Wastewater flowrates and constituent loadings

Overview of wastewater management

- Wastewater management infrastructure

  Consumer

  → wastewater collection system (sewer pipeline + pumping stations if needed)

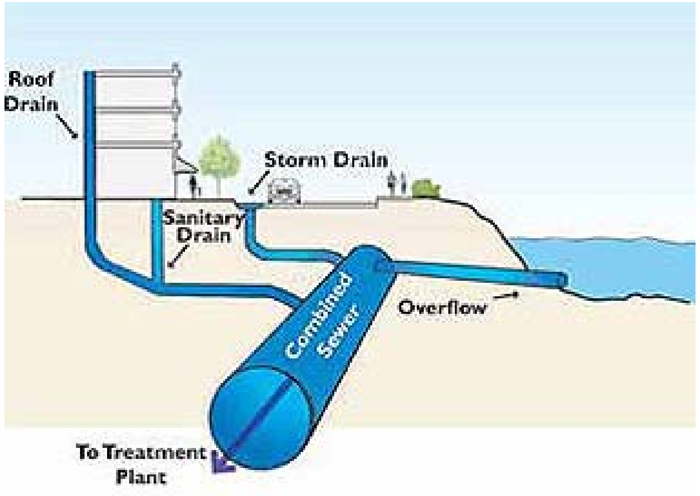
  → wastewater treatment facility

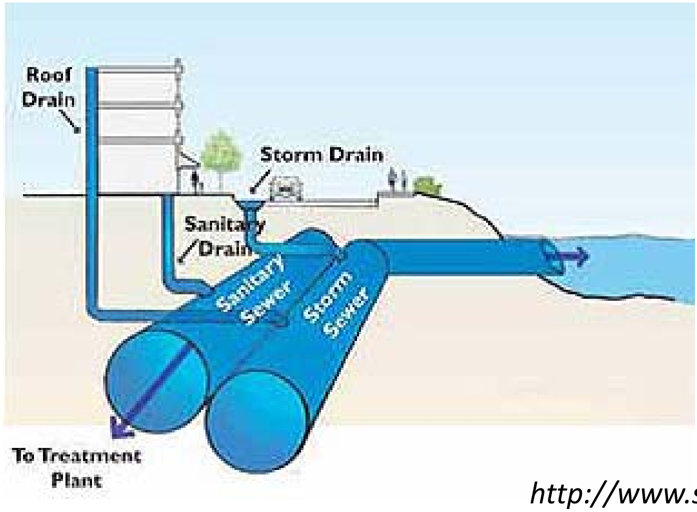
  → outfall to river or ocean

- Sewer system
  - **Combined sewer**: collects sanitary sewage and stormwater runoff in a single pipe system
  - **Separate sewer**: collects sanitary sewage and stormwater runoff separately

Overview of wastewater management

- Combined vs. separate sewer system





http://www.sfbetterstreets.org

- Wastewater and stormwater treatment systems
  - **Wastewater treatment facility**
  - Combined sewer overflow treatment facility
  - Stormwater treatment systems

Component of wastewater flows

1) **Domestic wastewater**: Wastewater discharged from residences and from commercial, institutional, and similar facilities.
2) **Industrial wastewater**: Wastewater in which industrial wastes predominate.
3) **Infiltration/inflow (I/I)**: Water that enters the collection system through indirect and direct means. Infiltration is extraneous water that enters the collection system through leaking joints, cracks, and breaks, or porous walls. Inflow is stormwater that enters the collection system from inappropriate connections.
4) **Stormwater**: Runoff resulting from rainfall and snowmelt.

- Sanitary sewer of separate system: 1) + 2) + 3)
- Combined sewer: all of above

Wastewater flowrate variations

- **Daily variations**

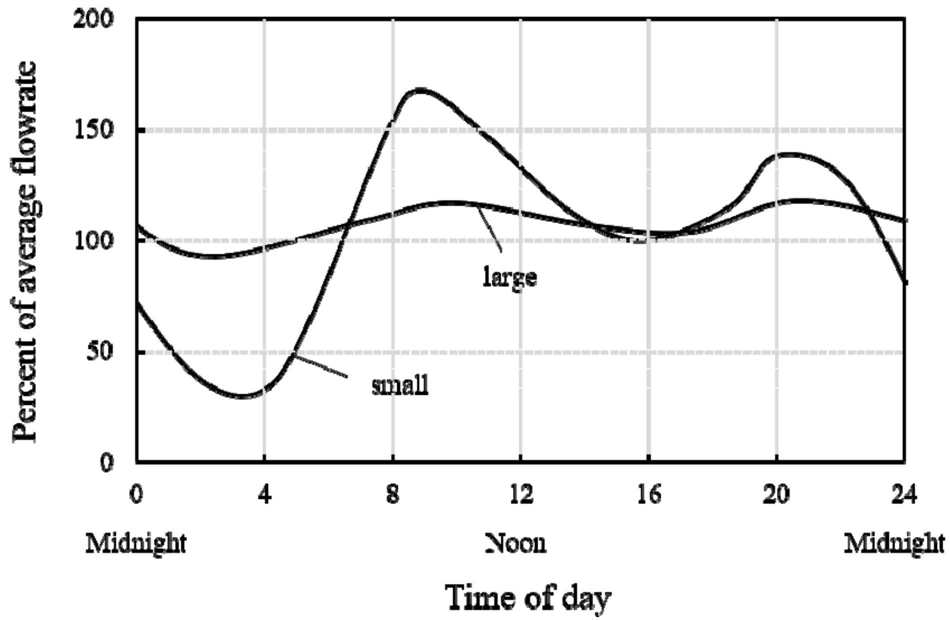
  For relatively small collection systems:

  – Minimum flow during the early morning hours

  – First peak in the late morning

  – Second peak in the early evening

  ** note the lag time for wastewater to reach the treatment plant*



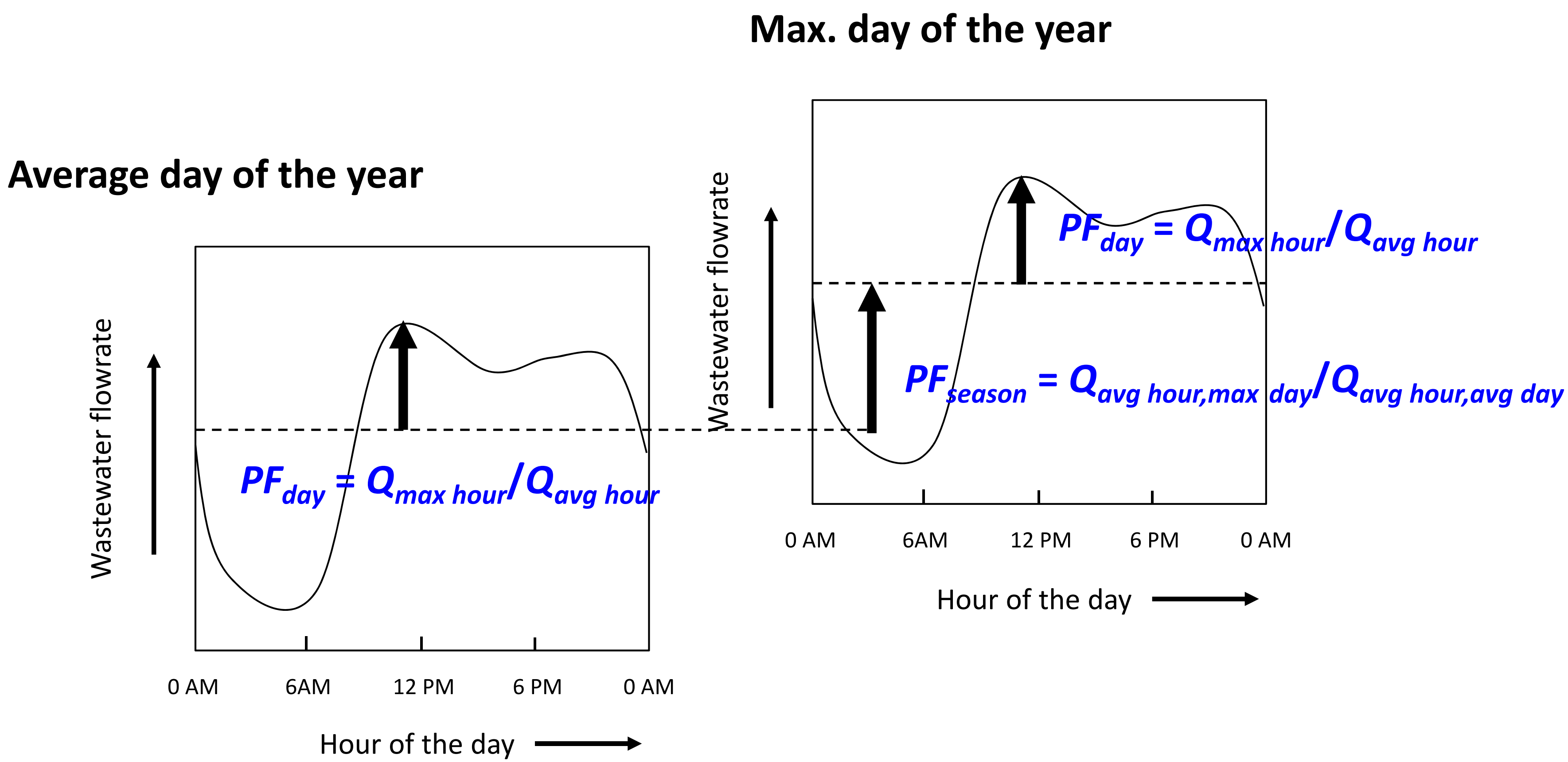
Wastewater flowrate variations

- **Seasonal variations**
  - Different seasonal patterns for different locations due to weather patterns (temp. and precipitation), specific activities (e.g., college campuses, ski resorts), etc.
  - Generally high flowrate in the summer and low flow rate in the winter in Korea

- **Peaking factor**: comparing the peak flowrates to average values

$$Peaking\ factor, PF = \frac{(hourly,\ \ daily,\ \ \dots)\ peak\ flowrate}{average\ flowrate}$$

Wastewater flowrate variations



Estimation of constituent concentrations

- Constituents discharged by individuals
  - Per capita mass constituent discharges: used as background data to design wastewater treatment systems

[Per capita waste discharges in the U.S.]

unit: g/capita/d

Constituent	Range	Typical without ground up kitchen waste	Typical with ground up kitchen waste
BOD_5	50-120	70	93
COD	110-295	180	230
TSS	60-150	70	87
NH_3 as N	5-12	7.6	7.9
Organic N as N	4-10	5.4	6.0
Total P as P	1.5-4.5	2.1	2.2
Potassium, K	4-7	6.0	6.2
Oil and grease	10-35	28	32

Estimation of constituent concentrations

[Per capita waste discharges for various countries]

unit: g/capita/d

Country	BOD	TSS	TKN	Total P
Brazil	55-68	55-68	8-14	0.6-1
Denmark	55-68	82-96	14-19	1.5-2
Egypt	27-41	41-68	8-14	0.4-0.6
Germany	55-68	82-96	11-16	1.2-1.6
Greece	55-60	ND	ND	1.2-1.5
India	27-41	ND	ND	ND
Italy	49-60	55-82	8-14	0.6-1
Japan	40-45	ND	1-3	0.15-0.4
Palestine	32-68	52-72	4-7	0.4-0.7
Sweden	68-82	82-96	11-16	0.8-1.2
Turkey	27-50	41-68	8-14	0.4-2
Uganda	55-68	41-55	8-14	0.4-0.6
United States	50-120	60-150	9-18	1.5-4.5
Korea*	***83.9***	***80.6***	***15.2***	***1.4***

*2011 Seoul, selected value for sewer system masterplan

Estimation of constituent concentrations

Q: Estimate the BOD, TSS, and ammonia nitrogen concentrations for the Gaza Strip assuming the wastewater flowrate of 60 L/capita-d. Use following average per capita discharge for the constituents:

BOD = 50 g/capita/d

TSS = 62 g/capita/d

NH_3-N = 4 g/capita/d

Estimation of constituent concentrations

[Typical unit loading factors and expected wastewater constituent concentrations from individual residences in the U.S.]

Constituent	Typical value, g/capita/d	Concentration, mg/L	
		Volume, L/capita/d	
		190	380
BOD_5	76.0	399.0	199.0
COD	193.0	1013.0	507.0
TSS	74.0	391.0	195.0
NH_3 as N	7.7	40.0	20.0
Organic N as N	5.5	29.0	14.0
TKN as N	13.2	70.0	35.0
Total P as P	2.1	11.0	5.6
Potassium	6.1	32.0	16.0
Oil and grease	29.0	153.0	76.0

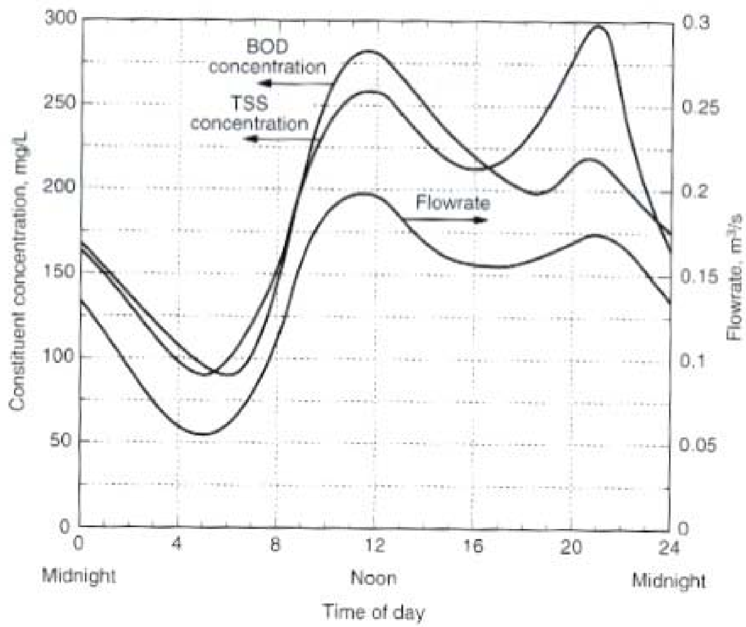
Estimation of constituent concentrations

- Determination of constituent mass loading rates and concentrations for wastewater treatment facilities:
  - Mass loading rates (e.g., in kg constituent/d)
    - Use per capita mass discharge and predicted population to obtain mass loading by residential sources
    - Add mass loadings by commercial, institutional, and industrial sources
  - Wastewater flow rates (e.g., in m^3/d)
    - Use per capita wastewater discharge and predicted population to obtain wastewater flow discharge by residential sources
    - Add flow discharge by commercial, institutional, and industrial sources
    - Add infiltration/inflow and stormwater (stormwater for combined sewer only)
  - Constituent concentrations (e.g., in mg/L)

    = (Mass loading rate) / (Wastewater flow rate)
  - **Consider daily/seasonal variations of mass loading & conc.**

Estimation of constituent concentrations

- **Daily variations in constituent concentrations**



- **Seasonal variations**
  - For domestic sources, the concentration may not change significantly (but mass loading & flowrate may change significantly (e.g., for resorts))
  - Infiltration/Inflow may result in seasonal variations of constituent concentration
    - High I/I in rainy seasons → lower concentrations of BOD, TSS, etc.
  - High seasonal concentration variations for combined sewers
    - Lower concentrations of BOD, TSS, etc. during storm events

Flow equalization

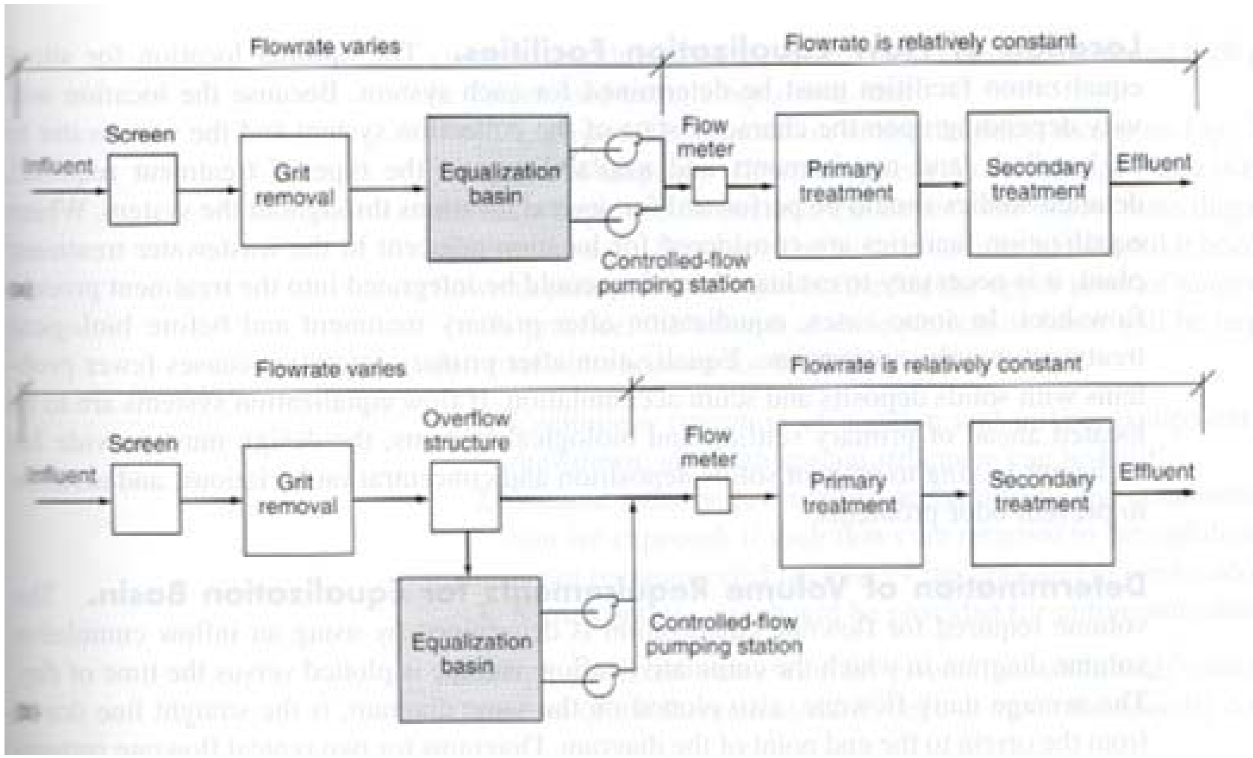
- Objective: dampen flowrate variations to
  - i) overcome the operational problems caused by flowrate variations
  - ii) improve the performance of the downstream processes
  - iii) reduce the size and cost of downstream treatment facilities

Flow equalization

- **Method of application: in-line or off-line**
  - In-line: can achieve dampening of constituent concentration in addition to the dampening of flowrate
  - Off-line: pumping requirements are minimized

[In-line]

[Off-line]



Flow equalization

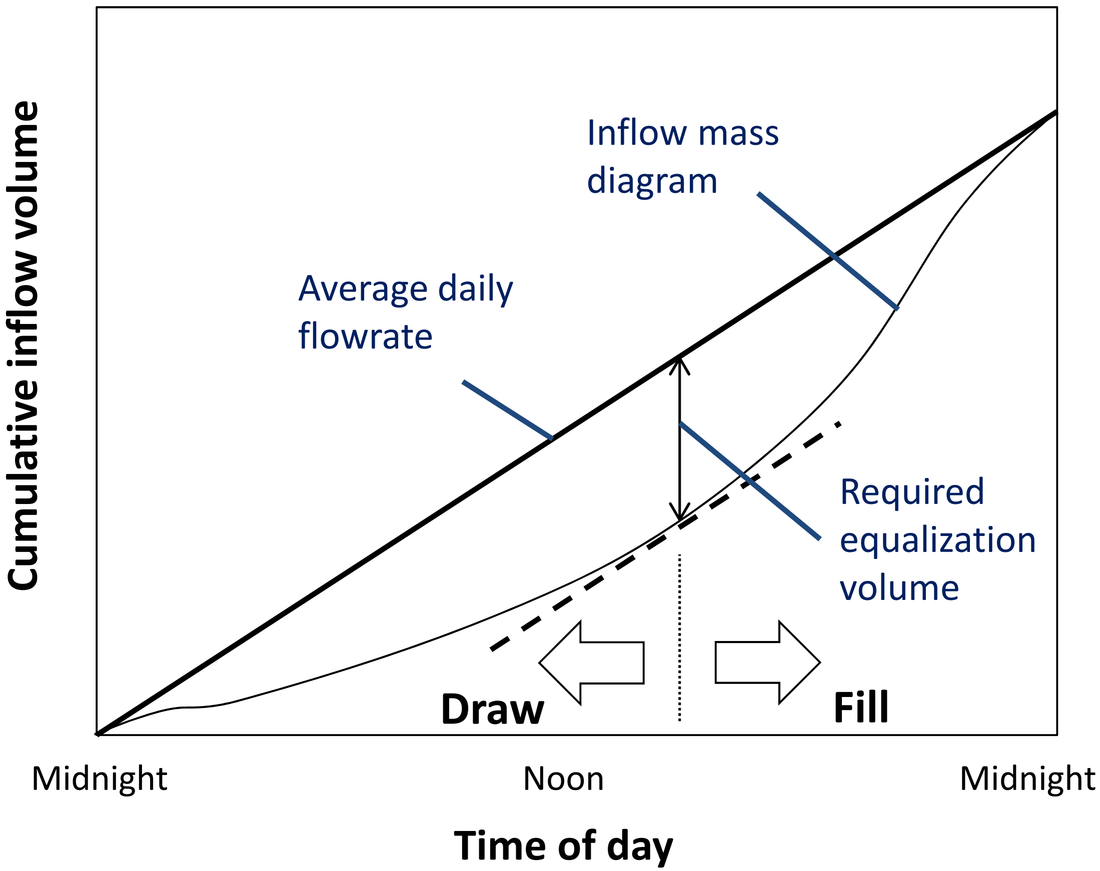
- **Benefits**
  - Biological treatment is enhanced because shock loadings are eliminated or minimized, inhibiting substances can be diluted, and pH can be stabilized
  - The effluent quality and thickening performance of secondary sedimentation tanks is improved through improved consistency in solids loading
  - Effluent filtration surface area requirements are reduced, filter performance is improved, and more uniform filter-backwash cycles are possible by lower hydraulic loading
  - In chemical treatment, dampening of mass loading improves chemical feed control and process reliability

Flow equalization

- **Drawbacks**
  - Relatively large land areas are needed
  - Equalization facilities may have to be covered for odor control
  - Additional operation and maintenance is required
  - Capital cost is increased

Flow equalization

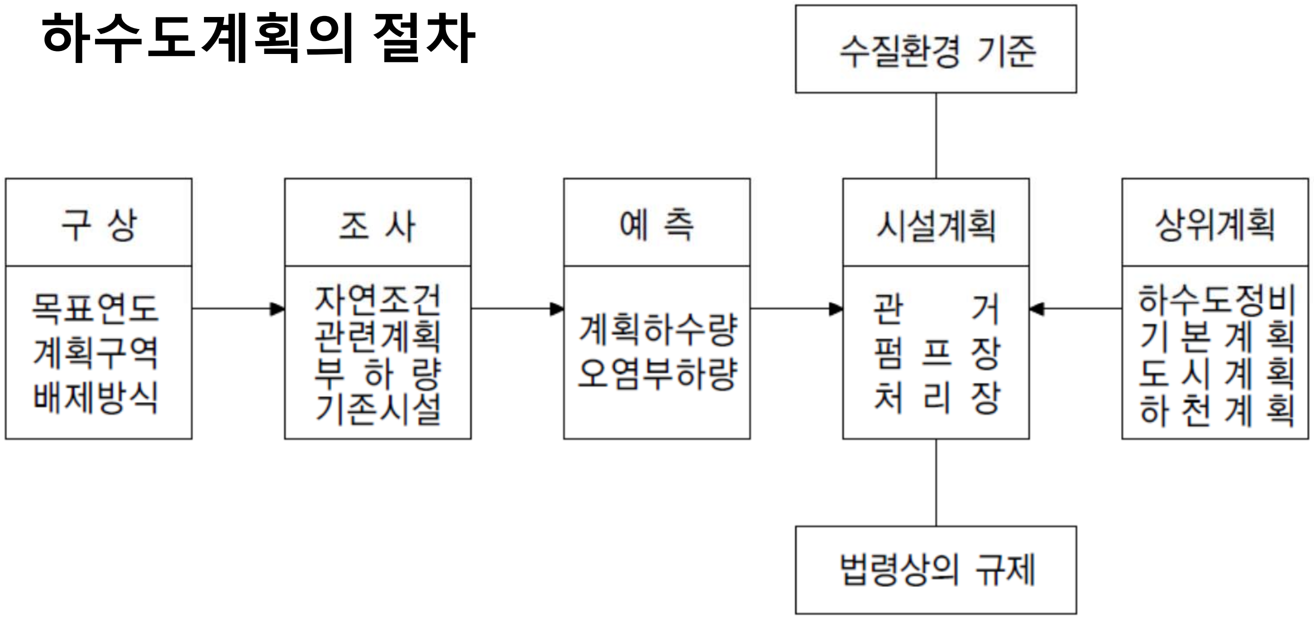
- Volume requirements for the equalization basin



In practice, the equalization basin volume will be larger than the theoretical value for several reasons

Master plan for wastewater infrastructure

- **하수도 시설기준**(2011 개정)
- **하수도계획의 절차**



Master plan for wastewater infrastructure

- **계획목표년도(design lifetime)의 설정**
  - 고려사항
    - 구조물과 기계설비의 내구년수
    - 확장공사의 난이도
    - 도시의 산업발전과 인구증가율에 대한 전망
    - 경제적 요인: 예산, 건설비, 화폐가치의 변동, 하수도 수입의 연차별 예상 등
  - 하수관로 등 비교적 증설이 어려운 시설의 경우 장기간을, 하수처리장 기계설비 등 비교적 변경이 용이한 시설의 경우 단기간을 설정
  - 우리나라의 경우, 하수도계획의 목표년도는 20년을 원칙으로 함

- **계획구역(drainage area)의 결정**
  - 원칙적으로 관할 행정구역 전체를 대상으로 함
  - 행정구역에 지나치게 구애됨 없이 분수령 등 자연조건과 장래 도시계획 등을 고려할 필요

Master plan for wastewater infrastructure

- **계획인구수(design population)의 추정**
  - 연평균증가수에 의한 방법, 연평균증가율에 의한 방법, 지수함수곡선식에 의한 방법, Logistic 곡선식에 의한 방법 등 다양한 수학적 모델 중 가장 잘 부합하는 방법 선정

[예] 연평균증가율에 의한 방법(등비급수법)

$$P_N = P_0(1+\gamma)^N$$

P_N: 현재로부터 N년 후의 추정 인구수
P_0: 현재 인구수
N: 설계기간 (year)
γ: 연평균 인구증가율 = $(P_0/P_t)^{1/t}-1$
P_t: 현재로부터 t년 전의 인구수

Master plan for wastewater infrastructure

- **계획하수량(design flowrate)**
  - **계획1일최대오수량 (design maximum daily sewage flowrate)**
    - 하수처리시설 용량 결정의 기준값
    - (계획1일최대오수량) = (1인1일최대오수량) × (계획인구수) + (공장폐수량) + (지하수량)
    - 1인1일최대오수량: 상수도계획 상의 1인1일최대급수량을 기준으로 함
    - 공장폐수량: 대규모 공장 및 사업장에 대하여 개별적으로 장래 폐수량 추정
    - 지하수량(I/I): 1인1일최대오수량의 10~20%로 가정하거나, 관거 연장/배수면적 등을 고려한 추정치를 사용

Master plan for wastewater infrastructure

- **계획1일평균오수량 (design average daily sewage flowrate)**
  - 펌프장 운용 및 하수처리에 사용되는 첨가제 비용 등의 계산에 필요
  - 하수처리장 유입수질의 예측에 필요
  - 계획1일최대오수량의 70~80%로 산정 $(1/PF_{season} = 0.7{\sim}0.8)$

- **계획시간최대오수량 (design maximum hourly sewage flowrate)**
  - 하수관거 및 펌프장 용량 결정의 기본값
  - 계획1일최대오수량의 시간당 값의 1.3~1.8배로 산정$(PF_{day} = 1.3{\sim}1.8)$
  - 대규모 하수도의 경우 오수량의 시간적 변동이 평균화되므로 낮은 배수(1.3)를, 중소규모 하수도의 경우 높은 배수(1.8 또는 경우에 따라 그 이상)를 적용

Master plan for wastewater infrastructure

– **계획우수량(design stormwater flowrate)**
  - 합리식

$$Q = \frac{1}{360} C \cdot I \cdot A$$

Q: 계획우수량 (m^3/s)
C: 유출계수
I: 유달시간 내의 평균강우강도 (mm/hr)
A: 배수면적 (ha)

  - 고려사항
    - 배수지역의 강우자료 및 확률년수(하수관거의 경우 10~30년빈도)
    - 배수지역의 유출계수, C (강우량 대비 유출량)
      예: 도심지역 0.70~0.95, 교외지역 0.25~0.40
    - 유달시간(유입시간+유하시간)
    - 배수면적

Master plan for wastewater infrastructure

– **계획하수량(design flowrate)의 결정**

- 분류식하수도의 오수관거(sanitary sewer): **<u>계획시간최대오수량</u>**
- 분류식하수도의 우수관거(storm drain): **<u>계획우수량</u>**
- 합류식 관거(combined sewer): **<u>계획시간최대오수량 + 계획우수량</u>**

Master plan for wastewater infrastructure

- **계획오염부하량 및 계획유입수질**
  - 계획오염부하량 (design pollutant mass loading)

    = 생활오수+영업오수+공장폐수+관광오수 오염부하량
  - 생활오수 오염부하량의 산정: 1인당 오염부하량 원단위 참고

우리나라 생활오수의 오염부하량 원단위(2011, 서울시; g/capita-d)

BOD	SS	T-N	T-P
83.9	80.6	15.2	1.4

  - 기타 항목은 기존 실측값/문헌값/세부항목별 원단위 등을 활용하여 계산
  - 계획유입수질 (design influent pollutant concentration)

    = (계획오염부하량) / (계획1일평균오수량)

Reading assignments

- Supplementary reading:

  하수도 시설기준, 2011, 한국상하수도협회, p. 1-60

  Or guideline for sewer systems in your own country