Wastewater Sources, Flows and Contaminants into Municipal Sewers Served by Publically Owned Treatment Works (POTW)

1. Domestic (household wastes): toilet, shower, cooking, washing and laundry
2. Commercial/service: schools, hospitals, restaurants, offices, hotels, small businesses
3. Industrial: processing wastewater, cooling water
4. Non-point sources:
    a. Infiltration from groundwater into sewers
    b. Inflow from stormwater surcharge into sewer manholes
    c. Combined storm/sewer overflows, older sewer systems where storm sewers discharge into sanitary sewers (Chicago, San Francisco, etc.)

Typical wastewater flowrates in US (from Metcalf and Eddy, 2003)

Source	gpcd except as noted	lpcd except as noted
Domestic	45-75	120-280
Commercial laundry	450 g/unit/d	1700 l/unit/d
Hospital	175-400 g/bed/d	660-1500 l/bed/d
School	25 g/student/d	100 l/student/d

Breakout of residential indoor water use in US with and without water conservation practices and devices*

	Flow (L/capita-day)	
Use	Without conservation	With conservation
Bathing	5	5
Showers	50	42
Dishwashing	4	4
Clothes washing	64	45
Faucets	43	42
Toilets	73	35
Leaks	36	18
Other domestic uses	6	6
Total	281	197

*Faucet aerators, flow-limited showerheads, low-flush toilets, pressure reducing valve, pressurized shower, retrofit kits for bathroom (toilet dam, leak detector, shower flow restrictor), vacuum toilet, water efficient dishwasher, water-efficient clothes washer.

Impact of water-saving toilets, showers, washing machines: reduce domestic flowrates from 281 gpcd to 197 gpcd.

International Comparison

Region	lpcd
World average	63
US	365
China	80
Sub-Saharan Africa	25
Algeria/Morocco	38
Latin America	130

Industrial wastewater generation: highly variable depending on industry. Estimating based on industrial area 7.5 to 28 m^3/ha-day for non-water using industry. For water using industries (food and beverage processing, manufacturing) without internal recycling, assume that 85-95% of water use will become wastewater. Sanitary wastewater from workers estimated from 30 – 95 L/capita-day. Pretreatment onsite (including flow equalization) can reduce impact of peak flows, high organic or toxics loading to POTW.

Infiltration/Inflow can have a significant impact on wastewater flow

Flows into collection systems from extraneous sources:

1. Infiltration. Inflows from service connections, cracks and joints in sewer pipes, or manhole walls. Wide range: 0.2 – 28 m^3/ha-day depending on lot size, sewer pipe age and composition. During a storm event, infiltration and leakage can reach 500 m^3/ha-day.
2. Steady inflow. Water from foundation, spring, or swamp drains, cooling water, generally constant and measured.
3. Direct inflow. Stormwater runoff in combined sewers, roof and yard drains, cross connections from storm drains, or through manhole covers.
4. Delayed inflow. Retarded stormwater discharge due to sump pumps, retention ponds, etc.
5. Total inflow. Sum of direct inflow at any point plus upstream flow from overflows and bypasses.

Wastewater Constituents

Important constituents:

Particulate matter characterization

a. Suspended solids size range: 0.01 (colloidal) to 100 μm Reference particles: viruses (0.01 – 0.05); bacteria (0.5 – 1); algae, organic debris or bacterial flocs: 5 – 100. Suspended solids often defined by filtration measurement (particle diameter > 0.45 μm.
b. Organic composition: percent volatile (organic) versus fixed.

Organic matter characterization

a. Biodegradability (direct assay): biochemical oxygen demand (BOD)
b. Aggregate organic content (chemical assay)
    i. Chemical oxygen demand (COD)
    ii. Total organic carbon (TOC)
    iii. Aromaticity (UV 254)
    iv. Volatile fatty acids
    v. Oil and grease : solvent extractable organic matter
    vi. Surfactants measured as reactivity with reagents: methylene blue active substances (MBAS) or cobalt thiocyanate active substances (CTAS)
c. Individual compounds
    i. 129 Priority pollutants (VOC's and SOC's as well as heavy metals, radionuclides)
    ii. Disinfection by-products: trihalomethanes, haloacetic acids, bromated, N-nitrosodimethylamine (NDMA)
    iii. Pesticides
    iv. Emerging organic contaminants: pharmaceuticals (anti-inflammatory's, antibiotics, synthetic hormones, painkillers, steroids, etc.), personal care products and plasticizers (detergents, nonylphenol, bisphenol A)

Nutrients.

a. Nitrogen
    i. Particulate: organic nitrogen (cells, organic debris)
    ii. Soluble species
        1. Soluble organic nitrogen (urea, cell compounds)
        2. Ammonium (NH_4^+)

        a. Total Kjeldahl Nitrogen (TKN) where TKN = ON + NH_4-N
    3. Nitrate (NO_3^-)
    4. Nitrite (NO_2^-)
    5. Nitrous oxide (N_2O) as greenhouse gas
- b. Phosphorus
    - i. Particulate (cells, and cell storage products)
    - ii. Soluble: orthophosphate (PO_4^{3-})

Other chemical characteristics

- a. pH
    - i. $5.5 < pH < 9$ for discharge and general microbial growth
    - ii. $pH > 6.5$ for nitrification
    - iii. $pH > 7.2$ for methane generation
- c. alkalinity: $HCO_3^- + CO_3^{2-} + OH^- - H^+$ pH buffering capacity may be added or consumed during biological treatment
- d. salinity (TDS, electrical conductivity, SAR, etc) rarely affects treatment in typical wastewater, may affect reuse

Pathogenic microorganisms

- a. Indicators: total coliform, fecal coliform, Salmonella, *Clostridium perfringens*, Enterovirus
- b. Specific organisms: *Giardia lamblia*, *Cryptosporidium parvum*

Toxicity, measured as potential for inhibition of bacteria and/or accumulation in biosolids

Constituents	terminology	definition
Total solids	TS	all non water constituents
Total volatile solids	TVS	~all soluble and particulate organic matter, oxygen demanding
Total fixed solids	TFS=TS=TVS	all soluble and particulate inorganic matter
Total suspended solids	TSS	all particulate matter (typically > 0.45 μm)
Volatile suspended solids	VSS	~particulate organic matter, oxygen demanding
Fixed suspended solids	FSS=TSS-VSS	particulate inorganic matter
Total dissolved solids	TDS = TS-TSS	all soluble constituents (typically < 0.45 μm)
Volatile dissolved solids	VDS	~ soluble organic matter, oxygen demanding
Fixed dissolved solids	FDS	soluble inorganic matter
Settleable Solids		solids that settle under gravity
Turbidity	NTU	approximately colloidal matter (non-settleable solids)
Color	brown, gray, black	measure of sewage age, redox state
Odor	TON	threshold odor number for odor control measures
Conductivity	EC	Measure of dissolved ions (salinity). TDS ~ 0.6*EC
Ammonia	NH_3/NH_4^+	nutrients, oxygen demanding
Total organic nitrogen	TON	fixed nitrogen, soluble or particulate, nutrient, oxygen demanding
Total Kjeldahl nitrogen	TKN = ON + NH_4-N	nutrient, oxygen demanding
Nitrate	NO_3^-	nutrient, oxidation product of NH_4,primary DW contaminant
Nitrite	NO_2^-	nutrient, intermediate oxidation product of NH_4
Total inorganic nitrogen	TIN	NH_4–N+NO_3–N+NO_2–N
Inorganic phosphorus	Inorg P ~ PO_4^{3-} and protonated species	orthophosphate
Organic phosphorus	Org P	biologically bound P
Total phosphorus	TP	nutrient
pH	-log[H^+]	measure of acidity or basicity, biological tolerance range
alkalinity	~ Σcarbonate species as mg/l $CaCO_3$	measure of buffering capacity
Chloride	Cl^-	agricultural and aquatic life effects
Sulfate	SO_4^{2-}	potential for odor formation, secondary DW contaminant
Metals	As, Cd, Cr, Co, Cu, Pb, Hg,	Toxic to biota, concern for reuse, irrigation, and biosolids

	Mo, Ni, Se, Zn	quality
Gases	O_2, CO_2, NH_3, H_2S, CH_4	indicators of redox conditions, treatment levels
5-day biochemical oxygen demand	BOD_5 (mg/L O_2)	oxygen required to stabilize readily biodegradable organic matter
Ultimate biochemical oxygen demand	BOD_u (mg/L O_2)	oxygen required to stabilize all biodegradable organic constituents
Nitrogenous oxygen demand	NOD (mg/L O_2)	oxygen required to oxidize ammonia and organic nitrogen to nitrate
Chemical oxygen demand	COD (mg/L O_2)	approximately all reduced carbonaceous compounds (oxidized by dichromate ion)
Total organic carbon	TOC	all organic carbon
Volatile Fatty Acids	VFA	R-COOH compounds produced by fermentation
Lipids, wax, oil, grease	Oil and grease	Solvent extractable compounds
Detergents	MBAS or CTAS	Surfactant properties, low biodegradability
Indicator bacteria: coliform species: total coliform, fecal coliform	MPN/100 ml	measure of disease-causing potential and requirement for disinfection
Other specific microorganisms: *Salmonella*, *Giardia lamblia* cysts, *Cryptosporidium parvum* oocysts, Enteroviruses, helminths, amoeba	total counts/100 ml	additional information for treated wastewater quality for reuse, biosolids quality for land application
Whole effluent toxicity	WET	acute (TU_a) and chronic (TU_c) toxicity units using bioassay (fathead minnows

Composition of untreated domestic wastewater (Metcalf and Eddy, 2003)

		Concentration		
Contaminant	Unit	Low strength[1]	Medium strength[2]	High strength[3]
Total solids (TS)	mg/l	390	720	1230
Total Dissolved Solids (TDS)	mg/l	270	500	860
Fixed	mg/l	160	300	520
Volatile	mg/l	110	200	340
Total Suspended Solids	mg/l	120	210	400
Fixed	mg/l	25	50	85
Volatile	mg/l	95	160	315
Settleable solids	ml/l	5	10	20
Biochemical Oxygen Demand (BOD_5)	mg/l	110	190	350
Chemical Oxygen Demand (COD)	mg/l	250	430	800
Total Organic Carbon (TOC)	mg/l	80	140	260
Total Nitrogen (as N)	mg/l	20	40	70
Organic nitrogen (as N)	mg/l	8	15	25
Ammonium (as N)	mg/l	12	25	45
Nitrite (as N)	mg/l	0	0	0
Nitrate (as N)	mg/l	0	0	0
Total Phosphorus (as P)	mg/l	4	7	14
Organic P	mg/l	1	2	4
Inorganic phosphate (as P)	mg/l	3	5	10
Chloride[a]	mg/l	30	50	90
Sulfate[a]	mg/l	20-30-50		
Oil and grease	mg/l	50	90	100
Volatile Organic Compounds (VOCs)	mg/l	<100	100-400	>400
Total coliform bacteria	#/100 ml	10^6-10^8	10^7-10^9	10^7-10^{10}
Fecal coliform bacteria	#/100 ml	10^3-10^5	10^4-10^6	10^5-10^8
Cryptosporidium oocysts	#/100 ml	10^{-1}-10^0	10^{-1}-10^1	10^{-1}-10^2
Giardia lamblia cysts	#/100 ml	10^{-1}-10^1	10^{-1}-10^2	10^{-1}-10^3

[1] Estimate for wastewater flow rate of 750 l/cap-day
[2] Estimate for wastewater flowrate of 460 l/cap-day
[3] Estimate for wastewater flowrate of 240 l/cap-day
[a] Add concentration to background in water supply

Design Considerations for Flow and Organic Mass Loading Rate Variation

Flow rate variability and facility design

Effects: hydraulic capacity: pipe, pump, and tank sizing, weir location, plant hydraulic profile, equalization storage

Factors for estimating:

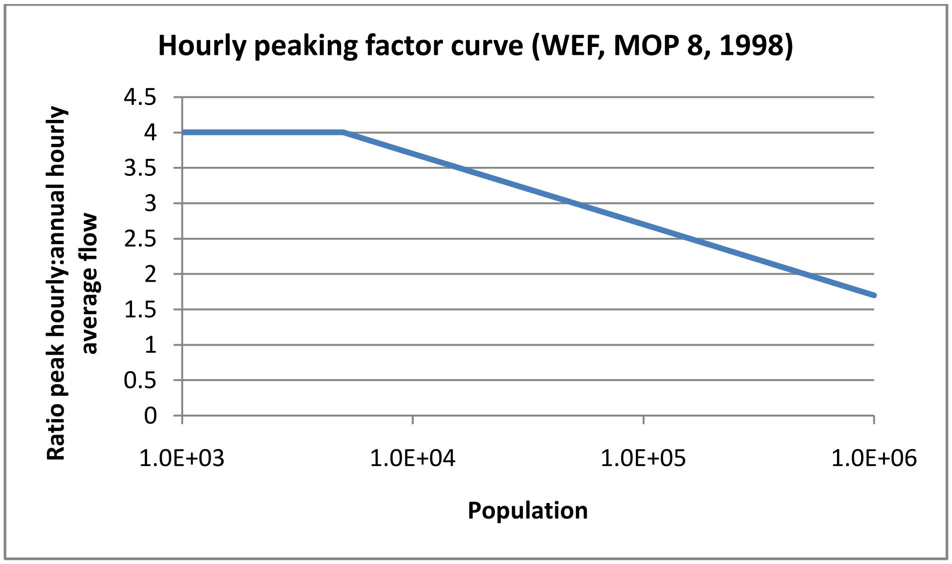
1. Base flow from historic population and flow data
2. Future flows from population growth, industrial development (+) and water conservation (-)
3. Infiltration/inflow, including collection system improvements

<u>Minimum flow rate level and duration</u>. Important for pump operation, requirement for minimum flows through some processes such as disinfection, biofilm wetting. Without data, assumed to be 30 to 70% of average for medium to large systems; may be significantly lower for small systems.

<u>Peak flowrate level and duration.</u>

a. Short duration (hourly) are used to size hydraulic conveyance fixtures, sedimentation tanks, and disinfection processes (chlorine, uv)
b. Longer duration (maximum week, maximum month) are used to size treatment processes that have storage capacity (lagoons, sludge and biosolids treatment) or excess biological capacity (activated sludge)

Peaking factors can be estimated from historic operating data or from design guidelines (e.g., WEF, MOP 8) as below.



Mass Loading Rate Variability and Design. Variability in the mass loading rate of various contaminants may affect biological process performance, sludge generation and treatment, especially when sustained over periods of many days.

$$Mass\ Loading\ Rate\ \left(\frac{kg}{d}\right) = \frac{C * Q}{1000}$$

Where: C = concentration of constituent (g/m^3); Q = volumetric flow rate (m^3/d) for data over a particular duration; 1000 g/kg conversion factor. Commonest constituent is BOD (or COD), also TSS, TKN.

Example: compute average daily BOD mass loading when annual daily average influent BOD_5 concentration = 200 mg/L, Q = 1 m^3/s.

$$Annual\ average\ daily\ BOD_5\ Mass\ Loading = \frac{\left(200\frac{g}{m^3}\right)\left(1\frac{m^3}{s}\right)\left(86400\frac{s}{d}\right)}{\left(1000\ \frac{g}{kg}\right)}$$

$$= 17{,}280\ \frac{kg{-}BOD_5}{d}$$

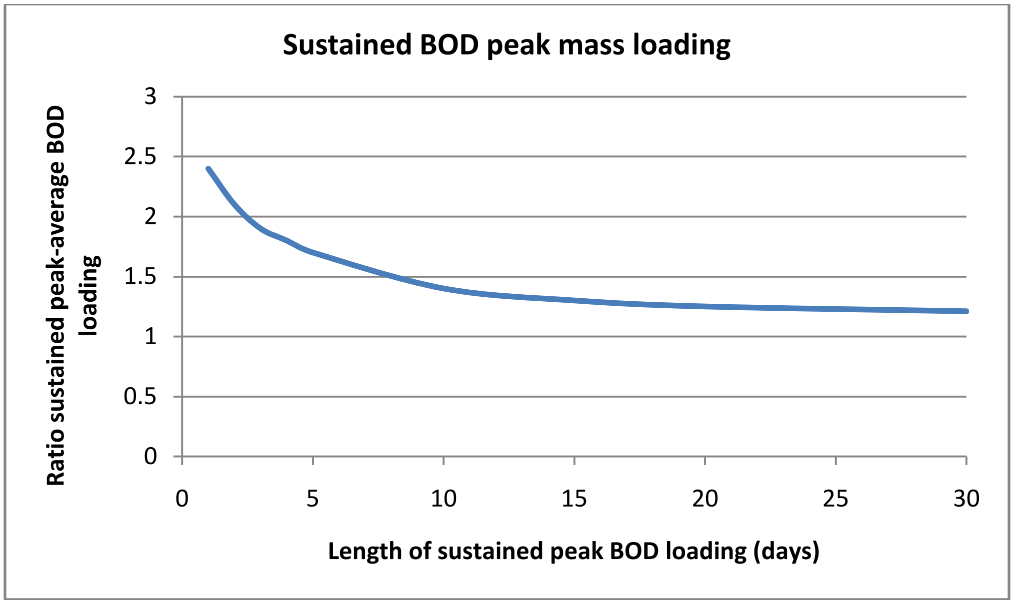
Since both BOD, TSS, and TKN concentrations and flow rate can vary over periods as short as hours, a daily mass loading rate can be calculated from hourly data:

$$Daily\ Mass\ Loading\ Rate\ \left(\frac{kg}{d}\right) = \sum_{i=1}^{24}\frac{(C * Q)_i}{1000}$$

Were $(C*Q)_i$ is the product of hourly concentration and flow rate data pairs.

Plots of ratios of both peak:average and low:average loading rates for BOD, TSS, and TKN sustained over durations ranging from 1 to as many as 30 days can be developed with data sequences for daily mass loading rates for these constituents.

A typical graph of sustained peak BOD mass loading is shown below for a typical wastewater is shown below.



Use of flowrate and mass loading factors in design (Metcalf and Eddy, 2003)

Flow/Loading Rate Factor	Significance for design and operation
Flowrate	
Annual average daily flow	Develop peaking factor ratios, pumping and chemical costs
Minimum hour (annual)	Pump turndown, flowmeter range
Minimum day (annual)	Sizing influent channels to prevent solids deposition, determines effluent recycle for trickling filter wetting
Peak hour	Sizing pumps, conduits, grit chambers, sedimentation basins, disinfection, equalization and by-pass channels
Maximum day	Sizing equalization basins, sludge pumping, chlorine contact tanks
Maximum month	Record keeping, sizing chemical storage facilities, sizing aeration basins
Mass loading	
Minimum month	Biological process turndown
Minimum day	Trickling filter recirculation for wetting
Maximum day	Sizing process units (aeration system)
Maximum month	Sizing sludge storage composting facilities
15-day maximum	Sizing anaerobic and aerobic digesters