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Chapter 60 - Pumps, Controls, and Flow Measurement

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60.2 - Objectives

All water-delivery or waterbone-waste systems require head for operation, provided in many instances by pumps. Liquid level control is essential to the efficient operation of systems and processes. The essential element of operational control is flow measurement. The purpose of this chapter is to provide the engineer with the design and operational features of the various pumping, control, and measurement devices, to help him select the most applicable devices.

60.8 - References

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2. Manual of Individual Water Supply Systems, Environmental Protection Agency Publication, EPA-430-9-73-003, 1973.

3. Ground Water and Wells, Johnson Division, Universal Oil Products Company, St. Paul, Minnesota, 1972.

4. Pumping Equipment and Pump Selection, Engineering Technical Report ETR-7400-2 USFS, Ron Schmidt, November 1972.

5. Manual of Information, "Rife Hydraulic Water Rams," Rife Ram and Pump Works-Rife Hydraulic Engine Manufacturing Company, Milburn, New Jersey.

6. Parshall Measuring Flume, Colorado Agricultural Experiment Station Bulletin, 423, 1936.

7. Fluid Meters: Their Theory and Application, 57th Edition, American Society of Mechanical Engineers, 1959.

61 - Pumps

When the movement of water or waste-water cannot be accomplished with gravitational forces, some mechanical means of moving the liquid must be used. Various types of pumps are used to supply the head required to move the liquid.

The following sections list the common types of pumps and their usual applications.

61.1 - Classification of Pumps and Their Application

Type	Application
1. Positive Displacement Pumps	
a. Bucket and plunger	Shallow well, hand pumps
b. Reciprocating	
(1) Plunger (diaphragm)	Mud, sludge, and trash pump; chemical addition
(2) Reciprocating (piston) single acting	Sludges single acting Chemical feeders
c. Rotary	
(1) Gear	Process air and mechanical
(2) Lobe	Process air and mechanical
(3) Helical (progressing cavity)	Water or waste water low Q, high H; Chemical feed, slurries, sludges
2. Airlift Pumps	Shallow wells Sludge lifts
3. Impulse Pumps	Low volume, low head water supplies, no Hydrualic rams external power source as there is a tolerance for high wasted volume
4. Velocity Pumps	
a. Centrifugal	
1. Single stage	High - and low-pressure water supply. General utility. Submersible sewage pumps. Some low-pressure capabilities
2. Multistage	
(a) Vertical turbine	Deep, high-production wells.
(b) Submersible	Wells, deep wells.
(c) Horizontal	Booster - low flow, high head.
b. Jet Pumps	

Type	Application
1. Ejector	Pumping-mixing-agitation of slurries and chemicals. Any pumping requirement where high volume flow at high pressure is available from other application.
2. Jet-centrifugal	Deep wells, shallow wells, misalined well holes.

61.2 - Basic Design Considerations

When specifying pumps, the engineer should dictate all the necessary equipment and operating characteristics to arrive at exactly the type of pump and performance desired. Pertaining to performance, the required pump discharge rate and the minimum and maximum total dynamic head (TDH) must be specified. The available net positive suction head (NPSH) should be specified if the pump is to be operated under suction-lift conditions. The maximum horsepower, voltage, phase, speed, and other critical parameters should be stated. Besides specifying performance and basic pump type, it may be desirable to specify certain pump construction and materials, such as mechanical seals, stainless-steel shafts or sleeves, bronze wear rings, split-case housing, and internal check valves, depending upon the particular use of the pump.

61.21 - Required Flow and Head

See chapter 30 for design flows.

Using exhibit 1 as a reference, the computations to determine the head required in a proposed pumping system are calculated using the following formulas:

Total static head = $(Z_2 - Z_3) + P_1 - P_2$

Total dynamic discharge head = $(Z_2 - Z_1) + P_1 + H_{f\,d}$

Total dynamic suction head = $(Z_3 - Z_1) + P_2 - H_{f\,s}$

Total dynamic head, TDH = (Total discharge head) - (Total suction head) TDH Total lift + line loss

$TDH = (Z_2 - Z_3) + P_1 - P_2 + h_{f\,d} + h_{f\,s}$

Z_1 = Pump centerline elevation, feet.

Z_2 = Discharge free surface elevation, feet.

Z_3 = Supply (inlet) free surface elevation, feet.

P_1 = Pressure on discharge surface, in feet of liquid.

P_2 = Pressure on supply surface, in feet of liquid.

h_{fd} = Friction losses on discharge line.

h_{fs} = Friction losses on supply line.

Note 1: When the total suction head is a negative value, it is referred to as the Total suction lift. In using the formulas, the negative value has the effect of increasing the total dynamic head.

Note 2: For most piping systems, it is desirable and economical to maintain the flow velocities at 5 feet per second or less. When this is true, the velocity head term, $\frac{V^2}{2g}$, is generally very small in comparison to other terms and may be neglected.

Note 3: When both the discharge and suction-free surfaces are at atmospheric pressures; that is P_1=P_2, the terms cancel. This gives the familiar, shortened formula for total dynamic head.

$$TDH = (Z_2 - Z_3) + h_{fd} + h_{fs}$$

61.21 - EXHIBIT 1 IS A SEPARATE DOCUMENT

Net positive suction head (NPSH) is usually associated with centrifugal pumps; however, the basic concept of NPSH applies to all pumping systems.

In pumping liquids, the absolute pressure at any point in the system must never be reduced to or below the vapor pressure of the liquid. This is most significant on the suction side of the pump where the total dynamic suction head is frequently negative, indicating a lift condition and negative gage pressures. When the absolute pressure is reduced below the liquid vapor pressure on the suction side of the pump, a phenomenon known as cavitation occurs which will eventually destroy a pump impeller.

To calculate the NPSH available at any point in the system, all pressures must be in units of feet of the liquid. The NPSH available on the suction side of the pump can be calculated from the following formula:

$NPSH_{available}$ = (Atmospheric) (pressure) + (Total dynamic) (suction head) - (Vapor pressure of the liquids at the given temperature)

$NPSH_{available}$ = atoms P + TDSH - P_{vapor}

Net positive suction head available is characteristic of the pumping system and must be calculated at the given conditions, or at the worst possible conditions of design.

A common part of pump curves for centrifugal pumps is the NPSH required at pump capacities. The NPSH required refers to the minimum value of NPSH which must be maintained at the inlet

to the pump in order for the pump to operate internally at the given capacity without cavitations occurring within the pump impeller and volute.

Net positive suction head required is a characteristic of a given pump at a given capacity. The value is determined by the pump manufacturer.

To differentiate $NPSH_{avail}$ and $NPSH_{required}$, the following summary should be understood:

1. $NPSH_{avail}$ is a function of the piping system at the given conditions.

2. $NPSH_{required}$ is a function of the pump at the given capacity.

3. $NPSH_{avail}$ must always equal or exceed $NPSH_{required}$ for the system to operate properly.

61.22 - Pump Operating Speed

In general, most pump applications in Forest Service systems and designs will be satisfied by choosing a standard manufactured pump with given characteristics. The impeller on centrifugal pumps may be trimmed to meet specific requirements and some form of flow regulation device may be used to control flow.

In most cases, the pump operating speed will be fixed by the manufacturer's motor application in his standard product. The designer may have a choice of operating speeds by having two different pumps which would meet his design criteria. In this case, the operating speed may be a deciding factor.

For large pump applications or those where a choice is available, the slower speed pumps are preferable to those operating at higher speeds. Motor, shaft-seal, packing, and bearing lives are generally longer in slow speed pumps. On transmission-drive centrifugals, the motor speed and pump speed can be different and will possibly allow the designer more latitude in selecting the operating speeds.

Variable speed pumps are available in which the operating speed and discharge are continuously variable over a given range. The variation in speed is accomplished by electronic control of motor voltage or mechanical control of pump rotation speed. Variable speed pumps are expensive and have specific applications (sec. 61.26).

61.23 - Shaft Seals and Packing

A seal is provided between the rotating impeller shaft and the pump case to prevent large quantities of the pumped liquid from escaping back along the shaft. There are two types of seals in general use today; packing seals and mechanical seals. The good and bad features of each should be considered as general and may change, depending upon service conditions and manufacturer. For unusual or severe service conditions, manufacturers should be contacted for information and recommendations.

1. Mechanical Seals. A mechanical seal is composed of two portions, one rotating with the pump shaft, the other mounted to the pump case. An O-ring or gasket seal protects against leakage at the joints. At the joint between the stationary and rotary portion of the seal are the seal faces. The seal faces are composed of dissimilar materials, one softer than the other. The two seal faces are very highly polished, thus accomplishing the liquid seal because large quantities of liquid cannot move between the two faces. A small amount of liquid escaping provides for the necessary lubrication of the faces.

All mechanical seals provide for axial movement and vibration by spring loading the rotating face against the fixed face and incorporating an axial seal either along the shaft or another portion of the rotating seal. The axial vibration and movement of the shaft will gradually wear down the axial seal.

A pump with mechanical seals should not be shut down and drained for long periods of time because the rubber portion of the seal may dry out. If this occurs, the seal will not be flexible and premature separation of the faces may occur. Some types of seals can be shut down without damage.

a. Advantages

(1) Do not leak in service.

(2) Perform acceptably when in dirt or severe service.

(3) Operate longer between maintenance and servicing.

(4) Some types of seals will not score shaft.

(5) Easier to replace if shaft is in bad condition.

b. Disadvantages

(1) Higher initial cost.

(2) Failure is sudden, requiring immediate maintenance.

(3) Should not be shut down and allowed to dry out for long periods.

(4) Will not perform satisfactorily when shaft is not running true or has end play.

(5) Replacement requires pump disassembly.

2. Packing Seals. A packing seal usually takes the form of a cylindrical-recess stuffing box in the pump case that will accommodate a number of rings of packing around the shaft or shaft sleeve. Packing is a cotton or asbestos braid filled with oil lubrication. A lantern ring may be used to separate the rings of packing into approximately equal sections. The packing is compressed into the desired fit on the shaft by an exterior sealing gland adjustable in an axial direction. A lantern ring may be used to provide additional cooling liquids or clean water to

flush dirt or grit out of the stuffing box. Arrangements and details of packing and lantern rings will differ between manufacturers.

A source of clean water is needed for lubricating and cooling the packing. When a pump is in clean water service, this seal water may be leakage from the pump case along the shaft. If the pump is pumping dirty, sandy, silt water or sewage, seal water should come from a clean-water source or be filtered prior to connection to the stuffing box. The seal water should be applied at 10 to 20 psi higher than the stuffing box pressure. A water seal may also be used to prevent the seal from leaking air into the pump casing when operating under suction pressure.

When the pump is running, a packing seal will leak at a rate of 10 to 20 drops per minute for a 1-inch-diameter shaft and twice this rate for a 2-inch-diameter shaft.

a. Advantages

(1) Less initial cost.

(2) Perform acceptably with slightly worn shaft sleeve.

(3) Cost less to replace (repack).
(4) Can perform acceptably with severely scored shaft sleeve for short periods.

(5) Performs acceptably under clean water service.

(6) May be shut down for long periods.

(7) Will perform acceptably when shaft has some end play.

(8) Repacking may be accomplished without disassembly of pump.

b. Disadvantages

(1) Requires more maintenance time to keep operating.

(2) Wears shaft sleeve.

(3) Worn shaft sleeve requires replacement to maintain acceptable length of service for the packing.

(4) Requires clean water flush for service under dirty water or sewage service.

(5) Acceptable service more dependent upon operator knowledge, such as adjustment of leak rate.

(6) Leak appreciably when in service.

(7) Easy to improperly repack.

(8) Will not perform acceptably when shaft is not running true.

61.24 - Materials of Construction

Selection of the materials of pump components can be a complex matter, depending upon the pump type and application. It is recommended that individuals not familiar with pump material consult manufacturer's representatives, preferably a qualified engineer, in selecting optional materials.

Consideration should be given to selecting optional materials such as bronze wear rings and mechanical seals. While such options will cost more initially, the overall cost and serviceability for the individual application can be very advantageous.

61.25 - System Aging

Water and waste-water systems are designed for use over extended periods. Therefore, the designer must consider the effects of system aging. Some of the possible effects of aging and use are:

Aging symptom or change	Effect of aging on system	When to expect symptoms
Pipe encrustation	Increased friction. Losses and restrictions in piping.	Hard water, high temperature, negative Langlier-pH value 1/
Pipe corrosion and erosion	Increased friction losses in piping, possible structural weakening of pipe.	High velocities, gritty material, low pH, positive Langlier-pH value 1/
Pump impeller	Lowered efficiency.	Gritty materials, Low pH, Low $NPSH_{available}$

1/ Langlier pH value is a measure of relative scale formation of corrosive potential; See Standard Methods, 13th Edition, p. 45.

The system designer must be familiar with the characteristics of the liquid being pumped and the possible effects they will have on the system. Reserve available head and flow-control devices must be provided to ensure adequate system capacity as the system ages.

61.26 - Cycle Times

1. When system conditions allow a choice of storage using a high-volume pump for short periods, or using a low-volume pump over an extended period, the designer should first analyze the cost of the options. The former has higher initial cost, but the high-volume pump offers greater operating efficiencies. In between these two alternatives is the use of a variable-speed pump which can increase or decrease discharge to suit the system demand. This type of system generally involves high capital, operations and maintenance costs and is used only where incompatibility of cycling time and storage volume cannot be reconciled. No rule of thumb solution is possible; however, the optimum solution can be approximated by an analysis of expected life, power cost, maintenance cost, comparative efficiency, reliability, and initial cost.

2. When system requirements leave no alternative except frequent cycling operations, the following timing considerations should be observed:

a. Rapid cycling is generally harder on the motor than on the pump.

b. Run time may be as long as desired without significant effect on pump or motor; however, pumps should be designed to run at least 5 minutes during normal operation.

c. Electric motors should be off for periods of at least 5 to 10 minutes between run starts in order to dissipate accumulated heat. The frequent application of starting currents can cause premature failure.

d. No reasonable off time for engines is known; however, frequent starts are not desirable and extended operation periods allow warming to operating temperatures and thus better efficiencies.

61.27 - Power Requirements and Availability

The system designer must be aware of the power availability at the pumping site. If electrical power is available, the characteristic of the power must be known. Items to be investigated are:

1. Voltage.

2. Single-phase or 3-phase.

3. Transformer capacities.

4. Power system capacity and ability to start motor(s) without excessive voltage drops.

In order to properly size a pump motor, the entire range of pump operation must be considered. It is common practice to size a pump based on only one operating condition - that of the maximum total dynamic head (TDH). However, this can lead to under sizing of the pump motor, as shown in exhibit 1. This figure shows typical pump performance curves with various RPM's and required brake horsepower for a given pump.

Consider a system where the TDH range is from 30 feet to 40 feet. For a given RPM of 1150, the curve shows that at a maximum head of 40 feet (point A) the pump will deliver 200 GPM, requiring a 5-horsepower motor. At the maximum head of 30 feet (point B), the same pump will deliver 420 GMP, but will require a 7.5-horsepower motor.

Therefore, all parameters which affect TDH must be considered in selecting a pump, including any drawdown range and possible options of pipe materials.

In this example, the proper design selection of a pump motor would be to select the 7.5-horsepower motor. The example typifies a common source of error which is in the estimate of the TDH of the system. Friction losses may be over- estimated, based on a worst case design; then the pump may actually operate at a lower head, causing the system operating point to shift

to the right on the pump curve, therefore requiring more horsepower. In any event, never try to specify pump motors and pumps without complete pump curves.

61.27 EXHIBIT 1 IS A SEPARATE DOCUMENT

61.28 - Operation and Maintenance Characteristics and Manpower Availability

One of the prime considerations in the design phase of a project should be the operation and maintenance the system will receive upon completion. The quantity and quality of required or available maintenance should be weighed against the complexity of design for both the pumps and controls. For example, complex automated pump and control systems may alleviate some need for operational manpower; but the more complex and sophisticated the system equipment is, the more highly trained and skilled must the maintenance personnel be. The need for system complexity should be predicated on overall reliability and not merely convenience of operation.

61.29 - Costs

Construction cost of any system is an important consideration in design and selection. It should not, however, be the uniquely deciding factor. Total annual cost, including operation and maintenance consideration (power costs, manpower, and replacement parts) as well as amortized construction costs, should determine the system to be selected.

61.3 - Operational Characteristics and Selective Applications

Only the centrifugal pump is explored in detail because of its universal application to water and waste-water systems. Other pumps commonly selected and cautionary items regarding their Forest Service applications are discussed in general.

61.31 - Centrifugal Pumps

The term "centrifugal" is commonly used to refer to pumps which utilize one of several types of high-speed impellers mounted on a shaft and rotated inside a housing. The rotating impeller imparts velocity to the water. The housing around the impeller (volute) is shaped to slow down the water and convert the velocity into pressure.

Centrifugal pumps differ from positive displacement pumps in that the impeller can be rotated freely even through the discharge value is closed. This is possible because the head or pressure developed is not due to impact or displacement but is entirely the result of velocity imparted to the water by the impeller. A centrifugal pump should not, however, be allowed to operate for a long period against a closed discharge value because the pump will overheat and may be damaged.

When a centrifugal pump is operated with a positive head applied to its suction side, it will utilize this pressure. A centrifugal pump can be installed as a booster in a pipeline at a point of positive pressure. Two or more pumps of similar capacity can be operated, one discharging into the other, that is, in series, to progressively develop a total head which is the sum of the heads developed by the individual pumps. Several impellers with separate volutes and mounted on a

common shaft rotated by a power supply build up the pressure in stages. The pump is then called a multistage centrifugal pump which can be of horizontal or vertical construction. The most common application of the vertical configuration is the submersible well pump.

Centrifugal pumps can be classed as end suction, side suction, and bottom suction, depending upon physical location of the inlet. Impellers for centrifugal pumps are classified as closed, semi-enclosed, open, open mixed flow, double suction, nonclog semi-closed, axial flow, propeller, and other variations, depending upon their design configuration. Each type or class of pump and impeller has its own characteristics, advantages and applications. Typical characteristics and applications are covered in section 61.1.

Centrifugal pumps are designed to operate at a definite head and capacity relationship at a given rate of rotation. If one of the interrelated factors is changed, the other two are affected. If the operating conditions are different from those for which a pump is designed, the pump will usually continue to deliver water but at a different capacity. The range of the head-capacity relationship for a given centrifugal pump is provided by the manufacturer, generally in the form of pump curves. Such curves tell what can be expected from the pump at various flow conditions. Care must be exercised in selecting a pump to ensure that the pump application range covers the range of service conditions.

1. Single-Stage Centrifugals. A single-stage centrifugal is one which utilizes only one impeller or stage to develop the required capacity and head. The capacity and head developed by an impeller depends on the design of the impeller, the speed of rotation, and diameter of the impeller. Maximum head for a single-stage pump is commonly about 250 feet.

2. Multistage Centrifugals. Two types of multistage centrifugal pumps in general use for water supply are the vertical-turbine and the submersible. The vertical-turbine pump is a small-diameter, multistage centrifugal with the pump and motor separated by a shaft. The pump is placed below the water level and is driven by a vertical shaft which extends to the surface where the pump motor is located.

Vertical pumps are readily available in capacities from 15 g.p.m. to 1,500 g.p.m. and for heads from 10 to 800 feet. For a specific installation, the desired discharge capacity and head should be given accurately because the pump operates most satisfactorily and efficiently at the head for which it is designed.

The submersible pump is a multistage centrifugal pump and motor combined in one unit at the end of the drop pipe and submerged in the water. There is no suction problem because the pump and motor are submerged. Priming is not necessary, the pump is very quiet in operation, and the cost of a frost proof structure for the pump is eliminated. Submersibles are available for wells from 4 inches in diameter and are best suited for depths from 60 to 400 feet. Capacities vary from 5 to 300 gallons per minute. Moving parts in both motor and pump are water-cooled and water-or oil-lubricated. The motor wire is waterproof cable.

Each of the impellers in a multistage centrifugal pump develops a certain head at a certain capacity depending upon operating speed and diameter. Impellers are assembled in series to develop the total head required.

61.32 - Helical-Rotary Progressing-Cavity

Helical-rotary progressing-cavity pumps are positive-displacement pumps which are suitable for low-flow facilities with high head requirements. In this type of pump, a stainless steel, helical rotor is rotated inside a helical rubber stator. There is a compressive watertight fit between rotor and stator and the rotation of the stator causes a series of cavities to progress from the inlet and of the pump to the outlet. This progression cavity allows suspended solids to pass through without significantly impairing the usable life of the pump, making the pump applicable to water, waste-water, chemical and slurry feed systems.

Although these pumps are capable of self-priming action, the rotor-stator friction may generate sufficient heat to damage the rubber stator when operating dry. Therefore, the optimum installation of a progressive-cavity pump is one with a flooded inlet to ensure pump lubrication.

Because the pump is a positive displacement type, it will develop destructive pressures if operated against a closed discharge line.

61.33 - Hydraulic Rams

The hydraulic ram is a self-acting impulse pump which utilizes the momentum of a slight fall of water to force a part of the water to a higher elevation. Water hammer is the chief characteristic of this type of pump, which makes it noisy in operation. It is practicable to operate a ram with a fall of only 18 inches, but as the fall increases, the ram can force water to proportionately greater heights. The discharge of a ram may be determined by the equation:

$$Q = \frac{eFH}{h+h_f}$$

Where Q = discharge of ram in g.p. m.

F = flow to ram in g.p.m.

H = difference in elevation between ram and supply (feet).

h = difference in elevation between ram and storage tank or other delivery point, in feet.

e = efficiency (as a decimal fraction -- see tabulation in next paragraph).

h_f = pipe friction (feet of water).

The efficiency of the ram may be approximated by use of the following table:

Ratio h/H	Efficiency (percent)
4	72
6	61
8	52
10	44

Points to be considered in installing a ram:

1. The drive pipe should be from 5 to 10 times as long as the fall is high, and the pipe used should be the size recommended by the ram manufacturer.

2. The discharge pipe should never be smaller than that recommended by the ram manufacturer. If a pressure tank is used, a relief value must be installed on the discharge line or storage tank.

3. The hydraulic ram is well suited for areas where power is unavailable or difficult to maintain and where an excess supply of water is available. There is at least one model manufactured which utilizes one source of water to develop pumping power while pumping water from another source. This model will permit use of another water source to pump potable water supply. The designer must ensure that there is a physical barrier to keep the nonpotable water from coming in contact with the potable water.

4. The design of a hydraulic-ram system should consider the selection of properly balanced units to include an adequate supply pipe and structural foundation. Manufacturers' operating characteristics should be consulted for all proposals.

5. Since the hydraulic ram is a pulsating device, the friction loss is not uniform but can be considered as such without significant error.

6. In general, because of cyclic water hammer, only steel pipe should be used for ram installations.

7. The pump should be firmly anchored to a suitable concrete base.

8. The volumetric efficiency (discharge flow/supply flow) may vary from a minimum of 4 percent to a usual maximum of 60 percent, depending upon the ratio of drive to delivery head.

61.34 - Airlifts

Air compressors are often incorporated with pressure tanks in water systems and aerated sewage treatment facilities. A convenient adjunct to them is use of an airlift pump for shallow wells or low sewage-sludge lifts.

Airlift pumps operate by forcing air from a blower or compressor down an air pipe, and discharging it inside a vertical section of discharge pipe. The mixture of air and water inside the discharge pipe is less dense than the water outside the pipe, and the air-water mixture is forced upward by hydrostatic pressure. The vertical distance from the water level in a well or tank to the point of discharge is the total life (dimension C, ex. 1). The submergence is the distance from the point where the air enters the discharge pipe to the water level when pumping (dimension A, ex. 1). The percent submergence is equal to dimension C divided by the sum of A and C. The air pressure required at the compressor is equal to the friction loss in the air pipe plus

the water pressure caused by the submergence. A submergence of about 2-1/4 to 3 times the lift can usually be expected to produce the maximum efficiency.

An airlift pump will produce a large volume of water from a small-diameter well. Sandy water does no harm and a crooked well may be pumped as easily and is easily operated and maintained. The pump, however, is very low in efficiency and little flexibility is possible in meeting variations in demand. Sufficient submergence may require that the well be deepened.

In table 1, airlift performance is tabulated corresponding to various conditions of submergence.

Table 1 -- Airlift performance corresponding to various conditions of submergence

Lift in Feet	Submergence (percent)	Lift (percent)	Rating	Submergence (feet)	Starting air pressure (Ib. per sq. in)	Gallons water per cu. Ft. air	Cubic Feet of air per gal. water
25	54	46	Minimum	29	13	4.55	0.22
	68	32	Best	53	23	8.34	.12
	76	24	Maximum	79	34	14.30	.07
50	51	49	Minimum	52	23	2.50	.40
	65	35	Best	93	40	4.35	.23
	72	28	Maximum	129	56	6.57	.15
100	47	53	Minimum	89	38	1.43	.70
	60	40	Best	150	65	2.70	.37
	67	33	Maximum	203	88	3.70	.27
150	43	57	Minimum	113	49	1.05	.95
	55	45	Best	183	79	2.04	.49
	62	38	Maximum	245	106	2.70	.37
200	41	59	Minimum	139	60	.85	1.18
	52	48	Best	216	94	1.54	.65
	59	41	Maximum	288	125	1.89	.53
250	39	61	Minimum	160	69	.71	1.41
	49	51	Best	240	104	1.21	.83
	56	44	Maximum	318	138	1.45	.69
300	37	63	Minimum	176	76	.60	1.67
	47	53	Best	266	115	.96	1.04
	53	47	Maximum	339	147	1.18	.85
350	36	64	Minimum	197	85	.53	1.88
	45	55	Best	287	124	.80	1.25
	50	50	Maximum	350	151	.94	1.06
400	35	65	Minimum	215	93	.48	2.07
	43	57	Best	302	130	.69	1.45
	48	52	Maximum	369	160	.79	1.26

61.34 – EXHIBIT 1 IS A SEPARATE DOCUMENT

62 - Liquid-Level and Other Control Devices

Liquid-level control is essential to the operation of most water and waste-water systems. Sections 62.1 - .64 discuss the various types of level-control devices. The scope of the discussion is by way of introduction only. Information on design procedures and standards must be obtained from the various manufacturers.

62.1 - Manual Controls

1. Uses.

a. To check the functioning of the system components.

b. To simulate automatic control and relay activation through bypassing of control devices with test switches.

c. To fill standby or fire-storage facilities.

d. To empty wet wells or tanks for servicing.

e. To regularly operate low-demand systems.

2. Advantages.

a. Not affected by liquids handled.

b. Low initial costs.

c. High mechanical and/or electrical reliability.

3. Disadvantages.

a. Require more operation time.

b. Low overall reliability due to human error, and possible damage to equipment, such as pumps running dry.

c. Distance from controls to location of pumps and motors may not allow desired timing for activation or deactivation.

62.2 - Time Controls

62.21 - Timer

A timer is a synchronous motor-driven, dial timeclock.

1. Uses.

a. To operate irrigation systems.

b. To backwash filters.

c. To operate aeration systems.
d. To actuate control valves.

e. To establish time delays.

2. Advantages.

a. Not affected by liquid handled.

b. Distance from control to pump is no factor.

c. Low maintenance cost.

d. Low initial cost.

e. Good for repeatable cycles with adjustable interval durations.

3. Disadvantages.

a. Moderate reliability. Temporary power failure will affect desired time of activation, unless a reserve time spring is used.

b. Flexibility. Moderate to low; set time of operation does not allow for demand changes.

62.22 - Time-Delay Relays and Timers

Uses are similar to those of timer (sec. 62.21, item 1).

1. Types Most Commonly Used as Defined by Modulation of Basic Time-Delay Function.

a. On Delay. Delays circuit activation for present time period after it is energized.

b. Off Delay. Delays circuit activation for present time period after it is deenergized.

c. Cycle Time. Alternately adjustable on-off time periods.

d. Instantaneous interval timer. Closes or opens circuit for present time period after initiated by momentary impulse.

2. Types as Defined by Basic Construction and Mode of Operation.

a. Mechanical. Synchronous motor-driven, some with indicator hands to show time in cycle.

(1) Advantages.

(a) Moderate cost.

(b) Reliable.

(c) Wide time ranges.

(2) Disadvantages.
(a) Should be used in fairly clean environment, dirt affects mechanical parts.

(b) Fairly large size.

b. Pneumatic. Solenoid actuated piston forces air out of orifice. Time delay varies with rate of air flow through orifice.

(1) Advantages.

(a) Cost moderate.

(b) Few moving parts.

(2) Disadvantages.

(a) Time accuracy poor.

(b) Must be used in fairly clean environment.

(c) Subject to dust and moisture.

(d) No indication of position in time cycle.

(e) Limited time range.

c. Electronic. Solid state electronic timers using transistorized timing circuits to energize either a solid-state or electromechanical output contact.

(1) Advantages.

(a) Reliable.

(b) Accurate.

(c) Low-to-moderate cost.

(d) Small size.

(e) Plug-in base for easy replacement.

(f) Some have readout of position in time cycle.

(g) Wide time range.

(2) Disadvantages.

(a) Must be used in fairly clean environment.

(b) Normally no indicator of position in time cycle.

3. Summary Tabulation of Available Timers by Function and Operation.

Function \ Operation	Mechanical	Pneumatic	Electronic
On delay	X	X	X
Off delay	X	X	X
Cycle	X		X
Interval	X		X

62.3 - Float Controls

62.31 - Mechanical-Linkage Floats

Floats and mechanical-linkage actuate pilot switches to control valves, pumps, and other electromechanical equipment.

1. Advantages.

a. Sensitivity - good.

b. Low maintenance with normal inspections.

c. Low-to-moderate initial cost.

2. Disadvantages.

a. Reliability - fair; icing and corrosion may affect linkage.

b. Floating debris may affect operation.

62.32 - Free-Hanging and Secured Floats

Encapsulated mercury switches actuate valves, pumps, and other electromechanical equipment. Floats should be NSF-approved for use in potable water.

1. Advantages.

a. Low initial cost.

b. Low maintenance.

c. Reliability - good; floating debris has little affect.

2. <u>Disadvantages.</u>

a. Icing.

b. Must be used with intrinsically safe control circuits in hazardous areas, such as sewage pump stations.

62.4 - Probes

62.41 - Conductance Probes

The liquid touching the copper or stainless steel probe closes a circuit to actuate valves, pumps, or other electromechanical equipment. The probes must be matched to the minimum conductivity of the liquid.

1. <u>Advantages</u>.

a. Initial cost - medium.

b. Sensitivity - very good.

c. Maintenance - low

d. Reliability - good with normal maintenance.

2. <u>Disadvantages</u>.

a. Often used in inaccessible locations, such as wells.

b. Maintenance high and reliability poor if used in liquids with high mineral concentrations or low in conductivity.

62.42 - Capacitance Probes

Electronic level probes using the mass of the liquid present to close a switch or contact do not depend on conductivity of liquid for operation. Used to detect level in tanks, partially filled conduits, etc.

1. <u>Advantages</u>.

a. Sensitivity - good.

b. Reliability - good if used in water or similar liquids free from particulate matter.

c. Accuracy - good.

2. Disadvantages.

a. Cost - high.

b. Qualified personnel required for adjusting.

c. Complex if used for level sensing.

62.5 - Ultrasonic Level Controls

Sonic pulses monitor the liquid level continuously to actuate switches operating valves, pumps, and other electromechanical equipment. Must be designed to fit geometry of tank.

1. Advantages.

a. Not affected by liquid handled.

b. Sensitivity - very good.

c. Reliability - very good.

d. Maintenance - very little.

e. Multiple set points.

f. Gives remote indication of liquid level in tank.

2. Disadvantages.

a. High initial cost.

b. Adjustments require very specialized personnel.

c. Distance from control panel to sensing device is limited - check with manufacturer.

d. Subject to secondary reflection.

e. Icing.

62.6 - Pressure Controls

Used to sense gas or liquid pressure differentials. If used in contaminated fluids, must incorporate an isolating diaphragm. If pressure switches are used to measure liquid levels, do not install in conduits with liquid flow. Any pressure switch should have pressure pulsation dampeners if used in pressure-transient systems.

62.61 - Bellows

Bellows expands or contracts with gas or liquid pressure differential. The bellows is fastened through a fulcrum to a pressure plate which includes a mercury switch to activate the control circuit.

1. Advantages.

a. Sensitivity - very good.

b. Maintenance - low.

c. Initial cost - low.

2. Disadvantages. Reliability - medium; usually no set point calibration to establish desired pressure. Recalibration is by trial and error.

62.62 - Bourdon Tube

Flexible brass tubing expands to move train and mercury or snap-action switch. Normally used with pressure vessels or conduits.

1. Advantages.

a. Calibrated dial to adjust set point.

b. Sensitivity - very good.
c. Maintenance - low.

d. Cost - moderate.

e. Reliability - very reliable, if properly designed.

f. Available with two differential set-point switches and reset lockout features.

2. Disadvantages. Accuracy highly dependent on cost.

62.63 - Pressure Transducers

1. Strain Gage Transducer. Using bellows or bourdon tube, an integral strain gage actuator changes a resistance element in proportion to pressure applied. Must be used in a combination set-point controller to actuate multiple set-point relays, and incorporates pressure or level indicator.

a. Advantages.

(1) Controller can be located remote from pressure transducer.

(2) No power needed at pressure transducer.

(3) Multiple set points for pressure or level indicators.

(4) Sensitivity - very good.

(5) Reliability - good.

(6) Accuracy - very good to excellent.

(7) Can be used to control variable-rate pump motors.

b. Disadvantages.

(1) Cost - high.

(2) Requires specialized personnel to calibrate.

2. Optoelectric Pressure Transducer. Normally used in hydropneumatic tanks. Combination pressure set-point controller and pressure gage, using a Bourdon-tube gage with a light in center. The light illuminates pressure set-point photocells on outside of gage case, which activates set-point relays.

a. Advantages.

(1) Reliability - very good.

(2) Sensitivity - very good.

(3) Accuracy - very good.

(4) Available with 3 to 30 set points on gage it illuminates; many switches.

(5) Gives system-gage pressure.

(6) May be mounted remotely from tank.

(7) Maintenance - low.

b. Disadvantages.

(1) Cost - high.

(2) Requires specialized personnel to repair.

62.64 - Bubbler Systems

Pressure switches react to hydrostatis pressure liquid level above the end of the bubbler tube as air is constantly purged through the tube from an air pump and compressed air cylinder. Used mainly in hazardous liquid locations.

1. Advantages.

a. Reliability - good.

b. Sensitivity - good.

c. No explosion-proof wiring required in wet wells.

2. Disadvantages.

a. Initial cost - medium to high.

b. Maintenance - Medium to high.

c. Many complex components.

d. Do not use copper tubing in sewage wet wells.

e. Somewhat outdated due to use of free hanging and secured floats.

62.7 - Flow Switch. Paddle-operated switch inserted into a liquid-carrying conduit to detect liquid movement as an indicator of actual output from a pump. A defective pump, motor or line blockage will cause switch to close or open and shut down motor or actuate other devices. Usually used with a time-delay relay to allow pump enough time to buildup pressure. It is not used as a flow-measuring device.

1. Advantages.

a. Detects actual flow of liquid, not pressure.

b. Cost - low to moderate.

c. Sensitivity - good.

d. Maintenance - low.

2. Disadvantages. Not usable in sewage.

62.8 - Indicating Devices

Indicating devices can be incorporated into control systems to facilitate operation and to indicate equipment failure. Basic types of indicators are discussed in section 62.81 - .85.

62.81 - Indicating Lights

Connected to motor starters to indicate whether or not motor is on. Connected to overload relays, they indicate if a motor is overloaded. Other uses are for status indication of solenoid valves, high- or low- level alarms in wet wells. Indicate if emergency bypass system is operating, or other mechanical or electrical failures have occurred.

62.82 - Audible Indicators

Alarm horns are the most common; used to alert personnel of critical failures, such as low or high levels in sewage pump stations, motor failures, low or high pressure in conduits, and flow. One horn may be energized by any failure in a system, thus simplifying controls.

62.83 - Remote Indicators

Remote indication of system operation or failure may be done by several methods; the three most common follow:

1. Telephone Cable. A contact closure or opening at the failed equipment by its control system energizes a relay at the receiving end which, in turn, activates either an audible or visual alarm or both.

The cost of this type of system is moderate if telephone cable is installed in the same trench with waterlines or sewer lines. Multiple conductor cable can be used; one pair per condition or function monitored. Reliability is good to excellent; simple to maintain.

2. Radio Transmitter. Similar to item 1, except contact at failed equipment energizes transmitter which sends a radio signal to receiver which is decoded and may, in turn, energize an audible or visual alarm or both. Usually limited to one alarm signal, unless special encoding and decoding equipment is used. Cost is moderate to high, depending on distance and number of points to monitor. Reliability is good to excellent, if maintained. Requires radio technician to maintain.
3. Telephone Cable Multiplex. Similar to item 1, except multiplex alarms are encoded and transmitted over one pair of wires. A receiver decodes the alarm signals and may energize an audible or visual alarm, or both.

The cost is high, but reliability is good to excellent, if properly maintained. Requires radio technician to maintain.

62.84 - Hour Meters

Used on motors to indicate total number of hours run for periodic maintenance, also give approximate indication of flow for pumps. (Sometimes called "running time Meters").

62.85 - Operation Counters

Used on motors to indicate the number of times the motor has started. Especially useful on duplex pumping applications to see if proper alternating is occurring. Good for maintenance records to record number of times system operates within a given time period.

62.9 - Electrical Safety

Exceptionally rigid electrical standards should be observed in those pumping installations where electrical power is used as a source of energy and control. The National Electrical Code and Occupational Safety and Health Act specify that any control panel should be located so as to have no grounded device within 30 inches from the edges and front of the control panel. The door of the control panel must be capable of opening at least 90 degrees.

Any planned or existing installations where a maintenance man must stand on, sit on, or reach over piping while working on any serviceable electrical equipment demonstrates a basic safety infraction which could prove deadly. Measures should be taken to correct such a situation.

62.91 - Hazardous Locations

Class I, Division I (N.E.C. 500-4) locations are locations in which flammable gases or vapors are or may be present in quantities sufficient to produce explosive or ignitable mixtures, including areas where these hazardous mixtures are likely to occur during normal operation or system failure. Locating control panels in these areas should be avoided if at all possible (due to extremely high cost and increased risk of explosion). Only control devices should be located in these areas.

If control panels are located in hazardous areas, they must be explosion proof. If control devices are located in hazardous areas, they must either be explosion proof with explosion proof wiring to them or an intrinsically safe control relay circuit must be used with the control devices.

Explosion proof means that the control panel is Underwriters Laboratory listed for the environment intended and any internal electrical arcing will not cause an explosion outside the control-device housing. Wiring to the control device must be in rigid conduit with all boxes and fittings explosion proof and seal-offs used where required by code.

Intrinsically safe means that the control relay used with the control device, such as pressure switch and float switch, will not release sufficient energy (electrical arcing) to cause an explosion in the specific environment when the control device contacts open or close. The control device and wiring need not be explosion proof but seal-offs must exist between hazardous and nonhazardous areas.

Hazardous areas include:

1. Storage areas for flammables, explosives, and chemicals used for treatment.

2. Lift stations where sewage gases such as methane or vapors from flammable liquids such as gasoline exist.

3. Manholes - Same as lift stations.

4. Other hazardous areas, such as waste-water-treatment plants, if applicable.

5. Sewage pumping stations are required to have a redundant-off level switch to shut off both pumps in case the primary off switch circuit fails. This applies only if pumps are not explosion proof and cannot operate out of water. This switch or control device must be placed above the top of the pumps, or above the inlet level of the pump, and below the normal off-level switch.

62.92 - Lightning Protection

Control panels and sensing devices should be provided with adequate lightning protection to prevent costly repairs and system down-time. This protection is available for both line-voltage and low- voltage equipment and should be properly grounded and placed as close as possible to the incoming conductors.

63 - Measuring Devices

Metering of water and waste-water flow may be required to determine adequacy of flow for consumption uses; to monitor effects of discharge on receiving waters; to cycle pumps and chemical dispensing equipment; to change treatment modes; to provide a basis for operation and maintenance or contracted service charges; or to establish collection and treatment system limits. Metering ranges from periodic flow approximations to accurate measurement of flow and the permanent recording of flow quantities and rates.

One of the most important entries on a system operation log is meter readings. The operation log is meter readings. The operation and maintenance of the system is dependent upon these entries and the subsequent design of similar systems may be more cost effective because of the availability of this information.

63.1 - Measurement of Flow in Pressure Conduits

Flow in pressure conduits can be metered by various methods. Each method or individual device has its own characteristics and applications.

63.11 - Differential-Head Meters

In a pressure conduit, flow through a constriction results in a localized drop in pressure at the constriction. This drop can be measured, using either manometers or pressure gages, and it is a function of the flow rate. Venturi meters, flow nozzles, and orifice meters are differential-head meters. Standard specifications (sec. 60.8, item 7) for the various types of differential-head meters and their coefficients are avail- able. However, for a high degree of accuracy, a meter should be calibrated in place. Due to a small head difference at lower flows, some accuracy is lost at very low flows.

Differential head meters have no moving parts and hold their initial accuracy as long as they are kept clean. These meters are not generally used in waste-water systems due to the potential for clogging of the pressure measurement devices. The Venturi is more complicated in shape and construction and therefore more expensive than an orifice, which is quite simple and inexpensive.

63.12 - Mechanical Meters

Mechanical meters are ordinarily used to measure total volume of flow. They require a timing device to permit direct reading or flow rate. Mechanical meters are not generally accurate at very low flow rates, and they are subject to wear of the moving parts and subsequent inaccuracies. Because of high head loss, they are not often used for very high flow rates. Because of their lower costs and small size, as compared to other recording meters, mechanical meters are widely used in water systems. Due to the potential for clogging, they are not recommended for waste-water systems.

1. <u>Nutating Disc.</u> A mechanical flowmeter generally used for accurate low-flow water service is the nutation-disc type. In this meter, flow of liquid causes the disc to nutate (rotational wobble) and this motion is transmitted by means of a gear to the meter spindle.

The meter spindle is connected by change gears to the register which indicates the total quantity of liquid metered. This meter is good for variable flows from 0 to 50 gpm, with relatively good accuracy.

2. <u>Turbine Meter</u>. Another mechanical flow meter is the turbine meter generally used for high flow, large diameter water supply lines. Flow of liquid through this meter causes rotation of the turbine wheel, which in turn is connected to a gear train. The output end of the gear train is connected to the meter spindle which transmits its motion through change gears to the register. The register indicates the total quantity of liquid metered.

3. <u>Compound Meter.</u> Compound meters offer a low loss-of -head and are designed for accurate measurement of both high and low flows. The meter contains a straight-through turbine, a disc chamber, and a register which totalizes flow through both measuring elements. Low loss-of-head is essentially provided by the turbine portion of the compound meter. Water first impinges on the turbine wheel, causing the wheel to rotate. It next passes through either the disc metering element or through a gravity operated valve that opens and closes in accordance with demand. Under high-flow conditions the valve opens to permit straight-through passage through the disc chamber to reduce the flow through that element. Under these conditions the totalizing register is driven only by the turbine.

Under low-flow conditions, the valve closes because of reduced differential pressure, causing the complete stream to pass through the turbine. At this reduced rate of flow, the disc alone drives the register, overriding the turbine.

61.13 - Sewage Force Mains

Meters for pressure sewers must be capable of accurately measuring flows in spite of solids and changes in fluid constituency and electrical conductivity. There are four types of meters well suited for this use.

1. <u>Ultrasonic.</u> Two sonic probes capable of generating and receiving sonic pulses are strapped to the outside of the pipe wall. Pulses of sound generated by the upstream probe propagate through the pipe wall and the fluid and they are received by the downstream probe.

Reception of a sonic pulse by the downstream probe triggers the transmission of another pulse from the upstream probe. In this manner, the pulse train is continuous and self-sustaining with a repetition frequency proportional to the sum of the velocity of sound in the fluid and the fluid velocity. This frequency is counted for a fixed period of time and stored in the register of an up-down counter. At the end of the fixed period, the roles of the two probes are interchanged and sound pulses are transmitted in an upstream direction. Now the pulse-repetition frequency is proportional to the difference between the sonic velocity in the fluid and the fluid velocity. This frequency is counted down in the up-down counter for the same fixed period of time so that the counter registers the difference between the upstream and downstream "sing-around" frequencies. This difference is directly proportional to fluid velocity and is converted to a direct current for indication of flow rate and to a pulse train for flow totalization.

2. Magnetic Induction. The magnetic-flow meter system measures flow by Faraday's law of magnetic induction. A low-level, alternating-current signal is generated by the movement of a conductive fluid in a magnetic field with the intensity of signal proportional to the flow rate. This signal is amplified by a solid-state transmitter to a level which may be used directly with receiving instruments such as controllers and recorders.

3. Solids-Bearing-Fluid Venturi Meter. Waste-water and slurry flows can be measured with the solids-bearing-fluid (SBF) Venturi meter. This type of meter is essentially a universal Venturi tube with a sealed, closed-loop manometric system for pressure sensing of the metered fluid across thin pressure-sensitive membranes. The manometric system is connected to a transducer to convert pressure differential readings to electrical signals which are transmitted to a recorder calibrated for flow rate.

4. Sewage Pump. A pump itself can be a fairly accurate meter if a running-time meter is connected to the pump motor and the pump suction line is flooded, thus preventing cavitation in the pump. The pump flow rate can be calibrated periodically by measurement of flow over a given time span.

63.2 - Measurement of Flow in Open Channels

Flow measurement in open channels is common, especially in irrigation and waste-water systems. Measurement of flow in open channels normally requires that some type of control section be established. The depth of flow past the section is then a function of the flow. The more common methods used include various types of weirs and flumes.

63.21 - Weirs

Ordinary types of weirs are sharp-crested, broadcrested, V-notch, Cipoletti, and Sutro. Formulas and weir coefficients used for calculating flows over the various types of weirs are available in the literature. Each type of weir has its special uses and advantages and one should use care in selecting the type to be used to ensure that it will have the required accuracy over the expected rate of flows.

63.22 - Flumes

Generally, most open-channel flows involving relatively clear water may be satisfactorily metered by weirs. With sewage, rags, and other items hang up on the weir crest at times of low flow, and deposition of putrescible solids takes place on the upstream side of the weir. Furthermore, the necessity for maintaining a gravity sewerage system generally means that the difference in head required to permit the use of a free-discharge weir is hard to obtain.

Because of this, sewer flows have been commonly metered by some device with smooth entrance and exit transition channels and a characteristic so designed as to produce critical flow conditions somewhere within the body of the metering device, so that only a single upstream-flow depth, which varies proportionately with flow, need be measured. Such a device is called a flume.

Three flumes commonly used are:

1. Kennison Nozzle or Parabolic Flume. This is used where head is sufficient to permit free fall at discharge and usually for small quantities.

The nozzle is illustrated in exhibit 1. The nozzle is designed so that the depth at the discharge end is always critical, hence the depth at the inlet end is proportional to the discharge. It is adapted to measuring flow through partly filled pipes and open channels under widely varying flow rates, with an accuracy of ± 3 percent. It comes in sizes from 6 to 35 inches.

The Simplex parabolic flume is a nozzle similar to the Kennison nozzle, but of parabolic cross-section. It likewise is available in 6 to 35 inches sizes and measures accurately over a 20 to 1 range of flows.

2. Parshall Flume. This is essentially a Venturi tube split in two longitudinally and provided with a drop at the throat to compensate for the pressure rise which would normally generate a standing wave at the constriction. It is adaptable to all magnitude of flow.

The Parshall flume was developed by Ralph L. Parshall about 1915 for measuring flow of irrigation water. It has proved to be a most versatile and accurate type of meter and is commonly used in sewage-treatment plants.

Because it requires an invert drop of 3 inches to establish a critical depth at the throat, it is not readily installed in existing sewers, but is often included in new treatment plants.

A dimensional drawing of the flume is shown in exhibit 2, taken directly from Parshall's original publication. Dimensions suitable for measurement of a wide range of flows are shown in table 1. The range of flows which can be accurately measured by the instrument is notably great. For example, at depths of from 0.20 to 2.5 feet in a flume with throat (crest) width of 1 foot, flows of from 0.35 to 16.1 cfs may be measured -- a range of about 45 to 1.

63.22 – TABLE IS A SEPARATE DOCUMENT

Like the Kennision nozzle and the parabolic flume, the Parshall flume produces a critical depth of flow at its throat, hence only the entrance depth, y, need be measured once the instrument has been calibrated by suitable calculation. This depth of flow can be translated directly into rate of flow in gallons per minute, cubic feet per second, etc., by means of an integrating recorder-type instrument.

3. Palmer-Bowlus Flume. This is similar to the Parshall flume except that it is readily adaptable to any size or shape of existing channel and is quite flexible in shape and dimension.

The Palmer-Bowlus flume, or P-B meter, like the Parshall flume, is an adaptation of the Venturi meter. It comprises a throat with inlet and outlet transitions. No invert drop is required in its construction, hence the meter is readily installed in existing conduits, such as sewer pipes and approach channels. To produce a critical section, however, it is necessary to constrict the channel by a slight rise in the channel bottom over a short distance, hence a slight backwater condition is created. Streamlining of the bottom and side constrictions results in a negligible loss of head through the meter. No objectionable upstream ponding results from the backwater and there is little obstruction to passage of suspended or floating solids which could clog the channel. The Palmer-Bowlus meter has become increasingly popular during the past 20 years because of its many advantages. Besides its adaptability to existing conduits which makes feasible its addition ahead of existing sewage-treatment works constructed without provision for metering, it has the following desirable advantages:

a. A rating curve for the meter can be rationally computed for any given shape and conditions. This means that the rating curve for the meter can be calculated on the basis of actual in-place measurements should its shape during construction become different than that shown on the design plans.

b. There is no dependence upon empirical formulations, hence no fixed dimensions need be complied with. It may be placed in an existing sewer in such simple shapes as a mere lead obstruction in the bottom of the sewer.

c. Uniformity or regularity of shape is not required.

Like the Parshall flume and other devices which depend upon the creation of a critical depth at some section of the meter, the P-B meter need be monitored only at one point in the approach channel in order to determine the flow at any instant in time. The P-B meter is illustrated in exhibit 3.

63.22 – EXHIBITS 1 THRU 3 ARE SEPARATE DOCUMENTS

63.23 - Measurement of Flow Depth

For determining flow through all weirs or flumes, it is necessary to make some measurement of flow depth. This can be accomplished through the use of simple devices such as staff gauges and floats, or the more complex ultrasonic, bubbler, or conductive probe type systems. For continuous recording of flow rates, a rotating disc or drum is commonly used.