PIPE SYSTEMS

The Surveyor and Pipe Systems - Among the engineering services called for in modern cities are those of stormwater and sanitary sewerage disposal, and water supply and reticulation. Each of these services will generally require survey, design and construction of a pipe system. At any one or more of these stages the surveyor may be expected to participate and contribute to the process.

Rather than attempt to discuss the practical aspects of pipe systems in their totality, these notes will direct attention towards one particular section of planning development, namely, new urban or broadacres. Within this restricted but important (to the surveyor) area, it is hoped that the role of the surveyor within the design team can be effectively presented.

Stormwater Drainage

Introduction - Stormwater drains are designed to carry surface runoff under storm conditions. They can be either pipes (circular) or open channels (trapezoidal) or a combination of both. Stormwater drains are designed to flow as open channels (gravity flow) and therefore should follow the natural fall of the land otherwise pumping will eventually be required.

If water enters a pipe at a constant rate and escapes freely at the lower end, steady uniform flow will soon be established. For this flow condition uniform flow formulae can be used in the calculation of pipe capacities. To ensure that uniform flow can exist, pipe mains are invariably laid straight for both line and grade.

Drainage pipes flowing full and under some pressure are said to be "surcharged".

Manholes and Pits - Essential a pipe system is a subterranean system. However there are several types of appurtenances which connect the system with the ground surface.

Manholes are used in any gravity pipe system as a means of access for inspection and cleaning. They are located at all changes of direction and/or grade, and at regular spacings (200 metres maximum) along straights.

Pits are permanent openings into stormwater systems for entrance of storm flow. Two types used in Victoria are side entry pits and grated pits. Pits are positioned in road channels at sag points, rapid changes in direction, and at regular spacings (200 metres maximum) along the channel. They may also be positioned at other suitable surface locations requiring entrance of storm flow. Pits can also serve as manholes.

In addition pit spacings, in roads, should be as such that the storm width of channel flow will not exceed 2.5 metres. This requirement limits any inconvenience to pedestrians and also reduces the possibility of hazards caused by water extending into traffic lanes.

Origin of Storm Flow - For any given design location storm flow will originate from:-

(a) Roads and paved surfaces,

(b) Roofs of dwellings and other buildings,

(c) Ground surfaces within the catchment.

Roads and Paved Surfaces - These have a high coefficient of runoff (0.90) and though covering only a small percentage of the total design surface area, still contribute significantly to the total runoff.

Rain which falls on a road surface flows towards the kerbs and eventually down the channels to be collected at regular intervals into pits. These pits act as the entry points to the underground pipe system.

Roofs of Dwellings and Other Buildings - As for (a) above, these surfaces contribute significantly to the total runoff and therefore require separation.

Rain collected off roofs is piped underground into "service pipes" which then connect to either "stormwater mains" or alternatively through the kerb into the channel at road frontages.

Ground Surface Within the Catchment - Amounts to the remainder of the catchment area after (a) and (b) above have been removed. Coefficients of runoff can vary considerably depending on the nature of the surface, soil, vegetation, etc. The ultimate land use should always be adopted, and the highest likely coefficient accepted.

It should be noted that catchments do not always coincide with titles. Any land outside of title but inside the catchment should be included in the design and at highest likely coefficient value.

Influence of Stormwater Drainage on Subdivisional Planning

Procedures - The natural flow lines of a catchment can be likened to the structure of a tree. Just as the trunk supports the branches and twigs, so also main streams reduce to tributaries and overland flows. The topography can be viewed in a similar manner; main valleys merging into side valleys and finally into hill slopes.

It can be seen that the larger any stream and the steeper any topography, the more restrictive will be these influences on the planning process. Without extensive earthworks the location of large drains can be varied little and the land use will be restricted accordingly. In addition, as stream size increases, the costs of piping become prohibitive and open channel design must be resorted to.

Hence stormwater drainage design and subdivisional planning design are mutually interwoven. Neither should proceed too far ahead of the other, otherwise undesirable and unneccesary costs may have to be accepted.

Steps in Stormwater Design

(1) Pre-Subdivisional Planning - (Main Drains)

(a) Firstly consider the larger streams in the area.

They can be:-

(i) piped,

(ii) improved as open channels,

(iii) left as is.

The ultimate choice will depend on factors such as hydraulic efficiency, economics, aesthetics, safety and maintenance.

Pipes are hydraulically efficient, safe, maintenance free and expensive.

Improved channels can be hydraulically efficient and cheaper than equivalent pipes, but require more maintenance. In addition they are safety hazard, especially to small children. Aesthetically and environmentally they are becoming less acceptable to the public. Natural channels or streams require little expense or maintenance but are hydraulically inefficient. They may be left as is if local flooding is publically acceptable.

(a) Locate and design open channels within the subdivision. This will include the selection of alignment, gradient of bed, cross sectional shape, depth of flow, and method of lining. It should also be remembered that legal easements or reserves often need to be created along the routes of open channels.

(c) Locate the piped main drains that might influence the layout and then complete the subdivisional planning design.

(2) Post-Subdivisional Planning - (Drainage Mains)

Once the road and other allotment boundaries have been designed stormwater design can proceed as follows:-

(d) Working from a plan at suitable scale and which records boundaries, kerb lines, and contours, mark (in red) at the lowest level corner of each allotment an arrow pointing in the direction of maximum slope.

(e) Select pit locations in roadways, and elesewhere, to take channel and other surface flow. Sag points are a good place to start.

Maximum spacings of 200 metres should be observed working towards or away from crowns of roads.

(f) Now draw lines in suitable location and direction to service all blocks. Mains must be laid straight both for line and grade. Satisfactory design is achieved if pits are interconnected by lines of straight laid pipes. Where the ground surface slopes away from the road rear boundary mains will be required. At changes of diretion or grade and where pits are not necessary, manholes will need to be introduced.

(3) Determination of Pipe Sizes and Final Levels

Having located line and position of all main drains and other drainage mains, calculation of pipe sizes and invert levels is now possible.

(g) Certain minimum and maximum design standards need to be set:-

(i) Minimum Pipe Cover - To ensure that bearing pressures do not damage or misalign pipes, all mains should be laid to provide sufficient cover.

Acceptable standards - under roads, say 900mm; elsewhere, 700mm.

(ii) Minimum Pipe Size - To ensure that surface debris passing through pits do not block pipes, minimum standards should be set.

Acceptable standards - connected to road pits, 150mm diameter; rear mains and others with direct connections (i.e. no pits), 100mm diameter.

(iii) Minimum Velocity - To prevent sand and grit carried in the flow from being deposited in the pipes.

Acceptable standard - 1 metre per second.

(iv) **Maximum Velocity - To prevent the abrasive properties of sand and grit carried in the flow from damaging the pipes.**

Acceptable standard - 2.5 metres per second.

(v) **Minimum Grade - This item is associated with that of minimum velocity. Regardless of pipe size, all grades should be kept in excess of recognised minimums.**

Acceptable standard - 1 : 100.

(h) Break the design area into catchments with pits as discharge points. Starting from the catchment most remote from the design terminal discharge point, proceed to take out areas, select coefficients of run-off, determine times of concentration, fix pipe invert levels, and using the Rational Method complete the pipe design.

Work from the initial catchment as far as the first branch line.

Design of the branch is then undertaken, starting from its most remote catchment. Continue in this manner down the main line, connecting in all branch lines as appropriate, until the design terminal discharge point is reached.

The results may be tabulated as follows:-

SHEET 1

Description of Catchment	A	C	$\frac{\Sigma AC}{360}$	T_c	I	Q

(T_c - time of concentration includes time of channel flow and time of pipe flow)

SHEET 2

Grade (S)	Length of Line	Pipe Dia (D)	Velocity (V)	Time of (T_p) Flow	Capacity

For the four values, discharge (Q), grade (S), diameter (D), and velocity (V), if two are known the other two can be found. To effect design the two generally varied are grade and diameter.

(i) At this point the design is complete. The information can now be recorded in either longitudinal or plan form.

Sanitary Sewerage

Introduction - Sanitary sewerage is the liquid wastes originating in (i) households, (ii) commercial buildings, (iii) industrial properties, and (iv) public institutions.

For efficient removal, these wastes are frequently conducted through underground pipes flowing under gravity. A network of such pipes constitutes a "sanitary sewerage pipe system".

Infiltration - Infiltration is additional ground and surface water which might enter a sewer through poor pipe joints, cracked pipes, walls and lids of manholes, and illegal connections. It is essentially a wet weather flow and can significantly affect the flow capacities of sewer mains. The magnitude of infiltration in any locality can be influenced by such factors as:- (i) nature of soil, (ii) ground water table level, (iii) material and size of pipes, (iv) quality of workmanship in pipe laying, (v) degree of policing of sewerage system.

Quantities of Sewerage - Sanitary sewerage is derived largely from water supply and bears a direct relationship to it, varying from 70% to 130% of water consumed (100% maximum in Melbourne).

Quantities will vary with, the season of the year, day of the week, and time of the day. For residential districts the greatest flow will occur about 9 A.M. In commercial and industrial districts peaks will be less pronounced.

Fluctuations from daily averages can vary as follows:-

(i) Small residential districts - 225%

(ii) Commercial areas - 150%

(iii) Industrial areas - 120%

M.M.B.W. in considering sewerage quantities have defined the following two terms:-

(a) Dry Weather Flow - which is the total of domestic sewerage, commercial and industrial waste, the permanent infiltration of ground water, and waste water flow.

(b) Wet Weather Flow - which is the sum of the dry weather flows plus the stormwater inflow.

The "average wet weather infiltration rate" adopted is 9200 litres per hectare per day (5000 gallons per acre per day), for a recurrence interval of 5 years.

From these values, the "average wet weather flow rate" can be determined for design purposes.

Influence of Sewerage Design on Subdivisional Planning Procedures - The influence of sewerage design is not as great as for stormwater design. Provided that gravity flow can be achieved, the location and direction of sewerage mains is not critical. Sewer lines tend to be designed parallel to road lines, rear boundaries or side boundaries.

This requires that subdivisional planning to fix all lot boundaries should precede the engineering design.

M.M.B.W. separate sewers into three separate categories:-

(i) Main sewers (over 900mm diameter) - which would follow valley floors.

(ii) Branch sewers (300mm dia. to 900mm dia.) - which would follow valley floors

(iii) Reticulation sewers (under 300mm dia.) - which are located along road lines or at the rears of properties.

Where any sewer scheme cannot connect into existing pipes, an acceptable procedure has been to provide "local purification plants" until such time as a satisfactory connection can be provided.

Steps in Sewerage Design

(1) Pre-Subdivisional Planning - (Main and Branch Sewers)

(a) These sewers would probably parallel stormwater main drains and be located in the valley floors. Engineering constraints are paramount, namely, good line and grade, and direct connection into existing mains.

(2) Post-Subdivisional Planning - (Reticulation Mains)

The requirements for sewer main locations are similar to those for drainage mains. However certain differences need to be recorded:-

(b) Working from the plan used for the design of the drainage mains or from an identical copy, draw lines in suitable location and direction. Start from the terminal discharge point and work towards the extremities designing such that every block is serviced. If choice is available prefer road locations to rear boundaries.

In general design should parallel the stormwater system. M.M.B.W. recommend the following offsets:-

Road Building lines - 1.3 metres

Side boundaries }
Rear boundaries } - > 1.15 metres - machine excavation
- > 0.7 metres - hand excavation

(c) Decide on manhole positions, i.e. at all changes of line, grade, and pipe size, and at regular spacings (100 metres) along straights.

(d) Design "house drains" for mains in roads, as far as block boundaries, and position junctions on mains in properties.

(3) Determination of Pipe Sizes and Final Levels

(e) Minimum and maximum design standards set for sewers can be as follows:-

(i) Minimum Pipe Cover - Requirement is as for drainage mains.

Acceptable standards - under roads, 1350mm; elsewhere, 1100mm.

(ii) Minimum Pipe Size - To ensure that pipe blockages do not occur, a minimum pipe size needs to be set.

Acceptable standards - reticulation mains, 150mm; house drains, 100mm.

(iii) Minimum Velocity - To prevent settlement of sewerage solids.

Acceptable standard - 600mm/second.

(iv) Maximum Velocity - As for drainage mains.

Acceptable standard - 2.5 metres per second.

(v) Minimum Grade - M.M.B.W. use the following rule for sewer grades:-

S = 1 : 300 x diameter in feet.

Acceptable standards - 100mm, 1 : 40,
150mm, 1 : 100,
225mm, 1 : 200.

(f) Break the design area into suitable catchments with manholes as discharge points. Starting from the catchment most remote from the design terminal discharge point, proceed to take out areas, estimate population densities and fix pipe invert levels.

Work through the system in a manner similar to that described under stormwater drainage. The results may be tabulated as follows:-

SHEET 1

Description of Catchment	Population	Area	Population Density	Q

SHEET 2

Grade (S)	Length of Line	Pipe Dia (D)	Velocity (V)	Capacity

For the four values, discharge (Q), grade (S), diameter (D), and velocity (V), if two are known the other two can be found. To effect design the two generally varied are grade and diameter.

For smaller residential catchments, the following catchments are acceptable:-

Maximum Number of Houses Normally to be Provided For	Diameter of Service (mm)
4	100
50	150
450	225

(g) At this stage the design is complete. The information can now be recorded in either longitudinal or plan form.

Water Supply

Introduction - A water supply system constitutes the means of distributing consumable water to users. It is essentially a pressure (non-gravity) system with mains laid in roads to form closed loops. Water is brought to the extremities of development from some supply point, the reverse of sewers, where wastes are removed from the extremities to some discharge point.

Forms of Water Consumption - These can be classified according to the ultimate or end use:-

(i) Domestic - is that water used in houses, flats, hotels, etc for sanitary, culinary, washing, bathing and drinking purposes,

(ii) Commercial and Industrial - Industries are heavy users of water and are often considered separately. Commercial usage may be assessed according to the number of occupants in the commercial location, or alternatively according to the floor area of building served,

(iii) Public Use - This will include water consumed in halls, gaols, schools, hospitals, etc, plus road and park sprinkling and fire protection,

(iv) Loss and Waste - These include water lost to meter and pump slippage and leakage in mains. Water is not necessarily lost to use but rather is not included in any of the above catagories.

Factors Affecting Water Consumption - Average daily per capita water consumption can vary from 150 to 2350 litres. Some of the factors which might be associated with such variation are:-

(i) Size of City - generally the larger the city the greater the consumption,

(ii) Presence of Industries - the percentage of land area allocated to existing or proposed industry is significant,

(iii) Quality of Water - good water encourages greater usage,

(iv) Cost of Water - cheap water encourages greater usage,

(v) Pressure in System - higher pressures encourages greater usage,

(vi) Climatic Conditions - hot weather encourages greater usage,

dry weather encourages greater usage,

(vii) Characteristics of Population - rich people use more water than poorer people,

(viii) Metering of Supply - in any given situation, metered users will consume less water than non-metered users,

(ix) Water Administration Efficiency - better efficiencies can avoid wasteful losses.

Quantities of Water Consumption "Steel" records the following figures for the typical Amercian City:-

Use	Litres per Capita per Day	Percentage of Total
Domestic	267	40.0
Industrial	142	21.3
Commercial	93	14.0
Public Use	68	10.0
Loss & Waste	98	14.7
	668	100.0

(150 gallons)

Quantities will vary with, the season of the year, the day of the week, and the time of the day. For residential districts the greatest consumption is on Mondays and the lowest on Sundays. Consumption peaks at about 8 A.M. and 6 P.M. on any given day.

Maximum daily consumption can equal 180% of the annual average, and, Maximum hourly consumption can equal 150% of the daily average.

Therefore, for design,

Maximum consumption = 668 x 1.8 x 1.5 = 1805 litres per capita per day.

Fire Demand - In addition to per capita usages, fire demand must also be considered. The amount of water used in firefighting is actually small but the rate of usage can be large. Hence minimum flow rates, 1110 litres/minute (250 galls/minute), need to be set as well as total usage rates.

"Steel" gives a formula sometimes used to assess usage rates as:-

$G = 4540\sqrt{P}\ (1 - 0.01\sqrt{P})$ where,

G = fire demand in litres/minute,

P = population in thousands,

Examples:-

(a) Find the design flow rate for a city of 22,000 population?

$G = 4540\sqrt{22}\ (1 - 0.01\sqrt{22})$

$= 20{,}295$ litres/minute

$$Q = 668 \times 1.8 + \left(20{,}295 \times \frac{60 \times 24}{22{,}000}\right)$$

$= 2530$ litres/capita/day

$= 1.76$ litres/capita/minute

(b) Find the maximum flow rate in a suburban court?

(Fire in house next door, at 6 P.M. on January 21st. Court population is 30 persons).

$$Q = \frac{668 \times 1.8 \times 1.5 \times 30}{60 \times 24} + 1110$$

$$= 37.6 + 1110$$

$$= 1147.6 \text{ litres/minute}$$

Distribution System - Water distributed to all consumers can be supplied by means of:-

(i) pumping with or without storage,

(ii) supply from elevated tanks,

(iii) supply from storage reservoirs.

The essential features of storage are that it equalizes pumping rates and also equalizes supply and demand over long periods of high consumption. In addition storage may be required for fire fighting.

The pipe system will comprise pipes of the following type:-

(a) Primary Feeders - or arterial mains which carry large quantities of water and follow main roads. They should be designed to form loops with valves at maximum spacing every 1500 metres. Location may be under the carriageway due to the size of the pipe and the fact that access to the pipe is not required except in emergency. There are no tappings to local services as pressures would be too high and interruption to flow could not be accepted.

(b) Secondary Feeders - are the same as primary feeders only smaller. They connect the primary feeders to the distribution mains and provide additional links for loop flow. They should be large enough to provide concentrations of water for fire fighting without incurring excessive head loss. Tappings for local services may be allowed.

(c) Distribution Mains - are the smallest and most frequent. They serve all residences and other buildings with normal supply. They can be located in the carriageway but the best place is in the nature strip behind the kerb. If there are any dead-end lines, provision should be made for cleaning.

(d) Valves - are fittings in the mains which allow for severance of the flow either, in both directions (gate valves) or in one direction (swing check valves). Severance of flow may be required for reasons of cleaning, maintenance, repairs or new connection. Valves should be located at regular intervals along mains (maximum spacing 200-300 metres) and preferrably at intersections.

(e) Hydrants - are fittings in the mains which provide temporary local supply at pavement level for fire fighting and pipe cleaning purposes. Hydrants should also be placed at low points in mains for blowoff purposes and at high points for air relief. Hydrants should be located to the same standards as for valves. Courts may require additional hydrants even if short in length.

(f) Service Pipes - are the smaller pipes between the mains and the property boundaries. In Melbourne tapping is done at completion of house construction. If the main is located on the opposite side of the road a core is drilled under the carriageway. Alternatively a service duct can be provided at the time of road construction.

Influence of Water Supply Design on Subdivisional Planning Procedures - The influence of water supply design is practically nil and hence subdivisional planning to fix all lot boundaries can precede the engineering design. Mains are placed in roads parallel to the carriageway and at uniform depth beneath the surface (clearance requirements for valves and hydrants). Pipes can follow even small radii curves as individual joints can deflect by as much as 12° (asbestos-cement pipes). Alternatively pipe bends are introduced into the line and the curve then becomes a series of chords.

An important requirement is that the pipes should at all places and at all times be below the hydraulic grade line (i.e. pressure in the pipe is positive). This may mean that certain areas, otherwise suitable for subdivision, need to be excluded from the design due to insufficient water pressure.

Steps in Water Supply Design

(1) **Pre-Subdivisional Planning - Primary & Secondary Feeders, Storage Reservoirs**

These parts of the distribution system are most likely already in existence, and even if not would be the responsibility of the supplying authority. Water would normally be supplied at a given point and at a given static pressure.

In any system, if pressures are too high problems with household water appliances can occur; if pressures are too low, not enough water can be delivered. Ideally mains pressure should range between 410 KPa (60 p.s.i) and 520 KPa (75 p.s.i.) with an absolute minimum of 140 KPa (20 p.s.i.). Where topography varies considerably pressure zones may be required to ensure that mains pressures do not become excessive.

(2) **Post-Subdivisional Planning - (Distribution Mains)**

Once the road and other allotment boundaries have been designed water supply design can proceed as follows:-

(a) Working from an identical copy to that used with drainage and sewerage mains, draw lines in suitable location and at suitable offset. Start from the supply point and work towards the extremeties designing such that each block is serviced. Ensure that the loop concept is maintained.

(b) If any road is wide and/or blocks are narrow, consider the possibility of a rider main.

(c) Select valve and hydrant locations at regular intervals and/or at intersections.

(3) **Determination of Pipe Sizes**

The following table is interesting in comparing pipe sizes:-

Size of pipe (mm)	100	150	225	300	...	900
Number of 100mm pipes to carry the same flow	(1)	(3)	(9)	(20)		(390)

Thus it can be seen that large pipes carry very large quantities of water.

To assess pipe size requirements an analysis will be made of flow through three pipes of different sizes, using the nomogram based on the Hazen-Williams Formula ($C = 100$). (Assume that flow velocity should lie within the range 0.6 to 1.2 m/sec with 1.8 m/sec maximum, otherwise excessive head loss will occur.

(a) <u>100mm</u> - <u>Consumption</u>

For 1.2 m/sec = 668 litres/min = 30 m/1000m head loss

= 375 people

For 0.6 m/sec = 334 litres/min = 8 m/1000m head loss

= 188 people

<u>Fire Fighting</u>

For 1110 litres/min = 2.0 m/sec = 70 m/1000m head loss

(b) <u>150mm</u> - <u>Consumption</u>

For 1.2 m/sec = 1650 litres/min = 17 m/1000m head loss

= 925 people

For 0.6 m/sec = 825 litres/min = 4.5 m/1000m head loss

= 463 people

<u>Fire Fighting</u>

For 1110 litres/min = 0.9 m/sec = 10 m/1000m head loss

(c) <u>300mm</u> - <u>Consumption</u>

For 1.2 m/sec = 6230 litres/min = 8 m/1000m head loss

= 3500 people

For 0.6 m/sec = 3115 litres/min = 2 m/1000m head loss

= 1750 people

<u>Fire Fighting</u>

For 1110 litres/min = 0.1 m/sec = 0.3 m/1000m head loss

Thus in terms of residential population densities, we can use:-

(a) Distribution mains = 100mm and 150mm

(b) Secondary feeders = 225mm and 300mm

(c) Primary feeders = above 300mm

As a final test, all mains should be checked for head loss and pressures to ensure that pipe flows conform to design standards.