The Process of Water Flowing through Control Structures and Treatment Facilities in a Developed Area

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I. INTRODUCTION

This paper describes the basics of water control and treatment systems (hereinafter defined as "water systems") in the vicinity of a city or a developed area. It describes the flow process of water from its source, passing through control structures and treatment facilities, returning to the stream of a river. This description is limited to the basic flow charts of the process, the function of a component in the flow chart, and the sketches of control structures. The details of the design, construction, maintenance, and operation of the water system are beyond the scope of this paper. As shown in Figures 1, land runoff from snow and/or rainfall is the main source of water, which reaches a river through drainage control structures (or storm sewer system). This drainage control system may not exist if the land of runoff is mostly pristine, i.e., little urban development exists in this land. Water is then pumped from the river or a multi-purpose reservoir to a water treatment plant for purifying and disinfection. The treated water is delivered to various water users such as residences, businesses, and industries through a water distribution system. Following water usage, the sewage or wastewater releasing from water users passes through a collection system to reach the wastewater treatment plant. The wastewater is clarified and disinfected through a series of treatments, eventually flowing back to the stream of a river.

The purposes of this paper are to identify the water systems and the components for each water system. It also provides a basic knowledge for each water system and the relationships among these systems. This is important for the contractors that they can better understand the essence of the water systems, and possibly pursue or work on the water-related projects. "Contractors" referred in this paper are constructors, engineers, and their related businesses and individuals.

II. WATER SOURCE

1. Runoff Water

The water source is either a river or the groundwater storage. Some of the runoff water generated from snow and/or rainfall flows into the river. One portion of the water is intercepted and eventually evaporated. Another portion of the water enters the earth to become subsurface flow. The remaining portion may further infiltrate into the soil to become groundwater. The subsurface flow, again, enters the river as runoff in a later stage. In most cases, some or all of the runoff have to go through the drainage control structures to reach a stream or groundwater storage. The function of drainage control structures is to protect a watershed from water damage and to enhance the quality of runoff water. A watershed is a bounded area in which all of its runoff flows to a common outlet. The amount and quality of runoff water generated from the rainfall depends on the characteristics of the watershed. For a watershed with higher degree of urban development (urbanization), the amount of runoff and the pollutant load associated with the runoff is generally higher. In addition, the concentrations for some key pollutants (or contaminants) in the runoff water are also higher (Reference 1, COA).

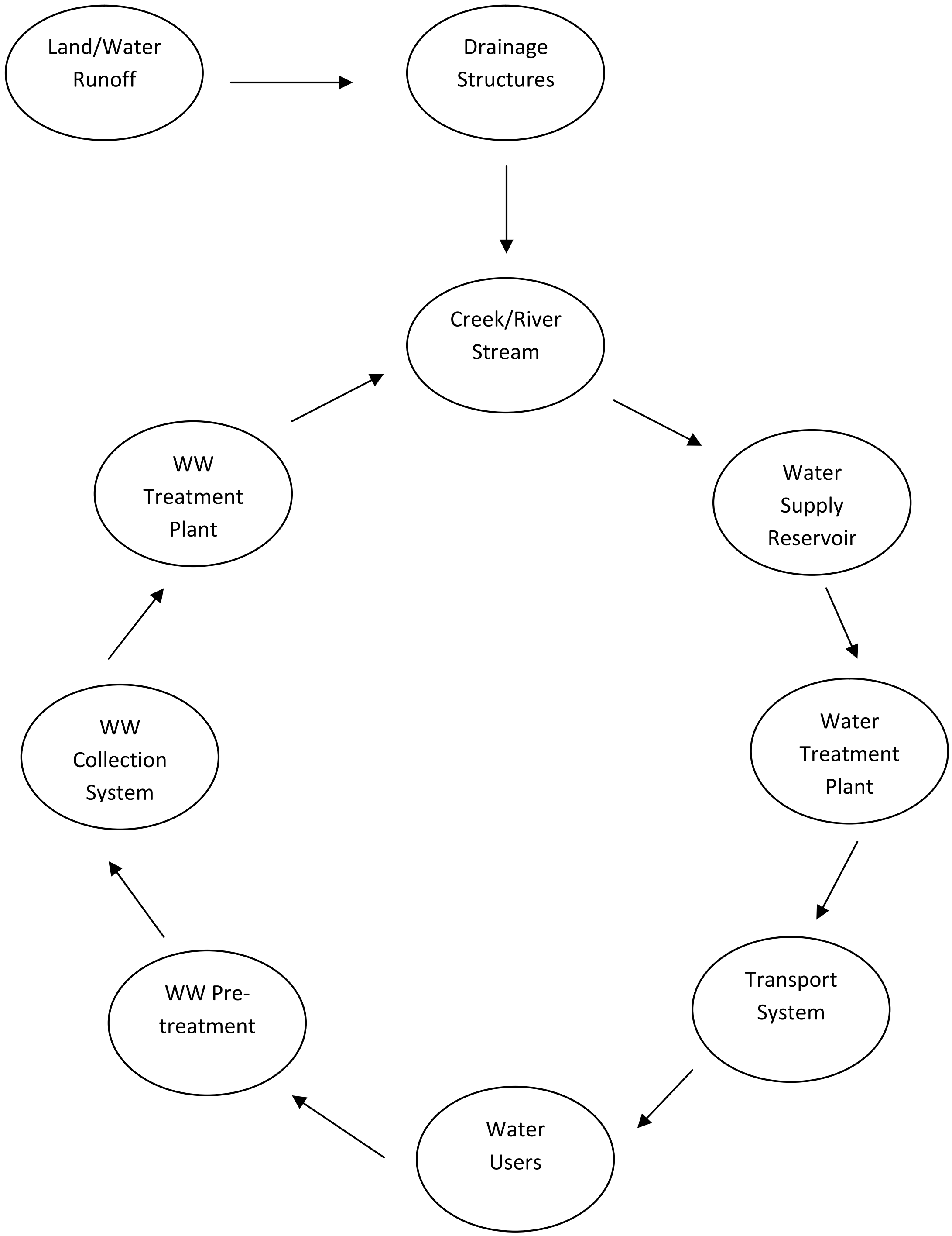


Figure 1: Water System and Water Flow Process in a Developed Area

The degree of urbanization can be represented by the percent impervious cover as measured on the ground of the watershed. In other words, the amount of runoff water and the deterioration of the associated water quality are proportional to the percentage or degrees of the impervious cover in the watershed. It's preferred that the water source is located in a watershed with the least development or impervious cover. On the other hand, the drainage control structures play an important role for the control and treatment of the runoff water.

The water coming out of the control structures in a watershed constitutes a portion or all of the existing streamflow or groundwater storage. From there, water is directed and pumped to a water treatment plant for purification and disinfection (as shown in Figure 2). An entity such as a city or urban region can use streamflow or groundwater, or a combination of them, for water supply. Theoretically, the water quality of groundwater is cleaner than that of the streamflow or surface water in considering the treatment it receives when it passes through the layers of soil. In reality, however, the groundwater often has high hardness and contains excessive minerals. Although higher degree of hardness and minerals might not be a health hazard, more concerns have raised concerning the difficulty of its treatment and the related impacts. After all, it's important to have a water source of good quality for water treatment, and in turn, for better water use.

For cities which have a river nearby or passing through it, one or more water supply reservoirs are constructed for water use. For example, the City of Austin (COA) has Lake Travis and Lake Austin for drinking water supply. These reservoirs are located upstream from the city, which have less developed watersheds. In addition, watershed ordinances have been enacted that require strict, structural and nonstructural controls for water quality protection.

2. Water Supply Reservoir

In general, a reservoir is an enlarged impoundment of water on or off a river. The essential elements of a reservoir have a dam, its connected embankments, an outlet structure, and the spillways. The dam must be established in a manner that provides a good foundation and a solid core in order to stand the thrust of the impounding water. The conceptual view of a dam and reservoir can be shown in Figure 3. The permanent pool of a reservoir is maintained at the service spillway level. An emergency spillway is necessary to release water during floods in order to prevent water from overtopping the dam. The outlet structure is a device to deliver water to the downstream side as necessary. There are many types of reservoirs. A larger, multiple-use reservoir can serve for water supply, flood control, hydraulic power, irrigation, and other uses. Based on the same concept or principle, there are other types of reservoirs for specific uses.

For better water treatment, a water supply reservoir is often established on the river, upstream from a city that the watershed of the reservoir is less urbanized. It is also desired that this watershed is mostly covered by the vegetation so that the runoff water entering the stream or groundwater storage has a good quality. Nevertheless, urbanization or urban development is an on-going process that it is difficult to avoid. Some control measures such as a watershed ordinance with various requirements of effective control measures should be implemented to enhance the quality and conservation of runoff water.

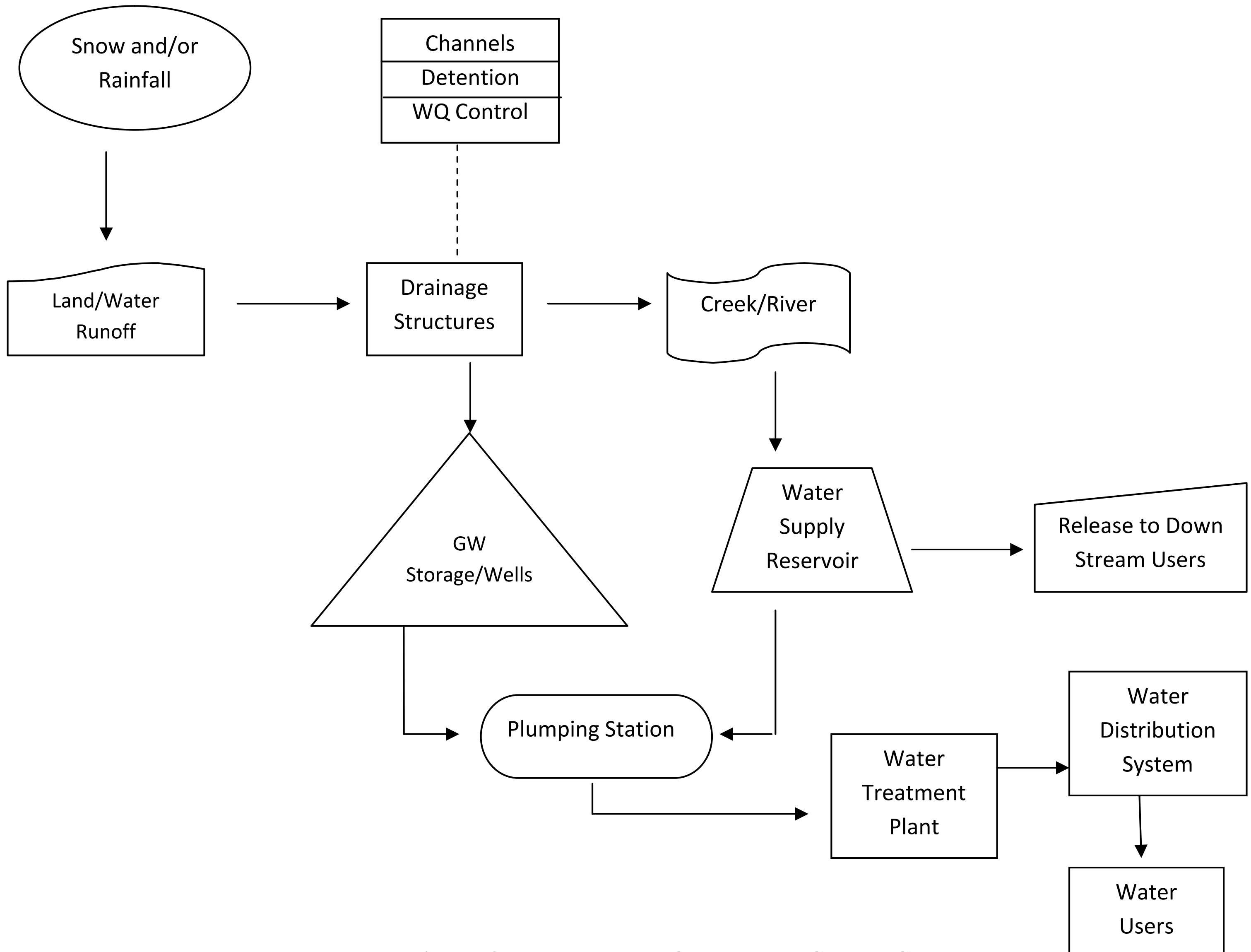
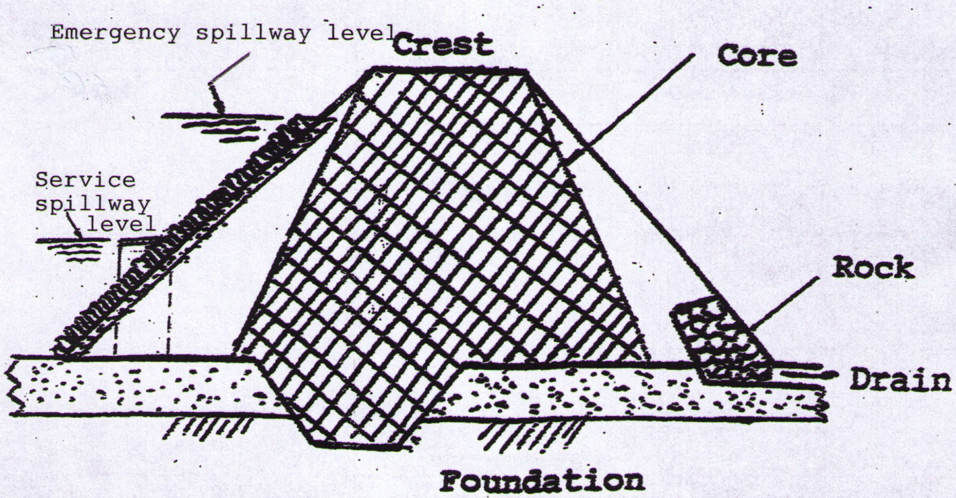


Figure 2: Flow Process for a Water Supply System



Figue 3. An earth dam with impoundment showing spillway crest levels

III. DRAINAGE CONTROL STRUCTURES

The purposes of drainage control structures are to guide the runoff flow, protect watershed from flood damage, and enhance the quality of runoff water entering the stream or groundwater storage. The runoff water generated by rainfall is routed through the drainage control structural network to enter a creek or river. Some of the runoff may infiltrate into groundwater storage, depending on the characteristics of the watershed.

The drainage control structures may consist of a channel network, the detention ponds, and the water quality control basins such as filtration basins and wet ponds. A channel network may have water inlets, outlets, drain pipes, open ditches, and even tunnels. The channel network caries water runoff to detention ponds and water quality control basin. Eventually it takes water flowing into a river or a branch of the river. A sub-network is established when there is a subdivision or a commercial district exists in the watershed. It may be implemented even the watershed is pristine, in order to direct the water runoff passing through a designated route.

Generally a detention pond is to retain runoff water temporarily so that the rate of flow is reduced and the time frame of flow is extended. The pond is usually designed for a 100-year flood, during which the downstream watershed is protected from possible water damage. Like a reservoir, the detention pond has a dam, low flow outlet, service spillway, and an emergency spillway. A detention pond is usually dry when there is no runoff flowing into the pond. In some cases, however, the pond is designed to maintain a permanent pool for better appearance and for water quality enhancement.

Some quantity of the runoff may be diverted to a water quality basin before it flows into a detention pond. As shown in Figure 4, there is a bypass that the first portion of runoff flows into a sand filtration basin (Reference 2, COA). A study (reference 3, Chang) shows that the first flush of runoff contains most of the containments for each of the pollutant parameter. Therefore it is preferable that the first 0.50" to 0.75" inch of runoff can be diverted to the water quality control basin for treatment and let the rest of runoff flowing into the detention basin.

Water quality pond is part of the drainage control structures. There are many kinds of water quality control structures such as wet land, wet pond, vegetated channels, sedimentation, and sand filtration. The City of Austin, Texas and some of its surrounding cities require a wet pond or sand filtration basin be implemented for most developments. A sand filtration basin consists of a detention pond and a sand filtration basin. Runoff water is first treated with sedimentation by passing through from the detention pond to the filtration basin. This water is further treated with filtration by draining through layers of sand, and eventually it goes out to a channel through the perforated pipes which are laid in the bottom of the sand filtration basin.

A wet pond (Reference 4, COA) can be designed for both flood and water quality controls. The St. Elmo Wet Pond (Figure 5) has the capability to serve for both purposes. This pond has a service spillway at the southwest side, and an earth-cut emergency spillway at the west end. The pond has a permanent pool which can go up to the crest of the service spillway.

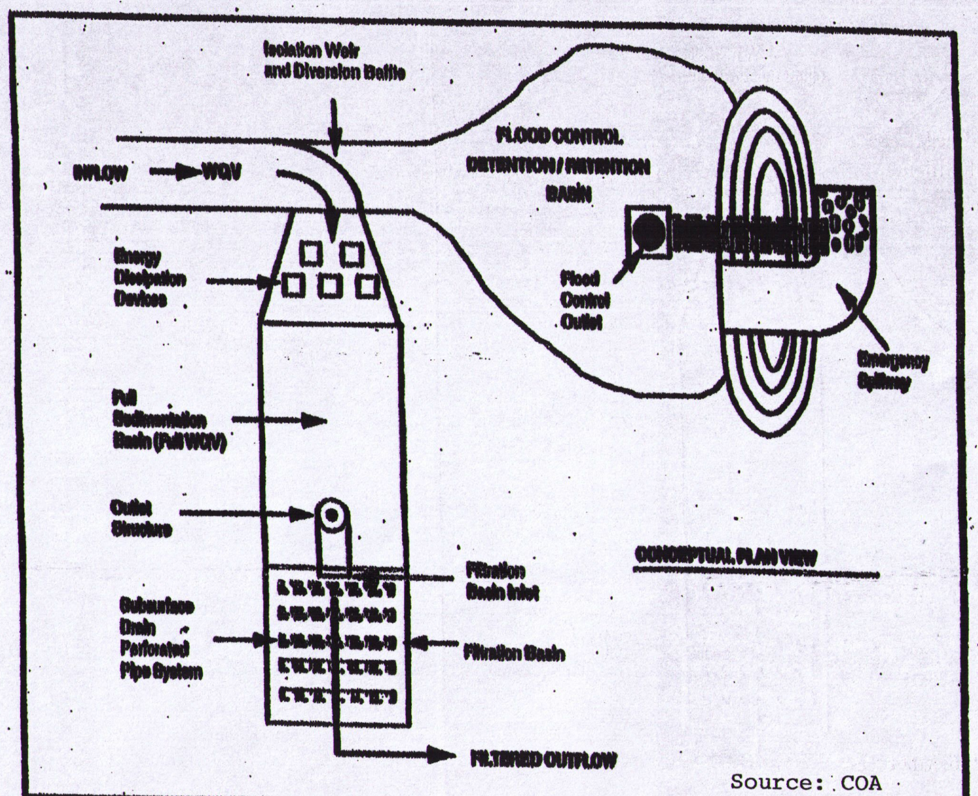


Figure 4. Detention pond and filtration basin with the first flush of water diverting to the sand filtration

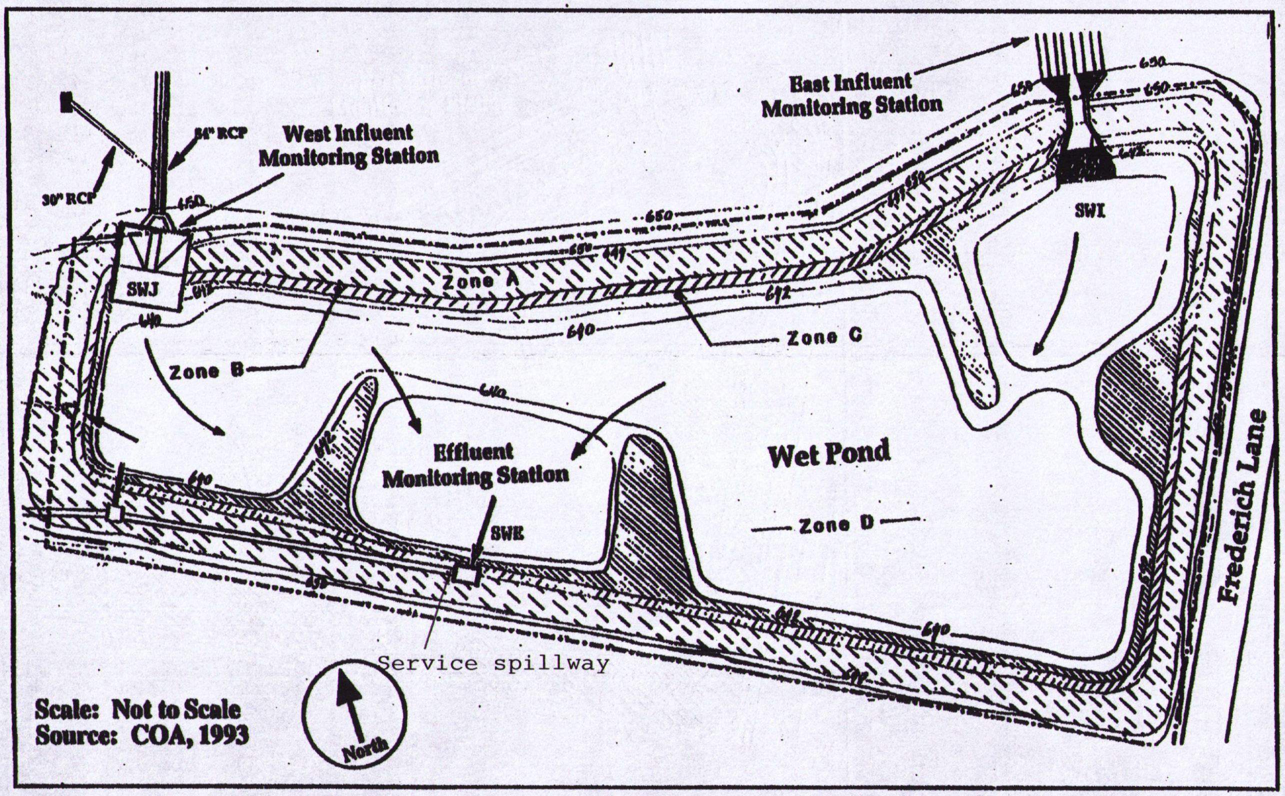


Figure 5. St. Elmo wet pond (also served as a detention pond)

St. Elmo Wet Pond has four ponding zones. Zones A to C are near the edges of the pond. They have different vegetation in association with a landscape design. Zone D is a permanent pool which may rise up to cover all zones. In general, a wet pond design is to use water retention and the absorption of vegetative plants to remove contaminants in the runoff water. The successive runoff flowing in should push the treated water out of the pond through the service spillway.

IV. WATER TREATMENT PLANT (WTP)

Successive runoff generated from rainfall in the watersheds eventually reaches the groundwater and/or surface water reservoir. This reservoir or storage is often the source of raw water for treatment and consumption. Figure 6 provides a diagram of flow chart to show the water treatment process in a water treatment plant.

1. Water Use

The treatment capacity of a WTP is generally measured as the rate of flow passed through the treatment system, such as a flow or treatment rate of million gallons per day (MGD). The designed capacity depends on the demand of water use and several other factors. A city or a developed region may have one, or more WTP's to satisfy the projected demands.

2 Preliminary and Primary Treatments

Generally, the raw water in the water supply reservoir is diverted through a channel to the pumping station. The raw water is then pumped to the WTP for treatment. Bar screens are usually placed on the way from reservoir to the WTP in order to remove larger debris from the raw water (a preliminary treatment). Primary treatment may include pre-sedimentation, reduction of hardness, and the aeration process. Pre-sedimentation is to remove some larger flocs of contaminants by sedimentation following a coagulation process. Reduction of hardness is often needed since higher hardness may present unfavorable appearance and can be harmful for some equipment or uses due to water corrosion. Hardness may be identified as the concentration of a combined calcium and magnesium. A value of hardness about 40 ppm (or mg/l) may be adequate. The method for hardness reduction is to add softeners or through an ion exchange in the water. Aeration removes gas and organic contaminants by blowing air into treatment chamber that introduces oxygen into the water and drives out the undesirable air (Reference 5, TEES).

3. Secondary Treatment

The essential elements for water treatment include, but not limited to, sedimentation, filtration, and disinfection. Disinfection is probably the most important treatment for drinking water. Some forms of chlorine have usually been used to eliminate waterborne pathogens, maintaining a minimum or safe level of bacterial population in the water. Sedimentation detains suspended and dissolved pollutants in the basin through water detention. For ease of sedimentation, there is a coagulation and flocculation process that mixes chemicals with incoming water to form flocs of contaminants. Eventually the flocs come together to become large particles which can settle in a better fashion (Reference 6, JMM).

Filtration takes place following sedimentation. It filters out suspended pollutants and pathogen materials. A filtration bed consists of layers of porous materials such as sand and gravel, and an underground drain. There is also a backwash device to clean out wastes filled in the sand layers, in order to maintain an adequate water head or pressure for proper filtration. Figure 6 provides a diagram of flow chart for the complete process of water treatment.

4. Flow Monitoring and Water Sampling

Water flows in and out of a WTP are monitored in order to know their quantities and qualities. Based on the monitoring, the efficiency of the treatment can be evaluated. For some of the treatment process, the flow quantity and quality are periodically measured using flow meters and water quality sampler. The results of measurement help for the improvement of treatment design and operation.

V. WATER DISTRIBUTION SYSTEM

The treated water coming out of a WTP initially enters a storage device before distribution. There are different types of storage facility such as a reservoir, a clear well, or an elevated tank. A storage tank can deliver water at a uniform flow rate to the distribution system, and thus keeps a sufficient supply during peak demands. An elevated supply has an advantage to establish a greater water head or pressure to deliver water to the distribution system. Water is pumped to the distribution main through a connection such as a pipe or tunnel.

1. Components of a Distribution System

Essentially, the water distribution system consists of a water main (or more than one), a pipe flow network, fire hydrants, pumps, elevated storage, and the pipe and meter connections to water users. When the service area is large, the piping network may be branched out to formulate sub-distribution systems. The pipe flow network must have sufficient capacity to carry the treated water and satisfy the water demand from the service area. At each place along the pipe lines, the flow has a specific water pressure requirement. Pumps and the elevated storage for the distribution system are to increase the water head or pressure of flow in the pipe network. Fire hydrants are established mainly for fire protection. Components of the distribution system require frequent maintenance and repairs. The ease and cost for such work have to be evaluated in the design and construction of the distribution system

2. Water Users

The water distribution system is designed to serve water users or consumers (as shown in Figure 7). Control valves are installed in the pipe lines and at the connections to water users. Meter(s) for each customer is necessary to measure the quantity of water consumed by the users. The water users are generally classified into residences, businesses, and industries. The classification is necessary as the purpose of usage and the sewage following water use are different among the water users.

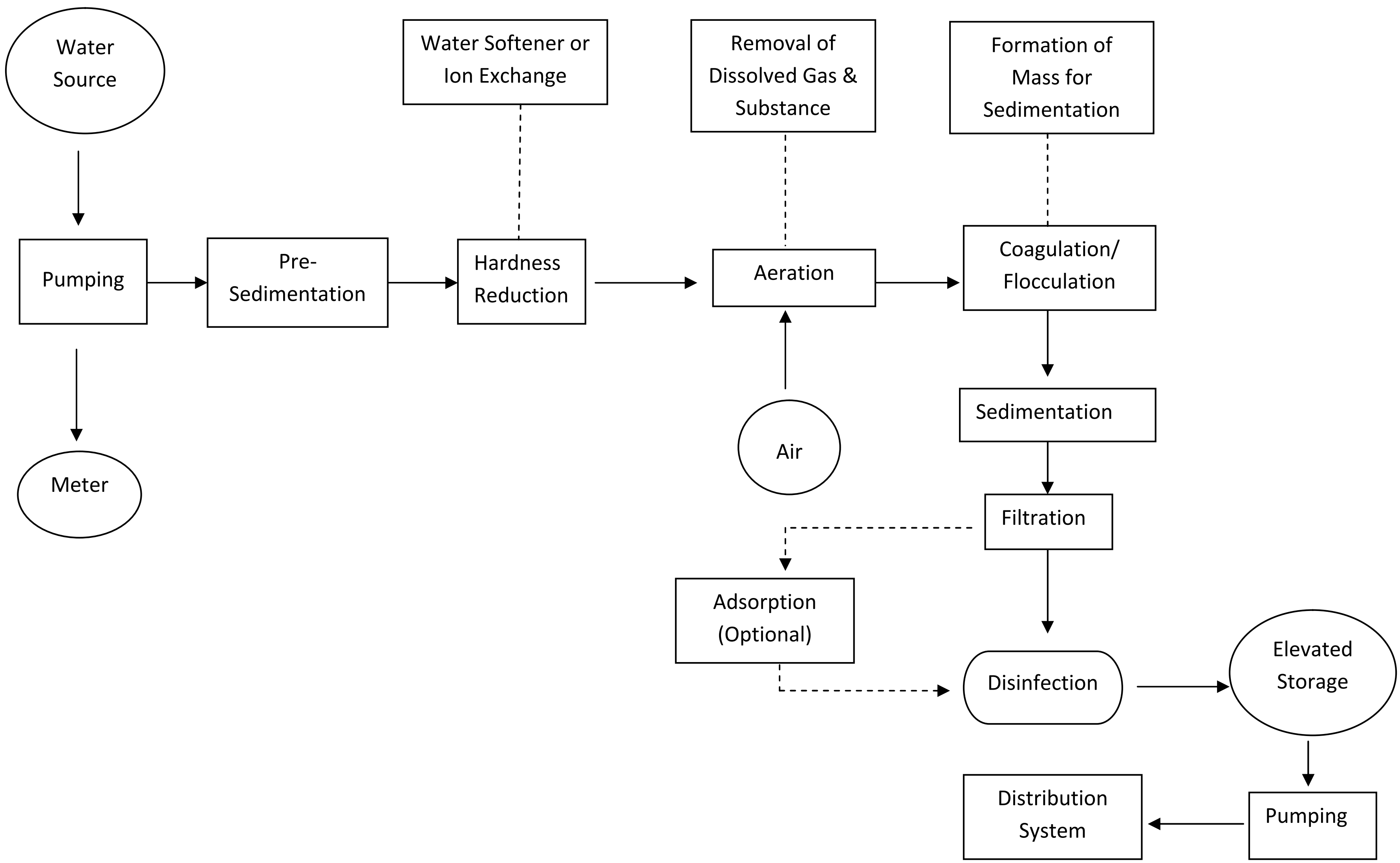


Figure 6: Components and Flow Process for a Waste Treatment Plant

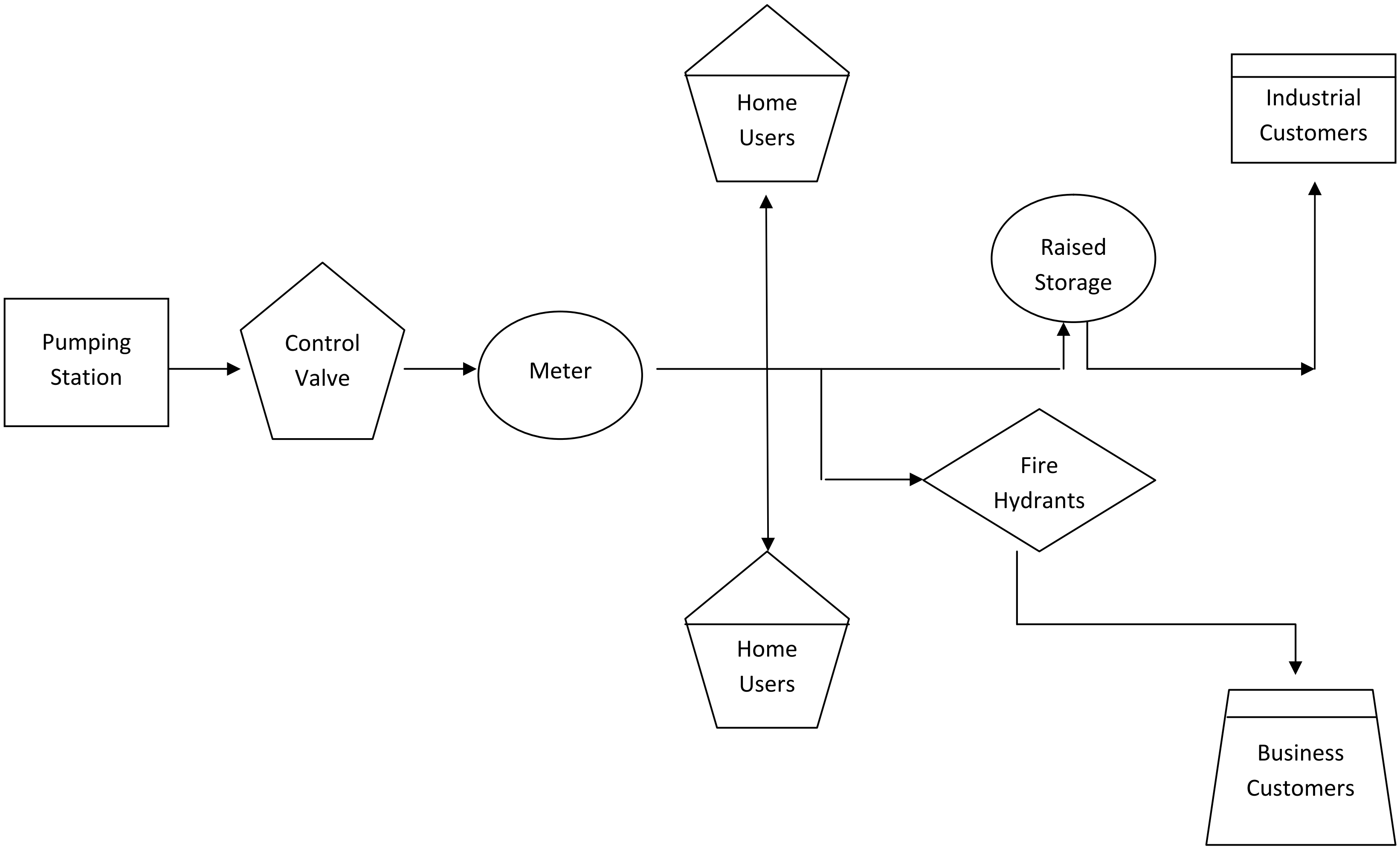


Figure 7: Components and a Flow Process for Water Distribution System

VI. WASTEWATER COLLECTION SYSTEM

A wastewater collection system is a sewerage network which collects the used water or sewage from water users and transports it to a wastewater treatment plant (Reference 7, CSU). This system is a part of the wastewater control facilities that protect the environment and public health of the community. Also, the design and/or planning for the system should consider other requirements such as the anticipated capacity, cost saving, and the ease of maintenance.

1. Components of a Collection System

A collection system is a complicate network which includes, but not limited to, sewer mains, submains, lateral lines, manholes, lift stations, and pumping equipment (Figure 8). Sewer lines usually have gravity and forced portions (reference 8, TEES). In the latter case the wastewater is pumped and forced to go upside. A pumping and/or lifting station is often required to raise water head or pressure so that the sewage flow can move upside or farther at a specific flow rate. Man holes are required to access sewer line and the related equipment for maintenance, cleaning, and flow monitoring. Inflow and infiltration (I & I) of runoff and ground water to sewer line is always a problem for the collection system and wastewater treatment. Proper design, construction, and maintenance and repairs of this system or sewer network is very necessary to minimize I & I, and thus to enhance wastewater treatment and prevent sewage overflow.

2. Sewage from Water Users

The sewage discharge from a water user is often connected to a lateral sewer line of a collection system. As described before, the water users or customers to a water utility are generally classified as residence, business, and industry. Most residential discharges are directly connected to the wastewater collection system. The business and industrial users, however, are required to have a pretreatment system. For example, a restaurant or trucking facility is required to have a grease or sand trap for sewage to pass through before it reaches the sewer line of the collection system. Various types of wastewater pretreatment systems are required for the industries depending on the size and type of the industry. These connections are shown in Figure 8, a diagram for the components and flow process of a wastewater collection system.

VII. WASTEWATER TREATMENT PLANT (WWTP)

WWTP treats waste discharge or wastewater (WW) from water users. Wastewater flows into a treatment plant through the above-described collection system. Like the WTP, the capacity of a WWTP is measured by the rate of flow passing through the plant, such as million gallons per day (MGD). A city or urban region may have one, or a number of WWTP's, depending on the size, population, and the types of business and industry it has.

1. Preliminary Treatment

The initial treatment of a WWTP is generally a mechanical and/or physical process which may consists of several elements**.**

Screening is to trap and remove large objects from sewage inflow using a bar screen. Grit removal equipment separates out the hard objects from wastewater in order to protect equipment and prevent stoppage of flows in the treatment system. Wastewater flows can be quantified following the elimination of these objects by installing a flow measurement control structure and a flow meter. Grease traps and aeration tanks may also be parts of the preliminary treatment. These devices can remove oil and undesirable gas from the wastewater. Additional equipment includes equalization ponds which stabilize water before it flows into the aeration basin for secondary treatment.

2. <u>Primary Treatment</u>

Primary clarifiers serve as initial treatment to reduce sludge from wastewater. It slows down the inflow and directs the suspended materials in the wastewater to settle toward the bottom of the clarifier. The settled sludge is removed and transported to the sludge digestion and/or dewatering devices. On the top of the clarifier, the cleaner wastewater flows out to the equalization ponds, at which the flow is stabilized before entering the aeration basins for secondary treatment.

3. <u>Secondary Treatment</u>

The secondary treatment is essentially an activated sludge process (Reference 9, Pudvan). This process directs the flow from aeration basins to secondary clarifiers, further to additional treatment processes such as chlorination and filtration. Part of the sludge generated from the secondary clarifiers is returned to aeration basins for repeated activation until all of the sludge is removed and sent out for sludge digestion and/or dewatering treatment. With air or oxygen being blew into aeration basin, the dissolved and suspended matters in the wastewater continues to combine with the organisms to form biological flocs or solids. The biologically active solid is defined as "activated sludge." This sludge is repeatedly treated as described above.

Additional treatment processes are necessary as shown in Figure 9. The waste or sludge removed from the secondary treatment goes through a digestion and/or dewatering process to form solid waste. This waste is either disposed, or screened and passed through a manufacturing process to become commodities. The cleaned water from the final treatment is monitored and guided to return to the river

VIII. CONCLUSION

This paper provides a basic description of water-related systems and their relationships for a developed area such as the vicinity of a city or urban region. The water systems are identified as water source, drainage control system (or storm sewer system), water treatment plant, water distribution system, wastewater collection, and wastewater treatment plant. The study also presents diagrams of flow charts to demonstrate how water passes through a series of control and treatment systems, and eventually returned to the stream of a river. It is hoped that this paper could assist contractors such as constructors and engineering-related professionals to better understand and to engage in the water-related projects.

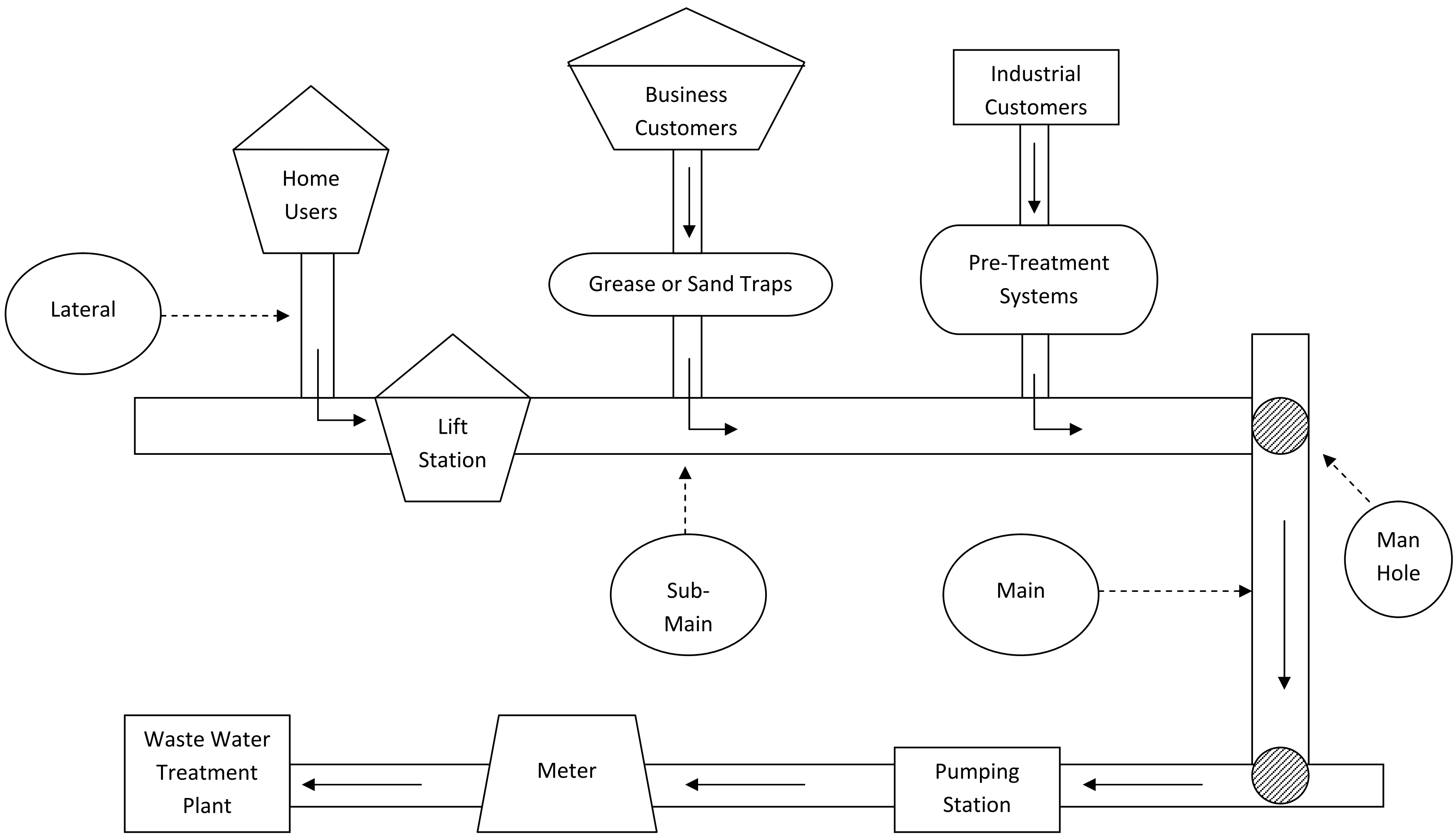


Figure 8: Components and the Flow Process for Wastewater Collection System

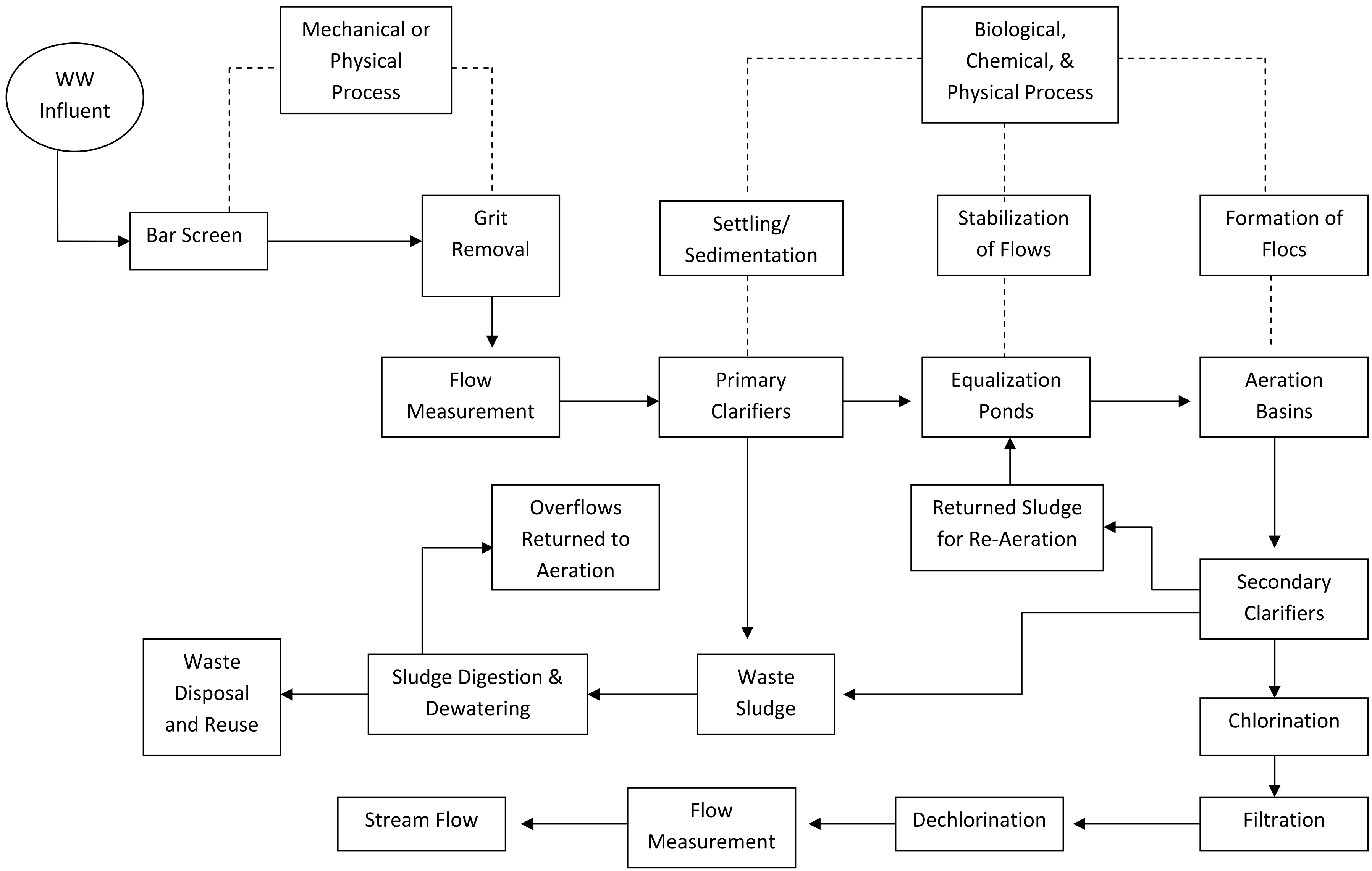


Figure 9: Components and Flow Process for a Larger-Scaled Wastewater Treatment Plant

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