# URBAN RESIDENTIAL INFRASTRUCTURE NETWORKS

BY

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B. Arch.
North Carolina State University (1968)

SUBMITTED IN PARTIAL FULFILLMENT

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Signature of Author ______________________________
Department of Architecture June 4, 1970

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Chairman, Departmental Committee on Graduate Students

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June 4, 1970

Dean Lawrence B. Anderson
School of Architecture
Massachusetts Institute of Technology
Cambridge, Massachusetts

Dear Dean Anderson:

In partial fulfillment of the requirements for the degree of Master of Architecture, I hereby submit my thesis entitled "Urban Residential Infrastructure Networks."

Respectfully submitted,

Reinhard K. Goethert

# URBAN RESIDENTIAL INFRASTRUCTURE NETWORKS

Reinhard K. Goethert

Submitted to the Department of Architecture June 4, 1970; in partial fulfillment of the requirements for the degree of Master of Architecture.

ABSTRACT:

1. The context of the thesis is in the urban residential areas with primary regard for the physical planner.

2. The secondary nature and the generous design parameters of current practice in the development of infrastructure systems is re-examined in light of the staggering demand for new housing stock within the next twenty years.

3. The large percent of the costs of urbanization that are directed into the investment of infrastructure systems is outlined in regard to the consequences of various layout patterns.

4. The major emphasis of the thesis involves a detailed survey of the primary infrastructures, but includes surveys of less vital networks also.

5. The collection and distribution systems of the infrastructure found in residential areas (water supply, sewer network, and storm drainage network) is stressed with respect toward the physical elements for proper planning.

6. Physical magnitudes and quantities are developed for the various networks for reference purposes to aid in the design process of the physical planner.

7. Comparisons are presented where available between practices in the United States and practices in developing countries, with primary focus on South America.

THESIS SUPERVISOR: Horacio Caminos, Professor of Architecture

# INTRODUCTION

The thesis is developed as an information document for urban residential planners. Current knowledge by planners of urbanizations include most of the physical and social aspects but preclude a concise, complete information background of utility networks. Generally, current planning volumes only include a sketchy data presentation with the underlying assumption that such aspects should be dealt with only on highly specialized engineering levels.

Infrastructure networks, particularly water, sewer and storm drainage, comprise a large percent of the cost of new urbanizations. Data from South America states that between 35% to 72% of the total costs of urbanizations are directed towards utility service requirements.

The residential infrastructure must be re-examined from many aspects but the fact that these elements constitute a major portion of the total cost of urbanization is the prime reason for a careful evaluation of current practices. Even a small saving in these utility systems would allow additional funds to be spent on other needed aspects of urbanization. The infrastructure cost becomes a large obstacle when discussed in the light of developing countries.

The planner should be more aware of where a major portion of the urbanization expenditures are invested. Apparently a contradiction exists in that the major portion of the planner's efforts are directed toward a minor portion of the urbanization costs.

The traditional approach of utility planning places its role as in a secondary service position; after a design has been established, the engineer installs a utility network that will answer the demands of the proposal, cost notwithstanding. The cost of the network layout will generally be the most efficient and economical under the circumstances, but perhaps the layout is not the most reasonable and economical when considered with the demands of the utility network as the determinate.

Undoubtedly there are various ways of developing urbanization which would benefit the added conditions of utility networks instead of forcing the utility network to be completely subservient to prior decisions.

The information here presented perhaps will make the planner more aware of the design conditions which a service network is forced to provide.

In the developing countries, and perhaps in the U.S. within the next 25 years as the population doubles, the traditional role of "secondary servant" of the utility networks will be reversed. Since the demand and need for housing is practically unlimited, the parameters of a utility network when optimized with minimum cost and highest efficiency should be a major design constraint of large scale urbanizations. With the infrastructure cost comprising a large percentage of total urbanization costs, better planning policies must be followed where the constraint of utility systems must be included.

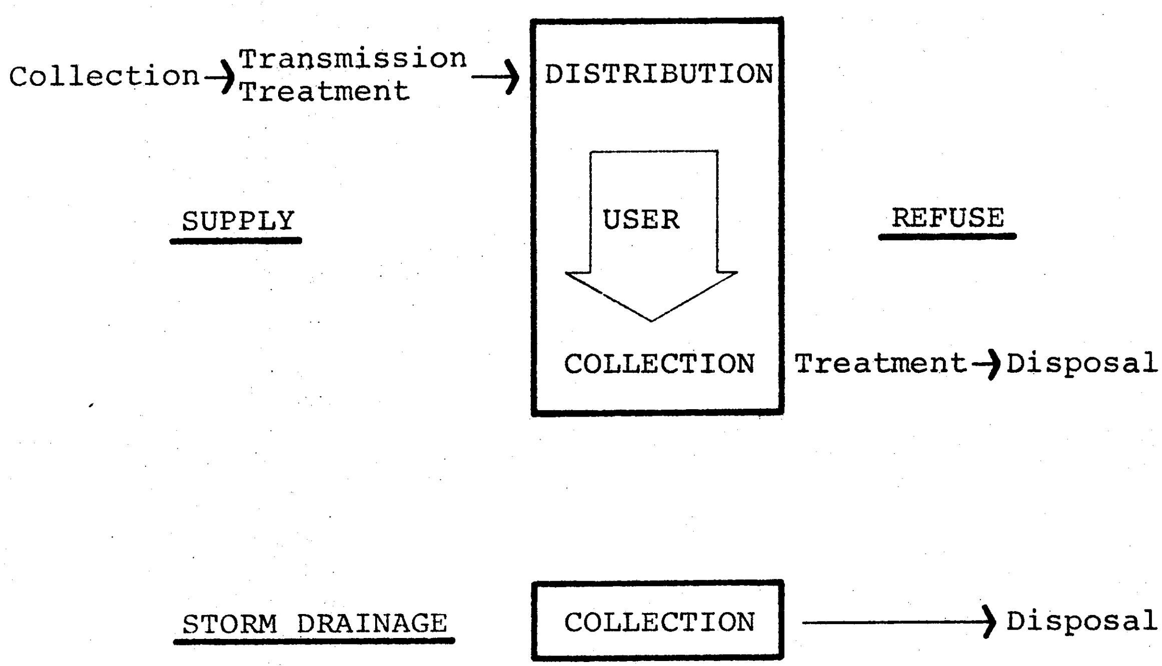
CONTENTS

## UNITS USED IN REPORT

| | UNITS UNIQUE TO WATER ENGINEERING | BRITISH SYSTEM (foot, pounds, second) | METRIC SYSTEM (meter, kilogram, second) | CONVERSION CONSTANTS |
|---|---|---|---|---|
| PRESSURE | head (hd) | pounds per square inch (psi) | kilograms per square centimeter ($k/cm^2$) | hd=psi x .434<br>psi=$k/cm^2$ x .34<br>$k/cm^2$=psi x .07 |
| VEL. | | feet per second (fps) | meters per second (mps) | mps=fps x 3.28<br>fps=mps x .305 |
| QUANTITY | | gallons per capita per day (gpcd) | liters per capita per day (lpcd) | gpcd=lpcd x 3.78<br>lpcd=gpcd x .265 |
| FLOW | gallons per minute (gpm) | cubic feet per second (cfs) | cubic meters per second (cms) | cfs=cms x 35.4<br>cms=cfs x .0283<br>gpm=cfs x 448.8 |
| VOL. | | gallons (gal) | liters (l.) | gal=3.785 liters<br>liters=0.2647gal |
| AREA | | acres (ac) | hectares (ha) | ac=.4047 ha.<br>ha=2.471 ac |
| DENSITY | | people per acre (p/ac) | people per hectare (p/ha) | p/ac=.4047 p/ha<br>p/ha=2.471 p/ac |
| LENGTH | | feet (ft) | meters (m) | ft=0.3048 meters<br>m=3.281 feet |

All pipe diameters are given in inches. Common practice in the North and South American continents is to use the size under which the pipes are manufactured, generally in North America and thus in inches.

THE WATER INFRASTRUCTURE



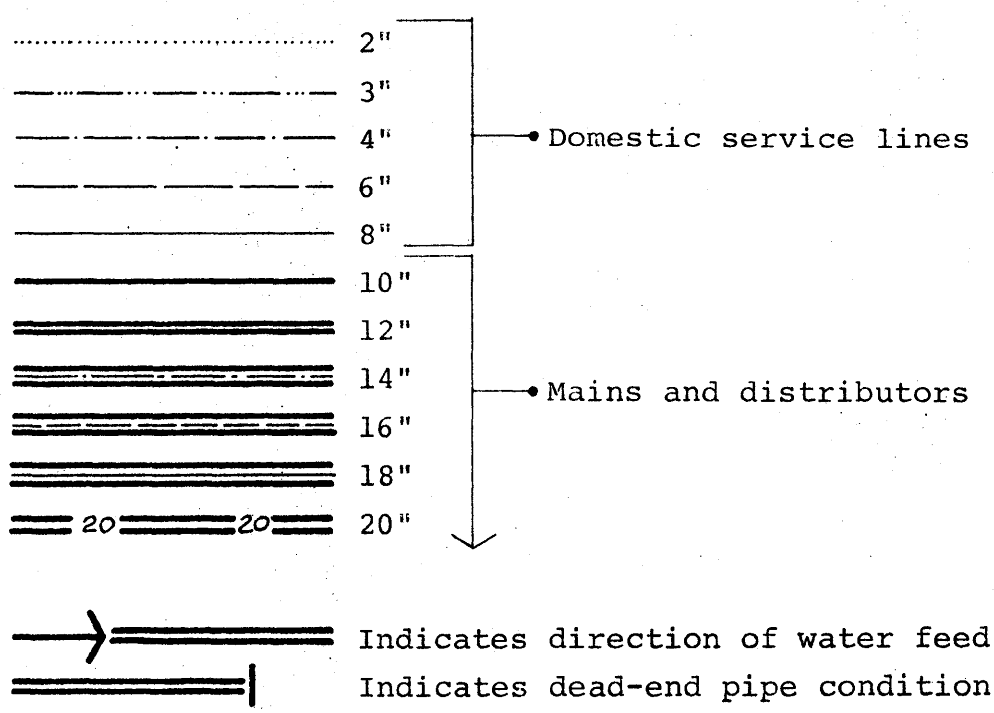

SCOPE OF THE STUDY

1: The context is considered to be in the urban residential context only

2: The major portion of the study is concentrated in the DISTRIBUTION and COLLECTION components of the water network since these components will have the greatest direct impact on the planning of a urbanization

## THE WATER SUPPLY INFRASTRUCTURE

KEY TO SYMBOLS USED



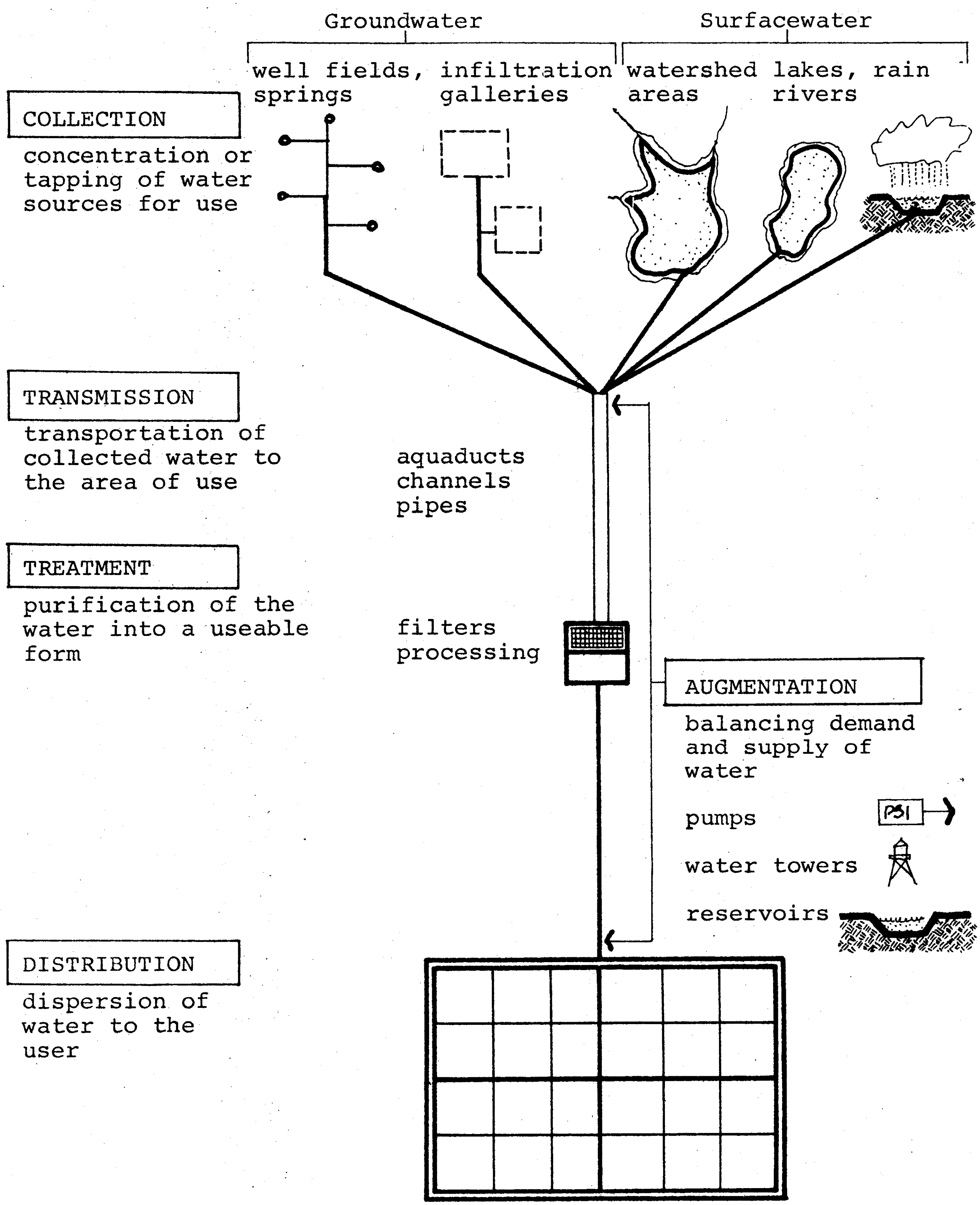
Today, about 1200 million people live in urban areas. In 1980, there will be about 1700 million (a 42% increase) and by the year 2000 there is the possibility of a population of more than 2500 million (a 47% increase). This vast scale of urban population growth is a measure of the magnitude of future water needs.

The provision of the urban water supply is a basic factor in economic development. If no adequate supplies exist, economic losses result. Manpower is wasted, production may decline of goods and foods, fire protection may become impossible and other urban improvement schemes such as housing and urban sanitation may fail.

Generally the pollution of water with human wastes is the chief reason for the spread of the enteric diseases. Such pollution constitutes a potential health hazard in all densely populated areas where drinking water is not supplied through a pipe network from properly treated supplies.

The primary uses of water are drinking, cooking, washing, and as a vehicle for the transport of human wastes. The largest percentage of water is used for waste transportation in the sewer network.

# COMPONENTS OF THE WATER SUPPLY NETWORK



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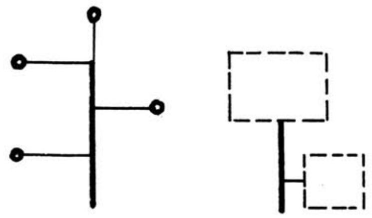
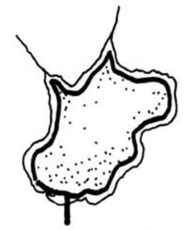
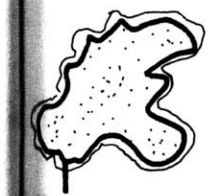
| |  |  |  |  |
| COMPONENT: | WELLS, SPRINGS, INFILTRATION GALLERIES | WATERSHED AREAS | ES, RIVERS | RAINFALL |
| FUNCTION: | receives water from underground seepage | receives water from surface runoff | eives water from natural llection source | receives water from rainfall |
| RESPONSIBILITY: | dependent on scale; large scale developer furnishes; small scale individual | developer installs, finance and maintains as needed | eloper finances as need- | usually individual responsibility |
| CONTROL: | collection systems deeded to | city in all cases<br>regional board controls | ional board trols | individual controls |
| CHARACTERISTICS: | system dependent on soil and geological conditions; generally used for individual use<br>best for large lots over 1,000 $m^2$ | size is dependent on rainfall, evaporation rate, and runoff<br>hilly terrain is best for use of the catchment area<br>a 25-50 year design period | t common system very large urban as | rarely used in urban areas<br>only used if no other alternative |
| SCALE OF DEVELOPMENT: | densities less than 10/ p/ha. if individual; suburbs 25,000 to 50,000 population if city system | supply determines scale<br>cities over 500,000 | ification cost determines scale; ies over 500,000 | usually individual dwellings |
| EXAMPLE OF USE: | Memphis, Tennessee | New York, Boston | cago | Bermuda |
| ADVANTAGES: | low cost | large scale econmical supply | imited supply | |
| DISADVANTAGES: | pollution danger; forced to connect to city system if individual well; wells drop water table level | dry seasons may affect supply; may require long distance transmission lines | be highly polted | dependent on weather; dry seasons may limit supply |

# TRANSMISSION LINES

| COLLECTION | - | **TRANSMISSION** | - | TREATMENT | - | DISTRIBUTION |
|---|---|---|---|---|---|---|

COMPONENT: Transmission lines

FUNCTION: conveys water from collection source to area of use; generally from watershed areas or distant lakes not used in connection with wells, adjacent lakes.

RESPONSIBILITY: developer finances and installs

CONTROL: deeded to city

CHARACTERISTICS: generally composed of pipe sizes over 24" or large covered channels; 48" not an uncommon size of pipe. For this use, New York City uses 180" & 204" pipe.

gravity flow systems mostly used and are the most economical. Sometimes the water is pumped if necessary. 20-25 yr. design period.

transmission lines should be kept to a minimum in length because of the high cost for installation.

SCALE OF DEVELOPMENT: determined by supply available, distance determined by the size of pipe and resultant pressure loss of transmission lines.

# TREATMENT SYSTEMS

COLLECTION - TRANSMISSION - **TREATMENT** - DISTRIBUTION

| | |
|---|---|
| COMPONENT: | Filtration plant |
| FUNCTION: | renders water in a more desirable form for consumption. generally water from lakes, rivers and watershed areas require treatment. |
| RESPONSIBILITY: | developer finances and installs |
| CONTROL: | deeded to city; American Public Health Service controls quality in the U.S. |
| CHARACTERISTICS: | treatment process consists of removing solids and purifying. Objectionable taste, odor, temperature and color are altered to desired quality of water. |
| | a service storage system is generally used to store the water supply after purifying. |
| | prime but remote areas may be developed by staging the filtration system. Only initial needs are met; they may then be economically annexed by the city as expansion occurs. |
| | initial costs are high. |
| | 20-25 year design period |

TREATMENT SYSTEMS - CONT'D.

STEPS IN PROCESS OF TREATMENT:

aeration: oxidation of iron, removal of $CO_2$ and other dissolved gases, and addition of oxygen to water

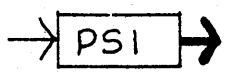
sedimentation: settling out of heavy suspended matter; process speeded by addition of $ALSO_4$ to coagulate colloidal matter

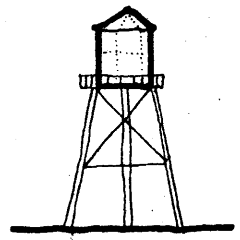
filtration: removal of solid particles

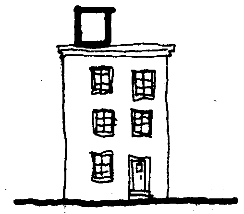
disinfection: addition of chemical which kills bacteria causing disease; usually chlorine is used.

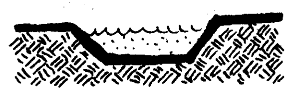
Treatment plants generally have a capacity of 1/2 to 1/3 of the required capacity for the system.

SCALE OF DEVELOPMENT: Limited by supply and cost which developer is willing to assume.



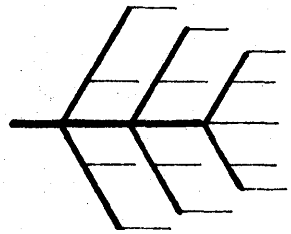
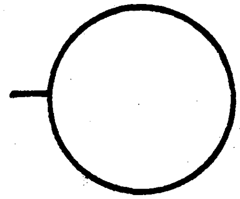
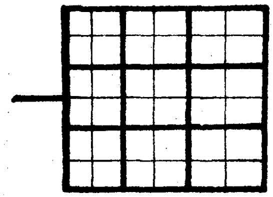







| COMPONENT: | BOOSTER PUMP | WATER TOWER | WATER TANK | RESERVOIRS |
|---|---|---|---|---|
| FUNCTION: | increase of line pressure for better service | communal scale backup supply; provides pressure also; | individual scale backup supply; also provides house pressure backup | stores water till use, controls fluctuations in supply and pressure |
| RESPONSIBILITY: | developer finances and installs | | individual | developer installs |
| CONTROL: | deeded to city | deeded to city | individual | deeded to city |
| CHARACTERISTICS: | generally raises pressure to increase distance and height of flow<br><br>used to maintain required pressure | pumps are used to fill towers<br><br>regulate flow if service is irregular or pressure varies<br><br>capacity: one to three day supply also used for fire storage<br><br>standard tanks are 50' diameter at 1 million gallons and 90' diameter at 2 million gallons<br><br>welded tanks available at 50,000 to 500,000 gallons | pressure when available fills tanks<br><br>regulates flow when service is highly irregular or pressure drops during peak conditions<br><br>capacity: one days supply | usually covered to keep out impurities<br><br>one to three day storage required<br><br>supply also used for maintenance of the fire supply<br><br>generally positioned on high elevations<br><br>filled by pumping or transmission line pressures |

## DISTRIBUTION SYSTEMS

| | | | |
|---|---|---|---|
| COMPONENT: | Tree system | Radial system | Grid system |
| RESPONSIBILITY: | developer | finances and installs | |
| CONTROL: | deeded to city | in all cases | |
| CHARACTERISTICS: | usually in low density, outlying regions. | surrounds several city blocks | most common system in urban areas |
| | dead ends need constant flushing to prevent bacterial growth | usually includes backup feeder pipes to augment flow | a hiearchial system, nested sizes increase as system grows in scale. |
| | min. main: 8" with 2", 4" or 6" feeders (USA) | | system is composed of tree and radial networks. |
| | usually a single main trunk, reducing in diameter as the pipes are located farther from the source. | | |
| SCALE OF DEVELOPMENT: | Best for a linear city growth pattern | relatively small scale | relatively large scale |

DISTRIBUTION SYSTEMS - CONT'D.

| | | | |
|---|---|---|---|
| ADVANTAGES: | avoids duplication of large feeder lines | provides flow backup if break occurs, allows easy maintenance, fits pattern of streets easily. | |
| DISADVANTAGES: | water liable to quick stagnation<br><br>No cross connections in reserve for repairs<br><br>usually difficult to size for fire flows | | Many duplicate lines<br><br>No clear idea as to how water flows in system |

# COMPONENTS REQUIRED IN NEW URBANIZATION

A developer is generally faced with three alternatives for the distribution of water for a proposed urbanization.

1: Connection to an existing system

2: Development of a new system

3: Reliance on individual systems

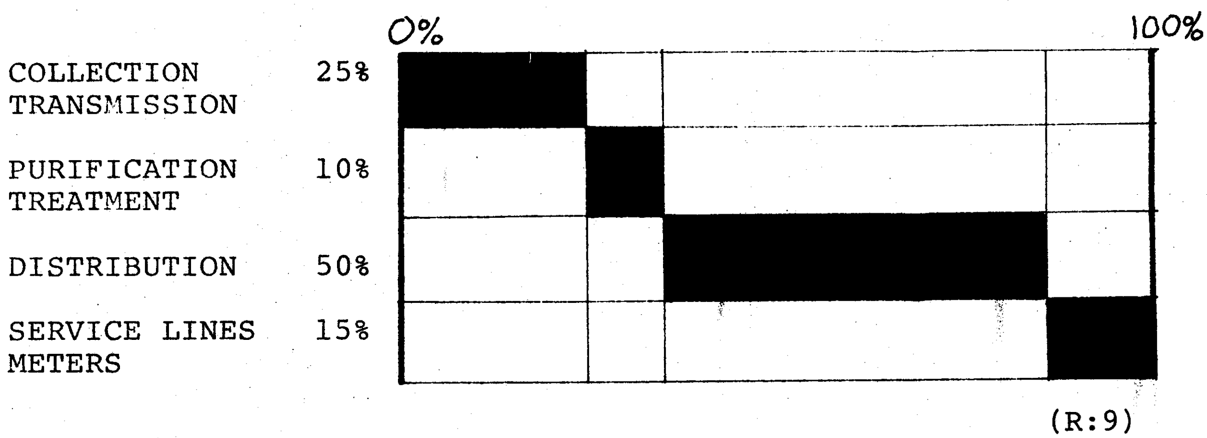
Whether the site under consideration is located within a major distribution grid, as in an urban area, or outside a major distribution grid, as in newly developed fringe areas, the alternatives remain the same. The various components necessary for each decision are illustrated in the following chart.

## REQUIRED COMPONENTS

### WATER SUPPLY SOURCE

| | EXISTING WATER SYSTEM | NEW SYSTEM | INDIVIDUAL SYSTEM |
|---|---|---|---|
| COLLECTION | not applicable | best source from rivers, lakes. well fields are more expensive | wells, cisterns |
| TRANSMISSION | (required if outside distribution area) | transmission lines should be minimized because of cost | not applicable |
| TREATMENT | not applicable | must meet U.S. public health standards | (sometimes chlorine treatment necessary) |
| DISTRIBUTION | connection of new system of mains and services to existing grid;might require pressure boost pumps | new distribution grid of mains and services must be laid | pumped flow to dwelling required |
| SCALE OF DEVELOPMENT | limited by city supply available; min.economical density: 10/ha. | limited by water supply and amount invested; min. economical density 10 p/ha. | individual lots; less than 10 p/ha. |
| ADVANTAGES: | lower costs, a proven reliable system | no dependence on city system if the supply is inadequate or faulty | an economical supply |
| DISADVANTAGES | if city supply is faulty, reliance on bad system | high first cost; duplication of city system | seasonal variation possible, danger of pollution, must tie-in with city |

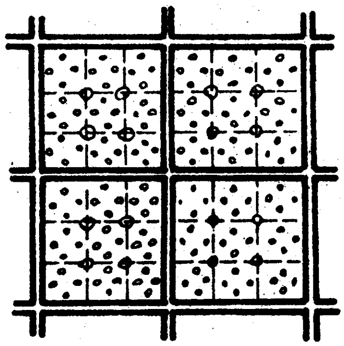
## RELATIVE COST OF COMPONENTS




The total first cost for a system is approximately $300 per person in the United States, based on estimates in 1965.

This figure may be contrasted with costs of $25 per person in developing countries as recommended by the World Health Organization in 1965. One must keep in mind, however, that consumption per person is appreciably lower and the type of service demanded is of a different standard in developing countries with predominately low income sectors.

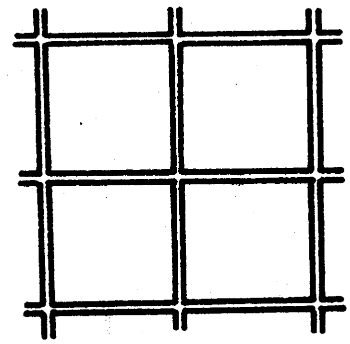
DISTRIBUTION SYSTEM



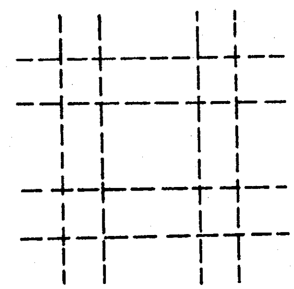
COMPONENTS OF THE SYSTEM

patterns

Distribution Mains

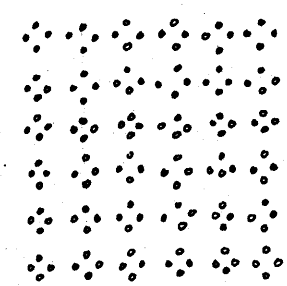


Distribution Lines



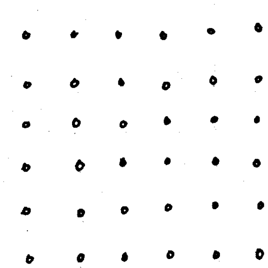
Distribution Points

1: Communal
2: Individual

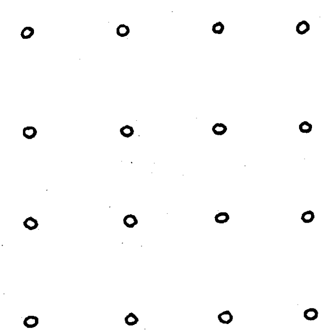


Control Elements

1: Meters
2: Free flow
3: Valves

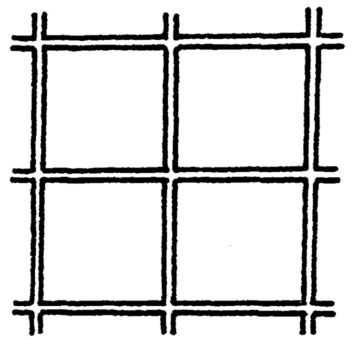
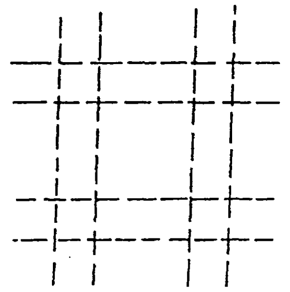
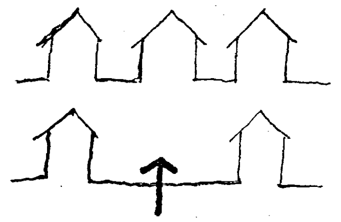
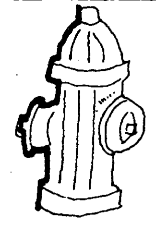


Fire Hydrants



DISTRIBUTION COMPONENTS

ACCESS POINTS

| |  |  | INDIVIDUAL<br> | COMMUNAL<br> | | |  | |
|---|---|---|---|---|---|---|---|---|
| COMPONENT: | DISTRIBUTION MAINS | DISTRIBUTION LINES | SERVICE LINES | STANDPIPES | FLOW METERS | FREE FLOW CONNECTIONS | FIRE HYDRANTS | VALVES |
| FUNCTION: | Supplies water to distribution lines | supplies water to house lines | supplies water to individual dwellings | supplies public faucet | controls flow of water | allows use of any amount; controls by cost of water | accessible water sources to smother fires | provides maintenance and failure cutoffs |
| RESPONSIBILITY: | developer finances and installs, if oversized (for expansion) city usually contributes to costs | | house lines are individual | installed by city or developer | individual | | installed by developer | |
| CONTROL: | deeded to city in both cases | | house lines are individual | deeded to city | | flat rate of water per time unit | deeded to city | |
| CHARACTERISTICS: | pipe sizes 12" and over are considered mains (U.S.)<br><br>max. pressure of 130 psi, 40 average, 20 psi min.<br><br>sized with 250 gpcd capacity<br><br>usually cast or spun iron; asbestos-cement, pvc or reinforced concrete also used<br><br>designed for peak daily flows<br><br>20-25 year design capacity<br><br>average miles of mains per 1000 population: 2.6: range: 0.7 to 5.3 in small communities | generally pipe sizes of 6"; also 2", 4" and 8"<br><br>pressure ranges from 20 to 60 psi, 40 average<br><br>designed for peak hourly flows<br><br>2": not suitable for extension;<br>4": not suitable if growth of demand;<br>6"; for bulk flows, extensions<br>8": for reinforcement lines | 3/4" min. house pipe USA Code; to 1 1/2"; sometimes 1/2"<br><br>min. pressure 8 psi for fauc flow<br><br>capacity varies from 20 to 150 gpcd (US)<br><br>copper most common pipe; steel, lead and pvc also used in pipes<br><br>designed for probability of use per minute<br><br>designed for full use | pipe size determined by expansion potential<br><br>capacity of 1.5 to 5 gpcd, dependent on distance from standpipe. 5 gpcd standard<br><br>designed for temporary use of full development | use of meters cuts use of water by approximately one-half<br><br>requires extra pressure for operation, high friction loss<br><br>first cost is high, $35-70 (US)<br><br>recommended when cost of operation high, quantity of water limited, and treatment of water required | usually higher water use than if with metered by a factor of 2<br><br>does not require extra pressures for operation<br><br>no installation costs<br><br>recommended if there is an inefficient collection and reading service and if water is relatively cheap and available | may only be placed on 6" pipe for adequate flow capacity<br><br>pressures of 20 to 60 psi allowed if fire department have pumper trucks; pressures above 60 psi necessary if no truck augumentation available<br><br>fire flows of approximately 175-250 gpm required, dependent on size of community and value of area<br><br>spacing of hydrants from 60 m. to 125 m., dependent on property value; usually placed at street intersections | usually placed at intersections<br><br>spacing is 100 m to 200 m. |
| SCALE OF DEVELOPMENT: | 400/600 meter distribution grid | each block of development | individual dwelling | 100 to 300 meter | | | | |

## QUANTITY OF WATER DEMANDED

DETERMINANTS: The quantity of water used by an area or by a person determines the supply necessary which the collection facilities must furnish. The quantity of water varies with several factors.

1. size of community
2. location of community in relation to climatic conditions; cities in northern areas generally use more water than comparable cities in the south.
3. rainfall; the more rainfall, the lower the water use since less water is expended for gardens and lawns.
4. character of an area; three classifications are used in connection with water demands: industrial, commercial and residential; residential areas may be broken down into high, medium and low cost areas, low cost areas generally use less water.
5. pressure; the higher the pressure, the more water used; more water is lost through leaks and the waste of water is increased in the faucets.
6. quality; better quality of water is known to instill confidence in its users and result in an increased use.
7. air conditioning; the seasonal demand of water for air conditioning use increases usage by as much as 5 to 7 times.
8. sewers; the installation of sewers increases water use from 50% to 100%.
9. cost of water; slight variations of water use are noted as the cost of water decreases.
10. use of meters; installation of meters decreases use by approximately 1/2.
11. rise in standard of living.

QUANTITY OF WATER DEMANDED - CONT'D.

MAIN DETERMINANTS:

1. Future population estimates, dependent on growth rates, migration shifts, etc.
2. Design year of system selected; a 20 year system must be designed larger than a 10 year system.
3. Per capita consumption of water.

UNITS:

- gallons per person per day: usual means of measurement
- acre feet of water: used in storage areas, reservoirs
- gallons per minute: rate of water demand.

DESIGN IMPLICATIONS:

The developer must know the area in which he is building in order to adequately judge the amount required, past use of neighboring areas may be used as guidelines.

When planning for various projects with variable income characteristics, the developer must include future potential use as standards of living rise, with the increase of air-conditioners, more pumping fixtures, and if not previously included, sewer lines.

# WATER DEMAND PER PERSON PER DAY

| | Per Person Per Day | | |
|---|---|---|---|
| | Liters | Gallons | |
| Physiological minimum | 1 | (1 quart) | |
| Communal Standpipe (varies with dist.) | 6 | 1.5 | Min. subsistence |
| | 20 | 5 | |
| | 40 | 10 | |
| Minimun, individual faucet, metered (US) | 80 | 20 | |
| | 120 | 30 | CINVA |
| | 160 | 40 | AID<br>WHO |
| Average use (US 1966) | 200 | 50 | |
| Single family dwellings (US 1960) | 240 | 60 | |
| | 280 | 70 | |
| | 320 | 80 | |
| | 360 | 90 | |
| Luxury dwellings (US 1960) | 400 | 100 | |
| | 440 | 110 | |
| | 480 | 120 | |
| | 520 | 130 | |
| | 560 | 140 | |
| | 600 | 150 | |

STATIC DEMAND constant per unit of pop.

RISING DEMAND due to higher standards and change in lifestyles

Range of use in the United States: 35 to 546 gallons/person/day

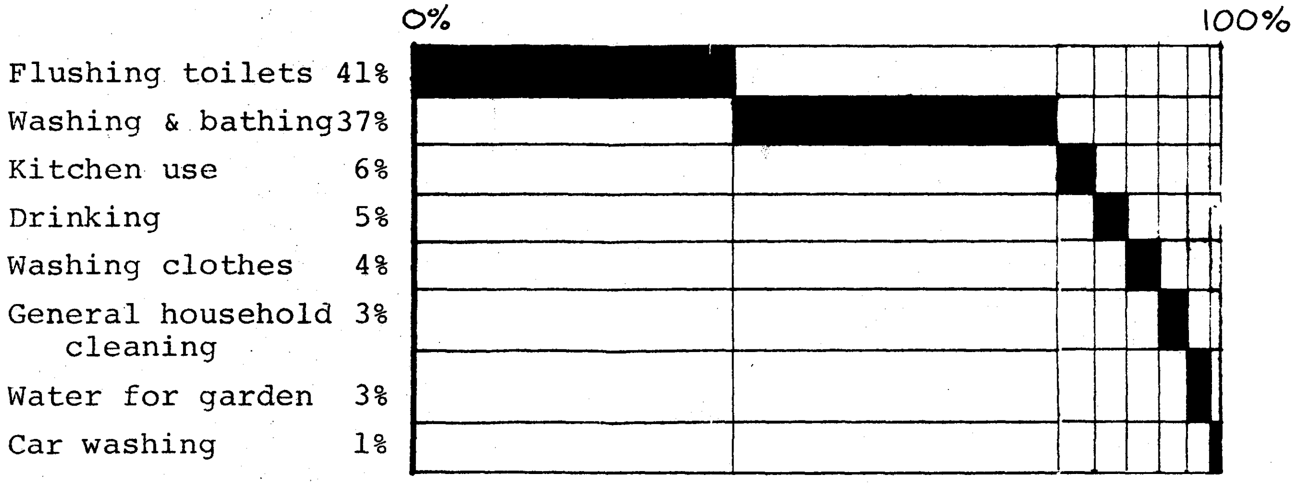
Range of use in England: 20 to 40 gallons/person/day

## OTHER WATER CONSUMPTION VALUES

| FACILITY | GALLONS PER DAY | UNIT | COMMENTS |
|---|---|---|---|
| SCHOOLS | 15 | per pupil | without gym, showers, cafeteria |
| | 25 | per pupil | with gym, showers, cafeteria |
| STORES | 400 | per toilet room | |
| OFFICES | 15 | per worker | |
| RESTAURANTS | 7 | per patron | without bar |
| | 12 | per patron | with bar |

Based on US standard practice (R:46)

PERCENTAGE USE OF DOMESTIC WATER




Based on study of 100 largest cities in the United States, 1962.
(R:9)

The major water use by the water closet should be re-examined in light of alternative disposal methods. The savings here would almost double the number of consumers which may be supplied with water.

## QUANTITY OF WATER FOR FIRE FLOWS (US)

Although the amount of water used yearly for fire fighting is small, the amount required for adequate protection for the area in the U.S.A. usually determines the size and supply of the entire system, especially in the smaller towns. Pumps, pipe sizes, supply requirements and storage facilities are all sized for the fire flow and usually not for the demands of per capita consumption.

| | |
|---|---|
| HYDRANT FLOW REQUIREMENTS: | minimum of 175 gpm in low risk areas;<br>250 to 300 gpm in high risk areas;<br>(four are required per area)<br>600 gpm used in normal design at each hydrant |
| SYSTEM FLOW REQUIREMENTS: | dependent on population and general structural conditions of area.<br>1,000 gpm for 1000 population<br>12,000 gpm for 200,000 population with max. of 20,000 gpm. |
| DURATION OF FIRE FLOWS: | five hours for towns of less than 2,500 population;<br>ten hours for larger cities. |

PRESSURE REQUIREMENTS: 20 psi minimum if mobile pumpers available (usually found in large cities); over 60 psi if pumpers not used (usually found in small cities); in some cities separate high pressure lines are located in areas of high intensity/high land value which are primarily used for fire fighting; booster pumps are used by some cities to augment the system pressure when a fire develops; waste losses are reduced and simpler operations result (found in medium to large cities).

The maximum amount of water needed in a system is the sum of the fire flows and the demands of the population. In practice, usually 40 gallons per person are added to take care of fire requirements, in the belief that the chance of a fire and the maximum peak demand of consumption are unlikely to occur at the same time.

It is estimated that 60% of the pipe network cost is due to oversizing of the system for fire flow standards. Perhaps other techniques as foam or fog systems for controlling fires should be investigated for smaller communities.

British requirements are not standardized nationally, but are left to each water system to decide. Usually the system is not designed for fire flows and the demands of consumption are first met; fire flow requirements are secondary. Therefore, it is not surprising that 50% of all pipes in London are 4'; whereas 6" is standard in the U.S.

The importance of fire flows in the United States context should not be underrated. The pipe network, the water source, hydrant spacing and even appointment of water officials are some of the criteria used in judging municipalities by the Fire Underwriters. A deficiency scale of one to ten is established by the Underwriters by which each community is rated. A low rating results in high fire insurance premiums for the city and its residents.

The cautious attitude toward fire dangers in the United States is understandable when onelooks back into its brief 200 year history. It will be seen that most of the major cities have suffered a severe or complete fire loss. San Francisco, Chicago and Boston are but a few that have suffered intensive damage due to fires. Perhaps the local availability of wood and its extensive use in structures allowed these holocasts to occur. Today, however, fire proof buildings are required. Perhaps the fire requirements of the past should be re-evaluated in planning new developments.

# FIRE ENGINE STATION REQUIREMENTS

REQUIRED SPACING:

| ENGINE COMPANIES (companies with mainly pumper fire engines for ground level fires) | | LADDER COMPANIES (companies with mainly ladder equipment for upper story fire demands) |
|---|---|---|
| 1200 m. | high value districts requireing 9,000 gpm fire flows | 1600 m. |
| 1600 m. | high value districts requireing 4,500 to 9,000 gpm | 2000 m. |
| 2400 m. | high value districts requireing less than 4,500 gpm | 3200 m. |
| 3200 m. | average residential requiring less than 2,000 gpm fire flow | 4800 m. |
| 2400 m. | residential areas of more than 2,000 gpm 3 or more stories apartments | 3200 m. |
| 1600 m. | high value residential high density situation | 2000 m. |

RECOMMENDED LOCATIONS:
at intersections, off main streets, ample space from curbs

LOCATIONS TO AVOID:
near railroad tracks,other barriers, hillsides, on bottom of hills, on main streets, on one way streets

(R:46)

# PRESSURE REQUIREMENTS

FUNCTION:

The amount of pressure in the system determines the rate of flow, or velocity, of the water. The higher the pressure, the greater the volume of water that will pass a given point.

Pressure is lost through friction of the pipe walls, fittings and bends. Thus, indirectly, the amount of pressure determines the distance that water will flow through a given pipe. For example, a 6" pipe will serve dwellings for a distance of x meters at y pressure; if one doubles the pressure, the pressure of 2y will serve dwellings for a distance of approximately 2x meters.

SOURCES:

Pressure is the potential energy unit of water. Two ways are used to develop increased pressure.

1. Elevation: gravity provides the energy.

2. Pumping: energy is induced artificially through the transfer of energy from electrical or mechanical modes.

UNITS:

Feet of head: historical measure from a gravity source
Pounds per square inch (PSI): pressure per unit area
Kilograms per square centimeter: metric pressure per unit area

PRESSURE REQUIREMENTS - CONT'D.

CRITERIA:

1. Minimum pressure needed for faucet flow is 8 psi. Thus, a minimum pressure of 8 psi should remain at the farthest reaches of the network for satisfactory service. (US).
2. Adequate pressure must be in a system to service an entire network along the lengths of pipe used. The minimum standard in the USA is 20 psi.
3. Pipes should be sized to achieve a minimum pressure (or friction) loss. 3-5 ft. head loss per 1000 ft. for 24"; 25 ft./1000 for 4" pipe.
4. Pressures over 60 psi are not needed for fire flow requirements.
5. A pressure of 130 psi is considered to be the upper limit.

DESIGN IMPLICATIONS:

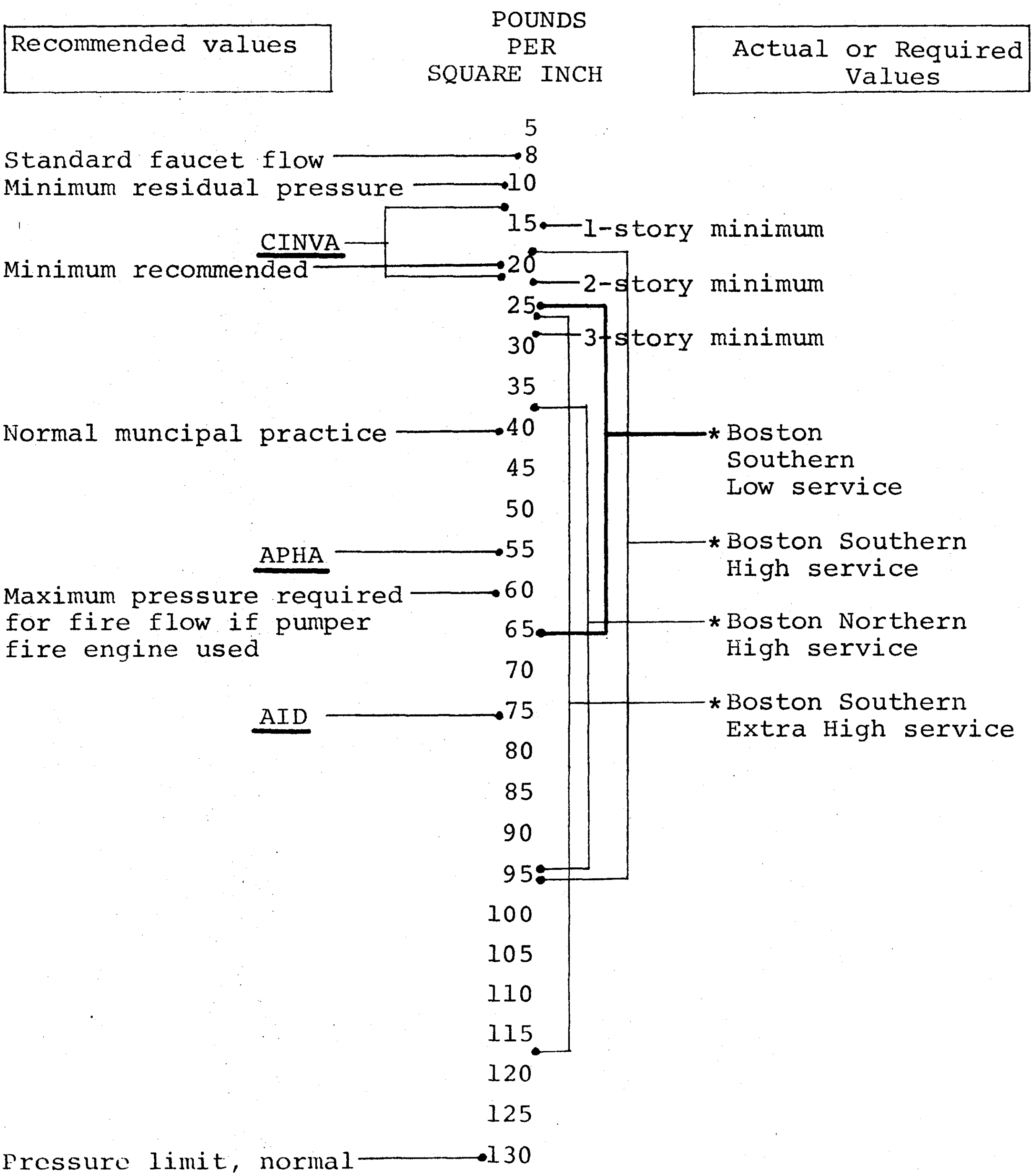
Pressure over 60 psi induces high leakage losses in a system.

The higher the pressure, the more water consumption per person.

Pressures over 60 psi necessitate stronger and consequently more costly pipe.

Since larger pipes have a smaller circumference to volume ratio, the friction (or pressure) loss will be proportionally less, so larger pipes allow greater lengths.

PRESSURE COMPARISONS




*High services are areas where elevation changes force higher than normal pressures in order to reach the peak elevations; elevation changes of more than 200' normally require separate service areas. (R:6,9)

## COMPARISONS OF PRESSURE REQUIREMENTS

| Housing Standard | Pressure Recommended |
|---|---|
| CINVA (Organization of American States) | 14 to 21 psi |
| APHA (American Public Health Association) | 55 psi |
| AID (Agency for International Development) | 75 psi |

Pressures above 60 psi require higher technical skills for jointing and proper pipe bedding. Stronger pipe and consequently more expensive pipe are required for the higher pressures. High pressures above 60 psi result in high leakage losses and increased consumption of water by the consumer.

In the U.S., 60 psi is the maximum recommended for a system if a pumper fire truck is utilized by the city. Pressures above 60 psi, and up to 130 psi, are recommended if the city relies on pipe pressures for fire fighting.

CINVA standards do not take into consideration fire flow requirements. The standards proposed are reasonable from technical proficiency aspects and use demands of developing countries.

APHA (US) plans for fire flows but the use of pumpers is required. Pressures are adequate for 4 to 5 story service as demanded in municipal areas.

AID standards, designed for low income developing areas, are impracticable. The system would be adequate for fire flows without the use of pumpers, which the case would be in developing areas. However, the technical skills needed for installation and the added expense of piping and water consumption nullify the gains for fire fighting. Developing areas are not likely to have a trained professional body of technicians available for water network installation. The higher costs of pipe and consumption are also not able to be justified when viewed from developing economic systems with their inherent capital shortages.

## LAYOUT OF WATER NETWORK

CRITERIA:

1. Adequate pressure of system to allow flow of water between grid spacing; dependent on pipe diameter, demand and initial system pressure.
2. Sufficient linkages in network to continue service to all dwellings in case of failure or fire demands.
3. Layout must respond to fire demand at all dwellings; the spacing of hydrants is based on the length of common fire hoses. Thus, networks must be within 100 meters of all dwellings or fire protected areas.
4. Networks must be sized to fulfill demands imposed on it from peak loads.
5. The network should use the minimum number of pipe sizes as possible.

STANDARD PRACTICE:

Main layout:

use of two smaller mains on separate blocks better than one large main

trunk mains (major feed lines) should not be located on major circulation routes

lines should be spaced 10' from sewers and at least 12" above sewer line to prevent infiltration

min. pipe size is 6" (U.S.).

Dead ends:

min. size is 8"; 4" are used for short runs (U.S.)

dead ends should be avoided if possible, fungus growth, high maintenance factors, regular cleaning of lines to inhibit stagnant water and poor fire fighting ability discourage common use.

## STANDARD LAYOUT PROCEDURE (US)

The standard layouts are based on fire flow parameters. The pipe sizes and the spacing are considered precise enough to only warrant the exact determination of the major supply lines.

GENERAL REQUIREMENTS:

Gate values are spaced every 240 meters; in high value areas spacing is 150 meters

Hydrants are spaced from 60 to 92 meters

A PSI of 30 is recommended; 20 PSI is accepted in non-peak hours; a residual pressure of 10 PSI is required

LIMITS OF ONE-WAY LAYOUT:

8" minimum dead-end size, no defined length limit

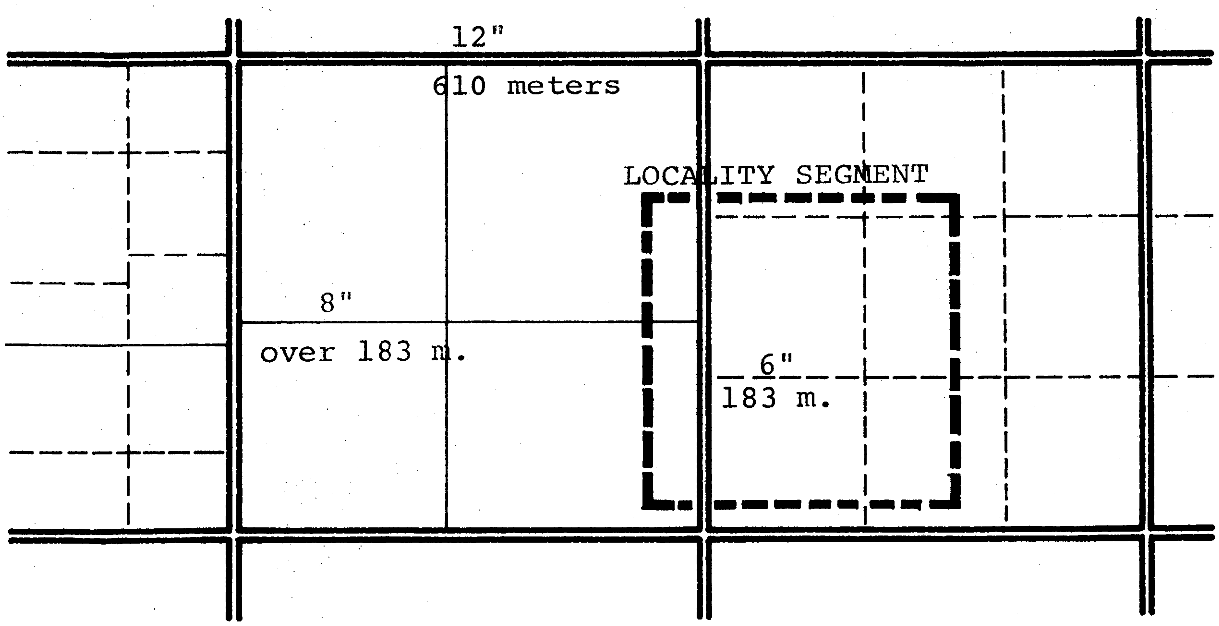
LIMITS OF TWO-WAY LAYOUT:

6" → - - - - ← 183 meters (smallest allowable pipe size)

8" → ———— ← over 183 meters; for high value areas

12" → ════ ← 610 meters; smallest main size

RESULTANT GRID LAYOUT:




(R:9)

## CALIFORNIA RECOMMENDATIONS WITHOUT FIRE FLOWS

This layout is developed for domestic use only; it will not meet standard fire flow conditions; pipe sizes of less than 6" will not support fire hydrant flow requirements.

LIMITS OF ONE-WAY LAYOUT:

2" → 92 meters

3" → 92 meters

4" → 400 meters

6" → 800 meters

LIMITS OF TWO-WAY LAYOUT: (maximum cross-main spacing is 183 m.)

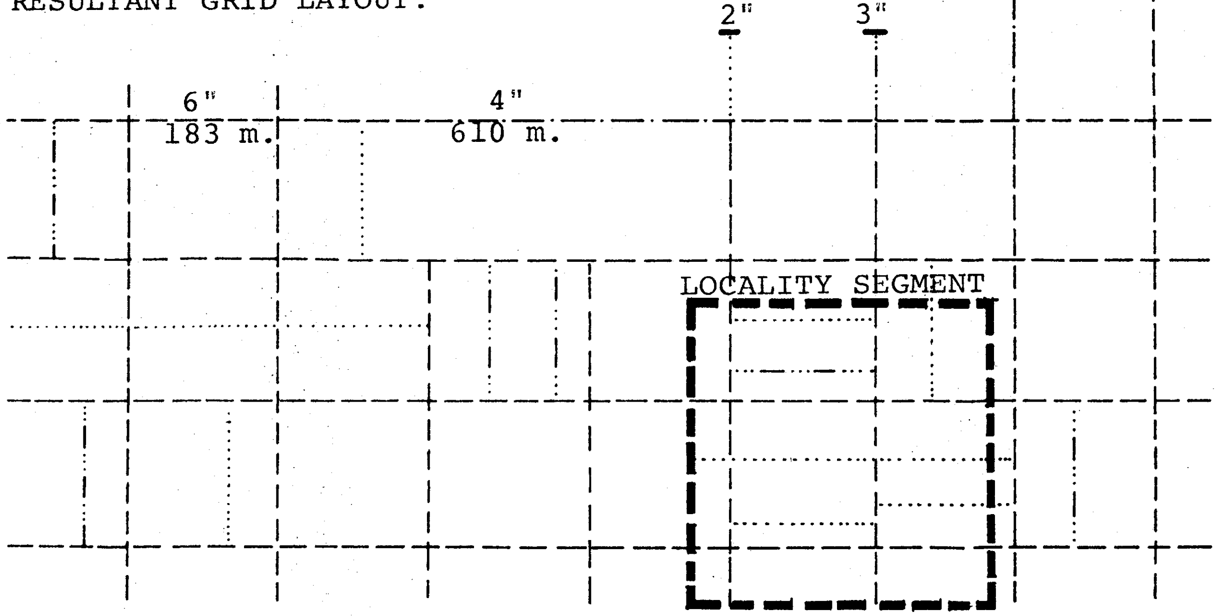
2" → ← 183 meters

3" → ← 183 meters

4" → ← 610 meters

6" → no defined limits

RESULTANT GRID LAYOUT:




(R:6)

CAMBRIDGEPORT, Boston

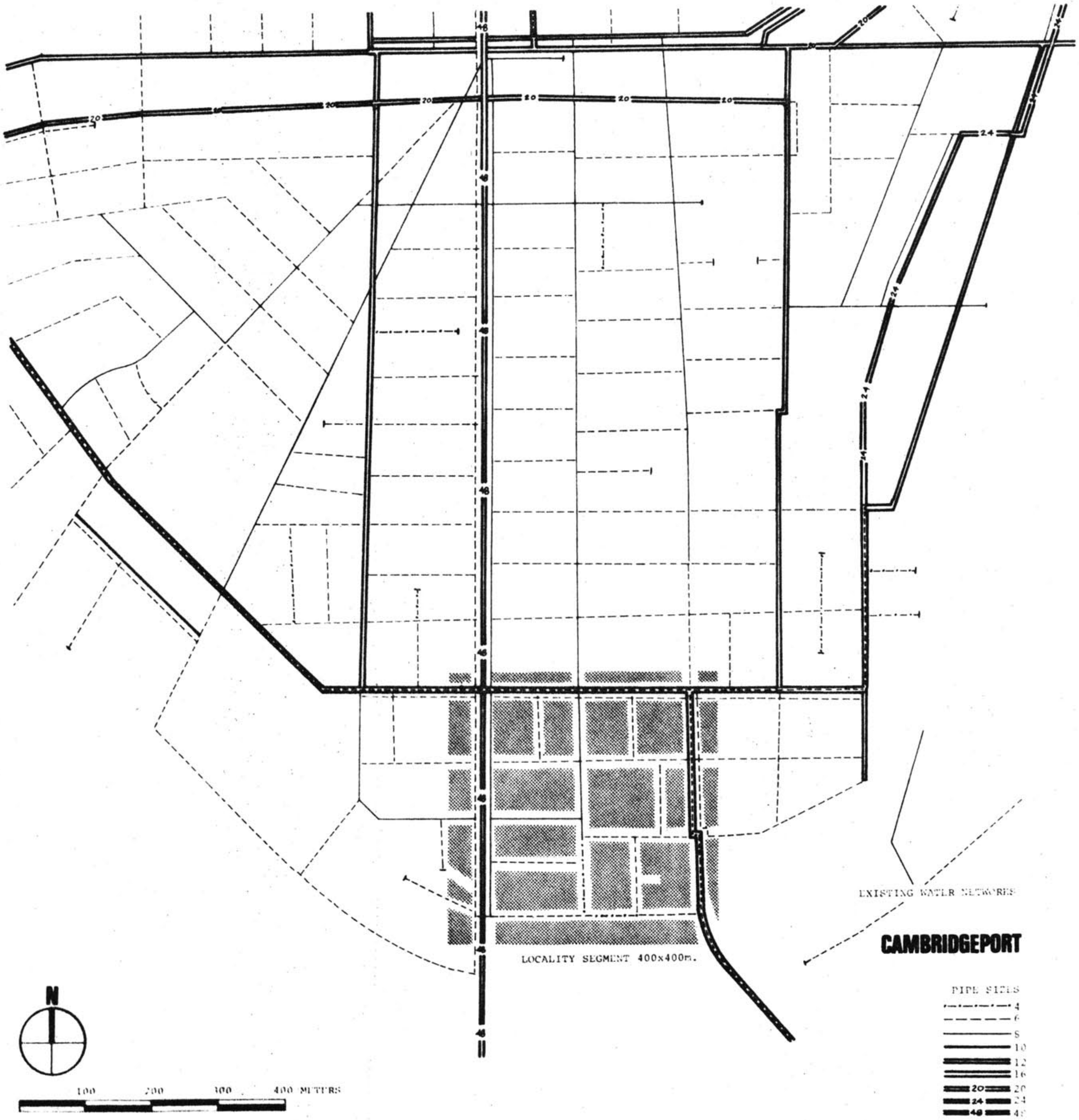
LOT AREA: 320 square meters

DENSITY: 80 people/ha.

20 dwellings/ha

AVERAGE INCOME: $5630/yr

(R:53)


EXISTING WATER NETWORKS
CAMBRIDGEPORT
PIPE SIZES
4
6
8
10
12
16
20
24
48
LOCALITY SEGMENT 400x400m.
N
100
200
300
400 METERS

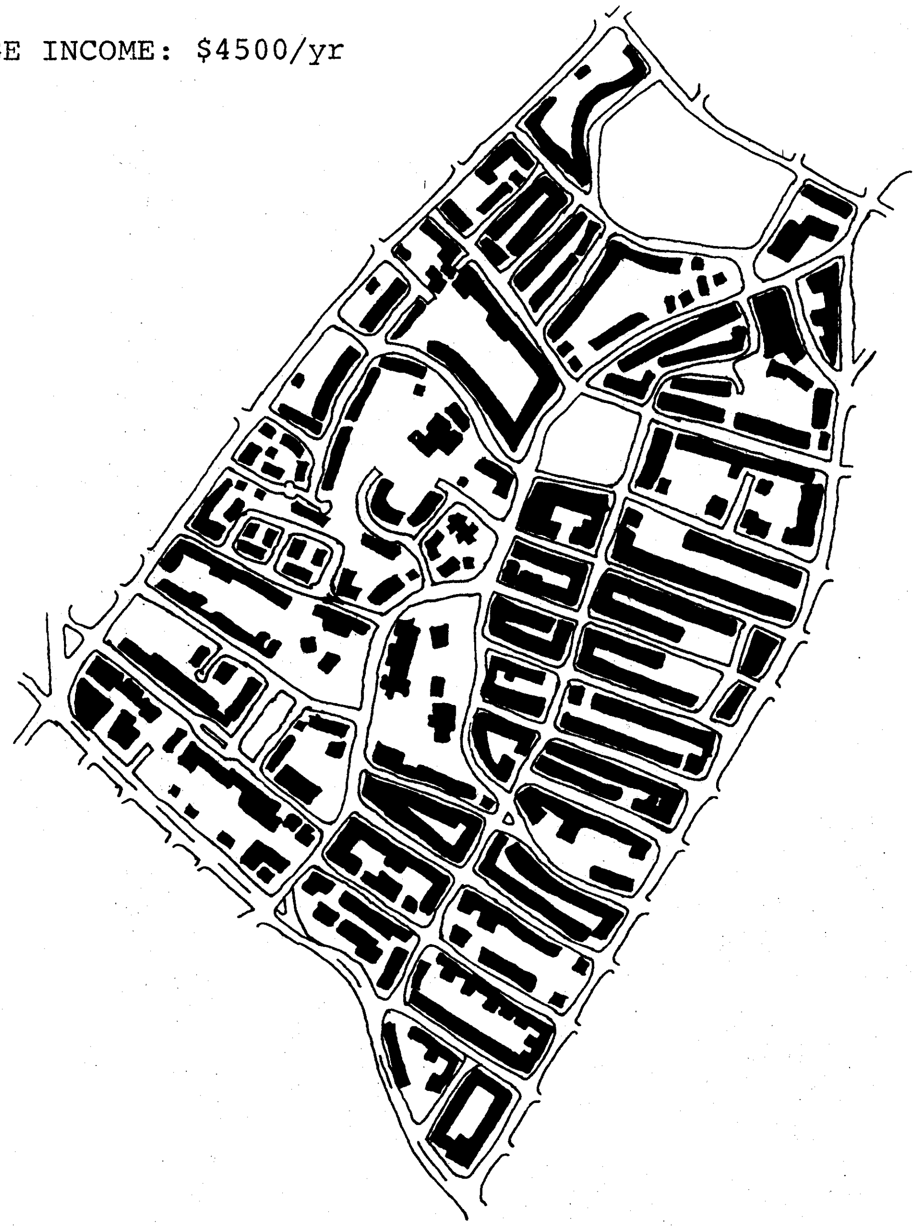
WASHINGTON PARK, Boston

LOT AREA: 243 square meters

DENSITY: 125 people/ha

31 dwellings/ha

AVERAGE INCOME: $4500/yr



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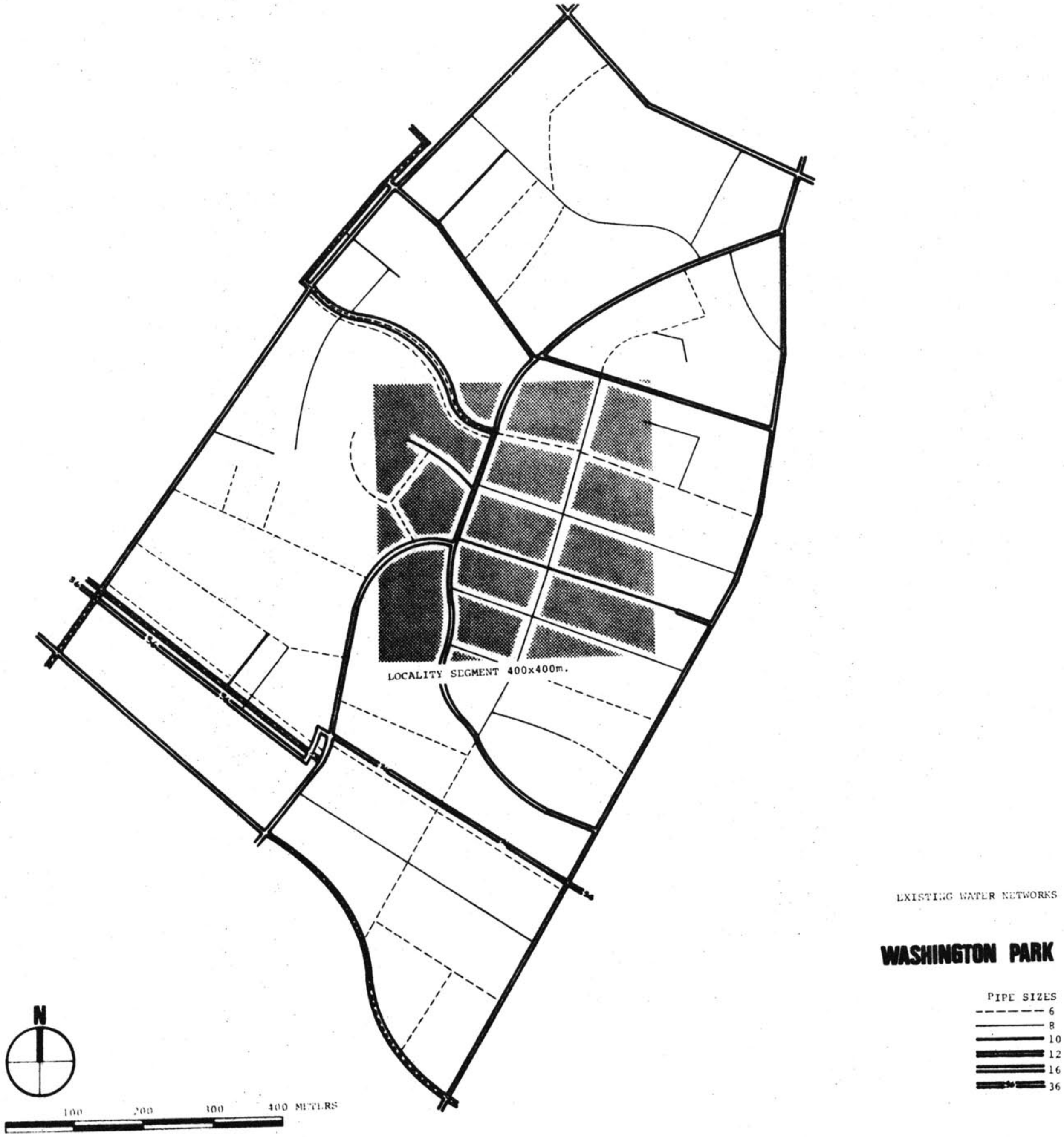

LOCALITY SEGMENT 400x400m.
N
100
200
300
400 METERS
EXISTING WATER NETWORKS
WASHINGTON PARK
PIPE SIZES
6
8
10
12
16
36

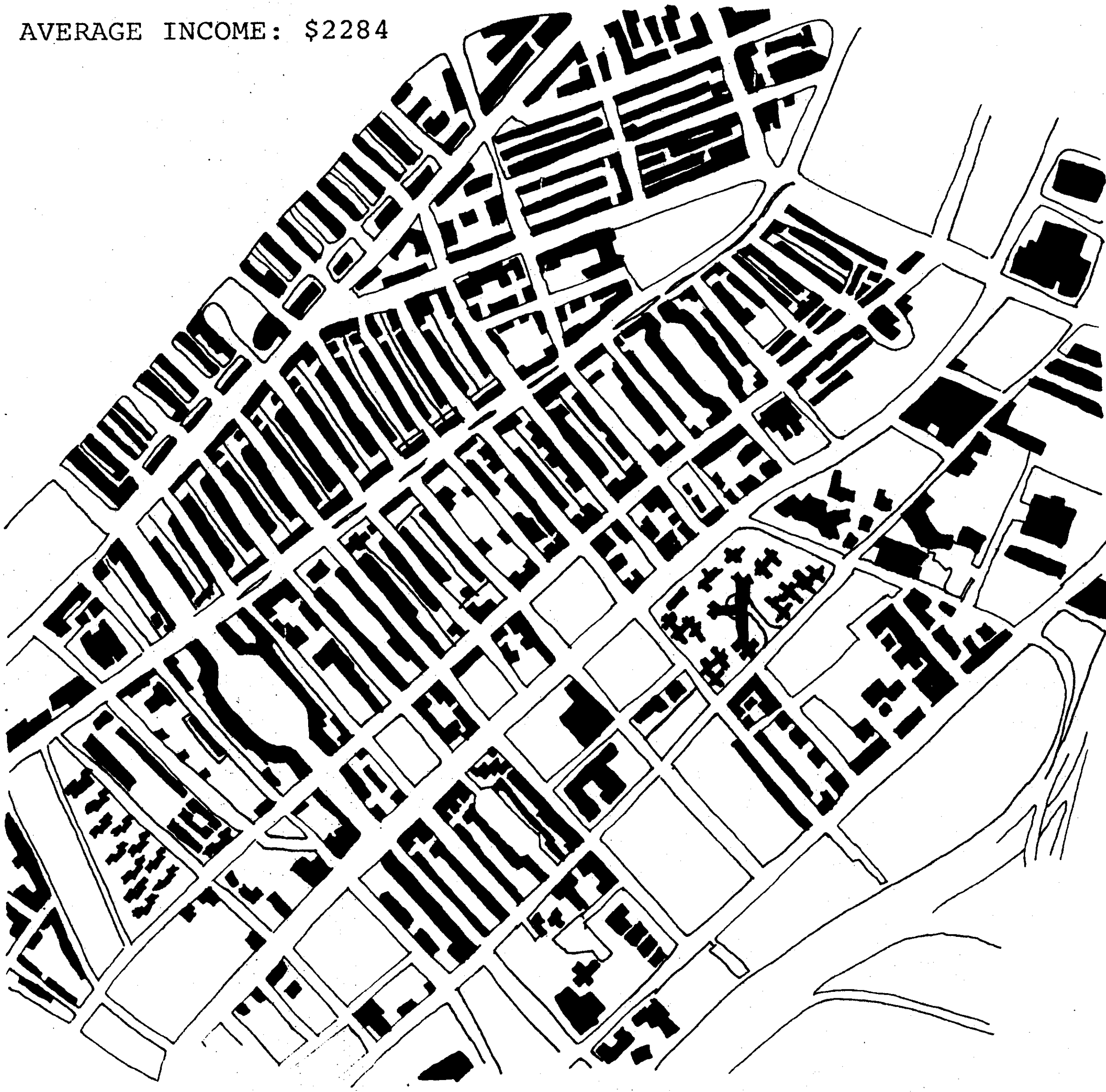
SOUTH END, Boston

LOT AREA: 144 square meters

DENSITY: 170 people/ha

100 dwellings/ha

AVERAGE INCOME: $2284



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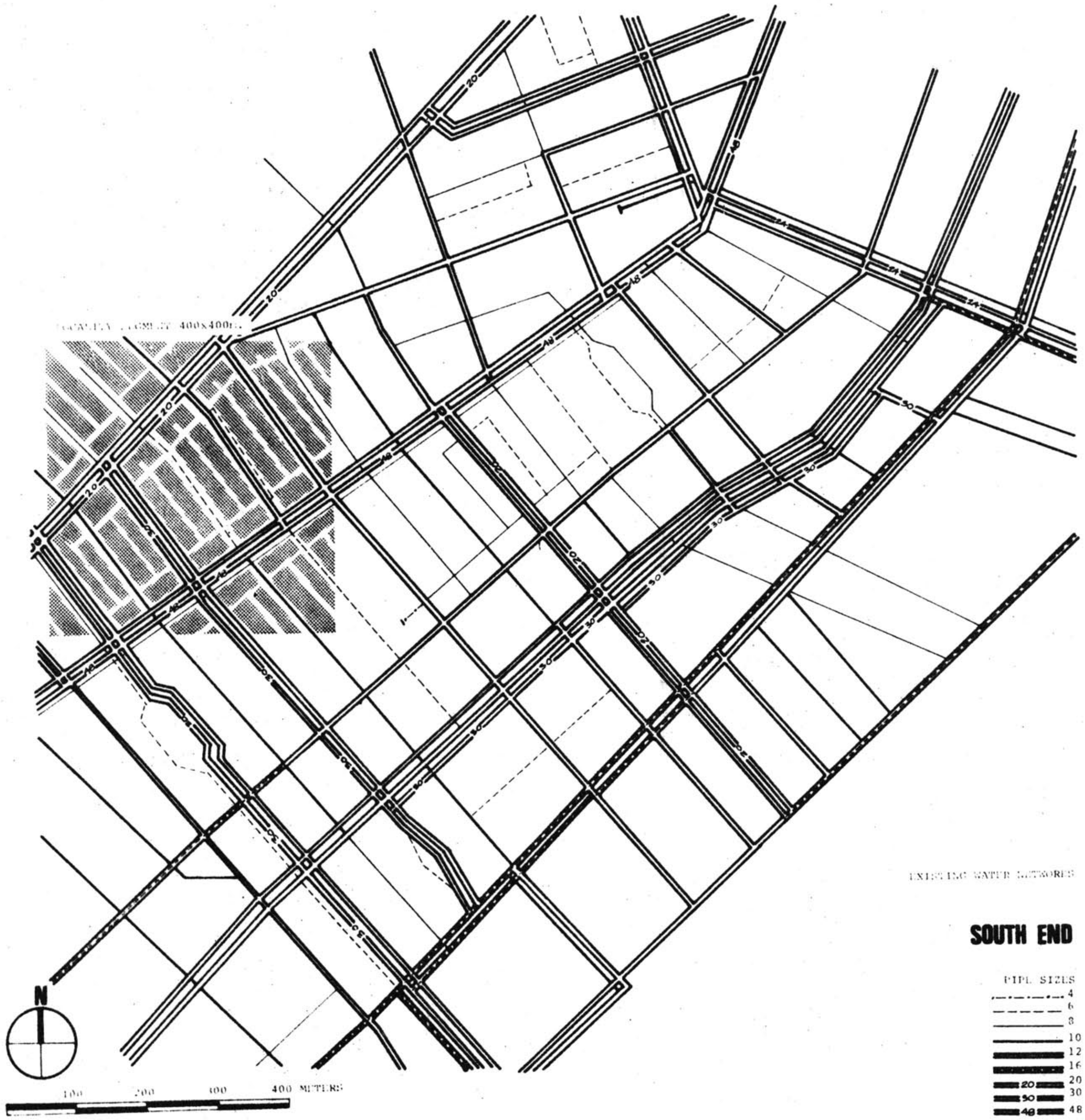
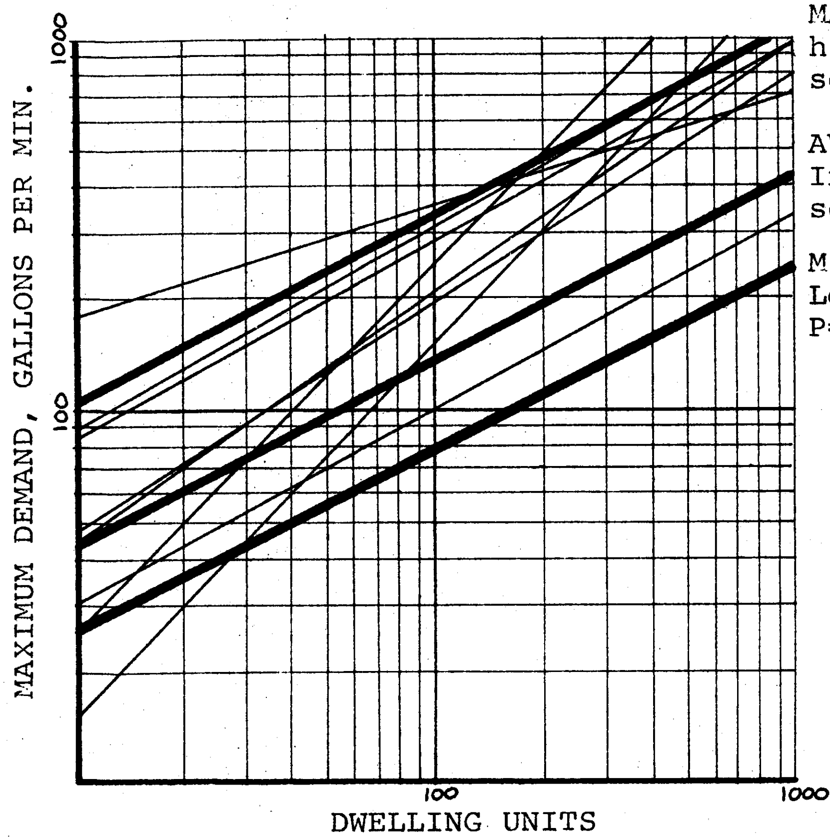

SOUTH END
PIPE SIZES
4
6
8
10
12
16
20
30
48
N
400 METERS

## SIZING OF PIPE LAYOUTS

The intent of this section is too give the planner an idea of the magnitudes and variables of pipe diameter to number of dwellings served

RELATION OF FLOW TO NUMBER OF DWELLINGS SERVED: P VALUES

This chart shows the various probilities of consumption related to the number of dwelling units as proposed by various authors. From this chart the quality of service, or 'P' value, is derived. The curve which best approximates the lines on the chart is the parabola: $(GPM)^2=2(P)(DU)$




MAXIMUM DEMAND CURVE
highest quality of service; P=500

AVERAGE DEMAND CURVE
Intermediate qualtiy of service; P=82.5

MINIMUM DEMAND CURVE
Low quality of service; P=12.5

CURVES AS PROPOSED BY VARIOUS AUTHORS

1. Maximum demand=9 x average daily flow
2. Maximum demand=100+25(no. of DU)$^{½}$ for less than 625, Calif.
3. Fixture unit basis,flush tanks;1 bath,10 f.u. per house
4. Kuranz; flush valve system
5. Kuranz; flush tank system
6. Taylor; small house, small lot, very little lawn sprinkling
7. Taylor; average 2-3 bedroom house, average lawn sprinkling
8. Fixture units; 2-bath house, 19 F.U. at peak discharge
9. Fixture units; 2-bath house, 19 F.U. average discharge

(R:6,159)

The graph is based on the average American family size of 3.0 (approximately) people per family. An average family population of 6.0 persons per family as found in many of the developing countries would not shift the graph down by a factor of two; but would increase the probability of use by some factor of less than two.

HIGHEST QUALTIY OF SERVICE: upper parabola curve of flow and dwelling relation; P=500.

A single dwelling unit is considered to use approximately 33 gpm at peak flow.

The dwelling would have:
- 2 bathroom groups
- 1 kitchen group
- 4 outdoor faucets
- 1 service sink
- washer, air conditioner, and lawn sprinkling

IMMEDIATE QUALITY OF SERVICE: middle parabola curve of flow and dwelling relation; P=82.5

A single dwelling is considered to use approximately 13 gpm peak flow.

The dwelling would have:
- 2 bathroom groups
- 1 kitchen group
- 2 outdoor faucets
- 1 service sink
- little lawn sprinkling, some washer use

MINIMUM QUALITY OF SERVICE: lower parabola curve of flow and dwelling relation; P=12.5.

A single unit is considered to use approximately 5 gpm at peak flow

A single unit would have the following:
- 1 water closet
- 1 kitchen faucet
- 1 bath faucet

## FORMULA USED IN DETERMINING FLOW VALUES

The Hazen-Williams formula based on empirical studies in the late 1800's is still accepted by hydraulic enginners as being a reasonable means of computation. Various of this formula have been proposed but most engineers resort to this formula in practical applications.

$$V=0.0131CH^{0.54}D^{0.632}$$

$$Q=0.0103CH^{0.54}D2.63$$

V=velocity in feet per second

C=coefficient of friction, varies with pipe interior and age; C=100

H=head friction loss, feet per 1000 feet of pipe

D=diameter of pipe in feet

Q=rate of flow in cubic feet per second

# NUMBER OF DWELLINGS PER GIVEN PIPE SIZE

PARAMETERS

## QUALITY OF SERVICE

Three levels of the quality of service are used:

1. High quality: P=500 above average dwelling in regard to water consumption
2. Intermediate quality: P=82.5 average water consumption per dwelling
3. Low quality: P=12.5 minimum consumption of water

## VELOCITIES OF FLOW

Velocity=2 feet per second
A minimum condition of water flow; below this value, water tends to stagnate and fine sediments settle out into the pipe network

Velocity=4 feet per second
Considered an economical flow for minimum friction loss with reasonable pressure requirements

Velocity=6 feet per second
Considered to be the upper economical range of water flow; above this value the high friction loss requires higher pressures with a greater pumping cost; higher pressures require stronger pipe and result in high water waste through leakage (flows may go up to 15-20 fps when fire flows dictate)

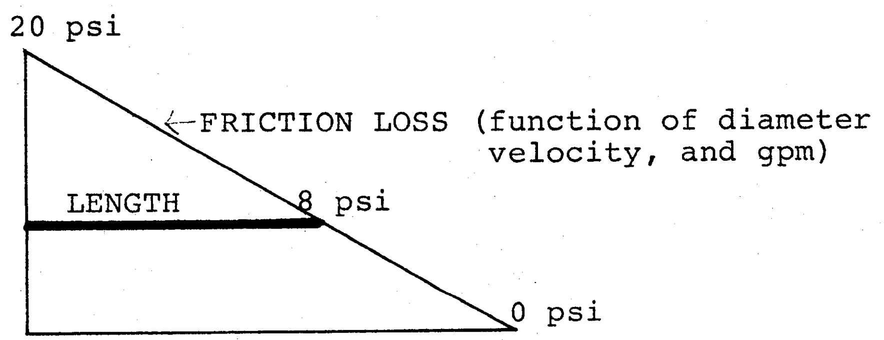
LENGTH

The length values are derived from the allowed friction loss, pipe diameter, and velocity parameters.

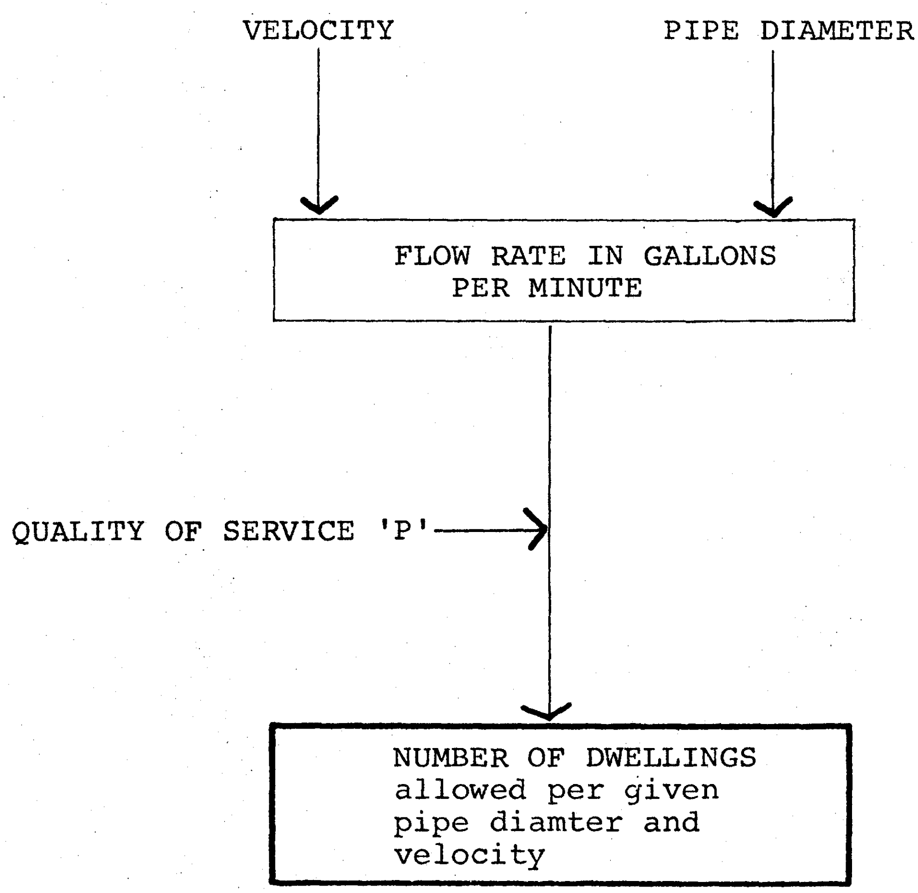
A pressure drop of 12 psi is considered to determine the length. Initial pressure in the most extreme case is taken to be 20 psi, the recommended lowest pressure in a residential situation. The end pressure is taken as 8 psi; the pressure required for proper faucet flow.

Fire flows are not considered in the determination of the length. An additional 600 gpm would be required to be added to the gpm derived from the velocity parameters.

The length is the maximum distance the water would flow in a one way system (feed from one end only) under the stated parameters.



# FLOW CHART OF DWELLINGS TO PIPE DIAMETER



VELOCITY= 2.

| | LENGTH | P VALUES= 12.5 | 82.5 | 500.0 |
|---|---|---|---|---|
| 1.INCH DIAMETER | 300. | 1. | 0. | 0. |
| 2.INCH DIAMETER | 676. | 16. | 2. | 0. |
| 3.INCH DIAMETER | 1086. | 79. | 12. | 2. |
| 4.INCH DIAMETER | 1521. | 248. | 38. | 6. |
| 5.INCH DIAMETER | 1974. | 606. | 92. | 15. |
| 6.INCH DIAMETER | 2444. | 1255. | 190. | 31. |
| 8.INCH DIAMETER | 3422. | 3963. | 600. | 99. |
| 10.INCH DIAMETER | 4444. | 9666. | 1465. | 242. |
| 12.INCH DIAMETER | 5501. | 20030. | 3035. | 501. |
| 14.INCH DIAMETER | 6588. | 37085. | 5619. | 927. |
| 16.INCH DIAMETER | 7703. | 63231. | 9580. | 1581. |
| 18.INCH DIAMETER | 8841. | 101236. | 15339. | 2531. |
| 20.INCH DIAMETER | 10002. | 154235. | 23369. | 3856. |
| 22.INCH DIAMETER | 11182. | 225730. | 34201. | 5643. |
| 24.INCH DIAMETER | 12381. | 319589. | 48423. | 7990. |
| 26.INCH DIAMETER | 13596. | 440049. | 66674. | 11001. |
| 28.INCH DIAMETER | 14828. | 591707. | 89653. | 14793. |
| 30.INCH DIAMETER | 16075. | 779543. | 118113. | 19489. |
| 32.INCH DIAMETER | 17337. | 1008897. | 152863. | 25222. |
| 34.INCH DIAMETER | 18611. | 1285445. | 194764. | 32136. |
| 36.INCH DIAMETER | 19899. | 1615289. | 244741. | 40382. |
| 48.INCH DIAMETER | 27865. | 5099264. | 772616. | 127482. |
| 96.INCH DIAMETER | 62715. | 81361488. | 12327500. | 2034037. |

VELOCITY= 4.

| | LENGTH | P VALUES= 12.5 | 82.5 | 500.0 |
|---|---|---|---|---|
| 1.INCH DIAMETER | 83. | 4. | 1. | 0. |
| 2.INCH DIAMETER | 187. | 62. | 9. | 2. |
| 3.INCH DIAMETER | 301. | 315. | 48. | 8. |
| 4.INCH DIAMETER | 421. | 993. | 151. | 25. |
| 5.INCH DIAMETER | 547. | 2423. | 367. | 61. |
| 6.INCH DIAMETER | 677. | 5021. | 761. | 126. |
| 8.INCH DIAMETER | 948. | 15852. | 2402. | 396. |
| 10.INCH DIAMETER | 1231. | 38666. | 5858. | 967. |
| 12.INCH DIAMETER | 1524. | 80119. | 12139. | 2003. |
| 14.INCH DIAMETER | 1825. | 148339. | 22476. | 3708. |
| 16.INCH DIAMETER | 2134. | 252925. | 38322. | 6323. |
| 18.INCH DIAMETER | 2449. | 404940. | 61355. | 10124. |
| 20.INCH DIAMETER | 2771. | 616933. | 93475. | 15423. |
| 22.INCH DIAMETER | 3098. | 902907. | 136804. | 22573. |
| 24.INCH DIAMETER | 3430. | 1278345. | 193689. | 31959. |
| 26.INCH DIAMETER | 3767. | 1760189. | 266695. | 44005. |
| 28.INCH DIAMETER | 4108. | 2366823. | 358609. | 59171. |
| 30.INCH DIAMETER | 4453. | 3118164. | 472449. | 77954. |
| 32.INCH DIAMETER | 4803. | 4035573. | 611451. | 100889. |
| 34.INCH DIAMETER | 5156. | 5141768. | 779056. | 128544. |
| 36.INCH DIAMETER | 5513. | 6461140. | 978961. | 161528. |
| 48.INCH DIAMETER | 7720. | 20396992. | 3090453. | 509925. |
| 96.INCH DIAMETER | 17374. | 325444864. | 49309856. | 8136126. |

VELOCITY= 6.

| | LENGTH | P VALUES= 12.5 | 82.5 | 500.0 |
|---|---|---|---|---|
| 1.INCH DIAMETER | 39. | 9. | 1. | 0. |
| 2.INCH DIAMETER | 88. | 140. | 21. | 4. |
| 3.INCH DIAMETER | 142. | 708. | 107. | 18. |
| 4.INCH DIAMETER | 199. | 2235. | 339. | 56. |
| 5.INCH DIAMETER | 258. | 5452. | 826. | 136. |
| 6.INCH DIAMETER | 320. | 11298. | 1712. | 282. |
| 8.INCH DIAMETER | 447. | 35666. | 5404. | 892. |
| 10.INCH DIAMETER | 581. | 86998. | 13182. | 2175. |
| 12.INCH DIAMETER | 719. | 180268. | 27313. | 4507. |
| 14.INCH DIAMETER | 861. | 333763. | 50570. | 8344. |
| 16.INCH DIAMETER | 1007. | 569074. | 86223. | 14227. |
| 18.INCH DIAMETER | 1156. | 911114. | 138048. | 22778. |
| 20.INCH DIAMETER | 1308. | 1388096. | 210318. | 34702. |
| 22.INCH DIAMETER | 1462. | 2031537. | 307809. | 50788. |
| 24.INCH DIAMETER | 1619. | 2876272. | 435799. | 71907. |
| 26.INCH DIAMETER | 1778. | 3960418. | 600063. | 99010. |
| 28.INCH DIAMETER | 1939. | 5325342. | 806870. | 133134. |
| 30.INCH DIAMETER | 2102. | 7015856. | 1063008. | 175396. |
| 32.INCH DIAMETER | 2267. | 9080024. | 1375761. | 227001. |
| 34.INCH DIAMETER | 2433. | 11568957. | 1752872. | 289224. |
| 36.INCH DIAMETER | 2602. | 14537543. | 2202658. | 363439. |
| 48.INCH DIAMETER | 3643. | 45893152. | 6953509. | 1147329. |
| 96.INCH DIAMETER | 8200. | 732250112. | 110946976. | 18306240. |

## DENSITIES OF A GIVEN PIPE GRID

The intent of this section is to show the resultant densities from variations of pipe diameters, water velocity, and size of area served. The density values are given in dwellings per hectare.

PARAMETERS: VELOCITY

Velocity of 2 feet per second:
Minimum condition of water flow to prevent stagnation and silting of pipes

Velocity of 4 feet per second;
Considered an economical flow for use in design of areas

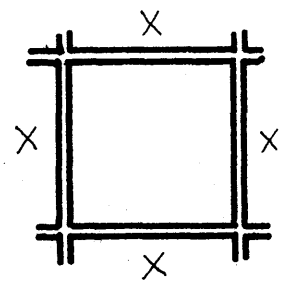
Velocity of 6 feet per second:
Considered to be the upper range of economical flows in pipes.

QUALITY OF SERVICE

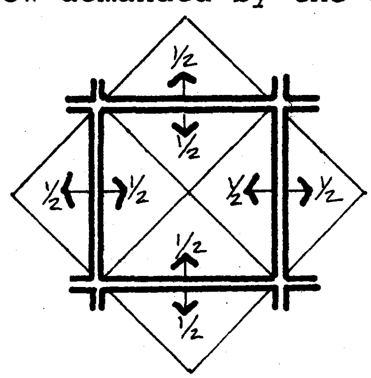
The three standard qualities of service are used: high, intermediate, and low.

THEORY OF FLOW INTO PIPE GRID

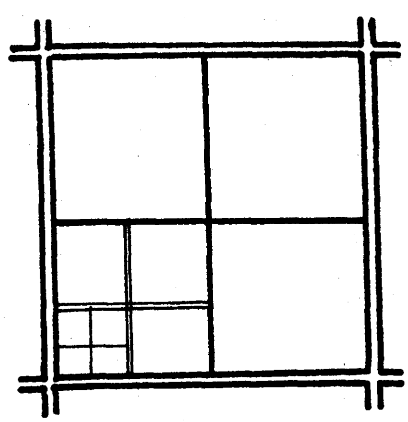
1: It is assumed that a grid composed of four sides would have equal diameters of pipe on its sides.




2: It is assumed that the capacity of a pipe on the grid side is related to the demand of the grid by a factor of two. The amount of flow of a pipe on a side of the grid is one quarter of the amount of the flow demanded by the entire area of the grid served.




3: It is assumed that the entire capacity of water of the pipe flow is expended. Since the pipe network is nested hierachly, each succeeding pipe size would furnish the demands of the next smaller size below it in rank.



## INTERPRETATION OF THE CHARTS

### LIMITS OF THE DENSITY VALUES

In the United States context with approximately 3.0 persons per family, the density value of 500 dwellings per hectare is taken as the upper reasonable limit. The upper limit is based on the maximum density of 1500 persons per hectare as found in Hong Kong.

For developing countries or situations where 6 persons per family is the rule, the limit of 250 dwellings per hectare is taken as the upper limit.

Values above 500 dwellings per hectare are not printed on the chart but are noted as '****'.

### LIMITS OF THE FRICTION LOSS VALUES

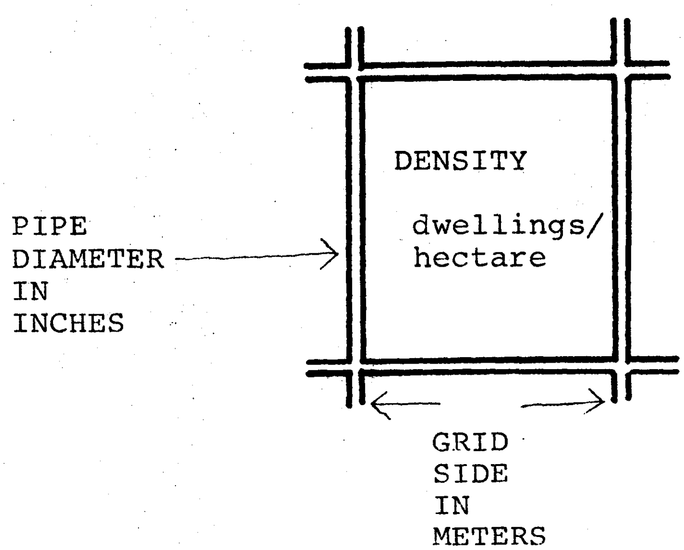
A loss of 25 feet of head for a 4" pipe per 1000 feet is considered to be the maximum allowed; for a 24" pipe, the allowed head loss is 4 feet of head per 1000 feet. Consequently, the charts are noted with "HIGH" above the pipe diameter if the graph of the limits are exceeded. As the pipe approaches zero (the worst condition) the friction loss approaches 30 feet of head per 1000 feet.

FORMULA: Allowed head loss=30-pipe diameter in inches

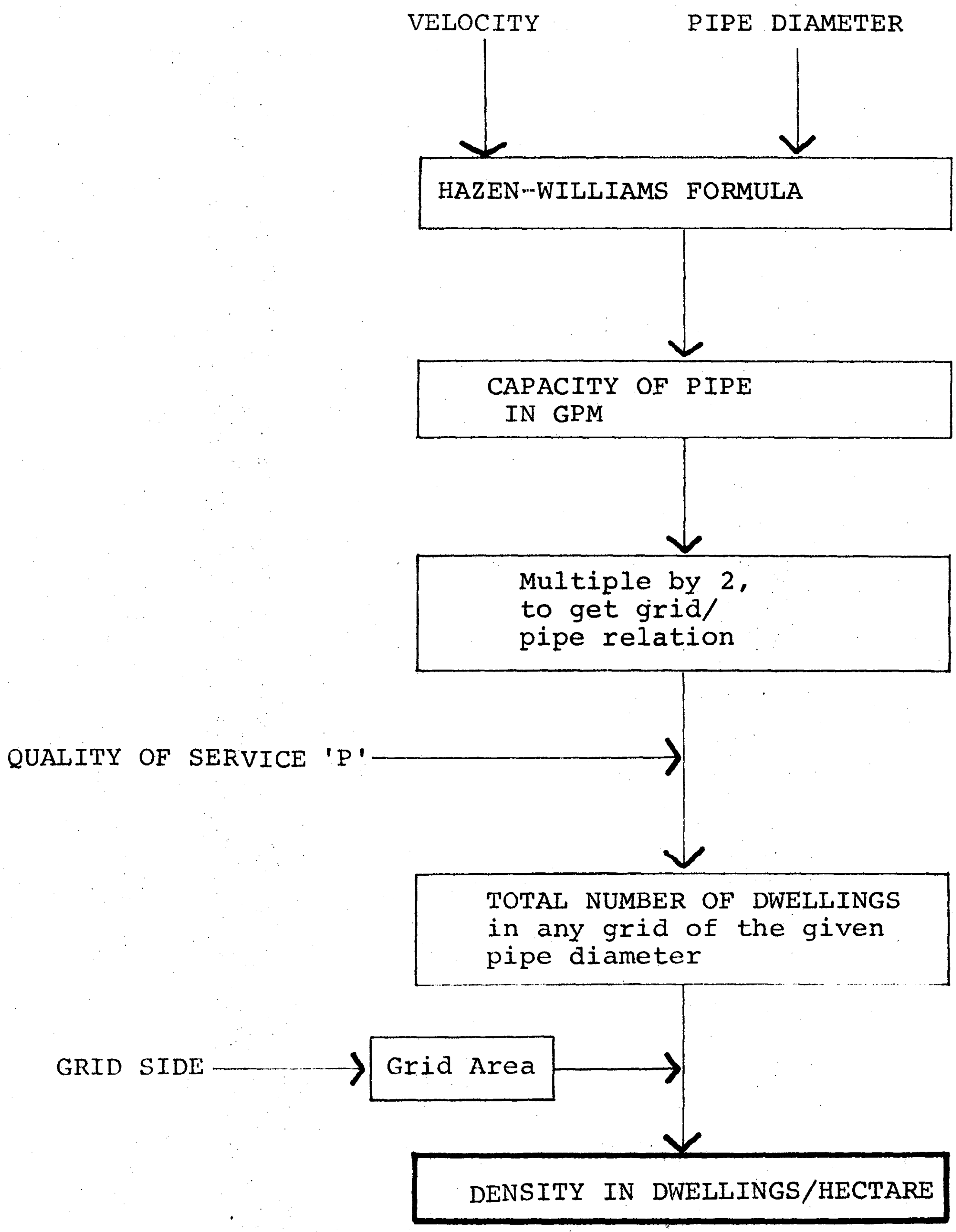
LIMITS OF THE SIDE LENGTH VALUES

The length conditions as derived in the first set of charts is the basis for determining if a pipe is capable of supporting a grid side dimension as indicated on the chart. If this length is exceeded by the grid side, 'A" is printed beside the density value. The length conditions could be satisfied if the parameters were changed, but with 20 psi initial and 8 psi the termination point, the lengths given govern.

RELATION OF THE CHART VALUES TO THE DISTRIBUTION GRID



FLOW CHART OF DENSITY VALUES



VELOCITY VALUE IS 2.0
WITH P VALUE OF 500.0

| PIPE DIAMETERS= | 1. | 2. | 3. | 4. | 5. | 6. |
|---|---|---|---|---|---|---|
| 100. GRID SIDE | 0. | 2. | 8. | 25. | 61. | 126. |
| 200. GRID SIDE | 0. | 0. | 2. | 6. | 15. | 31. |
| 300. GRID SIDE | 0. | 0. | 1. | 3. | 7. | 14. |
| 400. GRID SIDE | 0.A | 0. | 0. | 2. | 4. | 8. |
| 500. GRID SIDE | 0.A | 0. | 0. | 1. | 2. | 5. |
| 600. GRID SIDE | 0.A | 0. | 0. | 1. | 2. | 3. |
| 700. GRID SIDE | 0.A | 0.A | 0. | 1. | 1. | 3. |
| 800. GRID SIDE | 0.A | 0.A | 0. | 0. | 1. | 2. |
| 900. GRID SIDE | 0.A | 0.A | 0. | 0. | 1. | 2. |
| 1000. GRID SIDE | 0.A | 0.A | 0. | 0. | 1. | 1. |
| 1100. GRID SIDE | 0.A | 0.A | 0.A | 0. | 1. | 1. |
| 1200. GRID SIDE | 0.A | 0.A | 0.A | 0. | 0. | 1. |
| 1300. GRID SIDE | 0.A | 0.A | 0.A | 0. | 0. | 1. |
| 1400. GRID SIDE | 0.A | 0.A | 0.A | 0. | 0. | 1. |
| 1500. GRID SIDE | 0.A | 0.A | 0.A | 0. | 0. | 1. |
| 1600. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 0. | 0. |
| 1700. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 0. | 0. |
| 1800. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 0. | 0. |
| 1900. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 0. | 0. |
| 2000. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 0.A | 0. |
| 2100. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 0.A | 0. |
| 2200. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 0.A | 0. |
| 2300. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 0.A | 0. |
| 2400. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 0.A | 0. |
| 2500. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 0.A | 0.A |
| 2600. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 0.A | 0.A |
| 2700. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 0.A | 0.A |
| 2800. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 0.A | 0.A |
| 2900. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 0.A | 0.A |
| 3000. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 0.A | 0.A |
| 3100. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 0.A | 0.A |
| 3200. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 0.A | 0.A |
| 3300. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 0.A | 0.A |
| 3400. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 0.A | 0.A |
| 3500. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 0.A | 0.A |
| 3600. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 0.A | 0.A |
| 3700. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 0.A | 0.A |
| 3800. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 0.A | 0.A |
| 3900. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 0.A | 0.A |
| 4000. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 0.A | 0.A |

HIGH MEANS FRICTION LOSS ABOVE ACCEPTABLE LIMITS

VELOCITY VALUE IS 2.0
WITH P VALUE CF 82.5

| PIPE DIAMETERS= | 1. | 2. | 3. | 4. | 5. | 6. |
|---|---|---|---|---|---|---|
| 100. GRID SIDE | 1. | 9. | 48. | 151. | 367. | **** |
| 200. GRID SIDE | 0. | 2. | 12. | 38. | 92. | 190. |
| 300. GRID SIDE | 0. | 1. | 5. | 17. | 41. | 85. |
| 400. GRID SIDE | 0.A | 1. | 3. | 9. | 23. | 48. |
| 500. GRID SIDE | 0.A | 0. | 2. | 6. | 15. | 30. |
| 600. GRID SIDE | 0.A | 0. | 1. | 4. | 10. | 21. |
| 700. GRID SIDE | 0.A | 0.A | 1. | 3. | 7. | 16. |
| 800. GRID SIDE | 0.A | 0.A | 1. | 2. | 6. | 12. |
| 900. GRID SIDE | 0.A | 0.A | 1. | 2. | 5. | 9. |
| 1000. GRID SIDE | 0.A | 0.A | 0. | 2. | 4. | 8. |
| 1100. GRID SIDE | 0.A | 0.A | 0.A | 1. | 3. | 6. |
| 1200. GRID SIDE | 0.A | 0.A | 0.A | 1. | 3. | 5. |
| 1300. GRID SIDE | 0.A | 0.A | 0.A | 1. | 2. | 5. |
| 1400. GRID SIDE | 0.A | 0.A | 0.A | 1. | 2. | 4. |
| 1500. GRID SIDE | 0.A | 0.A | 0.A | 1. | 2. | 3. |
| 1600. GRID SIDE | 0.A | 0.A | 0.A | 1.A | 1. | 3. |
| 1700. GRID SIDE | 0.A | 0.A | 0.A | 1.A | 1. | 3. |
| 1800. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 1. | 2. |
| 1900. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 1. | 2. |
| 2000. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 1.A | 2. |
| 2100. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 1.A | 2. |
| 2200. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 1.A | 2. |
| 2300. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 1.A | 1. |
| 2400. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 1.A | 1. |
| 2500. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 1.A | 1.A |
| 2600. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 1.A | 1.A |
| 2700. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 1.A | 1.A |
| 2800. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 0.A | 1.A |
| 2900. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 0.A | 1.A |
| 3000. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 0.A | 1.A |
| 3100. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 0.A | 1.A |
| 3200. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 0.A | 1.A |
| 3300. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 0.A | 1.A |
| 3400. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 0.A | 1.A |
| 3500. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 0.A | 1.A |
| 3600. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 0.A | 1.A |
| 3700. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 0.A | 1.A |
| 3800. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 0.A | 1.A |
| 3900. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 0.A | 1.A |
| 4000. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 0.A | 0.A |

HIGH MEANS FRICTION LOSS ABOVE ACCEPTABLE LIMITS

VELOCITY VALUE IS 2.0
WITH P VALUE OF 12.5

| PIPE DIAMETERS= | 1. | 2. | 3. | 4. | 5. | 6. |
|---|---|---|---|---|---|---|
| 100. GRID SIDE | 4. | 62. | 315. | **** | **** | **** |
| 200. GRID SIDE | 1. | 16. | 79. | 248. | **** | **** |
| 300. GRID SIDE | 0. | 7. | 35. | 110. | 269. | **** |
| 400. GRID SIDE | 0.A | 4. | 20. | 62. | 151. | 314. |
| 500. GRID SIDE | 0.A | 2. | 13. | 40. | 97. | 201. |
| 600. GRID SIDE | 0.A | 2. | 9. | 28. | 67. | 139. |
| 700. GRID SIDE | 0.A | 1.A | 6. | 20. | 49. | 102. |
| 800. GRID SIDE | 0.A | 1.A | 5. | 16. | 38. | 78. |
| 900. GRID SIDE | 0.A | 1.A | 4. | 12. | 30. | 62. |
| 1000. GRID SIDE | 0.A | 1.A | 3. | 10. | 24. | 50. |
| 1100. GRID SIDE | 0.A | 1.A | 3.A | 8. | 20. | 41. |
| 1200. GRID SIDE | 0.A | 0.A | 2.A | 7. | 17. | 35. |
| 1300. GRID SIDE | 0.A | 0.A | 2.A | 6. | 14. | 30. |
| 1400. GRID SIDE | 0.A | 0.A | 2.A | 5. | 12. | 26. |
| 1500. GRID SIDE | 0.A | 0.A | 1.A | 4. | 11. | 22. |
| 1600. GRID SIDE | 0.A | 0.A | 1.A | 4.A | 9. | 20. |
| 1700. GRID SIDE | 0.A | 0.A | 1.A | 3.A | 8. | 17. |
| 1800. GRID SIDE | 0.A | 0.A | 1.A | 3.A | 7. | 15. |
| 1900. GRID SIDE | 0.A | 0.A | 1.A | 3.A | 7. | 14. |
| 2000. GRID SIDE | 0.A | 0.A | 1.A | 2.A | 6.A | 13. |
| 2100. GRID SIDE | 0.A | 0.A | 1.A | 2.A | 5.A | 11. |
| 2200. GRID SIDE | 0.A | 0.A | 1.A | 2.A | 5.A | 10. |
| 2300. GRID SIDE | 0.A | 0.A | 1.A | 2.A | 5.A | 9. |
| 2400. GRID SIDE | 0.A | 0.A | 1.A | 2.A | 4.A | 9. |
| 2500. GRID SIDE | 0.A | 0.A | 1.A | 2.A | 4.A | 8.A |
| 2600. GRID SIDE | 0.A | 0.A | 0.A | 1.A | 4.A | 7.A |
| 2700. GRID SIDE | 0.A | 0.A | 0.A | 1.A | 3.A | 7.A |
| 2800. GRID SIDE | 0.A | 0.A | 0.A | 1.A | 3.A | 6.A |
| 2900. GRID SIDE | 0.A | 0.A | 0.A | 1.A | 3.A | 6.A |
| 3000. GRID SIDE | 0.A | 0.A | 0.A | 1.A | 3.A | 6.A |
| 3100. GRID SIDE | 0.A | 0.A | 0.A | 1.A | 3.A | 5.A |
| 3200. GRID SIDE | 0.A | 0.A | 0.A | 1.A | 2.A | 5.A |
| 3300. GRID SIDE | 0.A | 0.A | 0.A | 1.A | 2.A | 5.A |
| 3400. GRID SIDE | 0.A | 0.A | 0.A | 1.A | 2.A | 4.A |
| 3500. GRID SIDE | 0.A | 0.A | 0.A | 1.A | 2.A | 4.A |
| 3600. GRID SIDE | 0.A | 0.A | 0.A | 1.A | 2.A | 4.A |
| 3700. GRID SIDE | 0.A | 0.A | 0.A | 1.A | 2.A | 4.A |
| 3800. GRID SIDE | 0.A | 0.A | 0.A | 1.A | 2.A | 3.A |
| 3900. GRID SIDE | 0.A | 0.A | 0.A | 1.A | 2.A | 3.A |
| 4000. GRID SIDE | 0.A | 0.A | 0.A | 1.A | 2.A | 3.A |

HIGH MEANS FRICTION LOSS ABOVE ACCEPTABLE LIMITS

VELOCITY VALUE IS 4.0
WITH P VALUE OF 12.5

| PIPE DIAMETERS= | 1. | 2. | 3. | 4. | 5. | 6. |
|---|---|---|---|---|---|---|
| 100. GRID SIDE | 16.A | 249. | **** | **** | **** | **** |
| 200. GRID SIDE | 4.A | 62.A | 315. | **** | **** | **** |
| 300. GRID SIDE | 2.A | 28.A | 140. | 442. | **** | **** |
| 400. GRID SIDE | 1.A | 16.A | 79.A | 248. | **** | **** |
| 500. GRID SIDE | 1.A | 10.A | 50.A | 159.A | 388. | **** |
| 600. GRID SIDE | 0.A | 7.A | 35.A | 110.A | 269.A | **** |
| 700. GRID SIDE | 0.A | 5.A | 26.A | 81.A | 198.A | 410.A |
| 800. GRID SIDE | 0.A | 4.A | 20.A | 62.A | 151.A | 314.A |
| 900. GRID SIDE | 0.A | 3.A | 16.A | 49.A | 120.A | 248.A |
| 1000. GRID SIDE | 0.A | 2.A | 13.A | 40.A | 97.A | 201.A |
| 1100. GRID SIDE | 0.A | 2.A | 10.A | 33.A | 80.A | 166.A |
| 1200. GRID SIDE | 0.A | 2.A | 9.A | 28.A | 67.A | 139.A |
| 1300. GRID SIDE | 0.A | 1.A | 7.A | 24.A | 57.A | 119.A |
| 1400. GRID SIDE | 0.A | 1.A | 6.A | 20.A | 49.A | 102.A |
| 1500. GRID SIDE | 0.A | 1.A | 6.A | 18.A | 43.A | 89.A |
| 1600. GRID SIDE | 0.A | 1.A | 5.A | 16.A | 38.A | 78.A |
| 1700. GRID SIDE | 0.A | 1.A | 4.A | 14.A | 34.A | 69.A |
| 1800. GRID SIDE | 0.A | 1.A | 4.A | 12.A | 30.A | 62.A |
| 1900. GRID SIDE | 0.A | 1.A | 3.A | 11.A | 27.A | 56.A |
| 2000. GRID SIDE | 0.A | 1.A | 3.A | 10.A | 24.A | 50.A |
| 2100. GRID SIDE | 0.A | 1.A | 3.A | 9.A | 22.A | 46.A |
| 2200. GRID SIDE | 0.A | 1.A | 3.A | 8.A | 20.A | 41.A |
| 2300. GRID SIDE | 0.A | 0.A | 2.A | 8.A | 18.A | 38.A |
| 2400. GRID SIDE | 0.A | 0.A | 2.A | 7.A | 17.A | 35.A |
| 2500. GRID SIDE | 0.A | 0.A | 2.A | 6.A | 16.A | 32.A |
| 2600. GRID SIDE | 0.A | 0.A | 2.A | 6.A | 14.A | 30.A |
| 2700. GRID SIDE | 0.A | 0.A | 2.A | 5.A | 13.A | 28.A |
| 2800. GRID SIDE | 0.A | 0.A | 2.A | 5.A | 12.A | 26.A |
| 2900. GRID SIDE | 0.A | 0.A | 1.A | 5.A | 12.A | 24.A |
| 3000. GRID SIDE | 0.A | 0.A | 1.A | 4.A | 11.A | 22.A |
| 3100. GRID SIDE | 0.A | 0.A | 1.A | 4.A | 10.A | 21.A |
| 3200. GRID SIDE | 0.A | 0.A | 1.A | 4.A | 9.A | 20.A |
| 3300. GRID SIDE | 0.A | 0.A | 1.A | 4.A | 9.A | 18.A |
| 3400. GRID SIDE | 0.A | 0.A | 1.A | 3.A | 8.A | 17.A |
| 3500. GRID SIDE | 0.A | 0.A | 1.A | 3.A | 8.A | 16.A |
| 3600. GRID SIDE | 0.A | 0.A | 1.A | 3.A | 7.A | 15.A |
| 3700. GRID SIDE | 0.A | 0.A | 1.A | 3.A | 7.A | 15.A |
| 3800. GRID SIDE | 0.A | 0.A | 1.A | 3.A | 7.A | 14.A |
| 3900. GRID SIDE | 0.A | 0.A | 1.A | 3.A | 6.A | 13.A |
| 4000. GRID SIDE | 0.A | 0.A | 1.A | 2.A | 6.A | 13.A |

HIGH MEANS FRICTION LOSS ABOVE ACCEPTABLE LIMITS

VELOCITY VALUE IS 4.0
WITH P VALUE OF 82.5

| PIPE DIAMETERS= | 1. | 2. | 3. | 4. | 5. | 6. |
|---|---|---|---|---|---|---|
| 100. GRID SIDE | 2.A | 38. | 191. | **** | **** | **** |
| 200. GRID SIDE | 1.A | 9.A | 48. | 151. | 367. | **** |
| 300. GRID SIDE | 0.A | 4.A | 21. | 67. | 163. | 338. |
| 400. GRID SIDE | 0.A | 2.A | 12.A | 38. | 92. | 190. |
| 500. GRID SIDE | 0.A | 2.A | 8.A | 24.A | 59. | 122. |
| 600. GRID SIDE | 0.A | 1.A | 5.A | 17.A | 41.A | 85. |
| 700. GRID SIDE | 0.A | 1.A | 4.A | 12.A | 30.A | 62.A |
| 800. GRID SIDE | 0.A | 1.A | 3.A | 9.A | 23.A | 48.A |
| 900. GRID SIDE | 0.A | 0.A | 2.A | 7.A | 18.A | 38.A |
| 1000. GRID SIDE | 0.A | 0.A | 2.A | 6.A | 15.A | 30.A |
| 1100. GRID SIDE | 0.A | 0.A | 2.A | 5.A | 12.A | 25.A |
| 1200. GRID SIDE | 0.A | 0.A | 1.A | 4.A | 10.A | 21.A |
| 1300. GRID SIDE | 0.A | 0.A | 1.A | 4.A | 9.A | 18.A |
| 1400. GRID SIDE | 0.A | 0.A | 1.A | 3.A | 7.A | 16.A |
| 1500. GRID SIDE | 0.A | 0.A | 1.A | 3.A | 7.A | 14.A |
| 1600. GRID SIDE | 0.A | 0.A | 1.A | 2.A | 6.A | 12.A |
| 1700. GRID SIDE | 0.A | 0.A | 1.A | 2.A | 5.A | 11.A |
| 1800. GRID SIDE | 0.A | 0.A | 1.A | 2.A | 5.A | 9.A |
| 1900. GRID SIDE | 0.A | 0.A | 1.A | 2.A | 4.A | 8.A |
| 2000. GRID SIDE | 0.A | 0.A | 0.A | 2.A | 4.A | 8.A |
| 2100. GRID SIDE | 0.A | 0.A | 0.A | 1.A | 3.A | 7.A |
| 2200. GRID SIDE | 0.A | 0.A | 0.A | 1.A | 3.A | 6.A |
| 2300. GRID SIDE | 0.A | 0.A | 0.A | 1.A | 3.A | 6.A |
| 2400. GRID SIDE | 0.A | 0.A | 0.A | 1.A | 3.A | 5.A |
| 2500. GRID SIDE | 0.A | 0.A | 0.A | 1.A | 2.A | 5.A |
| 2600. GRID SIDE | 0.A | 0.A | 0.A | 1.A | 2.A | 5.A |
| 2700. GRID SIDE | 0.A | 0.A | 0.A | 1.A | 2.A | 4.A |
| 2800. GRID SIDE | 0.A | 0.A | 0.A | 1.A | 2.A | 4.A |
| 2900. GRID SIDE | 0.A | 0.A | 0.A | 1.A | 2.A | 4.A |
| 3000. GRID SIDE | 0.A | 0.A | 0.A | 1.A | 2.A | 3.A |
| 3100. GRID SIDE | 0.A | 0.A | 0.A | 1.A | 2.A | 3.A |
| 3200. GRID SIDE | 0.A | 0.A | 0.A | 1.A | 1.A | 3.A |
| 3300. GRID SIDE | 0.A | 0.A | 0.A | 1.A | 1.A | 3.A |
| 3400. GRID SIDE | 0.A | 0.A | 0.A | 1.A | 1.A | 3.A |
| 3500. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 1.A | 2.A |
| 3600. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 1.A | 2.A |
| 3700. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 1.A | 2.A |
| 3800. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 1.A | 2.A |
| 3900. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 1.A | 2.A |
| 4000. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 1.A | 2.A |

HIGH MEANS FRICTION LOSS ABOVE ACCEPTABLE LIMITS

VELOCITY VALUE IS 4.0
WITH P VALUE OF 500.0

| PIPE DIAMETERS= | 1. | 2. | 3. | 4. | 5. | 6. |
|---|---|---|---|---|---|---|
| 100. GRID SIDE | 0.A | 6. | 31. | 99. | 242. | **** |
| 200. GRID SIDE | 0.A | 2.A | 8. | 25. | 61. | 126. |
| 300. GRID SIDE | 0.A | 1.A | 3. | 11. | 27. | 56. |
| 400. GRID SIDE | 0.A | 0.A | 2.A | 6. | 15. | 31. |
| 500. GRID SIDE | 0.A | 0.A | 1.A | 4.A | 10. | 20. |
| 600. GRID SIDE | 0.A | 0.A | 1.A | 3.A | 7.A | 14. |
| 700. GRID SIDE | 0.A | 0.A | 1.A | 2.A | 5.A | 10.A |
| 800. GRID SIDE | 0.A | 0.A | 0.A | 2.A | 4.A | 8.A |
| 900. GRID SIDE | 0.A | 0.A | 0.A | 1.A | 3.A | 6.A |
| 1000. GRID SIDE | 0.A | 0.A | 0.A | 1.A | 2.A | 5.A |
| 1100. GRID SIDE | 0.A | 0.A | 0.A | 1.A | 2.A | 4.A |
| 1200. GRID SIDE | 0.A | 0.A | 0.A | 1.A | 2.A | 3.A |
| 1300. GRID SIDE | 0.A | 0.A | 0.A | 1.A | 1.A | 3.A |
| 1400. GRID SIDE | 0.A | 0.A | 0.A | 1.A | 1.A | 3.A |
| 1500. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 1.A | 2.A |
| 1600. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 1.A | 2.A |
| 1700. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 1.A | 2.A |
| 1800. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 1.A | 2.A |
| 1900. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 1.A | 1.A |
| 2000. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 1.A | 1.A |
| 2100. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 1.A | 1.A |
| 2200. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 1.A | 1.A |
| 2300. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 0.A | 1.A |
| 2400. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 0.A | 1.A |
| 2500. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 0.A | 1.A |
| 2600. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 0.A | 1.A |
| 2700. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 0.A | 1.A |
| 2800. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 0.A | 1.A |
| 2900. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 0.A | 1.A |
| 3000. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 0.A | 1.A |
| 3100. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 0.A | 1.A |
| 3200. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 0.A | 0.A |
| 3300. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 0.A | 0.A |
| 3400. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 0.A | 0.A |
| 3500. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 0.A | 0.A |
| 3600. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 0.A | 0.A |
| 3700. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 0.A | 0.A |
| 3800. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 0.A | 0.A |
| 3900. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 0.A | 0.A |
| 4000. GRID SIDE | 0.A | 0.A | 0.A | 0.A | 0.A | 0.A |

HIGH MEANS FRICTION LOSS ABOVE ACCEPTABLE LIMITS

VELOCITY VALUE IS 2.0
WITH P VALUE OF 12.5

| PIPE DIAMETERS= | 8. | 10. | 12. | 14. | 16. | 18. |
|---|---|---|---|---|---|---|
| 100. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 200. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 300. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 400. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 500. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 600. GRID SIDE | 440. | **** | **** | **** | **** | **** |
| 700. GRID SIDE | 324. | **** | **** | **** | **** | **** |
| 800. GRID SIDE | 248. | **** | **** | **** | **** | **** |
| 900. GRID SIDE | 196. | 477. | **** | **** | **** | **** |
| 1000. GRID SIDE | 159. | 387. | **** | **** | **** | **** |
| 1100. GRID SIDE | 131. | 320. | **** | **** | **** | **** |
| 1200. GRID SIDE | 110. | 269. | **** | **** | **** | **** |
| 1300. GRID SIDE | 94. | 229. | 474. | **** | **** | **** |
| 1400. GRID SIDE | 81. | 197. | 409. | **** | **** | **** |
| 1500. GRID SIDE | 70. | 172. | 356. | **** | **** | **** |
| 1600. GRID SIDE | 62. | 151. | 313. | **** | **** | **** |
| 1700. GRID SIDE | 55. | 134. | 277. | **** | **** | **** |
| 1800. GRID SIDE | 49. | 119. | 247. | 458. | **** | **** |
| 1900. GRID SIDE | 44. | 107. | 222. | 411. | **** | **** |
| 2000. GRID SIDE | 40. | 97. | 200. | 371. | **** | **** |
| 2100. GRID SIDE | 36. | 88. | 182. | 336. | **** | **** |
| 2200. GRID SIDE | 33. | 80. | 166. | 306. | **** | **** |
| 2300. GRID SIDE | 30. | 73. | 151. | 280. | 478. | **** |
| 2400. GRID SIDE | 28. | 67. | 139. | 258. | 439. | **** |
| 2500. GRID SIDE | 25. | 62. | 128. | 237. | 405. | **** |
| 2600. GRID SIDE | 23. | 57. | 119. | 219. | 374. | **** |
| 2700. GRID SIDE | 22. | 53. | 110. | 203. | 347. | **** |
| 2800. GRID SIDE | 20. | 49. | 102. | 189. | 323. | **** |
| 2900. GRID SIDE | 19. | 46. | 95. | 176. | 301. | 481. |
| 3000. GRID SIDE | 18. | 43. | 89. | 165. | 281. | 450. |
| 3100. GRID SIDE | 16. | 40. | 83. | 154. | 263. | 421. |
| 3200. GRID SIDE | 15. | 38. | 78. | 145. | 247. | 395. |
| 3300. GRID SIDE | 15. | 36. | 74. | 136. | 232. | 372. |
| 3400. GRID SIDE | 14. | 33. | 69. | 128. | 219. | 350. |
| 3500. GRID SIDE | 13.A | 32. | 65. | 121. | 206. | 331. |
| 3600. GRID SIDE | 12.A | 30. | 62. | 114. | 195. | 312. |
| 3700. GRID SIDE | 12.A | 28. | 59. | 108. | 185. | 296. |
| 3800. GRID SIDE | 11.A | 27. | 55. | 103. | 175. | 280. |
| 3900. GRID SIDE | 10.A | 25. | 53. | 98. | 166. | 266. |
| 4000. GRID SIDE | 10.A | 24. | 50. | 93. | 158. | 253. |

HIGH MEANS FRICTION LOSS ABOVE ACCEPTABLE LIMITS

VELOCITY VALUE IS 2.0
WITH P VALUE OF 82.5

| PIPE DIAMETERS= | 8. | 10. | 12. | 14. | 16. | 18. |
|---|---|---|---|---|---|---|
| 100. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 200. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 300. GRID SIDE | 267. | **** | **** | **** | **** | **** |
| 400. GRID SIDE | 150. | 366. | **** | **** | **** | **** |
| 500. GRID SIDE | 96. | 234. | 486. | **** | **** | **** |
| 600. GRID SIDE | 67. | 163. | 337. | **** | **** | **** |
| 700. GRID SIDE | 49. | 120. | 248. | 459. | **** | **** |
| 800. GRID SIDE | 38. | 92. | 190. | 351. | **** | **** |
| 900. GRID SIDE | 30. | 72. | 150. | 277. | 473. | **** |
| 1000. GRID SIDE | 24. | 59. | 121. | 225. | 383. | **** |
| 1100. GRID SIDE | 20. | 48. | 100. | 186. | 317. | **** |
| 1200. GRID SIDE | 17. | 41. | 84. | 156. | 266. | 426. |
| 1300. GRID SIDE | 14. | 35. | 72. | 133. | 227. | 363. |
| 1400. GRID SIDE | 12. | 30. | 62. | 115. | 196. | 313. |
| 1500. GRID SIDE | 11. | 26. | 54. | 100. | 170. | 273. |
| 1600. GRID SIDE | 9. | 23. | 47. | 88. | 150. | 240. |
| 1700. GRID SIDE | 8. | 20. | 42. | 78. | 133. | 212. |
| 1800. GRID SIDE | 7. | 18. | 37. | 69. | 118. | 189. |
| 1900. GRID SIDE | 7. | 16. | 34. | 62. | 106. | 170. |
| 2000. GRID SIDE | 6. | 15. | 30. | 56. | 96. | 153. |
| 2100. GRID SIDE | 5. | 13. | 28. | 51. | 87. | 139. |
| 2200. GRID SIDE | 5. | 12. | 25. | 46. | 79. | 127. |
| 2300. GRID SIDE | 5. | 11. | 23. | 42. | 72. | 116. |
| 2400. GRID SIDE | 4. | 10. | 21. | 39. | 67. | 107. |
| 2500. GRID SIDE | 4. | 9. | 19. | 36. | 61. | 98. |
| 2600. GRID SIDE | 4. | 9. | 18. | 33. | 57. | 91. |
| 2700. GRID SIDE | 3. | 8. | 17. | 31. | 53. | 84. |
| 2800. GRID SIDE | 3. | 7. | 15. | 29. | 49. | 78. |
| 2900. GRID SIDE | 3. | 7. | 14. | 27. | 46. | 73. |
| 3000. GRID SIDE | 3. | 7. | 13. | 25. | 43. | 68. |
| 3100. GRID SIDE | 2. | 6. | 13. | 23. | 40. | 64. |
| 3200. GRID SIDE | 2. | 6. | 12. | 22. | 37. | 60. |
| 3300. GRID SIDE | 2. | 5. | 11. | 21. | 35. | 56. |
| 3400. GRID SIDE | 2. | 5. | 11. | 19. | 33. | 53. |
| 3500. GRID SIDE | 2.A | 5. | 10. | 18. | 31. | 50. |
| 3600. GRID SIDE | 2.A | 5. | 9. | 17. | 30. | 47. |
| 3700. GRID SIDE | 2.A | 4. | 9. | 16. | 28. | 45. |
| 3800. GRID SIDE | 2.A | 4. | 8. | 16. | 27. | 42. |
| 3900. GRID SIDE | 2.A | 4. | 8. | 15. | 25. | 40. |
| 4000. GRID SIDE | 2.A | 4. | 8. | 14. | 24. | 38. |

HIGH MEANS FRICTION LOSS ABOVE ACCEPTABLE LIMITS

VELOCITY VALUE IS 2.0
WITH P VALUE OF 500.0

| PIPE DIAMETERS= | 8. | 10. | 12. | 14. | 16. | 18. |
|---|---|---|---|---|---|---|
| 100. GRID SIDE | 396. | **** | **** | **** | **** | **** |
| 200. GRID SIDE | 99. | 242. | **** | **** | **** | **** |
| 300. GRID SIDE | 44. | 107. | 223. | 412. | **** | **** |
| 400. GRID SIDE | 25. | 60. | 125. | 232. | 395. | **** |
| 500. GRID SIDE | 16. | 39. | 80. | 148. | 253. | 405. |
| 600. GRID SIDE | 11. | 27. | 56. | 103. | 176. | 281. |
| 700. GRID SIDE | 8. | 20. | 41. | 76. | 129. | 207. |
| 800. GRID SIDE | 6. | 15. | 31. | 58. | 99. | 158. |
| 900. GRID SIDE | 5. | 12. | 25. | 46. | 78. | 125. |
| 1000. GRID SIDE | 4. | 10. | 20. | 37. | 63. | 101. |
| 1100. GRID SIDE | 3. | 8. | 17. | 31. | 52. | 84. |
| 1200. GRID SIDE | 3. | 7. | 14. | 26. | 44. | 70. |
| 1300. GRID SIDE | 2. | 6. | 12. | 22. | 37. | 60. |
| 1400. GRID SIDE | 2. | 5. | 10. | 19. | 32. | 52. |
| 1500. GRID SIDE | 2. | 4. | 9. | 16. | 28. | 45. |
| 1600. GRID SIDE | 2. | 4. | 8. | 14. | 25. | 40. |
| 1700. GRID SIDE | 1. | 3. | 7. | 13. | 22. | 35. |
| 1800. GRID SIDE | 1. | 3. | 6. | 11. | 20. | 31. |
| 1900. GRID SIDE | 1. | 3. | 6. | 10. | 18. | 28. |
| 2000. GRID SIDE | 1. | 2. | 5. | 9. | 16. | 25. |
| 2100. GRID SIDE | 1. | 2. | 5. | 8. | 14. | 23. |
| 2200. GRID SIDE | 1. | 2. | 4. | 8. | 13. | 21. |
| 2300. GRID SIDE | 1. | 2. | 4. | 7. | 12. | 19. |
| 2400. GRID SIDE | 1. | 2. | 3. | 6. | 11. | 18. |
| 2500. GRID SIDE | 1. | 2. | 3. | 6. | 10. | 16. |
| 2600. GRID SIDE | 1. | 1. | 3. | 5. | 9. | 15. |
| 2700. GRID SIDE | 1. | 1. | 3. | 5. | 9. | 14. |
| 2800. GRID SIDE | 1. | 1. | 3. | 5. | 8. | 13. |
| 2900. GRID SIDE | 0. | 1. | 2. | 4. | 8. | 12. |
| 3000. GRID SIDE | 0. | 1. | 2. | 4. | 7. | 11. |
| 3100. GRID SIDE | 0. | 1. | 2. | 4. | 7. | 11. |
| 3200. GRID SIDE | 0. | 1. | 2. | 4. | 6. | 10. |
| 3300. GRID SIDE | 0. | 1. | 2. | 3. | 6. | 9. |
| 3400. GRID SIDE | 0. | 1. | 2. | 3. | 5. | 9. |
| 3500. GRID SIDE | 0.A | 1. | 2. | 3. | 5. | 8. |
| 3600. GRID SIDE | 0.A | 1. | 2. | 3. | 5. | 8. |
| 3700. GRID SIDE | 0.A | 1. | 1. | 3. | 5. | 7. |
| 3800. GRID SIDE | 0.A | 1. | 1. | 3. | 4. | 7. |
| 3900. GRID SIDE | 0.A | 1. | 1. | 2. | 4. | 7. |
| 4000. GRID SIDE | 0.A | 1. | 1. | 2. | 4. | 6. |

HIGH MEANS FRICTION LOSS ABOVE ACCEPTABLE LIMITS

VELOCITY VALUE IS 4.0
WITH P VALUE OF 12.5

| PIPE DIAMETERS= | 8. | 10. | 12. | 14. | 16. | 18. |
|---|---|---|---|---|---|---|
| 100. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 200. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 300. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 400. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 500. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 600. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 700. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 800. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 900. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1000. GRID SIDE | ****A | **** | **** | **** | **** | **** |
| 1100. GRID SIDE | ****A | **** | **** | **** | **** | **** |
| 1200. GRID SIDE | 440.A | **** | **** | **** | **** | **** |
| 1300. GRID SIDE | 375.A | ****A | **** | **** | **** | **** |
| 1400. GRID SIDE | 324.A | ****A | **** | **** | **** | **** |
| 1500. GRID SIDE | 282.A | ****A | **** | **** | **** | **** |
| 1600. GRID SIDE | 248.A | ****A | ****A | **** | **** | **** |
| 1700. GRID SIDE | 219.A | ****A | ****A | **** | **** | **** |
| 1800. GRID SIDE | 196.A | 477.A | ****A | **** | **** | **** |
| 1900. GRID SIDE | 176.A | 428.A | ****A | ****A | **** | **** |
| 2000. GRID SIDE | 159.A | 387.A | ****A | ****A | **** | **** |
| 2100. GRID SIDE | 144.A | 351.A | ****A | ****A | **** | **** |
| 2200. GRID SIDE | 131.A | 320.A | ****A | ****A | ****A | **** |
| 2300. GRID SIDE | 120.A | 292.A | ****A | ****A | ****A | **** |
| 2400. GRID SIDE | 110.A | 269.A | ****A | ****A | ****A | **** |
| 2500. GRID SIDE | 101.A | 247.A | ****A | ****A | ****A | ****A |
| 2600. GRID SIDE | 94.A | 229.A | 474.A | ****A | ****A | ****A |
| 2700. GRID SIDE | 87.A | 212.A | 440.A | ****A | ****A | ****A |
| 2800. GRID SIDE | 81.A | 197.A | 409.A | ****A | ****A | ****A |
| 2900. GRID SIDE | 75.A | 184.A | 381.A | ****A | ****A | ****A |
| 3000. GRID SIDE | 70.A | 172.A | 356.A | ****A | ****A | ****A |
| 3100. GRID SIDE | 66.A | 161.A | 333.A | ****A | ****A | ****A |
| 3200. GRID SIDE | 62.A | 151.A | 313.A | ****A | ****A | ****A |
| 3300. GRID SIDE | 58.A | 142.A | 294.A | ****A | ****A | ****A |
| 3400. GRID SIDE | 55.A | 134.A | 277.A | ****A | ****A | ****A |
| 3500. GRID SIDE | 52.A | 126.A | 262.A | 484.A | ****A | ****A |
| 3600. GRID SIDE | 49.A | 119.A | 247.A | 458.A | ****A | ****A |
| 3700. GRID SIDE | 46.A | 113.A | 234.A | 433.A | ****A | ****A |
| 3800. GRID SIDE | 44.A | 107.A | 222.A | 411.A | ****A | ****A |
| 3900. GRID SIDE | 42.A | 102.A | 211.A | 390.A | ****A | ****A |
| 4000. GRID SIDE | 40.A | 97.A | 200.A | 371.A | ****A | ****A |

HIGH MEANS FRICTION LOSS ABOVE ACCEPTABLE LIMITS

VELOCITY VALUE IS 4.0
WITH P VALUE OF 82.5

| PIPE DIAMETERS= | 8. | 10. | 12. | 14. | 16. | 18. |
|---|---|---|---|---|---|---|
| 100. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 200. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 300. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 400. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 500. GRID SIDE | 384. | **** | **** | **** | **** | **** |
| 600. GRID SIDE | 267. | **** | **** | **** | **** | **** |
| 700. GRID SIDE | 196. | 478. | **** | **** | **** | **** |
| 800. GRID SIDE | 150. | 366. | **** | **** | **** | **** |
| 900. GRID SIDE | 119. | 289. | **** | **** | **** | **** |
| 1000. GRID SIDE | 96.A | 234. | 486. | **** | **** | **** |
| 1100. GRID SIDE | 79.A | 194. | 401. | **** | **** | **** |
| 1200. GRID SIDE | 67.A | 163. | 337. | **** | **** | **** |
| 1300. GRID SIDE | 57.A | 139.A | 287. | **** | **** | **** |
| 1400. GRID SIDE | 49.A | 120.A | 248. | 459. | **** | **** |
| 1500. GRID SIDE | 43.A | 104.A | 216. | 400. | **** | **** |
| 1600. GRID SIDE | 38.A | 92.A | 190.A | 351. | **** | **** |
| 1700. GRID SIDE | 33.A | 81.A | 168.A | 311. | **** | **** |
| 1800. GRID SIDE | 30.A | 72.A | 150.A | 277. | 473. | **** |
| 1900. GRID SIDE | 27.A | 65.A | 135.A | 249.A | 425. | **** |
| 2000. GRID SIDE | 24.A | 59.A | 121.A | 225.A | 383. | **** |
| 2100. GRID SIDE | 22.A | 53.A | 110.A | 204.A | 348. | **** |
| 2200. GRID SIDE | 20.A | 48.A | 100.A | 186.A | 317.A | **** |
| 2300. GRID SIDE | 18.A | 44.A | 92.A | 170.A | 290.A | 464. |
| 2400. GRID SIDE | 17.A | 41.A | 84.A | 156.A | 266.A | 426. |
| 2500. GRID SIDE | 15.A | 37.A | 78.A | 144.A | 245.A | 393.A |
| 2600. GRID SIDE | 14.A | 35.A | 72.A | 133.A | 227.A | 363.A |
| 2700. GRID SIDE | 13.A | 32.A | 67.A | 123.A | 210.A | 337.A |
| 2800. GRID SIDE | 12.A | 30.A | 62.A | 115.A | 196.A | 313.A |
| 2900. GRID SIDE | 11.A | 28.A | 58.A | 107.A | 182.A | 292.A |
| 3000. GRID SIDE | 11.A | 26.A | 54.A | 100.A | 170.A | 273.A |
| 3100. GRID SIDE | 10.A | 24.A | 51.A | 94.A | 160.A | 255.A |
| 3200. GRID SIDE | 9.A | 23.A | 47.A | 88.A | 150.A | 240.A |
| 3300. GRID SIDE | 9.A | 22.A | 45.A | 83.A | 141.A | 225.A |
| 3400. GRID SIDE | 8.A | 20.A | 42.A | 78.A | 133.A | 212.A |
| 3500. GRID SIDE | 8.A | 19.A | 40.A | 73.A | 125.A | 200.A |
| 3600. GRID SIDE | 7.A | 18.A | 37.A | 69.A | 118.A | 189.A |
| 3700. GRID SIDE | 7.A | 17.A | 35.A | 66.A | 112.A | 179.A |
| 3800. GRID SIDE | 7.A | 16.A | 34.A | 62.A | 106.A | 170.A |
| 3900. GRID SIDE | 6.A | 15.A | 32.A | 59.A | 101.A | 161.A |
| 4000. GRID SIDE | 6.A | 15.A | 30.A | 56.A | 96.A | 153.A |

HIGH MEANS FRICTION LOSS ABOVE ACCEPTABLE LIMITS

VELOCITY VALUE IS 4.0
WITH P VALUE OF 500.0

| PIPE DIAMETERS= | 8. | 10. | 12. | 14. | 16. | 18. |
|---|---|---|---|---|---|---|
| 100. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 200. GRID SIDE | 396. | **** | **** | **** | **** | **** |
| 300. GRID SIDE | 176. | 430. | **** | **** | **** | **** |
| 400. GRID SIDE | 99. | 242. | **** | **** | **** | **** |
| 500. GRID SIDE | 63. | 155. | 320. | **** | **** | **** |
| 600. GRID SIDE | 44. | 107. | 223. | 412. | **** | **** |
| 700. GRID SIDE | 32. | 79. | 164. | 303. | **** | **** |
| 800. GRID SIDE | 25. | 60. | 125. | 232. | 395. | **** |
| 900. GRID SIDE | 20. | 48. | 99. | 183. | 312. | 500. |
| 1000. GRID SIDE | 16.A | 39. | 80. | 148. | 253. | 405. |
| 1100. GRID SIDE | 13.A | 32. | 66. | 123. | 209. | 335. |
| 1200. GRID SIDE | 11.A | 27. | 56. | 103. | 176. | 281. |
| 1300. GRID SIDE | 9.A | 23.A | 47. | 88. | 150. | 240. |
| 1400. GRID SIDE | 8.A | 20.A | 41. | 76. | 129. | 207. |
| 1500. GRID SIDE | 7.A | 17.A | 36. | 66. | 112. | 180. |
| 1600. GRID SIDE | 6.A | 15.A | 31.A | 58. | 99. | 158. |
| 1700. GRID SIDE | 5.A | 13.A | 28.A | 51. | 88. | 140. |
| 1800. GRID SIDE | 5.A | 12.A | 25.A | 46. | 78. | 125. |
| 1900. GRID SIDE | 4.A | 11.A | 22.A | 41.A | 70. | 112. |
| 2000. GRID SIDE | 4.A | 10.A | 20.A | 37.A | 63. | 101. |
| 2100. GRID SIDE | 4.A | 9.A | 18.A | 34.A | 57. | 92. |
| 2200. GRID SIDE | 3.A | 8.A | 17.A | 31.A | 52.A | 84. |
| 2300. GRID SIDE | 3.A | 7.A | 15.A | 28.A | 48.A | 77. |
| 2400. GRID SIDE | 3.A | 7.A | 14.A | 26.A | 44.A | 70. |
| 2500. GRID SIDE | 3.A | 6.A | 13.A | 24.A | 40.A | 65.A |
| 2600. GRID SIDE | 2.A | 6.A | 12.A | 22.A | 37.A | 60.A |
| 2700. GRID SIDE | 2.A | 5.A | 11.A | 20.A | 35.A | 56.A |
| 2800. GRID SIDE | 2.A | 5.A | 10.A | 19.A | 32.A | 52.A |
| 2900. GRID SIDE | 2.A | 5.A | 10.A | 18.A | 30.A | 48.A |
| 3000. GRID SIDE | 2.A | 4.A | 9.A | 16.A | 28.A | 45.A |
| 3100. GRID SIDE | 2.A | 4.A | 8.A | 15.A | 26.A | 42.A |
| 3200. GRID SIDE | 2.A | 4.A | 8.A | 14.A | 25.A | 40.A |
| 3300. GRID SIDE | 1.A | 4.A | 7.A | 14.A | 23.A | 37.A |
| 3400. GRID SIDE | 1.A | 3.A | 7.A | 13.A | 22.A | 35.A |
| 3500. GRID SIDE | 1.A | 3.A | 7.A | 12.A | 21.A | 33.A |
| 3600. GRID SIDE | 1.A | 3.A | 6.A | 11.A | 20.A | 31.A |
| 3700. GRID SIDE | 1.A | 3.A | 6.A | 11.A | 18.A | 30.A |
| 3800. GRID SIDE | 1.A | 3.A | 6.A | 10.A | 18.A | 28.A |
| 3900. GRID SIDE | 1.A | 3.A | 5.A | 10.A | 17.A | 27.A |
| 4000. GRID SIDE | 1.A | 2.A | 5.A | 9.A | 16.A | 25.A |

HIGH MEANS FRICTION LOSS ABOVE ACCEPTABLE LIMITS

VELOCITY VALUE IS 2.0
WITH P VALUE OF 12.5

| PIPE DIAMETERS= | 20. | 22. | 24. | 26. | 28. | 30. |
|---|---|---|---|---|---|---|
| 100. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 200. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 300. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 400. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 500. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 600. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 700. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 800. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 900. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1000. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1100. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1200. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1300. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1400. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1500. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1600. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1700. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1800. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1900. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2000. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2100. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2200. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2300. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2400. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2500. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2600. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2700. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2800. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2900. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 3000. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 3100. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 3200. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 3300. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 3400. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 3500. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 3600. GRID SIDE | 476. | **** | **** | **** | **** | **** |
| 3700. GRID SIDE | 451. | **** | **** | **** | **** | **** |
| 3800. GRID SIDE | 427. | **** | **** | **** | **** | **** |
| 3900. GRID SIDE | 406. | **** | **** | **** | **** | **** |
| 4000. GRID SIDE | 386. | **** | **** | **** | **** | **** |

HIGH MEANS FRICTION LOSS ABOVE ACCEPTABLE LIMITS

VELOCITY VALUE IS 2.0
WITH P VALUE OF 82.5

| PIPE DIAMETERS= | 20. | 22. | 24. | 26. | 28. | 30. |
|---|---|---|---|---|---|---|
| 100. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 200. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 300. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 400. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 500. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 600. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 700. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 800. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 900. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1000. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1100. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1200. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1300. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1400. GRID SIDE | 477. | **** | **** | **** | **** | **** |
| 1500. GRID SIDE | 415. | **** | **** | **** | **** | **** |
| 1600. GRID SIDE | 365. | **** | **** | **** | **** | **** |
| 1700. GRID SIDE | 323. | 473. | **** | **** | **** | **** |
| 1800. GRID SIDE | 289. | 422. | **** | **** | **** | **** |
| 1900. GRID SIDE | 259. | 379. | **** | **** | **** | **** |
| 2000. GRID SIDE | 234. | 342. | 484. | **** | **** | **** |
| 2100. GRID SIDE | 212. | 310. | 439. | **** | **** | **** |
| 2200. GRID SIDE | 193. | 283. | 400. | **** | **** | **** |
| 2300. GRID SIDE | 177. | 259. | 366. | **** | **** | **** |
| 2400. GRID SIDE | 162. | 238. | 336. | 463. | **** | **** |
| 2500. GRID SIDE | 150. | 219. | 310. | 427. | **** | **** |
| 2600. GRID SIDE | 138. | 202. | 287. | 395. | **** | **** |
| 2700. GRID SIDE | 128. | 188. | 266. | 366. | 492. | **** |
| 2800. GRID SIDE | 119. | 174. | 247. | 340. | 457. | **** |
| 2900. GRID SIDE | 111. | 163. | 230. | 317. | 426. | **** |
| 3000. GRID SIDE | 104. | 152. | 215. | 296. | 398. | **** |
| 3100. GRID SIDE | 97. | 142. | 202. | 278. | 373. | 492. |
| 3200. GRID SIDE | 91. | 134. | 189. | 260. | 350. | 461. |
| 3300. GRID SIDE | 86. | 126. | 178. | 245. | 329. | 434. |
| 3400. GRID SIDE | 81. | 118. | 168. | 231. | 310. | 409. |
| 3500. GRID SIDE | 76. | 112. | 158. | 218. | 293. | 386. |
| 3600. GRID SIDE | 72. | 106. | 149. | 206. | 277. | 365. |
| 3700. GRID SIDE | 68. | 100. | 141. | 195. | 262. | 345. |
| 3800. GRID SIDE | 65. | 95. | 134. | 185. | 248. | 327. |
| 3900. GRID SIDE | 61. | 90. | 127. | 175. | 236. | 311. |
| 4000. GRID SIDE | 58. | 86. | 121. | 167. | 224. | 295. |

HIGH MEANS FRICTION LOSS ABOVE ACCEPTABLE LIMITS

VELCCITY VALUE IS 2.0
WITH P VALUE CF 500.0

| PIPE DIAMETERS= | 20. | 22. | 24. | 26. | 28. | 30. |
|---|---|---|---|---|---|---|
| 100. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 200. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 300. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 400. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 500. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 600. GRID SIDE | 428. | **** | **** | **** | **** | **** |
| 700. GRID SIDE | 315. | 461. | **** | **** | **** | **** |
| 800. GRID SIDE | 241. | 353. | 499. | **** | **** | **** |
| 900. GRID SIDE | 190. | 279. | 395. | **** | **** | **** |
| 1000. GRID SIDE | 154. | 226. | 320. | 440. | **** | **** |
| 1100. GRID SIDE | 127. | 187. | 264. | 364. | 489. | **** |
| 1200. GRID SIDE | 107. | 157. | 222. | 306. | 411. | **** |
| 1300. GRID SIDE | 91. | 134. | 189. | 260. | 350. | 461. |
| 1400. GRID SIDE | 79. | 115. | 163. | 225. | 302. | 398. |
| 1500. GRID SIDE | 69. | 100. | 142. | 196. | 263. | 346. |
| 1600. GRID SIDE | 60. | 88. | 125. | 172. | 231. | 305. |
| 1700. GRID SIDE | 53. | 78. | 111. | 152. | 205. | 270. |
| 1800. GRID SIDE | 48. | 70. | 99. | 136. | 183. | 241. |
| 1900. GRID SIDE | 43. | 63. | 89. | 122. | 164. | 216. |
| 2000. GRID SIDE | 39. | 56. | 80. | 110. | 148. | 195. |
| 2100. GRID SIDE | 35. | 51. | 72. | 100. | 134. | 177. |
| 2200. GRID SIDE | 32. | 47. | 66. | 91. | 122. | 161. |
| 2300. GRID SIDE | 29. | 43. | 60. | 83. | 112. | 147. |
| 2400. GRID SIDE | 27. | 39. | 55. | 76. | 103. | 135. |
| 2500. GRID SIDE | 25. | 36. | 51. | 70. | 95. | 125. |
| 2600. GRID SIDE | 23. | 33. | 47. | 65. | 88. | 115. |
| 2700. GRID SIDE | 21. | 31. | 44. | 60. | 81. | 107. |
| 2800. GRID SIDE | 20. | 29. | 41. | 56. | 75. | 99. |
| 2900. GRID SIDE | 18. | 27. | 38. | 52. | 70. | 93. |
| 3000. GRID SIDE | 17. | 25. | 36. | 49. | 66. | 87. |
| 3100. GRID SIDE | 16. | 23. | 33. | 46. | 62. | 81. |
| 3200. GRID SIDE | 15. | 22. | 31. | 43. | 58. | 76. |
| 3300. GRID SIDE | 14. | 21. | 29. | 40. | 54. | 72. |
| 3400. GRID SIDE | 13. | 20. | 28. | 38. | 51. | 67. |
| 3500. GRID SIDE | 13. | 18. | 26. | 36. | 48. | 64. |
| 3600. GRID SIDE | 12. | 17. | 25. | 34. | 46. | 60. |
| 3700. GRID SIDE | 11. | 16. | 23. | 32. | 43. | 57. |
| 3800. GRID SIDE | 11. | 16. | 22. | 30. | 41. | 54. |
| 3900. GRID SIDE | 10. | 15. | 21. | 29. | 39. | 51. |
| 4000. GRID SIDE | 10. | 14. | 20. | 28. | 37. | 49. |

HIGH MEANS FRICTICN LOSS ABOVE ACCEPTABLE LIMITS

VELOCITY VALUE IS 4.0
WITH P VALUE OF 12.5

| PIPE DIAMETERS= | 20. | 22. | 24. | 26. | 28. | 30. |
|---|---|---|---|---|---|---|
| 100. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 200. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 300. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 400. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 500. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 600. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 700. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 800. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 900. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1000. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1100. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1200. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1300. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1400. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1500. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1600. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1700. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1800. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1900. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2000. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2100. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2200. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2300. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2400. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2500. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2600. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2700. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2800. GRID SIDE | ****A | **** | **** | **** | **** | **** |
| 2900. GRID SIDE | ****A | **** | **** | **** | **** | **** |
| 3000. GRID SIDE | ****A | **** | **** | **** | **** | **** |
| 3100. GRID SIDE | ****A | ****A | **** | **** | **** | **** |
| 3200. GRID SIDE | ****A | ****A | **** | **** | **** | **** |
| 3300. GRID SIDE | ****A | ****A | **** | **** | **** | **** |
| 3400. GRID SIDE | ****A | ****A | **** | **** | **** | **** |
| 3500. GRID SIDE | ****A | ****A | ****A | **** | **** | **** |
| 3600. GRID SIDE | ****A | ****A | ****A | **** | **** | **** |
| 3700. GRID SIDE | ****A | ****A | ****A | **** | **** | **** |
| 3800. GRID SIDE | ****A | ****A | ****A | ****A | **** | **** |
| 3900. GRID SIDE | ****A | ****A | ****A | ****A | **** | **** |
| 4000. GRID SIDE | ****A | ****A | ****A | ****A | **** | **** |

HIGH MEANS FRICTION LOSS ABOVE ACCEPTABLE LIMITS

VELOCITY VALUE IS 4.0
WITH P VALUE OF 82.5

| PIPE DIAMETERS= | 20. | 22. | 24. | 26. | 28. | 30. |
|---|---|---|---|---|---|---|
| 100. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 200. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 300. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 400. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 500. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 600. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 700. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 800. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 900. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1000. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1100. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1200. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1300. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1400. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1500. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1600. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1700. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1800. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1900. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2000. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2100. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2200. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2300. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2400. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2500. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2600. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2700. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2800. GRID SIDE | 477.A | **** | **** | **** | **** | **** |
| 2900. GRID SIDE | 445.A | **** | **** | **** | **** | **** |
| 3000. GRID SIDE | 415.A | **** | **** | **** | **** | **** |
| 3100. GRID SIDE | 389.A | ****A | **** | **** | **** | **** |
| 3200. GRID SIDE | 365.A | ****A | **** | **** | **** | **** |
| 3300. GRID SIDE | 343.A | ****A | **** | **** | **** | **** |
| 3400. GRID SIDE | 323.A | 473.A | **** | **** | **** | **** |
| 3500. GRID SIDE | 305.A | 447.A | ****A | **** | **** | **** |
| 3600. GRID SIDE | 289.A | 422.A | ****A | **** | **** | **** |
| 3700. GRID SIDE | 273.A | 400.A | ****A | **** | **** | **** |
| 3800. GRID SIDE | 259.A | 379.A | ****A | ****A | **** | **** |
| 3900. GRID SIDE | 246.A | 360.A | ****A | ****A | **** | **** |
| 4000. GRID SIDE | 234.A | 342.A | 484.A | ****A | **** | **** |

HIGH MEANS FRICTION LOSS ABOVE ACCEPTABLE LIMITS

VELOCITY VALUE IS 4.0
WITH P VALUE OF 500.0



| PIPE DIAMETERS= | 20. | 22. | 24. | 26. | 28. | 30. |
|---|---|---|---|---|---|---|
| 100. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 200. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 300. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 400. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 500. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 600. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 700. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 800. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 900. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1000. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1100. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1200. GRID SIDE | 428. | **** | **** | **** | **** | **** |
| 1300. GRID SIDE | 365. | **** | **** | **** | **** | **** |
| 1400. GRID SIDE | 315. | 461. | **** | **** | **** | **** |
| 1500. GRID SIDE | 274. | 401. | **** | **** | **** | **** |
| 1600. GRID SIDE | 241. | 353. | 499. | **** | **** | **** |
| 1700. GRID SIDE | 213. | 312. | 442. | **** | **** | **** |
| 1800. GRID SIDE | 190. | 279. | 395. | **** | **** | **** |
| 1900. GRID SIDE | 171. | 250. | 354. | 488. | **** | **** |
| 2000. GRID SIDE | 154. | 226. | 320. | 440. | **** | **** |
| 2100. GRID SIDE | 140. | 205. | 290. | 399. | **** | **** |
| 2200. GRID SIDE | 127. | 187. | 264. | 364. | 489. | **** |
| 2300. GRID SIDE | 117. | 171. | 242. | 333. | 447. | **** |
| 2400. GRID SIDE | 107. | 157. | 222. | 306. | 411. | **** |
| 2500. GRID SIDE | 99. | 144. | 205. | 282. | 379. | 499. |
| 2600. GRID SIDE | 91. | 134. | 189. | 260. | 350. | 461. |
| 2700. GRID SIDE | 85. | 124. | 175. | 241. | 325. | 428. |
| 2800. GRID SIDE | 79.A | 115. | 163. | 225. | 302. | 398. |
| 2900. GRID SIDE | 73.A | 107. | 152. | 209. | 281. | 371. |
| 3000. GRID SIDE | 69.A | 100. | 142. | 196. | 263. | 346. |
| 3100. GRID SIDE | 64.A | 94.A | 133. | 183. | 246. | 324. |
| 3200. GRID SIDE | 60.A | 88.A | 125. | 172. | 231. | 305. |
| 3300. GRID SIDE | 57.A | 83.A | 117. | 162. | 217. | 286. |
| 3400. GRID SIDE | 53.A | 78.A | 111. | 152. | 205. | 270. |
| 3500. GRID SIDE | 50.A | 74.A | 104.A | 144. | 193. | 255. |
| 3600. GRID SIDE | 48.A | 70.A | 99.A | 136. | 183. | 241. |
| 3700. GRID SIDE | 45.A | 66.A | 93.A | 129. | 173. | 228. |
| 3800. GRID SIDE | 43.A | 63.A | 89.A | 122.A | 164. | 216. |
| 3900. GRID SIDE | 41.A | 59.A | 84.A | 116.A | 156. | 205. |
| 4000. GRID SIDE | 39.A | 56.A | 80.A | 110.A | 148. | 195. |

HIGH MEANS FRICTION LOSS ABOVE ACCEPTABLE LIMITS

VELOCITY VALUE IS 2.0
WITH P VALUE OF 12.5

| PIPE DIAMETERS= | 32. | 34. | 36. | 48. | 72. | 96. |
|---|---|---|---|---|---|---|
| 100. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 200. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 300. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 400. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 500. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 600. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 700. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 800. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 900. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1000. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1100. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1200. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1300. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1400. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1500. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1600. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1700. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1800. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1900. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2000. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2100. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2200. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2300. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2400. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2500. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2600. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2700. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2800. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2900. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 3000. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 3100. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 3200. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 3300. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 3400. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 3500. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 3600. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 3700. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 3800. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 3900. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 4000. GRID SIDE | **** | **** | **** | **** | **** | **** |

HIGH MEANS FRICTION LOSS ABOVE ACCEPTABLE LIMITS

VELOCITY VALUE IS 2.0
WITH P VALUE OF 82.5

| PIPE DIAMETERS= | 32. | 34. | 36. | 48. | 72. | 96. |
|---|---|---|---|---|---|---|
| 100. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 200. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 300. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 400. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 500. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 600. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 700. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 800. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 900. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1000. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1100. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1200. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1300. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1400. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1500. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1600. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1700. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1800. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1900. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2000. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2100. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2200. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2300. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2400. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2500. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2600. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2700. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2800. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2900. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 3000. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 3100. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 3200. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 3300. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 3400. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 3500. GRID SIDE | 499. | **** | **** | **** | **** | **** |
| 3600. GRID SIDE | 472. | **** | **** | **** | **** | **** |
| 3700. GRID SIDE | 447. | **** | **** | **** | **** | **** |
| 3800. GRID SIDE | 423. | **** | **** | **** | **** | **** |
| 3900. GRID SIDE | 402. | **** | **** | **** | **** | **** |
| 4000. GRID SIDE | 382. | 487. | **** | **** | **** | **** |

HIGH MEANS FRICTION LOSS ABOVE ACCEPTABLE LIMITS

VELOCITY VALUE IS 2.0
WITH P VALUE OF 500.0

| PIPE DIAMETERS= | 32. | 34. | 36. | 48. | 72. | 96. |
|---|---|---|---|---|---|---|
| 100. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 200. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 300. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 400. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 500. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 600. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 700. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 800. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 900. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1000. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1100. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1200. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1300. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1400. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1500. GRID SIDE | 448. | **** | **** | **** | **** | **** |
| 1600. GRID SIDE | 394. | **** | **** | **** | **** | **** |
| 1700. GRID SIDE | 349. | 445. | **** | **** | **** | **** |
| 1800. GRID SIDE | 311. | 397. | 499. | **** | **** | **** |
| 1900. GRID SIDE | 279. | 356. | 447. | **** | **** | **** |
| 2000. GRID SIDE | 252. | 321. | 404. | **** | **** | **** |
| 2100. GRID SIDE | 229. | 291. | 366. | **** | **** | **** |
| 2200. GRID SIDE | 208. | 266. | 334. | **** | **** | **** |
| 2300. GRID SIDE | 191. | 243. | 305. | **** | **** | **** |
| 2400. GRID SIDE | 175. | 223. | 280. | **** | **** | **** |
| 2500. GRID SIDE | 161. | 206. | 258. | **** | **** | **** |
| 2600. GRID SIDE | 149. | 190. | 239. | **** | **** | **** |
| 2700. GRID SIDE | 138. | 176. | 222. | **** | **** | **** |
| 2800. GRID SIDE | 129. | 164. | 206. | **** | **** | **** |
| 2900. GRID SIDE | 120. | 153. | 192. | **** | **** | **** |
| 3000. GRID SIDE | 112. | 143. | 179. | **** | **** | **** |
| 3100. GRID SIDE | 105. | 134. | 168. | **** | **** | **** |
| 3200. GRID SIDE | 99. | 126. | 158. | 498. | **** | **** |
| 3300. GRID SIDE | 93. | 118. | 148. | 468. | **** | **** |
| 3400. GRID SIDE | 87. | 111. | 140. | 441. | **** | **** |
| 3500. GRID SIDE | 82. | 105. | 132. | 416. | **** | **** |
| 3600. GRID SIDE | 78. | 99. | 125. | 393. | **** | **** |
| 3700. GRID SIDE | 74. | 94. | 118. | 372. | **** | **** |
| 3800. GRID SIDE | 70. | 89. | 112. | 353. | **** | **** |
| 3900. GRID SIDE | 66. | 85. | 106. | 335. | **** | **** |
| 4000. GRID SIDE | 63. | 80. | 101. | 319. | **** | **** |

HIGH MEANS FRICTION LOSS ABOVE ACCEPTABLE LIMITS

VELOCITY VALUE IS 4.0
WITH P VALUE OF 12.5

| PIPE DIAMETERS= | 32. | 34. | 36. | 48. | 72. | 96. |
|---|---|---|---|---|---|---|
| 100. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 200. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 300. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 400. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 500. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 600. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 700. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 800. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 900. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1000. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1100. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1200. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1300. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1400. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1500. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1600. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1700. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1800. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1900. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2000. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2100. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2200. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2300. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2400. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2500. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2600. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2700. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2800. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2900. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 3000. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 3100. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 3200. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 3300. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 3400. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 3500. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 3600. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 3700. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 3800. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 3900. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 4000. GRID SIDE | **** | **** | **** | **** | **** | **** |

HIGH MEANS FRICTION LOSS ABOVE ACCEPTABLE LIMITS

VELOCITY VALUE IS 4.0
WITH P VALUE OF 32.5

| PIPE DIAMETERS= | 32. | 34. | 36. | 48. | 72. | 96. |
|---|---|---|---|---|---|---|
| 100. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 200. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 300. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 400. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 500. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 600. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 700. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 800. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 900. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1000. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1100. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1200. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1300. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1400. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1500. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1600. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1700. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1800. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1900. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2000. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2100. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2200. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2300. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2400. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2500. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2600. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2700. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2800. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2900. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 3000. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 3100. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 3200. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 3300. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 3400. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 3500. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 3600. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 3700. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 3800. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 3900. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 4000. GRID SIDE | **** | **** | **** | **** | **** | **** |

HIGH MEANS FRICTION LOSS ABOVE ACCEPTABLE LIMITS

VELOCITY VALUE IS 4.0
WITH P VALUE OF 500.0

| PIPE DIAMETERS= | 32. | 34. | 36. | 48. | 72. | 96. |
|---|---|---|---|---|---|---|
| 100. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 200. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 300. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 400. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 500. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 600. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 700. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 800. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 900. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1000. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1100. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1200. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1300. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1400. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1500. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1600. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1700. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1800. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 1900. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2000. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2100. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2200. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2300. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2400. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2500. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2600. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2700. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2800. GRID SIDE | **** | **** | **** | **** | **** | **** |
| 2900. GRID SIDE | 480. | **** | **** | **** | **** | **** |
| 3000. GRID SIDE | 448. | **** | **** | **** | **** | **** |
| 3100. GRID SIDE | 420. | **** | **** | **** | **** | **** |
| 3200. GRID SIDE | 394. | **** | **** | **** | **** | **** |
| 3300. GRID SIDE | 371. | 472. | **** | **** | **** | **** |
| 3400. GRID SIDE | 349. | 445. | **** | **** | **** | **** |
| 3500. GRID SIDE | 329. | 420. | **** | **** | **** | **** |
| 3600. GRID SIDE | 311. | 397. | 499. | **** | **** | **** |
| 3700. GRID SIDE | 295. | 376. | 472. | **** | **** | **** |
| 3800. GRID SIDE | 279. | 356. | 447. | **** | **** | **** |
| 3900. GRID SIDE | 265. | 338. | 425. | **** | **** | **** |
| 4000. GRID SIDE | 252. | 321. | 404. | **** | **** | **** |

HIGH MEANS FRICTION LOSS ABOVE ACCEPTABLE LIMITS

## WATER SUPPLY IN DEVELOPING COUNTRIES

Water supply has become a critical factor in public health and economic development in most parts of the world, particularly in the developing countries. Deficiencies and backlogs have created conditions that call for immediate efforts by governments and local agencies to promote the construction of new supplies and to improve existing schemes.

A study made by the World Health Organization in 1963 in the developing countries of Africa, Latin America and Asia concisely points out the problems faced by those countries. The very considerable shortages in urban water supply reported for nearly every country in this study are obviously a result of a complex set of conditions--among them urban trends, limited national economic resources, shortage of investment capital, inept and inadequate operation and management, lack of training facilities, poor financial support for water systems, and in some cases, insufficient action on part of the governments.

The study identified the factors which in their opinion have the greatest effect on the cause of water deficiencies. They are as follows:

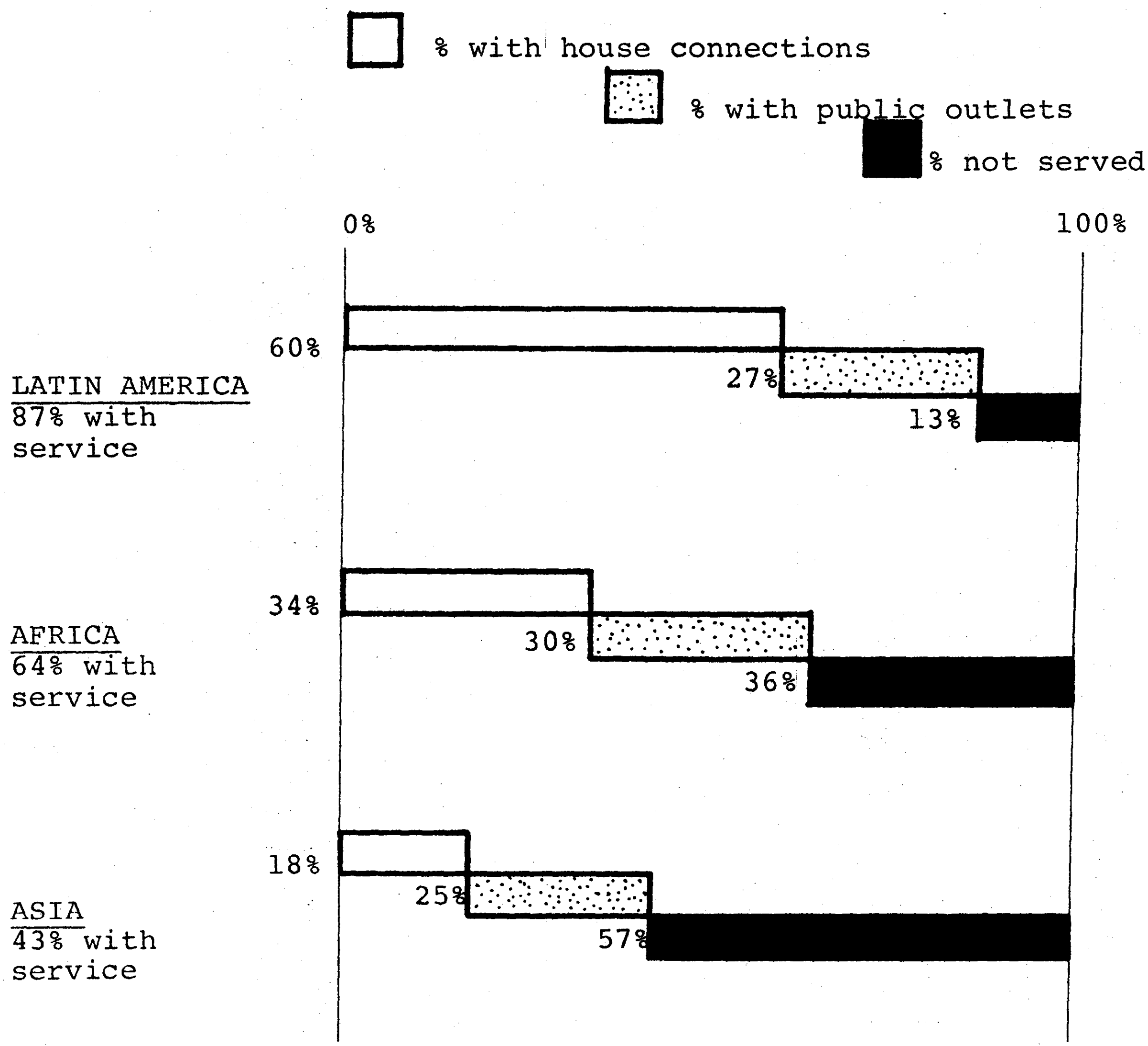
1. Although the improvement of water supplies in developing countries depends largely on government support, many governments do not make water requirements a matter of governmental policy.
2. Schemes for community water supplies are often not included in national development plans.
3. Urban water needs are often insufficiently represented in the general development of water resources because no priority policies have been established and no general master plans are in effect.
4. The most significant factor is the lack of adequate financial support.
5. Inept and inadequate operation and management, lack of an effective administrative machinery and lack of a technical staff to promote and design water supply systems and to improve existing systems are additional handicaps faced by developing countries.
6. The legislation is inadequate, water rights are poorly defined, and clear demarcation of responsibilities are lacking.
7. The role of ministries of health in community water supply development are not always defined.

Because of the factors stated above, over 70% of the urban population has an inadequate system of piped water, or is being supplied with unsafe water, or both. This existing backlog is overshadowed by the anticipated backlog due to the rapid population expansion. With whatever effort is now made to close the existing gap or improve present conditions, it must be doubled over the next 15 years to provide future needs. By 1977, approximately 450 million urban dwellers in the developing countries will be in need of new, extended, or improved water supplies.

Unless these deficiencies are eliminated, present shortages will continue to exist. If no piped water is available, people turn to sources that are likely to be unsafe and consequently expose themselves to various water borne diseases.

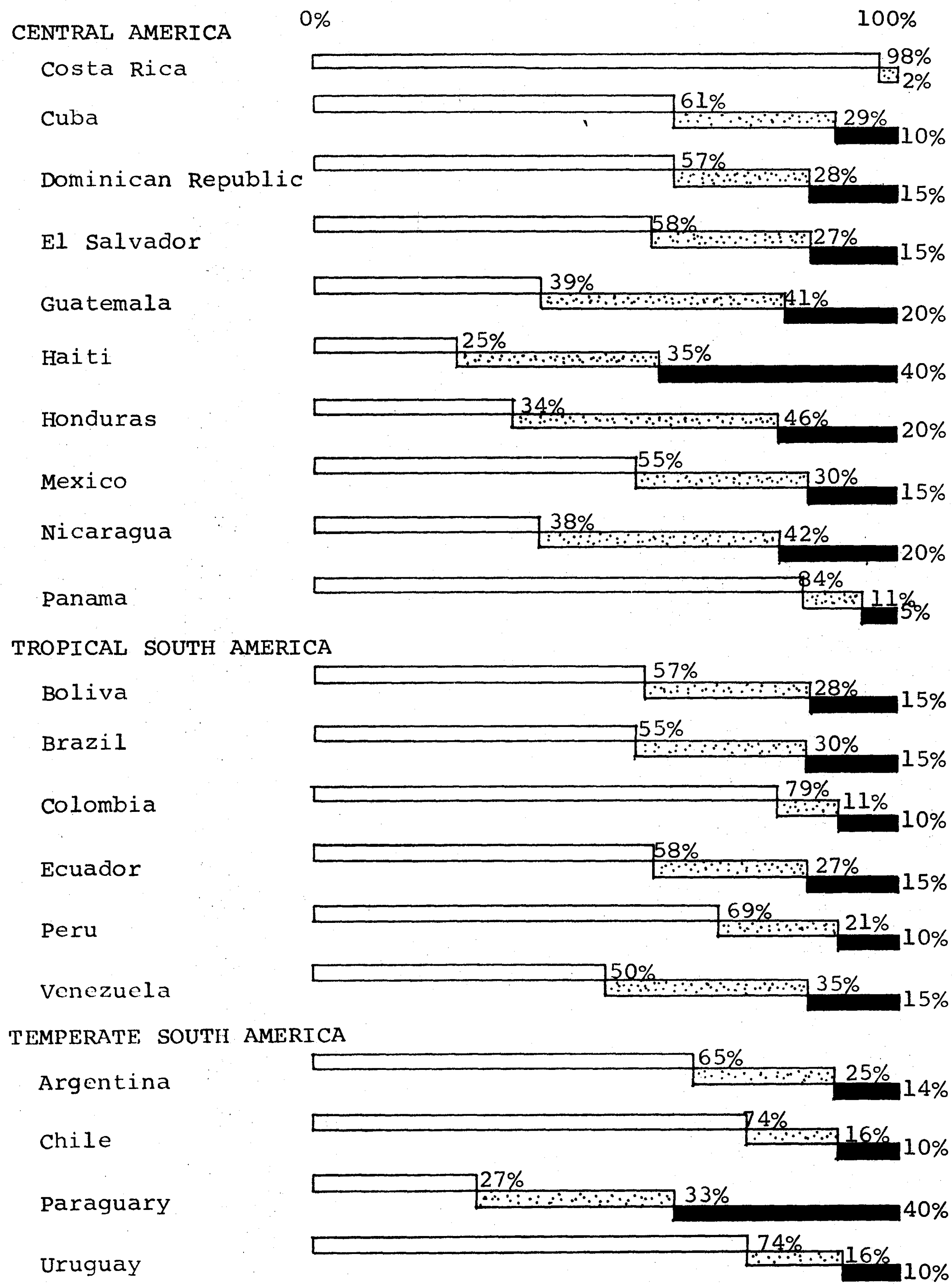
(adapted from R:19)

URBAN WATER SERVICE IN DEVELOPING COUNTRIES




(R:19)

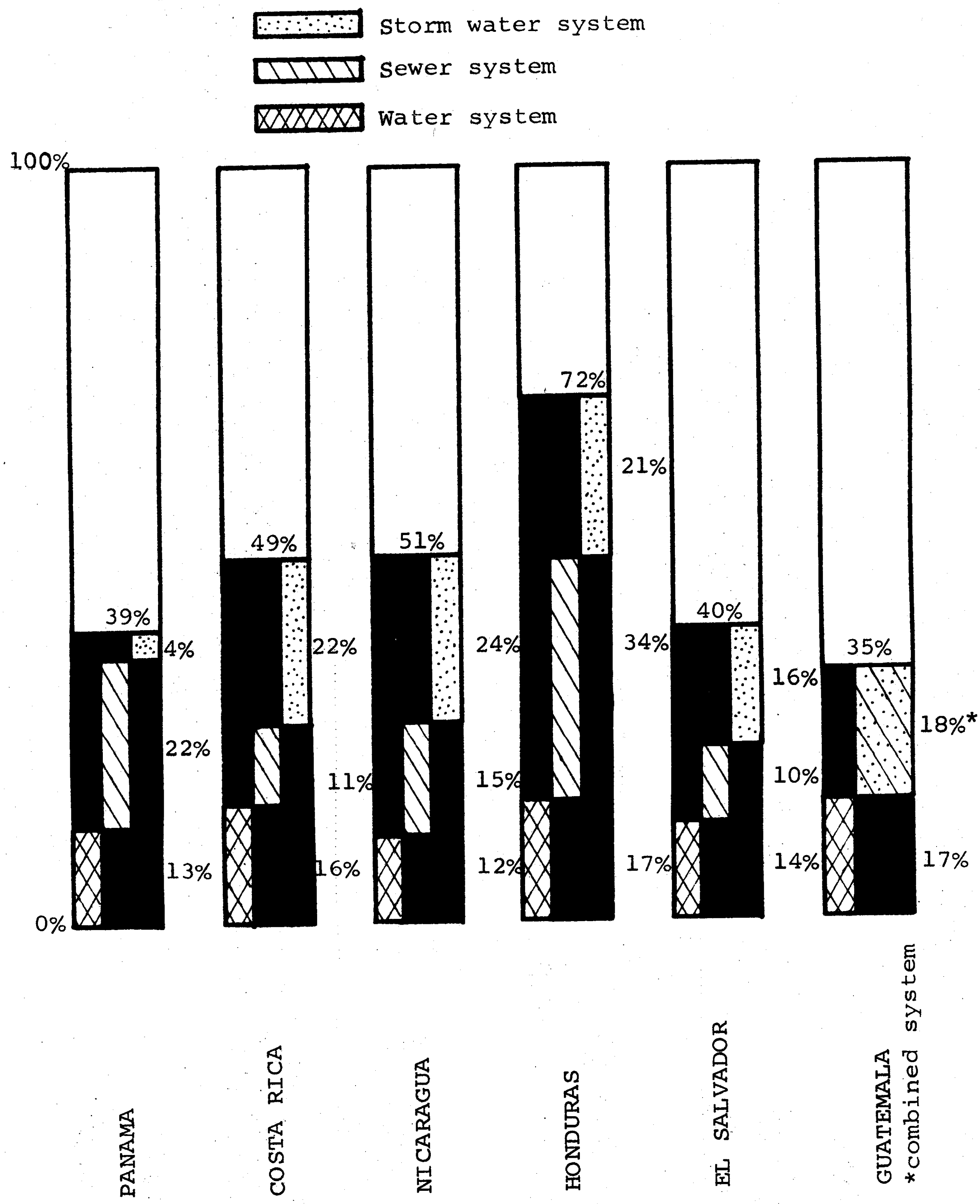
WATER SERVICE IN SOUTH AMERICA




(R:19)

## WATER INFRASTRUCTURE COSTS

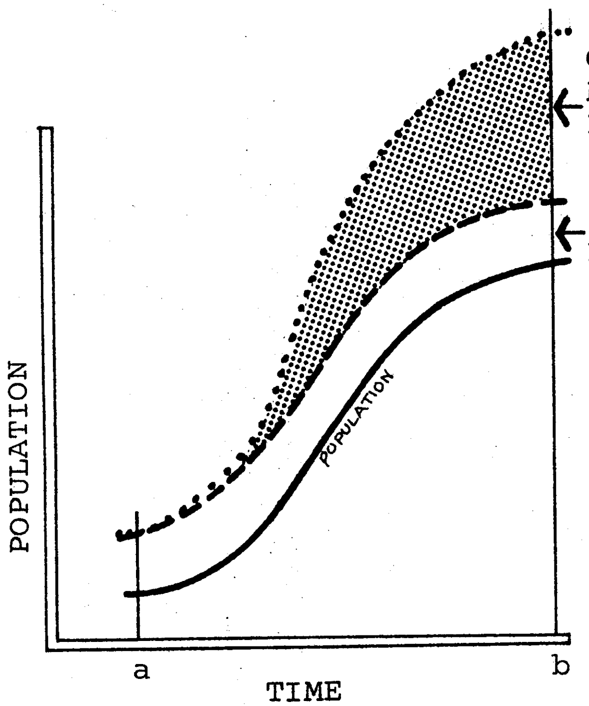
The data is taken from recently planned projects in Central America. The total cost is considered to include urbanization costs only (land and services).




(R:51)

## PLANNING FOR FUTURE NETWORK CAPACITIES

Developing countries are faced with two possible situations in their future planning of utility systems.

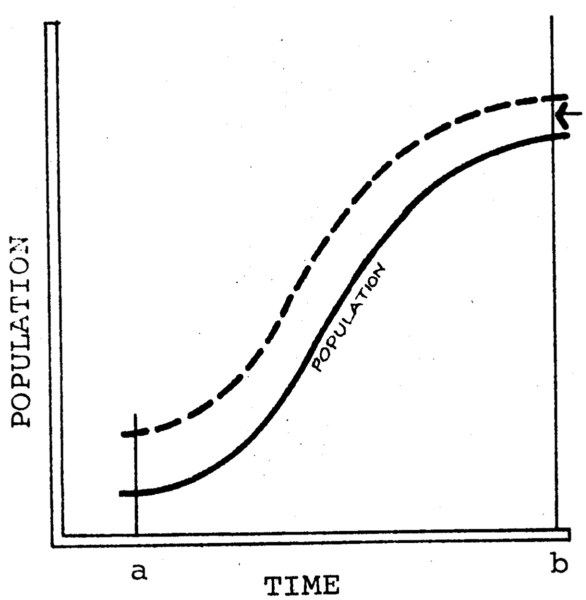



GEOMETRIC INCREASE OF WATER DEMAND DUE TO RISING STANDARDS WITH INCREASES DEMAND PER PERSON (2 to 5 times the static demand*)

STATIC INCREASE OF WATER DEMAND DUE TO POPULATION GROWTH

SITUATION 1:
An increase of the general welfare of the population with a rising GNP shared among the various sectors.

*With the development of more efficient water consumption devices (particularly water closets) the increase due to the rise in the standard of living may be less.




STATIC INCREASE OF WATER DEMAND DUE TO POPULATION GROWTH

SITUATION 2:
No increase of the general welfare of the population. Either a rising GNP not shared among the various sectors or a static GNP.

With either situation 1 or 2, the problem of water supply for urban areas is composed of three factors of demand:

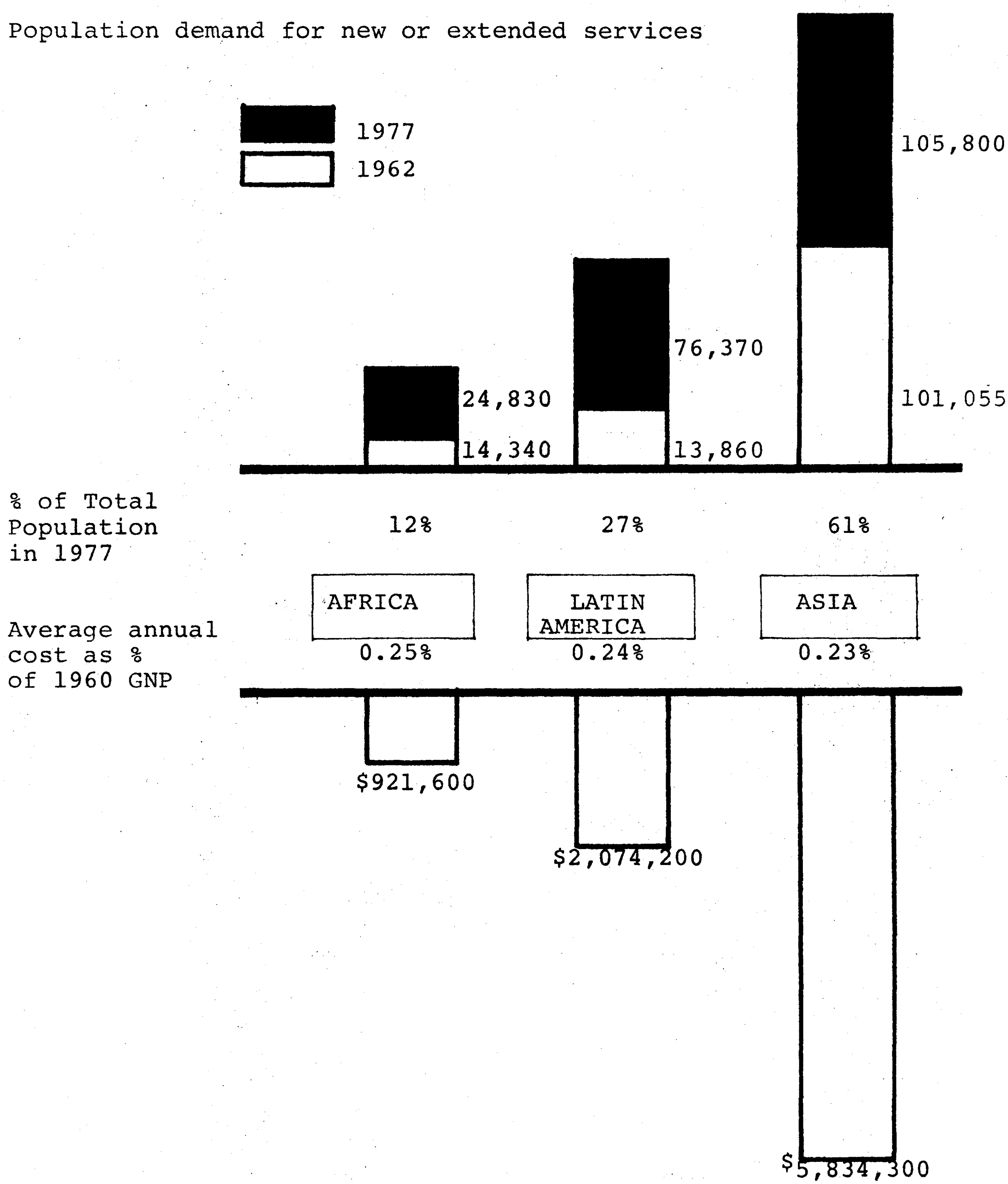
1: Meeting the demands of the backlog for water demand

2: Meeting the static demand of the population

3: Meeting the increased demand due to a rising standard of living

Perhaps one of the most reasonable alternatives to decrease the required future water supply is to develop more efficient methods of water use. For example, the current standard water closet uses up to 41% of the total domestic consumption. Many alternative methods of disposal are available and should be seriously considered when planning large scale urbanizations.

URBAN WATER DEMANDS AND COSTS




CONSTRUCTION COSTS TILL 1977 FOR WATER SERVICES (US Dollars 1960)
(R:19)

## THE VALUE OF METERS IN DEVELOPING COUNTRIES

The cost of meters will materially increase the cost per person of the water network. Operating costs of meters with billing, meter reading, and maintenance are substantial. In the case of developing countries, inadequate or incompetent management allows the meters to become inoperative and they result in a wasted investment. Without the use of meters, water supply demands become prohibitive and are unable to be met.

Meters per se are not required, but what is needed is a flow limiting device that does not require reading or billing on an individual basis. By lowering water system construction costs relative to the metering system, the device would also have the effect of increasing the percentage of dwellings connected and of decreasing the need for public hydrants. Flow constricting faucets have not been successful up to this point for flows of even 1 liter per minute would result in a waste of over the design value and result in intermitant service.

Examples of metering vs non-metering:

1. Municipal water use in two adjacent small towns in the U.S. with similar socio-economic conditions:

| | liters per capita per day | |
|---|---|---|
| | metered | un-metered |
| Average use, Annual | 260 | 1,130 |

2. Venezuela design criteria 1959

| | | |
|---|---|---|
| Under 20,000 population | 200 | 400 |
| 20,000-50,000 | 250 | 500 |
| over 50,000 | 300 | 600 |

Several devices are now being tested that offer flow reductions without compromising the consumer or making undue demands on the water supply system.

(R:19)

CONCLUSIONS:

1. Urban water supply conditions are unsatisfactory or grossly unsatisfactory in most of the developing countries.
2. Urban waterworks construction in the developing countries are too slow to close the existing gaps and match future needs.
3. Urban water supply conditions have reached a point where shortcomings are a potential danger to urban health and economic development.

RECOMMENDATIONS:

1. Urban water supply must be recognized as a national responsibility.
2. A government water supply policy should be established; it should contain basic recommendations of legislation, funding and establishment of guiding principles.
3. Existing legislation should be revised and modern water laws established.
4. Organizational steps should be taken by governments to adapt government and administrative structure to legislation and policy.
5. Whenever the country's constitution and effective water laws allow, local authorities or private bodies should be given the responsibility of construction and operation of facilities for water supply and water protection under the supervision of the governmental authorities.
6. Any program designed to improve water supply and reduce water pollution should include appropriate measures at various levels for the provision of training courses and research.
7. Governments should adapt, to suit the conditions in their own countries, ultimate and intermediate urban supply goals, which should comply with desirable standards of health and with the country's need for economic progress.
8. Local authorities and governments should devote more time to the evaluation of urban water supply conditions by establishing a system of fact reporting and data collection that not only imposes the necessity of keeping records of the actual operation of waterworks but also marks the progress achieved in waterworks construction.

(adapted from R:19)

## THE SEWER INFRASTRUCTURE

DEFINITIONS

Sewer: the pipe or pipes that carry liquid waste

Sewage: the liquid waste carried by the pipe network

Sanitary sewage: the sewer network which only carries sewage from domestic sources; storm water is excluded from the system

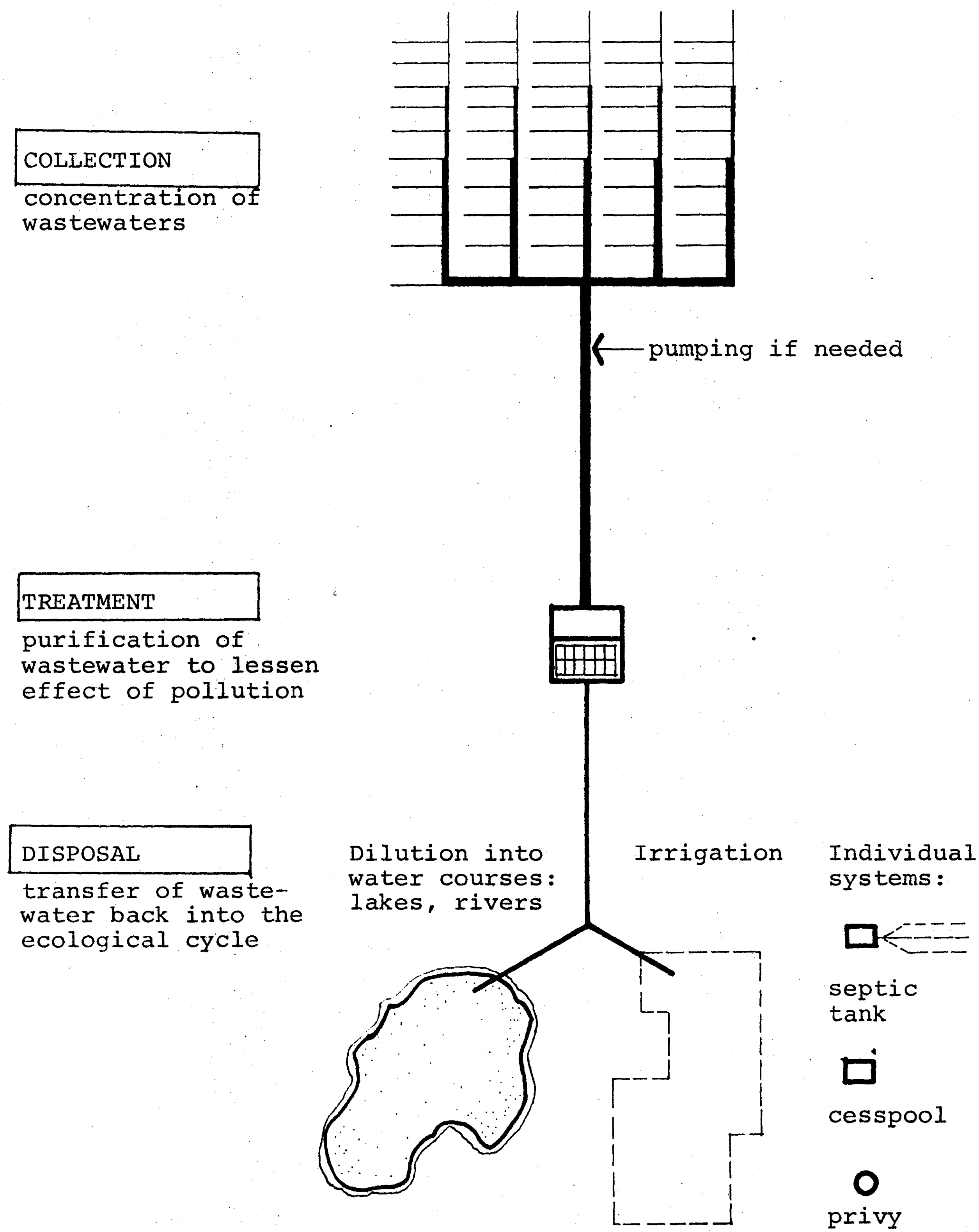
The provision of an adequate supply of water and the provision of an adequate means of disposal of household wastes in a manner acceptable for proper health conditions are the first essentials in planning residential neighborhoods.

The sewer system is probably the more important of the two systems. The method of sewage disposal pre-determines the mode of water supply in many situations; therefore the sewage disposal system must be solved first. For example, a well system of water supplies would be more subject to contamination if septic tanks or cesspool systems were established.

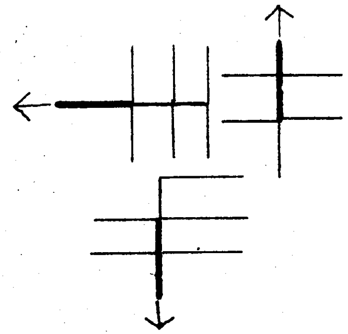
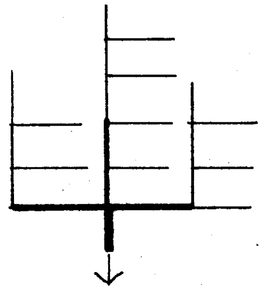
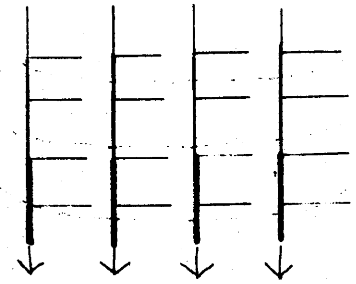
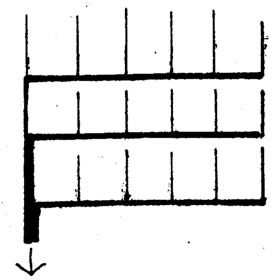
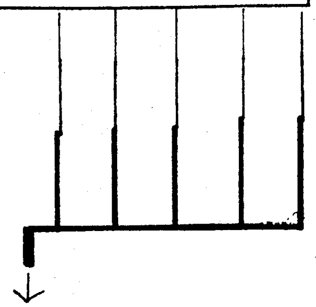
After the sewer network has been established, it becomes very costly to alter the system; consequently, the initial planning must take into careful consideration all the possible demands imposed upon the network.

The primary purpose of the sewer network is to transport human wastes in a sanitary manner to prevent the spread of disease and to remove the waste from the individual dwellings for sanitary disposal.

# COMPONENTS OF THE SEWER NETWORK



## COLLECTION COMPONENTS

| COMPONENT: | RADIAL SYSTEM | FAN SYSTEM | PERPENDICULAR SYSTEM | ZONE SYSTEM | INTERCEPTOR SYSTEM |
|---|---|---|---|---|---|
| RESPONSIBILITY: | developer finances and installs in all cases | | | | |
| CONTROL: | systems deeded to city in all cases | | | | |
| CHARACTERISTICS: | for both combined and sanitary system<br><br>used for flat sites | for sanitary systems | storm sewers or combined systems<br><br>rarely used for combined systems | for combined systems<br><br>for irregular topographical areas | for combined systems<br><br>usually sized for only small rain flows<br><br>requires water course to dump storm flows which system cannot handle |
| EXAMPLE OF USE: | Berlin | Vienna | Manhatten, New York | Boston | Cleveland, Ohio |
| ADVANTAGES: | easy to expand | allows single treatment plant;<br><br>concentrates flow into a single outfall | shortest route to disposal;<br><br>allows direct dumping of heavy storm flows | eliminates major pumping<br><br>good for flat areas | allows single treatment plant |
| DISADVANTAGES: | requires multiple treatment plants | difficult to expand | pollution dangers of water disposal areas<br><br>requires multiple treatment plants | requires large main sewer<br><br>difficult to expand | requires large sewer as main<br><br>difficult to expand<br><br>pollution danger |

TREATMENT SYSTEMS

COLLECTION - **TREATMENT** - DISPOSAL

COMPONENT: Treatment plant

RESPONSIBILITY: developer finances and installs if plant needed

CONTROL: deeded to city

CHARACTERISTICS: treatment consists of removing solids and objectionable material from water carrier to prevent pollution of outfall areas. In some cases, temperature of the effluent must be altered to match the outfall streams if streams are small in relative scale.

design period from 20 to 25 years; 10 to 15 years if interest rates are high.

PROCESS

Primary treatment: (large solids)
grit chambers
settling tanks
sludge drying beds

Secondary treatment: (suspended matter)
trickling filter
activated sludge
sand filtration

Disinfection: chlorine usually used

Lagoons are sometimes used with remarkable success; they have no odor and are simple to operate. (See following page).

SCALE OF DEVELOPMENT: Limited by the degree of purity demanded for specific situations; it is directly proportional to cost.
10,000 gpd is classified as the threshold of large systems.

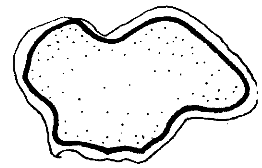
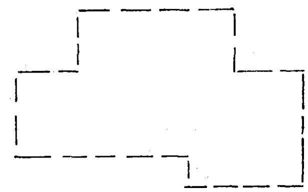
LAGOONS: TREATMENT AND DISPOSAL SYSTEM

| | |
|---|---|
| COMPONENT: | Lagoons (also called oxidation ponds) |
| FUNCTION: | the use of bacterial and algae action to digest wastes; in the cycle the bacteria converts the sewage into food for the algae which releases oxygen which the bacteria feeds on in return; the algae eat the $CO_2$, nitrates and other products of the bacteria process. Raw or secondary treated sewage may be the input into the lagoon. |
| RESPONSIBILITY: | the developer is responsible for his own system, the city provides system if used for the whole area |
| CONTROL: | city policy controls system; health laws govern |
| CHARACTERISTICS: | minimum depth of 1 meter to prevent weeds from growing; maximum depth of 1.5 meters since the sunlight necessary for the photosynthesis action of algae does not penetrate any deeper than this; the depth should be uniform throughout. |
| | the bottom may be paved or unpaved, sandy or soil; it may need to be paved if the input flow of sewage is less than the seepage rate and evaporation. Avoid irregular shoreline; shape is not critical in any respect. |
| | system is balanced in size so input flow equals seepage and evaporation loss, for smaller system secondary overflow field must be provided. |
| | should not be located near water supplies; 400-800 meters from residential area for safety reasons |
| | supports 17 to 60 pounds/acre of B.O.D. (solids) |
| | climate critical in location; needs sunlight, windy weather aids mixing process; if ice covered may have temporary odor upon thawing in spring |

LAGOONS: TREATMENT AND DISPOSAL SYSTEM -- CONT'D.

| | |
|---|---|
| SCALE OF DEVELOPMENT: | supports 100 to 500 houses per acre of pond |
| ADVANTAGES: | no treatment plant needed, low cost; no maintenance problems; more efficient digester of bacterial waste, no odor, less than conventional plants; accepts raw sewage; allows pipe network with future hook-up to city service without loss; land may be reused. Approx. 1/10 to 1/50 of the cost of septic tanks. |
| DISADVANTAGES: | requires large areas of low cost land; not efficient on cloudy days; no long term experience (25-50 years) with system; odor when system overloaded |

## DISPOSAL METHODS

| |  |  |
|---|---|---|
| COMPONENT: | Dilution in water courses | Irrigation fields |
| RESPONSIBILITY: | developer | developer |
| CONTROL: | regional or local board | |
| CHARACTERISTICS: | may be emptied into water without treatment if diluted to 2.5 cps of water per 1,000 persons in swift streams and 10 cfs of water per 1,000 persons into sluggest streams. (6 cfs average) | May be either sub-surface or surface irrigation<br><br>Subsubsurface requires drain field. |
| EXAMPLE: | New York | Berlin |
| SCALE OF DEVELOPMENT: | Dependent on the size of the water course used for dumping | Dependent on soil characteristics; also on the water table and geological conditions. |
| ADVANTAGES: | Easy access<br>Low cost. | A satisfactory alternative if no water courses are accessible for dumping.<br><br>May be used for crops if water is scarce. |
| DISADVANTAGES: | Danger of pollution in the water courses. | Danger of the contamination of groundwater supplies.<br><br>More expensive for municipal if no cheap land available. |

INDIVIDUAL DISPOSAL

| | | | |
|---|---|---|---|
| COMPONENT: | SEPTIC TANK | CESSPOOL | PRIVY |
| RESPONSIBILITY: | individual | individual | individual |
| CONTROL: | individual | individual | individual |
| CHARACTERISTICS: | requires drain field to take care of effluent<br><br>system dependent on soil and geological conditions<br><br>sized at 50/75 gpcd; 500 gallons minimum capacity; no storm flows allowed<br><br>drain field max. length of 100' on flat site; 6' spacing of lines; 4" tile for drain; 100' from water source<br><br>percolation of waste acts as treatment plant; tank stores solids<br><br>min. slope of 3/4" 100 feet of drains; if too steep; drains fail | does not require drain field<br><br>store effluent in large fluid filled tank where liquid slowly spees out<br><br>highly dependent on soil and geological conditions | consists of hole in ground<br><br>short term use only<br><br>1.5 m. min. depth<br><br>treat with lime and cover with 18" of soil after use<br><br>1 seat per 15 people on communal scale |
| SCALE OF USE: | individual only; lots over 2 acres | individual only in both cases | |
| ADVANTAGES: | | low cost | low cost, or no cost |
| DISADVANTAGES: | may not be used with wells; more expensive first costs than public system<br><br>cannot expand easily<br><br>requires maintenance | may not be used with wells pollution and disease dangers; contaminates water supplies easily; more than septic tank | |

## COMPONENTS REQUIRED IN NEW URBANIZATION

A developer is generally faced with three alternatives for the collection and final disposal of sewage:

1. Connection to an existing system
2. Development of a communal system
3. Reliance on individual systems

CRITERIA FOR CHOICE OF ALTERNATIVES

1) Location of project: if the project is within an existant sewer system, it is most reasonable to rely on the city system; if it is infeasible to connect to an existing system because of distance, other possibilities should be weighted against cost of a pressure transmission sewer for connection. Dwelling within 30 m. generally must connect.

2) Size of lot: very large suburban lots may wish to use own septic tank systems to avoid service line cost; usually decided by location.

3) Local laws for utility systems: some systems require connection without choice.

# REQUIRED COMPONENTS

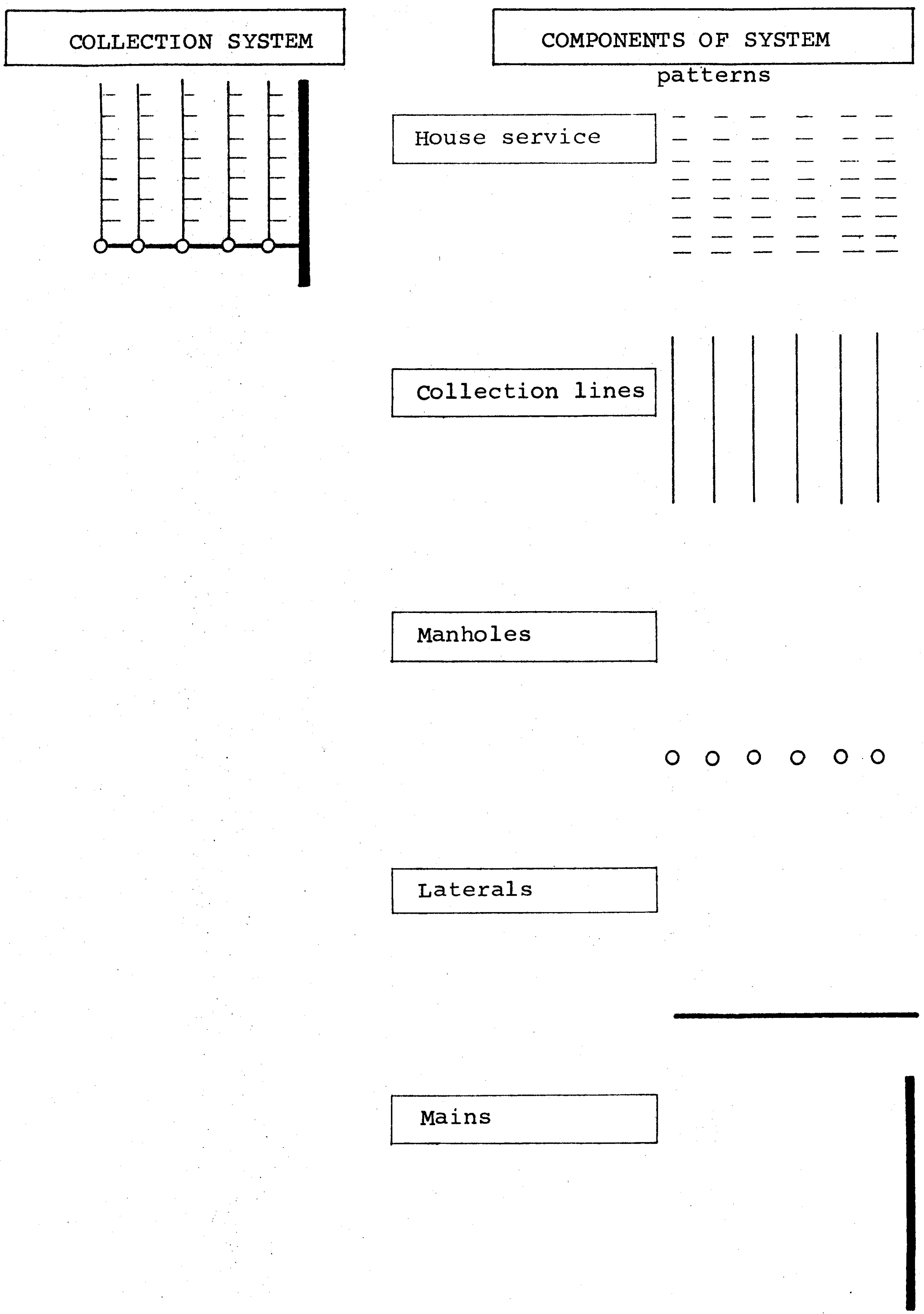
TYPE OF SYSTEM

| | EXISTING SEWER SYSTEM | COMMUNAL SYSTEM | INDIVIDUAL SYSTEM |
|---|---|---|---|
| COLLECTION | connection of new system to existing city network | provision of pipe network and connection to private disposal | individual pipe service lines |
| TREATMENT | not required | complete plant of primary and secondary treatment lagoon may be used | not required |
| DISPOSAL | not required | dilution in water course, irrigation or lagoon must be provided | septic tank with drain field, or cesspool or privy must be provided |
| SCALE OF DEVELOPMENT | no limits if city pipe net able to handle additional capacity | usually more than 100 dwellings make communal systems economically competitive | large lot conditions of low density; generally greater than $1500m^2$; dependent on soil |
| ADVANTAGES | reliable system; lower cost per unit; no treatment plant must be provided | no dependence on city system if inadequate | feasible alternative on small scale |
| DISADVANTAGES | may inherit bad system | high first costs; usually not well maintained; loss of investment if city expands | pollution dangers; loss of investment if city expands |

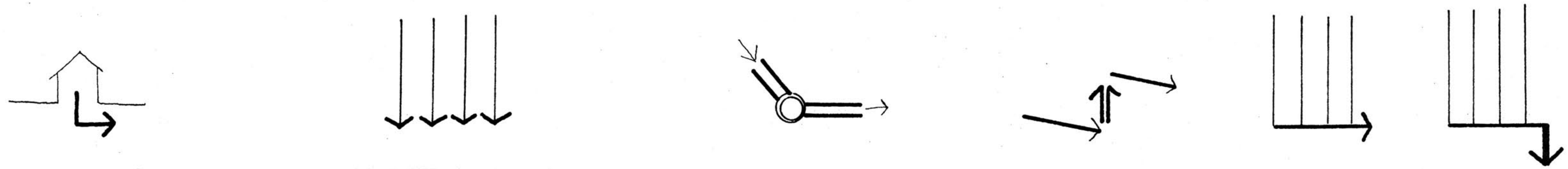
## TREATMENT AND DISPOSAL COSTS

The cost of the treatment and disposal of sewage costs approximately 50 to 100 dollars per million gallons.

(R:9)


COLLECTION SYSTEM
COMPONENTS OF SYSTEM
patterns
House service
Collection lines
Manholes
Laterals
Mains

COMPONENTS



| COMPONENT: | HOUSE SERVICE | COLLECTION LINES | MANHOLES | LIFT PUMPS | LATERALS | MAINS |
|---|---|---|---|---|---|---|
| FUNCTION: | connection for each dwelling to convey sewage to system | supplies sewage to main lines | clean out access points; velocity & pressure drop points; changes in directions | forces sewage to higher elevation to avoid deep pipe network | combines flow from collection lines | combines flow from laterals |
| RESPONSIBILITY: | individual | developer installs and finances | developer installs and finances | | | |
| CONTROL: | individual | deeded to city | deeded to city | | | |
| CHARACTERISTICS: | cast iron pipe becomes service line into house<br><br>4" min. size (US) | min. size of pipe is 8" (US)<br><br>pipe sized by min. cleaning velocity and physical cleaning potential<br><br>6" pipe sometimes acceptable if no extensions are planned | .6 to 1.0 meter in diameter<br><br>spacing of 90-120 meters if pipe under 24"; if over, may be spaced at 180 meters and up<br><br>required at all bends and changes in elevation<br><br>may become "drop" manholes to protect against excessive velocity | may be optional<br><br>usually duplicate pumps located in manholes<br><br>requires maintenance on regular basis; usually not desirable to install | designed for 400 gcd | designed for 250 gcd<br><br>the depth of this pipe is critical in the system layout, since all laterals and service lines must be above the main for economical flow |
| SCALE OF DEVELOPMENT: | each dwelling | each block of development | 300-600 meter spacing | as needed | | |

## SEWAGE QUANTITIES

Sewage quantities are generally between 70% to 90% of the compliment of the water system. The range of sewage varies from 60 gpcd to 200 gpcd in the United States. Water infiltration and illegal connections from storm drains increase the quantity; generally, 100% of the water compliment is used in design for the sewage component in order to provide some allowance for the infiltration and illegal hook-ups.

MINIMUM DESIGN QUANTITY: 100 gpcd

STANDARD QUANTITIES USED IN DESIGN: (US) laterals and sub-mains: 400 gpcd

mains: 250 gpcd

mains have a lower design value since peak fluctations are dampened because of the larger input volume.

EFFECT OF GARBAGE GRINDERS:

present systems are adequate to handle increased loads due to increased use of garbage disposals. Treatment works may be required to be increased to handle increased solids. Solids increase by 100%; grits increase by 40%.

PIPES:

over 48", the cost of the pipe increases over the increase in capacity, use a multiple of smaller mains at a lower cost

the use of larger pipes with less slope allows reduction in the trench depth; the reduction in grading cost is generally more than the additional cost of the larger pipe

poured in place concrete pipes may result in 40% savings of the construction costs

LAYOUT:

the flow should be kept as dispersed as much as possible before concentrating into a pipe network

water should be retained on the individual lots to lower the amount of immediate runoff; thus allowing the use of smaller pipes

pipe networks may be designed with open joints or perforated pipes when ground water is not in danger of contamination and soil porosity allows it; a large amount of the storm flows may be appreciably reduced in this way

# LAYOUT OF SEWER NETWORK

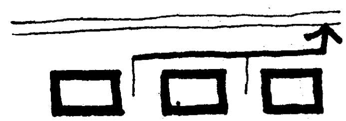
CRITERIA:

1. Adequate capacity of lines for demands imposed.
2. The network should use the minimum number of pipe sizes as possible
3. Only gravity flows should be planned

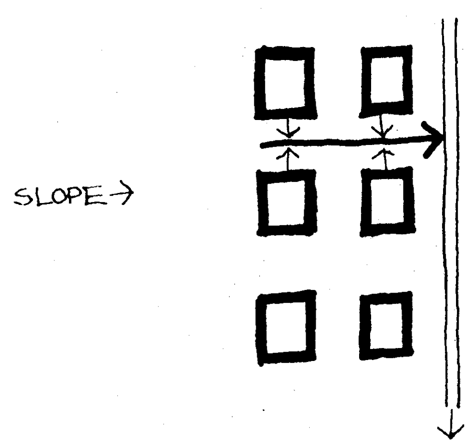
STANDARD PRACTICE:

Main layout:

- sub mains should follow line for natural drainage
- laterals should be laid along lines of greatest slope
- interceptors should be placed parallel with slope
- one should use short mains and long laterals
- sectional drainage is often more economical than duplicate networks, particularly with setback dwellings as in housing projects



If layout is on steep slope, common drains are used for several houses before connection with lateral



# DWELLINGS PER A GIVEN SEWER PIPE DIAMETER

PARAMETERS

## QUALITY OF WATER USED PER DWELLING

100% of the compliment of the water quantity from the water supply is used in the determination of the number of dwellings per sewer pipe.

1. This allows for infiltration of ground water into the network

2. This also allows for fluctuation in demand

## VELOCITIES USED IN THE CHART

Velocity=2.5 feet per second
This minimum velocity is required at the initial stage of the network development which determines the slope of the pipes; this velocity is also the minimum required to suspend sewage solids without settling out into the pipe network

Velocity=8.0 feet per second
The average velocities of flow in pipe networks; above this value (around 15 fps) the velocities become destructive to the walls of the pipes and the pipes must be coated with protective linings

## FAMILY SIZE

The average American family size of approximately 3.0 people/family is assumed in the charts

For conditions of developing countries with family sizes of 6.0 people/family, divide the number of dwellings per pipe diameter by half

## SECTIONAL FLOW

The initial stage is developed at full section of flow; the developed stage is also with full sectional flow but under pressure of the volume and velocity of the sewage

Flow at partial sectins develop higher velocities so there is no danger of clogging of the pipes at smaller flow values

## QUALITY OF SERVICE

The three qualities of service as developed in the water flow charts are used for sewer also

High quality: P=500

Intermediate: P=82.5

Low: P=12.5

NUMBER OF DWELLINGS FOR GIVEN SEWER PIPE SIZE

VELOCITY VALUE OF= 2.5

| P VALUES OF= | 12.5 | 82.5 | 500.0 |
|---|---|---|---|
| 1.INCH DIAMETER | 2. | 0. | 0. |
| 2.INCH DIAMETER | 24. | 4. | 1. |
| 3.INCH DIAMETER | 122. | 18. | 3. |
| 4.INCH DIAMETER | 385. | 58. | 10. |
| 5.INCH DIAMETER | 940. | 142. | 24. |
| 6.INCH DIAMETER | 1950. | 295. | 49. |
| 8.INCH DIAMETER | 6162. | 934. | 154. |
| 10.INCH DIAMETER | 15045. | 2279. | 376. |
| 12.INCH DIAMETER | 31196. | 4727. | 780. |
| 14.INCH DIAMETER | 57795. | 8757. | 1445. |
| 16.INCH DIAMETER | 98596. | 14939. | 2465. |
| 18.INCH DIAMETER | 157932. | 23929. | 3948. |
| 20.INCH DIAMETER | 240713. | 36472. | 6018. |
| 22.INCH DIAMETER | 352427. | 53398. | 8811. |
| 24.INCH DIAMETER | 499135. | 75626. | 12478. |
| 26.INCH DIAMETER | 687493. | 104166. | 17187. |
| 28.INCH DIAMETER | 924714. | 140108. | 23118. |
| 30.INCH DIAMETER | 1218596. | 184636. | 30465. |
| 32.INCH DIAMETER | 1577510. | 239017. | 39438. |
| 34.INCH DIAMETER | 2010444. | 304613. | 50261. |
| 36.INCH DIAMETER | 2526901. | 382864. | 63173. |
| 48.INCH DIAMETER | 7986239. | 1210036. | 199656. |
| 96.INCH DIAMETER | 127779088. | 19360464. | 3194477. |

VELOCITY VALUE OF= 8.0

| P VALUES OF= | 12.5 | 82.5 | 500.0 |
|---|---|---|---|
| 1.INCH DIAMETER | 15. | 2. | 0. |
| 2.INCH DIAMETER | 246. | 37. | 6. |
| 3.INCH DIAMETER | 1248. | 189. | 31. |
| 4.INCH DIAMETER | 3944. | 598. | 99. |
| 5.INCH DIAMETER | 9628. | 1459. | 241. |
| 6.INCH DIAMETER | 19966. | 3025. | 499. |
| 8.INCH DIAMETER | 63102. | 9561. | 1578. |
| 10.INCH DIAMETER | 154056. | 23342. | 3851. |
| 12.INCH DIAMETER | 319451. | 48402. | 7986. |
| 14.INCH DIAMETER | 591816. | 89669. | 14795. |
| 16.INCH DIAMETER | 1009620. | 152973. | 25241. |
| 18.INCH DIAMETER | 1617213. | 245032. | 40430. |
| 20.INCH DIAMETER | 2464865. | 373464. | 61622. |
| 22.INCH DIAMETER | 3608809. | 546789. | 90220. |
| 24.INCH DIAMETER | 5111182. | 774422. | 127780. |
| 26.INCH DIAMETER | 7039985. | 1066664. | 176000. |
| 28.INCH DIAMETER | 9468999. | 1434696. | 236725. |
| 30.INCH DIAMETER | 12478525. | 1890685. | 311963. |
| 32.INCH DIAMETER | 16153835. | 2447550. | 403846. |
| 34.INCH DIAMETER | 20586784. | 3119211. | 514670. |
| 36.INCH DIAMETER | 25875264. | 3920495. | 646882. |
| 48.INCH DIAMETER | 81778448. | 12390676. | 2044461. |
| 96.INCH DIAMETER | 1308467712. | 198252704. | 32711696. |

## ALLOWED LENGTH OF SEWER PIPE NETWORK

The length is a function of the slope and the depth limitations of the trenching equipment.

PARAMETERS

VELOCITY

The velocity of 2.5 feet per section is taken as the minimum value. At this velocity, solids will not settle out and clog the network.

FORMULA

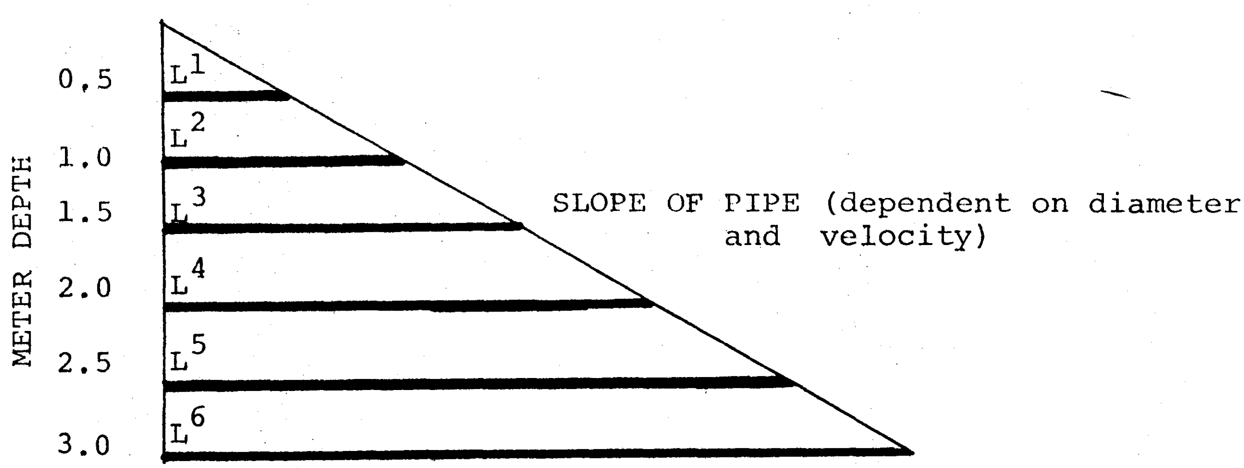
With the given velocity, the minimum slope may be derived.

$$S=(vel/(1.486N)(R/2)^{.66})^{2}$$

S= slope in feet per 1000 feet
N= friction constant for pipe material
R= radius in feet

INTERPRETATION OF THE CHART

L= length values as found in chart



LENGTH OF PIPE PER ALLOWED DROP AS NOTED

MIN VELOCITY OF= 2.5

| METER DROP OF= | 0.5 | 1.0 | 1.5 | 2.0 | 2.5 | 3.0 |
|---|---|---|---|---|---|---|
| 1.INCH DIAMETER | 4501. | 9002. | 13502. | 18003. | 22504. | 27005. |
| 2.INCH DIAMETER | 11341. | 22683. | 34024. | 45365. | 56707. | 68048. |
| 3.INCH DIAMETER | 19474. | 38948. | 58422. | 77895. | 97369. | 116843. |
| 4.INCH DIAMETER | 28578. | 57157. | 85735. | 114313. | 142891. | 171470. |
| 5.INCH DIAMETER | 38481. | 76962. | 115444. | 153925. | 192406. | 230888. |
| 6.INCH DIAMETER | 49071. | 98142. | 147213. | 196284. | 245355. | 294426. |
| 8.INCH DIAMETER | 72013. | 144026. | 216038. | 288051. | 360064. | 432077. |
| 10.INCH DIAMETER | 96967. | 193934. | 290901. | 387867. | 484834. | 581801. |
| 12.INCH DIAMETER | 123651. | 247302. | 370953. | 494604. | 618255. | 741906. |
| 14.INCH DIAMETER | 151866. | 303731. | 455597. | 607463. | 759329. | 911195. |
| 16.INCH DIAMETER | 181461. | 362921. | 544382. | 725842. | 907303. | 1088763. |
| 18.INCH DIAMETER | 212318. | 424635. | 636953. | 849271. | 1061588. | 1273906. |
| 20.INCH DIAMETER | 244340. | 488681. | 733021. | 977361. | 1221701. | 1466041. |
| 22.INCH DIAMETER | 277451. | 554902. | 832353. | 1109804. | 1387255. | 1664706. |
| 24.INCH DIAMETER | 414828. | 829655. | 1244482. | 1659310. | 2074136. | 2488965. |
| 26.INCH DIAMETER | 461547. | 923095. | 1384642. | 1846189. | 2307736. | 2769284. |
| 28.INCH DIAMETER | 509482. | 1018964. | 1528445. | 2037927. | 2547411. | 3056893. |
| 30.INCH DIAMETER | 558574. | 1117147. | 1675719. | 2234294. | 2792867. | 3351440. |
| 32.INCH DIAMETER | 608769. | 1217537. | 1826305. | 2435074. | 3043842. | 3652611. |
| 34.INCH DIAMETER | 660019. | 1320038. | 1980058. | 2640077. | 3300097. | 3960116. |
| 36.INCH DIAMETER | 712287. | 1424574. | 2136862. | 2849149. | 3561436. | 4273724. |
| 48.INCH DIAMETER | 1045300. | 2090599. | 3135898. | 4181198. | 5226498. | 6271797. |
| 96.INCH DIAMETER | 2633989. | 5267979. | 7901969. | 10535959. | 13169950. | 15803939. |

## THE STORM DRAINAGE INFRASTRUCTURE

DEFINITIONS

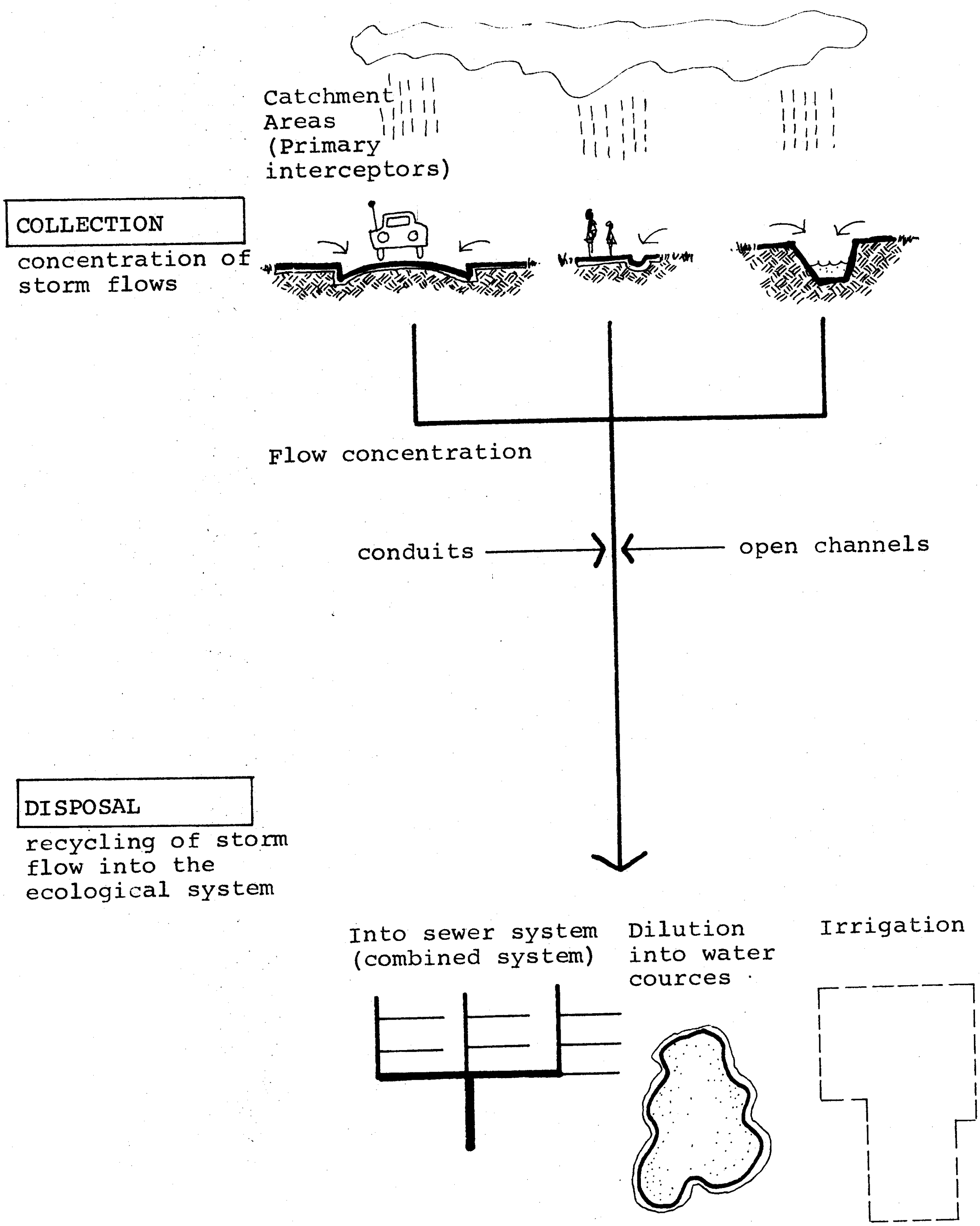
Runoff: The amount of rainfall that does not absorb into the soil or surface but remains free to follow the topography

The removal of water runoff in order to prevent flooding is the primary purpose of the storm water network.

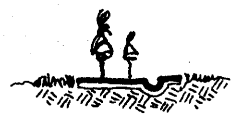
Flooding results in high material damages; it washes away streets, sidewalks, and undermines footings of dwellings. In addition, it threatens the water supplies by the contamination of either the sources or through the infiltration of the water network, with the consequence of large scale epidemics.

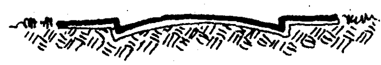
It is very costly to plan for all eventualities of flooding. A compromise between the degree of flooding and the amount of money willing to spend on a pipe network to carry away runoff is necessary in most cases. High central districts generally have a low tolerance for flooding whereas residential areas may tolerate appreciably more. Residential areas generally allow the street and sidewalk network to carry a large portion of the runoff without harm to the area.

THE STORM DRAINAGE NETWORK



COLLECTION:
Primary Interceptors

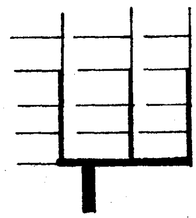


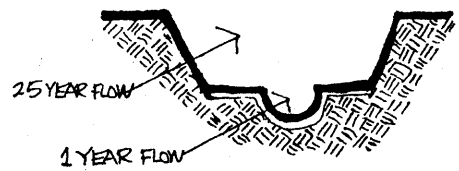


| | | | |
|---|---|---|---|
| COMPONENT: | WALKWAYS | ROADWAYS | DITCHES |
| FUNCTION: | immediate control of water runoff, allowing dispersed runoff til need for pipes required | | |
| RESPONSIBILITY: | developer is responsible for financing and installation | | |
| CONTROL: | city controls and maintains all three components | | |
| CHARACTERISTICS: | curbed sidewalk controls runoff into desired direction<br><br>walkways are sloped to keep pedestrians dry but still allow water control | 15-23 cm. curbs channel water to inlets and concentrate water into desired volume for given pipe diameter<br><br>roads are crowned to keep water out of normal vehicular travel sections under normal runoff conditions<br><br>since emergency vehicles normally have a higher body and larger tires, they may easily negotiate the streets when they are flooded | swallow ditches are standard requirements (FHA-US)<br><br>usually located on sides of streets to drain road bed |
| SCALE OF DEVELOPMENT | as needed | access to each DU | along roads |

| | WALKWAYS | ROADWAYS | DITCHES |
|---|---|---|---|
| ADVANTAGES: | allows water concentration for economical pipe sizing | allows econom-ical sizing for pipes<br><br>allows multiple use of existing system | inexpensive |
| DISADVANTAGES: | heavy rains flood sidewalk | 25-50 year rains flood roadway | constant maintenance required |

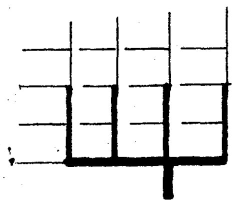
COLLECTION
Flow Concentration

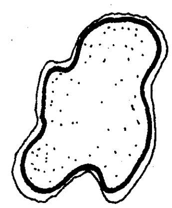


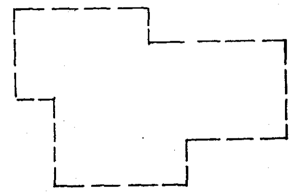



| | | |
|---|---|---|
| COMPONENT: | PIPE NETWORK | CHANNEL NETWORK |
| RESPONSIBILITY: | developer connects to city | developer established |
| CONTROL: | city maintains systems in each case | |
| CHARACTERISTICS: | gravity flow system | gravity flow system |
| | min. vel: 2.5 fps when flow at full section; max. flow of 8 fps. if pipe unlined, 15 fps if concrete lined. 12" min. recommended pipe size (U.S.) | 2.5 fps min. flow<br><br>brick lined to prevent scouring |
| | 2 centimeters per 100 meter slope a common recommendation | |
| | layout related to street drain system | |
| SCALE OF DEVELOPMENT: | economy dictates scale | large areas; dependent on rainfall intensity and duration |
| ADVANTAGES: | good for small rainfall control | inexpensive system for large flows |
| DISADVANTAGES: | difficult to change or alter as area becomes built-up and runoff increases | becomes a physical boundry |
| | unable to design for large flows economically | becomes trash collection site, health hazard |

DISPOSAL SYSTEMS







| COMPONENTS: | SEWER SYSTEM | DILUTION | IRRIGATION |
|---|---|---|---|
| RESPONSIBILITY: | connected by developer | | |
| CONTROL: | deeded to city | regional board | regulates use |
| CHARACTERISTICS: | system called "combined" when connected to sewer | most common system in urban areas | used in flat areas<br><br>used where water is at a premium |
| EXAMPLE OF USE: | Boston | | Berlin |
| SCALE OF DEVELOPMENT: | limited by existing net-work size | limited by size and flow of water course | limited by soil drainage ability |
| ADVANTAGE: | only one pipe network needed | inexpensive | may be used as water source in arid areas; agriculture value |
| DISADVANTAGES: | impossible to adequately de-sign; pipe sizing must resort to over-flow which re-sults in con-tamination of area and health dangers | pollutes water system easily during heavy rains | only useful if land is inex-pensive<br><br>danger of pollution of ground water |

## QUANTITY OF WATER IN PLANNING

### SIZING OF SYSTEM

1. AMOUNT OF WATER

   A. Intensity and duration of storm: the longer the storm, the more runoff occurs due to saturated ground conditions. The more development, the more runoff and less infiltration into the ground. Strong, short duration storms have a greater runoff than light, long duration storms because of the greater ground infiltration.

   B. Size and runoff of tributaries: the larger the water tributary, the more water able to be handled. The faster the flow of the water tributary, the more water is able to be absorbed without flooding.

2. CRITERIA USED IN DESIGN OF SYSTEM

The criteria is based on what degree of flooding an urbanization will tolerate. The tolerance level is usually expressed in years of design period; or probability of amount and duration of rainfall in a period of years.

SUBURBAN CRITERIA: Since land values are relatively low and since there are no dangers to large segments of the population, the year design period is usually 1 to 2 years; a network that will accomodate the flows occurring within one to two years. Other means are employed to control runoff and excess water flows. Streets and sidewalks are allowed to flood the few days out of the year when the anticipated rainfalls occur.

CHARACTERISTICS: rainfalls fill pipe system at full design potential several times within year, relatively inexpensive pipe network, may be altered since not excessive investment involved.

CENTRAL AREA CRITERIA: Relatively high land values and relatively vital to a large segment of the population demands a high design period. Usually 25 to 50 year design periods are used.

CHARACTERISTICS: a relative expensive system, difficult to change because of investment and size and location, pipes mostly handle minor flows, only once in 25 to 50 years are the pipes filled to full potential.

FORMULA USED IN DESIGN:

The Rational Method: the most commonly used formula for handling storm flows

$$Q = CiA$$

Q = rate of runoff in cubic feet per second
C = coefficient of runoff dependent on the character of the land
i = average intensity of rainfall in inches/hour
A = size of the drainage area in acres

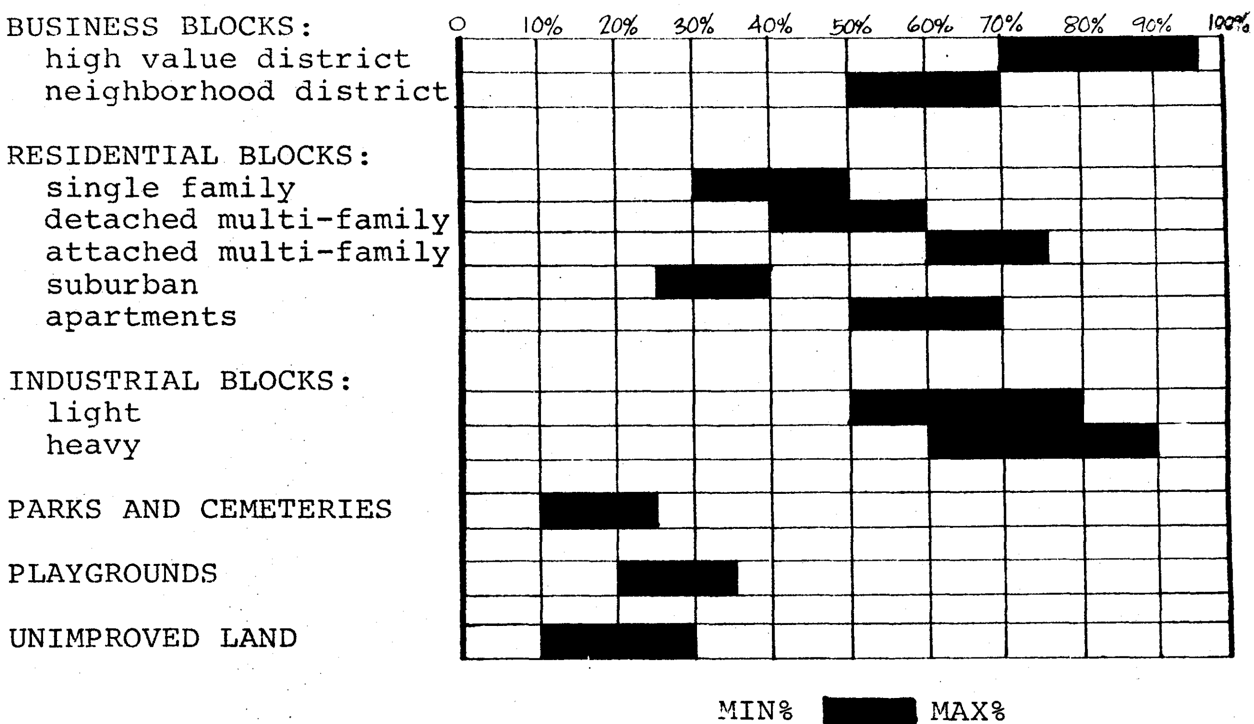
The basic assumption behind the rational method is that the runoff rate for a given intensity will increase and reach its maximum when the duration of the rainfall reaches the time of concentration of the area; the time when the runoff from the most remote point of the area in question reaches the point where the 'Q' is being measured.

The intensity of rainfall used in design is based on the criteria of suburban or central areas. The amount of runoff is dependent on the nature of the area in question.

The staging of developments becomes critical when viewed from storm drainage design factors. Initial stages would have low runoff characteristics whereas final stages would have high values demanding a well developed drainage system.

PERCENT OF RUNOFF IN RELATION TO AREA

(R:21)




IMPLICATIONS:

It can be seen that built-up areas prevent rainfall penetration into the soil and consequently these areas will have more runoff water to cope with. Allowing green areas spaced between buildings provides some area, admittedly small in most cases, where rainfall may be absorbed.

Approximately 50% of the residential neighborhood rainfall will result in runoff. Whether or not to provide a pipe network to carry the anticipated rain amount depends directly with the anticipated rains of an area and the degree of flooding to tolerate. Whether the costs are worth the result must be faced by each individual community.

## COMBINED OR SEPARATE SEWAGE SYSTEMS

| | COMBINED SYSTEM | SEPARATE SYSTEM |
|---|---|---|
| FUNCTION: | Domestic, industrial and storm waters drained in one system of pipes. The system historically developed when open drains were covered and converted into all-purpose systems. Boston, among many others, is one of these. | Domestic and industrial wastes are carried in one pipe system; storm waters are carried in another pipe network |
| ADVANTAGES: | Lower cost since only one pipe network | More economical to maintain while in operation |
| DISADVANTAGES: | High operating costs, high treatment costs | Demands two separate pipe network systems |
| | Pollution dangers very high | |
| | Impossible to design for heavy rains economically; only sized for dry weather flows | |

## THE ELECTRICAL NETWORK

DEFINITION

Electricity:
A fundamental quality of nature; the potential energy developed from a force field which when moving in a stream gives rise to electric current; it allows the transfer of energy over long distances and premits the subsequent transformation into a useable energy form

UNITS OF MEASURE

Volt: unit of electrical potential

Kilovolt: 1000 volts; measure used in high voltage transmission lines; also written as (k).

Although electricity is not necessary for the direct substaining of life, it has become a vital service to the function of urban areas. Without electricity, urban life would be greatly changed and not be able to support the wide range of activities that are now offered to the urban dweller. The more urbanized an area, the more it is dependent on electricity for functioning. The other residential services are directly or indirectly dependent on electricity. Without electricity, urban functions invariably cease.

1. The utility services are genrally dependent on electrical power. Wells, pumps, sewer lift pumps, treatment plants, and pressure boasting devices are made possible by inexpensive electrical power. Various services may be offered for greater distances and reach the tallest buildings only through the use of electrical power.

2. Electricity provides security through the medium of lights. Street illumination and dwelling illumination allow activities to span a longer time span and increase the functionality of an area.

3. Electricity provides convenience services for the individual homeowner which frees him for other activities.
4. Communication is vital to the functioning of the high density urban areas. Electricity allows the development and the use of telephone, telegraph, television, and radio services to the residential areas.
5. The standard of living of an area is intimately coupled with the amount of electricity furnished to the individual dwellings. Electricity allows the increase of dwelling standards.

REQUIREMENTS FOR INSTALLATION

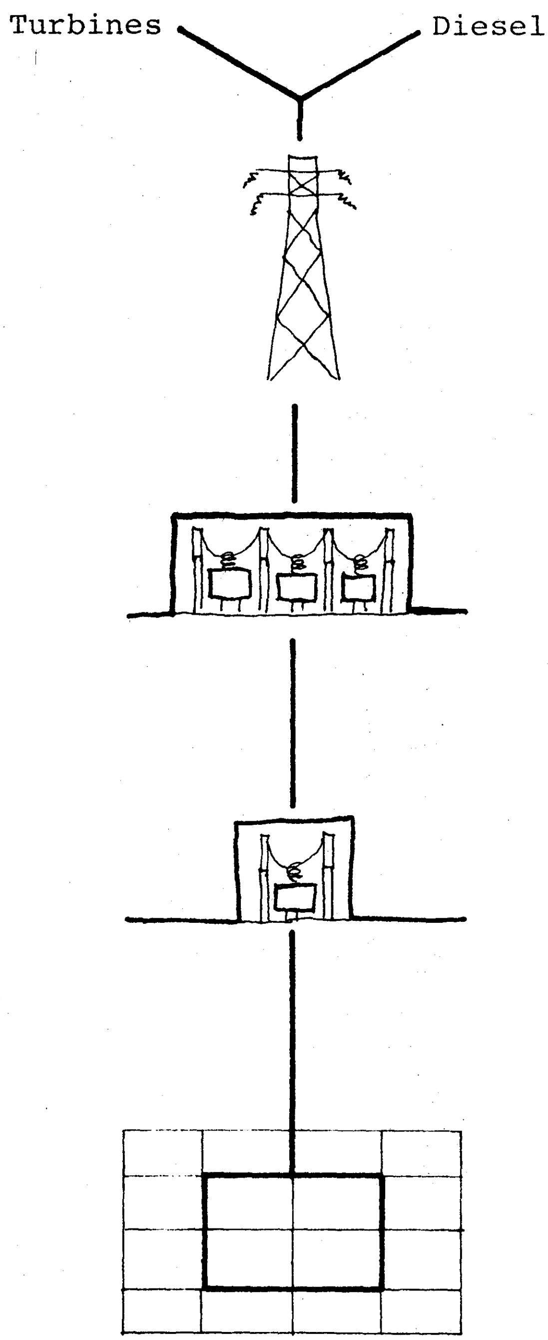
1. Highly technical specialists are imperative

2. Highly sophisticated equipment is required for the service

3. Large scale regional planning is demanded

4. Misuse after installation is dangerous to life and property

# ELECTRICAL NETWORK COMPONENTS




**GENERATION**
produces electricity

**TRANSMISSION**
transports energy to user groups

**DISTRIBUTION STATION**
divides power among main user groups

**SUBSTATION**
manipulates p' power into useful energy levels for consumption

**DISTRIBUTION NETWORKS**
provides electric service to user

## GENERATION COMPONENTS

| **GENERATION** | Transmission Dist. | Station Substation | Dist. Network |
|---|---|---|---|

| | | |
|---|---|---|
| COMPONENT: | Turbine Generation | Diesel Generation |
| RESPONSIBILITY: | provided by company | |
| CONTROL: | regional public board | company controls |
| CHARACTERISTICS: | turbines may be energized by water power or steam generation systems; steam is produced by coal, gas, oil, or nuclear heat generators<br><br>water motivated systems generally require a damed water supply | diesel systems are generally powered by electricity, gas or oil motors |
| SCALE OF DEVELOPMENT: | usually many cities are served by one plant | usually for small systems only; mainly a backup use in most cases |
| ADVANTAGES: | inexpensive production of power | portable system; not dependent on fixed power supply for motivation |
| DISADVANTAGES: | requires transmission lines and a water storage system; high first cost | expensive means of electric supply |

## TRANSMISSION COMPONENTS

| Generation | **TRANSMISSION** | Dist. Station | Substation | Dist. Network |
|---|---|---|---|---|

| | |
|---|---|
| COMPONENTS: | Tower and Cable Lines for transmission |
| FUNCTION: | supports cables for long range transmission |
| RESPONSIBILITY: | company installs and finances |
| CONTROL: | regional control |
| CHARACTERISTICS: | towers are approximately 45 meters high, 9 to 18 meter bases; require 30 to 60 meter easements |

# DISTRIBUTION STATIONS

| Generation | Transmission | **DIST. STATION** | Substation | Dist. Network |
|---|---|---|---|---|

COMPONENTS: Distribution Station (transformer station)

FUNCTION: maintains power pressure and boosts transmission distances

RESPONSIBILITY: company installs, finances and maintains

CONTROL: company control

CHARACTERISTICS: from hdro power sources, lowers power from 230 kv to 115/69 kv

from steam sources, lowers power from 138/115 kv to 34.5/13.2 kv

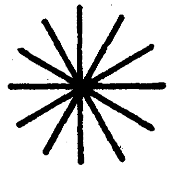
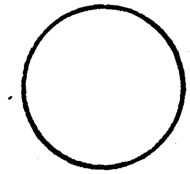
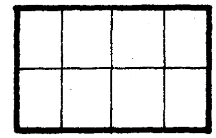
SUBSTATION COMPONENTS

| Generation | Transmission | Dist. Station | SUBSTATION | Dist. Network |
|---|---|---|---|---|

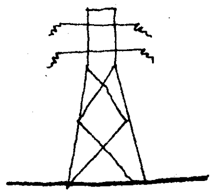
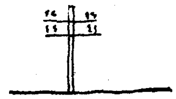
| | |
|---|---|
| COMPONENTS: | Substations |
| FUNCTION: | furnishes power to dwellings and street lights |
| RESPONSIBILITY: | company finances, installs and maintains |
| CONTROL: | controlled by company |
| CHARACTERISTICS: | usually located as close to users as possible |
| | lowers power from 13.2/46 kv to 2400/7200 volts |
| | usually widely spaced at low densities; spacing decreases as density increases |

## DISTRIBUTION NETWORK

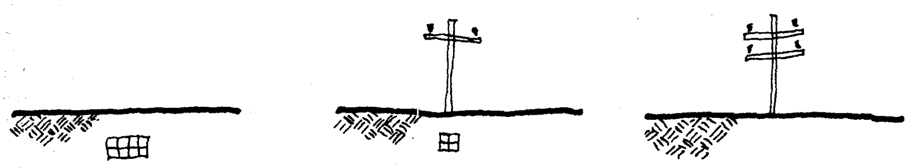
| Generation | Transmission | Dist. Station | Substation | **DIST. NETWORK** |
|---|---|---|---|---|

| | | | |
|---|---|---|---|
| |  |  |  |
| COMPONENT: | Radial Layout | Ring Layout | Network Layout |
| RESPONSIBILITY: | all financed, installed and maintained by company | | |
| CONTROL: | controlled by company in all cases | | |
| CHARACTERISTICS: | earliest system for layouts<br><br>used in low density remote areas | used for large population centers | combination of ring and radial systems; developed as result of growth of ring and radial layouts |
| ADVANTAGES: | avoids duplication of cables | allows backup for emergencies | allows backup line for emergencies |
| DISADVANTAGES: | no emergency backup line | | |

## DISTRIBUTION COMPONENTS

| | | | |
|---|---|---|---|
| |  |  |  |
| COMPONENT: | Transmission Cable | Poles Or Channels | Transformers |
| FUNCTION: | carries power to user | supports cable provides protection to lines | converts power to useable voltage |
| RESPONSIBILITY: | installed, financed and maintained by company | | |
| CONTROL: | public policy and safety requirements dictate control | | |
| CHARACTERISTICS: | 5.5 m. above street surface or buried underground in conduits | 30 to 55 m. spacing; 15 to 30 cm. from curb 9 to 11 m. high poles; channels come in 9" by 9" sections; they are used when changes are anticipated in underground services; channels are based on 5 to 10 year design period; manholes are needed for channels every 150 to 210 m.; poles are cheaper; channels are used in urban areas where the cables are more subject to change | transformers may be on pads, buried, or suspended from poles<br>transformers may be increased if additional power is demanded |

## ELECTRICAL NETWORK LAYOUT



| | | | |
|---|---|---|---|
| METHOD: | Total Underground | Partial Underground | All on Poles |
| CHARACTERISTICS: | all lines in channels; used in congested areas | primary voltage system of power on poles, secondary voltage system in channels; used in residential areas | primary and secondary voltages on poles, low density areas |
| ADVANTAGES: | no interference with traffic; favorable visual aesthetics<br><br>no climatic problems of maintenance<br><br>low maintenance costs in general | lower cost than if all underground<br><br>makes use of existing light poles for primary voltage system | lowest cost |
| DISADVANTAGES: | high cost of installation | climatic problems with cables (sleet failures) | climatic problems (sleet danger causes cable failure)<br><br>relatively high maintenance |

## STREET LIGHTS

FUNCTION:
1. provides safety to pedestrians and drivers by increasing night visual distance
2. provides sense of security to inhabitant of dwellings

RESPONSIBILITY: developer finances and installs

CONTROL: city maintains and controls

CHARACTERISTICS: on residential streets, 40-49 meters spacing with 6 to 7.5 m. height; located on alternate sides of the street

for business streets, spacing is 21 to 37 meters with 9 meter height

criteria of height to spacing is based on glare reduction and placement of light out of the vision range; a rough approximation is that spacing is 8 times the height; minimum height is 4.5 to 6.1 meters.

intersections require street lights

## THE TELEPHONE NETWORK

| | |
|---|---|
| COMPONENTS: | INDIVIDUAL TELEPHONE<br><br>SHORT TRANSMISSION LINE (each customer)<br><br>CENTRAL OFFICE, SWITCHBOARD<br><br>TRUNK LINES, LONG DISTANCE TRANSMISSION<br><br>AREA SWITCHING CENTERS:<br>Toll centers<br>Primary centers<br>Sectional centers<br>Regional centers |
| PROCESS: | The system depends on the correct switching from unit to desired unit with the adequate transmission of sound. Switching occurs on the levels dependent on the distance of the call. Local calls utilize switching from the central office; long distance calls may go from primary to sectional to regional centers. |
| RESPONSIBILITY: | all components are provided by the company |
| CONTROL: | semi-private company; limited public law control |
| CHARACTERISTICS: | the system runs on direct current from its own power sources; backup systems of batteries provide for breakdowns; consequently, telephones usually are available during regular power failures for emergency use<br><br>carrier systems have been developed whereby the sound transmission is carried over power lines, thus allowong cheaper installation and less cables<br><br>the central office controls 35,000 customers and 2,000 trunk lines; design period is 15 to 20 years |

cables are usually underground in urban areas in ducts; in low density areas overhead aerial cables are used since they cost less; long distance intercity trunk lines are usually buried without ducts since they are not subject to frequent change

## GAS NETWORK

FUNCTION: natural gas is used in homes for heating and cooking

RESPONSIBILITY: private or public utility companies install and provide all components

CONTROL: usually considered a public utility; it is under the control of a public board

CHARACTERISTICS: usually small, high pressure lines

pressure regulating devices are located as needed in the network, usually buried with the pipe

pipes are usually located in the sidewalk region

gas leaks may saturate area and cause violent castastrophes; old, poorly maintained pipes are subject to major problems

gas leakage may penetrate PVC water pipe and contaminate water supply

STEAM NETWORKS

| | |
|---|---|
| FUNCTIONS: | steam lines are used for heating in highly congested areas |
| RESPONSIBILITY: | usually a private company which sells services |
| CONTROL: | usually regarded as public utility |
| CHARACTERISTICS: | steam lines require underground tunnels for installation |
| | high heat and pressure losses force use for only relatively short distances |
| | steam source is from a central heating plant for service to high use area |

# THE REFUSE NETWORK

## DEFINITIONS

Waste: useless, unwanted or discarded liquids, solids, or gases

Refuse: solid wastes; not liquid or gaseous

Garbage: a subgroup of refuse; organic, putrescible refuse; mainly results from handling and preparation of foodstuffs

Rubbish: a subgroup of refuse; non-putrescible refuse; may be combustible or non-combustible; bottles, cans, paper, etc. are some examples of this catagory

## UNITS OF MEASURE

Acre-foot: a measure of volume; one acre of area, one foot deep

Pounds per capita: a measure of the amount of refuse produced per person; usually based on per day or per year

Consumer refuse will continue to be a major problem of urban areas. With a rising population, an increase of refuse production per capita and coupled with a rapidly inadequate means of handling refuse disposal, the problem demands new solutions and better utilizations of the current methods.

The amount of waste generated is generally too great to insure individual disposal in a desirable manner; consequently, urban areas usually provide the service of removal and final disposal.

The increased population with its increased refuse production results in greater dangers of ground pollution. Great care must be exercised in the placement of the disposal areas to insure the proper respect for economic as well as environmental costs.

# REFUSE DISPOSAL NETWORK

**PREPARATION OF REFUSE**

separation of refuse by each dwelling

**STORAGE**

concentration of refuse till pick-up

**POINT OF PICK-UP**

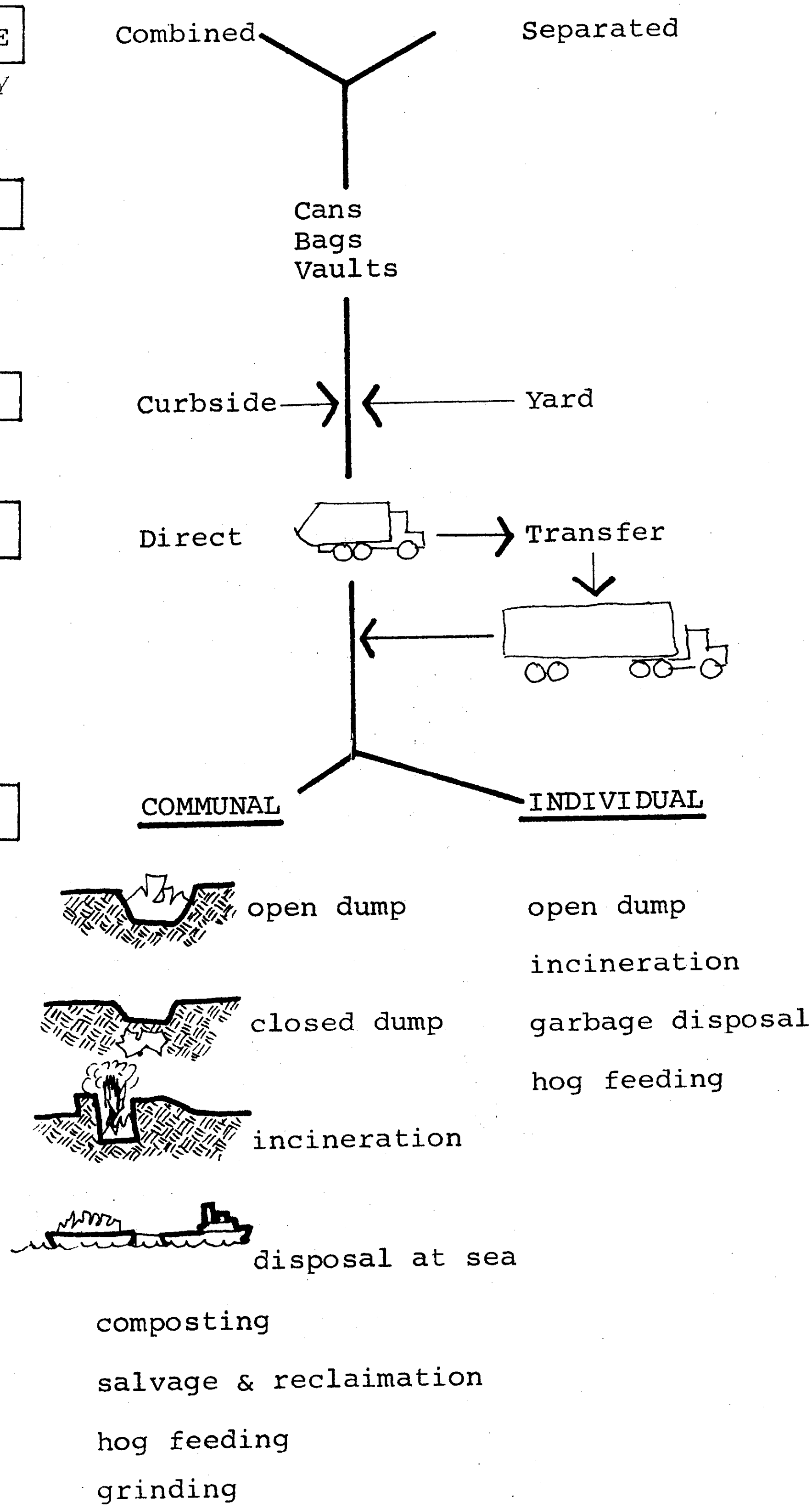
collection of refuse

**TRANSPORTATION**

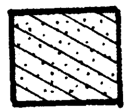
movement of refuse for disposal site

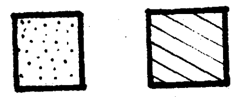
**DISPOSAL**

final removal of waste



# PREPARATION OF REFUSE

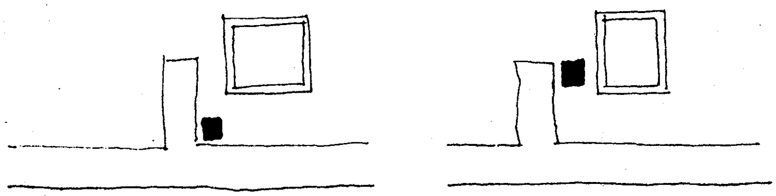




| | | |
|---|---|---|
| COMPONENT: | Combined | Separate |
| RESPONSIBILITY: | individuals of each dwelling prepare refuse | |
| CONTROL: | public law determines process required | |
| CHARACTERISTICS: | all types of refuse are in one lot; garbage, rubbish, ashes, street refuse, and industrial wastes<br><br>becoming more favorable than separate systems in most urban areas | the garbage is separated from the rubbish and ashes<br><br>this method is essential if hog feeding is a major form of disposal<br><br>bottles, cans must be washed to remove food particles |
| USE EXAMPLE: | | BOSTON (U.S.) |
| ADVANTAGES: | most practical, simple for homeowner<br><br>most economical for pickup | allows the use of selective disposal methods; salvage, hog feeding, etc.<br><br>good where individual garbage disposals are used and refuse already separated<br><br>more effort on part of home owner<br><br>requires two pickup times and two pickup vehicles; higher cost<br><br>requires two disposal methods |

| METHOD: | METAL CANS | PLASTIC CANS | BAGS | INDIVIDUAL VAULTS | COMMUNAL VAULTS |
|---|---|---|---|---|---|
| FUNCTION: | mainly for rubbish, also for garbage | mainly for garbage | mainly for garbage | for rubbish | for rubbish |
| RESPONSIBILITY: | individual provides in most case; in rare situations the city will provide to promote standardization | | | individual | developer or disposal firm |
| CONTROL: | public law controls methods and procedures in all cases | | | | |
| CHARACTERISTICS: | must have lid to prevent odor and flies from penetration; must be waterproof and lightweight; must be easy to clean; must be within size what one man can carry, usually 75 to 100 pounds; must control rubbish to prevent spread | | highly sanitary easy to handle no need to return<br><br>some cities require plastic bags for garbage<br><br>paper bags are used for rubbish<br><br>use is very efficient but the cost is high<br><br>allows reduction in pickup crews<br><br>not widely used in the US | usually constructed of brick or concrete<br><br>requires shoveling of refuse into truck; a slow and costly operation | metal construction<br><br>refuse dumped directly into truck or hauled in container to disposal |
| | usually required by city for its strength and durability<br><br>must be kept off ground to prevent rusting; life is 2-3 years<br><br>if underground, invites problems of freezing and water infiltration; but cannot be tipped and it is concealed<br><br>55 gallon drums not recommended | ligher than metal;<br><br>will not rust<br><br>tends to crack in cold weather<br><br>rodents may chew through walls<br><br>susceptable to fire | | usually garbage is disposed into them also resulting in objectional odors and difficulty in keep them clean; freezing weather prevents adequate dumping; the danger of fires in vaults is a continual danger | |
| | | | | usually difficult to keep surrounding area clean<br><br>located in alleys generally | difficult to keep surrounding area clean<br><br>located in special areas concealed from buildings<br><br>holds volumes up to 15 cu.yards |
| SCALE OF USE: | each dwelling | each dwelling | each dwelling | each dwelling | multifamily housing |
| EXAMPLE OF USE: | Boston, for rubbish | | Boston requires plastic bags for garbage | | |

## POINT OF PICKUP



| | | |
|---|---|---|
| METHOD: | CURBSIDE | YARD |
| RESPONSIBILITY: | owner must move to curb or alley | pickup men must move to truck |
| CONTROL: | public law determines | public law or added payments by owner provide service |
| CHARACTERISTICS: | refuse contained in cans or other enclosure to prevent scattering | garbage men pick up refuse container from door step and transport to truck; sometimes container returned to yard as part of the service |
| EXAMPLE OF USE: | Boston (U.S.) | |
| ADVANTAGES: | lower cost to city | convenient to owner<br><br>allows neater street; easier and less street maintenance |
| DISADVANTAGES: | less convenient to owner<br><br>litters streets with overturned refuse containers | higher cost to city if not borne by added payments of owner |

METHOD: DIRECT TRUCK PICKUP — TRANSFER PICK-UP METHOD

RESPONSIBILITY: city or private contractor provides service

CONTROL: city policy sets service requirements

CHARACTERISTICS: Pick-up vehicle must be odor free, water tight, clean and psychologically obstruse; loading height is the most critical factor for efficient use; size, height and width of vehicle determined by road parameter; vehicles usually also used for snow removal and other services.

| Open Top | Enclosed | Compactor | |
|---|---|---|---|
| low cost; in most cities; capacity of 10-20 yds; may be used for odd refuse; refuse blows away easily; odor common | same as open but no odor or littering by wind; limited in size of refuse capacity | compresses refuse; saves man-hours; allows large capacity without exceeding street parameters | In this method the trucks are emptied into a larger transfer van holding 10-20 small truck loads<br><br>system allows savings in running time to disposal area<br><br>largest savings is possible if disposal area is 10 miles distant |

The trucks are emptied directly into disposal area.

Frequency of pickup is related to temperature and weather; the hotter the weather, the more frequent the pickup requirements; twice a week in warm climates to once a week in cold are common; once every two weeks in small cities; if garbage is separated from rubbish, it does not require as frequent pickups in hot climates

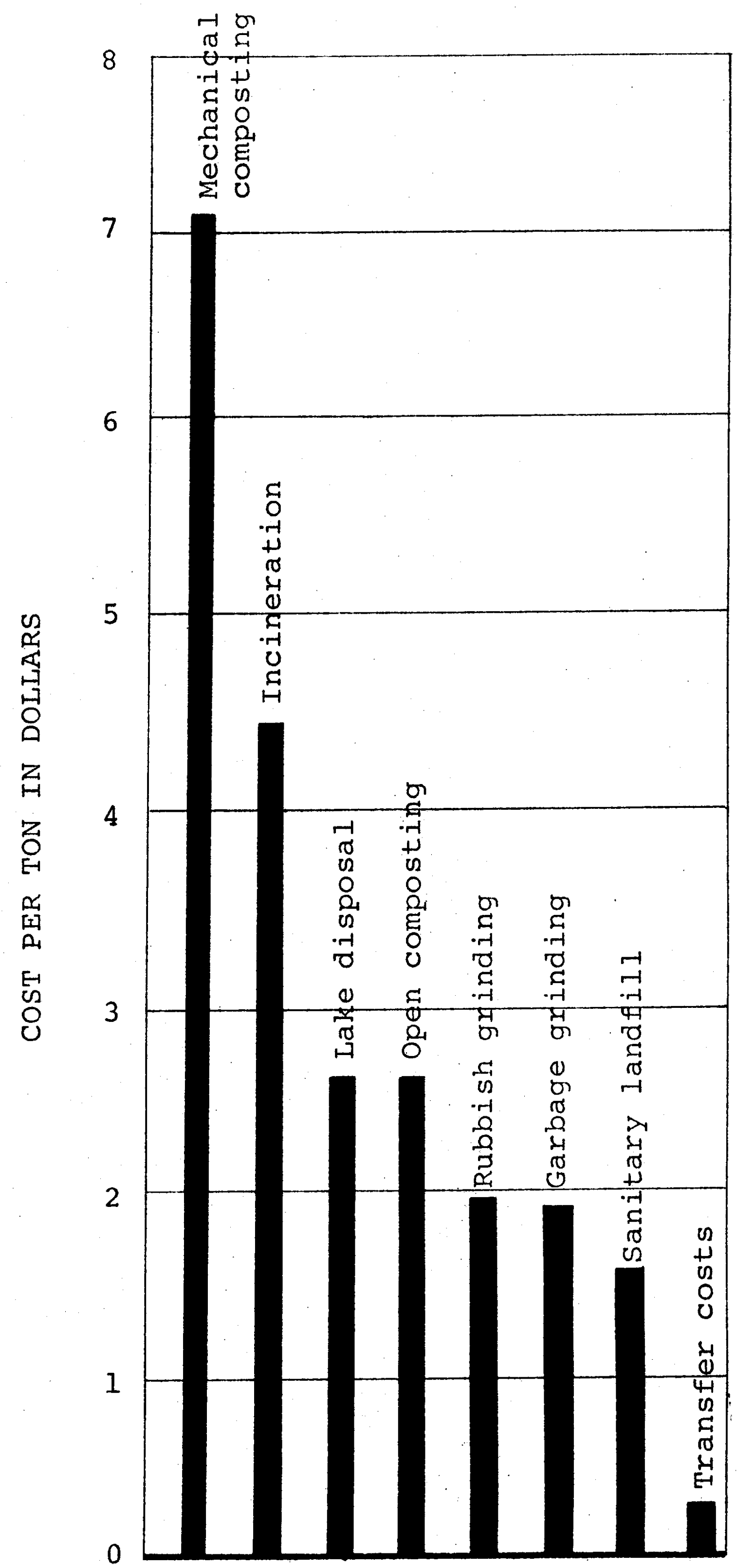
| | | | DISPOSAL | |
|---|---|---|---|---|
| METHOD: | OPEN DUMPS | CLOSED DUMPS | INCINERATION | DISPOSAL IN LAKES,OCEAN |
| FUNCTION: | all refuse into pits or on land sites | all refuse buried into margin al land | combustion of all refuse | dumping of all waste into available water course |
| RESPONSIBILITY: | city or private contract company provides service | | | |
| CONTROL: | city policies and health codes | | | |
| CHARACTERISTICS: | located in unwanted areas such as quarries, and marsh lands; on inexpensive land; articfical trenches may be dug if no depressions available<br><br>must be located in areas not subject to flooding and with proper drainage; geological conditions important to prevent contamination of the water table | requires two foot dirt cover per day | volume reduced .5 to 20%; eliminates moisture and gases;<br><br>requires 1,250-1,800 F temper-ature, multiple burners reduce pollution by better combustion individual incinerations illegal in most cities<br><br>taxes pay for system; 3,000-4,000 dollars per ton initial cost; $4-6 per ton operating cost | barges are used to deposit refuse in water |
| LOCATION: | downwind,from residential areas; within 10 miles of city; in industrial areas; on marginal land | | in industrial areas; wind not a factor | |
| SCALE OF DEVELOPMENT: | small communities<br>412 people/ac.foot of dump | medium to high denisty areas<br>1,430 people/ac.foot of dump | large, high density urban areas<br>2,080 people/ac.foot of space | |
| ADVANTAGES: | requires only one collection trip per area<br>low cost, no machines,<br>no supervision,simple<br><br>allows explosive methane gas to escape | reclaims marginal land; no odor, no health hazard<br><br>allows 50% reduction in vol. | convenient location, little need for land; not affected by weather, flexible operation<br><br>bottles and metals may be sold<br><br>heat may be utilitized if on large scale (Chicago) | no land requied for dumps<br><br>no eyesore, odor, no health hazard |
| DISADVANTAGES: | uses large amounts of land difficult to reuse<br><br>spreads odor holds water, fly danger, eyesore, may pollute water supply ruins future land use fire hazard | may pollute water supply<br><br>high cost, requires special machines, emits explosive methane gas which must be vented; settles 10-25% with-in 6 months; 2 yrs before light load support; does not allow basements | high cost, skilled labor, high maintenance costs; ashes must still be removed to dump<br><br>not justified if land fill available<br><br>air pollution hazard<br><br>salvage may be carried on in other methods also | high extra hauling cost by barge<br><br>water becomes polluted<br><br>storage needed when lake freezes |

MINOR DISPOSAL METHODS

| METHOD: | HOG FEEDING | SALVAGE & RECLAMATION | GARBAGE GRINDING | MECHANICAL COMPOSTING |
|---|---|---|---|---|
| FUNCTION: | maintenance of farm for profit by feeding garbage | use of materials to be sold | shredding of garbage and washing into sewe | biochemical degradation of organic material |
| RESPONSIBILITY: | private company | city or private company | city, company or individual | |
| CONTROL: | health codes | market values | city policies | |
| CHARACTERISTICS: | traditional method of disposal; treated with heat to kill bacterial trickinosis<br><br>25% of garbage in US fed to hogs in 1961 (R:31)<br><br>restaurants and hotels contribute most to program | 15% reduction in volume<br><br>useful for a small portion of refuse only | may be handled by city or by individual<br><br>older sections of city don"t have disposal units so individual systems must be augmented by city system | resultant fertilizer of very high quality<br><br>not successful in the US because of the high cost and no market<br><br>used in European countries extensively |
| ADVANTAGES: | provides income from refuse<br><br>minimum effort, inexpensive | potential sale of end products | convenient to owner<br><br>sanitary method of disposal | end product of fertilizer may be sold |
| DISADVANTAGES: | most of refuse not eatable; dependent on separated pickup<br><br>hazard of disease spread<br><br>usually distant from sources of supply | high labor cost of separation<br><br>uncertain of product or market<br><br>unsanitary process | only small portion may be grinded<br><br>must have two systems<br><br>high costs difficult to justify<br><br>might overload sewers; solids increase by 100%; grit by 40%; demands higher pressure and supply | 50% of refuse is non-compostible and must still be disposed of in other manner<br><br>no or little market in the US |

## COMPARISON OF DISPOSAL COSTS

Cost does not include collection costs or profits from possible sale of end products

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# COMPOSITION OF REFUSE

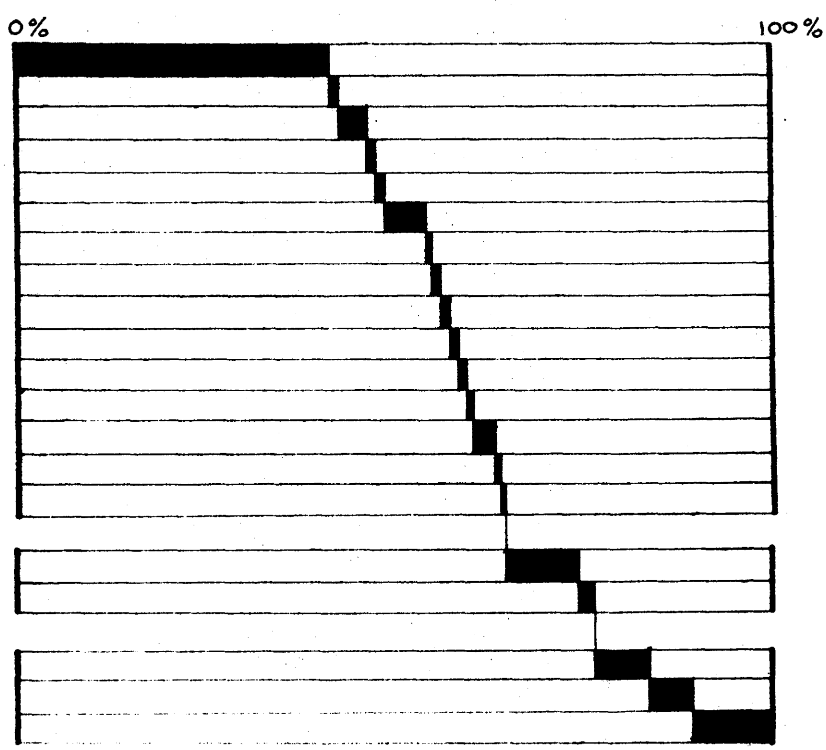
CLASSIFICATION OF REFUSE:

Organic (mostly combustible)
- -garbage
- -paper
- -wood
- -plastics
- -grass
- -trimmings

Inorganic (mostly noncombustible)
- -metals
- -glass
- -ashes
- -ceramics
- -stones
- -dirt

PERCENT OF ALL REFUSE BY WEIGHT (U.S.)

| | |
|---|---|
| paper | 42.0% |
| wood | 2.4% |
| grass | 4.0% |
| brush | 1.5% |
| greens | 1.5% |
| leaves | 5.0% |
| leather | 0.3% |
| rubber | 0.6% |
| plastics | 0.7% |
| oils,paints | 0.8% |
| linoleum | 0.1% |
| rags | 0.6% |
| street sweep. | 3.0% |
| dirt | 1.0% |
| unclass. | 0.5% |
| garbage | 10.0% |
| fats | 2.0% |
| metals | 8.0% |
| glass,ceramics | 6.0% |
| ashes | 10.0% |




(R:31)

## QUANTITY OF REFUSE

There is a difference between refuse produced and refuse collected. Some refuse produced goes to garbage grinders, incineration or to hog farms; therefore, collected refuse varies from 50% to 75% of the total.

QUANTITY DETERMINANTS:

1. population increase
2. increase of refuse per capita

TRENDS OF QUANTITY (U.S.):

1. There is an increase of the volume of the refuse produced with a decrease of the weight of refuse produced. Current and future uses for new container materials encourage this increase in volume.
2. There is an increase of rubbish produced with a decrease of garbage and ashes. Again, current and future methods of packaging encourage this increase.

SEASONAL VARIATION:

Summer months result in an increase of garbage and yard refuse because of the availability of fruits, vegetables and other organic products.

Winter seasons result in an obvious increase of ashes and decrease of garbage refuse.

PER CAPITA PRODUCTION:

In 1965, the average refuse per person was 4.5 pounds per capita per day; with a peak value of 8 pounds per capita per day.

The trend is upward at the rate of 0.07 pounds per capita per year.

On a yearly basis, per capita production was 1,650 pounds, with an increase of 25 pounds per capita per year.

PER CAPITA PRODUCTION IN RESIDENTIAL AREAS: In 1965 (U.S.) the range of production was 1.1 p/c/d to 3.2 p/c/d, or 386 p/c/yr to 1,152 p/c/yr.

(R:31)

Refuse disposal has become an ever growing problem throughout the world. More and more consumer goods are being presented in single use disposal packages. As income and tastes change, the emphasis focuses on an ever greater variety of products beyond than the basic necessities. With paper products already comprising over 40% of the total refuse, the farther advancement of advertising and consumer convenience products will undoubtedly produce an ever larger percentage of refuse to useable product; a higher proportion of package to containers.

In highly developed countries, the situation is now at a crossroads. The point is reached where a formal attack must be presented against the multiplication of refuse. But at what point in the refuse cycle should the attack focus?

We have reached a philosophical crossroad where there are two opposing approaches available:

1. Emphasis of the collection and disposal components of the refuse cycle. The focus here would be on efficiencies of quick and sanitary means of removing the refuse from the user, and cheap and efficient elimination. Some approaches would be to improve and develop high compaction vehicles for instant disposal, chemical means of removal and individual "vanishers." The community would eventually accept and support the refuse engineer as a respected and honored profession; the refuse specialist would become an indispensable asset to community functions. Schools would develop, socities would form and a refuse disposal elite would arise in society.

2. Emphasis of the reduction in disposal materials. The focus would be on the elimination of the refuse products of the consumer. Articles such as bottles, cartons and bags would be redesigned or re-packaged to reduce the refuse production to a minimum level. Systems could be set up whereby all consumer disposals would, for example, be required to dissolve in water so that existing sewer systems might be used. Development of "non-packages" which would be part of the function of the article is another possibility. In all cases, the unrestricted flow of consumer refuse would decrease. Refuse collection and disposal services would become unnecessary, or at least down graded by several magnitudes.

It would be more reasonable to combine the two approaches to the problem. Recycling operations would be stressed as an integral part of community functions; where each product would become a component of a larger system. Products would be divided into short and long-term cycles. The short-term cycle would include items where the stress would be on the elimination of waste products. The long-term cycle would be for items where the waste would be the product itself and no reduction of the waste when it is discarded is possible.

1. Short-term cycle: The second alternative of discouraging the production of disposal items could result in the instant removal, alteration or elimination of the consumer packages. Items in the short cycle would be articles where the use life is on a daily to a weekly basis. Foodstuff packaging, carrying disposals (bags, etc.) and protective wrapping would be in this cycle.

2. Long-term cycle. Large items such as automobiles, appliances, tools, etc. would be programed to be part of a larger energy cycle. The stress would be on the refuse of the articles for alternate functions with only small added operations.

In summation, the emphasis on short-term cycles would be to eliminate the resultant refuse by altering or preventing the production of daily consumer refuse. For long-term cycles of large consumer products, an eco-cycle would be established to handle the refuse products. Here emphasis would be on the establishment efficient collection and disposal (or alternate operation) system.

# COMPARISON AND CORRELATION OF INFRASTRUCTURES

COMPARISONS

| SYSTEM: | WATER SUPPLY | SEWER SYSTEM | STORM DRAINAGE |
|---|---|---|---|
| FUNCTION: | the supply of potable water for health, cleanliness and cooking; required for substaining life | the disposal of domestic waste in a sanitary and unobjectionable manner | prevention of flooding for protection of health and property |
| LAYOUT: | a closed grid network; not dependent on the terrain | a tree or branching system; dependent on topography; a sloped network | a tree or branching system dependent on topography; a sloped network |
| PIPE LOAD: | water only | floating suspended solids; 0.1% solids in domestic system; 1/2 pounds/person/day | floating suspended material 40% more putrescible matter than sewage |
| PIPE FLOW: | uniform steady pressure flow at the full section of the pipe; velocity of 2 fps minimum, 4 fps average | unsteady nonuniform gravity flow; may be a full section of pipe but usually at partial section; velocity of 2.5 fps to 15 fps | unsteady nonuniform gravity flow at full section at peaks, normally only partial; velocity of 3 fps minimum; 15 fps maximum |
| PIPE MATERIAL: | cast iron if over 12", spun iron most common; asbestos cement, concrete, cement lined steel (over 10"), plastic for service lines | house service line is cast iron; vitrified clay for small pipe; prefabricated concrete for large pipe; same as water if infiltration danger | same as sewer lines |
| PIPE SIZES: | 6" minimum with fire flows (US) | 8" (US) | 12" (US) |
| LOCATION OF PIPE: | in streets or right-of way; 3 meters away and above sewer by 15 cm. | preferred in alleys; or center of street | in streets; opposite water lines |
| DEPTH OF PIPE: | determined by frost and crushing danger; 90 cm. normal, 60 cm. required for crushing protection | 90 cm. below basement level; 3.4 meters below foundations i commercial buildings | crushing and frost demands dictate depth |
| DESIGN CRITERIA: | economical flows dictate; acceptable friction losses with fire flows set sizes | hydraulic demands dictate; minimum velocity determines size and slope | hydraulic demands dictate minimum velocity sets pipe sizes and slope |
| DESIGN QUANTITIES: | 50 to 150 gallons per person per day (US) | 70% to 90% of the domestic water consumption | quantity set by degree of tolerance to flooding |

# SEQUENCING OF THE INFRASTRUCTURE

| Low standards<br>Marginal population | STANDARD OF LIVING, INCOME SCALE | High standards<br>Consolidated population |
|---|---|---|

## WATER SUPPLY SYSTEM

| | | | |
|---|---|---|---|
| Communal faucets to family groups | Service to high use/intensity areas with hydrant potential | Service to all dwellings; hydrants in high use/intensity areas only | Hydrants and service in all areas |

## SEWER NETWORK

| | | | |
|---|---|---|---|
| Communal facilities (not recommended) | Individual outhouses, cesspools, privy or septic tanks | Service to high use/intensity areas only | Service to all dwellings |

## STORM DRAINAGE

| | |
|---|---|
| Use of circulation elements to channel and control flow (streets, walks) | Service of pipe network to high use/intensity areas only |

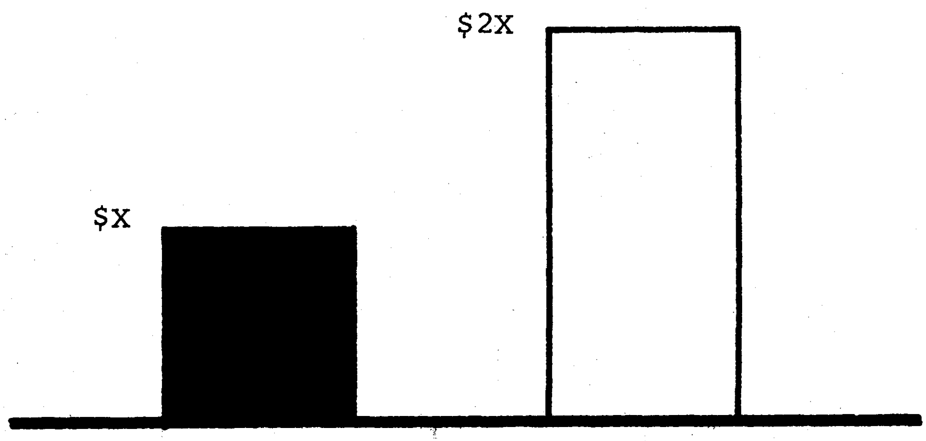
## ELECTRICAL SYSTEM

| | | |
|---|---|---|
| Public taps | Service to high use/intensity areas | Service to all dwellings |

## COMPARATIVE COSTS: WATER vs SEWERS (US)

WATER SEWER

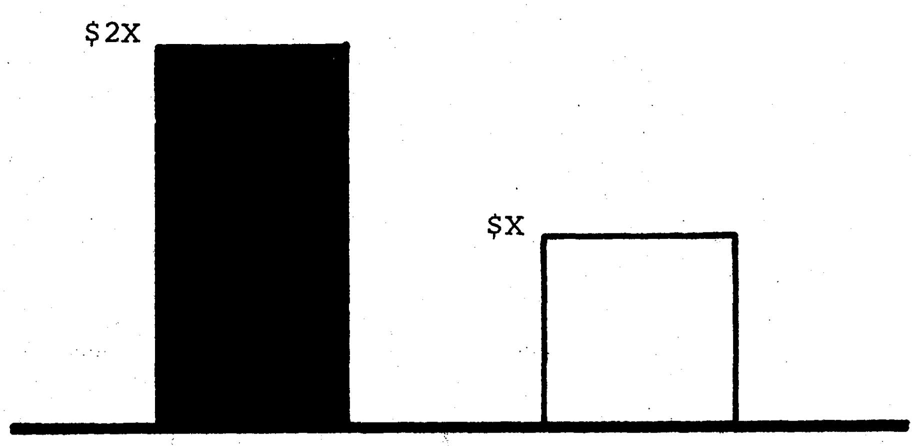
TREATMENT FACILITIES




**Water:** Most water sources are relatively pure at initial stages

**Sewer:** More impurities are found in sewage than water; more effort must be directed toward filtering and removal of dissolved particles

DISTRIBUTION NETWORK




**Water:** Pressure pipe for water systems require costly materials and skillful jointing and positioning

**Sewer:** Cheaper materials and less precise install-ation requirements result in lower costs

(R:9)

## RELATIVE PROJECT COSTS

**URBANIZATION COSTS**

| | | | | Urbanization costs | Communal facilities and urbanization costs |
|---|---|---|---|---|---|
| Excavation | | | 834 | 13% | 7.6% |
| Sidewalks | 459 | | | | |
| Streets | 850 | | 1769 | 27% | 16.0% |
| Curbs | 460 | | | | |
| ELECTRICITY | 1014 | 30% | | | |
| WATER SUPPLY | 1177 | 34% | 3436 | 52% | 31.2% |
| SEWER | 1245 | 36% | | | |
| Landscaping | | | 515 | 7% | 4.7% |
| TOTAL | | | 6554bs | 100% | |

**COMMUNAL FACILITIES**

| | | |
|---|---|---|
| Primary schools | 2100 | |
| Kindergartens | 600 | |
| Childrens park | 300 | |
| Communal center | 180 | |
| Public garden | 120 | |
| Sport field | 800 | |
| Clinic | 300 | |
| TOTAL | 4400bs | 40.0% |
| TOTALS | 10954bs | 100% |

The cost is in terms of 1000's of Bolivars (bs); the data is taken from ciudad Guayana, the proposed costs of the Dalla Costa area (1965), for 1000 dwellings, 1,500 lots.

## RIGHT-OF-WAY

Utilities are laid in public right-of-ways in order to allow access to networks when maintenance is required. Existing street right-of-ways are used when possible for the network layout.

1. they border most of the potential users
2. they provide access to all users with generally a minimum length
3. they are controlled by the municipality and allow immediate access

## CRITERIA FOR LOCATION

1. Minimum distance to user (results in economical pipe network
2. Ease of relocation after burial (for maintenance and alteration)
3. Minimum disruption of right-of-way functions with installation and maintenance activities

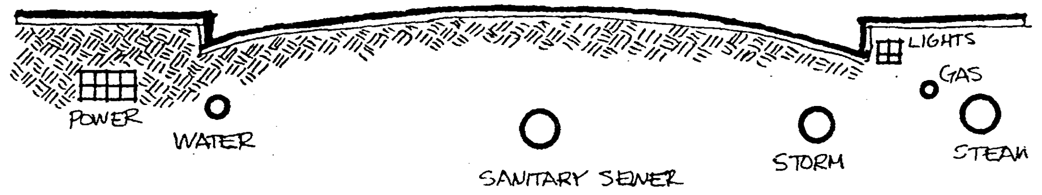
## CRITERIA FOR STAGING

if unpaved; as needed by users and provided by city funds

if paved: all utilities, distribution lines and service lines, which are to be used within five years are to be buried initially before paving of roadbed.

CRITERIA FOR TRENCH

- minimum depth of .6 meter (24") for crushing protection
- when over 2 meters deep, stronger pipe must usually be used to support soil pressure
- all pipes and service should be lower than 3 meters or close to surface if subways are planned in future
- minimum trench width is .6 meter (24 inches)
- if a common trench is used, sufficient space must be required for each line to facilitate maintenance



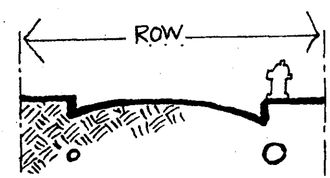

| UTILITY: | ELECTRIC & TELEPHONE POLES | POWER LINES, BURIED | WATER DISTRIBUTION | SANITARY SEWER | STORM NETWORK | TELEGRAPH/TELEPHONE CABLES | GAS LINES | STEAM LINES | STREET LIGHTING, TRAFFIC LIGHT CABLES |
|---|---|---|---|---|---|---|---|---|---|
| LOCATION CRITERIA: | located .15m(6") to .6m(24") from curb for protection of automobiles; 1 meter from hydrants<br><br>spacing of 30 to 55 meters; 40 meters average | located in sidewalk area opposite storm drain side to prevent water infiltration | 1.8 to 4 meters from right of way to allow flexible joint (goose-neck) and shut off value installations; 3 meters away and .3 meters above sewer | centered in street, prevents infiltration and illegal connections; minimum access to dwellings of both sides; 3 m. from water main and below | opposite street from side of water network to prevent infiltration | (combined with fire alarms & police alarms) | located under sidewalks | generally in enclosed, underground gallery | under widewalks |
| CHARACTERISTICS: | usually wood, steel or concrete<br><br>6 to 10 meters tall<br><br>wire clearance of 5.5 meters minimum above roadway<br><br>located to prevent tree interference | cables are pulled into vitrified clay, asbestos or concrete tiles; .6 meter (24") minimum depth<br><br>manholes are required every 60 to 300 meters to allow maintenance<br><br>basic size is 22" x 22" with 16 slots, may be multiplied as needed<br><br>5 to 10 year design period of cables<br><br>cables may be buried directly without tile cover if no changes are anticipated<br><br>2.5 x 1.5 meters to 4.5 x 1.5 meters is manhole size required<br><br>service boxes pushed under pavement; 8 units per box, max. dist. is 40 meters | usually .6 - .9 m. deep for crushing and frost protection if over 1.8 m., extra strength required<br><br>recommended put in alley or under pavement; but practiced anyway since no other space available<br><br>may be on surface if there is no danger of freezing. European practice uses this principle frequently which results in cheaper installation and easy maintenance. Temperature of water may be unacceptable in some cases | sewers have a longer design period and hence allow positioning in center road since less change is likely<br><br>depth varies from .9 to 3.7 meters; dependent on available excavation machinery; dependent on footings or basement levels<br><br>sewers require larger pipes hence need more excavation space<br><br>center location avoids tree root problems which cause clogging<br><br>sewer has 1st priority in location | depth from .9 to 3.7 meters<br><br>should be buried under street to prevent tree root infiltration | buried in vitrified clay tile, asbestos cement, or concrete slots<br><br>requires manholes at 15 to 21 meter intervals<br><br>may be combined with power lines | requires buried pressure regulators<br><br>gas leakage always a danger with poor maintenance | only found in center cities or industrial areas<br><br>pipe galleries may assume multiple use when power, water, gas and telephone cables are included | may be connected to power lines or may have individual networks |

## DUPLICATE NETWORKS

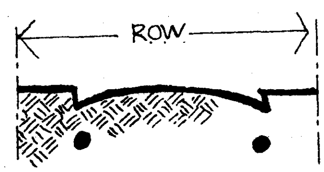
CRITERIA:

1. used when excessive street widths allow savings in service lines if smaller mains are duplicated on both sides of the street
2. used when the street surface is prohibitively costly

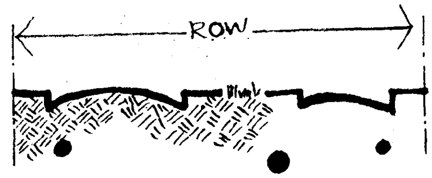
WATER:
-used when streets are wider than 25 meters; used when streets are wider than 15 meters in row house conditions
-hydrant for fires placed on side of street with larger pipe, if applicable




SEWER:
-used if streets are wider than 25 m.; in row house conditions may be economical to duplicate if 15 m. wide streets

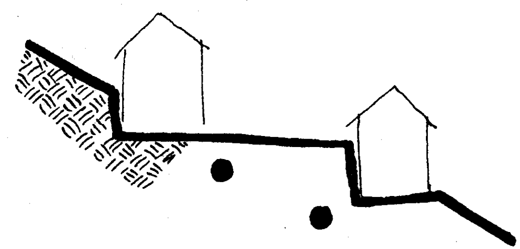



GREEN CENTER STRIP CONDITION
-center strips allow placement of large community mains for both water and sewer lines; maintenance is effected with no disruption to traffic or surface; if system fails catastrophically there is less danger to surroundings



DUPLICATE CONDITIONS ON SLOPE SITES

-duplication of sewer lines avoids deep trenching costs; not dependent on street width



## USE OF ALLEYS IN UTILITY LAYOUT

Alleys are secondary auxiliary circulation networks traditionally planned in congested areas. Servants, rear deliveries and rear parking all contributed to the use of alleys. Utility lines are often preferred in alley locations. Fire hose requirements initially made alleys required.

CRITERIA FOR USE:

1. may be advisable when lots are 12m. or less in width for fire fighting access
2. used for group type of buildings
3. used with apartments or stores
4. used when loading or unloading procedures would prohibitively disrupt traffic flow on primary front circulation lanes

LOCATION OF UTILITIES IN ALLEYS

The alley width plus easements of 2.4m. on each lot provide space for most of the utility functions. Sewer lines are recommended to be placed in alleys. Telephone and power poles may be placed in alleys to avoid clutter in front of lot.

WIDTH: 4.9 meter min.; 6m. better, plus 2.4 meter easements on facing both lots for power lines

ADVANTAGES: eliminates unsightly power poles in front of lot;
provides utility space with easy maintenance and minimum disruption of traffic flow;
provides delivery access; parking access saves costs of individual driveways if rear garages are available

DISADVANTAGES: utilities may be placed in easements in back of lot without expense of alley maintenance;
alleys are generally not an economical use of land;
maintenance costs of alleys for lights, pavement, and cleaning make their use prohibitive;
no longer required for safety since fire fighting may now take place from front of lot.

USE OF AREAWAYS (Pipe Tunnels)

In high density areas; expecially commercial areas, the use of large underground passages for pipe networks and electrical systems is recommended. The underground passages usually allow the entry of a man for maintenance.

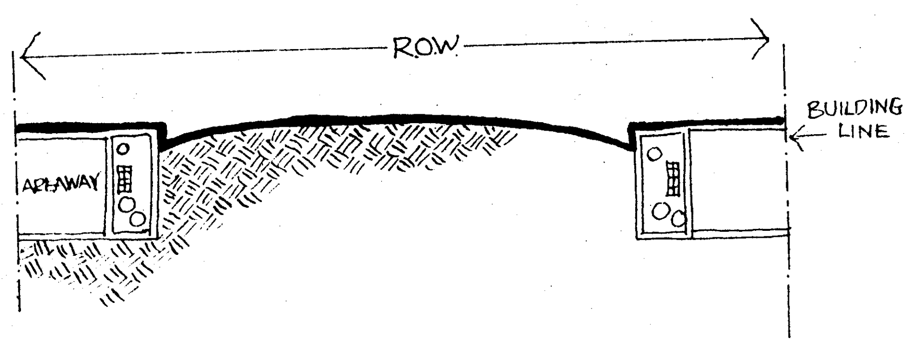
ADVANTAGES:

- -easy maintenance of networks
- -no costly disruption of the road surface; no repaving necessary and no tie up in traffic flow
- -simple installation of lines for expansion

DISADVANTAGES:

- -high initial cost of passage
- -rapid expansion may overload areaway and require additional trenching
- -areaways require extra drainage lines

SAMPLE LAYOUT



# EASEMENTS

FUNCTION:

When right of ways are not available for utility line location, the use of easements is required to allow utility network installation and maintenance.

DEFINITION:

Easements are sections of privately owned land which are controlled by public offices. The land is leased in perpetuity or controlled by the utility companies by the purchase of stated obligations. Obligations of the easement usually requires no erection of a permanent structure or planting of large trees. The utility receives the right of access for maintenance and installation at their discretion. Utility companies have the power of condemination when required.

CRITERIA:

1. assessibility of excavation machinery and installation machinery
2. safety to area from potential catastrophic failures

| | Electric poles | Transmission lines, electric | Gas & oil | Sewer & water, storm drains |
|---|---|---|---|---|
| WIDTH: | 2.4-3.7m. | 30-60m. | 3-6m. | 3-6m. |
| LOCATION: | rear lots if deeper than 40m. 15 cm. from curb 9 m. from hydrant | as needed, rear of lots preferred | as needed, in rear of lots if deeper than 40m. | |

| | Electric poles | Transmission lines, electric | Gas & oil | Sewer & water, storm drains |
|---|---|---|---|---|
| CHARACTERISTICS: | must be protected from fall-ing trees | may be fenced<br><br>usually a hazard and eyesore to area | the systems are under high pressure and dangerous to surroun-dings | accessibility is the main concern |

## RELATION OF DESIGN PERIOD AND COMPONENTS AT A 3% URBAN GROWTH RATE

ANNUAL URBAN GROWTH RATE OF 3% (World average)

| WATER SYSTEM | POPULATION base of 100 | DESIGN PERIOD years | SEWER SYSTEM |
|---|---|---|---|
| SERVICE PIPE (under 12") | 100 | 0 | LATERALS AND SUBMAINS (pipe less than 15") |
| | 115 | 5 | |
| | 135 | 10 | |
| TREATMENT FACILITIES (high interest rates) | 150 | 15 | TREATMENT FACILITIES (high interest rates) |
| MAINS (12" and over) | 180 | 20 | |
| TREATMENT FACILITIES (low interest rates) | 200 | 25 | TREATMENT FACILITIES (low interest rates) |
| | 240 | 30 | |
| | 280 | 35 | |
| | 325 | 40 | |
| | 375 | 45 | |
| | 440 | 50 | MAIN SEWERS, INTERCEPTERS (pipe over 15") |

(R:9)

RELATION OF DESIGN PERIOD AND COMPONENTS AT 6% URBAN GROWTH RATE

| WATER SYSTEM | ANNUAL URBAN GROWTH RATE OF 6% (developing countries) POPULATION base of 100 | DESIGN PERIOD years | SEWER SYSTEM |
|---|---|---|---|
| SERVICE PIPE (under 12") | 100 | 0 | LATERALS AND SUBMAINS (less than 15") |
| | 135 | 5 | |
| | 180 | 10 | |
| TREATMENT FACILITIES (high interest rates) | 240 | 15 | TREATMENT FACILITIES (high interest rates) |
| MAINS (12" and over) | 320 | 20 | |
| TREATMENT FACILITIES (low interest rates) | 430 | 25 | TREATMENT FACILITIES (low interest rates) |
| | 575 | 30 | |
| | 770 | 35 | |
| | 1030 | 40 | |
| | 1376 | 45 | |
| | 1840 | 50 | MAINS, INTERCEPTERS (over 15") |

(R:9)

IMPLICATIONS:

A 3% urban growth rate as in the United States would demand the design of a treatment facility of twice its initial capacity. This facility would just meet the static demand due to growth of the population.

A 6% growth rate as found in many urban areas of developing countries would demand a treatment facility over designed by 3 to 5 times its capacity at its initial state. This is not taking into consideration the demand per person as to rising standards, or lifestyle.

Water mains would have to be over sized by a factor of approximately 2 when the growth rate is 3%. The factor of increase would be 3 to 4 when the growth rate is 6%.

The sewer system is more expensive than a water system in most cases. Because the sewer system is dependent in a large degree on topography if costs are to remain low, and because the sewer lines are several scales larger than water lines and consequently initially more expensive, the design period of the sewer mains are proportionally greater. In developing countries or in areas with a high growth rate, the design of sewer systems becomes extremely difficult. Obviously, designing for an increase of demand by a factor of four as found in areas of a growth rate of 3% is vastly different than designing for a growth rate factor of 18!

Along with the problem of design, developing countries often lack the funds to oversize systems to such a large degree; usually, the funds are not even available for the initial system, let alone when planning for an exceedingly large growth rate.

## GENERAL PIPE REQUIREMENTS FOR WATER, SEWER AND STORM DRAIN LINES

### 1. CHEMICAL RESISTANCE

The pipe must withstand soluble and insoluble particle action against the walls of the pipe. The pipe must be inherently imprevious or may be coated to prevent corrosion.

### 2. MINIMUM FLOW INHIBITATION

The walls of the pipe must be as smooth as possible to provide minimum frictional resistance. The walls must be strong enough to resist wearing of surfaces from friction of particles suspended in the water. Smooth walls inhibit slime growth and minimize buildup of particle deposition. Pipes may be sheathed with plastic sleeves to reduce friction of walls.

### 3. INTERNAL STRESS RESISTANCE

The pipe must be able to withstand internal pressure stresses if used for water or pressure sewers. It must be able to withstand expansion and contraction due to small temperature changes. They must withstand vacuum stresses imposed from high pumping requirements which might result in collapse.

### 4. EXTERNAL STRESS RESISTANCE

The pipe must withstand the loads imposed on it from soil backfill or traffic overhead. It must be able to withstand hydrostatic pressure from surrounding soil. .9 to 2.1 meters are the ranges of adequate load protection.

### 5. FREEZING PROTECTION

The water must normally not be allowed to freeze in the pipes. Either heating or by burial of the pipe to a sufficient depth to prevent frost penetration is required. .9 meters is normal for frost protection if water flows constantly.

### 6. WORKABILITY

The pipes must be able to be easily jointed, cut and handled during construction of the pipe network.

7. LOW COST

All of the above requirements must be met and still be within a reasonable cost and allow long life of the network.

## SERVICE PIPE MATERIAL

Service pipes are the pipes transferring water from the distribution system to the user (cast iron and asbestos cement pipes are not available in small sizes under 2"; usually not used for service connections.

| | |
|---|---|
| COPPER: | expensive, durable, high corrosion resistence, capable of high pressures; flexible; easily jointed; low flow resistence; compatible with brass fittings. |
| WROUGHT IRON: | more corrosion resistent than steel; not widely used |
| STEEL: | relatively inexpensive; high pressure capability; may easily be bent; must be coated for resistence against corrosion; requires threaded joints |
| POLYTHENE: | resistent to corrosion; light-weight; flexible; smooth interior offers low flow resistence; heat and sunlight cause weakening; it absorbs gas through the walls of the pipe; available in cut lengths or on spools |
| PVC: | semi-rigid; high tensile strength; corrosion resistent; lightweight; available from 1/2" to 12" in diameter |
| BRASS: | used only in a limited extent; rigid; requires threaded joints; relatively expensive |
| LEAD OR LEAD ALLOY: | most commonly used pipe since Roman days; low flow resistence; relatively high cost; ductile, easy jointing; corrosion resistent except with acidic water which reacts with pipe to form lead salts which are poisonous; not used except in rare, special cases. |

## DISTRIBUTION PIPES. WATER NETWORK

| | |
|---|---|
| SPUN IRON: | stronger and lighter than cast iron; available in various strength catagories; usually coated internally and externally with bituminous enamel or cement coatings; sometimes pipes are plastic lined; fittings are usually cast elements; 2" to 24" diameters available in 12', 18' or 5 meter lengths; 100 to 250 psi ratings; 80-100 yr. expected life |
| CAST IRON: | not in common use for pipe today; mainly still used for pipe over 48' or for fittings for spun iron pipe; cast iron pipe was the traditional material for many decades. |
| ASBESTOS CEMENT: | composed of cement and asbestos fiber; highly resistent to corrosion effects of water; a brittle pipe with difficulty in making connections and tapping; the strength of the pipe increases with age; easily cut & filed; no expansion joints needed; 13 ft. lengths |
| PRESTRESSED CONCRETE: | cheaper than steel if over 24" in diameter if used for high pressures; high corrosion resistence; difficult in connections and tapping; used mainly for larger pipe requirements, as for transmission lines and distribution mains over 16"; low maintenance costs; cracks can cause leakage; low transport costs. |
| STEEL PIPE: | lighter but less durable and more expensive than spun iron pipe; usually coated internally and externally to withstand corrosion; cannot resist high internal pressures; life expectancy of 50 to 75 years, available in 6" to 36", up to 40 foot lengths; usually used for large mains |
| PVC (plastic) | light in installation & handling; high resistence to corrosion; low flow resistence; flexible, may collapse under vacuum; service connections are relatively difficult; may absorb gas leaks into water; available up to 12" in diameter |

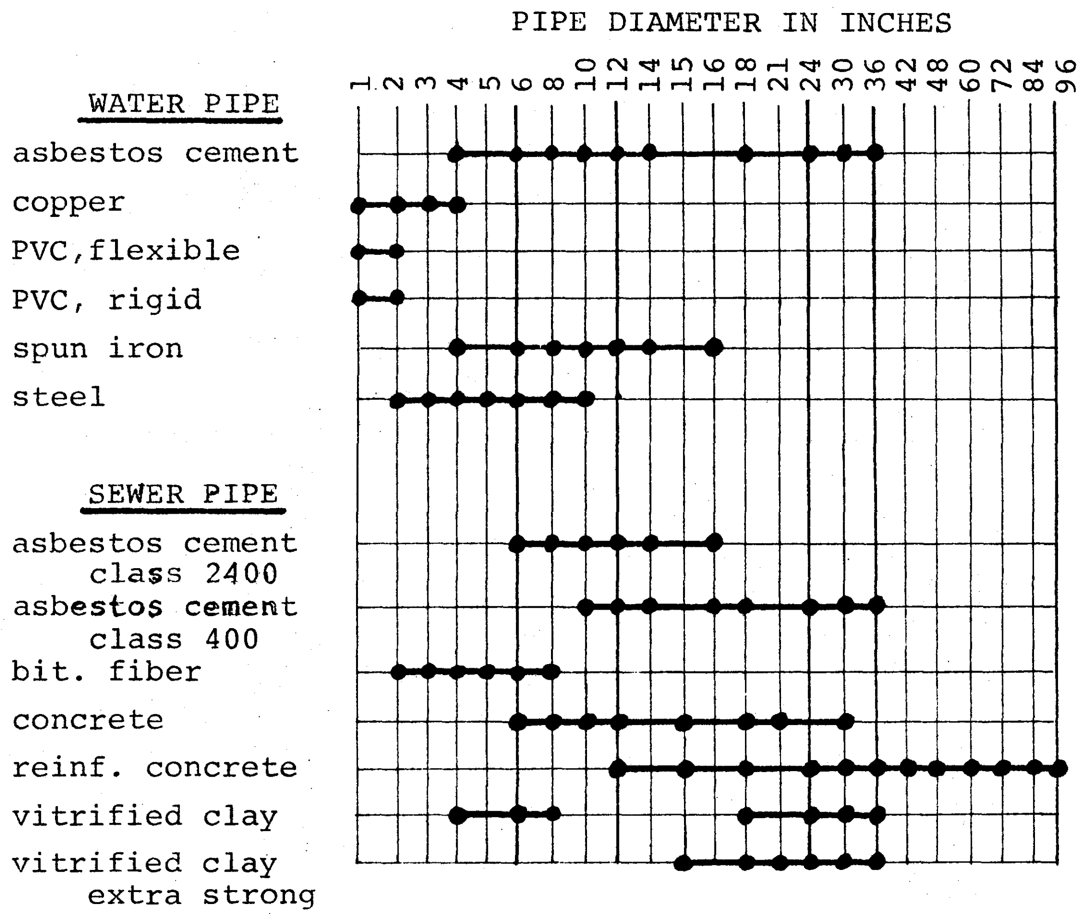
| | |
|---|---|
| PLAIN CONCRETE: | only used for low pressures and short distances; a relatively cheap pipe; difficult to repair; peak of 10 psi only; over 12" diameter most common |
| ALUMINUM PIPE: | rarely used, a relatively new development |
| WOOD PIPE: | used where cost of pipe is more advantageous; redwood can last indefinitely; banded with steel; the interior is easily attacked by organic acids and plant growths; best for constant full condition; available up to 48" dia.; high construction labor costs; high carrying capacity which does not decrease with age |

## SEWER PIPE MATERIAL (also used for storm water systems)

| | |
|---|---|
| Asbestos Cement: | lightweight; highly resistant to corrosion effects of water; easily worked; difficult to join; brittle; 10 to 13 foot lengths are common |
| Spun Iron: | used for pressure sewers; used for service lines into buildings or near buildings; structural requirements dictate its use; coated internally and externally |
| Concrete: | Unreinforced types are available from 4" to 24"; reinforced pipe is available from 12" to 108"; available in two strength classes; comes in 2 1/2 and 3 foot lengths; pipe subject to corrosion from acidic condition; pipe may decompose if water left to stand in pipe |
| Vitrified clay: | available in two strength classes; resistent to acids; 2 to 3 feet minimum laying length sizes |
| Plastic: | resistant to highly acidic waters; a relatively recent innovation in sewer line usage. |

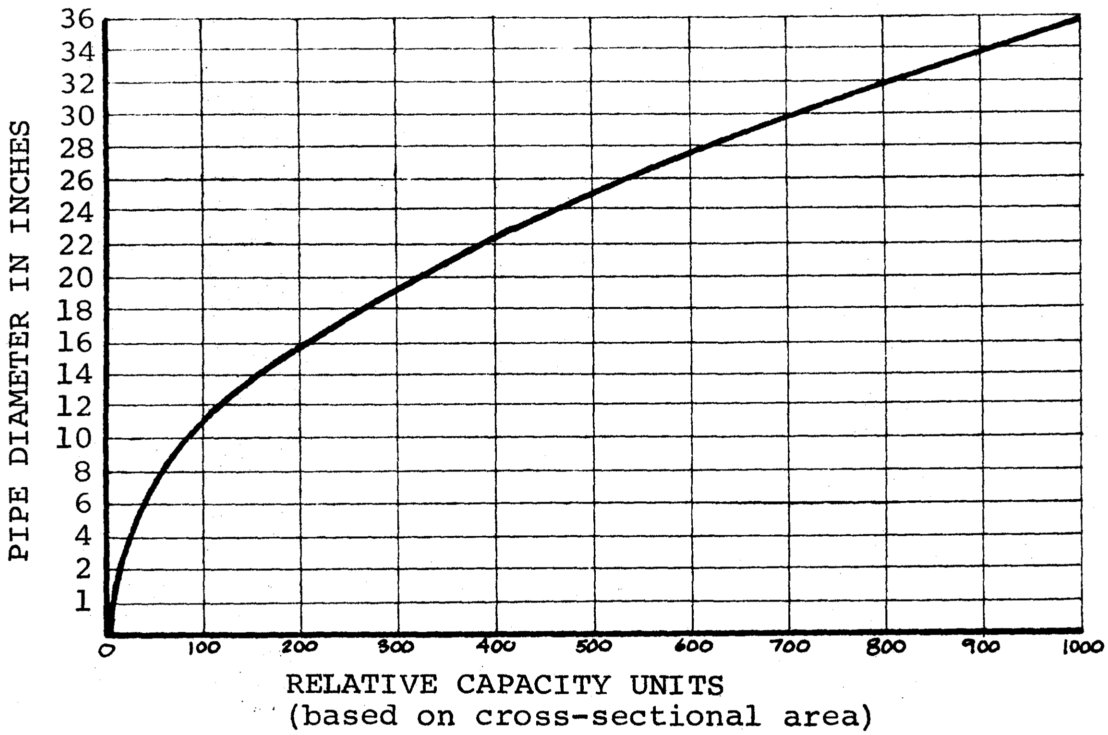
# PIPE MATERIAL AND SIZES AVAILABLE

The following chart represents the standard pipe sizes and the corresponding materials that they are available in the United States, 1969.

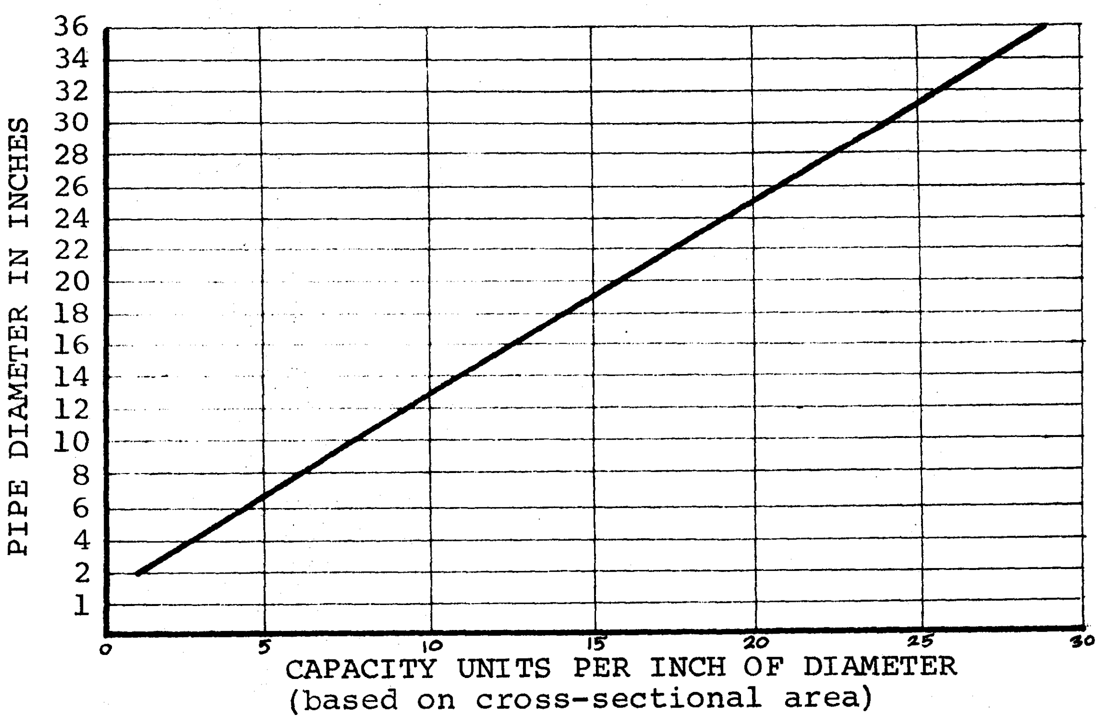



(R: 28)

RELATION OF PIPE DIAMETER TO PIPE CAPACITY




CAPACITY PER INCH OF DIAMETER



RELATION OF PIPE DIAMETER TO PIPE CAPACITY

The flow varies as the square of the radius

if the diameter is doubled, the capacity is increased by a factor of 4

EXAMPLE: a 12" pipe has 4 times the capacity of flow than a 6" pipe

if the diameter is tripled, the capacity is increased by a factor of 6

EXAMPLE: a 18" pipe has 6 times the capacity of flow than a 6" pipe

CAPACITY PER INCH OF DIAMETER

The flow varies as the multiple of the proportional increase

if the diameter is doubled, the capacity per inch is increased by a factor of two

EXAMPLE: a 12" pipe will give you twice as much water per inch of diameter than a 6" pipe

if the diameter is tripled, the capacity per inch of diameter increases by a factor of three

EXAMPLE: a 18" inch pipe will give you three times as much water per inch of diameter than a 6" pipe

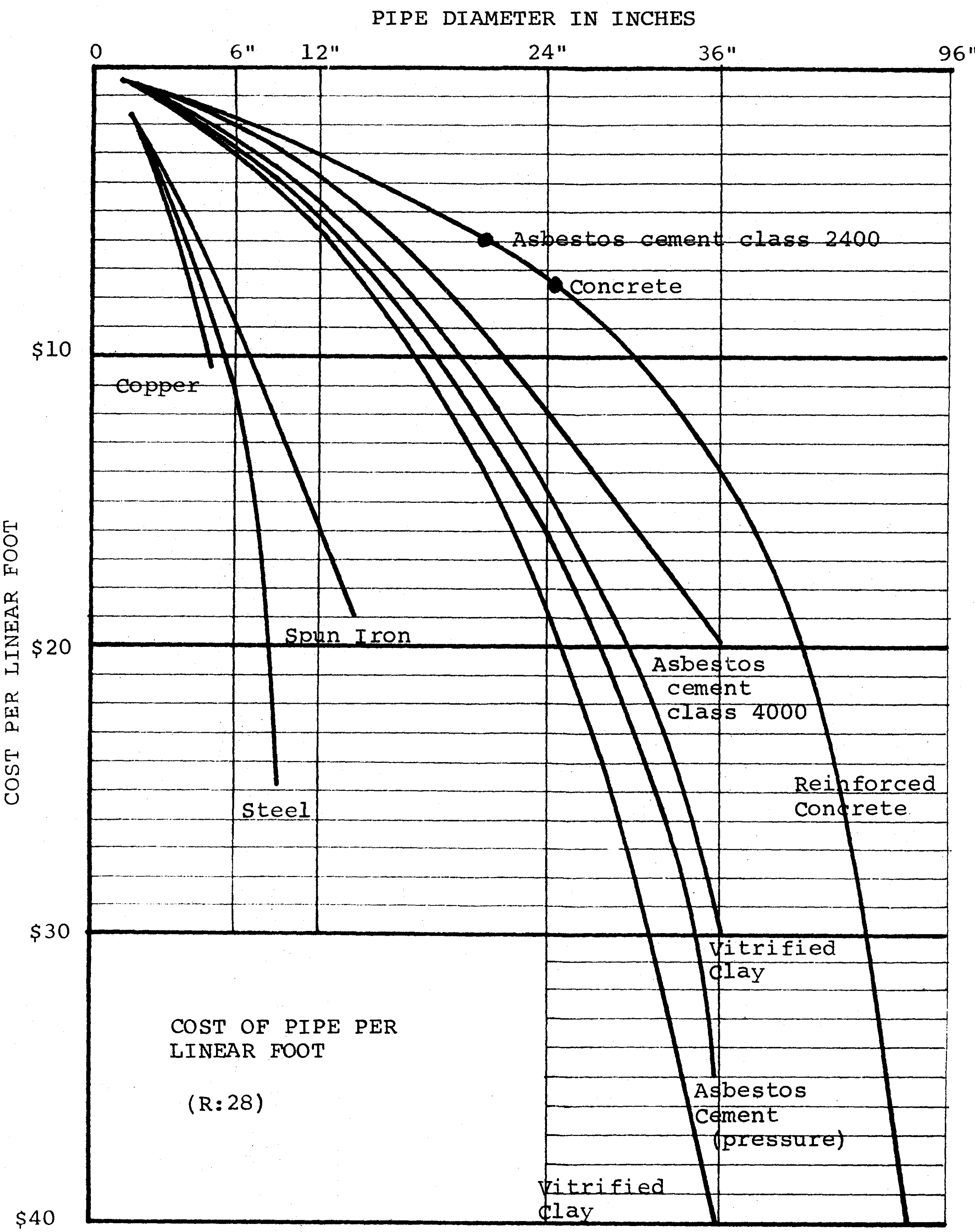
## COST PER LINEAR FOOT OF PIPE

As will be seen from the following chart, the cost per linear foot of pipe rises sharply as the pipe diameter increases. After 36", the costs increase so rapidly that it is best to duplicate pipe lines and not replace the existing lines with a large diameter pipe as required when expanding.

It is obvious that the smaller the pipe used, the more economical system will result.

In choosing a pipe, one would choose the largest pipe available at a given cost. Or, one would choose the most economical pipe at a given price. For example, the most economical 6" pipe is the bituminous fiber. Or, the largest pipe available for $3/ft. is concrete, a 12" pipe.

Prices for pressure pipe (water) generally are more expensive. Costs increase dramatically with an increase in diameter.


PIPE DIAMETER IN INCHES
0
6"
12"
24"
36"
96"
COST PER LINEAR FOOT
$10
$20
$30
$40
Asbestos cement class 2400
Concrete
Copper
Spun Iron
Steel
Asbestos cement class 4000
Reinforced Concrete
Vitrified Clay
Asbestos Cement (pressure)
Vitrified Clay
COST OF PIPE PER LINEAR FOOT
(R:28)

(R:28)

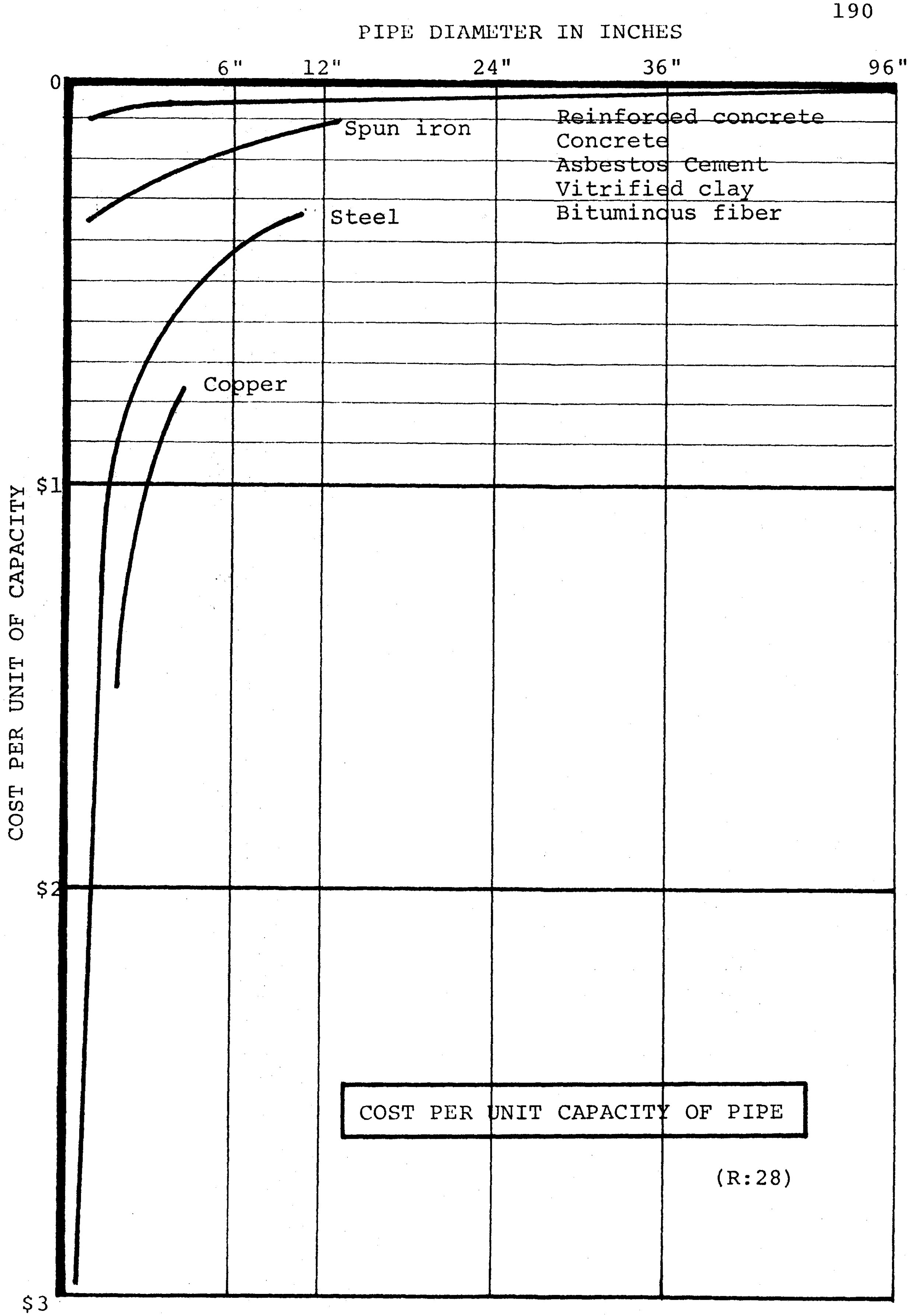
## PIPE COST PER UNIT OF CAPACITY

In comparison to the previous chart, it may be seen that the cost per unit of capacity of pipe is approximately the same for the various classes. The price does not increase per unit of capacity as seen in the cost per linear foot of pipe, but remains relatively stable.

Generally, the smaller the pipe, the more one pays for the amount of water available. In choosing a pipe to be used, one should pick a pipe with the lowest cost per unit capacity delivered. For example, if faced with the selection of a 18" pipe for sewer lines, the concrete pipe is the most economical; if strength requirements are not met by this pipe, the next choice would be the reinforced concrete pipe, followed by the vitrified clay.

For water networks where the pressure requirements must be met, the most economical is the spun iron pipe with coated interior and exterior. Perhaps the flexible PVC pipe will become more useful as production increases and allows lower prices.

Each system would have to be evaluated on the market in each particular locality for final determination of pipe materials. Either the availability in a particular locality or the physical requirements of corrosion resistence, etc., would dictate the final choice.


PIPE DIAMETER IN INCHES
6"
12"
24"
36"
96"
0
$1
$2
$3
COST PER UNIT OF CAPACITY
Spun iron
Reinforced concrete
Concrete
Asbestos Cement
Vitrified clay
Bituminous fiber
Steel
Copper
COST PER UNIT CAPACITY OF PIPE

(R:28)

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