MINISTRY OF LOCAL GOVERNMENT, HOUSING AND CONSTRUCTION

NATIONAL WATER SUPPLY AND DRAINAGE BOARD

SRI LANKA

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DESIGN MANUAL D4

GROUND WATER

MARCH, 1989

WATER SUPPLY AND SANITATION SECTOR PROJECT

(USAID SRI LANKA PROJECT 383-0088)

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1. OCCURRENCE OF GROUNDWATER

A water-bearing bed or stratum of earth, gravel or porous stone can be called an aquifer. Some strata are good aquifers, whereas others are poor. The most characteristic feature is that the stratum must have interconnected openings or pores through which water can move. The nature of the aquifer depends on the material of which it is composed; its origin, the relationsip of the constituents grains or particles and associated pores, its relative position in the earth's surface, its exposure to a recharge source, and other factors. The main different types of aquifer are described in the following sections.

1.1. Sedimentary Rocks

In general, the best aquifers are the coarse-grained, saturated portions of the unconsolidated, granular schementary cover which overlies the consolidated rocks of the surface of the earth. Widespread occurrence of unconsolidated sediments is more common at lower elevations in proximity to streams. These sediments consist of stream alluvium, glacial outwash, wind-deposited sand, alluvial fans, and similar water or wind deposited coarse grained, granular materials. In addition some residual materials resulting from the weathering in place of consolidated rock are good aquifers.

The coarser-grained consolidated rocks such as conglomerates and sandstones are also often good aquifers, but are usually found below the unconsolidated granular sedimentary mantle. Their value as aquifers depends to a large extent on the degree of cementation and fracturing to which they have been subjected. In addition, some massive sedimentary rocks such as limestones, dolomite and gypsum may also be good aquifers. These rocks are relatively soluble and over the years, solution along fractures or partings may form voids which range in size from a fraction of 1 mm to several hundred meters. Cavernous limestones are also good aquifers.

1.2 Igneous and Metamorphic Rocks

The value of igneous and metamorphic rocks as aquifers depends greatly on the amount of stress and weathering to which they have been subjected after their initial formation. In general, crystalline igneous rocks are very poor acquifers if they remain undisturbed. However, mechanical and other stresses cause fractures and faults in these rocks in which groundwater may occur. Such openings may range from few mm to several cm.

In coarse-grained crystalline rocks, where in-place weathering has occurred, a thin permeable zone may be found in the transition zone between the sound rock and the thoroughly weathered, usually relatively impermeable, overlying residual material.

1.3 Confined and Unconfined Aquifers

An unconfined aquifer is one that does not have a confining layer overlaying it. It is often referred to as a free or "water table" aquifer or as being under "water-table conditions", water infiltrating into the ground surface percolates downward through air-filled interstices of the material above the saturated zone and joins the groundwater body. The water table, or upper surface of the saturated groundwater body is in direct contact with the atmosphere through open pores of the material above and is everywhere in balance with atmospheric pressure. Movement of the groundwater is in direct response to gravity.

A confined or artesian aquifer has an overlying, confining layer of lower permeability than the aquifer and has only an indirect or distant connection with the atmosphere. Water in an artesian aquifer is under pressure and when the aquifer is penetrated by a tightly cased well or piezometer, the water will rise above the bottom of the confining bed to an elevation at which it is in balance with the atmospheric pressure and which reflects the pressure in the aquifer at the point of penetration. If this elevation is greater than most of the land surface at the well, water will flow from the well. The imaginary surface, conforming to the elevations to which water will rise in wells penetrating an artesian aquifer, is known as the potentiometric or piezometric surface.

1.4 Perched Aquifers

Beds of clay or silt, unfractured consolidated rock, or other material with relatively lower permeability than the surrounding materials may be present in some areas above the regional water table. Downward percolating water may be intercepted and a saturated zone of limited areal extent formed. This results in a perched aquifer with a perched water table. An unsaturated zone is present between the bottom of the perching bed and the regional water table. A perched acquifer is a special case of an unconfined aquifer. Depending on climatic conditions or overlying land use, a perched water table may be a permanent phenomenon or one which is seasonally intermittent.

1.5 Occurrence in Sri Lanka

Sri Lanka is divided into wet and dry zones, the line dividing the two zones being based on an average annual rainfall of 1700-2000mm. About 25 percent of the land surface lies in the wet zone, while 75 percent covers the dry zone.

Annual precipitation is 1778-5588mm in the wet zone and 635-1778mm in the dry zone. This precipitation comes from two monsoons: the southwest monsoon (April to September) which affects the wet zone and the northeast monsoon (October to December) which benefits the dry zones. Of the estimated 110,000Mm^3 of rainfall which falls over the island, 36 percent falls in the wet zone and 64 percent falls over the much larger dry zones. The portion of the total rainfall which percolates to the groundwater basins is reported to be 7,300Mm^3 per year (6.6 percent).

The island of Sri Lanka has been divided into six hydrogeological regions, based on geology and rainfall, by the Geological Survey Department of the Ministry of Industries and Scientific Affairs. Mr. V.S. Balendran in "Groundwater in Ceylon", Mineral Information Series No.1, 197, lists these six regions as follows:

1. The northwestern and northern coastal belts
2. The eastern and southeastern coastal belts
3. The areas occupied by laterite
4. The narrow faulted basins
5. The wet zone region occupied by crystalline rocks
6. The dry zone region occupied by crystalline rocks

Region 1 consists of Recent and Pleistocene deposits to Miocene and older rocks. Three formations supplying groundwater are the Jaffna Miocene limestone, Vannativillu limestone and Moongilaru formation limestones. Some wells have been reported to produce from 270–910m^3/d in this cavernous limestone filled with solution channels. Large diameter dug wells in the limestone and overburden in the Jaffna area are producing water from the fresh water lens floating on the underlying salt water.

Region 2 consists of dune and lagoonal sands 12–18m thick, which yield limited quantities of groundwater.

Region 3, the laterites, along the southwestern coastal area from Negombo to Matara, yield groundwater from the weathered zone, 12–30m thick, overlying the Pre-Cambrian basement rock. Rapid changes in water levels following monsoon rains indicate the effect of rainfall on these lateritic insitu deposits. Raolin and quartz lie between the bedrock and laterite. A capping of limanitic nodules and clayey sand comprises the topsoil.

Region 4, comprising the narrow faulted basins, a small area of about 80km, provides a large thickness of sediments up to 460m. The succession of shales and arkosic sandstones confine or partially confine the aquifers giving rise to artesian or semi-artesian conditions.

Region 5, the crystalline rocks of the wet zone, is a highly faulted area of gneissic and metasediments which extends from the area of Kurunegala and Matale in the north almost to Galle and Matara in the south, and from the Badulla area westward to just east of Colombo and Kalutara. Water is produced from the fissures and joint planes of the crystalline limestones, quartzites, and gneisses which are aligned primarily in north-south trending bands. Many springs occur in the ridges of quartzites and gneisses and in the limestones underlying the valley areas.

Region 6, is the crystalline rocks of the dry zone. In this region groundwater is produced mainly from Pre-Cambrian gneisses and metasediments, from highly fractured and jointed areas. The overburden is about 12-30m thick and provides some aquifers that are separate and discontinuous. Faults are aligned northwest-southeast and northeast-southwest. A line of cold springs and mineralised springs are generally aligned in a north-south direction from Trincomalee to Hambantota. This line is thought to be the contact between the Pacific and Indian continental plates.

2. WELL HYDRAULICS AND ANALYSIS OF DISCHARGING WELL

2.1 Definitions

The terms mostly used in well hydraulics are given below;

Aquifer – is a formation, or group of formations which yields water in sufficient quantity to be of consequence as a source of supply.

Aquitard – is a formation or group of formations which yields inappreciable quantities of water to a well compared to an aquifer but through which appreciable leakage of water is possible.

Aquiclude – is a formation or group of formations which yields inappreciable quantities of water to a well and through which there is inappreciable movement of water.

Unconfined Aquifer – is one in which the groundwater possesses a free surface open to the atmosphere. The upper surface is called the water table.

Confined Aquifer – is one in which the groundwater is confined under pressure by overlying and underlying aquitards or aquicludes and water levels in wells rise above the top of the aquifer. Artesian aquifers are classified as leaky or non-leaky depending upon whether groundwater in the aquifer is confined by aquitards or aquicludes.

Static Water Level (SWL)– is the level at which water stands in a well when no-water is being taken from the aquifer either by pumping or free flow. The water levels are expressed as the distance from ground level or from a suitable measuring point near gound surface, to the water level in the well.

Pumping Water Level (PWL) – is the level at which water stands in a well when pumping is in progress. This level is variable and changes with time as well as with quantity being pumped. This is also called the dynamic level.

Drawdown (S) – is the distance the static level lowers under a given rate of pumping. It is the actual distance between static level and dynamic level.

Residual Drawdown (S) – After pumping is stopped, water level rises and approaches the static level observed before pumping started. The distance that the water level is found to be below the initial static level at any instance during recovery is called residual drawdown.

Well Yield (Q) – is the volume of water discharged from a well per unit of time, either by pumping or by free flow. It is measured as pumping rate in Litres/mm or Litres/second.

Specific Capacity (Q/S) – of a well is its yield per unit of drawdown. Dividing the yield by the drawdown, each measured at the same time, gives the value of specific capacity.

Storage Coefficient (S) – of an aquifer is the volume of water released from storage, or taken into storage, per unit of surface area of the aquifer per unit change in head. In water-table aquifers, S is the same as the specific yield of the material dewatered during pumping. In artesian aquifers, S is the result of two elastic effects – compression of the aquifer and expansion of the contained water – when the head or pressure is reduced during pumping. The coefficient of storage is a dimmensionless term. Values for S for water-table aquifers range from 0.01 to 0.35; values for artesian aquifers range from 0.00001 to 0.001.

Transmissivity Coefficient (T) – of an aquifer is the rate at which water will flow through a vertical strip of the aquifer extending through the full saturated thickness.

2.2 Types of Pumping Test

The main idea of a groundwater study is to determine how much groundwater can be extracted safely from the aquifer under study. A number of standard methods have been developed for evaluating pumping and aquifer test data. The principles of occurrence of groundwater can differ according to rock and soil type. Even for the same rock or soil type occurrence can vary from place to place. Therefore pumping test data should be analyzed with caution and with the maximum information on the well to be tested.

Pump testing should, if possible, be carried out on all wells drilled, including wells scheduled for hand pumps. Either the compressor or the drill rig or a separate air compressor should be used to airlift water while drawdown measurements are taken. The flow rate divided by the drawdown gives a specific capacity value, a useful calculation in a newly constructed well that can be compared with later pumping tests during redevelopment to indicate if the well is getting worse as far as production is concerned. In limestone wells, specific capacity has been known to increase with time.

Following a pumping test for a recommended minimum period of 8 hours, a recovery test should be made as the static level recovers at or near the static level at the start of the pumping test. The distance between the stabilized pumping level and static level after a certain time period can be used to calculate the volume of water and when divided by the average time, will give a rate of intake to the well which can be considered as a 'safe yield' for planning purposes or pump selection, if a power pump is used.

A pumping test is conducted on an individual well to obtain information about the performance of that well.

Data Collected : Discharge, drawdown and recovery

Calculated : Transmissivity from drawdown and recovery data, well loss and aquifer loss constants from step drawn-down data, actual and corrected values of specific capacity.

Results : The head and capacity of a pump for the tested well can be selected. The nature of aquifer can be determined, that is normal, limited, recharging or anisotropic. The pumping period can be recommended.

A second type of test is called an aquifer test. An aquifer test is a test in which one well is pumped and measurements of drawdown and recovery are made in both the pumped and observation well(s). The main purpose of the test is to determine the hydraulic characteristics of the aquifer.

Data Collected : Discharge of the pumped well, and drawdown and recovery of both the pumped and observation well(s).

Calculated : Transmissivity and storage coefficient from drawdown and recovery data in both the pumped and observation well(s), well loss and aquifer loss constants from step-drawdown data, actual and corrected values of specific capacity, and well efficiency.

Results : If enough observation wells are available, the effect of a limited or recharging boundary can be noted as well as the direction of such an effect. The effect of interference can be determined enabling the proper spacing of wells. The results of a pumping test listed above can be determined.

2.3. Testing Methodology

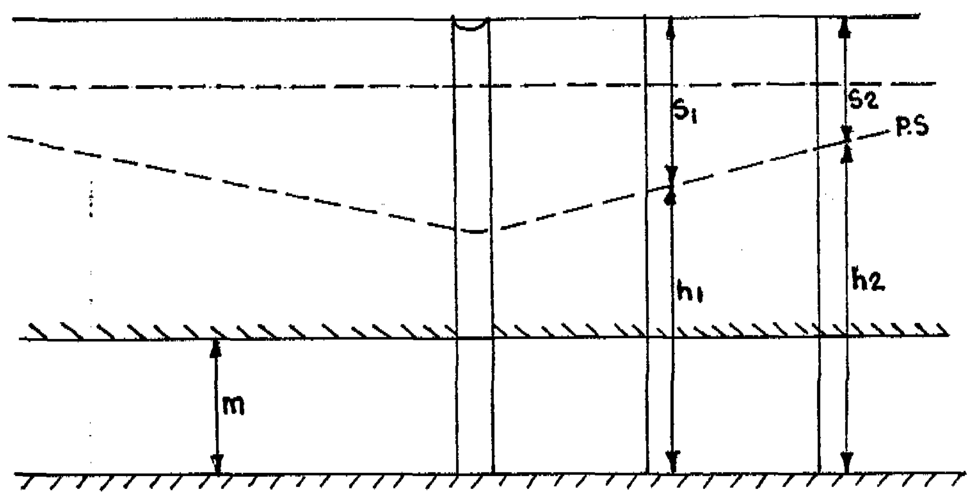
Before a pumping or aquifer test, certain information about the well must be prepared. This information will facilitate the selection of the pump for the test, conductance of the test, and interpretation of test data. Information to be collected are, diameter of bore and bit caliper log to help in the selection of pump diamter, depth of bore, length and diameter of casing pipe, strata log of the well, depth to aquifer(s), relative yield of an aquifer; and nature of aquifers(s).

There are two types of tests that can be conducted. They are step drawdown test and constant-rate test. In a step drawdown test the well is pumped at various discharges. In a constant-rate test, the well is pumped at a constant discharge for a fixed priod of time and recovery is measured for the same duration as pumping. A step drawdown test can be used for determining the capacity of a pump to be installed in a tested well. If values of transmissivity and storage coefficient to be calculated, a constant-rate test must be conducted.

2.4 Analysis of Discharging Well

There are a number of standard methods in use today for anlysing pumping and aquifer test data. This section contains a brief discussion of some common methods.

a) Theim-Forchheimer or equilibrium equation for confined aquifers under steady state conditions:



$$Q = \frac{2 \pi KM (S_1 - S_2)}{\log_e(r2/r_1)}$$

where

$\log_e$ = natural log = (common log x 2.303)

k = permeability or hydraulic conductivity (L/t)

Q = discharge of the test well (L^3/t)

M = saturated thickness of the aquifer (L)

T = KM = transmissivity of the aquifer (L^2/t)

L = unit length

t = unit time

$r_1 r_2$ horizontal distance from centerline of test well to centerline of observation well (L)

$h_1 h_2$ saturated thickness or piezometric head of the aquifer at distasnces r_1, r_2 from the test well (L).

$S_1 S_2$ drawdown in observation wells at distances r_1, r_2 from the test well (L).

The following assumptions are made for the above equation.

i) The aquifer is homogeneous, isotropic, and of uniform thickness.

ii) The discharging well penetrates and receives water through the entire thickness of the aquifer.

iii) The coefficient of transmissivity of permeability (hydraulic conductivity) is constant at all times and at all locations.

iv) Discharging has continued for a sufficient duration for the hydraulic system to reach a steady state.

v) Flow to the well is horizontal, radial and laminer, and originates from a circular open water source with a fixed radius and elevation which surrounds the well.

vi) The rate of discharge from the well is constant.

b) Theim-Dupuit - Forchchiemer equation for Unconfined Aquifers.

$$Q = \frac{\pi K (h_2^2 - h_1^2)}{\log_e(r_2/r_1)}$$

In addition to the assumptions made under confined aquifers, following assumptions are made for unconfined aquifers:

vii) The velocity of flow is proportional to the tangent of the hydraulic gradient.

viii) The flow is horizontal and uniform everywhere in a vertical section through the axis of the well.

c) Theis or non-equilibrium equation

In 1935, Theis perceived the analogy between flow of heat and flow of water and adapted the equation for the flow of heat in a conducting solid to the flow of water to a well in a confined aquifer.

$$S = \frac{Q}{4\pi T} \int_u^{\infty} \frac{e^{-u}}{u} du$$

where, $u = \frac{r^2 S}{4Tt}$

S = the drawdown at any point or on the cone of depression (L).

Q = Uniform discharge of a well per unit time (L^3/t)

T = KM, the transmissivity (L^2/t)

r = the distance from the center of the discharging well to the point of measurement of s

S = the storativity or coefficient of storage (non-dimensional)

t = the time since discharge of the well began.

The assumptions on which the non-equilibrium equation is based are:

i) The aquifer is homogeneous isotropic of uniform thickness and of infinite areal extent.

ii) The discharging well is of infinitesimal diameter, completely penetrates and is open to the aquifer.

iii) The discharge of water from storage is instantaneous with the reduction in pressure due to drawdown.

iv) The flow to the well is radial and horizontal.

The exponential integral of u is frequently expressed as W (u) the well function of u, and the equation can then be rewritten as,

$$S = \frac{QW\ (u)}{4\,\pi\,T}$$

However the above assumptions are rarely all present in actual situations. This equation is theoretically applicable only to confined aquifers.

The error in the analysis of free aquifers is minor provided the drawdown at the point of observation does not exceed 25 percent of the aquifer thickness. Use of the nonequilibrium equation permits analysis of aquifer conditions and predictions of aquifer behaviour that change with time and involve storage. This makes possible many of the modern modelling and computer techniques used in groundwater analyses.

d) <u>Jacob's approximation solutions for the non-equilibrium equation</u>

A method developed by Cooper and Jacob permits an approximate solution to the Theis nonequilibrium equation using a straight line graphical approach, which is simple and may offer advantages over the type curve methods.

$$S = \frac{Q}{4\pi T}\left(\log_e \frac{2.25\,Tt}{r^2 S}\right)$$

$$= \frac{2.303\,Q}{4\pi T}\log\left(\frac{2.25\,Tt}{r^2 S}\right)$$

A plot of the drawdown S versus the logarithm of distance r or time is a straight line; two simple semilog graphical methods can be used to solve for transmissivity and storativity.

i) Distance - Drawdown Solution:

In this method, drawdowns taken at the same time in each of three or more obervation wells are plotted against the distance on a log scale of each observation well from the test well. The straight line portion of this curve is projected to cover least one log cycle and the zero drawdown axis.

Transmissivity is calculated by

$$T = \frac{2.303\,Q}{2\pi\,\Delta S}$$

where ΔS

is the difference in drawdown over one log cycle.

Storativity is determined by projecting the straight line to the zero drawdown interception which defines the distance r_o, and substituting the value of r_o into

$$S = \frac{2.25\,Tt}{r_o^2}$$

ii) Time - Drawdown Solution:

Drawdown in each observation well since pumping began is plotted against time on the log scale. The straight line portion of the plot is projected to intercept one or more log cycles and the zero drawdown axis.

The value of transmissivity and storativity can be calculated by

$$T = \frac{2.303\ Q}{4\pi \Delta s}$$

$$S = \frac{2.25\ T\ t_o}{r^2}$$

Δs = drawdown over one log cycle

t_o = time at zero drawdown intercept

r = distance from the test well to the observation well.

e) Theis Recovery Test

If a borehole is pumped at a constant rate and then pumping is stopped, the well will recover from its lowest drawdown of h_T, at time T' when pumping is stopped, to reach a value of $h' > h_{T'}$ at time t' counted from the time of shut down;

t = O ——— t = T' ——→ t

h = H ——— $h = h_{T1}$

Start of test ——— Shut down ——→ t'

$t' = o \quad h = h'$

$$S' = H - h' \qquad - 1$$

S' = residual drawdown

H = initial value of head

h' = value of head at time t'

Assume the discharge of the well is at same rate of Q for $t > T'$ but that at $t = T'$ a recharge well of strength Q is superimposed on the discharge so that the net discharge is zero from $t = T'$.

From Eqn 1:

$$S' \quad (H-h) + (h-h')$$

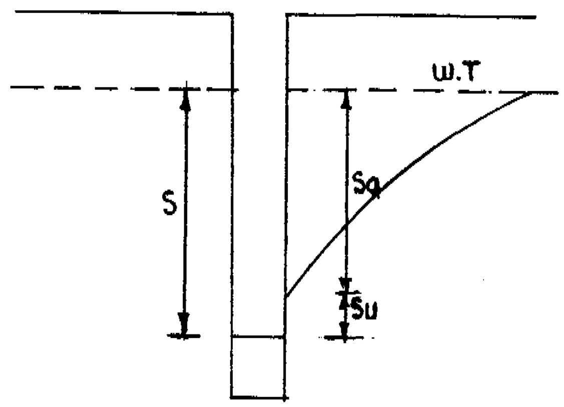
$$S' = \left\{\frac{Q}{4\pi T}\left(\ln \frac{4Tt}{r^2 S}\right) - 0.5772\right\} - \left\{\frac{Q}{4\pi T}\ln \frac{4Tt'}{r^2 S}\right) - 0.5772\right\}$$

If u $\left(u = \frac{r^2 S}{4Tt}\right)$ is small compared with ln u

$$s' = \frac{2.3\ Q}{4\pi T} \log \frac{t}{t'}$$

If residual drawdown (s') is plotted against log t/t_1, a straight line will result, the gradient of which gives the value of T if the discharge, Q is given.

f) <u>Step Drawdown Test</u>



In this method, drawdown in a pumped well includes head loss in the water bearing formation (aquifer loss) and head loss in the well itself including head loss in areas close to the well caused by higher velocities due to converging flow, head loss caused by well screen, and head loss inside the well around the pump intake. The latter head losses are termed well loss. Another way of separating the two components of drawdown is to consider that head loss is caused by laminar flow (aquifer loss) and turbulent flow (well loss)

Sa = Aquifer or formation loss due to laminar flow throughout aquifer with discharge Q.

Su = Well loss due to turbulant flow through well construction with discharge Q^n.

$Sa = BQ$

$Su = CQ^n$

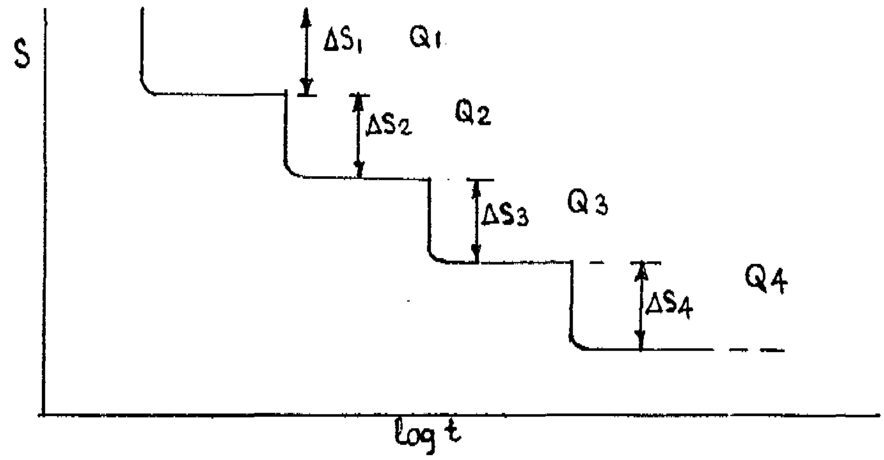
B and C are constants and n is said to vary between 1 and 3.5 but is usually taken as 2.

The total drawdown is expressed by

$$S = BQ + CQ^2$$

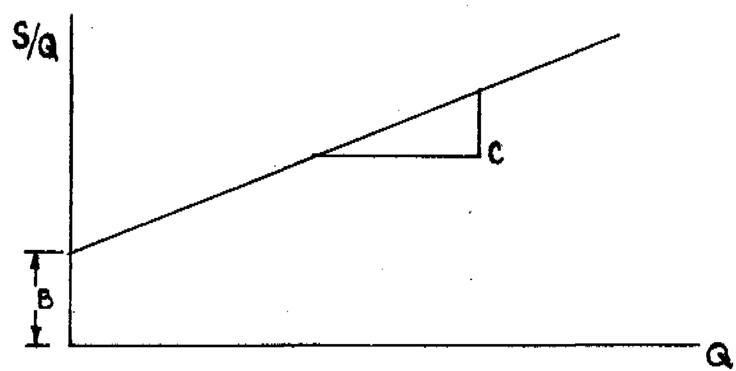
$$\frac{S}{Q} = B + CQ$$

Thus if S/Q is plotted against Q, a straight line results with an intercept of B and a slope of C. S is taken for the total drawdown in a step drawdown test and not the individual drawdown for that step.



At least four steps should be carried out. Time intervals should be equal and should be 100 minutes to 2 hours.

Total S for the pumping rate of Q_3 is $S = \Delta S_1 + \Delta S_2 + \Delta S_3$



$$\text{Well efficiency} = \frac{B\,Q \times 100}{(BQ + CQ^2)}\ \%$$

Transmissivity (T) can be calculated using the approximate equilibrium formular:

$$T = \frac{2.3\,Q}{2\pi S} \log \frac{r_s}{r_w}$$

r_s = radius of influence
r_w = effective well radius

(It has been shown that $\log \frac{r_s}{r_w}$ could be taken approximately as 3.3).

$$\therefore\ T = \frac{1.22\ Q}{S}$$

3. GROUNDWATER INVESTIGATIONS

Investigations for groundwater may involve a number or procedures which could be adopted, according to the situation and the problems existing, as follows:

1. Hydrometeorological studies

2. Hydrogeological studies

   a) Geological mapping
   b) Landform studies
   c) Test drilling, sampling and logging
   d) Aquifer tests

3. Aerial photographic surveys:

   a) Black and white
   b) Colour
   c) Infra-red
   d) Satellite imagery

4. Geophysical surveys:

   a) Surface geophysical surveys:

      - Seismic surveys
      - Electrical resistivity surveys
      - Magnetic surveys
      - Gravimetric surveys

   b) Drill hole surveys:

      - Electrical logs
      - Caliper logs
      - Temperature logs
      - Radio-activity logs

5. Tracer techniques

6. Geochemical and geothermal surveys

7. System analysis, mathematical modelling and computer applications for groundwater basin management.

8. Water balance studies.

The objectives of these hydrogeological investigations are:

- o To define recharge and discharge areas.
- o To define water bearing formations
- o To define location, extent and inter-relationship of aquifers.

- To establish hydrogeological parameters, such as transmissivity, storage coefficient and specific yield.
- To estimate total subsurface storage capacity.
- To establish hydrogeological factors relating to groundwater quality
- To identify location of well sites, and predict depth of drilling and yield.

4. ESTIMATE OF AQUIFER YIELD, HYDRAULIC BUDGETS AND INVENTORIES

4.1 Aquifer Yield

An adequate estimate of the availability of groundwater in storage beneath an area requires determination of the groundwater basin boundaries both vertical and horizontal, and of aquifer dimensions and characteristics. Since groundwater is a dynamic resource with constantly changing water levels caused by natural or artificial influences, interpretation is facilitated by careful analysis of water level fluctuation as related to such influences.

For assessments of longtime aquifer yield and performance, evaluations are based on an average annual basis and maximum high and low water conditions. The basic results of a groundwater inventory are the determination of the total water in storage and the annual change.

The techniques of groundwater evaluation are relatively subjective and the degree of accuracy and the reliability of initial results are often questionable. Many evaluation studies involve a continued reassessment and refinement of the estimates as more data on actual response of the aquifer to development become available.

A groundwater study involves consideration not only of groundwater but also of surface water. The boundaries of a groundwater reservoir may or may not coincide with those of an overlying surface water basin. In many investigations, the setting of arbitrary boundaries may be required.

4.2 Hydrologic Budgets

The hydrologic budget is a quantitative evaluation of the total water gained or lost from a basin or part of a basin during a specific period of time. It considers all water, whether surface or groundwater, entering, leaving or stored within the area of study. The hydrologic budget is summarized in the following equation.

$$\Delta S = P - E \pm R \pm u$$

where,

ΔS = changes in storage in channels and reservoirs in groundwater storage and in soil moisture.

P = precipitation on the area of study

E = evapotranspiration from the area

R = difference between stream outflow and inflow

u = groundwater outflow and inflow.

The components of ΔS are: changes in surface storage, changes in stream channel storage, changes in soil moisture and changes in groundwater storage which can be estimated from contour maps of the water table or piezometric surface and the storativity of the aquifer at the beginning, during and end of the study period.

Precipitation consists of all the rain falling in the area. The estimating of long-term evapotranspiration has been studied and numerous methods have been adopted, all of which are approximate. Evaporation pan records, when corrected, give a value of evaporation from open water, but evapotranspiration from soil is more complex.

Streamflow consists of surface runoff of precipitation within the area, surface inflow to the area and groundwater seepage to streams. Surface inflow can be estimated from stream gauging records.

Groundwater flow components are the underflow from and to adjacent basins. Flow can be estimated by determining the width of the flow path from knowledge of the aquifer dimensions, the gradient from water level contour maps, and the transmissivity from results of pumping tests or other sources.

4.3 Groundwater Inventories

The groundwater components of the hydrologic cycle used in estimating a groundwater budget are summarized as follows:

$$G - D = S$$

where,

G = recharge to the aquifer

G = discharge from the aquifer

ΔS = change in storage in the aquifer

The components of D may include deep percolation from precipitation, seepage from surface water bodies, groundwater underflow from adjacent areas, artificial recharge including deep percolation from irrigation, sewage disposal facilities, and recharge wells and leakage through confining beds.

Components of D may include evapotranspiration, seepage to surface water bodies, groundwater underflow to adjacent areas, discharge of springs, artificial discharge including drainage systems, wells and infiltration galleries and discharge through confining beds.

Changes in groundwater storage are reflected by fluctuations in the groundwater levels. Since most assessments are based on long term averages with the beginning and end of the study period about the same season of the year, changes in soil moisture can be ignored.

4.4 Groundwater Reports

A groundwater report may range from a simple one page document containing a statement of the problem, with conclusions and recommendations, to a comprehensive document containing text, maps, charts, graphs, and tables. The importance and complexity of the task and the time, money and facilities available generally determine the length and content of the report. The main body of the report may contain some or all of the following data in greater or lesser detail as required to clearly state the problems, conclusions and recommendations. An outline of a typical report could be as follows:

1. Objective of the study.

2. Location and size of the area under study.

3. Cultural or sociological aspects of the area.

   a) Public utilities
   b) Water supplies
   c) Sewage disposal
   d) Transportation
   e) Settlement
   f) Vegetation
   g) Irrigation

4. Climate

5. Surface hydrology

6. Geology and geomorphology

7. Groundwater hydrology.

   a) Location, depth, thickness, lithology, areal extent and types of aquifers.

   b) Water table and piezometric surface gradients, direction of flow, recharge and discharge areas etc.

   c) Seasonal and annual fluctuations in groundwater levels, etc.

   d) Present groundwater development including number of wells, locations, depths, yields, drawdowns, pumping lifts, etc.

   e) Well history

   f) Transmissivity and storativity of aquifers etc.

   g) Quality of groundwater

   h) Suitability of aquifers for proposed development or use.

8. Proposed groundwater development program.

   a) Number, location etc.

   b) Probable capacities

   c) Proposed well design

   d) Recharge possibilities.

9. Factors and facilities for groundwater development.

   a) Number of drilling agencies available.

   b) Regional and local laws and regulations governing groundwater rights, drilling permits, design and construction of wells, etc.

   c) Water well supply dealers, pipe dealers, chemical and bacteriological testing laboratories, well logging and geophysical survey institutions, etc.

10. Maps

   a) The location map of the study area.

   b) Maps of the study and adjacent areas:

      - Planimetric: existing location of wells, towns, highways, railroads, etc.
      - Topographic
      - Geologic
      - Groundwater
      - Isobathic or depth of water
      - Surface water
      - Landownership/land use
      - Quality of water
      - Aquifer characteristics
      - Isohyetal or rainfall

11. Cross sections, fence diagrams end hydrographs.

   a) Geologic
   b) Hydrologic

12. Graphs, charts and tables.

   a) Temperatures

   b) Average annual and monthly precipitation

   c) Annual precipitation, minimum, mean and extreme.

   d) Cumulative precipitation

   e) Stream and lake hydrographs

   f) Quality of water

g) Projections of water use, population

h) Ground and surface water use

i) Chemical and bacteriological analyses

j) Pump test measurements and analyses

k) Mechanical analysis of aquifer samples

l) Well logs

m) Geophysical surveys

n) Evapotranspiration

13. Drawings

a) Well and/or infiltration gallery design

b) Test site layouts.

c) Special equipment designs

5. WELL DRILLING

Most wells are drilled by mechanically-powered equipment referred to as drill rigs. There are mainly two types of drilling; namely Hammer drilling and Rotary drilling.

5.1 Hammer Drilling

In hammer drilling the impact mechanism strikes against the drill bit, which rotates a little between each impact. There are three modes of operation in hammer drilling:

a) Down the hole (DTH) drilling

The principle for down-the-hole drilling is that the rotary unit is positioned on a feed above ground, while the impact mechanism is located just behind the drill bit. The piston always strikes directly against the drill bit. Either button bits or insert bits are used in down-the-hole drilling, depending upon the formation.

b) Top hammer drilling

The principle top hammer drilling is that both the impact mechanism and rotary unit are positioned on a feed above ground. In this method the impact energy must travel all the way through the drill string before it reaches the drill bit.

c) Cable tool drilling

The cable tool method of drilling is one of the oldest and simplest methods and is also relatively slow. The cable tool drills by lifting and dropping a string of tools suspended on a cable. A bit or chisel at the bottom of the tool string stikes the bottom of the hole, crushing and breaking a few mm of formation at each impact , and mixing the cuttings. The string of tools consists of, in ascending order, a bit, a drill stem, jars and a swivel socket, which is attached to the cable.

5.2 Rotary Drilling

In rotary drilling the drill bit cuts or crushes its way down through the formation under high pressure. No impact is used in this method.

a) Rotary cutting drilling or auger drilling

This method of drilling is a fast method and neither rock drill nor flushing agent are required. Auger drilling is used in loose formations where there are no boulders or stones and in soft formations. A drilling tube looks like a cork screw which is rotated down into the formation under high feeding pressure. Different bits are used in different formations.

b) <u>Rotary crushing drilling</u>

In rotary crushing drilling, roller bits are used. These bits are subjected to a very high pressure and crush the formation. If the rock is very hard, the cemented carbide bits are used. In looser formations, toothed roller bits are used.

Rotary drilling with mud flushing is often used in the drilling of holes with large diameters.

5.3 Drilling Procedures in Hard Rock

Drilling through the overburden that lies above the hard rock surface sometimes causes problems in keeping the borehole open. Drilling mud is rarely used. Although thicknesses of overburden vary considerably throughout the hard rock areas, the separated depositional fillings of intermontane basins or weathered in-situ laterite usually do not exceed 30m.

Normally a borehole of 165 mm diameter is made through the overburden and carried up to 1 m into the bedrock. A 140 mm PVC casing is installed to the bottom of the borehole and cemented in place, which acts as a seal. Then a smaller diameter hole is drilled in the bedrock to a selected depth depending on the water level in the hole, and the number of fractures, joints, shears, or solution channels encountered and required to produce the quantity of water needed. This portion of the borehole remains an open hole. Samples of drill cuttings are taken every 3m or at the change of formation (colour change).

Drillng mud would help in keeping the borehole open while drilling through the overburden with the down-the-hole-hammer or standard rotary rig. In the absence of proper drilling mud a substitute can be the material of termite mounds. After the casing is in place and sealed, the mud and water mixture should be pumped out (airlifted) prior to drilling in.

Water tables are generally 18m or more below ground surface in the hard rock areas. Since it takes eight 3m lengths of pump rod to balance the heavy metal handle of the pump, a minimum well depth of 24m has been used in some regions. For areas where the water table is shallower a short handle pump can be installed and the minimum depth can be reduced to about 18m.

Recommended improvements in procedures are as follows:

o Development time in well construction should be increased from the present practice of between 30 minutes and 1 hour (see section 6.4)

- Pumping tests should be performed on every well whether it be equipped with a hand pump or power pump (See Chapter 2).

- It is recommended that a heavier gauge PVC be used for well casing rather than the thin-walled pipes presently used.

- All completed wells should be disinfected by shock chlorination of 50-100 mg/L of chlorine for a 24-hour period before allowing public use of the well. At the end of the 24-hour period the chlorinated water must be pumped to waste. (See Chapter 7).

6. WELL DEVELOPMENT

The main purpose of well development is to obtain maximum production efficiency from the well. Benefits are stabilization of the structure, minimization of sand pumping and the improvement of corrosion and encrustation conditions. Proper and careful development will improve the performance of a well. Well development is not expensive in view of the benefits derived. Depending on the circumstances, a number of methods and supplemental chemicals may be used in developing a well.

6.1 Development in Unconsolidated Aquifers

a) Overpumping

Pumping a well at a discharge rate considerably higher than the design capacity is the method used for development of wells in unconsolidated aquifers.

The pump is normally set above the top of the screen. With the water moving in one direction only, stable bridging of the sand grains occurs so long as pumping continues. When pumping is stopped, the water in the column pipe drops back into the well causing a reverse flow which destroys the bridging, causing loose sand to enter the well. The procedure is repeated several times until the aquifer around the screen stabilizes and no more sand is being pumped.

b) Rawhiding (pumping and surging)

The procedure for rawhiding is similar to overpumping. The pump must not be equipped with either a rachet or other device that would prevent reverse rotation of the pump, or a check valve. The well is pumped in steps such as 1/4, 1/2, 1, 1 1/2 and 2 times the design capacity. At the beginning of each step the well is pumped until the discharge is relatively sand free. The pump is stopped and the water in the column pipe is allowed to surge back into the well to break up bridging. This procedure is repeated till discharge clears. The rate of discharge is then increased and the same procedure followed at each of the higher rates.

c) Surge block development

Surge block development is one of the oldest and most effective methods of well development. Surge blocks are particularly applicable for use with cable tool rigs and often such a rig equipped with a surge block is used to develop a well drilled by other methods. Solid, vented and spring-loaded surge blocks are used. The solid surge block has a solid body, whereas the vented one has a number of holes drilled through the parallel to the axis.

As the block is moved up and down in the screen, the solid surge blade imparts a surging action to the water which is about equal in both directions. The gentler downstroke of the vented surge block causes only sufficient backwash to break up any bridging which may occur and the strong upstroke pulls in the sand grains freed by the destruction of the bridging. The solid surge block is usually most effectively in dirty sands containing large percentages of clay, silt, and organic matter, while the vented surge block is best in cleaner sands. The spring loaded surge block, which may be vented or solid, is more effective than the other two types of block, and offers some advantage in avoiding sand or locking in the screen.

d) Development with air

Development of wells using compressed air is an effective method that requires considerable equipment and skill on the part of the operator. Two methods, backwashing and surging and generally used.

In the backwashing system water is alternately pumped from the well by airlift and then forced through the screen and into the water-bearing formation by compressed air introduced through a tight seal at the top of the casing. When the discharged water becomes clear, the supply of air is cut off and the air cock is opened. The water in the well is allowed to return to the static level, which can be determined by listening to the escape of air through the air cock as the water rises in the casing.

e) Hydraulic jetting

Hydraulic jetting is most effective in open rock holes and in wells having a cage-type wire-wound screen and some types of louvre screen. The jetting tool consists of a head with two or more jet nozzles equally spaced in a plane above the circumference. The head is attached to the bottom of a string or larger pipe that is connected through a swivel and hose to a high pressure, high capacity pump. Water is pumped down the pipe in sufficient quantity and at sufficient pressure to give a nozzle velocity of 45 m/s or more. Pumping pressure may have to be somewhat higher, depending on the number of nozzles, required volume, and the sizes and arrangement of the plumbing.

The jetting tool has been effective in removing stubborn mud cakes from some holes and in opening up formations of dirty sand which have been plugged by too rapid and vigorous development by surging. The jet is particularly effective in developing gravel-packed wells.

6.2 Development in Hard Rocks

All the developing methods described for well development in unconsolidated aquifers can be used effectively in open-hole hard rock wells. Under some circumstances, some additional practices may also be effective.

In consolidated granular materials, a mud cake forms and fines are forced into the walls of the hole by the drilling operation. In fractured and jointed rocks where water yields depend upon the interception by the well bore of water-filled cracks or solution openings - such openings are frequently sealed by much the same action as well as by mud invasion.

Wells in carbonate rocks are often developed by the addition of sulfamic acid or muriatic acid which attacks the carbonate rock and enlarges existing openings and creates new ones. After the acid has been used it is pumped to waste and the well treated with poly-phosphates, and by surging or jetting. Under some circumstances, shooting a well with dynamite or other explosives is used to fracture the rock and this has been effective. However there is a definite risk associated with all of these procedures and they should be planned and carried out only under experienced and informed direction using adequate equipment and safeguards.

Wells in sandstone drilled with cable tool or down the hole rigs should be developed using polyphosphates and vigorous surging. Wells drilled with rotary rigs are sometimes under-reamed by about 10 mm using plain water as a drilling fluid, after which the well is bailed clean. The well is further developed using polyphosphates and strong surging. Regardless of the method of drilling, wells in crystalline rocks should be developed using polyphosphates and jetting, vigorous surging or both..

Hydraulic fracturing has been of limited effectiveness in increasing yields of sedimentary and crystalline rocks. Inflatable packers on a pipe leading to the surface are used to isolate 15 to 30m lengths of the hole. The pipe and isolated section are filled with water and pump pressure is applied to fracture the rock. Continuous pumping may result in another buildup in pressure and additional fracturing.

6.3 Chemicals Used in Well Development

Numerous chemicals are used to aid in development. The most common are probably the photophates: sodium tripolyphosphate ($Na_5P_3O_{10}$), sodium pyrophosphate ($Na4P_2O_7$), tetra sodium pyrophosphate ($Na_4P_2O_7$) and sodium hexametaphosphate ($(Na\ PO_2)_6$. These compounds act as deflocculants and dispersants of clays and other fine-grained materials and permit the mud cake on the wall of a hole and the clay fractions in the aquifer formation to be more readily removed by the development. There are also chelating agents available for some of the heavy minerals and nearly all of them are mixtures of a polyphosphate and minor amounts of other compounts such as wetting agents, sterilants and chelating compounds.

6.4 Practical Aspects

Current practice is for very little development time to be spent on each well, either because drilling schedules are tight or because it is the belief that once the water clears no further increase in flow rate can be obtained. Only 30 minutes to an hour is usually scheduled for development. A quote from the Groundwater Manual of the US Department of the Interior, states in Section 17-3, page 413:

"Open hole wells drilled in hard rock supposedly do not benefit from development, but experience has shown this to be in error. Practically all the methods used in developing screened wells can be used effectively in open-hole hard rock wells. Regardless of the method of drilling, wells in basalt and crystalline rocks should be developed using polyphosphates and jetting, vigorous surges, or both."

Experience by GTZ in Sri Lanka has shown a one-third increase in water production if the well is surged; a minimum of 3 hours is recommended, preferably extending up to 8 hours or until the flow rate no longer shows any increase. Both groundwater quality and discharge rate of the well can be improved by longer development periods. The turbid water in the well may clear up temporarily and at this time the development process is usually stopped. The compressed air used in surging and airlifting of drill cuttings from the borehole forces fine sand, silts and clays back into the fractures. Subsequently, when a pump is installed and begins removing water for use, this water held in the partings of rocks moves back into the well along with the fine grained materials and is drawn into the pump. Rubber cups wear out quickly from contact with these fine sediments. The quality of this water may be worse than that of the water removed during the development stages. A minimum development time is 3-4 hours.

7. WELL STERILIZATION

The main purpose of the process of sterlization of wells is to assure the absence of pathogenic bacteria. All wells regardless of the water use should be sterilized on completion to prevent or retard the growth of corrosion or incrustation fostering organisms. Many of these organisms are not harmful, but they can accelerate and aggrevate corrosion and incrustation problems and reduce the life of a well. Although sterilization may not always eliminate such problems, it is a worthwhile and relatively inexpensive precautionary measure.

7.1 Chlorination

Sterilization is usually accomplished by introducing chlorine, or a compound yielding chlorine into the water in the well and the immediate aquifer surrounding the well.

Chlorine gas may also be used, but the safest and usually most readily available materials to furnish chlorine for field operations are calcium hypochlorite $(Ca(ClO)2)$ or sodium hypochlorite $(Na(clO)_2)$ and chlorinated lime. Calcium hypoclorite is available in granular or tablet form and contains about 70 percent available chlorine by weight. Sodium hypochlorite is available in aqueous solutions ranging from 3 to 15 percent chlorine. However, calcium hypochlorite is probably the least costly and most convenient material to use for sterilization.

Wells containing considerable oil or organic material in the water, or in which the aquifer contains considerable organic matter, should be thoroughly chlorinated.

Sterilization of a well, except possibly for some pathogens, is seldom 100 percent effective. Organisms may be covered with incrustation or corrosion products or lodged in crevices not readily penetrated by the sterilization solutions. While most such organisms may be destroyed, the few remaining continue to multiply and, depending upon conditions, periodic sterilization may be required at intervals to control them. In some instances, continuous chlorination may be required to control mineral incrustation in addition to organisms.

Some deep wells are disinfected prior to installing the pump and constructing the pedestal while others are not. A strong solution of chlorine should be placed in the well, and the pump disinfected also before installation, then after the pump is intact, the chlorine solution should be pumped to waste. Approximately 50 to 100 mg/L solution should be used.

Those wells not disinfected will permit iron bacteria growth to develop encrustations on metal parts in contact with the water. Chemical and bacteriological analyses should be carried out prior to the well being put into service.

7.2 Other Sterilants

A number of other sterilants are equal or superior to chlorine or chlorine compounds for controlling certain organisms. Such sterilants are usually more expensive and less readily available than chlorine and some are too toxic for use in potable water supply wells. Some of those which are suitable in potable water supplies are:

- o A mixture of a polyphosphates detergent and anthium dioxide (chlorine dioxide) for control of filamentous algae.

- o Cocomines and cocochiamines for sulphate-reducing bacteria.

- o Quaternary ammonium chloride compounds for general use.

Other sterilants not recommended for use in water supply wells but which might be used in waste disposal or similar wells are:

- o Copper sulphate
- o Formaldehyde
- o Some mercury compounds.

7.3 Sterilization of Gravel Pack

When wells are constructed using a gravel pack or formation stabilizer, sterilization of the pack at the time it is installed in the well is recommended. A fairly common and acceptable practice in most cases is to mix 0.6 kg of calcium hypochlorite in each cubic metre of gravel (1lb to each cubic yard) as it is installed in the well. Another method is to pour one of the chlorine compound solutions down the tremie pipes with the gravel. When sterilization is completed, the well should be sealed and pumped to waste until there is no odour or taste of chlorine in the discharge.

8. EQUIPMENT AND MATERIALS

8.1 Pumps

Although field testing programmes for testing various types of hand pumps have been conducted in Sri Lanka, in addition to years of experience with a number of makes of pumps, no standard pump has yet been selected. Criteria for such hand pumps are:

1. Reliable with low maintenance requirements, durable and trouble free.
2. Inexpensive.
3. Locally manufactured.
4. Easily operated by women and children
5. Be field tested with satisfactory results.
6. Can be used for deep and shallow wells.
7. Non-corrodible materials used in those parts in contact with water.

Present problems encountered with India Mark II pumps are:

- o Excessive wear of foot valve and cups;
- o Metal parts made of steel and easily corroded in aggressive water.

The first hand pumps were installed in February 1981. Later these were modified to include oiling points and flanged type cylinder connecting points.

Various makes of pumps tested in a field programme at Kalutara include: India Mark II, Wasp (Sri Lanka), Tara (Bangaladesh), Inalsa (India), Sihilasa (Sarvodaya) and L-4 (Sarvodaya). Of these, the Tara L-4 and Sihilasa use riser pipes of PVC; the rest use galvanised iron (G.I.) risers.

It is the goal of NWSDB that the maintenance of pumps be taken over by local authorities, but NWSDB will train the mechanics for the different regions. A hand pump maintenance crew has included: one mechanic; 2 labourers; 1 driver. With wells drilled into bedrock, most of the repairs involve the pump, since the PVC casing above the bedrock and open hole in the hard rock are long lasting.

To improve the action of the Mark II pump riser pipes, pump rods and pump parts should be made of stainless steel, alloy or other non-corrosive material. It is imperative that one make of pump be selected and:

1. All agencies and foreign consultants that drill deep wells in the hard rock areas of the country must utilize the standard pumps;

2. Spare parts and spare pumps shall be stocked;

3. Purchase should be in large lots, based on projected annual need, to reduce the price and motivate private manufacturers to tool their plants to produce a high quality, reliable and trouble free pump;

4. An inspector should be placed at the manufacturing plant to observe methods of manufacture, and to refuse to accept those pumps that do not meet the standard specifications;

5. Preventive maintenance programmes must be implemented to extend the life of the pumps installed;

6. A programme of rehabilitation of pumps on abandoned wells should be developed. If the well is no longer of use the pump should be repaired and placed in stock as a replacement unit.

Local authorities, responsible for installation of shallow wells, utilize a variety of pumps without thought of standardization. Meetings must be held with these local authorities and non-governmental organizations prior to equipping the wells they construct, and the reasons explained for using the standardized pump model and advantages thereof. Foreign aid projects should not be permitted to import pumps from their countries unless their projects include responsibility for maintaining the wells after the wells are constructed.

8.2 Well Life

Corrosion of the steel parts of the pump and steel riser pipes begins weeks after installation and wells equipped with steel materials or galvanized iron can be out of service in 3 to 5 years. Shallow wells drilled in sediments, utilising gravel packs and well screens of G.I. casing and slotted screens and in contact with aggressive waters, may last less than a year. Deep wells in bedrock supplied with PVC casing through the overburden will have a long life and it is only the pump, pump rod and riser pipe that will corrode. If these parts can be made from non-corrosive materials the well should have a useful life of 15 to 20 years. Hand dug wells can be repaired, cleaned or modified because of the shallow depth and the provision of a manhole through the cover for a workman to enter. Open dug wells, without sanitary covers, go out of service most often by trash, garbage or pollution from drainage, flood waters, or disposal of other liquids by man.

8.3 Casing Pedestal and Drain

Technical assistants trained in building the cement pedestal and pump base and installing the pump, complete the well. Casual labourers, temporarily on staff, assist the technical assistants.

A typical base and pedestal arrangement should be constructed with the the slope of the platform towards the drain to carry excess run-off, wash water or water for bathing, away from the well to prevent recirculation of this water back into the well. There is generally a raised ridge around the edge of the pedestal to contain the water on the cement surface until it can drain away.

An improvement in the design would be to also place an extension beneath the cement pedestal, around the perimeter, to prevent water, either from the well or flood water, from running under the pedestal to the side of the casing or edge of the sanitary seal.

9. WELL REHABILITATION

Water well rehabilitation includes the repair of wells which have failed because of collapse, broken casing and screen, or other similar major damage, and the treatment of wells which have begun to pump sand have experienced a change in water quality, or have shown a marked decrease in discharge and efficiency because of incrustation, corrosion, or other factors which tend to reduce the intake area of the screen or permeability of the adjacent aquifer. Normally, well rehabilitation does not include deepening or other major changes in the well structure necessitated by declining water levels, a need for increased discharge or other similar factors.

In some instances of well deterioration, rehabilitation may be impracticable, so construction of a replacement well may be necessary. Furthermore, a major problem in well rehabilitation may be in determining the exact nature of the deterioration since the screen and other components most likely to deteriorate are not subject to direct visual inspection or testing. Accordingly, well rehabilitation could involve the risk of further damaging a well or destroying its usefulness.

9.1 Sand Pumping

Most wells pump sand to some degree. However proper design and adequate develpment usually can limit sand pumping to an acceptable concentration. Excessive sand pumping of a well is accompanied by numerous undesirable side effects. Pump bowls and impellers may be eroded by sand and require frequent replacement. Not all sand entering a well is pumped out with the discharge. A certain amount settles to the bottom of the well where it may encroach on the screen and reduce well efficiency. This results in increased drawdown, increased entrance velocity, and accelerated corrosion and incrustation.

If sand pumping is due to a broken screen or casing or faulty packer, the location and nature of the break can be determined by sounding and verified by a photographic survey of the well. The break may consist only of a parting of the casing or screen at a joint with no offset of the axis. This is the easiest type of break to repair. In most cases the break will be associated with displacement of the axis and possibly defermation of the casing and screen on one or both sides of the break. The correct procedure is to run a hydraulic or mechanical casing swage into the well to round out and if possible, realine the casine or screen. In some instances, the casing and screen may be so far out of line that it is impossible to realine them without causing buckling of the casing elsewhere. In such circumstances, there is no fully satisfactory solution, although the well may be modified by insertion of a liner to produce sand-free water at a lower discharge and specific capacity.

If a broken or defective seal is involved, several possibilities may exist. It is impossible to remove a seal without pulling the casing or screen. One solution is to telescope 3m or more of liner with neoprene rubber seals sized to both the smaller and larger casings into the smaller casing. Another solution is to swage a liner into the smaller casing with the end extending about 1m above the original packer and then fill the annular space with a neat cement grout.

If the problem is due either to localized enlargement of screen slots or to a hole in the casing or screen as a result of corrosion, a liner may sometimes be swaged in place opposite the corroded section. The liner in all cases, should be of the same material as the casing or screen within which it is placed.

If sand pumping is due to poor initial slot selection or due to enlargement of slot sizes over the greater length of a screen because of corrosion, insertion of a liner is impractical. However, rehabilitation can be made on single string designs by ripping the original screen to increase the open area and then telescoping a smaller diameter screen inside it. This may be used as a temporary expedient, but is not recommended as a permanent repair.

Where sand pumping has resulted from settlement and bridging of a gravel pack, the best procedure is to vigourously redevelop the well while injecting large quantities of water into the pack from the surface.

9.2 Decline in Discharge

A decline in discharge and an increase in drawdown are usually caused by a decline in the static water level, the installation of additional nearby wells that have overlapping areas of influence, an accumulation of sediment on the bottom of a well sufficient to cover a significant part of the screen, collapse of the screen, or incrustation of the screen and gravel pack.

Where the decline in yield is the result of a decline in the static water level or interference from other wells, it may be possible to correct the situation by merely lowering the pump bowl and, if necessary, adding additional bowls and a larger motor. If regular measurements are made of static and pumping levels in the well, the course is usually apparent.

If declining yield is due to loss of screen length resulting from accumulation of sand over part of the screen, this can be determined by sounding the well. The solution is to bail the well clean.

If collapse of the casing is suspected, lowering a bailer or dolly down the hole on a cable will usually show the location of trouble. If collapse is indicated, a television or photographic survey should be made to determine the nature or the damage and the possibility of repair. If the casing or screen is not broken, the trouble may be corrected by using a hydraulic or mechanical casing swage.

9.3 Acidizing

The problem of reduced yield can occur due to incrustation of the screen or pack. The first step in rehabilitation is to scrape the inside of the screen with a steel disk on a drill stem or rod to break loose some of the incrusting materials which will settle to the bottom of the well. These scrapings should be examined to determine the nature and chemical composition of the incrustation. If it consists primarily of calcium, magnesium and iron carbonates, or iron hydroxides, rehabilitation using sulfamic or hydrochloric acid may be possible.

9.4 Chlorine Treatment

Where screen blockage is caused by slime—forming organisms, chlorine gas may be an effective treatment agent; chlorine gas is dangerous to use without experienced personnel and adequate equipment.

However, hypochlorite solutions are cheaper, more convenient, and safer to use than gas but generally less effective.

9.5 Rehabilitation of Rock Wells

The fractures and other voids in uncased rock wells may become clogged and sealed by deposition products similar to incrustation of a well screen. Hydrochloric acid is commonly used to treat rock wells. In some open hole rock wells, shooting has been more effective than acid treatment and at times a combination treatment has been used. Dynamite shots are fired separately beginning at the bottom of the open hole. After shooting is completed, the well should be bailed clean and developed.

There are in Sri Lanka a large number of deep, hard rock wells that have been abandoned . Possible reasons why this has occurred are the following:

1. Failure of the well casing within the zone of overburden, above the bedrock, because of the thin—walled PVC casing, aggressive water action on G.I. casing, or steadily increasing earth side pressures.

2. Failure of the pump, either from corrosion or encrustations or mechanical failure while the well itself may be intact.

3. Bad tastes and odours.

4. Water quality changes, or inferior quality water that did not meet water quality standard when the well was completed; polluted or contaminated water moving through the fracture and joint system to the well; or following a rainy season, increased flows and pressures may force bad quality water ahead of the better quality rainwater toward the well.

5. A better source of water nearby, rendering the well no longer of value.

6. To avoid paying a water rate for a piped system delivering water to standposts or a house-to-house system, people may use hand dug wells or shallow pitcher-pump wells bottomed in sediments. This shallow source may be nearer a person's home and shortens the distance to carry the water.

7. Cultural restraint to use the well, especially after chlorine treatnment.

8. Poor production from the beginning of its construction or decreasing over a period of time.

Although this list is not necessarily complete it provides an indication of why wells are abandoned.

Abandoned wells are examples of wasted money, manpower, or equipment and should either be put back in operable condition again or permanently destroyed, as they can be avenues for polluted or contaiminated surface waters to easily reach the groundwater basin and degrade the water in the basin. Sometimes abandoned wells are used for disposal of human wastes from overloaded septic tanks or cesspools.

The worst conditions exist for safety, sanitation and aesthetics when there is no pump on the well and the top is open. If there is a pump on the well at least it is known that the well has been sealed and rehabilitation will be an easier task.

The following preliminary steps are presented for rehabilitation of abandoned wells:

1. Collect information on wells in the area and search files for data.

2. If a pump is on the well it must be removed. Try it first to ascertain if it still works.

3. Sound the bottom of the well and compare it to the original depth on the construction record, if it is available, to determine how much sediment has accumulated in the well.

4. Draw a water sample from the well and test for electrical conductivity, iron, chloride, sulphate, nitrate (or ammonia). This may give an indication of why the well was abandoned.

5. Question local residents near the well for clues or reasons for the well's abandonment.

6. Place a temporary cover on the well to discourage anything being thrown into it.

7. Make an evaluation of whether the well is still needed, is in a repairable condition, or should be destroyed.

Secondary steps to take, if the well condition and water quality are satisfactory are:

1. Set the drill rig over the well and begin bailing the sediment and debris in the well while airlifting the turbid water to the surface.

2. Open and close the valve on the airline to surge the water into and out of the fractures.

3. As the water clears, keep checking its clarity until no more sand or silt settles out of a water sample in a glass container or Imhoff cone.

4. Measure the flow.

5. Sound the bottom depth again to determine how much debris has been taken out of the well and if the original depth has been reached.

6. Disinfect the well with a concentration of chlorine of 100 mg/L. Set pump into the chlorinated water and allow to set for 24 hours.

7. Secure the pump and then pump the chlorinated water to waste until there is no longer any chlorine odour or taste, or if a chlorine kit is available, pump until tests show all the chlorine is gone.

8. Conduct a pumping test for at least 4 hours if a power pump has been installed. If a hand pump is installed, a pump test would have no validity.

9. Compare the flow rate with that shown on the original construction record.

10. Prepare a before/after report to show the improvement of rehabilitation.

The rehabilitation crew can move from well to well on a scheduled course with a projected rate of two wells per week.

10. GROUNDWATER QUALITY

The chemical quality of groundwater is a complex subject because of the continual increase in concentration of mineral constituents in the water which occurs during its transition from rainwater to groundwater in storage. Even as groundwater in storage, the water is affectd by many conditions such as gases, organisms, and solutions of rock minerals, hence the gradual increase in mineral levels continues. Only the percolation of a better quality water to naturally recharge the groundwater, or artificial recharge using a water of higher quality, can improve the quality of the groundwater through dilution. Therefore, any improvement of the quality of water that enters the well must be made on the water produced from the well. Since groundwater quality is affected by so many factors, it is not surprising to find a number of different problems throughout Sri Lanka. The most common problems are as follows:

10.1 Iron

In-situ weathering of bedrock produces a thick zone of lateritic soil and residuum up to 35 m. Colour may range from yellow to orange to dark red. Rain waters infiltrating and percolating through these iron oxide soils dissolves iron which is carried downward to the water table. When this water, which is charged with carbon dioxide, or carbonic acid, comes in contact with metal parts such as metallic pipes or pump parts, corrosion of these materials is the result. Those wells in areas where the groundwater contains high iron concentratioins should be equipped with iron removal plants to lower the iron concentration. Such plants are used in Kalutara and a few isolated areas but their use should be extended to more areas. However, the level of maintenance must be improved..

The uppermost layer of sand in this filter is the one that clogs up with iron particles and iron coatings around the sand grains, and stops the flow of water through the outlet pipe. Exchanging this layer of sand or scarifying it every six months would keep the plant in operation. The effectiveness of the plant can be determined by monitoring the iron in the water as it comes from the well and comparing it to that which comes out of the plant discharge pipe. When this differential of iron concentration between raw water and treated water becomes small and the amount of water issuing from the outflow also gets small, these are signs that the plant needs reconditioning. Present practice is to wait until the plant completely fails and complaints are received, then it remains idle, out of use.

Where iron problems occur, there are usually high manganese concentrations also, however, chemical analyses have not included this metal in the analyses.

10.2 Fluoride

Groundwater containing high fluoride concentration up to 8 mg/L have been encountered in Sri Lanka. Wells containing fluoride are somewhat aligned in a north-south direction in the eastern part of Sri Lanka corresponding to what is believed to be the contact between the Pacific and Indian continental plates. Other fault structures can also be a source of high fluoride values. In the Ampara region wells are abandoned because the guideline limit is 1.5 mg/L. However, people in many countries are drinking water with higher fluoride concentrations and in the absence of any other better quality water, it could be blended with rain water to reduce this value. Defluoridation plants to remove high fluorides are only economical in larger water facilities and not on individual wells. However, wells in areas of high fluorides could perhaps be of use as water for washing and bathing and, if no better quality water is available, could be used on a temporary basis for domestic water providing the fluoride concentrations are not more than 3 mg/L. However, it should be labelled 'non-potable'.

10.3 Hydrogen Sulphate

Sulphate-containing groundwater occurs in water produced in wells located in land-locked marine basins where hydrogen sulphide has developed, or along faults where sulphate waters rise to a point near the surface.

10.4 Chlorides

Chlorides in groundwater are usually encountered in coastal regions. Wells drilled to depths near the interface between salt water and the overlying fresh water can, if over-pumped, produce an increase of saline water into the well. However, those wells equipped with hand pumps and which produce smaller quantities of groundwater are generally not affected. Infiltration galleries (horizontal wells) where the intake is at an elevation one or more metres above mean sea level will reduce the risk of salt water occurrence. During the drilling of a well, a conductivity meter should be at the well site to take periodic readings. In drilling shallow wells along the coast, a chloride kit is required so that drilling will not penetrate through the fresh water lens and into the underlying saline water or sea water. As soon as the readings of chloride begin to increase, drilling should cease; otherwise, if the well is drilled into the saline zone it will have to be abandoned. This also applies to hand dug wells when they are located in beach sediments, dune materials, alluvial or colluvial deposits. Infiltration galleries are more practical for areas where fresh water lenses lie above salt water.

10.5 Other Problems and Solutions

Maps showing the concentration of these troublesome chemical concentrations on an area-wide basis, can help in the investigation of better drilling sites. A single agency will have a policy of coordinating such data and producing such maps.

Bacteriological improvements for well water that may be contaminated requires chlorine applications, whether on a scheduled batch basis or continually by pot chlorinators or line chlorinators.

Periodic well cleaning and bailing followed by heavy doses of chlorine can reduce encrustations and screen deposits caused by bacterial action.

Acidic well water can be neutralised by running the water over a tank or container of limestone. This raises the pH of the water to near the neutral level of 7.0.

Blending well water with collected rainwater can reduce the concentration of mineral concentrations.

Contaminated or polluted water can travel long distances through faults, joints or fractures in bedrock without natural purification. If there are aquifer materials above the bedrock the contained water will be naturally filtered and purified during its passage downward or laterally within these sediments. Hence the well would be better stopped at this level rather than to drill in the bedrock below the sediment aquifer. Prevention of contamination and industrial pollution is the best way to protect the groundwater in storage. Once a groundwater basin is polluted or contaminated it may take many years for the water to return to its original potability.

Placing sanitary seals in the annular space between the casing and borehole of shallow drilled wells to a maximum depth of 3m is the best preventive measure to protect these wells.

11. COSTS OF WELL CONSTRUCTION

11.1 Actual Costs

The local cost for construction of a deep well, as furnished by NWSDB in 1986 was Rs.17,000 plus a foreign cost of US$945. (Total cost about Rs.43,500).

Tube wells drilled by UNICEF average about Rs.26,000, at current exchange rates, for a well 150 mm in diameter and average depth of 43m. Hand pump installations cost between Rs.7,000 and Rs.25,000, depending on the type and source. The cost of constructing hand dug wells varies with the labour costs in each area and the amount of volunteer help from the community.

Iron removal plants to treat groundwater in areas where iron concentrations are high cost about Rs.4,000.

Early costs of drilling deep wells were higher than present day costs because of the large number of trainees originally attached to the crews. The salaries, transportation and other expenses for these trainees must be added to the normal expenses of drilling the wells.

11.2 Ways of Reducing Costs

Some ways by which costs could be reduced are as follows:

- Standardization of equipment and materials allowing purchase of these items in large quantities.
- Improved preventive maintenance and repair.
- Local manufacture of equipment, especially pumps, pipes and cement to standard specifications.
- Computerised data handling.
- Reduction in the size of drilling crews through on-the-job training of technicians
- Training drillers and drilling crew members to drive the drill rigs and support vehicles and eliminate the need for drivers.
- Improvement in regional stores of equipment and materials to reduce the long shipment from Central Stores in Colombo.
- More community participation in constructing hand-dug wells or infiltration galleries as a result of a coordinated policy of community involvement.

12. OPERATION AND MAINTENANCE OF WELLS

Operation of wells should be under the control of local authorities. However, for a period of 6 months to 1 year after the well is completed, and until caretakers can be trained to make minor repairs, the agency drilling the well should be responsible for this task. Major repairs for wells drilled by NWSDB are made by a mechanic in each region. These mechanics use motorcycles to cover the area and this mode of transportation creates a problem if anything heavier than just tools must be conveyed from the well site to the workshop and back. Use of pickup trucks is recommended in place of motorcycles.

Repairs should be made when the well starts causing trouble and not wait until the pump has failed. By that time the repairs may take longer, be more expensive and cause a longer disruption in water service than if repairs are made earlier.

Communities must be made aware that it is their responsibility to maintain the wells, with assistance from government agencies, and not solely that of the agency drilling the wells. A one-year to five-year maintenance stipulation should be written into all drilling agreements to ensure that this important item of well construction will not be neglected. The life of the pump depends on the maintenance.

Preventive maintenance schedules should be spaced at 6-month intervals to check the operation, oil and lubricate parts, and sample the water quality of the well for signs of corrosion (increasing iron or sulphur concentrations. This chemical analysis will indicate what is happening inside the wells.

Once a year the pump should be pulled and parts replaced. Should user complaints increase or the well become inoperable, so that people stop using the well, a more complete repair must be made.

13. SHALLOW WELLS

All open shallow wells should have sanitary covers provided with openings for the riser pipe, manhole, and aeration pipe for the release of odours and to allow oxygen to enter the well to satisfy traditional cultural restraints against covered wells. Alternatively, wells could be covered by light-weight plastic or fibreglass sheeting to allow sunlight to enter the well. Covering of wells should not be carried out until the users have been convinced of the benefits through a concerted community education programme, otherwise they may revert to using sources which are potentially more dangerous.

Shallow dug wells are frequently poorly constructed and are subject to pollution.

The potential health hazard due to pollution is a serious consideration and if the wells represent the best available source and must be used, they should be rehabilitated in such a way that people can be reasonably sure of obtaining good quality water. This rehabilitation should comprise the following:

a) Each well must be equipped with a hand pump so that pails, sections of old tyre tubes and other tubes and other bailing devices cannot be used.

b) Each well must be covered so that excess water raised by the pump does not run back into the well.

c) The area immediately around the well must be properly drained so that surface drainage cannot seep directly into the well.

d) The seepage path from the ground surface around the well must be made as long as possible and directed through fine-grained soil and not directly through the masonry of the actual well.

Figure 1 illustrates a typical rehabilitated well in which the following reconstruction method has been used.

a) Remove all wood cribbing and casing from the well.

b) Excavate around the well to a depth of 300 to 500 mm below natural ground surface for a width of about 200 mm to form a footing.

c) Place wood or metal formwork in this excavation to prevent concrete from flowing into the well.

d) Pour the concrete footing making sure that the top surface is fairly flat and level.

SHALLOW WELL RECONSTRUCTION

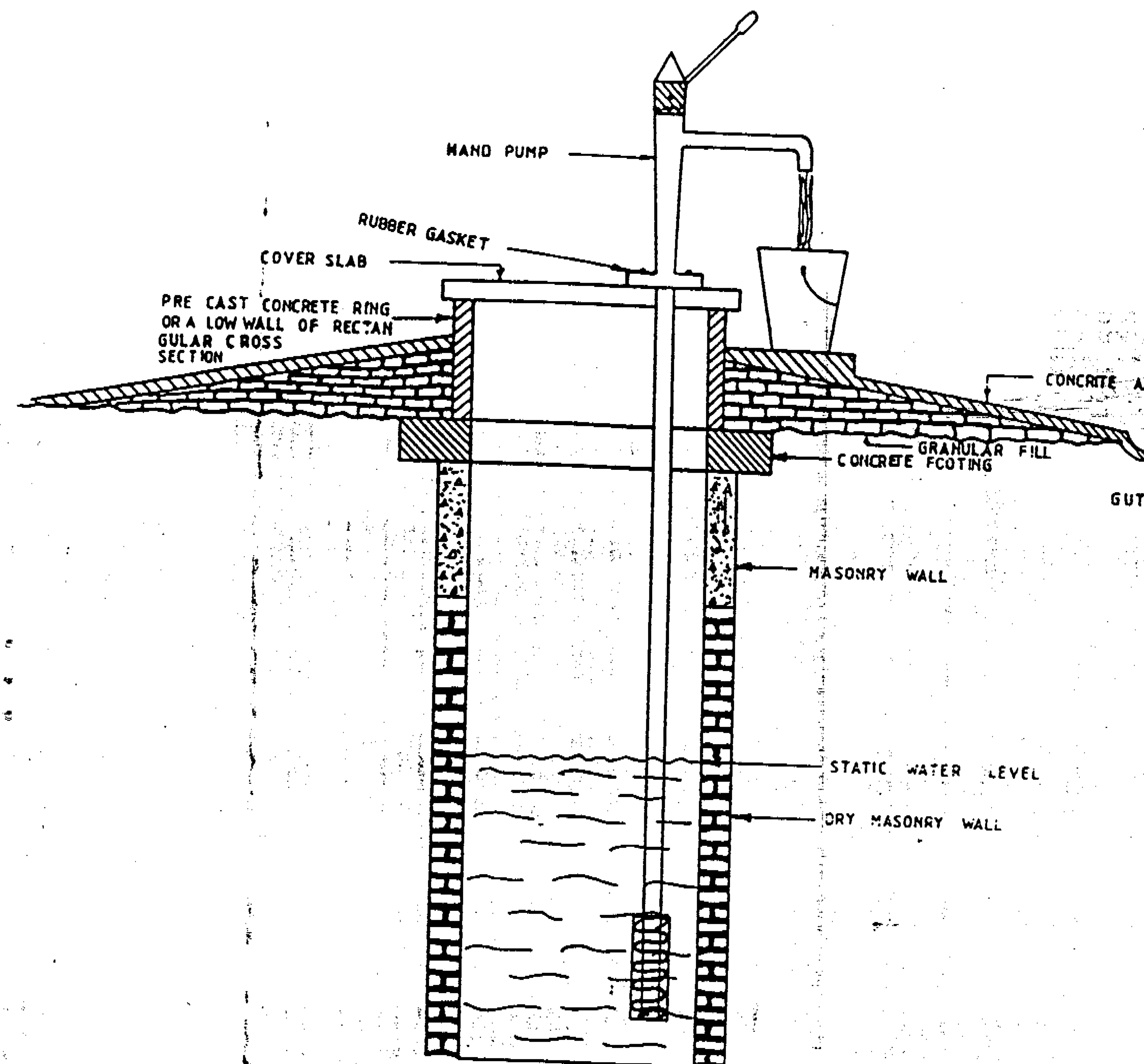


FIGURE 1

e) On top of this footing place the main surface casing of the well which may consist of a pre-cast concrete ring or, in the case of a few wells of rectangular cross section, a low wall about 1m in height.

f) Around the surface casing of the well, place sufficient granular well-compacted fill to produce a slope of about 1 in 5 away from the well. The width of the fill should be at least 1.5m.

g) On the fill pour a concrete apron containing steel reinforcing mesh.

h) Around the apron construct a small concrete gutter to guide surface water away from the well.

i) Remove as much debris, silt, etc., as possible from the well and place a sturdy one-piece reinforced concrete top on the well overlapping the casing so that water from the top will drip onto the apron rather than follow the joint between casing and top into the well.

j) Equip the well with a sturdy long-lasting hand pump sealed at the well top with a rubber gasket.

The pump must be dependable with low maintenance requirements. Some existing wells supply a large number of people, perhaps 2,000 or more, so that the pump may be in operation many hours each day.

Prior to selecting a well for reconstruction, it should first be confirmed that the dry season yield is adequate, and a water sample should be obtained and analysed for nitrate, which, if above 50 mg/L is unacceptable and the well should be abandoned.

The reconstruction work and future maintenance could be carried out by cooperation between NWSDB and local authorities.

14. PLANNING AND RESOURCE MANAGEMENT

14.1 Guidelines

Management of groundwater resources requires that hydrologic balances for each basin be prepared and updated each year. This requires the following data:

1. Aquifer parameters such as transmissivity and storage potential.
2. Water level elevations to show direction of groundwater movement.
3. Area, depth and volume of the groundwater basins.
4. Annual precipitation over the area.
5. Estimate of amount of rainfall infiltrating and percolating to the groundwater basin in all parts of the basin area.
6. Surface inflows and outflows to and from the basin.
7. Subsurface losses to the atmosphere from all open water bodies and soil.
8. Evaporation losses to the atmosphere from all open water bodies and soil.
9. Effective evapotranspiration from the areas of the basin covered by foliage.
10. Total annual extractions of water from the basin.
11. Annual quantity of artificial recharge to the basin.

All items of supply to the basin minus all items of discharge equals the annual change of storage. Reasonable estimates of these items where no data exists must be made. Basic meteorological and agricultural data must be obtained from the relevant agencies. Infiltration rates from channel deposits will correspond to losses between gauging stations. Those items in the balance equations that are estimated may need modifying to bring the change of storage to zero. When the new data are considered each year the total extractions needed to make the equation equal zero will be equivalent to the 'safe yield' of the basin.

Observation wells in each basin will provide the average water level changes and quality needed to indicate how the basin is reacting to the seasonal changes of precipitation. This will show how rapidly the basin recovers following heavy rains and dry spells. NWSDB has some Stevens Water Level Recorders which should be installed on observation wells.

If there is a serious threat to the groundwater supply from a quick drop in water levels it should be known in time to limit the supply by cutting down on the operational hours at each well.

Elevations should be established at each well so that a groundwater elevation map can be produced to study the direction of groundwater flow. Abandoned wells may be used to advantage for this purpose.

A team of hydrogeologists should be assigned to the task of collecting and evaluating the data required for the water balances. One hydrogeologist for each region or each two regions would become thoroughly familiar with conditions within their assigned area. Each time they calculated the water balance the task would become easier.

Hydrological balances of groundwater basins or drainage areas should be up-dated each year to prevent over abstraction.

14.2 Control of Rate of Abstraction

In areas where groundwater does not exist in adequate quantities, a conjunctive programme using surface water is the appropriate alternative, with rain water collection a third alternative. Even in areas underlain by a highly fractured, jointed or faulted crystalline hard rock, seasonal changes in groundwater levels and quality call for control of production and new developements so that over-extraction does not occur.

To ensure that the water contained in fractures and joints and faulted zones will continue to be available year after year, a network of monitoring wells should be established to monitor water levels and quality and determine if the rapid changes are due to seasonal fluctuations or a mining process. In the limestone areas of the north and northwest, over-pumping can increase salinity, thus rendering the water non-potable.

Over-abstraction of groundwater in hard rock areas can cause a rapid lowering of the groundwater table because of the limited quantities of water stored in the fractures, joints and rock partings. If this occurs at the beginning of the dry season, water levels may not return to normal until the next season. Bad quality water may also be drawn into the wells and pumps may need to be lowered or may not function at all.

Heavy extraction in the shallow sedimentary deposits of intermontane valleys may dewater the basins entirely and render the wells useless. In coastal sediments adverse effects may include:

1. Sea water intrusion if water levels are drawn below sea level.

2. Ingress of bad quality water from peat bogs and marine swamps.

3. Drawing water levels below the bottom of hand dug wells, causing them to go dry.

4. Subsidence in areas underlain by clay, silt or fine sand.

Water from hot springs, which is highly mineralised, can move laterally through sediments to areas of lowered water levels thus degrading the quality of well water. The same conditions can occur in the thin sediments of the dry zone, because even though the wells are sealed through the overburden, there is a hydraulic connection between the overburden and bedrock fractures. Sulphite and fluoride waters can migrate from source areas to pumping depressions. Careful spacing of wells, and pumping only quantities equal to the safe yield of the groundwater basin will prevent depressions in the water level from occuring.

The practice of locating wells in highly fractured zones, which is necessary to obtain producing wells, can encounter heated waters or bad quality water moving up towards the ground surface through the fracture system.

Benefits from over-abstraction include:

1. Provision of capacity for the storage of recharge water from infiltration of rainfall, inflow from rivers, smaller streams, unlined canals and lakes and ponds during the wet season.

2. Intentional dewatering near an area of construction of a dam to lower the water table and reduce hydraulic pressure, or to reduce inflow or outflow.

3. Induced infiltration from a stream.

14.3 Cultural Constraints to Well Improvements

The time-honoured cultural belief that water exposed to the sum is pure has led to the construction of open dug wells. There is an opposition to providing covers for these wells and this reluctance works against the improvements in potable water quality and water-borne or water-related diseases. Sunlight in shallow waters causes the growth of algae and one-celled water plants which, particularly on decay, can give rise to taste and odour problems. The purifying effect of ultra-violet rays on shallow depths of water in an open well is countered many times over by the adverse effects from:

1. Dead rodents and other animals.

2. Trash and garbage thrown into the well.

3. Dirty hands, ropes, containers.

4. Settling of airbone dust, bacteria and viruses.

5. Evaporation from the water surface leaving the remaining water in the well higher in dissolved minerals.

6. Unsafe open hole in which young children can drown.

7. Bird excreta into the well, raising the bacteria and virus counts.

The consumers and owners of open dug wells have a choice of staying with cultural beliefs, refusing to put sanitary covers on them, and thereby incurring the risk of water-borne or water-related diseases. It is strongly recommended that all open dug wells be covered. However, it is recognised that this cannot be achieved until the users are convinced of the advantages, otherwise they may turn to even less safe sources. A concentrated community education campaign is mandatory. Meetings by health authorities to educate the people on hygiene and sanitation should, over a period of time, breakdown these constraints. Comparisons of disease levels in areas where covered wells are situated with those of uncovered wells will show the positive effects of covering wells.

14.4 Data Bank

Well data needed for groundwater basin management are:

- o Location: District, AGA Division
- o Well completion data
- o Altitude
- o Depth of drilled borehole
- o Diameter of casing and length
- o Depth of top of aquifer and thickness of aquifer
- o Static water level
- o Drawdown
- o Electrical conductivity
- o Type of pump
- o Estimated or measured flow
- o Specific capacity

Data should be collected twice a year, at the end of the rainy season and at the end of the dry season.

A file of meteorological and surface water data should be maintained for use by those persons responsible for managing the groundwater, developing and updating the groundwater hydrologic balance studies. Meteorological data needed are:

- o Annual precipitation
- o Evaporation from water and land surfaces
- o Evaporation losses from plants

Surface water data are also required.

- o Streamflows into and out of the districts or groundwater basins.
- o Infiltration rates in stream channels.
- o Quantities of inflow and outflow of the basin.
- o Infiltration from lakes, ponds and unlined canals.

The printouts of data should be in a matrix form with wells listed along the ordinate and important criteria along the abscissa so that a quick comparison can be made of all the wells in a district or AGA Division without searching through data for each well individually.

14.5 Procedure for Siting of Well

The location of suitable sites for tube wells with handpumps involves many different aspects to be considered. Any well construction programme follows a different policy and emphasizes different aspects. Sometimes the hydrological aspect prevails, sometimes the proposals of political and government authorities determine a location, etc.

The approach that is followed by GTZ's Rural Water Supply and Sanitation Project in Kurunegala emphasizes community participation, and is as follows:

a) Political leaders, the AGA and the project staff identify certain areas where the scarcity of drinking water is greatest. The most affected Grama Sevaka Divisions are determined and served "fully" with tube wells, applying the undermentioned criteria.

b) In the selected GS-Division the Development Officer (DO) of the AGA organises and conducts village meetings (approx. 2-7) with the assistance of the project. In these meetings the advantages (better health, etc.) and disadvantages (breakdowns, costs) of tube wells are explained and also general hygiene education carried out.

c) In these village meetings the women are encouraged to propose suitable sites where they want a well.

d) The project staff together with local leaders including women visit all proposals, make sketches of the villages and decide upon the locations for tube wells.

e) The decision is normally announced to the people in the afternoon of the same day and caretakers and volunteers are chosen.

f) The sites are preliminarily investigated on the availability of groundwater and given to the hydrogeologist for further examination.

14.6 Standardization

Standardization of all types of equipment and materials should be the aim of all groundwater agencies to improve efficiency, lower costs, facilitate purchase and storage of spare parts, simplify training, and allow uniform procedures to be developed for operation, preventive maintenance and repair.

Drilling equipment of different types from Japan, Sweden and Germany makes training difficult as crews trained on one kind of drill rig would require additional training to work on another type of rig.

A standardized depth for wells drilled in hard rock areas, that is now practiced, causes overdrilling and wasted money. Well depth should be decided at each site, while drilling, rather than by applying a standard depth.

Methods of development and pumping tests on the wells differ also, which affects the life of the well and pump and results in variable production rates which, if too low, may cause the well to be abandoned.

Advantages of standardization are:

a) Larger orders can be placed with local manufacturers to make it profitable to tool their plants to make the equipment.

b) Stocks of spare parts can be stored at the central storage and regional warehouses.

c) Trained personnel for major repairs, and minor repairs by caretakers can be easily made, as tools and workbend facilities and methods will be geared to the standard model.

d) Parts can be interchanged and rehabilitation of equipment can result in replacement units.

e) Training of crew, mechanics, technical assistants and field assistants will be simplified and require less time.

f) Costs of well construction will be reduced.

g) No waiting time for parts, as would be the case if foreign equipment is used.

h) One agency taking over maintenance from another would know how the well was constructed, if standard methods of construction are used.