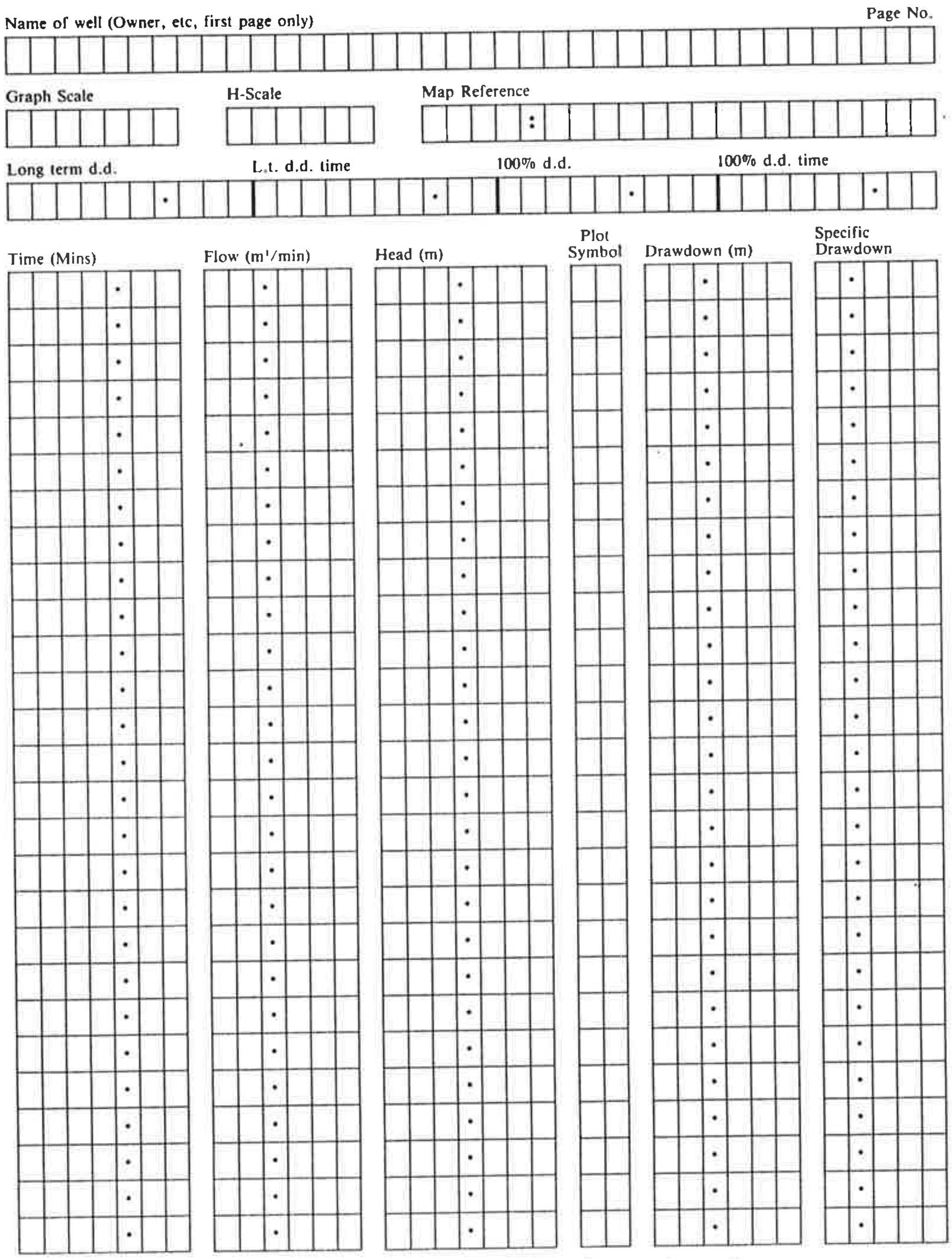
Water tables vary naturally according to season, rainfall, tides, floods in nearby rivers, or even barometric pressure. Where a test is run for a period of more than a day and drawdowns are small, such natural variations can lead to incorrect values being obtained and hence false conclusions drawn. It is necessary in such cases to have a control well, beyond the area of influence of the pumped well but in the same aquifer system, in which these background changes can be monitored and corrections to drawdowns made. Where such a control well is not available, readings made in the test wells before and after the test may be used, with interpolation, to obtain data for the period of the test.

Pumping in adjacent wells can also interfere with these tests. Such interference can be detected if a water level recorder is installed in a test well before the test and the record examined for anomalous changes. Any well within 1 km of the pumped test well should be regarded with suspicion.

A.3.5 Recycling of pumped water

Where the aquifer being tested is unconfined, there is a possibility that the water pumped from the well during testing may seep back into the aquifer if it is discharged too close to the well head. Because this recycling of water invalidates the test assumptions the point of discharge should desirably be into a stormwater system, natural channel, or stockrace. If these are not available, then it should be carried by a temporary pipeline to a distance of at least 300 m from the well head.

Figure A.3 Field data sheet for step drawdown test. (Adopted from format required for computer analysis by N.Z.A.E.I.)



Notes: Long-term d.d. is the maximum drawdown acceptable under normal operating conditions. L.t. d.d. time is the time at which the drawdown might occur, i.e., the longest estimated pumping period. 100 percent d.d. is the maximum drawdown possible, i.e., from the static water level to the top of the pump.

Write numbers as far to right as possible, using the decimal point. Head can be measured as depth below well head, depth below initial water-level or gauge pressure in an artesian well.

APPENDIX B:—Standard Contract for Water Well Drilling and Construction

Use of Contract Documents

This is a standard contract, set out in the form of a legal document. It should apply, with small amendments, to most water well drilling and repair situations, but for unusual projects or where difficult drilling conditions are anticipated may need to be revised more comprehensively.

B.1 Agreement

AGREEMENT made this day of 19 between

(hereinafter called "the Owner")

and

(herinafter with his/her/its successors, executors, adminstrators and permitted assigns called "the Contractor")

WHEREAS the Owner requires the work set out in the first schedule to be carried out;

AND WHEREAS the Contractor is prepared to enter into a contract with the Owner to carry out this work;

NOW THEREFORE IT IS HEREBY AGREED between the Owner and Contractor as follows:

1. IN this agreement the "Owner" means the person or persons who own or have legal control of the land where the well is to be drilled. The "work" means the work detailed in the attached first schedule.

2. IN consideration of the payments set out in the second schedule the Contractor agrees to complete the work in accordance with the terms and conditions hereof.

3. THE work shall be carried out under the general supervision and to the satisfaction of the Owner. Nevertheless it is agreed and acknowledged that the Contractor is an independent agent and not an employee of the Owner. The Contractor shall determine the time, manner and method of doing the work, subject only to the descriptions, conditions and standards set out in the second schedule and attached specification.

4. THE Contractor shall supply all necessary labour, vehicles and suitable items of plant to carry out the work without unreasonable delay, and shall proceed diligently with the work to the satisfaction of the Owner.

5. QUANTITIES given in the second schedule are estimates only. The actual quantities shall be determined by measurement during and after completion of the work and the Contractor shall be entitled to be paid at the various rates set out in the second schedule for these measured quantities. Should it be necessary during the course of drilling to change the diameter of the casing (e.g., by telescoping) the rates in the second schedule may be varied accordingly by mutual written agreement.

6. AT the end of each four-weekly period during the term of this agreement the Contractor shall prepare and submit to the Owner a statement of all agreed work performed during that period. Payment assessed at the rates set out in the second schedule shall be made by the Owner to the Contractor.

7. THE rates set out in the second schedule are considered to cover all costs of complying with conditions and obligations of the agreement necessary for satisfactory performance of the work, including all materials, supplies, labour, plant, tools, machinery, maintenance, supervision and overhead.

8. THE Contractor shall carry out the work without infringing any Act, regulation or by-law and shall be solely responsible for any infringement which may occur. The Contractor shall, at his/her own cost obtain all necessary licences and permits to carry out the work and shall abide by the conditions imposed therein.

9. THE Owner warrants that he/she has full right to enter into this contract and to authorise the Contractor to work on the property located at

10. THE Contractor shall be solely liable for and shall indemnify the Owner against any actions, claims, demands, damages and costs, whatsoever in respect of injuries or damage to property, or personal injury or death of any person whomsoever arising out of or caused by the execution of the work of the Contractor or by any subcontractor, unless solely due to negligence at common law on the part of any person for whom the Owner is responsible.

11. THE Contractor shall certify that he/she holds current insurance against any liability, loss, claim or proceedings in respect of which he/she is required by clause 10 above to indemnify the Owner. The policy or policies shall be with a reputable insurance company for at least $20,000 for any one claim or series of claims arising from the same occurrence.

12. THE Owner accepts full responsibility for selecting the exact site for drilling.

13. THE Owner agrees that the casing and all other materials installed in the well by the Contractor remain the property of the Contractor until fully paid for.

14. IT is understood and agreed by both Owner and Contractor that neither can tell what will be found underneath the surface of the earth and that the work of the Contractor is subject to those conditions which he may find underneath the surface, therefore:

The Contractor does not agree to find or develop water, nor does he guarantee the quantity or quality of water, if any, which may be encountered. Drilling is at the risk of the Owner unless negligence by the Contractor can be proven. Failure to locate sufficient water shall in no way release the Owner from payment of the full contract price.

15. THE Contractor shall not be liable for any damage arising out of any delay or failure due to the hazards of drilling, but in the event of unreasonable delay or failure, this contract may be terminated by the Owner, upon payment to the Contractor for all work done and materials installed.

16. IF the Contractor shall:

(a) Fail to begin work within 30 days of the estimated starting date or fail to pursue the work diligently, or
(b) Fail to use adequate, suitable labour or plant for the work, or
(c) Fail to complete the work according to the specification, or
(d) Fail to comply with any requirements of this agreement, or
(e) Become bankrupt or mentally defective or die, or, being a Company, appoint a receiver or go into liquidation;

then the Owner may forthwith terminate this agreement by notice in writing to the Contractor, and neither the Contractor nor any persons claiming through him/her shall be entitled to any compensation or damages in respect of such termination.

17. THIS work shall be considered complete when one or more of the following is achieved:

(a) Sufficient sand free water is obtained to meet the Owner's needs.
(b) The Owner requests that the work be terminated.
(c) The Contractor has drilled to a maximum depth of metres.
(d) The Contractor considers that further drilling would be impractical.

Upon reaching the maximum depth if water is not found or at any time prior, as set forth in (a) through (d) above, the Contractor shall stop drilling, remove the casing, materials and property and be entitled to full payment for work done to that point, irrespective of whether or not water has been found in the desired quantities.

18. THIS agreement shall be considered complete when all monies owing to the Contractor for agreed work have been paid.

19. IN the event of a dispute arising between the Owner and the Contractor whch cannot be resolved by discussion, over any matter relating to this work or interpretation of the specification, the dispute shall be taken to a mutually acceptable arbitrator whose decision shall be binding and final.

This arbitrator is agreed to be

of

If an Arbitrator cannot be mutually agreed upon, appointment shall be made under the provisions of The Arbitration Act, 1908.

SIGNED by ____________________
as (authorised agent of) the Owner in the presence of: ____________________ Date: ____________________

Witness: ____________________

Occupation: ____________________

Address: ____________________

SIGNED by ____________________
as (authorised agent of) the Contractor in the presence of: ____________________ Date: ____________________

Witness: ____________________

Occupation: ____________________

Address: ____________________

B.2 First Schedule—General Well Drilling Specification

1. INTRODUCTION

This specification is for the drilling of a well for water production.

2. LOCALITY

The Owner will indicate the exact drilling position to the Contractor.
The well will be located on the property of
which is km from the Post Office.

3. EXTENT OF WORK

The work for which this specification is written comprises:

(a) Obtaining a drilling permit from the regional water board. (But not the obtaining of a water right.)
(b) Drilling a mm diameter well to a depth of approximately m.
(c) Recording details of strata penetrated and water levels, plus taking samples for inspection.
(d) Developing a water bearing stratum (if located) involving supply and installation of casing, supply and installation of a slotted well screen, well development, and testing by pumping.
(e) Supplying all materials, consumables, labour, plant and equipment to complete the specified work.

4. WELL DEPTH

It is expected that the well will be drilled to a depth of approximately metres. However, the Owner reserves the right to vary the depth according to the results of drilling.

5. ACCESS TO SITE

The Owner will arrange access to the site for the Contractor, employees and suppliers, and an adequate working area will be made available.

6. SERVICES

Before drilling, the Contractor shall check with all relevant local authorities for the absence of service lines at the site.

7. DRILLING

Contractors are expected to have visited the site, be familiar with the nature of the country and shall provide suitable equipment to cope with all surface and subsurface conditions which can be reasonably anticipated. Drillers engaged on the work shall be well trained and thoroughly experienced in all phases of well drilling, screen setting, developing and testing. Care shall be taken to ensure that the drilling is kept sufficiently vertical and straight to enable a submersible pump to be used in the well.

8. CASING AND DRIVE SHOE

Casing shall be of the best quality available and shall conform to a recognised standard specification. It shall have sufficient strength to withstand all shocks and stresses of placing and withdrawing. It shall also have strength to resist earth and water pressure during well operation. The Contractor shall provide full details of the casing, system of jointing and specification with which it complies.

The driving shoe must be sufficiently robust to withstand all shocks and stresses during driving. Any failure of the shoe shall be made good at the Contractor's expense unless failure occurred while operating under the explicit instruction of the Owner.

9. WELDING

Welding shall be done by a competent welder to best standards of workmanship. Any failure of welds during driving or withdrawal of casing must be made good at the Contractor's expense unless failure occurred while operating under the explicit instruction of the Owner.

10. RECORDING

The Contractor shall keep a record, to an accuracy of 10 cm, of the depth below ground of each change of material and shall provide a written description of it. Depth of standing water level in each water-bearing layer shall be recorded. Where drilling mud is not in use, water levels shall be recorded prior to work beginning each day, and during drilling note shall be taken of strata where water is lost or gained. A copy of this information in the form of a well log shall be supplied to the Owner. Where required by the Owner, the Contractor shall take samples of at least 1 kg weight in fine material and 5 kg in gravels. These shall be stored in sealed plastic bags, with labels showing the depth from which they were taken.

11. PRELIMINARY TESTING

The Owner may direct the Contractor to do a preliminary test of yield of water and drawdown for each water-bearing stratum encountered as drilling progresses.

12. WELL SCREEN

When the Owner is satisfied that a satisfactory aquifer has been located, a screen shall be installed. Full details of the type of screen to be used and the methods of jointing, of placement and of sealing with the casing shall be given by the Contractor. Slot opening size, determined from sieve analysis of the aquifer material, shall retain at least 30 percent of aquifer materials in well mixed materials and 40 percent in poorly mixed materials.

The length of the screen shall be determined from the aquifer thickness and wherever possible shall be long enough to give an average velocity through the slots of less than 3 cm per second at the intended production rate. The depth to the bottom of the screen shall be accurately recorded.

13. WATER ANALYSES

The Contractor shall arrange with a competent water quality laboratory to take samples of water. These shall be checked for tendencies to corrode, to incrust and for general suitability for the intended water use, including bacteriological testing if the well is to be used for drinking water.

14. DEVELOPMENT

The Contractor shall give full details of the method of development proposed and of how sand content of the water will be determined. Development and testing will continue until the sand content of the water is 5 parts per million or less.

15. FINAL TESTING

The Contractor shall provide all necessary equipment and labour to carry out a production test on the well. The test pump shall be capable of pumping at 120 percent of the planned production rate for 24 hours continuously. Actual pumping rate and duration of test will be determined by the Owner after well development is complete. Water pumped during testing shall be disposed of by the Contractor without damage or nuisance.

The pumping rate shall be measured by means of a measuring weir, orifice meter or other approved method, to an accuracy of ± 5 percent.

The drawdown during pumping and water level during recovery shall be determined to an accuracy of ± 5 mm. Measurements of both flow and drawdown shall be checked every minute for the first 5 minutes, every 5 minutes for the first hour and every 15 minutes thereafter until pumping is stopped. Measurements during recovery shall be made at the same intervals until the water level is within 10 cm of the rest position.

16. WELL HEAD FINISHING

The Contractor shall provide approximately 300 mm of casing above ground level and fit this with a secure cap to prevent interference with the well.

17. CLEANUP

On completion, all materials from the drilling operation shall be removed and the work area left tidy.

18. PAYMENT

Payment will be made on a 'Schedule of Rates' basis according to the attached contract schedule.

'Drilling' includes the provision of casing in place. Where casing is withdrawn the Contractor shall credit the Owner with its value at the rate per metre shown in the schedule.

Payment for the screen shall be per metre in place, all inclusive.

Development and testing shall be paid for at an hourly rate for working time only.

No extras will be allowed for standby due to equipment failure, loss of tools down hole, scheduled equipment maintenance, bad weather or any other cause whatsoever.

B.3 Second Schedule—Rates and Prices

No.	Schedule Item	Unit	Quantity	Rate	Amount
1	Establishment on a clear site	Lump Sum			
2	Drilling of mm diameter well, supply of casing, drive shoe, mud cement, etc.	m			
3	Preliminary well tests of water-bearing strata	Each			
4	Supply of mm diameter slotted well screen including associated packers. In place.	m			
5	Development of well	hrs	24		
6	Final testing of well	hrs	8		
7	Well capping	Lump Sum			
8	Clean up and disestablishment	Lump Sum			
	Total cost of well				
9	Credit allowance for casing withdrawn	m			

The Contractor must supply the following information:

1. Method of drilling to be used ....
2. Well casing — Material ....
   Internal Diameter ....
   Wall Thickness ....
   Joint System ....
   Complying with .... standard specification
3. Method of preliminary testing ....
4. Screen — Material ....
5. Water quality laboratory to be consulted ....
6. Development method(s) available ....
7. Method of flow measurement to be used ....
8. Approximate start date ....
9. Approximate finish ....
10. Public Liability Insurance held with ....

WATER AND SOIL TECHNICAL PUBLICATIONS

1.	Liquid and waterborne wastes research in New Zealand 1976. Sally Davis. ($1)	1977
2.	Sampling of surface waters. M. Kingsford, J. S. Nielsen, A. D. Pritchard, C. D. Stevenson. ($1)	1977
3.	Water quality research in New Zealand 1976. Sally Davis. ($1)	1977
4.	Shotover River catchment. Report on sediment sources survey and feasibility of control 1975. (out of stock)	1978
5.	Late Quaternary sedimentary processes at Ohiwa Harbour, eastern Bay of Plenty with special reference to property loss on Ohiwa. J. G. Gibb. ($1)	1978
6.	Recorded channel changes of the Upper Waipawa River, Ruahine Range, New Zealand. P. J. Grant. (out of stock)	1978
7.	Effects of domestic wastewater disposal by land irrigation on groundwater quality of the central Canterbury Plains. G. N. Martin and M. J. Noonan. ($1)	1978
8.	Magnitude and frequency of floods in the Northland-Auckland region and their application to urban flood design. J. R. Waugh. ($1)	1978
9.	Research and Survey annual review 1977. (out of stock)	1978
10.	The problem of coastal erosion along the "Gold Coast", western Wellington, New Zealand. J. G. Gibb. (out of stock)	1978
11.	The Waikato River: A water resources study. ($12)	1979
12.	A review of the habitat requirements of fish in New Zealand rivers. Compiled by D. F. Church, S. F. Davis, and M. E. U. Taylor. ($3)	1979
13.	The Ruahine Range: A situation review and proposals for integrated management of the Ruahine Range and the rivers affected by it. A. Cunningham and P. W. Stribling. ($5)	1978
14.	A Survey of New Zealand peat resources. A. Davoren. ($10)	1978
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