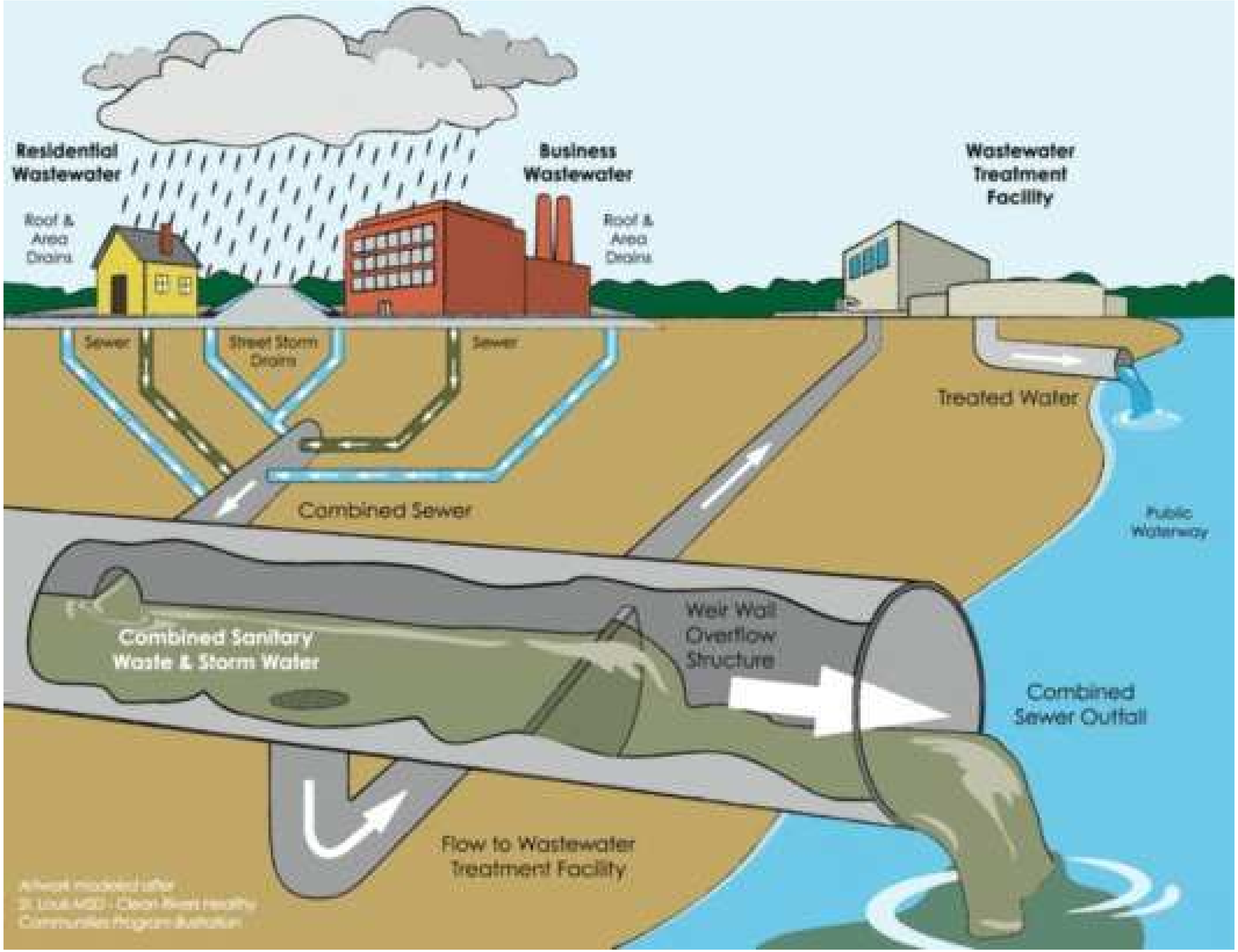
Wastewater management: Collection and masterplan

#1



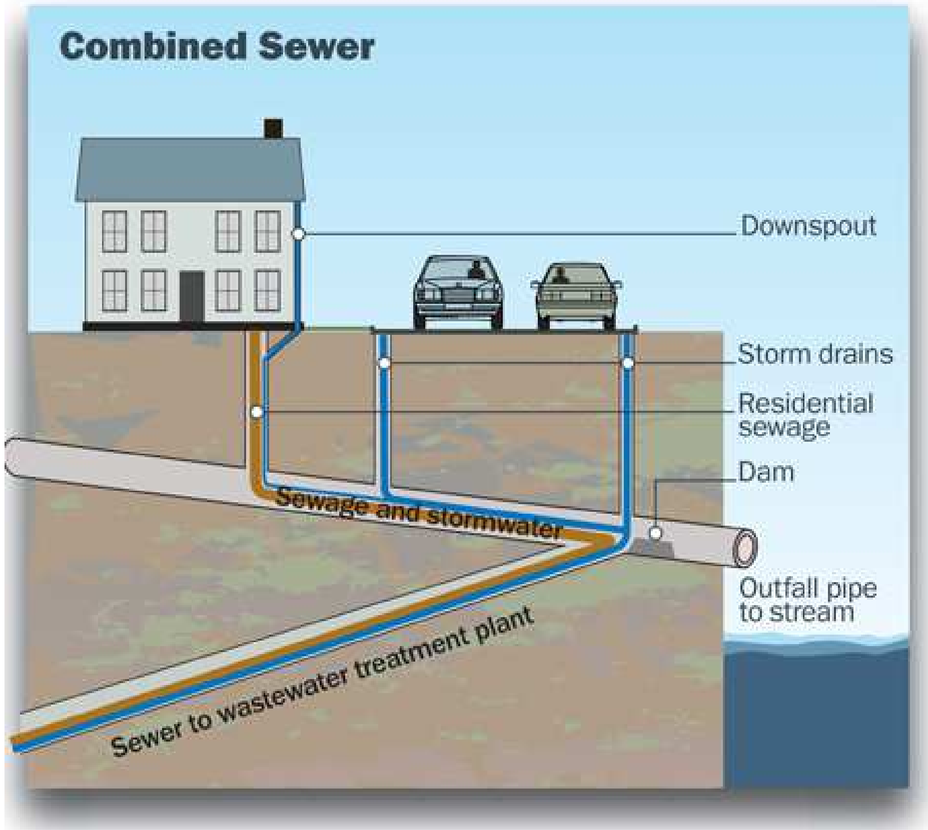
Collection + Treatment (+ Reuse)

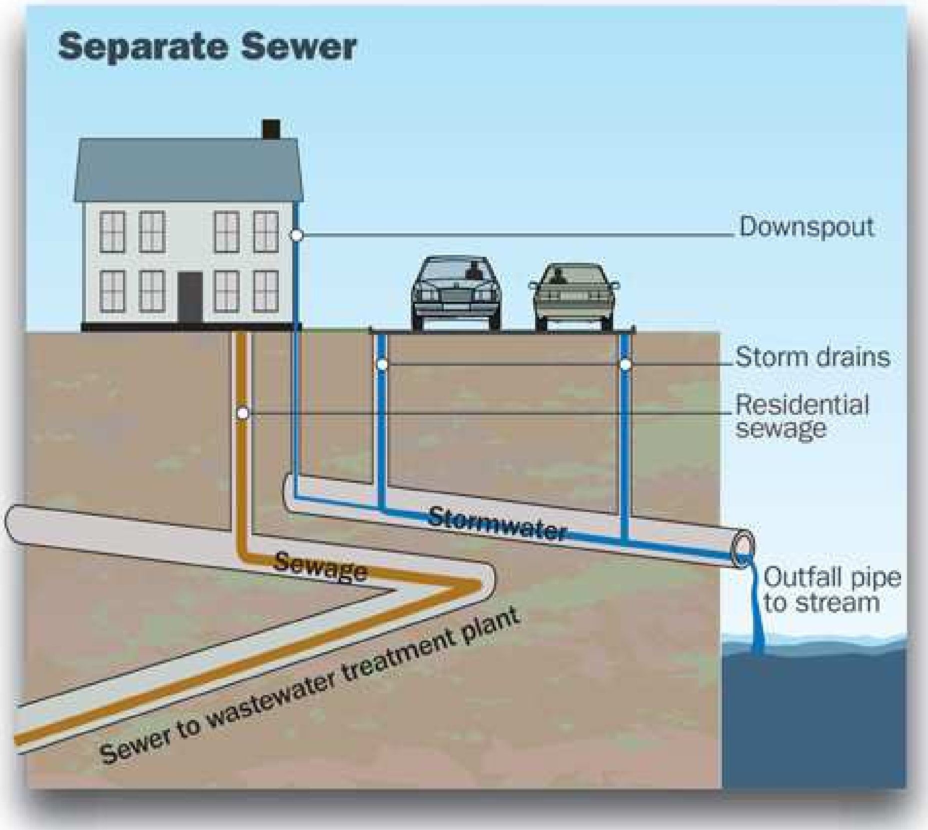
Wastewater collection

- Rely on gravity flow as much as possible, install pumping stations if needed
- Pipe sizing important – should prevent overloading, but cost is also an issue!
- Quite costly and difficult for renovation
- Combined vs. Separate sewer

Combined vs. Separate sewer system

#2





Combined vs. Separate sewer system

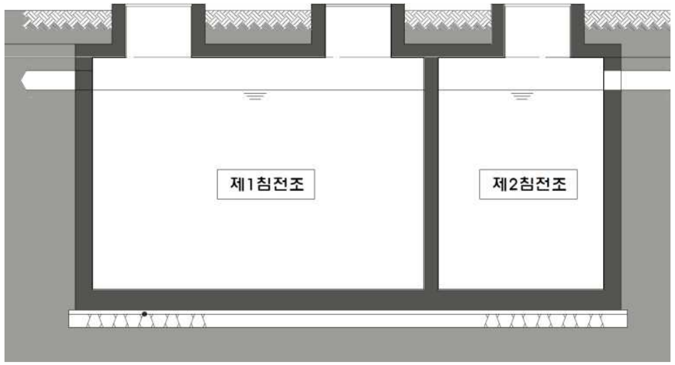
- **Combined sewer**
  - Single network
  - Sewage and stormwater runoff are collected in the same system pipeline
  - During rainfall, discharge the excess amount of water that the wastewater treatment plant (WWTP) cannot handle to water bodies (**C**ombined **S**ewer **O**verflow problem)
- **Separate sewer**
  - Dual network
  - Sewage and stormwater runoff are collected separately
  - Sewage is directed to the WWTP; runoff discharged to water bodies

Septic tank

- **Underground chamber in which domestic wastewater flows for basic treatment**
  - Typically receives toilet flush water only
  - Settling + anaerobic (septic) degradation by microorganisms
  - The liquid fraction is discharged into the sewer pipeline
  - The solid fraction settled at the bottom is pumped and transported by trucks
  - May needed when combined sewer is installed and/or sufficient gravity-driven flow velocity cannot be obtained in the sewer pipeline

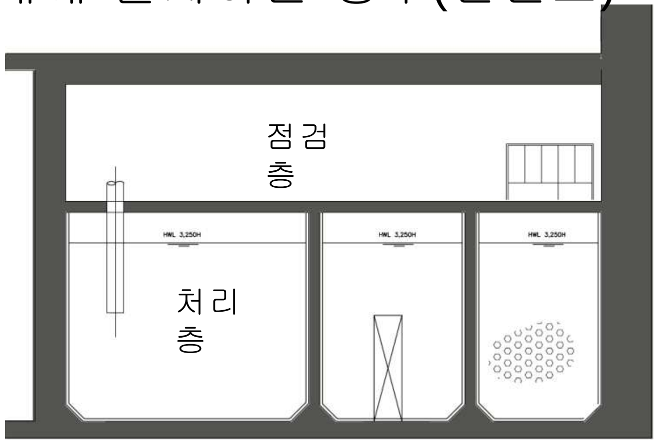
#3

실외에 설치하는 경우(단면도)



점검구를 지상에 설치

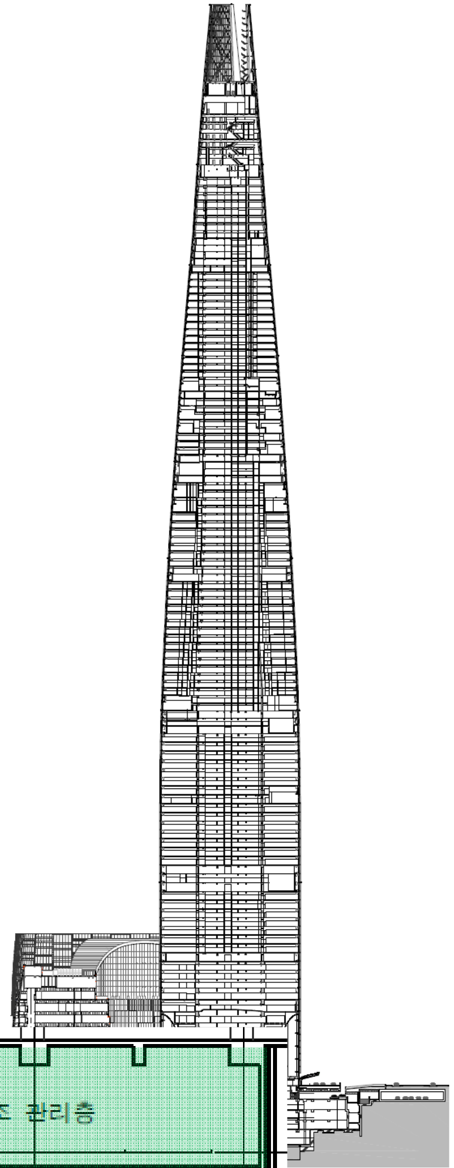
실내에 설치하는 경우(단면도)

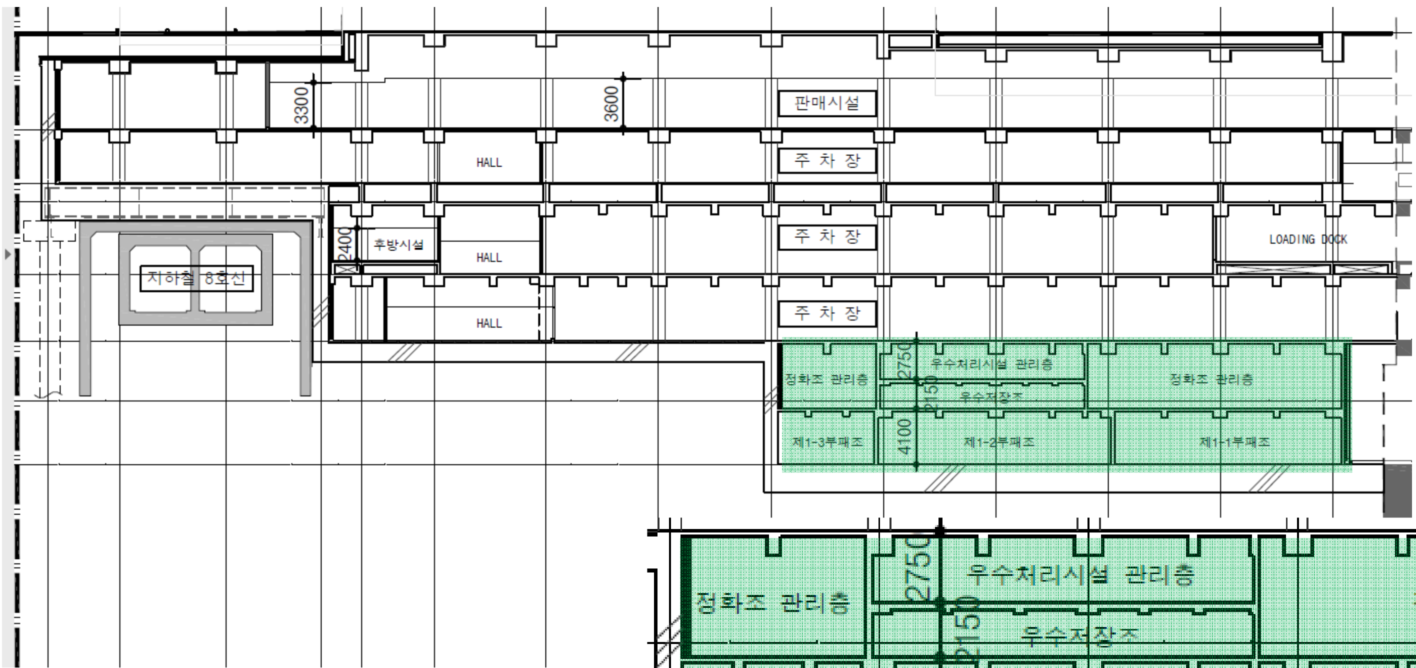


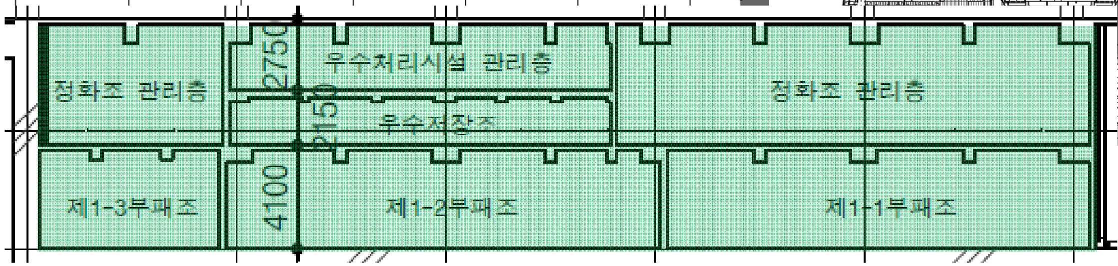
별도의 점검 층을 설치하여 냄새확산을 막는 구조

Courtesy: Kyuhong Park, Chungang Univ.

- Septic tank at a 123-story building
- Located on B6 floor
- ~10,000 m^3/d capacity
  (serving 50,000 people everyday)
- Separated into three chambers (occupies ~3600 m^2 in total)
- Toilet flush water introduced by gravity flow
- Liquid fraction is pumped into public sewer pipeline at the ground level







Courtesy: Kyuhong Park, Chungang Univ.

Treatment facilities

- **Domestic wastewater treatment**
  - Domestic wastewater (sewage)
  - May also receive night soil, septic tank sewage & pre-treated industrial wastewater
- **Industrial wastewater (pre-)treatment**
  - Pre-treatment: when industrial wastewater is released to the sewer system, pre-treatment may be needed
    - To reduce the loading of routine pollutants (e.g., BOD, nutrients) to the domestic wastewater treatment plant
    - To reduce the concentrations of toxic compounds – may affect the biological treatment processes, may not be sufficiently reduced by routine wastewater treatment processes
- **CSO treatment**
- **Stormwater treatment**

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**

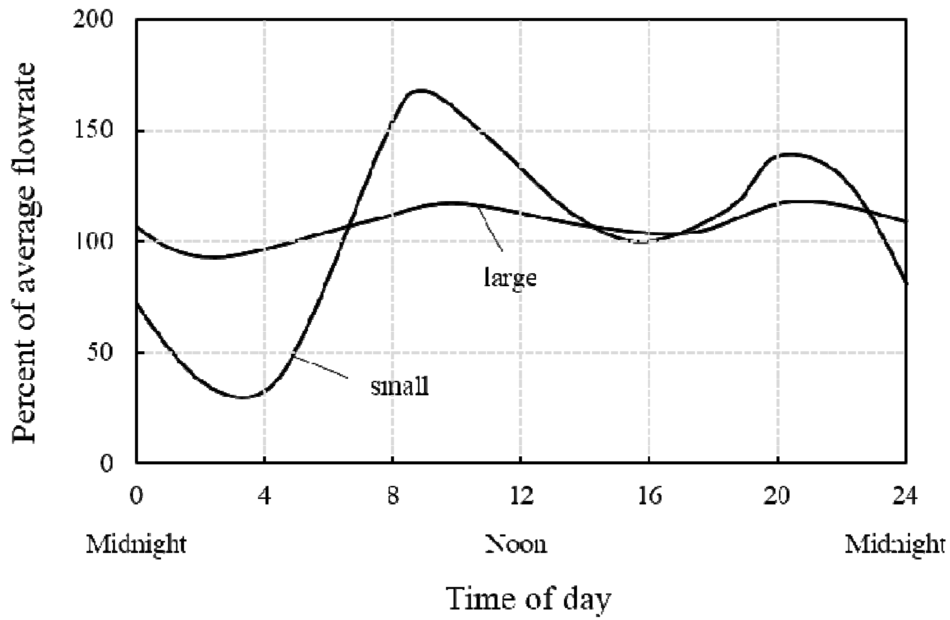
  For relatively small collection systems:

  – 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*



#4

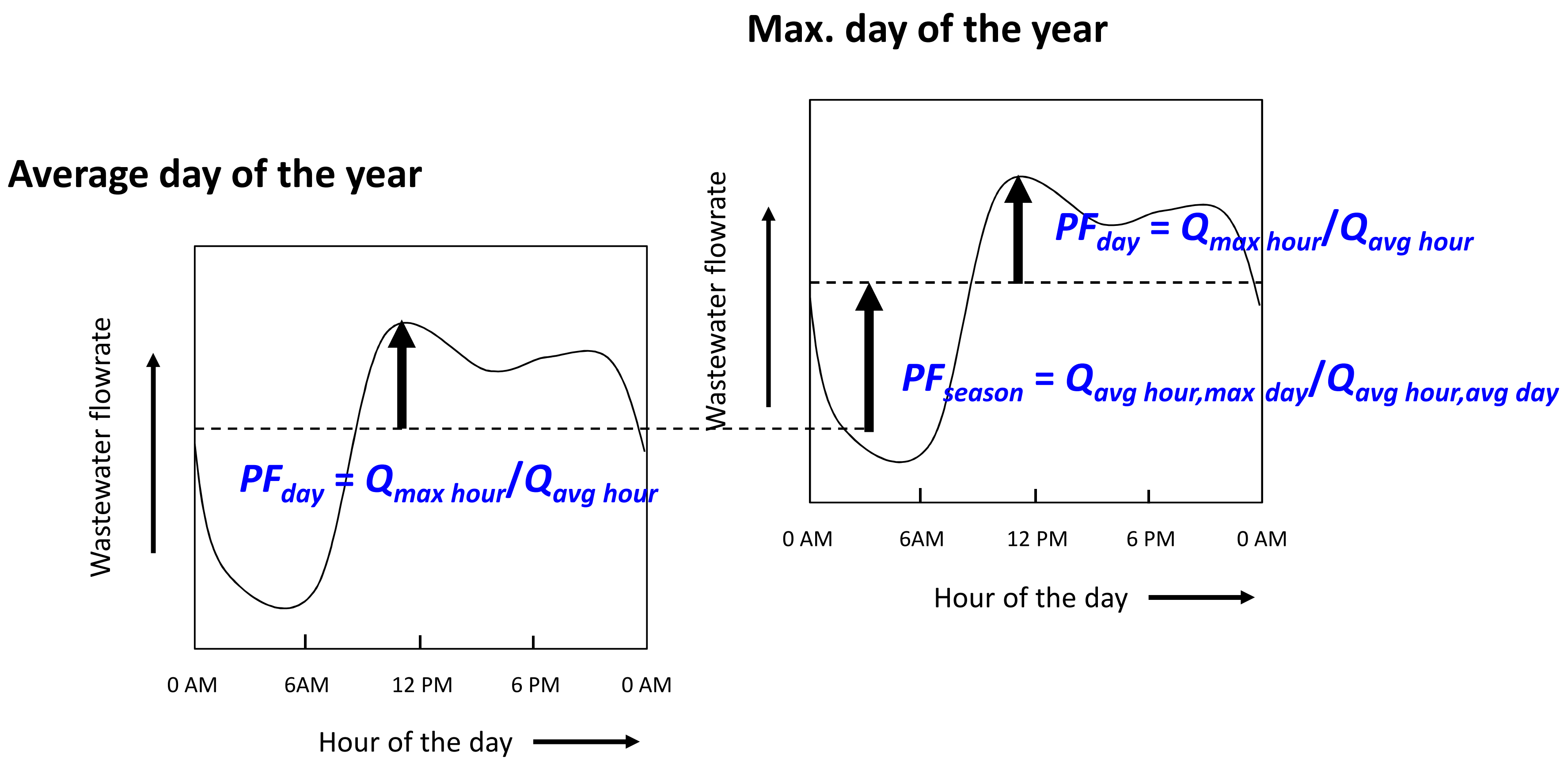
Wastewater flowrate variations

- **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

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

Wastewater flowrate variations



Estimating mass loading and concentration

- 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.**

Per capita waste discharge

- 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

Per capita waste discharge

[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

[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

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

$$BOD = \frac{50\ g/capita/d}{60\ L/capita/d} \times 10^3\ mg/g = 833\ mg/L$$

$$TSS = \frac{62\ g/capita/d}{60\ L/capita/d} \times 10^3\ mg/g = 1033\ mg/L$$

$$NH_3 - N = \frac{4\ g/capita/d}{60\ L/capita/d} \times 10^3\ mg/g = 66.7\ mg/L$$

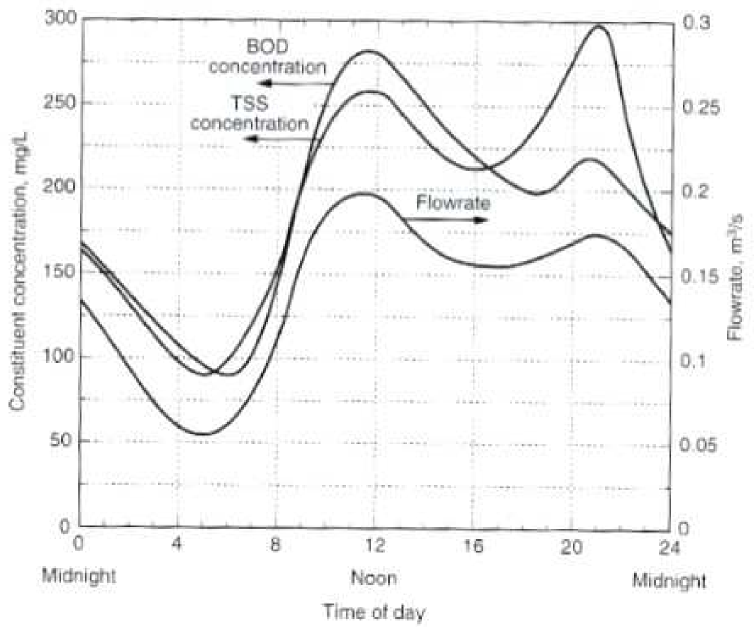
Note the difference between the U.S. value (BOD 199-399 mg/L; TSS 195-391 mg/L; NH_3-N 20-40 mg/L) and the calculated Gaza Strip value..

Per capita waste discharge cannot be substantially reduced under water-shortage conditions, while per capita water usage can be quite smaller.

Therefore, waste concentration is generally higher at water-shortage conditions.

Variations in constituent concentrations

- **Daily variations in constituent concentrations**



#5

- **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

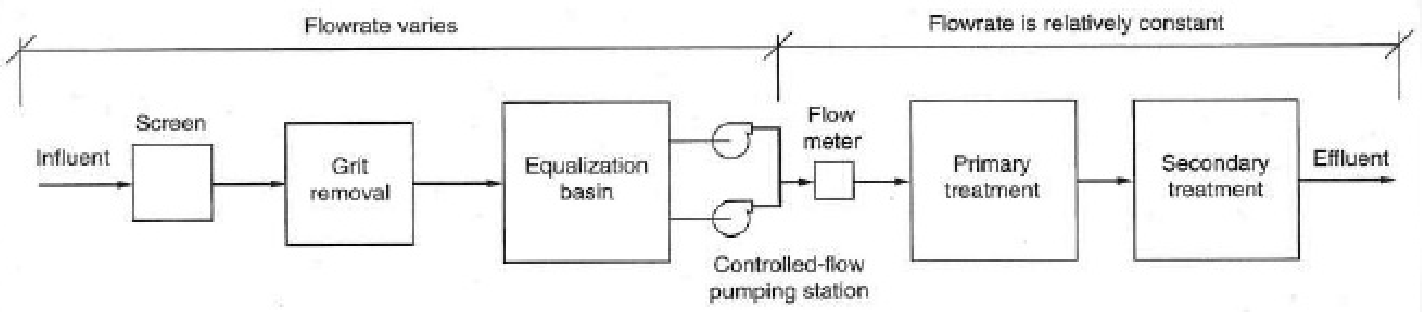
- Objective: dampen flowrate variations to
  1. i) overcome the operational problems caused by flowrate variations
  2. ii) improve the performance of the downstream processes
  3. iii) reduce the size and cost of downstream treatment facilities

Flow equalization

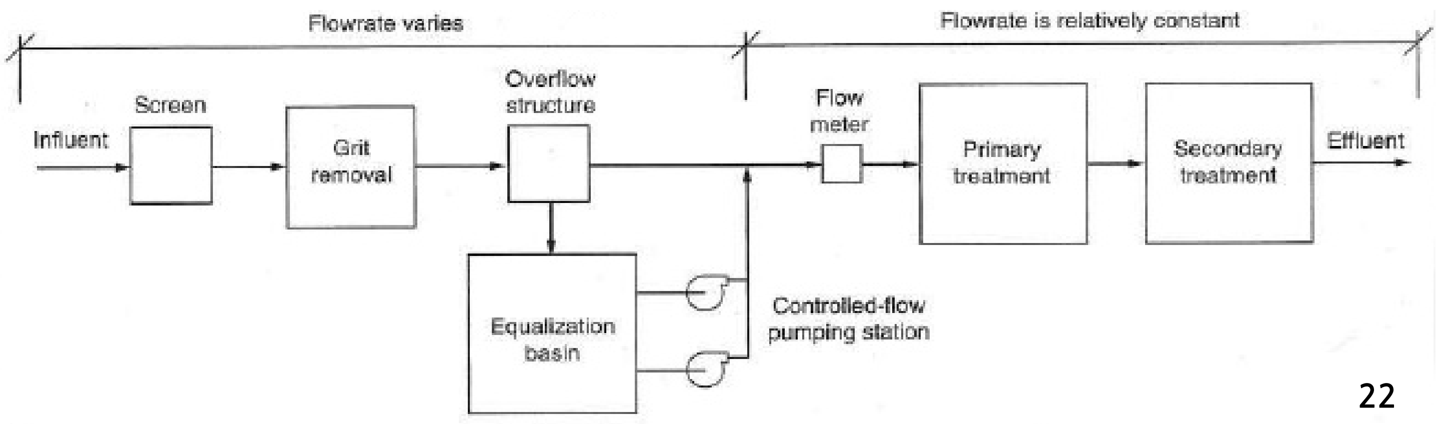
- **Method of application: in-line or off-line**
  - In-line: can achieve dampening of constituent concentration in addition to the dampening of flowrate
  - Off-line: pumping requirements are minimized

#6

[In-line]



[Off-line]



Flow equalization

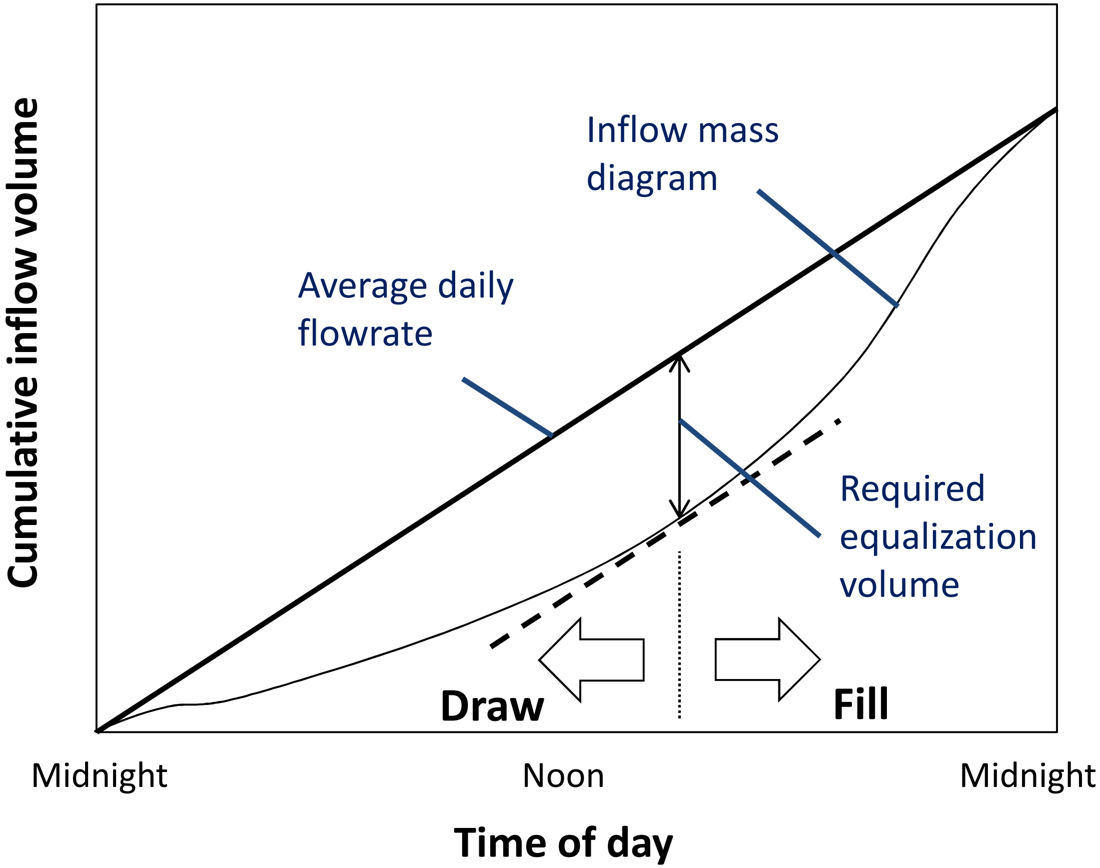
- **Benefits**
  - Biological treatment is enhanced because shock loadings are eliminated or minimized, inhibiting substances can be diluted, and pH can be stabilized
  - The effluent quality and thickening performance of secondary sedimentation tanks is improved through improved consistency in solids 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

Masterplan for wastewater infrastructure

- **하수도 시설기준**(2019 개정) #7
- **하수도계획의 주요내용**

항목	주요내용
기본사항	- 계획목표년도 - 계획구역 - 배제방식: 분류식/합류식 - 분뇨처리와 하수도: 수세분뇨 직투입이 원칙 - 하수도시설의 배치, 구조 및 기능: 자연조건, 환경영향, 사회변화, 안전(침수, 함몰 등), 유지관리 등 고려 - 법령상의 규제: 관련법과의 정합성
조사	- 자연적 조건: 지형, 하천/호소/해역, 기상현황 등 - 관련계획: 국토계획, 환경계획, 국가하수도계획, 도시계획, 하천계획, 오염총량관리계획, 재해대책계획 등 - 오염부하량 - 기존시설 - 하수의 자원화 및 하수시설의 다목적 이용

Masterplan for wastewater infrastructure

항목	주요내용	
우수배제 계획	- 계획우수량 - 우수관로계획 - 빗물펌프장계획	- 우수유출량 저감계획 - 하수저류시설계획
오수배제 계획	- 계획오수량 - 오수관로계획 - 오수펌프장계획	- 불명수(I/I) 유입량 저감계획 - 오수이송계획 - 악취저감계획
하수처리 계획 및 재이용계획	- 계획인구 - 계획오수량 - 계획오염부하량 및 계획유입수질	- 처리방법 - 처리장계획 - 하수처리수 재이용 기본계획 - 하수처리수 재이용 시설계획
⋮	⋮	

이외 항목: 슬러지 처리·이용계획, 분뇨처리계획, 합류식하수도 강우시 방류부하량 저감계획, 시설계획, 설계기준, 유역별 통합운영관리계획

Design lifetime & drainage area

- **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

Design population

- **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

Design flowrate - 1

- **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
    - 불명수량(I/I): 1인1일최대오수량의 10~20%로 가정하거나, 관거 연장/배수면적 등을 고려한 추정치를 사용

Design flowrate - 2

– **계획1일평균오수량 (design average daily sewage flowrate)**
  - 펌프장 운용 및 하수처리에 사용되는 첨가제 비용 등의 계산에 필요
  - 하수처리장 유입수질의 예측에 필요
  - 계획**1**일최대오수량의 **70~80%**로 산정 **(**$1/PF_{season}=0.7\sim0.8$**)**

– **계획시간최대오수량 (design maximum hourly sewage flowrate)**
  - 하수관거 및 펌프장 용량 결정의 기본값
  - 계획**1**일최대오수량의 시간당 값의 **1.3~1.8**배로 산정**(**$PF_{day}=1.3\sim1.8$**)**
  - 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

Design flowrate - 3

- **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

Design flowrate - 4

– **계획하수량(design flowrate)의 결정**

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

Design pollutant mass loading & conc.

- **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)

Estimation of constituent concentrations

Q: Following information is collected for a wastewater drainage region. Determine the maximum hourly sewage flowrate (in m3/d), BOD mass loading (in kg/d), and BOD concentration (in mg/L) for the drainage region. Consider wastewater from residential sources only, in other words, neglect wastewater from any other sources, infiltration/inflow, and stormwater.

Population = 250,000

Per capita BOD discharge = 85 g/capita/d

Per capita wastewater discharge = 250 L/capita/d

$PF_{season} = 1.4$; $PF_{day} = 1.6$

Estimation of constituent concentrations

$$Average\ daily\ sewage\ flowrate = 250{,}000\ capita\ \times 250\ L/capita/d \times 10^{-3}\ m^3/L$$

$$= 6.25 \times 10^4\ m^3/d$$

$$Maximum\ hourly\ sewage\ flowrate$$

$$= Average\ daily\ sewage\ flowrate \times PF_{season} \times PF_{day}$$

$$= 6.25 \times 10^4\ m^3/d \times 1.4 \times 1.6$$

$$= 1.4 \times 10^5\ m^3/d$$

$$BOD\ mass\ loading = 250{,}000\ capita\ \times 85\ g/capita/d \times 10^{-3}\ kg/g$$

$$= 2.13 \times 10^4\ kg/d$$

$$BOD\ concentration = BOD\ mass\ loading/Average\ daily\ sewage\ flowrate$$

$$= (2.13 \times 10^4\ kg/d)/(6.25 \times 10^4\ m^3/d\ )$$

$$= 0.34\ kg/m^3 = 340\ mg/L$$

References

#1) https://scienceaid.net/Surface_Runoff

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#3) https://en.wikipedia.org/wiki/Septic_tank

#4) Metcalf & Eddy, Aecom (2014) Wastewater Engineering: Treatment and Resource Recovery, 5th ed. McGraw-Hill, p. 197

#5) Metcalf & Eddy, Aecom (2014) Wastewater Engineering: Treatment and Resource Recovery, 5th ed. McGraw-Hill, p. 222

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#7) 환경부 (2019) 하수도 설계기준, KDS 61 00 00 : 2019