HYDRAULIC STRUCTURES FOR PUMPING EQUIPMENT: CIVIL, MECHANICAL, AND ELECTRICAL CONSIDERATIONS

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Summary

The pump is probably the single most important mechanical device developed and used all over the world today in the water supply industry. Without pumps it would not be possible to transport and distribute water over long distances and widespread areas to a variety of different consumers as are currently being served by pumping stations.

In this respect, the centrifugal pump is an extremely important, reliable, and efficient item of mechanical equipment commonly used worldwide. Because of its characteristics and simplicity, it is being used in an ever increasing number of applications. It is the only effective way to pump large quantities of water reliably.

Many different technological disciplines are being applied to satisfy the need to pump water. The components most relevant to pumping stations are discussed in this article. Considerations are the different types of pumps and their applications, various sources of motive power, and specifically electricity distribution at a pumping station. The civil-engineered structure including the intake and other aspects are discussed in detail from a functional point of view to ensure a reliable life support system.

Further aspects that are closely related to pumping stations, such as the pipeline in which the water is transported, surges in pipelines, and water hammer, are dealt with in other articles.

1. Introduction

In the development of water resources, hydraulic structures for pumping equipment feature prominently and are associated with pumping stations and all their components that are used for water supply purposes. Pumping station design depends on a large number of aspects, each of which must be considered carefully. Such aspects include the size of the city, town, community, or industry to be served; the type and location of the water source(s); the topography of the works site in relation to the water supply source(s); the location of consumers; and the routing of supply lines, along with the trends of consumer demand and the stages of proposed future extensions.

The degree of sophistication and automation that would be most suitable for the application, seen in conjunction with the operation and maintenance skills available, is of the greatest importance, especially in developing countries.

A pumping station primarily comprises the pumps, the associated pipe-work, the other mechanical and electrical equipment, and the civil-engineered structure that has to be specifically designed to house all this equipment. All components, including the intake and delivery structures, must be optimized, duly considering the various engineering disciplines, so as to arrive at the most suitable pumping station layout that would be appropriate for the specific flow requirements and site conditions.

When establishing, and also when refurbishing, a water scheme, there are a great variety of different options that can be considered in selecting suitable mechanical and electrical equipment for it. These options can entail different designs and layouts, product ranges, product quality, and equivalent patent devices. The equipment and plant selected must also comply with the philosophy outlined for the complete works and their environment, along with codes of practice, bylaws, and regulations that are in force.

The materials used in the construction of pumps should also be carefully considered, as many pump failures have resulted from the incorrect selection of pump materials and their combinations. Maintenance of pumps can be reduced and their operational life greatly extended when the correct selection and use of materials are made.

The aspects further described herein should provide an appreciation of good state-of-the-art practices and philosophies that can be adopted in pumping station design and the selection of equipment.

2. Pumps

Pumps are predominantly used in the water industry for the transfer of water. Many of the major cities in the world are examples of densely populated areas remotely situated from their main sources of water supply. Both raw (untreated) and purified water is transferred from remote sources and distributed over long distances and large areas by means of pumping. Pumps are also used for a wide variety of applications in some form or another, even in the remotest areas of the world.

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The transfer of liquids is briefly discussed. The handling of water in terms of the defined service pressures, or heads, and the input power required is considered first. The classification and characteristics of pumps, together with some practical guidelines as to the fields of application and how to decide on the number of pumps required in a typical pumping station, are dealt with next.

2.1. The Handling of Liquids by Pumping

The energy transferred to the pumped liquid, generally water, in terms of its unit weight due to gravitational attraction is expressed in terms of length units (measured in the vertical direction), and is known as the *hydraulic head, H*. This total head, H_t, needed for the pumping plant to operate at a specified flow can be expressed, as derived from the Bernoulli equation, in the following form, Eq. (1):

$$H_t = \frac{P_a - P_e}{\rho g} + Z_a - Z_c + \frac{V_a^2 - V_e^2}{2g} + H_{vs} + H_{vd} \qquad (1)$$

The head losses in the intake and delivery lines can be calculated from hydraulic principles as given by Stephenson (see *Fluid Mechanics in Pipelines*).

There is a more complete discussion of fluid mechanics principles and the theory of hydraulic resistance in another article (see *Fluid Mechanics*).

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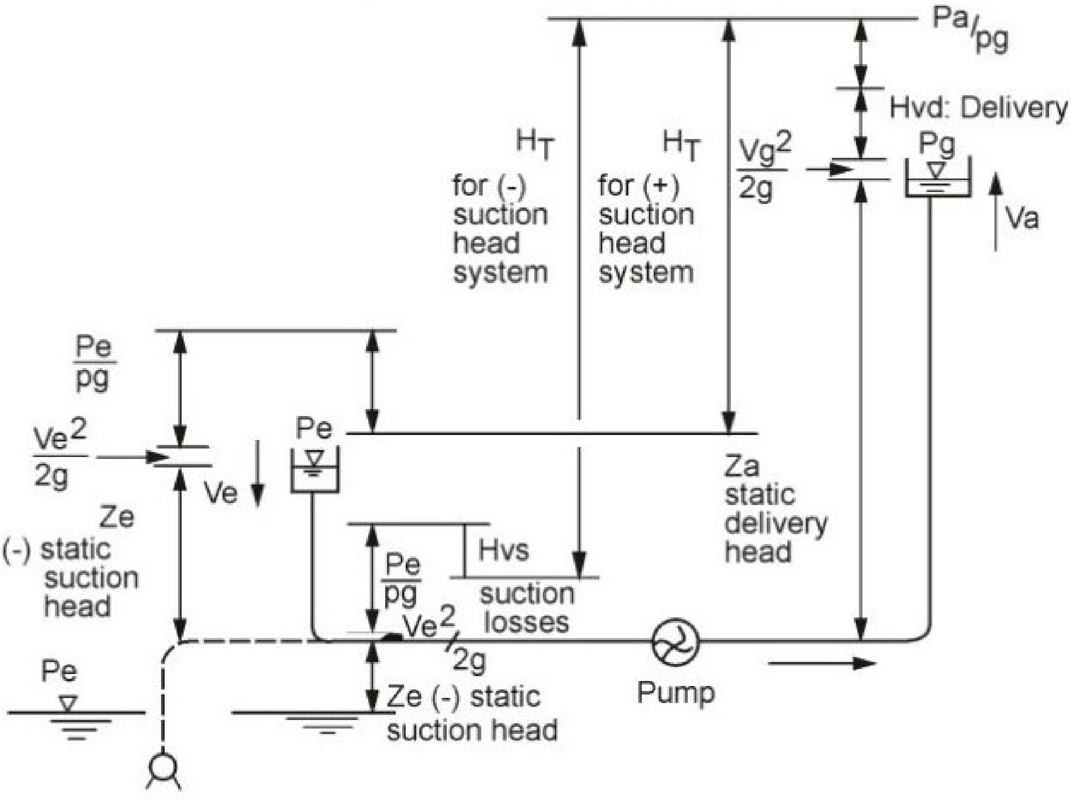

Figure 1. Diagram illustrating the Bernoulli equation applied to a pumping system

In Figure 1, a diagrammatic illustration is given of the application of the Bernoulli equation to a pumping system. It also serves as a definition sketch for the various symbols used in Eq. (1). Z and H is in m of fluid, P in P_a, V in m/s, ρ in kg/m^3, and g in m/s ^{2}.

The *power* input to a pump required to provide the desired flow rate, Q, at the system head, H, is defined as follows, Eq. (2):

$$P = \frac{\rho g \cdot Q \cdot H}{1000\,\eta}\ \text{kW}$$

$$P = \frac{\rho\, Q \cdot H}{102\,\eta} \quad \text{kW} \quad \text{for } g = 9.81\text{m/s}^2 \qquad (2)$$

where Q is in m^{3}s^{-1}, H in m, ρ in kg/m^{-3}, and η is the efficiency; for cold water it is approximately 0.82 in the case of a centrifugal pump. The types of pumps are described in the next section (see *Classification of Pumps*).

The pump efficiency, η, is defined as the ratio of effective pump output power, P_Q, the useful hydraulic power, to the power input, P, at the pump drive. The efficiency is a factor less than unity and incorporates all the energy and other losses such as due to hydraulic resistance, leakage, mechanical friction, and so on, and is expressed as, Eq. (3):

$$\eta = \frac{P_Q}{P} \qquad (3)$$

In pumping units, *cavitation* can occur in the pump should the pressure at any point in the casing, impeller, or interior fall below the vapor pressure of the water at that temperature. This condition in a pump leading to cavitation is determined by the value of the NPSH (net positive suction head) at the pump intake, is dependent on various pump characteristics, and is defined as given in Eq. (4):

$$\text{NPSH} = \frac{P_e}{\rho g} + Z_e - H_{vs} - H_{va} \qquad (4)$$

P_e, Z_e, and H_{vs} are as shown in Figure 1, and H_{va} is the vapor pressure at the temperature of the water.

2.2. Classification of Pumps

Pumps come in many types that can be classified into three main categories, namely *centrifugal, special types* and *positive displacement* pumps. Most of these types of pumps are successfully being used in the fields of water supply and treatment. This is depicted diagrammatically in Figure 2:

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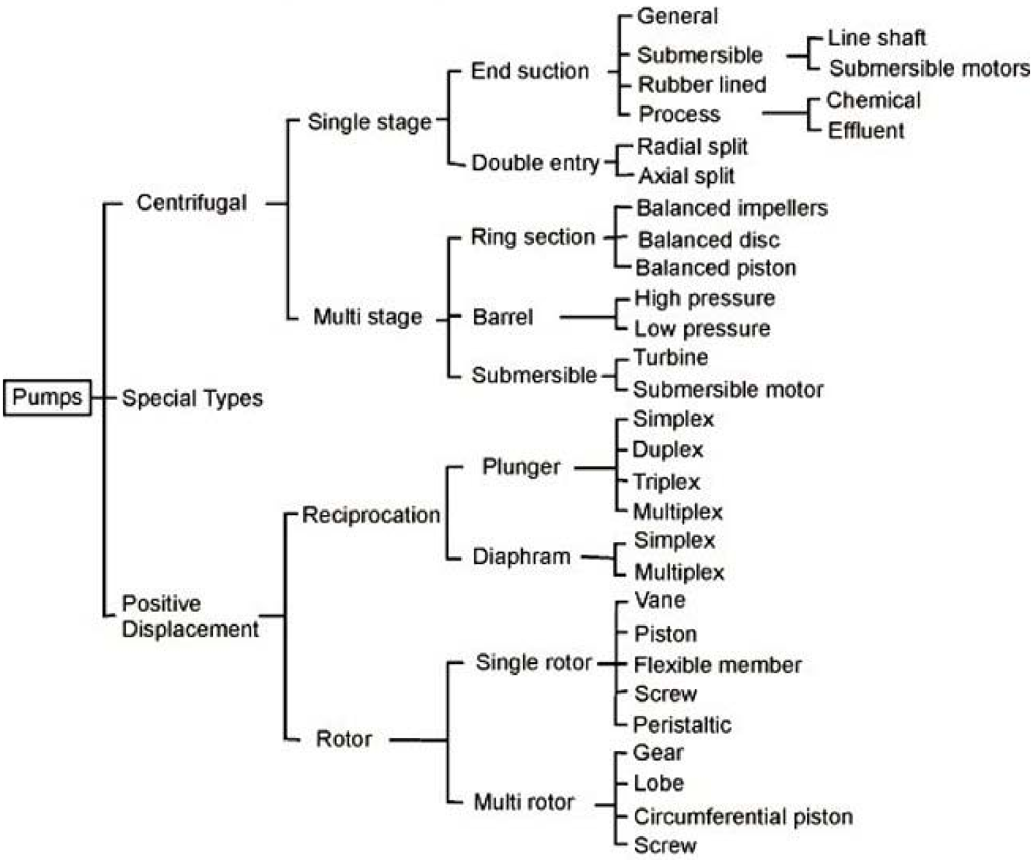


Figure 2. Types of pumps

In a *centrifugal pump* the liquid is inducted by means of atmospheric or other external pressure into a set of driven rotating vanes, constituting the impeller, which then discharges the liquid at a higher pressure and velocity around its periphery. The water so discharged is collected by means of a casing in the form of a spiral volute surrounding the impeller and is thus conducted from the pump outlet into the delivery pipeline or force main. Centrifugal pumps generally are further classified into three categories relating to the pump impeller shape and the main flow direction, with reference to the axis of rotation, as shown in Figure 3.

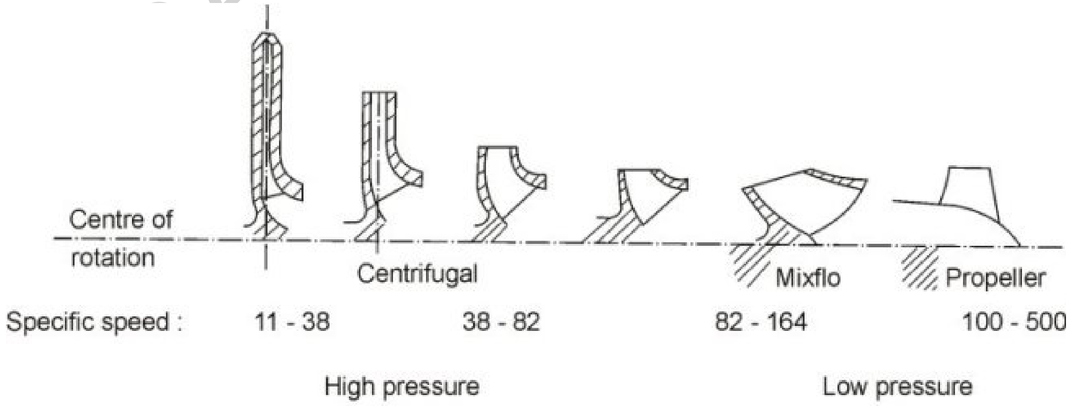


Figure 3. Comparative impeller shapes for different pump types.

Impellers are further classified according to the flow arrangement at the entry or suction side, namely *single* and *double suction* classes, and with respect to the mechanical construction of the housing on either side of the impeller vanes, referred to as the shroud, namely *open, semi-open,* and *closed* shroud types. Should the required delivery head be developed by a single impeller, the pump is referred to as a *single-stage* pump, and if two or more impellers in series are required, it is referred to as a *two-stage* or *multistage* pump. Figure 4 illustrates the various classes, types, and staging of pumps.

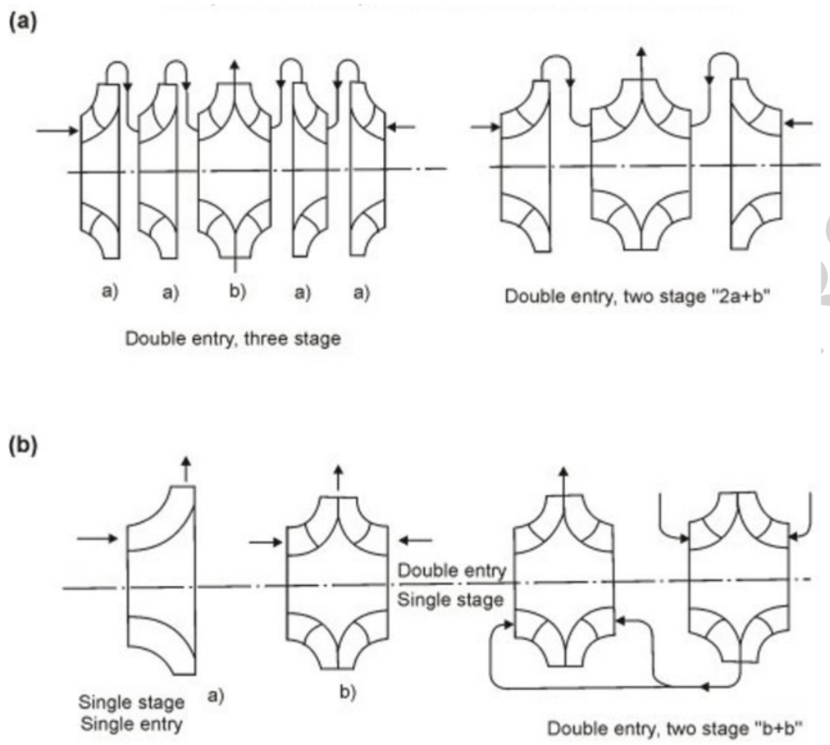


Figure 4. Impeller arrangements referring to class, type, and staging of pumps

Centrifugal pumps may also be equipped with submersed motors and are then referred to as submersible pumps. They can also be provided with either horizontal or vertical spindle drives, as well as with inclined short or long spindle drives as shown in Figure 11.

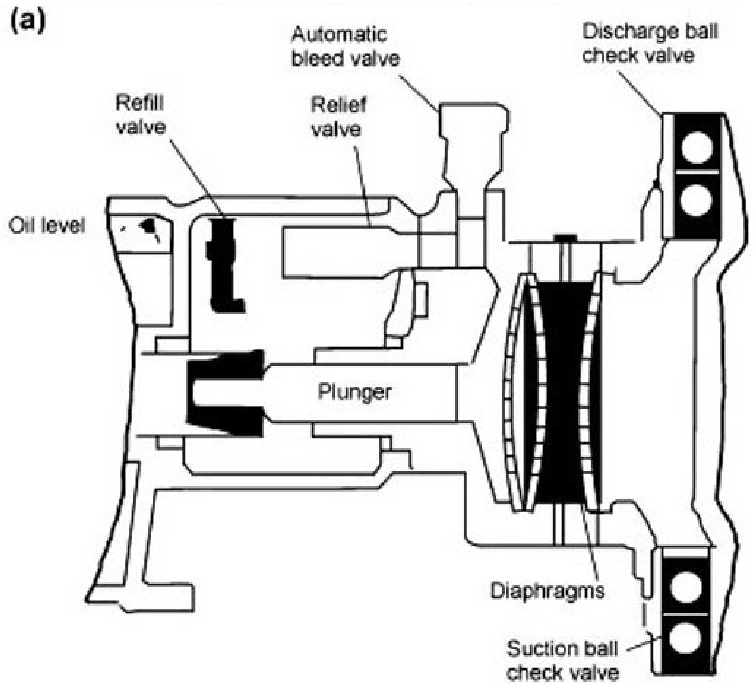
Special pumps such as airlift and jet pumps, are generally not used in the water transfer industry, but are found in installations such as water-well test rigs.

Positive displacement pumps are of two types, namely *linear reciprocating* and *rotary* pumps. Their principle consists in the impelling of a defined quantity of fluid per stroke or revolution from the low-pressure side to the high-pressure side, which always remains the same, regardless of the system's delivery side pressure.

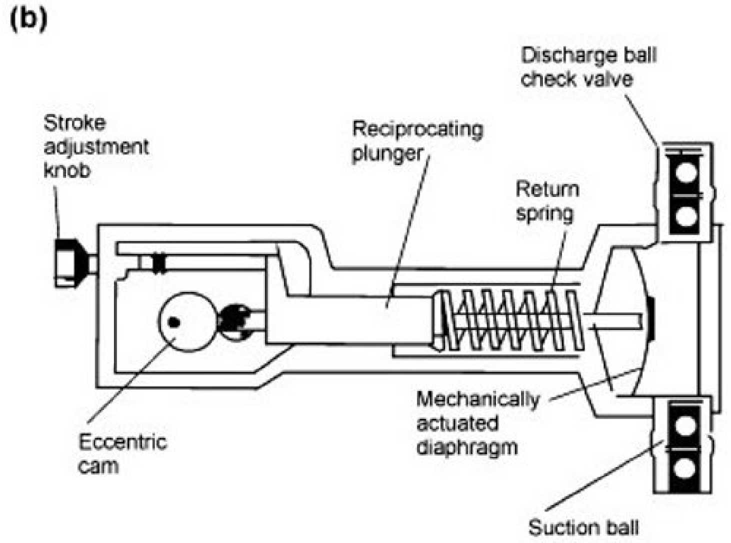
Reciprocating pumps comprise two types, namely the *piston* (or *plunger*) and the *diaphragm* (or *controlled volume*) pumps. Besides these, other variations of reciprocating pumps such as *lift, force, lift-force,* and *deep well* pumps are widely used for the supply of water to small communities in rural and developing areas.

Reciprocating pumps are generally not used for bulk water supply. Examples of reciprocating pumps are shown in Figure 5.

If operating at a constant speed, the plunger pump essentially will deliver the same rated capacity of liquid at whatever discharged pressure occurs as long as it lies within the capability of the driving unit and the design strength of the pump casing. It has a high efficiency, which is almost independent of the discharge pressure and rated capacity.



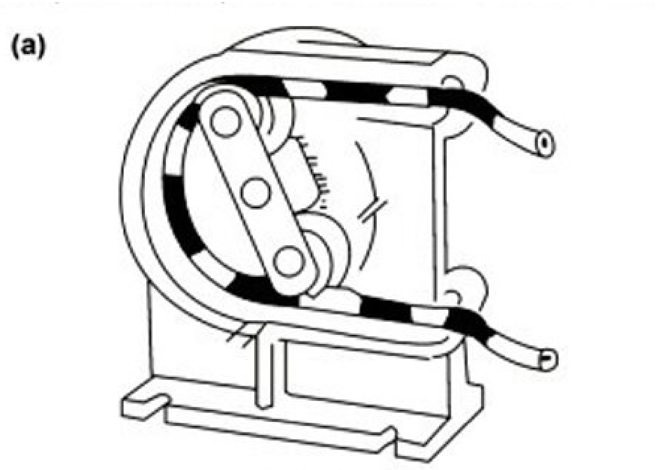
Double - disk diaphragm liquid end design



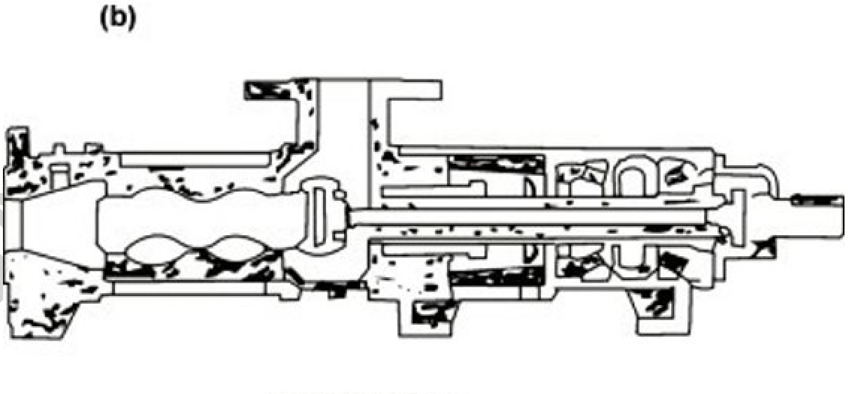
Eccentric cam drive

Figure 5. Typical linear diaphragm-type reciprocating pumps

There is a variety of *rotary pumps,* namely *screw*, *progressive cavity,* and *peristaltic* pumps. In *progressive cavity* or *screw* pumps, such as the *mono* pump, the fluid is pumped in an axial direction via the spaces formed between the meshing internal stator screw threads and the rotor or impeller, which also has the form of a screw (generally manufactured of stainless steel) and is of reduced diameter, making linear, helical contact with the surrounding rubber stator (see Figure 6). *Double helix screw* pumps are mainly used for lubricating fluids and hydraulic oil control systems.



Peristaltic pump



Screw (mono) pump

Figure 6. Types of rotary positive displacement pumps
(a) Peristaltic (flexible membrane) pump, (b) Screw (mono) pump

Except for the widespread use of screw pumps for the supply of water to small communities in rural and developing areas, rotary positive replacement pumps are generally not used for bulk water supply. They are, however, ideally suited to the transfer of chemical solutions used for water treatment and for pumping *sludges* due to their high accuracy, with capacities ranging up to approximately 36 m^3/hr. They are also used for pumping mixed-concrete mortar.

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Biographical Sketch

Alex Bell is a graduate of Pretoria University, South Africa, where he obtained the degree B.Sc. Eng. (Civil Engineering) in 1962. He has been closely associated with the development of the water supply systems in South Africa for more than 37 years. He has been intensively involved in the planning, design, and construction of various regional and interbasin water transfer and conveyance schemes while employed by the Department of Water Affairs and Forestry.

He was senior project manager with the implementation of rural water supply schemes, the operational components of turnkey contracts for water supply and sanitation in the Mpumalanga Province, and the coordination of the planning and design of bulk water supply and sanitation projects for the city of Johannesburg. He also evaluated the proposed conversion of a 90 MW hydropower plant to a pumped-storage system.

From 1990 to 1995 he was Deputy Chief Engineer: Civil Contract Administration and responsible for the project management activities of various schemes, namely the Lower Sundays River and the Komati Basin Development schemes. From 1978 to 1990, he was Deputy Chief Engineer for planning and design of regional water projects, including the Tugela-Vaal Scheme, the South Namaqualand Scheme, and the Klein Karoo Scheme.

His experience prior to 1978 involved the design of water supply augmentation projects involving pipelines, canals, siphons, and water purification plants. From 1963 to 1968, he was employed as engineer by the Department of Water Affairs on the construction of dams, including the Midmar Dam (having an earth-zoned embankment) and the Lubisi Dam (double curvature gravity arch). Other experience involved the design of a 160-megaliters-per-day reverse osmosis desalination plant.

His professional affiliations are the following: Fellow, South African Institution of Civil Engineers; Member, Engineering Council of South Africa, and Registered Professional Engineer in South Africa.

He serves as director of the Komati Basin Water Authority, a bilateral regional authority constituted by the Republic of South Africa and Swaziland. He was member of the editorial committee of the *Handbook on the Design of Drinking Water Treatment Plants,* produced by the Water Research Commission, South Africa.

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