#### 5.2.6.4 Filter Basins

When there is a perennial flow in a river and the sub-soil met with is hard rock below an average depth of 1.5 to 3 m filter basins are constructed to take advantage of the perennial flow, assuming a filter rate similar to that of a slow sand filter. Sand in this area is removed and under-drains, usually loose jointed stoneware pipes or perforated PVC pipes, are laid and covered with sand. The water from the under-drains will be led to a collecting well by C.I. or R.C.C. pipes. The collecting well which is also used as pump house is located on the bank of the river.

#### 5.2.6.5 Syphon Wells

When the depth of saturated aquifer is 20 - 30 m and the conventional wells and galleries cannot be laid to take full advantage of such depths, certain alternate devices have to be tried. A syphon well will be most suitable in this case. A syphon well consists of a masonry well, 4-5 m diameter, sunk to a shallow depth and sealed at the bottom. Tube wells are to be sunk all round the well to the full depth of the aquifer and syphoned into the central well from where the water is pumped.

#### 5.2.6.6 Determination Of The Specific Capacity Of A Well

The specific capacity of a well is the discharge per metre of drawdown at the well. In the case of artesian wells it is usually assumed that the specific capacity is constant within the working limits of the drawdown. The specific capacity decreases with duration of pumping, increase in drawdown and the life of well. High specific capacity can be ensured by proper selection of screens and gravel and thorough development.

***(a) Measurement of Drawdown***

The actual drawdown in wells under pumping is ascertained in several ways. In the case of shallow tubewells, dug or sunk wells, the more common method is to drop a weighted string upto the water level, before and during pumping and computing the difference. In the case of deep tubewells, a satisfactory procedure is to adopt the air pressure method. An air tube is inserted into the well to reach below the anticipated maximum depressed water level. Air is pumped into the tube and based on the air pressure initially required to depress the water level in the air tube down to its bottom and the reduction in such pressure with increasing drawdown in the well under pumping, the drawdown during the pumping operations is measured by a calibrated gauge at the top.

The specific capacity may be determined either by the discharge method or by the recuperation method.

***(b) Discharge Method***

Using a pump discharging at a constant rate, the water level is lowered in a well and at intervals of time $\Delta t$, the water levels are noted.

The discharge equation for this method will be:

$$Q\Delta T = A\Delta h + Kh\Delta t. \qquad (5.13)$$

where,

Q = steady rate of pumping;

A = area of section of well;

K = specific capacity of the well;

h = average drawdown during the interval $\Delta t$;

$\Delta t$ = interval of time; and

$\Delta h$ = depression during the interval $\Delta t$.

In the above equation, Q, A and $\Delta t$ are known, $\Delta h$ is observed, h is measured and K can be calculated for each set of observation.

The selection of the pump capacity should be such that a desirable depression is obtained finally. The time interval $\Delta t$ should be such that the depressions during the time interval are neither too great nor too small.

When the water level is maintained constantly after a particular drawdown, the equation becomes:

$$Q\Delta t = Kh\Delta t \tag{5.14}$$

or

Q = Kh, i.e., the rate of pumping equals the yield for that particular drawdown and sp. cap. = Q/h

A practical way to confidently predict yields and drawdowns for larger dia gravel packed permanent production wells is to construct two 65 mm dia test-wells, 0.6 m apart, pumping one well with a centrifugal pump (about 30 KL/min capacity) and measuring the drawdown in the other. The resulting discharge divided by the drawdown in the well 0.6 m away is the expected specific capacity of 1.2 m gravel packed well to be drilled at the site.

### 5.2.6.7 Maximum Safe Yield And Critical Yield

If the well is not developed to the full capacity of the aquifers, the maximum yield is limited by the maximum permissible drawdown at the well and by the size and the method of construction of the well. In the case of shallow tubular wells, the maximum permissible draw-down may be limited by the suction lift of the pumps or by the depth of the wells. In the case of masonry sunk wells as well as tubewells, the drawdown can be further restricted with a view to preventing sand blows which may disturb the aquifer unduly. Sand blows which help to remove the fines and help in the training of the yield are, however, desirable. The maximum quantity that can be drawn may be fixed with reference to the diameter of the well and the hydraulic subsidence value of the largest size of the particles proposed to be removed during the training of the yield to get the best results. This may be termed the critical yield.

### 5.2.6.8 Maximum Safe Head Of Depression Or Critical Head Of Depression

From the maximum safe yield and the calculated specific capacity, the safe maximum head of depression can be calculated. The maximum safe head of depression, usually termed the critical head of depression is the limit which, when exceeded, may cause serious sand blows which will disturb the aquifer and cause damage to the well.

### 5.2.6.9 Other Influencing Factors

*(a) Head Losses*

The resistances to flow not usually considered are the friction of entrance into the well-tube or well, friction in the tube itself and the velocity head.

Inadequate area of openings into the well and the effects of clogging and corrosion may cause the loss of head of entrances to be a good proportion of the total head. The velocity head is usually too small to be worth considering. The friction head in wells upto 30 metres in depth is usually small, but in deeper wells of small diameter, it is often a very large item and needs to be carefully considered. If the well is cased for large portion of its length, the friction in the casing pipe may be taken into account. Where not cased, the friction would probably be greater, the amount depending on the roughness of the well surface. It may be assumed as 25 percent greater than that for smooth pipes.

Where friction head is of considerable amount, the yield will not be proportional to drawdown but to drawdown minus friction head. For deep wells of small diameter and with high pressures the yield is largely dependent on the pipe friction but with large diameters the yield depends rather upon the ground friction and is little affected by the diameter. Thus, while predicting performance of wells at a site, based on the equations earlier given, well losses must be computed and added.

If the well does not penetrate to the impervious stratum, but reaches short of this, there will be increased resistance near the well for higher quantities of water or, for the same head, the flow will be decreased. This added resistance due to decreased cross-section occurs only in the immediate vicinity of the well and if the total loss of head or total depression is great and if the well extends half or twothird through the porous stratum, the added resistance will be but a small proportion. Where the water bearing formation is made up of layers of different degrees of porosity and the resistance to flow from the stratum to another is great, the yield will be largely influenced by the depth of the well.

***(b) Rate of Draw and replenishment***

In the case of shallow groundwater supplies, conditions of equilibrium between flow of groundwater and draft from wells are established and the yield of a collecting system will continue from year to year with little variation except that due to rainfall. In the case of deep and artesian supplies of large capacity, however, this is generally not true. The effect of the immense reservoir of stored water commonly present in such cases is such that equilibrium of slope of pressure is established very slowly and the pressure head or groundwater level is likely to continue to decrease for many years. It would be necessary in this case to widen the area of the well system constantly to increase the depth of pumping.

### *(c) Yield from Fissures*

Where groundwater flow takes place through fissures and not through the interstices of a porous material, the effect is greatly to increase the capacity of the material and at the same time to modify the law of flow. The resistance to flow through large fissures will vary approximately as the square of velocity instead of the first power. As a result, the yield of a well supplied through fissured sources will not increase at the same rate as the lowering of the water in the well, but much more slowly.

### *(d) Draft and Total Flow*

When developing a collecting system, the problem to be decided is the extent to which the groundwater flow can be tapped or utilised. In the case of shallow seated supplies, almost the entire flow over a given width can be captured by suitable design and the ultimate capacity may be a question of total percolation in the tributary area. With a system of wells, the total flow can be utilised only when the water is lowered such that there is no head to cause flow away from the wells on the lower side.

### *(e) Mutual Interference*

If two or more wells penetrating to the same stratum are placed near together and are simultaneously operated, the total yield will be relatively much less than the sum of their individual yields when pumped independently to the same level. This mutual interference in wells depends upon the size and spacing of the wells, the radius of the circle of influence of the wells when operated singly and upon the drawdown. The amount of the interference is expressed as the percentage of reduction in yield per well below that of a single well uninfluenced by others.

### *(f) Arrangement of Wells*

The most favourable arrangement for a system of small wells is in a line at right angles to the direction of flow of the groundwater, as in this way the largest possible area will be drawn upon. By placing the wells across the line of flow or along a groundwater contour, the advantage of equal heads in the several wells is also secured. Where, an area of small width needs to be drawn upon, the arrangement is not so material, as the water will flow towards the wells from all directions. But with a long line of wells and a large draw off, it is of much importance.

### *(g) Spacing of Wells*

The amount of water which can be obtained from a system of wells depends upon the extent by which the water level can be lowered along the line of wells. The maximum amount of water obtainable from a given system of wells would be when they are spaced for enough apart so that their circles of influence will not over-lap. But on account of cost of piping and loss of head by friction, this would not be the most economical spacing. If wells are deep and therefore, expensive, they should be spaced to interfere comparatively to a lesser extent than the shallow wells which could be spaced closer. The extent of mutual interference can be judged by pumping tests on trial wells, or on those first sunk, the wells being operated at different rates and in various combinations. With the information so obtained together with a knowledge of comparative costs of wells, the best spacing of subsequent wells could be determined.

The economical spacing for deep wells will be much greater than for shallow wells and likewise the economical draw-down and yield per well will be much greater. Questions of the size and spacing also depend upon the economy of different types of pumps and a correct solution requires a careful study of all relevant factors governing local conditions.

*(h) Coastal Aquifer and Salinity Ingress*

In coastal areas, the principal aquifers are the unconsolidated quarternary sedimentary formations deposited under various sedimentary environments. Occasionally, the underlying tertiary formations also contain potential aquifers. Generally, the aquifers in coastal areas occur under confined conditions under high hydraulic head. Often the potential fresh water aquifers are overlying the saline water aquifer or more commonly wedged between the overlying and underlying saline water bodies. Development of such potential fresh water aquifers brings in problems of unusual lowering of piezometric surface coupled with decrease in yields controlled by the reservoir capacity of the aquifers.

Construction of suitable groundwater structures in coastal aquifers is also beset with hazards like vertical downward percolation and/ or upcoming of saline water and corrosion of casing of tubewells while taping the multilayered fresh water aquifers wedged between the saline water aquifers. The peculiar problem of sand rushing in tubewells tapping finegrained aquifers is also observed very frequently.

The variability of geologic conditions and that of groundwater occurrence in the coastal tracts demands special attention for hydrogeological investigations both in exploratory and development stages. Continuous research for improvements in well screens and well design to cater to the special needs of the groundwater development in the coastal tract is essential. Monitoring of groundwater regime consequent to extensive groundwater development would help in suggesting suitable methods to prevent salt intrusion and land subsidence hazards.

State Groundwater Departments and Central Groundwater Board have a good network of observation stations to monitor the water levels and water quality. Some reports on specific studies are also available which may be consulted.

### 5.2.6.10 Well Development

The object of well development is the removal of silt, fine sand and other such materials from a zone immediately around the well screen, thereby creating larger passages in the formation through which water can flow more freely towards the wells and the development process continued until the stabilisiation of sand and gravel-pack is fully assured. Well development incidentally corrects any clogging or compacting of the water bearing formation which has occurred during drilling and also grades the material in the water bearing formation immediately around the screen in such a way that the well yields sand free water at the maximum capacity. Well development includes the operations of flushing, testing and equipping the wells before they are put into service.

### *(a) Flushing*

Flushing can be done either by (i) surging including washing and agitating or by (ii) pumping and back washing with an air lift.

### *(i) Surging*

If the development operation is to be effective, it must cause reversal of flow through the screen opening of the formation immediately around the well. This is necessary to avoid the bridging of openings by groups of particles as can occur when flow is continuously in one direction. Reversals of flow are caused by forcing the water out of the well through the screen and into the water bearing formation and then removing the force to allow flow to take place from the formation through the screen and back into the well. This process is known as surging. The outflow (with respect to the well) portion of the surge cycle breaks down any bridging of openings that may occur while the inflow portion moves the fine material towards and through the screen into the well from which it is later removed: Surging is done by raising and lowering a plunger which on the downstroke forces water outwards through the screen, the plunger being of either solid plunger or valve type.

### *(a) Solid type plunger*

A simple solid type surge plunger consists of two leather or rubber belt discs sandwiched between wooden discs, all assembled over a pipe nipple with steel plates serving as washers under the end couplings, the leather or the rubber discs forming a reasonably close fit in the well casing.

Before surging, the well should be washed with a jet of water and bailed or pumped to remove some of the mud cake on the face of the bore hole and any sand that may have settled in the screen. This ensures that a sufficiently free flow of water will take place from the aquifer into the well to permit the plunger to run smoothly and freely. The surge plunger is then lowered into a well to a depth of 3 to 5 m under the water but above the top of the screen. A spudding motion is then applied, repeatedly raising and dropping the plunger through a distance of 0.5 to 1 m. If a cable tool drilling rig is used, it should be operated on the long stroke spudding motion. It is important that enough weight be attached to the surge plunger to make it drop readily on the down-stroke. A drill stem or heavy string of pipes is usually found adequate for this purpose.

Surging should be started slowly, gradually increasing the speed but keeping within the limit at which the plunger will rise and fall smoothly. Surging is done for several minutes, the speed, stroke and time for this initial operation being noted. Then the plunger is withdrawn and the bailer or sand-pump lowered into the well and the sand accumulation in the screen bailed out and measured. The surging and bailing operations are repeated until little or no sand is pulled into the well. The time should be increased for each successive period of surging as the rate of entry of sand into the well decreases. The sand-pump type of bailer is generally favoured for removing sand during development work.

### (b) Valve type plunger

The valve type surge plunger differs from the solid type surge plunger in that the former carries a number of small port holes through the plunger which are covered by soft valve leather.

Valve type surge plungers are operated in a similar manner to solid plungers. They pull water from the aquifer into the well on the upstroke and by allowing some of the water in the well to press upward through the valves on the down-stroke to produce a smaller reverse flow in the aquifer. This creation of a greater in- rush of water to the well than the out-rush during the surging operation is the principal and most important feature of this type of plunger. The valve type surge plunger, because of this feature, is particularly suited to use in developing wells in formations with low permeabilities, since it ensures a net flow of water into the well rather than out of it. A net outward flow can result in the water moving upwards to wash around the outside of the casing since the low permeability of the aquifer will not permit flow readily into it. Washing around the outside of the casing could cause caving of the upper formations and thus create very difficult problems. An incidental benefit gained from the use of this type of plunger is the accumulation of water above the plunger with the eventual discharge of some water, silt and sand over the top of the well. The valves in effect produce a sort of pumping action in addition to the surging of the well and thus reduce the number of times it is necessary to remove the plunger to bail sand out of the well.

Surge plungers can also be operated within the screen. This may be desirable in developing wells with long screens. By operating a plunger within the screen, the surging action can be concentrated at chosen levels until the well is fully developed throughout the entire length of the screen. The surge plungers should, for much use, be sized to pass freely through the screen and its fittings and not form a close fit in them, as is the case when operating within the well casing. Special care must be exercised when surging within the screen to prevent the plunger from becoming sandlocked by settling of sand above it. For this reason the use of plunger within the screens should only be attempted by experienced drillers. Care must also be exercised when using surge plungers to develop wells in aquifers containing many clay streaks or clay balls. The action of the plunger can, under such conditions, cause the clay to plaster over the screen surface with a consequent reduction rather than increase in yield. In addition, surging of the partly or wholly plugged screen can produce high differential pressures, with a possiblity of collapse of the screen.

### (ii) Pumping and Backwashing

### (a) High velocity jetting

High velocity jetting or back washing of an aquifer with high velocity jets of water directed horizontally through the screen opening is generally the most effective method of well development. The principal items of equipment required are a simple jetting tool, a high pressure pump, the necessary hose, piping, swivel and water tank or other source of safe water supply.

The procedure is to lower the tool on the jetting pipe to a point near the bottom of the screen. The upper end of the pipe is connected through a swivel and hose to the discharge and of a high pressure pump such as the mud pump used for hydraulic rotary drilling. The pump should be capable of operating at a pressure of atleast 7 $kg/cm^2$ and preferably at about 10.5 $kg/cm^2$ while delivering 40 to 45 liters per minute for each 5 mm nozzle. While pumping water through the nozzles and screen into the formation, the jetting tool is slowly rotated, thus washing and developing the formation near the bottom of the well screen. The jetting tool is then raised at intervals of a few centimetres and the process repeated until the entire length of the screen has been back washed and fully developed. It has been found that about 10 to 15% more water should be removed from the well than jetted into it, creating a cone of depression and ensuring that the undesirable fines loosened by jetting are purged from the well. Often air lift or centrifugal pumps are used, the major portion of the water being recirculated through a settling tank to be used to supply the high pressure pump for the jetting. Simultaneous pumping and jetting provides the means for measuring the progress of the work. If both are terminated for a few minutes until water levels return to static, the pumping alone can be commenced with periodic water level measurements to determine the specific capacity with time of pumping. Such measurements provide the theoretical expected specific capacity, the actual specific capacity (and therefore instantaneous efficiency measurement) and whether or not improvements are being made with increased development activity can be ascertained.

The high velocity jetting method is more effective in wells constructed with continuous slot type well screens. The greater percentage of open area of this type of screen permits a more effective use of the energy of the jet in disturbing and loosening formation material rather than in being dissipated by merely impinging upon the solid areas of the slotted pipe. Jetting is the most effective of development methods because the energy of the jets is concentrated over small areas at any particular time and every part of the screen can be selectively treated. Thus uniform and complete development is achieved throughout the length of the screen. This method is also relatively simple to apply and not likely to cause trouble as a result of over application.

*(b) Pumping*

Another back washing method of development, suitable for use in small wells is one which uses a centrifugal pump with a suction force connected directly on the top of the well casing and carrying a sluice valve on the discharge end. This procedure simply involves the periodic opening and closing of the discharge valve when the pump is in operation. This creates a surging effect on the well. This process is continued until the discharge is clear and sand-free. The method is only applicable where static water levels are such as to permit pumping by suction lift. Some damage can be caused to the pump through the wearing of its parts by the sand pumped through it, particularly if in large quantities. The use of the pump to be permanently installed at the well is, therefore, not recommended for use in development of a well by this method.

Development of gravel packed wells is aimed at removing the thin skin of relatively impervious material which is plastered on the wall of the hole and sandwiched between the natural water-bearing formation and the artificially placed gravel. The presence of gravel envelope creates some difficulty in accomplishing the job. Success depends upon the grading of the gravel, the method of development and the avoidance of an excess thickness of gravel pack. The jetting method, because of its concentration of energy over small areas, is usually more effective than the other methods in developing gravel packed wells. The thinner the gravel pack, the more likely is the removal of all the undesirable material, including any fine sand and silt.

The use of dispersing agents such as polyphosphates at about 6 kg per kiloliter of washwater effectively assist in loosening and removing silt and clay from the aquifer as well as the face of the drilled hole. Flushing is stopped when the presence of fine sand in the discharging water is insignificant. During development, the discharge should correspond to the depression of 50 per cent higher than the normal depression at which the tubewell is later pumped on continuous duty. Where a depression of 50 per cent higher than the normal depression can not be arranged, the tubewell may be over developed so as to yield a discharge 20 per cent in excess of the rated discharge.

***(c) Testing***

A tubewell out of alignment and containing kinks or bends should be rejected because such deviations cause severe wear on the pump-shaft, bearings and discharge casing and, in a severe case, might make it impossible to get a pump in or out. If a deep well turbine pump is to be installed in a tubewell, the housing should be true to line within permissible limits of deviation from its top to a point just below the maximum depth at which it is proposed to set the pump. If an air lift or suction pump is used for pumping, the alignment is not so important and the same claim has been advanced for the submersible type of pump. It is suggested, however, that even if it is intended to install a type of pumping equipment that will function satisfactorily in an out of line well, the requirements of these specifications should be enforced.

Tubewells are to be tested for plumbness and alignment normally after completion of drilling but immediately after the housing pipes are installed but prior to commencing the gravel filling in the case of gravel-shrouded tubewells.

In the case of gravel-shrouded tubewells, if the pipe assembly is found inclined in a slant position before filling the gravels, the assembly should be pulled in a desired direction by applying force through jacks or by other means with a view to rectifying the slantness and bringing the pipe assembly within the permissible limits of verticality. The gravel operation should be undertaken immediately after the verticality has been tested and rectified. If necessary, remedial measures should be adopted in between by means of jacks or any other means to bring the pipe assembly within the permissible limits of verticality.

For wells encased with pipes less than 350 mm diameter, the verticality of the tubewell shall have a deviation not exceeding 10 cm per 30 m of depth of the tubewell and the deviation shall be in one direction and in one plane only. The deviation of the tubewell shall be determined according to the method as recommended in IS: 2800-1964.

After the tubewell is completed, step drawdown tests and recuperation tests are done to determine the well characteristics such as specific capacity and coefficients of transmissibility and permeability of the aquifer to select suitable size and type of pumps to be installed in the tubewells as also well spacing.

The water is also collected during aquifer performance test and analysed chemically for the different constituents depending upon the use to which the tubewell water is to be put.



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### (d) Equipping

#### (i) Selection of Pumps

Depending upon the discharge and drawdown noted during the tests, a suitable pump, such as a centrifugal pump, vertical turbine pump, submersible pump or reciprocating pump shall be fitted to the tubewells.

A recent innovation is to use airtight packers or seals between pump columns and well casings to (i) produce less than atmospheric pressures beneath them which enables more draw-down (a maximum additional of about 6m) and concomitant additional yield to be produced from a well and (ii) prevent oxygen from entering the lower portion of the well and thus inhibiting the growth of aerobic iron bacteria.

#### (ii) Sanitary Sealing

For all drinking water tubewells it is necessary that the annular space between the bore and the housing pipe be cement grouted upto atleast 5 m below ground level or upto first impermeable layer like clay bed. In gravel packed tubewells, two gravel feeding pipes on either side of the housing pipe should be provided to the full depth of foundation.

## 5.2.6.11 Failure Of Wells And The Remedial Measures

The clogging of wells by filling with sand or by corrosion or incrustation of the screen may reduce the yield very greatly. Wells may be readily cleaned of sand by means of a sand pump or bucket but if the strainers are corroded, they must be pulled out, cleaned and renewed or replaced. If the clogging is due to fine sand collecting outside the tube, it may be removed to some extent by forcing water into the wells under high pressure, or by use of a hose or by other suitable means. Sometimes instead of the yield of a well becoming less through continued operation, it is actually increased owing probably to the gradual removal of the fine material immediately surrounding the well.

### (a) Surging

The principal purpose of surging a well is as described in 5.2.6.10(a) (i), to dislodge clogging and incrusting material from the screen. Immediately after a well has been surged, it should be strongly and continuously pumped until all dislodged material has been removed. Otherwise, the improvement resulting from surging will be only temporary. Surging is not always successful and occasionally it may cause permanent damage.

In surging with a plunger, the drop pipe is removed from the well and a solid plunger fitting the wells of the casing is lowered beneath the water in the well. The plunger is attached to a well rig and is moved violently up and down as in spudding, causing water to rush into and out of the well through the screen. By placing a check valve in the plunger, water can be forced through the screen in one direction only. If the top of the well casing is sealed, compressed air can be discharged into it to force water violently back through the screen. If air is permitted to flow through the aquifer, it may cause "air-logging" or clogging of the aquifer with pockets of air.



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### (b) *Use of Dry Ice*

Dry ice or solidified carbon dioxide when dropped into a well quickly turns to a gas generating a strong pressure if the gas is confined. The charge is suddently released to fall into the well and vaporise, generating pressure. The method has its own dangers such as freezing the hands and suffocation of the operators due to fumes of carbon dioxide and rupture or lifting of the casing or collapse of the screen. The method is also not to be advocated because of its practical limitations in operation and utility.

### (c) *Chemical Treatment*

Chemicals such as acids, chlorine and sodium hexametaphosphate may be added to a well for the purpose of dissolving or dislodging clogging meterial or incrustation on the screen or in the sand surrounding the screen.

#### (i) Acids

Acid treatment may be resorted to only where the metal of the screen will not be seriously attacked by them. They should be introduced in sufficiently high concentrations, that the acid concentration will reach at least 25 per cent near the screen, by means of a wide mouthed funnel and 25 mm or smaller dia black iron or plastic pipe. When used in long screens, acid should be added in quantities to fill 1.5 m of the screen and the conductor pipe raised 1.5 m after pouring each instalment. The acid solution in the well should be agitated by means of a surge plunger or other suitable means for 1 to 2 hours following which the well should be bailed until the water is relatively clear and the operation repeated twice or thrice as necessary. If acid is added in granular form, the quantity added should be based on the total volume of water standing in the well, and not on that in the screen only. A number of precautions must be exercised like, all persons handling the acid wearing goggles and water proof gloves, pouring the acid slowly into the water to prepare the solution, provision of adequate ventilation in pump houses or other confined spaces around treated wells and disallowance of personnel to stand in a pit or a depression around the well during treatment (as the heavier toxic gases lend to settle in the lowest areas). After a well has been treated, it should be pumped to waste to ensure the complete removal of all acid before it is turned to normal supply.

#### (ii) Chlorine

Chlorine treatment (100 to 200 mg/l of available chlorine is needed) with usually calcium or sodium hypochlorite being used as source of chlorine, with proper agitation by the use of high velocity jetting or surging with a surge plunger is found to be more effective than acid treatment, particularly in loosening bacterial growths and slime deposits which often accompany the deposition of iron oxide. The recirculation provided with the use of the jetting technique greatly improves the effectiveness of the treatment. The treatment should be repeated 3 or 4 times to reach every part of the formation that may be affected and it may also be alternated with acid treatment, the latter being performed first.

#### (iii) Polyphosphates

Polyphosphates effectively disperse silts, clays and the oxides and hydroxides of iron and manganese and the dispersed materials can be easily removed by pumping. In addition they are safe to handle and, therefore, find considerable application in the chemical treatment of wells.

For effective treatment, 12.5 to 25 kg of polyphosphates are needed for every kilolitre of water in the well. A solution is usually made by suspending a wire basket or gunny bag containing the polyphosphate in a tank of water. About a kg. of calcium hypochlorite should be added for every kilolitre of water in the well in order to facilitate the removal of iron bacteria and their slimes and also for disinfection purposes. After pouring this polyphosphate and hypochlorite solution into the well, a surge plunger or the more effective high velocity jetting technique is used to agitate the water in the well. Two or more successive treatments may be used for better results.

No single treatment is suitable for all tubewells. But with proper diagnosing of the well sickness and taking appropriate steps as discussed above the best and cost effective method can be selected. Table 5.3 gives well clogging problem and suggested treatment and Table 5.4 gives application of various well rehabilitation methods on different types of formations.

**(iv) Disinfection**

The procedure to be adopted for disinfection of new or renovated wells etc. is presented in Appendix 5.8.

**TABLE 5.3**

**WELL CLOGGING PROBLEMS AND SUGGESTED TREATMENTS**

| Sl.No. | Problem | Treatement Suggested |
|---|---|---|
| 1. | Clogging due to fine sand, clay and silts. | Sodium hexametaphosphate 50 g/l depending on the capacity of well bore be left therein for 24 hrs. The same should be followed by surging, jetting with chemical mix or normal development till well is freed from clogging. |
| 2. | Chemical clogging | Hydrochloric acid or sulphuric acid with inhibitor are added to the well. The dosage can be kept as in the case of sodium hexametaphosphate. |

| | | |
|---|---|---|
| 3. | Bacterial clogging | Chlorine has been found to be effective in loosening this type of clogging. It not only kills the bacteria but it oxidises the material, so that it is dissolved. Calcium hypochlorite should be used to form solution of 200mg/litre which is introduced in well through small polythene pipe. We need 280 gm of hypochlorite at 70% concentration for 1,000 litres in water to give a solution of 200 mg/litres for the killing of bacteria. The well is agitated through surging method, then left for 10 hrs for removal of slimes by bailing/surging or air jetting or air lifting |

**TABLE 5.4**

**WELL REHABILITATION FOR VARIOUS ROCK FORMATIONS AND METHODS EMPLOYED**

| Sl. no. | Method Employed | Unconsolidated (a) | Consolidated Sand Stone (b) | Consolidated Lime Stone (c) |
|---|---|---|---|---|
| 1. | Use of compressed air | Removes the settled deposits of fine silt and clay. | Not very applicable | Not very applicable |
| 2. | Use of Polyphosphates | Removes fine sands, silt, shale and soft iron deposits | Not very effective | Not very effective |
| 3. | Use of hydrochloric acid, followed by chlorine | Removes sulphates, carbonates and iron deposits | Not very effective | Sometimes beneficial, acid treatment is recommended |
| 4. | Dynamiting | Not used | Effective for all types of well screen deposits | Effective if large charges are introduced |
| 5. | Surging | Same as compressed air | Rarely used | Rarely used |

| Sl. no. | Method Employed | Unconsolidated (a) | Consolidated Sand Stone (b) | Consolidated Lime Stone (c) |
|---|---|---|---|---|
| 6. | Dry ice (compressed) carbon dioxide gas) | Same as compressed air | Rarely used | Not effective |
| 7. | Chlorine | Removes iron and other bacteria | Same as under (a) | Same as under (a) |
| 8. | Caustic soda | Removes oil scum left by oil lubricated pump | Same as under (a) | Same as under (a) |

#### 5.2.6.12 Design Criteria

***(a) Tubewells***

Design of the tubewell is based on the following considerations:

(i) The effective area of opening of the strainer (the length and diameter of a strainer) is based on the critical velocity of entry of water through the strainer openings (normally 1 to 6 cm/s).

(ii) Velocity of rise in the pipe is usually restricted to 0.6 to 1.2 mps.

(iii) The allowable drawdown arrived at by the formula is usually restricted to 3 to 6 m in soft rocks.

(iv) In a well under water table conditions at least one-third to half the bottom of the aquifer should be screened.

***(b) Dugwells***

In a shallow dug well, the allowable pumping rate depends on the critical draw-down where the velocity of entry of water may carry the sand, thus resulting in the wells, in tilting.

### 5.2.7 Development of Surface Sources

#### 5.2.7.1 Intakes

A water works intake is a device or structure placed in a surface water source to permit the withdrawal of water from the source. They are used to draw water from lakes, reservoirs or rivers in which there is either a wide fluctuation in water level or when it is proposed to draw water at the most desirable depth.

***(a) Types of Intakes***

(i) Wet intakes;

(ii) Dry intakes;

(iii) Submerged intakes; and

(iv) Moveable and floating intakes.

***(b) Location***

The following factors should be considered for locating the intake:

(i) The location where the best quality of water is available

(ii) Absence of currents that will threaten the safety of the intake

(iii) Absence of ice float etc

(iv) Formation of shoal and bars should be avoided

(v) Navigation channels should be avoided as far as possible

(vi) Fetch of wind and other conditions affecting the waves

(vii) Ice storms

(viii) Floods

(ix) Availability of power and its reliability

(x) Accessibility

(xi) Distance from pumping station

(xii) Possibilities of damage by moving objects and other hazards.

Conditions affecting the quality of water will include currents due to wind, temperature and seasonal turnover and other causes that will bring water of unsuitable quality at the intake. Channels with high velocity currents carrying floating debris and ice are hazardous to the safety of the structure. Navigation channels add to the danger of pollution from toilets and other refuse discharged from ships. Ice flocs are hazardous because of its impact on the structure and closing of the ports even 10 metres below the water surface. Waves are hazardous to the superstructure of an intake; also they stir up mud and silt from the bottom in such quantity as to affect the quality of the water.

A study of the currents in a lake or river should be made before the location of an intake is selected in order to ensure water of the best quality and the avoidance of polluted water.

An intake in an impounding reservoir should be placed in the deepest part of the reservoir, which is ordinarily near the dam, to take full advantage of the reservoir capacity available. Provision for ports at different depths to take advantage of better water quality should be made.

***(c) Design Considerations***

The intake structures design should provide for withdrawal of water from more than one level to cope up with seasonal variations of depth of water. Undersluices should be provided for release of less desirable water held in storage.

In the design of intake a generous factor of safety must be allowed as forces to be resisted by intakes are known only approximately. The intake in or near navigable channels should be protected by clusters of piles or other devices, against blows from moving objects.

Undermining of foundations due to water currents or overturning pressures, due to deposits of silt against one side of an intake structure, are to be avoided.

The entrance of large objects into the intake pipe is prevented by coarse screen or by obstructions offered by small openings in the crib work placed around the intake pipe. Fine screens for the exclusion of small fish and other small objects should be placed at an accessible point. The area of the openings in the intake crib should be sufficient to prevent an entrance velocity greater than about 8 metres per minute to avoid carrying settlable matter into the intake pipe. Submerged ports should be designed and controlled to prevent air from entering the suction pipe, by keeping a depth of water over the port of at least three diameters of the port opening.

The conduit for conveying water from the intake should lead to a suction well in or near the pumping station. For conduits laid under water, standard cast iron pipe may be used. Larger conduits may be of steel or concrete. A tunnel, although more expensive, makes the safest conduit.

The capacity of the conduit and the depth of the suction well should be such that the intake ports to the suction pipes of pumps will not draw air. A velocity of 60 to 90 cm/s in the intake conduit with a lower velocity through the ports will give satisfactory performance. The horizontal cross-sectional area of the suction well should be three to five times the vertical cross- sectional area of the intake conduit.

The intake conduit should be laid on a continuously rising or falling grade to avoid accumulation of air or gas pockets of which would otherwise restrict the capacity of the conduit.

### 5.2.7.2 Impounding Reservoirs

Impounding reservoir is a basin constructed in the valley of a stream to store water during excess stream flow and to supply water when the flow of the stream is insufficient to meet the demand for water. For water supply purposes the reservoir should be full when the rate of stream flow begins to become less than the rate of demand for water.

#### *(a) Choice of Reservoir Site*

The suitability of a site must be judged from the following stand points:

(i) Quantity of water available.

(ii) Quality of source.

(iii)Possibility of the construction of a reasonably water tight reservoir.

(iv)Distance of the source from the consumer.

(v) Elevation of the supply.

(vi)Possibility of biological troubles in the case of a shallow reservoir.

#### *(b) Physical Considerations*

The estimation of the quantity of water which any impounding works will yield is the first consideration in any scheme. This consists essentially of relating the capacity of the reservoir (and therefore the height of the dam) to the distribution of run-off from the catchment area (i.e. the variations in a steam flow) during a dry period. Each catchment area should receive consideration on its merits as it may prove economical to construct sufficient storage to provide the increased yield from the driest five or more consecutive years.

In the preliminary choice of the site for a dam to impound the required quantity of water, the first study will be the topography of the valley under consideration. From an examination of contour maps, alternative sites will probably present themselves as worthy of investigation. A natural construction in the valley will suggest a possible site for a dam; prelimnary calculations of the potential capacity of reservoirs which might be so formed, will indicate whether such a site could be developed to yield the quantity required.

Any scheme designed to develop a particular source only partially should, if possible, be conceived so as to be capable of further expansion. However, if an earthwork dam is to be built, it should be for the full development of the source. Even with the present knowledge of the behaviour and design of earth structures, there is an element of finality in the construction of an earth dam which makes it difficult to raise its height afterwards to any great extent.

From topographical considerations the choice between alternative sites can be resolved in such terms as, the length of dam required, its height, the value of the land and property to be submerged, the effect of its loss on agricultural production, the length of roads to be diverted around or over the new reservoir, the proximity and the elevation of the supply. A careful comparison of all these factors will determine which site is to be preferred.

***(c) Geological Considerations***

The decision as to the practicability of dam construction on a particularly favoured site is one which rests largely on geological considerations; these fall into three categories, viz, the geology of the catchment area, of the reservoir area and of the dam site itself.

The geological maps should be used to study the nature of the catchment area, the reservoir area and the dam site. In addition, the latter demands a particularly detailed and exhaustive geological exploration. The geological features and sequence of the strata in a catchment may have a profound effect on the distribution of the run off. The presence of permeable strata may account for high percolation losses, particularly if the general direction of the dip is away from the valley. Permeable strata dipping into a catchment area from a neighbouring valley may result in increased run-off and a higher dry-weather flow, since the tendency will be for the water stored underground to issue from the strata as springs.

***(d) Site Exploration***

The geological investigation should not stop at the determination of a suitable stratum into which a water-tight cut-off can be made, but it should extend to the exploration of the foundations to determine their ability to carry the structure. This will involve the sinking of numerous trial holes or borings in addition to those sunk along the centre line of the dam.

Preliminary exploration work should also include an examination of the valley slopes above the dam in order to discover whether the ground in the vicinity of the dam has been subject to disturbances in the past and whether further movement may occur to endanger the safety of the dam and its ancillary works.

In general, therefore, the preliminary geological investigations should be as complete and exhaustive as possible and the expense of such work (often considerable) will be well justified. Inadequate examination may prove calamitous.

### *(e) Computation of Storage*

To determine the required capacity of a storage reservoir, the first step is to prepare a table showing the amount of rain fall by months for as long a period in the past as possible. Rain records of the Meteorological Department for the locality under consideration are best. If they are not available, the best possible data should be obtained from places at which conditions correspond as closely as possible to those at the place under consideration. The required storage is then based on the drought year expected once in 30 years. In exceptional cases, the figures for the drought year expected once in 20 years may be adopted and during the drought years worse than anticipated once in 20 years, rationing of supplies and more rational use of water will have to be enforced.

The second step is to obtain and study run off records, if there are any, to determine for each month of the year the percentage of rainfall available as run off. Usually such data are very limited and it may be necessary to use known data from an area having similar characteristics.

The third step is to establish and tabulate monthly evaporation losses. These are based on reservoir area, which is not known before hand but generally ranges from 3 to 10 per cent of the water shed area. A table is then prepared to show the expected draft or consumption for each month of the year. The amount of stream flow for each month is determined from runoff records or multiplying the rainfall by the percentage of runoff. The required quantity of water is found by adding the consumption and the estimated losses from evaporation, percolation and leakage.

These data will show the difference between supply and demand for each month. The required storage capacity will be the greatest total deficiency during any succession of months when the stream flow is less than the draft on the reservoir.

A mass diagram can be drawn to determine the required storage. The deficit value occurring one in 30 years may be statistically worked out and used.

Other information furnished by the mass diagram includes; (1) date that the reservoir is full and stops overflowing; (2) dates that the reservoir is full and starts overflowing; (3) the dates that the reservoir is empty; (4) the dates that the level of the surface of the water in the reservoir stops falling and starts to rise, the reservoir not being completely empty; and (5) whether the flow of stream is sufficient or insufficient to fill the reservoir.

The volume of water that can be held in the impounding reservoir can be determined approximately by multiplying average surface areas between contours by contour interval or the prismoidal formula may be used.

$$V = \frac{h}{6}\left(A_1 + A_2 + A_3\right) \tag{5.15}$$

Where,

V = Volume between contours, corresponding to surface areas $A_1$ and $A_3$.

$A_1$, $A_2$ & $A_3$ = Respective areas enclosed within lower, medium and upper contour, where contour interval is h.

### (f) Biological Considerations

The catchment area should be prepared so that water from the collecting grounds can flow quickly into the reservoir instead of collecting in pools and swamps where it can pick up organic matter. The area to be submerged should be prepared by cutting all the trees and bushes close to the ground and burning out the vegetation. Roots that may be exposed to wave action should also be removed. Buildings, barnyards, manure heaps and such sources of pollution should also be carefully removed from the area to be flooded. The margins of the reservoir should be dressed to avoid irregularities where the water may collect in stagnant pools and favour the growth of weeds. Plants can be removed physically from margins or in reservoirs which may be tedious and may not be very efficient. Caution has to be exercised in the use of herbicides, as it can impart oily or musty odour to water and can be toxic to fish. Channels should be cut to pockets within the reservoir bottom to promote self-draining when the level is lowered. The reservoirs should be made as deep as practicable. They should consist of at least two compartments for reasons explained in 9.2.3.2 c(l) (i) (dd). The intake should permit water to be drawn off at different depths so that the operator can change the depth of draft to exclude the algae-laden water.

### (g) Reservoir Management

#### (i) Silting

Loss of capacity due to the deposition of silt in a reservoir may impair, if not destroy, the usefullness of the reservoir in a few years. It may be minimised by proper site selection, erosion control, reservoir operation and desilting works. The reservoir site may preferably be chosen on a non-silt bearing stream, or the reservoir may be located in a basin off the main channel so that heavily silt-laden waters may be by-passed around the basin. Reservoirs should be located on the smallest drainage area possible. The rate of silting (hectare metres per year per sq. kilometre ) under Indian conditions varies from 0.1 to 0.2

After silt has been deposited in a reservoir, there is no practicable method, widely applicable, for removing it other than to operate gates in the dam to flush out the silt to some extent at times of high stream flow. Dredging is expensive and the disposal of the dredged material presents a serious problem

Soil erosion and control are closely related to the silting of reservoirs since without erosion there would be no silting. Erosion prevention methods recommended for soil conservation include proper crop rotation, ploughing on contours, terracing, strip cropping, protected drainage channels, check dams, reforestation, fire control and grazing control.

Hence it is necessary to provide for silting capacity for all impounding reservoirs, based on studies or data pertaining to similar catchments.

#### (ii) Evaporation

By evaporation, a process by which water passes from the liquid state to the vapour state, water is lost from water surface and moist earth surfaces. Hence it is of importance in determining the storage requirements and estimating losses from impounding reservoirs, and other open reservoirs. Evaporation from water surface is influenced by temperature, barometric pressure, mean wind velocity, vapour pressure of saturated vapour and vapour pressure of saturated air and dissolved salt content of water. The evaporation loss in storage tanks in India amounts to 2-2.5 m/year. It is essential that the available surface storage is adequately protected from evaporation as losses upto 30% can be reduced economically.

A number of liquid and solid organic compounds have the property of spreading on the water surface and forming a thin film. It is possible to select organic compounds which give monomolecular films and are capable of expansion and contracton by wave action thus being undamaged under field conditions. Such a monomolecular film offers resistance to the evaporating water particles as a result of which the rate of evaporation is reduced.

Hexadecanol or Cetyl alcohol and Octadecanol or Stearyl alcohol or a mixture of these two chemicals is commonly used for suppressing evaporation from lakes and reservoirs. NOIGEN-101, which is mixture of Cetyl and Stearyl alcohols and indigenously available may be used for suppressing evaporation from lakes and reservoirs by spraying on water surface so as to cover the entire surface with this film. The chemical can be used in solution, in powder form or as an emulsion. Spraying in powder form is the simplest and most widely used process. A dose of 1.2 kg/hectare/ day is adequate for wind velocities below 8 kmph.

**(iii) Seepage**

Seepage occurs wherever the sides and bottom of the reservoir are sufficiently permeable to permit entrance of water and its discharge through the ground beneath the surrounding hills. Apart from making them impermeable to the extent possible economically, erosion control measures such as proper crop rotation, contour ploughing, terracing, strip cropping, reforestation or afforestation, cultivation of permanent pastures and the prevention of gully formation though the construction of checkdams could also be useful on a long term basis.

**(iv) Algal Problems**

Reservoir management is also of value in reducing the algal problems. Small inflows of water rich in organic matter should be bypassed wherever possible instead of allowing them to infect the main body of the water. The water weeds in the reservoir should be controlled by suitable methods such as dragging and under-water cutting. Algicidal measures as described in chapter 9 may be adopted to control algae in reservoirs.

# CHAPTER 6
# TRANSMISSION OF WATER

Water supply system broadly involves transmission of water from the sources to the area of consumption, through free flow channels or conduits or pressure mains. Depending on topography and local conditions, conveyance may be in free flow and/or pressure conduits. Transmission of water accounts for an appreciable part of the capital outlay and hence careful consideration of the economics is called for, before deciding on the best mode of conveyance. While water is being conveyed, it is necessary to ensure that there is no possibility of pollution from surrounding areas.

## 6.1 FREE FLOW AND PRESSURE CONDUITS

### 6.1.1 OPEN CHANNELS

Economical sections for open channels are generally trapezoidal while rectangular sections prove economical when rock cutting is involved. Uniform flow occurs in channels where the dimensions of the cross-section, the slope and the nature of the surface are the same throughout the length of the channel and when the slope is just equal to that required to overcome the friction and other losses at the velocity at which the water is flowing.

Open channels have restricted use in water works practice in view of the losses due to percolation and evaporation as also the possibility of pollution and misuse of water. Also they need to be taken along the gradient and therefore the initial cost and maintenance cost may be high. While open channels and canals are not recommended to be adopted for conveyance of treated water, they may be adopted for conveying raw water. Sometimes diversion channels meant for carrying floodwaters from other catchments are also used to augment the yield from the reservoirs.

### 6.1.2 GRAVITY AQUEDUCTS AND TUNNELS

Aqueducts and tunnels are designed such that they flow three quarter full at required capacity of supply in most circumstances. For structural and not hydraulic reasons, gravity tunnels are generally horseshoe shaped.

Gravity flow tunnels are built to shorten the route, conserve the head and to reduce the cost of aqueducts, traversing uneven terrain. They are usually lined to conserve head and reduce seepage but they may be left unlined when they are constructed by blasting through stable rock.

Mean velocities, which will not erode channels after ageing, range from 0.30 to 0.60 mps for unlined canals and 1 to 2 metres per second for lined canals.

### 6.1.3 Pressure Aqueducts And Tunnels

They are ordinarily circular in section. In the case of pressure tunnels, the weight of overburden is relied upon to resist internal pressure. When there is not enough counter-balance to the internal pressure, steel cylinders or other reinforcing structure, for example, provide necessary tightness and strength.

### 6.1.4 Pipelines

Pipelines normally follow the profile of the ground surface quite closely. Gravity pipelines have to be laid below the hydraulic gradient. Pipes are of cast iron, ductile iron, mild steel, prestressed concrete, reinforced cement concrete, GRP, asbestos cement, plastic etc..

## 6.2 HYDRAULICS OF CONDUITS

The design of supply conduits is dependent on resistance to flow, available pressure or head, allowable velocities of flow, scour, sediment transport, quality of water and relative cost.

### 6.2.1 Formulae

There are a number of formulae available for use in calculating the velocity of flow. However, Hazen-Williams formula for pressure conduits and Manning's formula for free flow conduits have been popularly used.

***(a) Hazen-Williams Formula***

The Hazen-Williams formula is expressed as:

$$V = 0.849\, C\, r^{0.63}\, S^{0.54} \qquad (6.1)$$

For circular conduits, the expression becomes

$$V = 4.567 \times 10^{-3}\, C\, d^{0.63}\, S^{0.54} \qquad (6.2)$$

and

$$Q = 1.292 \times 10^{-5}\, C\, d^{2.63} S^{0.54} \qquad (6.3)$$

Where,

Q = discharge in cubic metre per hour

d = diameter of pipe in mm

V = velocity in mps

r = hydraulic radius in m

S = slope of hydraulic gradeline and

C = Hazen-Williams coefficient.

A chart for the Hazen-Williams formula is given in Appendix 6.1.

**(b) *Manning's Formula***

The Manning's formula is:

$$V = \frac{1}{n} r^{2/3} S^{1/2} \quad (6.4)$$

For circular conduits:

$$V = \frac{3.968 \times 10^{-3} \times d^{2/3} \times S^{1/2}}{n} \quad \text{and} \quad (6.5)$$

$$Q = 8.661 \times 10^{-7} \times \frac{1}{n} d^{8/3} \times S^{1/2} \quad (6.6)$$

Where,

Q = discharge in cubic metre per hour

S = slope of hydraulic gradient

d = diameter of pipe in mm,

r = hydraulic radius in metres,

V = velocity in mps, and

n = Manning's coefficient of roughness

A chart for Manning's formula is given in Appendix 6.2.

**(c) *Darcy-Weisbach's Formula***

Darcy and Weisbach suggested the first dimensionless equation for pipe flow problems as,

$$S = \frac{H}{L} = \frac{f V^2}{2 g D} \quad (6.7)$$

Where,

H = head loss due to friction over length L in metres

f = dimensionless friction factor, and

g = acceleration due to gravity in $m/s^2$

V = velocity in mps

L = length in metres

D = dia in metres

*(d) Colebrook-White formula*

The Colebrook - White formula for calculation of frictional coefficient is

$$\frac{1}{\sqrt{f}} = -2\log_{10}\left[\left(\frac{k}{3.7d}\right) + \frac{2.51}{R_e\sqrt{f}}\right]$$

Where

f = Darcy's Friction Coefficient

$R_e$ = Reynold's Number = Velocity x Diameter/Viscosity

d = Diameter of pipe ; k = Roughness projection

For more details of the Colebrook-White formula, reference may be made to any standard reference book on Fluid Mechanics. Recommended Design Values of roughness (k) for pipe materials are shown below.

| S.No. | Pipe Material | Value of 'k' mm | |
|---|---|---|---|
| | | New | Design |
| 1. | Metallic Pipes - Cast iron and Ductile Iron | 0.15 | * |
| 2. | Metallic Pipes - Mild Steel | 0.06 | * |
| 3. | Asbestos Cement, Cement Concrete, Cement Mortar or epoxy lined Steel, C I and D I pipes | 0.035 | 0.035 |
| 4. | PVC,GRP and other plastic Pipes | 0.003 | 0.003 |

* *Reference may be made to IS : 2951 for roughness values of aged metallic pipes.*

### 6.2.2 Coefficient Of Roughness

In today's economic climate, it is essential that all water utilities ensure that their resources are invested judiciously and hence there is an urgent need to avoid over designing of the pipelines. Despite technological advancements, improved methods of manufacturing of all types of pipes and advent of new pipe materials, the current practice of adopting conservative Coefficient of Roughness (C values) is resulting in under utilization of the pipe materials.

The coefficient of roughness depends on Reynolds number (hence on velocity and