APPENDIX 3B:

Details of Operational Phase Air Quality Assessment

CE 62/2000 San Wai STW and Ha Tsuen PS - EIA
Air Quality - Operational Phase Odour Impact Assessment

H_2S build-up in Sewerage System Leading to Ha Tsuen PS and San Wai STW

Assumptions for H_2S Buildup in Sewer

pH	7.00	
BOD_5	250	mg/L
Temperature	30	^oC

H_2S Buildup Equations

A. Equations for Pumping Main

A1. H_2S flux from wall slimes

Pomeroy's equation

$G = M [BOD_5]1.07^{T-20}$

where

G = H_2S flux (g/m^2-h)

T = temp in ^oC

M = coefficient (m/h) 1.00E-03 (for normal pressure mains)

G used in estimation = 0.492 g/m^2-h

A2. H_2S buildup mass balance equation

$Cs = 4G(1+0.4D)t/D$

where

Cs = H_2S concentration build-up (mg/L)

D = diameter (m)

t = retention time (h)

B. Equations for Gravity Sewer

B1. Solving for P and w	**Sample Calculations**		
theta = half of angle subtended at centre (degree)	109.4	degree	(to be calculated)
d = depth of flow (m)	0.200	m	(to be found by varying "design velocity")
D = pipe diameter (m)	0.300	m	
w = surface width of flow (m)	0.283	m	\
P = wetted perimeter (m)	0.573	m	useful in using the Pomeroy and
A = cross-sectional area of flow (m^2)	0.050	m^2	Parjurst equation (calculating a and b)
r = Hydraulic radius (m)	0.087	m	/
Average flow (m^3/s)	0.100	m^3/s	
Design velocity (m/s)	2.0	m/s	

B2. Pomeroy and Parkurst equation

$S_2 = [(aS_1-b)e^{-at}+b)]/a$ (for gravity sewer with known retention time)

where

S_2 = $[H_2S]$ at the end of section (mg/L)

S_1 = $[H_2S]$ at the start of section (mg/L)

$a = [N(SV)^{3/8}]/dm$

$b = (M'[BOD_5]1.07^{T-20})/r$

t = retention time (h)

N = constant used in H_2S build-up equation 0.96 (for partially filled pipes under average condition)

S = total energy head gradient

V = sewage velocity (m/s)

dm = mean hydraulic depth (m) = A/w

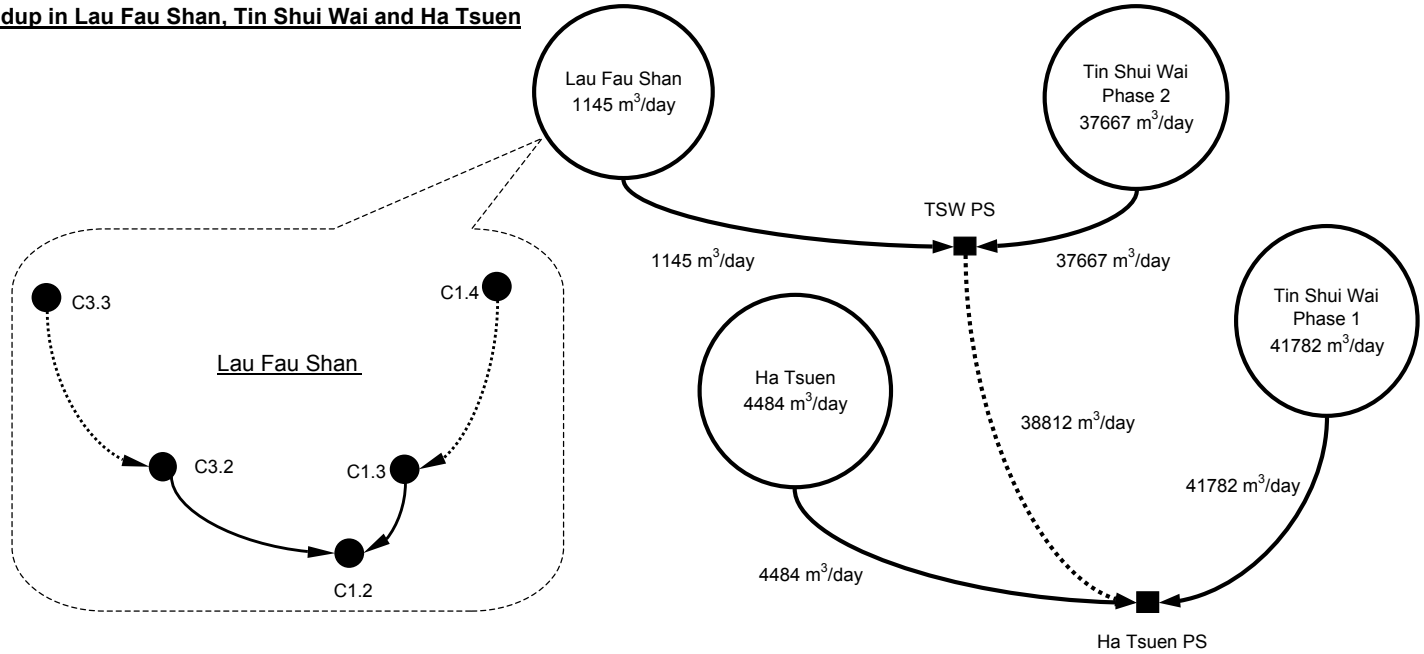
M' = specific H_2S flux (m/h) 0.00032 (for partially filled pipes under average condition)

$[BOD_5]$ = 5-day biochemical oxygen demand (mg/L)

T = temp in ^oC

H_2S build-up in Sewerage System Leading to Ha Tsuen PS and San Wai STW

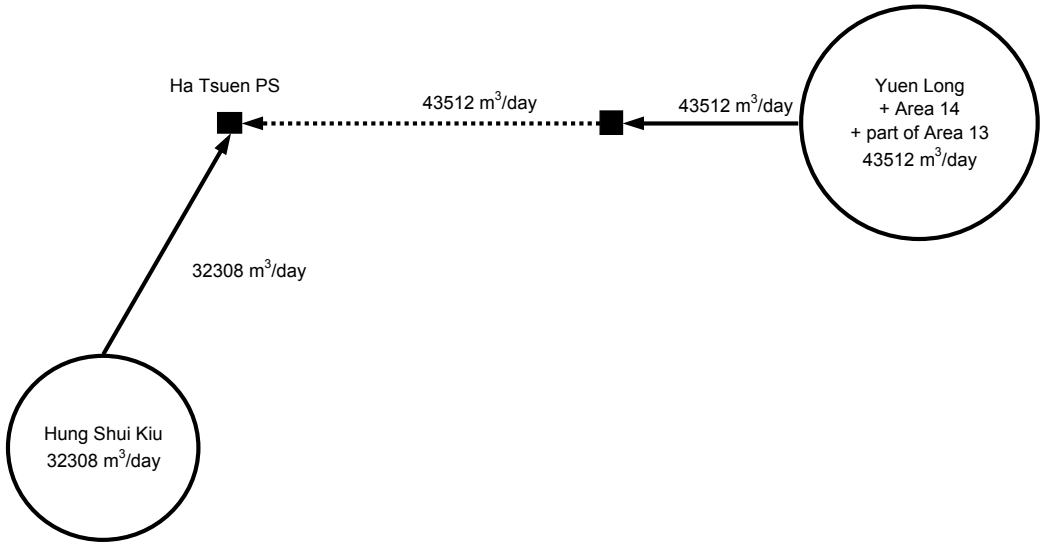
H_2S Buildup in Lau Fau Shan, Tin Shui Wai and Ha Tsuen



Area/Location	Upstream	Point	Sewer	Q (m^3/day)	Retention (h)	$[H_2S]_{init}$ (mg/L)	$[H_2S]_{final}$ (mg/L)	H_2S flow (g/day)
Lau Fau Shan	C3.3	C3.2	Pumping	172	0.16	0	2.219	382
	C3.2	C1.2	Gravity	1055	0.23	0.362	0.968	1022
	C1.4	C1.3	Pumping	91	0.31	0	4.300	391
	C1.3	C1.2	Gravity	91	0.10	4.300	1.450	132
	C1.2	TSW PS	Gravity	1146	0.07	1.007	1.125	1289
Tin Shui Wai Phase 2	TSW II	TSW PS	Gravity	37667	0.14	0	0.139	5250
	TSW PS	HT PS	Pumping	38813	0.07	0.168	1.422	55189
Tin Shui Wai Phase 1	TSW I	HT PS	Gravity	41782	0.29	0	0.371	15517
Ha Tsuen	HT	HT PS	Gravity	4484	0.32	0	0.601	2696

H_2S build-up in Sewerage System Leading to Ha Tsuen PS and San Wai STW

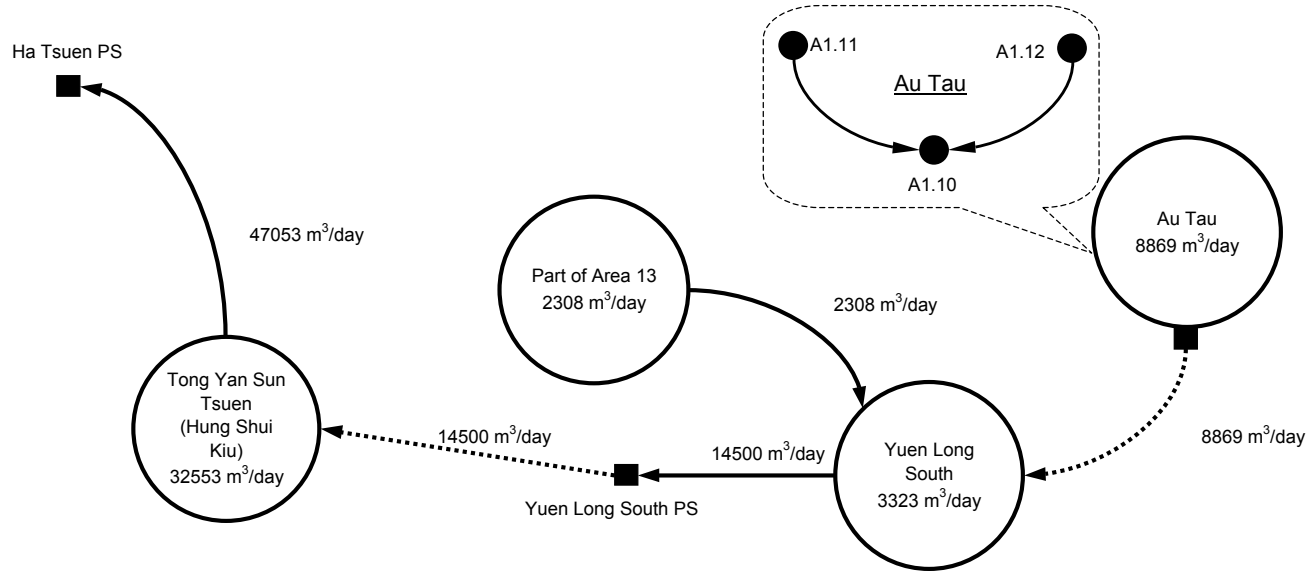
H_2S Buildup in Yuen Long and Hung Shui Kiu



Area/Location	Upstream	Point	Sewer	Q (m^3/day)	Retention (h)	$[H_2S]_{init}$ (mg/L)	$[H_2S]_{final}$ (mg/L)	H_2S flow (g/day)
Yuen Long	Area 13/14	PSS PS	Gravity	17660	0.63	0	0.569	10055
	YL Town	PSS PS	Gravity	25852	0.14	0	0.124	3211
	PSS PS	HT PS	Pumping	43512	0.41	0.305	1.440	62671
Hung Shui Kiu	HSK	HT PS	Gravity	32308	0.34	0	0.276	8906

H_2S build-up in Sewerage System Leading to Ha Tsuen PS and San Wai STW

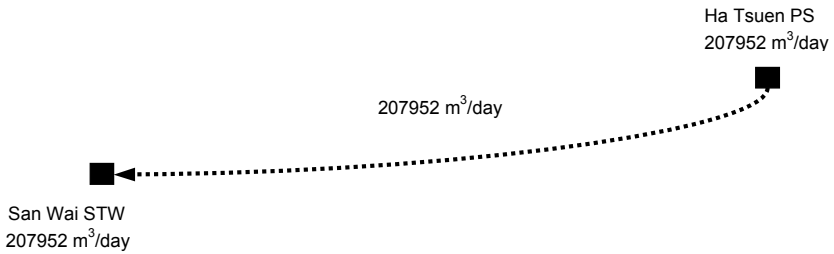
H_2S Buildup in Au Tau, Yuen Long South and Tong Yan Sun Tsuen



Area/Location	Upstream	Point	Sewer	Q (m^3/day)	Retention (h)	$[H_2S]_{init}$ (mg/L)	$[H_2S]_{final}$ (mg/L)	H_2S flow (g/day)
Au Tau	A1.11	A1.10	Gravity	8343	0.20	0	0.308	2566
	A1.12	A1.10	Gravity	526	0.16	0	0.749	394
	AT PS	YL South	Pumping	8869	0.23	0.334	1.438	12754
Yuen Long South	Area 13	YL South	Gravity	2308	0.17	0	0.426	983
	YL South	YLS PS	Gravity	14500	0.57	0.947	1.000	14495
	YLS PS	TYST	Pumping	14500	0.19	1.000	1.679	24345
Tong Yan Sun Tsuen	TYST	HT PS	Gravity	47053	0.36	0.517	0.646	30414

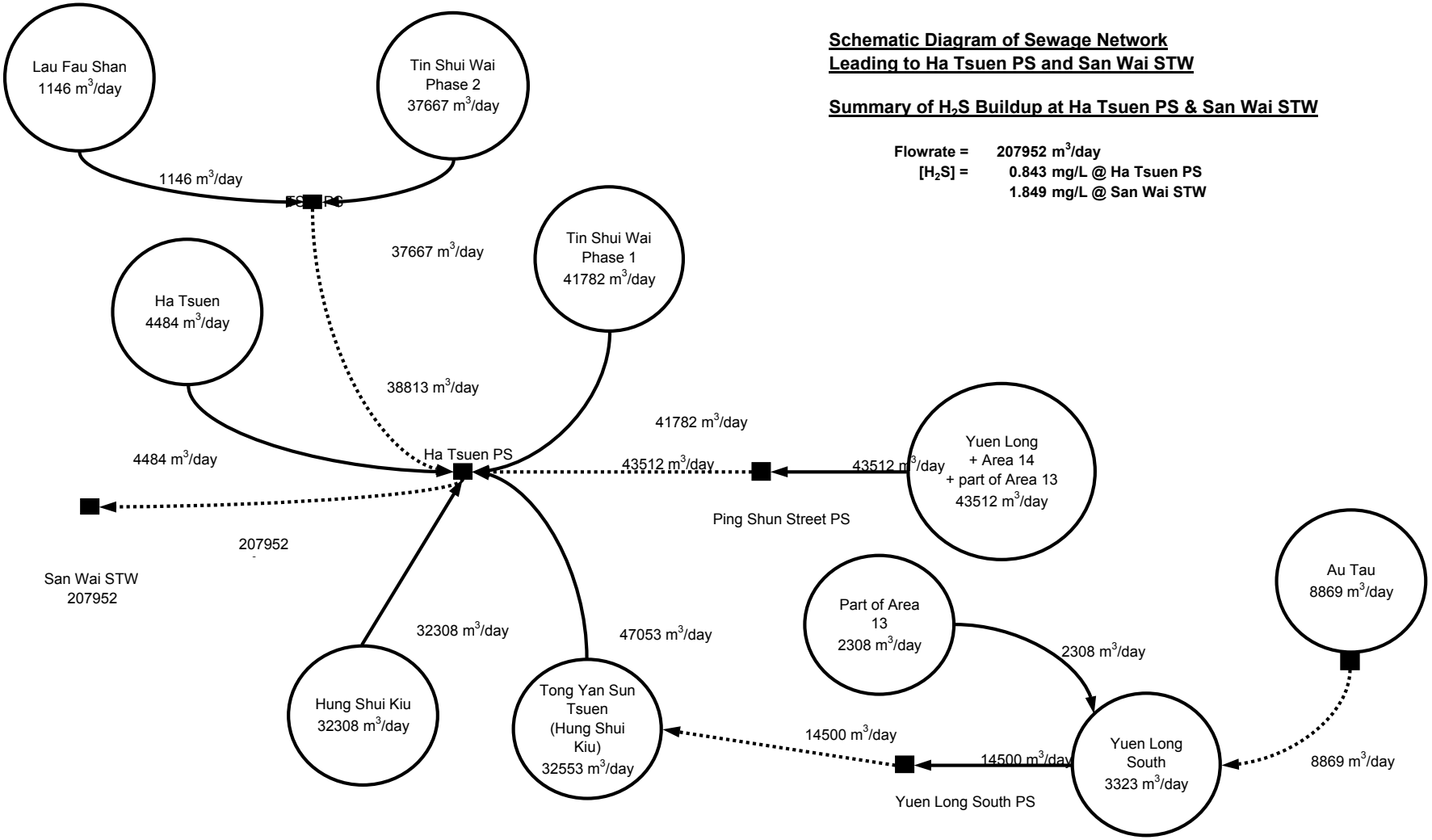
H_2S build-up in Sewerage System Leading to Ha Tsuen PS and San Wai STW

H_2S Buildup from Ha Tsuen PS to San Wai STW



Area/Location	Upstream	Point	Sewer	Q (m^3/day)	Retention (h)	$[H_2S]_{init}$ (mg/L)	$[H_2S]_{final}$ (mg/L)	H_2S flow (g/day)	Reference Sheet
Ha Tsuen PS	TSW PS	HT PS	Pumping	38813	-	-	1.422	55189	LFS+TSW+HT
	HT	HT PS	Gravity	4484	-	-	0.601	2696	
	TSW I	HT PS	Gravity	41782	-	-	0.371	15517	
	PSS PS	HT PS	Pumping	43512	-	-	1.440	62671	TL+HSK
	HSK	HT PS	Gravity	32308	-	-	0.276	8906	
	TYST	HT PS	Gravity	47053	-	-	0.646	30414	AT+YLS+TYST
Ha Tsuen PS	As above	HT PS	-	207952	-	-	0.843	175393	This sheet
San Wai STW	Ha Tsuen PS	SW STW	Pumping	207952	0.41	0.843	1.849	384533	

H_2S build-up in Sewerage System Leading to Ha Tsuen PS and San Wai STW



Schematic Diagram of Sewage Network Leading to Ha Tsuen PS and San Wai STW

Summary of H_2S Buildup at Ha Tsuen PS & San Wai STW

Flowrate = 207952 m^3/day
[H_2S] = 0.843 mg/L @ Ha Tsuen PS
1.849 mg/L @ San Wai STW

CE 62/2000 San Wai STW and Ha Tsuen PS - EIA
Air Quality - Operational Phase Odour Impact Assessment

H_2S Emission Estimation in San Wai STW

Basis of Estimation

Sewage Flow Conditions

ADWF	207952	m^3/day
Flow velocity	1.3	m/s
Inlet Pipe Diameter (2 in parallel)	1200	mm
[H_2S]	1.849	mg/L or g/m^3

Assumptions - Raw Sewage and H_2S emission within STW

1. Depth of unit is assumed to be 2m
2. Width of channels 2m except the main channels connecting from inlet chamber and to detritors/rapid mix&floc tanks (4 to 5m wide)
3. Raw Sewage:

pH	7.00	
BOD_5	250	mg/L
Temperature	30	^oC

List of Odour Emitting Inventories

Name	Phase of Treatment	Odour Potential	Calculation Method	Reference
Primary Sedimentation Tank	Primary	Medium	Open Channel	ASCE 1989
Rapid Mix & Flocculation Tank	Primary	Medium	Open Channel	ASCE 1989
Fine Screen	Preliminary	Medium	Open Channel	ASCE 1989
Sludge Holding Tank	Sludge Treatment	High	Assume = Max of Open Channels	-
Sludge Dewatering House	Sludge Treatment	High	Assume = Max of Open Channels	-
Extg. Solid Handling House	Sludge Treatment	High	Assume = Max of Open Channels	-
Detritors	Primary	Medium	Open Channel	ASCE 1989
Inlet Chamber	Primary	High	Open Channel	ASCE 1989

Other Odour Emission Inventories	Odour Potential	Calculation Method	Reference
Channels connection inlet chamber to fine screen	High	Open Channel	ASCE 1989
Channels connection fine screen to detritors	High	Open Channel	ASCE 1989
Channels connection detritors to rapid mix & flocculation tank	High	Open Channel	ASCE 1989

Open channel H_2S release equation

Manning's equation (employed to estimate S based on R, V and n)

$V = R^{2/3}S^{1/2}/n$

R = hydraulic mean radius = X-sectional area/wetted perimeter

n = Manning's equation 0.013 (Default value)

Dissociated equilibria for H_2S in aqueous solution

Fraction of H_2S in molecular form 0.49 (@ 30^oC and pH = 7.00)

H_2S emission rate equation

$phi = 0.69(SV)^{3/8}[H_2S]$

where

phi = H_2S flux (g/m^2-h)

S = total energy head gradient

V = sewage velocity (m/s)

[H_2S] = soluble H_2S in molecular form (mg/L) 0.906 mg/L

H_2S Emission Estimation in San Wai STW

Emission Rate for Units

Open Channels

Unit Operations	Inlet Chamber	Fine Screen	Detritors	Mix & Floc	Sedi. Tanks
Unit Specification					
Number of unit(s)	1	1	5	2	10
Effective Length (m)	7.2	14.92	8	68	68
Effective Width (m)	4.8	6.56	9.6	8	8
Depth (m) of unit	2	2	2	2	2
Surface area (m^2)	34.56	97.82	384.00	1033.60	5331.20
X-sectional area (m^2)	9.6	13.12	19.2	16	16
H2S flux estimation					
Velocity (m/s)	0.3	0.3	0.1	0.1	0.01
R	1.09	1.24	1.41	1.33	1.33
S (from Manning's equation)	1.35E-05	1.14E-05	1.07E-06	1.15E-06	1.15E-08
Soluble [H_2S] in molecular form (mg/L or g/m^3)	0.906	0.906	0.906	0.906	0.906
phi (g/m^2-h)	5.95E-03	5.57E-03	1.52E-03	1.56E-03	1.17E-04
Emission rate in unit area (ug/m^2-s)	1.652	1.548	0.422	0.434	0.033
Emission rate (ug/s)	**57.10**	**151.43**	**162.04**	**448.79**	**173.59**

Sludge Treatment Facilities

Unit Operations	Sldg. Hold.	Sldg. Dewat.	Extg. Hse.
Unit Specification			
Number of unit(s)	3	1	1
Effective Length (m)	11.2	22.4	16
Effective Width (m)	21.6	10.4	14.4
Surface area (m^2)	708.48	232.96	230.40
Emission rate in unit area (ug/m^2-s)	1.652	1.652	1.652
Emission rate (ug/s)	**1170.46**	**384.87**	**380.64**

H_2S Emission Estimation in San Wai STW

Emission Rate for Connection Channels

Inlet Chamber to Fine Screen

Effective Length (m)	7
Effective Width (m)	5
Depth (m)	2
Surface area (m^2)	35
X-sectional area (m^2)	10
H_2S flux estimation	
Velocity (m/s)	0.3
R	1.11
S (from Manning's equation)	1.32E-05
Soluble [H_2S] in molecular form (mg/L or g/m^3)	0.906
phi (g/m^2-h)	5.89E-03
Emission rate in unit area (ug/m^2-s)	1.637
Emission rate (ug/s)	**57.29**

Fine Screen to Detritors

Connection Specification	Stream #1	Stream #2	Stream #3	Stream #4	Stream #5	Stream #6	Stream #7
Effective width (m)	5	2	2	2	4	2	2
Depth (m)	2	2	2	2	2	2	2
Surface area (m^2)	56	4	18	33	65	3	3
X-sectional area (m^2)	10	4	4	4	8	4	4
H_2S flux estimation							
Velocity (m/s)	0.3	0.2	0.2	0.2	0.2	0.2	0.2
R	1.11	0.67	0.67	0.67	1.00	0.67	0.67
S (from Manning's equation)	1.32E-05	1.16E-05	1.16E-05	1.16E-05	6.76E-06	1.16E-05	1.16E-05
Soluble [H_2S] in molecular form (mg/L or g/m^3)	0.906	0.906	0.906	0.906	0.906	0.906	0.906
phi (g/m^2-h)	5.89E-03	4.82E-03	4.82E-03	4.82E-03	3.94E-03	4.82E-03	4.82E-03
Emission rate in unit area (ug/m^2-s)	1.637	1.339	1.339	1.339	1.094	1.339	1.339
Emission rate (ug/s)	**91.67**	**5.36**	**24.11**	**44.20**	**71.08**	**4.02**	**4.02**

Detritors to Mix&Floc Tanks

Connection Specification	Stream #1	Stream #2	Stream #3	Stream #4	Stream #5	Stream #6
Effective width (m)	2	2	2	2	2	5
Depth (m)	2	2	2	2	2	2
Surface area (m^2)	24	24	27	16	17	50
X-sectional area (m^2)	4	4	4	4	4	10
H_2S flux estimation						
Velocity (m/s)	0.2	0.2	0.20	0.2	0.2	0.3
R	0.67	0.67	0.67	0.67	0.67	1.11
S (from Manning's equation)	1.16E-05	1.16E-05	1.16E-05	1.16E-05	1.16E-05	1.32E-05
Soluble [H_2S] in molecular form (mg/L or g/m^3)	0.906	0.906	0.906	0.906	0.906	0.906
phi (g/m^2-h)	4.82E-03	4.82E-03	4.82E-03	4.82E-03	4.82E-03	5.89E-03
Emission rate in unit area (ug/m^2-s)	1.339	1.339	1.339	1.339	1.339	1.637
Emission rate (ug/s)	**32.14**	**32.14**	**36.16**	**21.43**	**22.77**	**81.85**

CE 62/2000 San Wai STW and Ha Tsuen PS - EIA
Air Quality - Operational Phase Odour Impact Assessment

H_2S Emission Estimation in San Wai STW

Summary and Deodourisation Requirement

Sources of H_2S	Emission rate	H_2S flux
Primary Sedimentation Tank	173.59 ug/s	0.033 ug/m^2-s
Rapid Mix & Flocculation Tank	448.79 ug/s	0.434 ug/m^2-s
Fine Screen	151.43 ug/s	1.548 ug/m^2-s
Sludge Holding Tank	1170.46 ug/s	1.652 ug/m^2-s
Sludge Dewatering House	384.87 ug/s	1.652 ug/m^2-s
Extg. Solid Handling House	380.64 ug/s	1.652 ug/m^2-s
Detritors	162.04 ug/s	0.422 ug/m^2-s
Inlet Chamber	57.10 ug/s	1.652 ug/m^2-s
Connections (Inlet Chamber->Fine Screen)	57.29 ug/s	1.637 ug/m^2-s
Connections (Fine Screen->Detritors)	244.44 ug/s	from 1.094 to 1.637 ug/m^2-s
Connections (Detritors->Rapid M/F Tanks)	226.49 ug/s	from 1.339 to 1.637 ug/m^2-s
Total Emission	**3457.12 ug/s**	

Deodourisation Unit Loading		
Total Area	8428.02	m^2
Headspace	0.5	m
Air Change per Hour	6.0	
Required Ventilation Rate	7.02	m^3/s
H_2S emission rate	3457.12	ug/s
$[H_2S]_{in}$	492.23	ug/m^3
$[H_2S]_{in}$	0.3591	ppmv

Deodourisation Unit Emission Requirement		
Emission gas exit velocity	10	m/s
Removal efficiency required	**96%**	
Design exit gas [H_2S]	138.28	ug/s
Exit gas flowrate	7.02	m^3/s
$[H_2S]_{out}$	19.69	ug/m^3
$[H_2S]_{out}$	0.0144	ppmv
Exhaust Air Velocity	10	m/s
Point Source Diameter	0.946	m
Emission Height of DO Unit Exhaust	5	m

CE 62/2000 San Wai STW and Ha Tsuen PS - EIA
Air Quality - Operational Phase Odour Impact Assessment

H_2S Emission Estimation in Ha Tsuen PS

Basis and Estimation

Sewage Flow Conditions

ADWF	207952	m^3/day
[H_2S]	0.843	mg/L or g/m^3

Assumptions - Raw Sewage and H_2S emission within PS

1. Exposed area of wetwell = 280 m^2 per wetwell (as measured from the basemap)
2. Depth of sewage is assumed to be 2m
3. Henry's constant for H_2S @ 30°C and 1 atm = 2.21 mg/L (in aqueous) per mg/L (in atmosphere) [m_{H2S}*H=y_{H2S}*P]
4. Raw Sewage:

pH	7.00	
BOD_5	250	mg/L
Temperature	30	°C

H_2S Estimation in Ha Tsuen PS

Reference
Compilation of Air Pollutant Emission Factors, AP-42, Fifth Edition, Volume I: Stationary Point and Area Sources
Chapter 4: Evaporation Loss Sources, Section 4.3 Waste Water Collection, Treatment And Storage

Dimensions of the Unit

A = Surface area (m^2)	280	m^2
D = Depth of sewage (m)	2	m

Parameters

rho_A = Air density (g/cm^3)	1.18E-03	g/cm^3
rho_W = Water density (g/cm^3)	0.996	g/cm^3
R = Universal gas constant (atm-m^3/gmol-K)	8.21E-05	atm-m^3/gmol-K
T = Temperature of water (K)	303	K
U_{10} = Wind speed at 10 m above the liquid surface (m/s)	2	m/s
mu_A = Air viscosity (g/cm-s)	1.86E-04	g/cm-s
mu_W = Water viscosity (g/cm-s)	7.98E-03	g/cm-s
D_A = Diffusivity of H_2S in air (m/s)	0.181	m/s
D_{ether} = Diffusivity of ether in water (cm^2/s)	9.68E-06	cm^2/s
D_W = Diffusivity of H_2S in water (cm^2/s)	1.83E-05	cm^2/s
H = Henry's law coefficient of constituent (atm-m^3/gmol)	0.0206	atm-m^3/gmol
Q = Sewage flowrate (m^3/s)	207952	m^3/s
C_O = Initial H_2S concentration (mg/L)	0.843	mg/L

Calculations leading to emission rate

$U^* = (0.01)(U_{10})(6.1+0.63(U_{10})^{0.5}$	(*Ibid*, p.4.3-9)	where	U^* = Friction velocity (m/s)	0.0543 m/s
$Sc_L = mu_W/(rho_W x D_W)$	(*Ibid*, p.4.3-9)	where	Sc_L = Liquid side Schmidt number	436.82 (dimensionless)
$F/D = 2(A/pi)^{0.5}/D$	(*Ibid*, p.4.3-9)	where	F/D = Fetch to depth ratio	9.44 (dimensionless)
$k_l = (2.78x10^{-6})(D_W/D_{ether})^{2/3}$	(*Ibid*, p.4.3-9)	where	k_l = Liquid phase mass transfer coefficient (m/s)	4.26E-06 m/s
$Sc_G = mu_A/(rho_A x D_A)$	(*Ibid*, p.4.3-9)	where	Sc_G = Gas side Schmidt number	0.871 (dimensionless)
$d_e = 2(A/pi)^{0.5}$	(*Ibid*, p.4.3-9)	where	d_e = Effective diameter (m)	18.88 m
$k_g = (4.82x10^{-3})(U_{10})^{0.78}(Sc_G)^{-0.67}(d_e)^{-0.11}$	(*Ibid*, p.4.3-9)	where	k_g = Gas phase mass transfer coefficient (m/s)	6.57E-03 m/s
$K_{eq} = H/(RT)$	(*Ibid*, p.4.3-10)	where	K_{eq} = Partition coefficient	0.827 (dimensionless)
$K = k_l K_{eq} k_g/(K_{eq} k_g + k_l)$	(*Ibid*, p.4.3-10)	where	K = Overall mass transfer coefficient (m/s)	4.25E-06 m/s
$C_L = QC_O/(KA+Q)$	(*Ibid*, p.4.3-10)	where	C_L = H_2S concentration in the liquid phase (g/m^3)	0.843 g/m^3
$N = 10^6 K C_L A$	(*Ibid*, p.4.3-10)	where	N = H_2S emission (ug/s)	1004.23 ug/s

H_2S emission rate **3.59 ug/m^2-s**

H_2S Emission Estimation in Ha Tsuen PS

Summary and Deodourization Requirement

Ventilation Rate Estimation

	Existing Wetwell		Expanded Wetwell	
Space with emission				
Emission Area (m^2)	280	m^2	280	m^2
Headspace of Emission Area (m)	2	m	2	m
Volume of Air in Wetwells (m^3)	560	m^3	560	m^3
Space over the building (measured from the basemap)				
Length of Wetwell (m)	27	m	29	m
Width of Wetwell (m)	22	m	21	m
Wetwell Area (m^2)	594	m^2	609	m^2
Height of Building Ceiling (m)	4.15	m	4	m
Volume of Air in whole Building (m^3)	2465.1	m^3	2496	m^3
Total Volume of Air in Building (m^3)	3025.1	m^3	3056	m^3
Air Change per Hour	6		6	
Ventilation Rate (m^3/hr)	18150.6	m^3/hr	18336	m^3/hr
Ventilation Rate (m^3/s)	5.04	m^3/s	5.09	m^3/s

Deodourization Requirement

Emission rate (ug/s)	1004.23	ug/s	1004.23	ug/s
$[H_2S]_{in}$ (ug/m^3)	199.18	ug/m^3	197.17	ug/m^3
$[H_2S]_{in}$ (ppmv)	0.14530	ppmv	0.14383	ppmv
H_2S removal efficiency	**97%**		**97%**	
H_2S emission after deodourization (ug/s)	30.13	ug/s	30.13	ug/s
$[H_2S]_{out}$ (ug/m^3)	5.98	ug/m^3	5.91	ug/m^3
$[H_2S]_{out}$ (ppmv)	0.00436	ppmv	0.00432	ppmv
Exhaust Air Velocity	8.00	m/s	8.00	m/s
Point Source Diameter	0.896	m	0.900	m
Emission Height of DO Unit Exhaust	8	m	4	m