Expert System for Strategic Evaluation of Wastewater Technologies and Sewer Networks

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UNESCO-IHE
Institute for Water Education


Institute for Postgraduate Education, Training and Capacity Building in Water, Environment and Infrastructure

UNESCO-IHE

1955 Origins - Her Excellency Begum Ra'ana Liaquat Ali Khan, Bangladesh Ambassador to the Netherlands requests transfer of Dutch expertise in Hydraulic Engineering to Bangladesh

1957 Birth - IHE established as an International Education Institute

1991 Transformation - IHE Delft becomes an independent Foundation

2003 Operational - UNESCO-IHE Institute for Water Education becomes operational

Staff and Outputs

160 Staff (80 Academic, 80 Support)

300 Guest Faculty

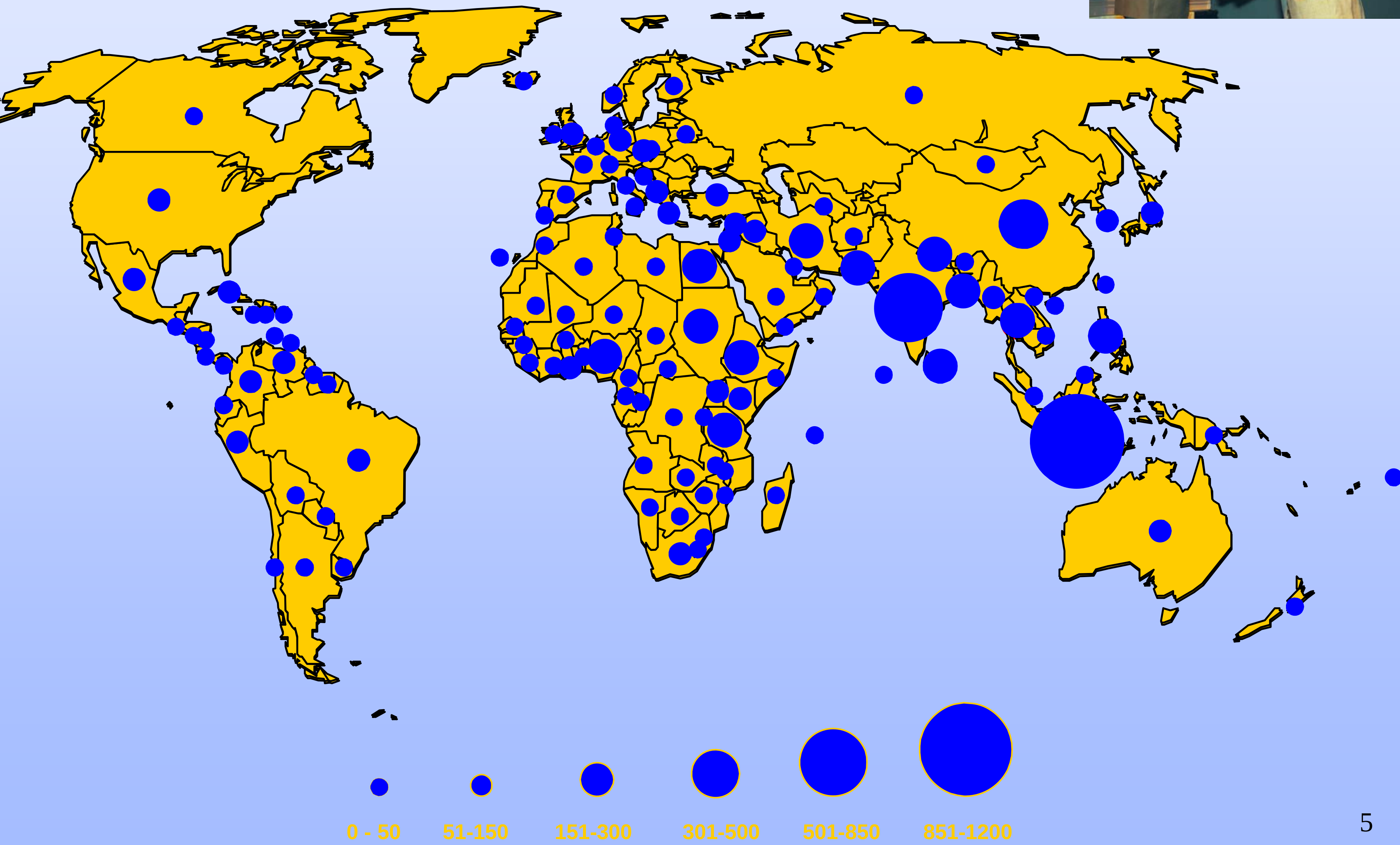
4 Water and Environment Academic Programmes:

- 222 MEng participants)
- 92 MSc participants) From about 80 countries
- 53 PhD fellows)
- 250 Short Course Participants

R&D: 170 Publications / year

187 Projects 2010 (Capacity Building, research, tailor made training, advisory services)

Connecting the Community of 14,000 Alumni



WaMEX Outline

- Introduction
- Development to date
  - Treatment technologies
- Further work
  - Scenario assessment
  - Integrated assessment

Introduction – Project Background

- ADB-DMC Sanitation Dialog 3-5 March 2009 identified the following focus points:
    - institutions and policies,
    - technology options,
    - financing options,
    - information,
    - education and communication, and
    - economics of sanitation
- As one of the knowledge products, the need for an Expert System has emerged with the aim to assist in the evaluation of wastewater management options
- UNESCO-IHE teamed up with an Asian/Australian partners to undertake the above work.

Objectives of the development work

- To develop a tool that enable decision makers to carry out “what-if-scenario” at a higher planning (or scoping) level:
  - Evaluation in relation to effluent and influent characteristics;
  - Preliminary cost estimates of WWT technologies and sewer reticulation works

- To develop two separate modules:
  - Wastewater technologies evaluation module;
  - Sewer network evaluation module;

End Users

- Planners
- Decision makers
- Project developers and implementers
- Operators

Work to date

- Several real-world tests have confirmed that the tool is useful but further refinements (i.e., technologies, costs, standards, correction factors for local conditions, functionalities, scenario builder) are ongoing;

- Developments are planned through 3 phases (2nd phase is complete);

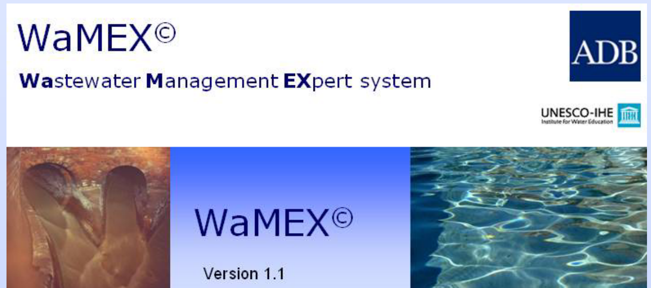
- Important points:
  - The tool is not meant for detailed engineering design purposes!
  - Current technologies are sewer-based with minor septage;
  - No tool can produce estimates that anticipate all possibilities of unplanned events and unanticipated local factors that a real-world job can entail (strengths vs. limitations)!

The team and external inputs

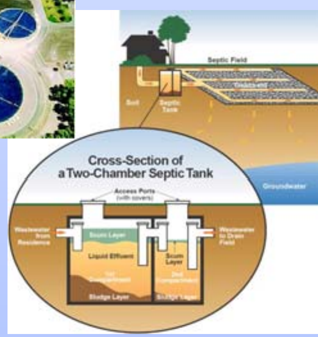
- UNESCCO-IHE's HI & Sanitation core teamed up with Beijing Richway Tech & Development Co. Ltd and Worley Parsons Ltd.

- Throughout the project comments were received from ADB, World Bank, IWA and other international experts in the field.

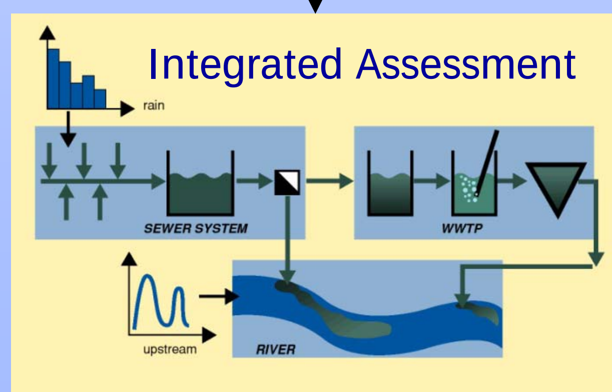
DSS/ES functional illustration
Code Name: WaMEX



Treatment



Sewers



Architecture

TECHNOLOGY SELECTION MODULE

Wastewater treatment technologies

- Pollutants
- Treatment methods
- Technology selection criteria
- Von Sperling's book and other references
- Demonstration of the module

MAIN MECHANISMS FOR THE REMOVAL OF POLLUTANTS IN WASTEWATER TREATMENT

Solids

Coarse
- *screening*

Suspended
- *sedimentation*

Dissolved
- *adsorption*

Organic matter

Particulate
- *sedimentation*
- *adsorption*
- *hydrolysis*
- *stabilization*

Soluble
- *adsorption*
- *stabilization*

Nitrogen

Organic
- *ammonification*

Ammonia
- *nitrification*
- *bacterial assimilation*
- *stripping*
- *break-point chlorination*

Nitrate
- *denitrification*

Phosphorus

Phosphate
- *bacterial assimilation*
- *precipitation*
- *filtration*

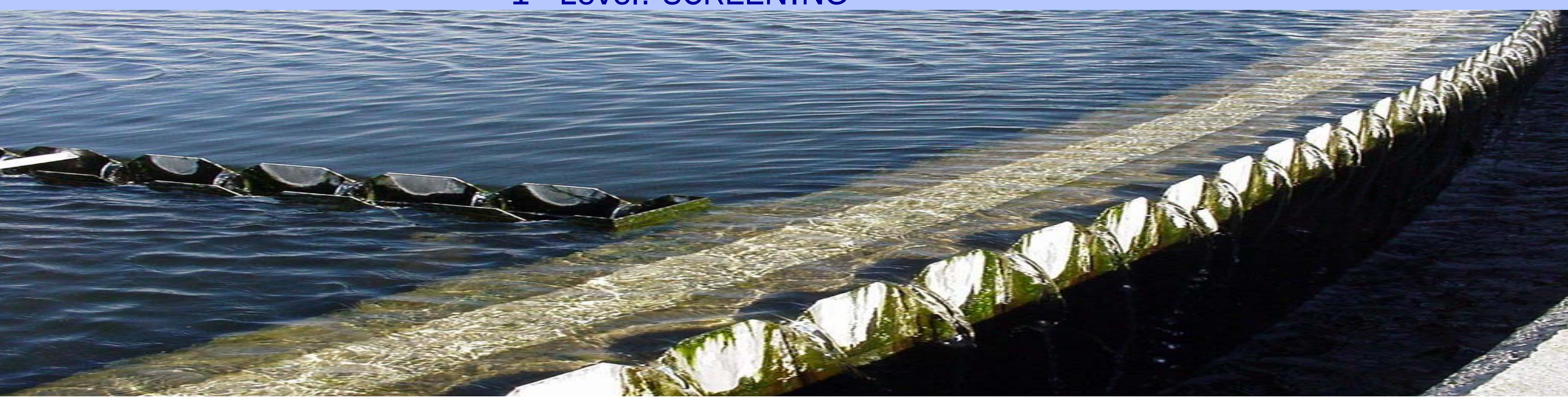
Pathogens

Protozoa/eggs
- *sedimentation*
- *filtration*

Bacteria/viruses
- *adverse env. cond*
- *UV radiation*
- *disinfection*

Logarithmic scale

1st Level: SCREENING



TECHNOLOGY SELECTION METHODS

2nd Level: RANKING

- **descriptive documents**
- **checklists**
- **selection matrices**
- **algorithms**
- **models**

EXAMPLE SELECTION MATRIX: MCA

Selection criteria

Weights

Range 0-10

6	8	1	2	4	9	3	5	7	8	9	1	2	0	5

Technologies

Scores

Range 0-5

3	3	0	1	2	4	5	4	3	2	1	0	4	3	2
5	4	2	2	2	1	1	1	4	4	4	3	3	5	2
3	3	2	4	5	1	3	5	5	3	2	1	5	2	3
2	4	5	1	1	1	5	4	2	2	2	1	1	1	4
1	1	5	4	2	2	2	1	5	4	2	2	2	1	5
2	4	5	2	4	5	2	4	5	2	4	5	1	1	1

weights x scores

total
256
307
188
399
300
229

Criteria for wastewater technology selection

Local conditions

- Climate
- Hydrology
- Footprint size
- Land availability

Processes

- Process applicability
- Removal efficiency
- Resistance/robustness
- Sludge generation
- Sludge handling/processing
- Water efficiency/losses

Environment

- Soil pollution
- Air pollution
- Water resources pollution
- Devaluation of area
- Inconvenience

Health and Safety

- Odour
- Noise
- Aerosols
- Insects & worms
- Occupational safety

Economics

- Construction costs
- Chemicals
- Energy
- Personnel
- Land costs
- Other resources

Operation & Maintenance

- Operational attention
- Reliability
- Complexity/Simplicity
- Compatibility

Social aspects

- ...

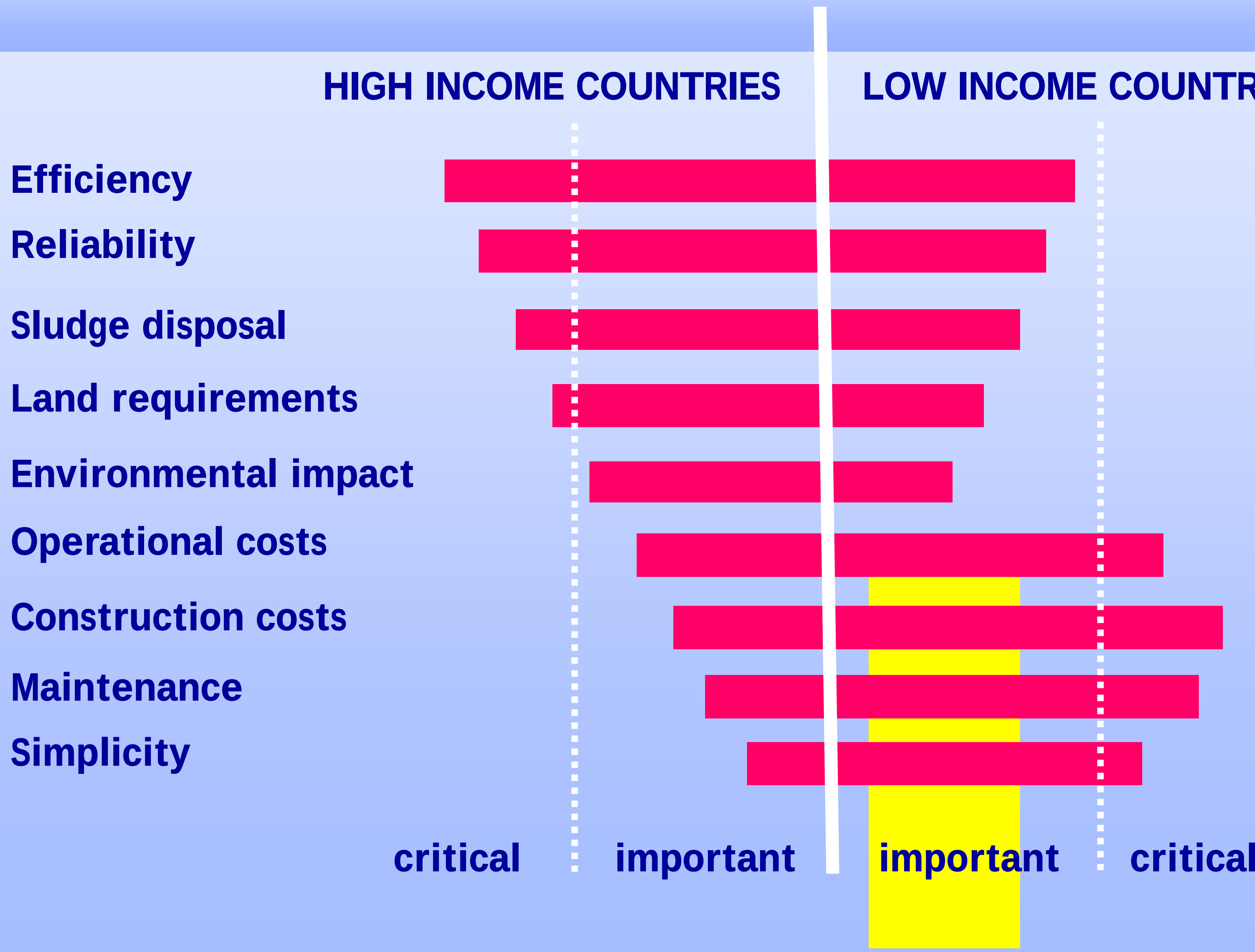
Institutional aspects

- ...

Political aspects ...

- ...

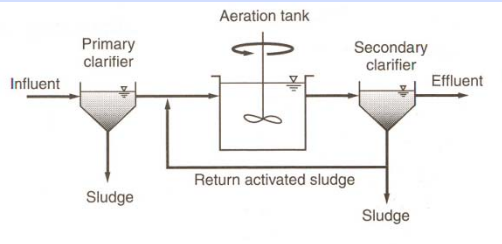
IMPORTANCE OF CRITERIA FOR TECHNOLOGY SELECTION:
Perspective of developed and developing countries



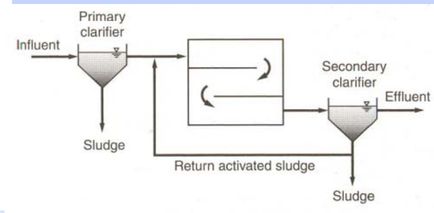
COD removal - nitrification plants

3rd Level: Selection at the individual technology level
Not In the SCOPE

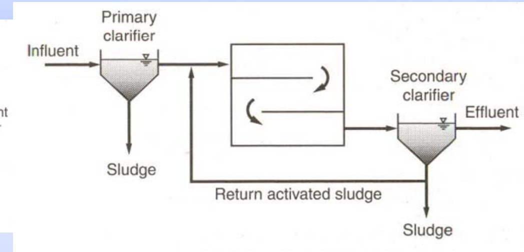
(a) Complete-mix activated sludge - CMAS



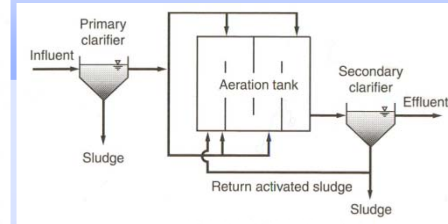
(b) Conventional plug-flow



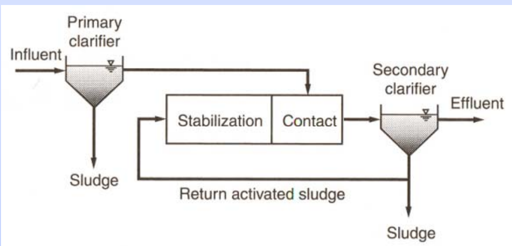
(c) High-rate aeration



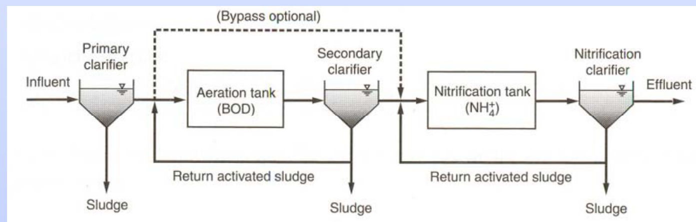
(d) Step feed



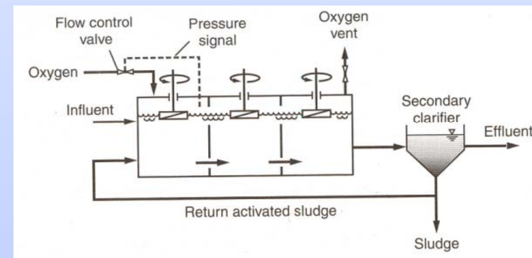
(e) Contact stabilization



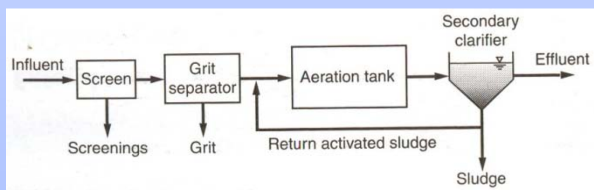
(f) Two-sludge



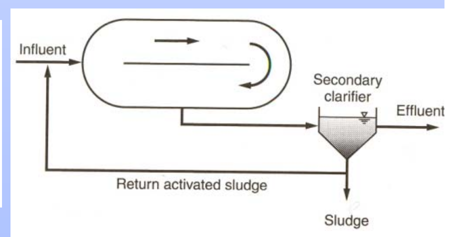
(g) High-purity oxygen



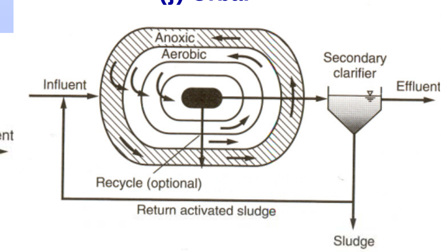
(h) Conventional extended aeration



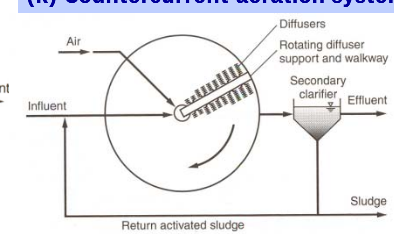
(i) Oxidation ditch



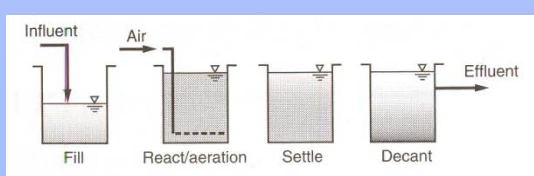
(j) Orbal



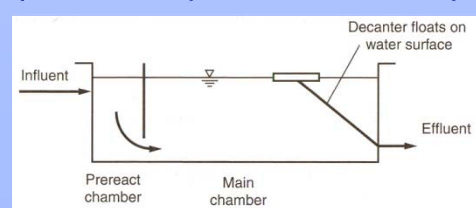
(k) Countercurrent aeration system



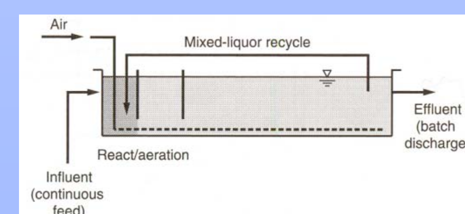
(l) Sequencing batch reactor - SBR



(m) Intermittent cycle extended aeration system

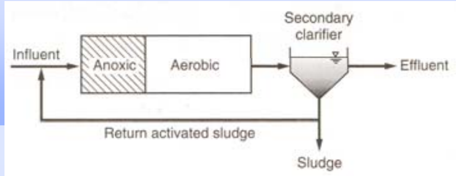


(n) Cyclic activated sludge system - CAAS

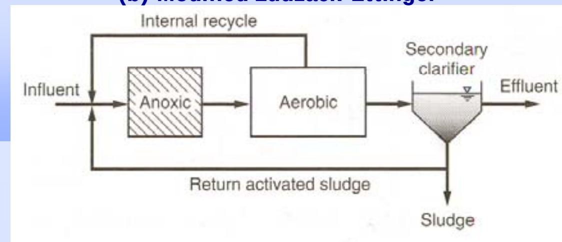


COD and N removal plants – nitrification and denifitrication plants Not In the SCOPE

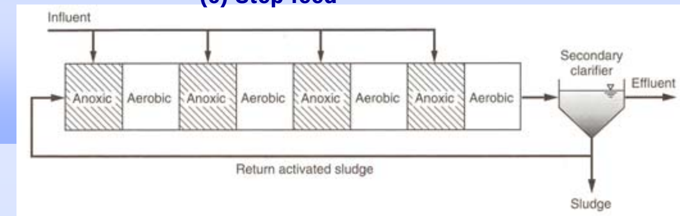
(a) Ludzack-Ettinger



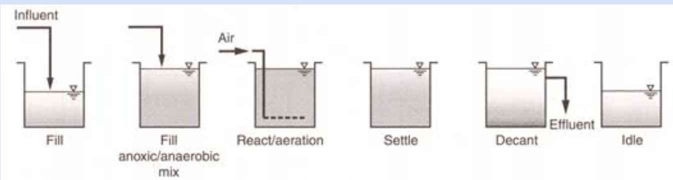
(b) Modified Ludzack-Ettinger



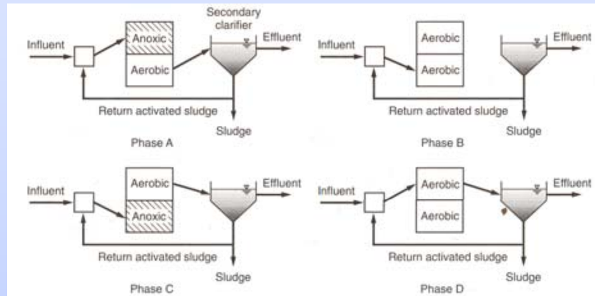
(c) Step feed



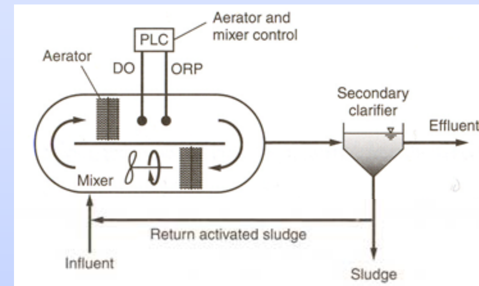
(d) Sequencing batch reactor - SBR



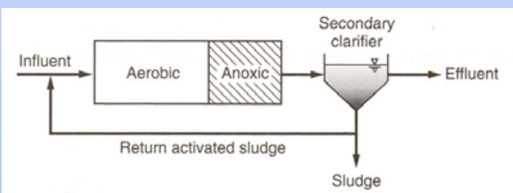
(e) Bio-denitro



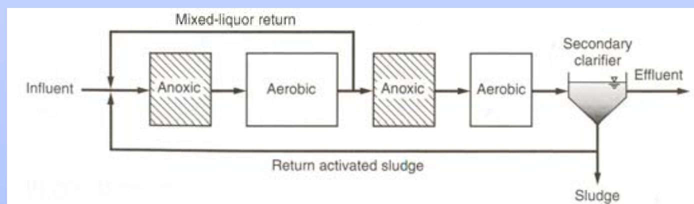
(f) Nitrox



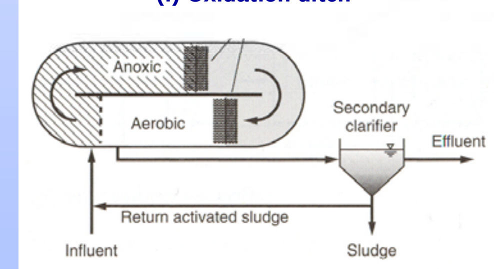
(g) Single-sludge



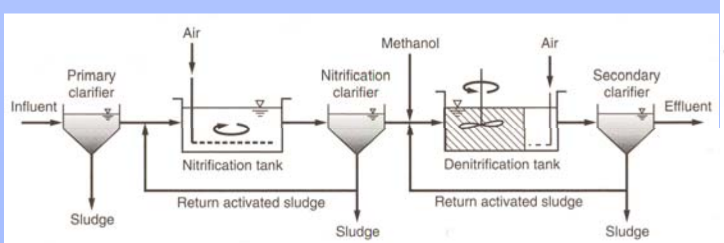
(h) Bardenpho (4 stage)



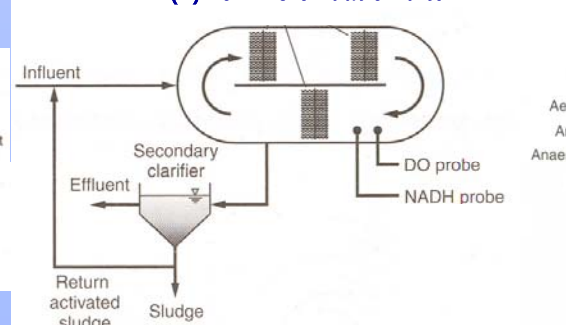
(i) Oxidation ditch



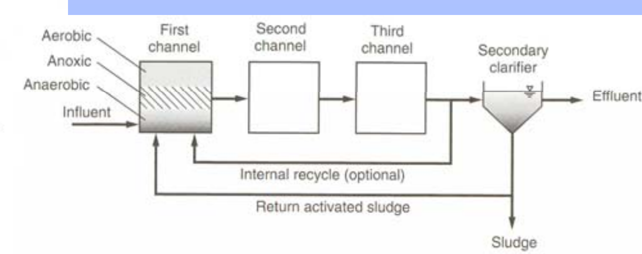
(j) Two-sludge



(k) Low DO oxidation ditch



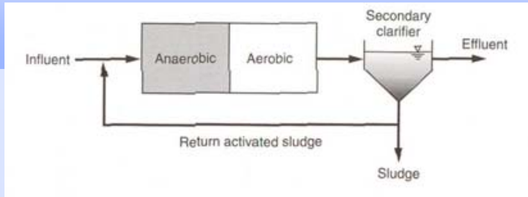
(l) Orbal



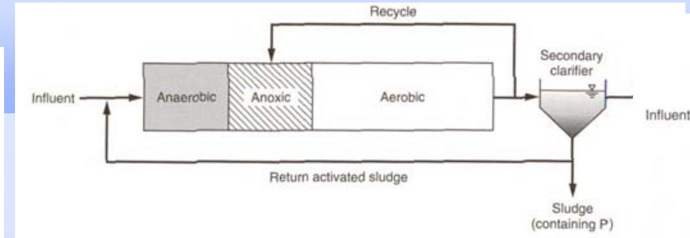
COD, N and P removal plants - nitrification and denifitrication and phosphorus removal plants

Not In the SCOPE

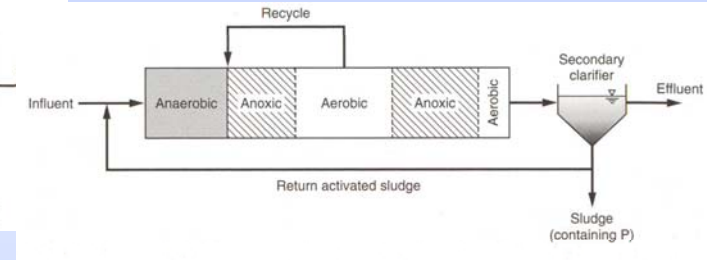
(a) Phoredox (A/O)



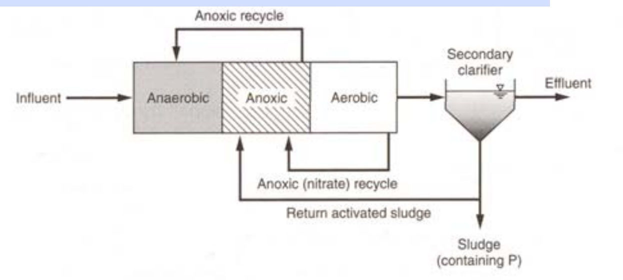
(b) A2/O



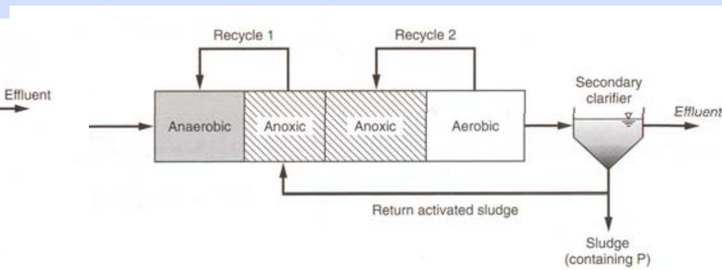
(c) Modified Bardenpho (5 stage)



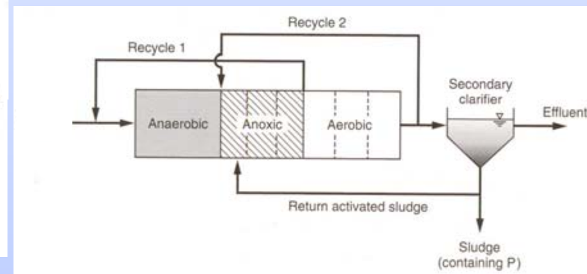
(d) UCT



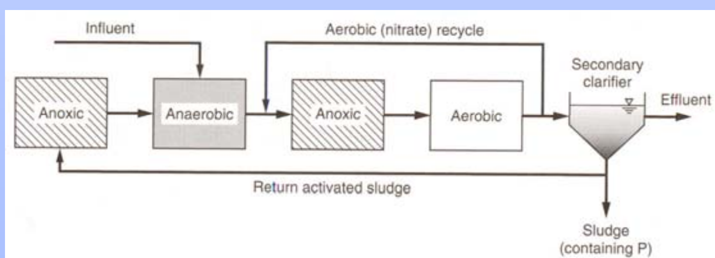
(e) Modified UCT



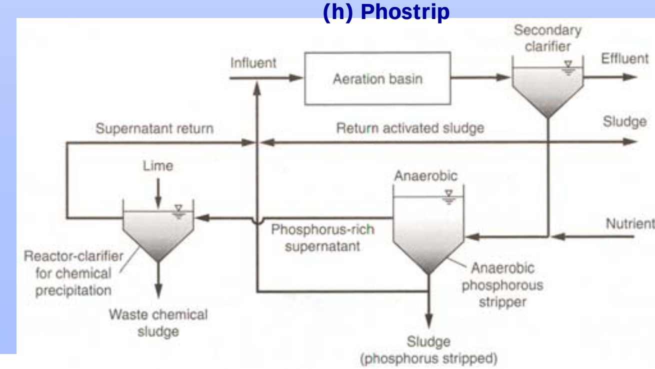
(f) VIP



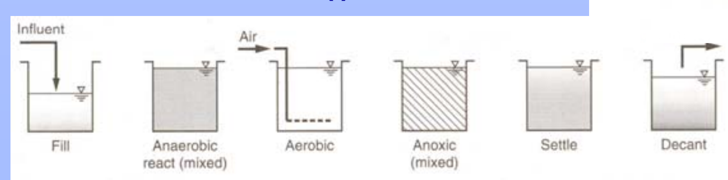
(g) Johanesburg



(h) Phostrip



(i) SBR



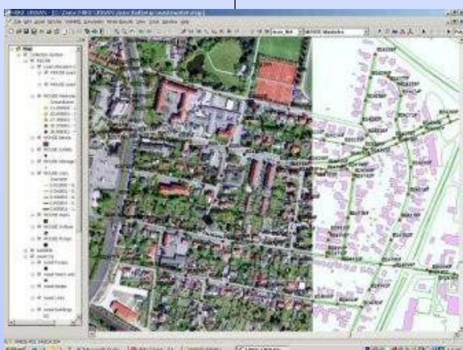
TECHNOLOGY SELECTION MODULE - DEMO

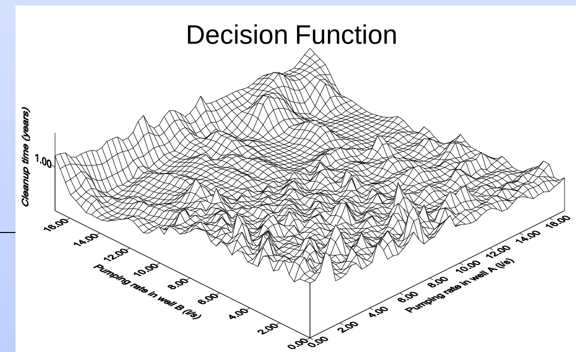
Selection of technologies in relation to:

- Different Effluent Standards
- Different Wastewater Characteristics

WaMEX functional illustration – Reticulation

Sewers



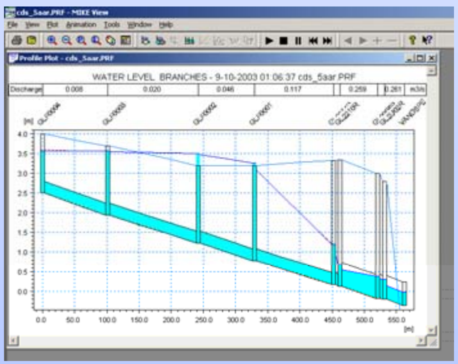


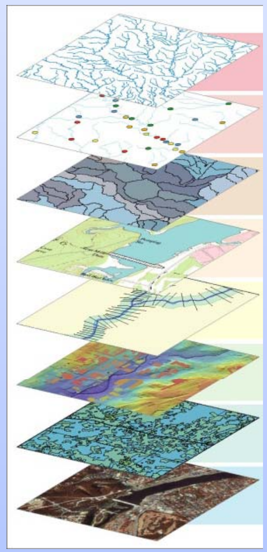
Optimal Solution

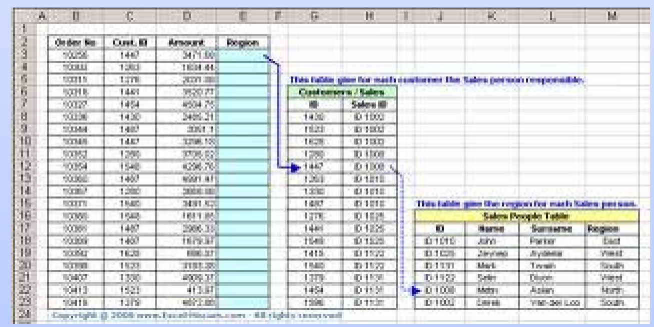
Approach undertaken

- Simplified (a library of model runs and the lookup table),

Off line - dynamic simulations with optimisation

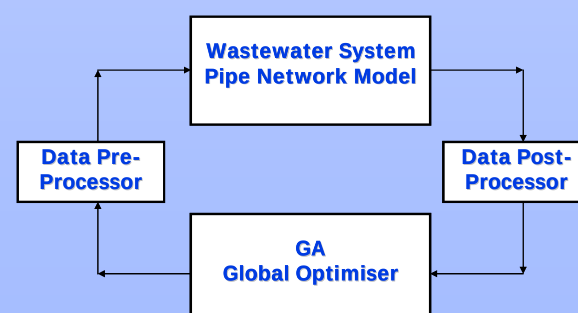






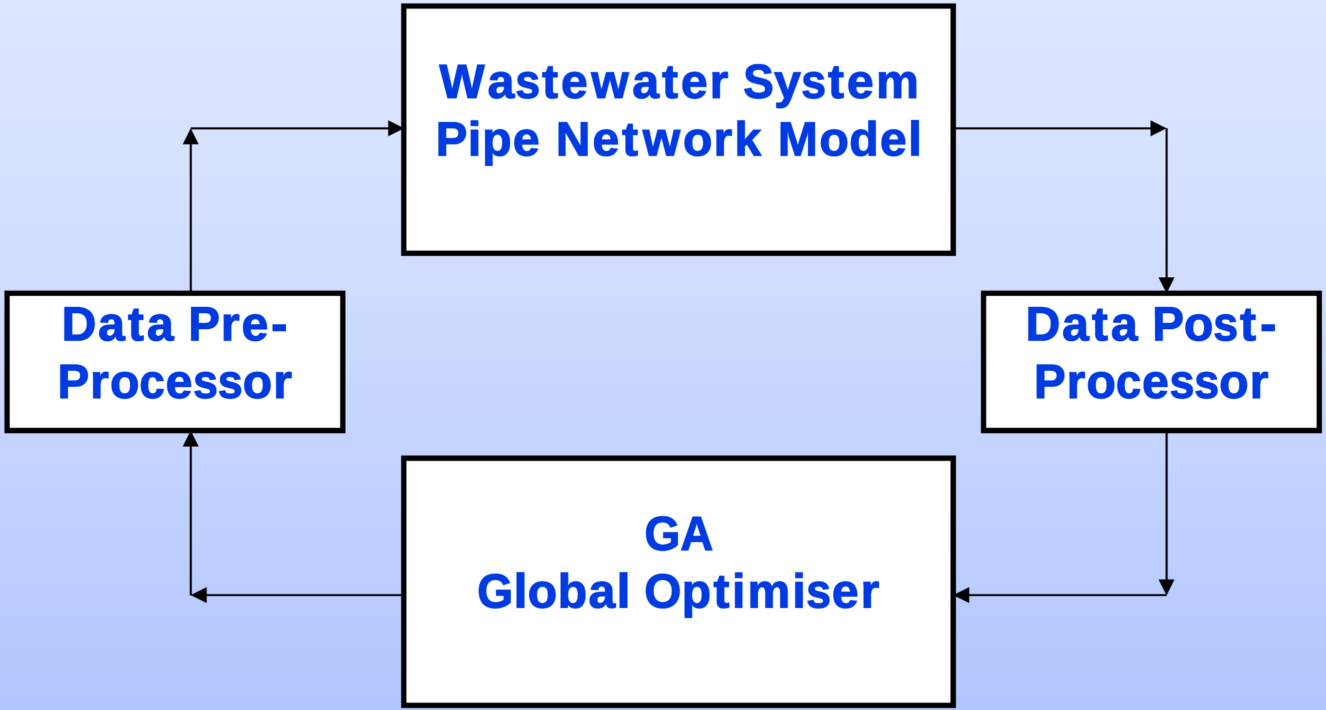
- Uses complex computations

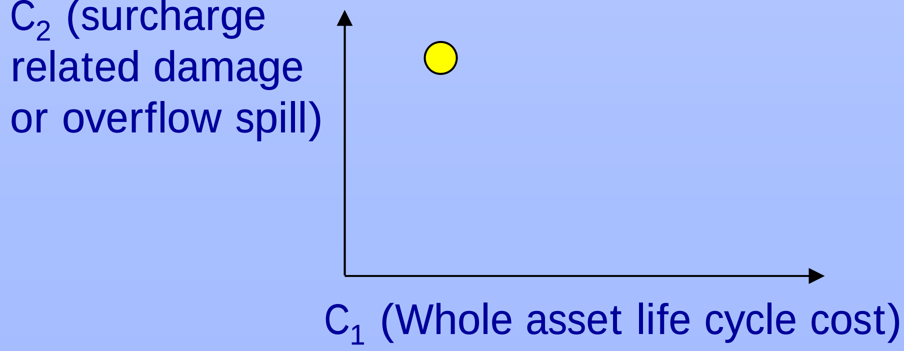
On line - dynamic simulations with optimisation (GA)



Dynamic analysis approach: Tools used

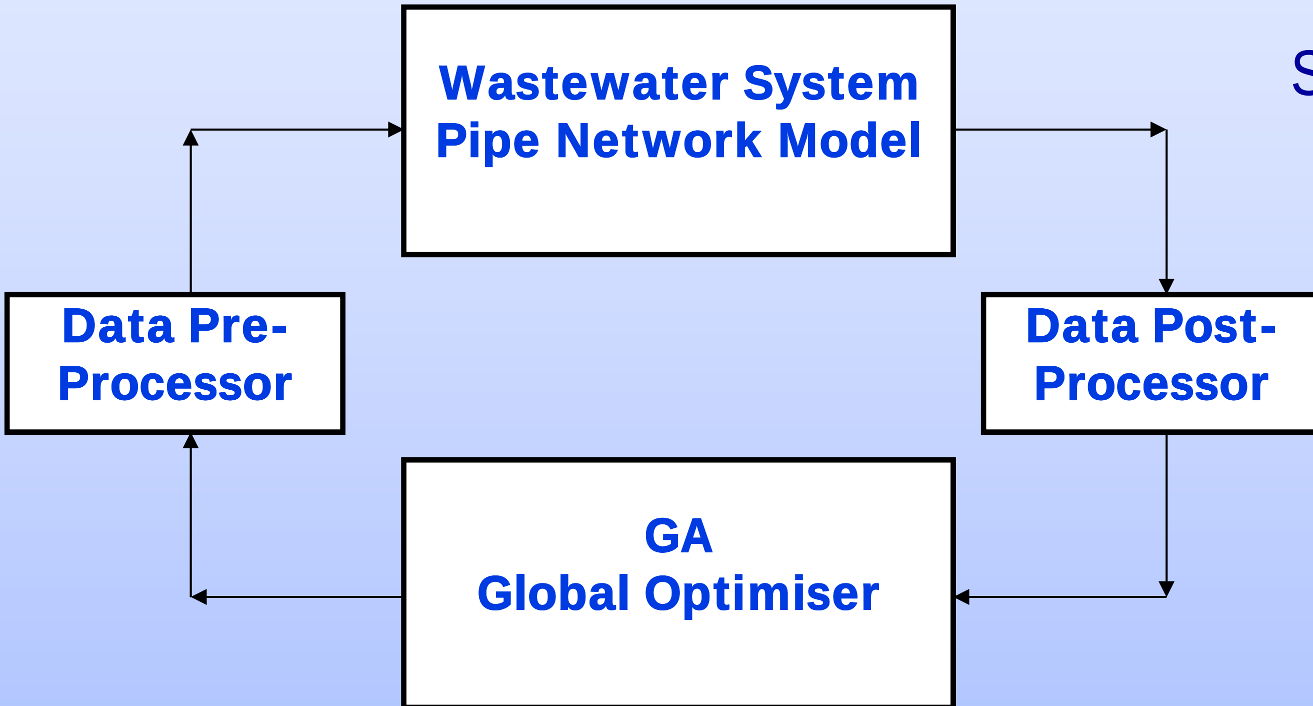
First Iteration!

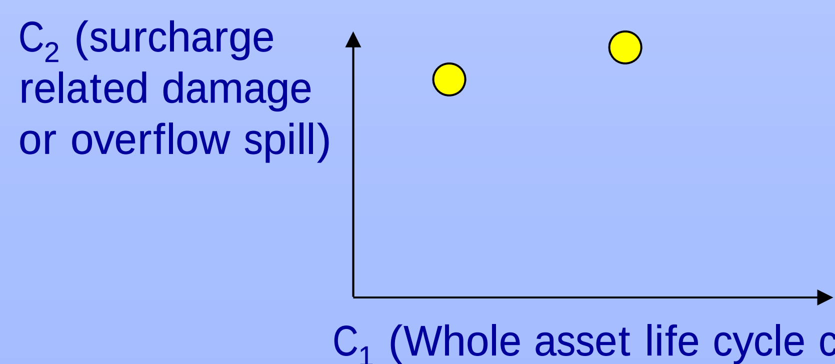




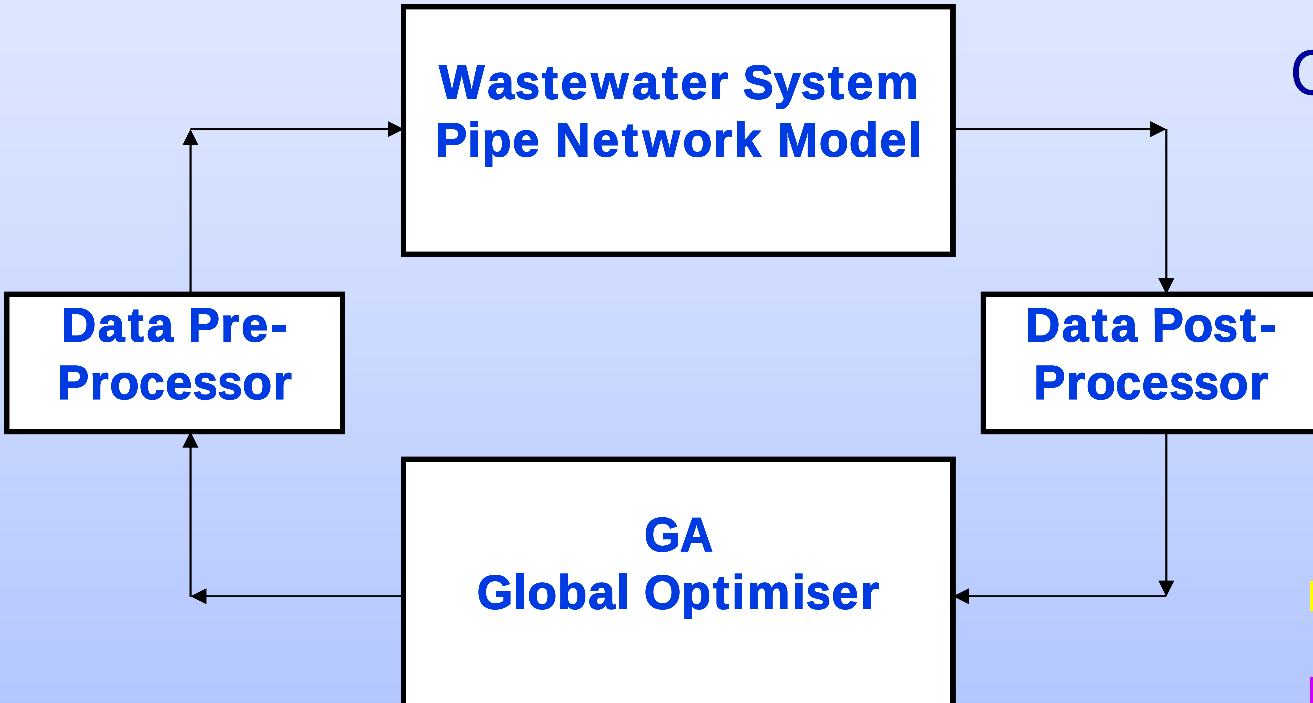
Dynamic analysis approach: Tools used

Second Iteration!





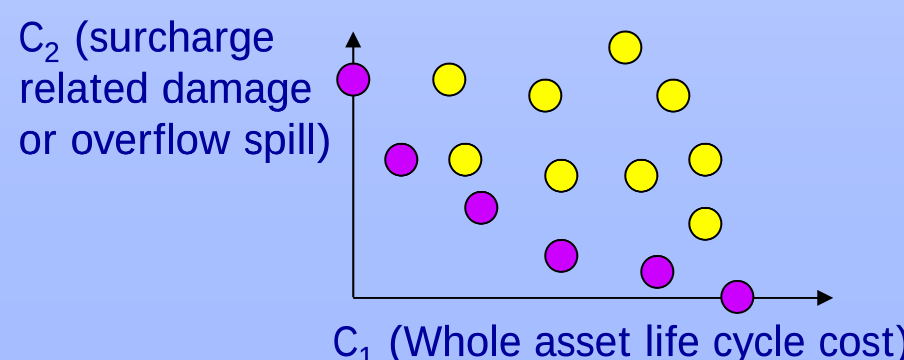
Dynamic analysis approach: Tools used



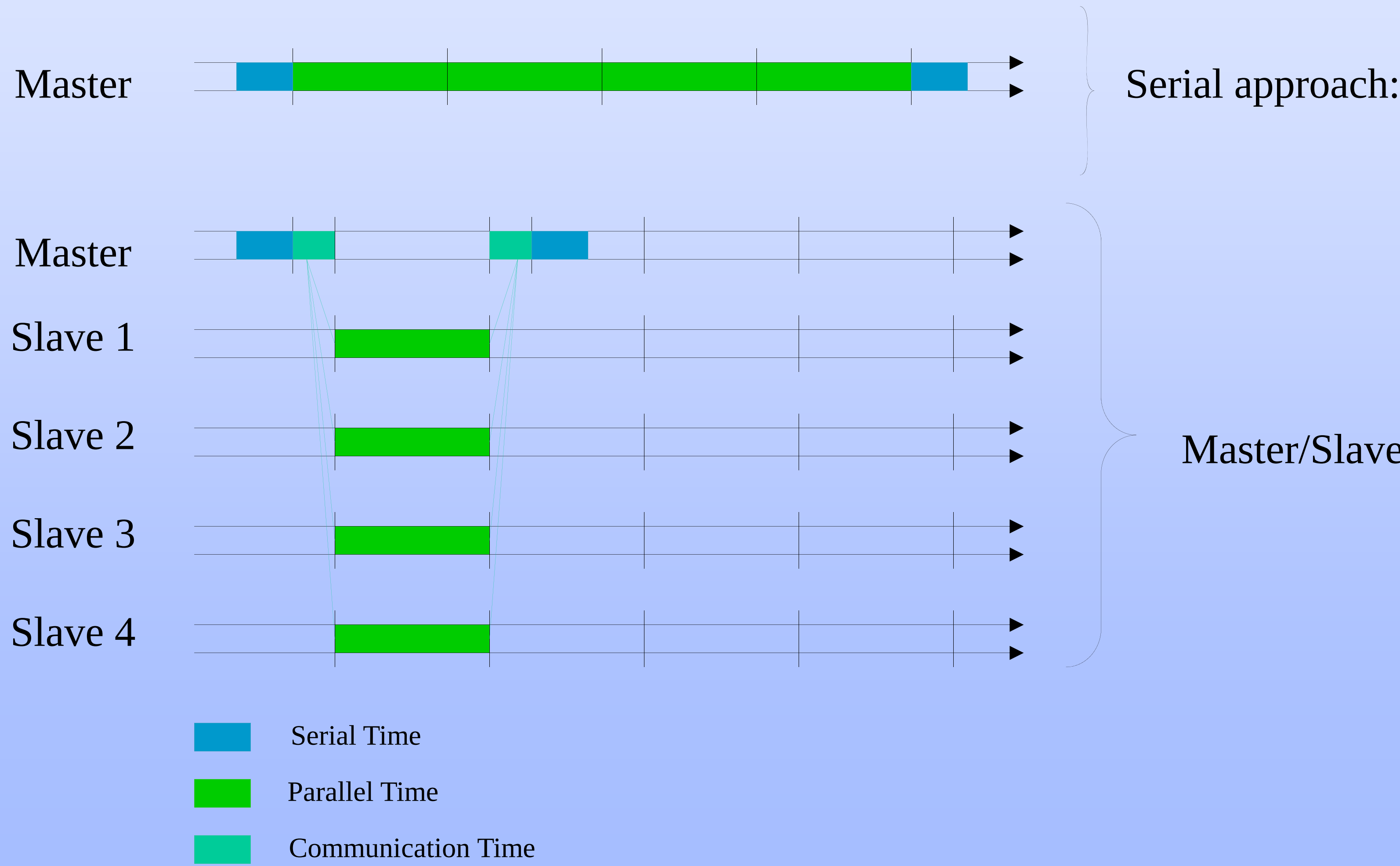
Other Iterations!

Dominated Solutions!

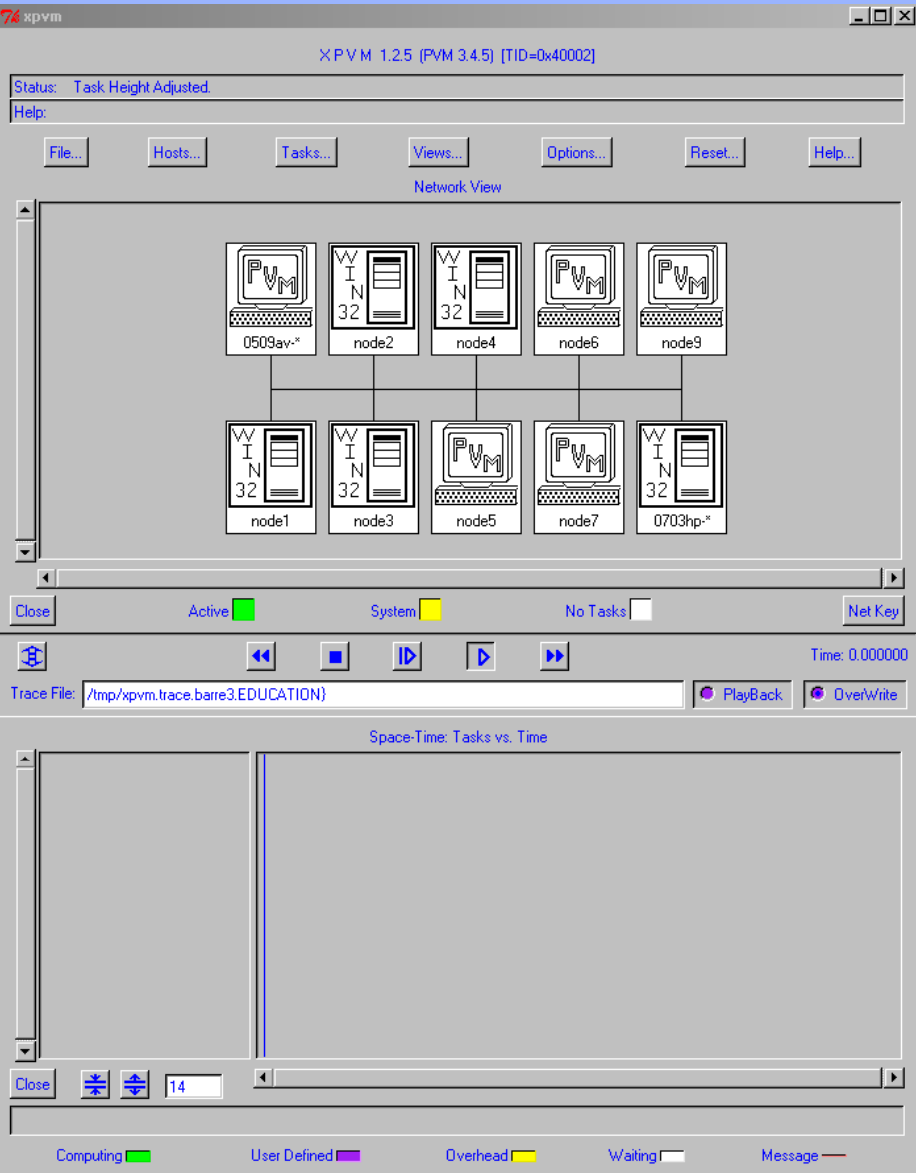
Nondominated Solutions!

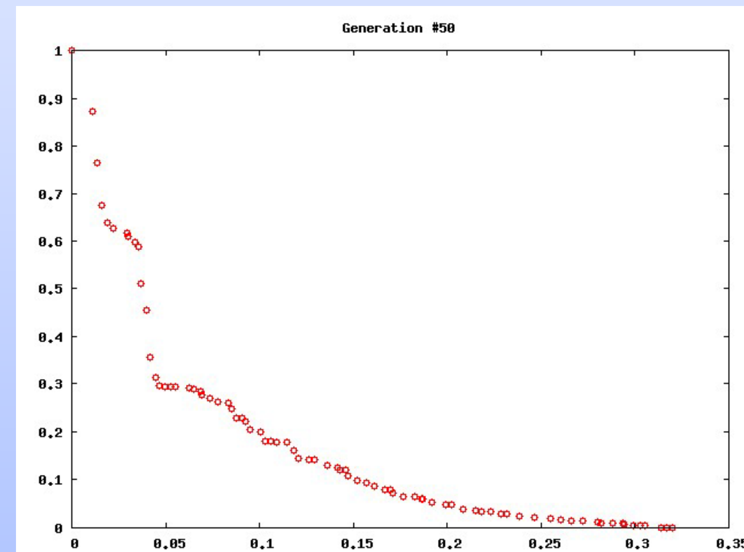


A parallel computing platform has been developed and used in the present work



A parallel computing platform has been developed and used in the present work





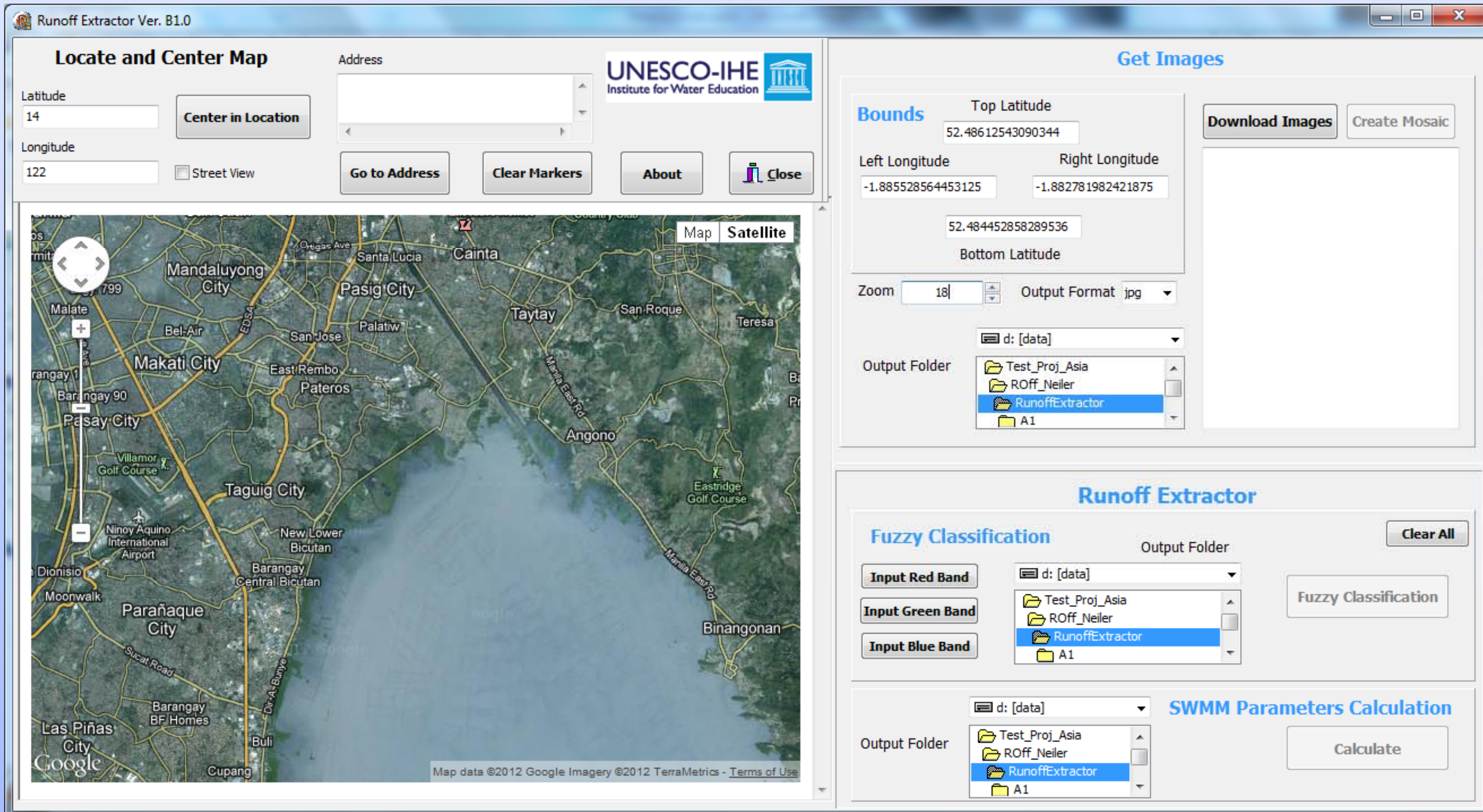
Implementation

- Conventional: separate and combined
- Simplified

Implementation

- Known cases: details from several cases available
- Unknown cases: details determined using specialised tools

Hydrologic / Hydraulic Parameters



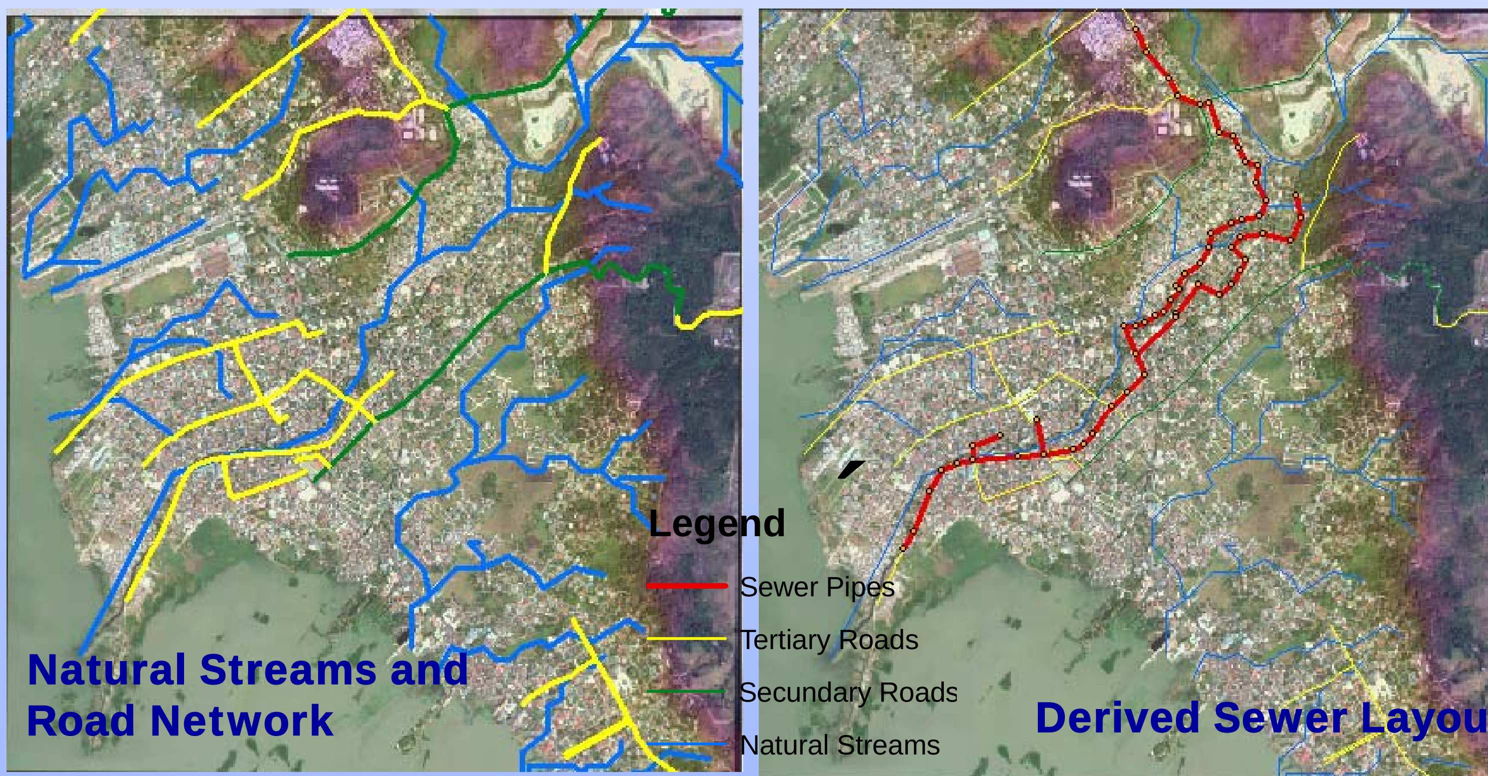
Design Parameters

Depend on local conditions and regulations

- Slope
- Population density
- Minimum Diameter (Security Factors)
- Minimum/Maximum Velocity (Self cleaning, water quality considerations, Hazardous gases (security), maintenance, etc).

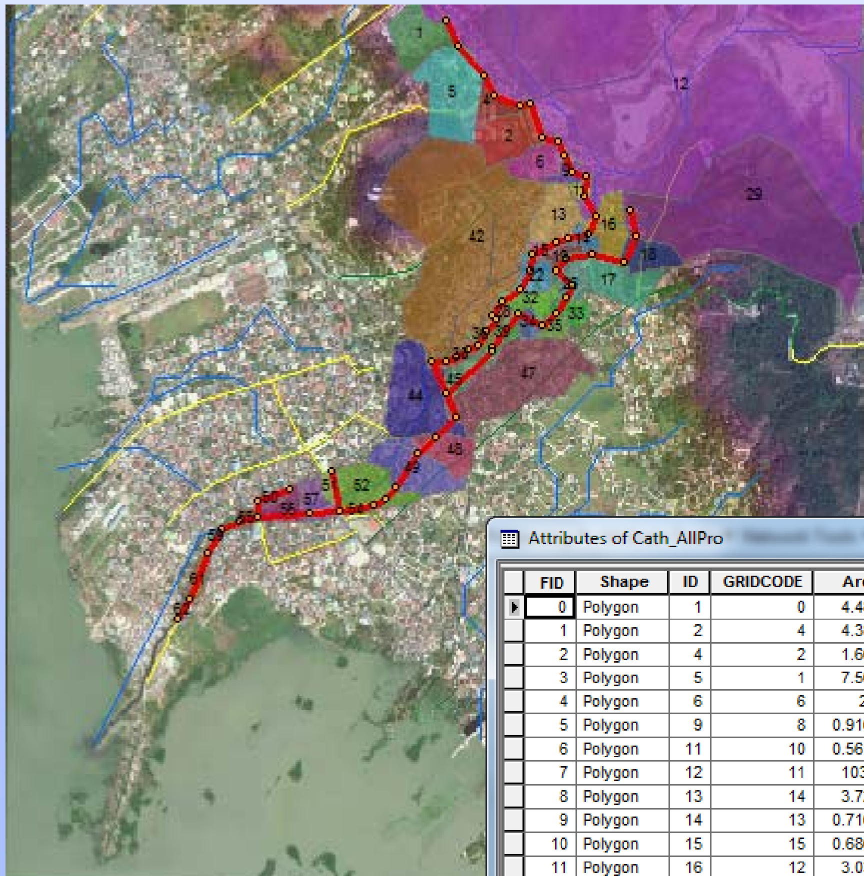
Layout of the System

- Based on the local topography.
- Pipes follow topography and road network.



Catchment Delineation

Based on the topography, pipe layout and flow direction.

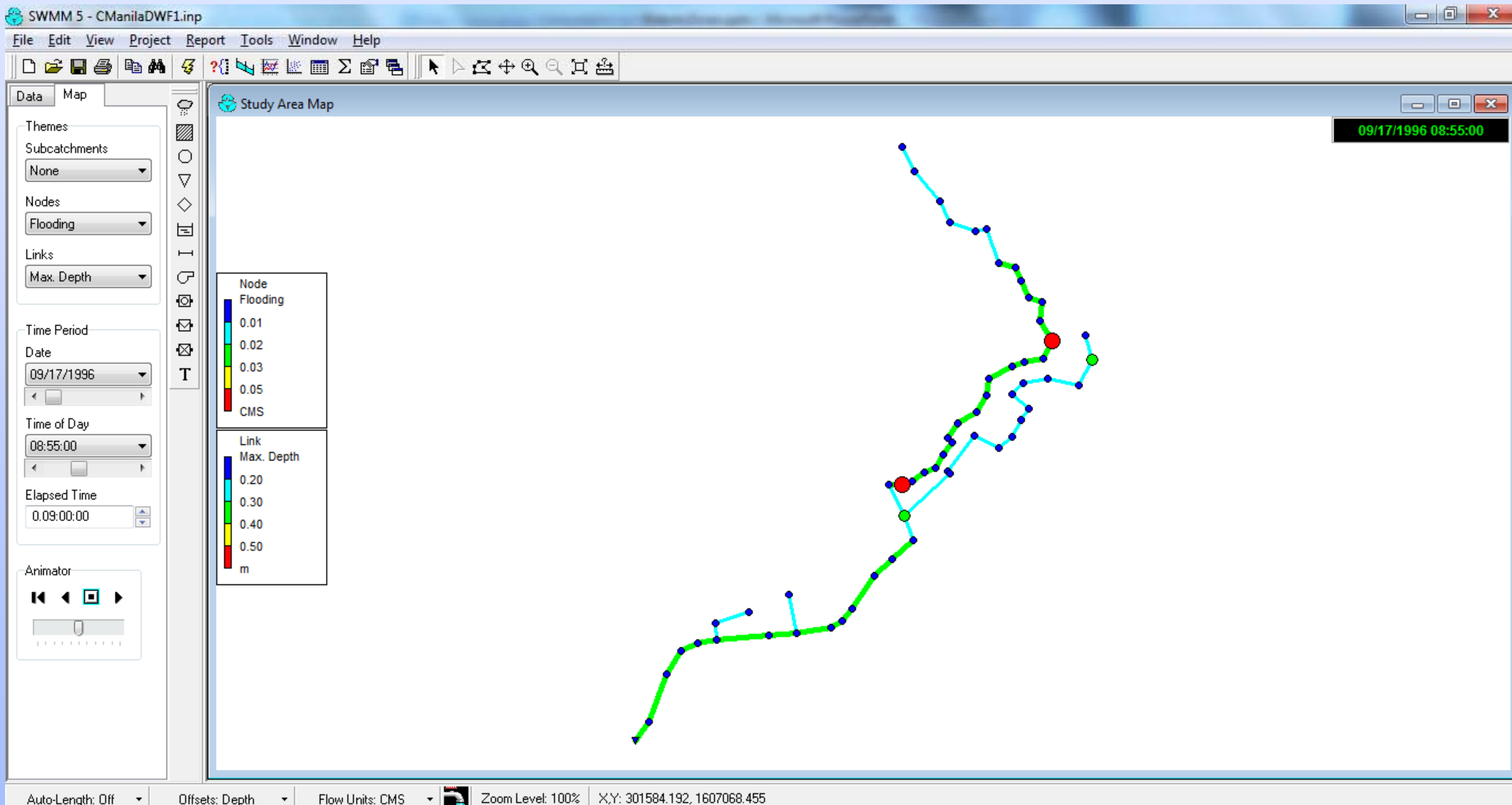


Attributes of Cath_AllPro

FID	Shape	ID	GRIDCODE	Area	Outlet	MEAN	MEAN_1	MEAN_12	MEAN_12_13	Width	WT
0	Polygon	1	0	4.48629	1	0.243066	0.004437	0.491212	0.350259	915.065	230
1	Polygon	2	4	4.38313	5	0.35407	0.002489	0.648076	0.19613	943.78302	220
2	Polygon	4	2	1.66138	7	0.345237	0.003388	0.630674	0.264649	677.82703	98.041496
3	Polygon	5	1	7.56983	3	0.373198	0.001885	0.685351	0.150087	1165.59	259.77701
4	Polygon	6	6	2.794	9	0.367707	0.001843	0.677127	0.147692	807.70801	138.367
5	Polygon	9	8	0.916558	10	0.326267	0.002746	0.625661	0.21969	510.10001	120
6	Polygon	11	10	0.561479	12	0.294822	0.003348	0.591339	0.269786	343.72101	80
7	Polygon	12	11	103.283	13	0.363016	0.002172	0.671569	0.172132	5578.5698	1500
8	Polygon	13	14	3.72711	16	0.313216	0.003113	0.606589	0.24861	763.64502	195.22701
9	Polygon	14	13	0.716836	33	0.358625	0.002002	0.671489	0.160653	450.43301	63.657501
10	Polygon	15	15	0.686862	17	0.386194	0.001609	0.702382	0.127332	403.09698	68.158501
11	Polygon	16	12	3.03583	14	0.365782	0.001872	0.67948	0.149649	788.57599	170
12	Polygon	17	31	4.59911	34	0.374345	0.001821	0.684519	0.145346	1121.33	164.05901
13	Polygon	18	32	0.18716	32	0.473754	0.000381	0.807896	0.030629	687.13599	110
14	Polygon	19	33	0.842219	35	0.37117	0.001623	0.688597	0.130995	527.26599	63.893299
15	Polygon	22	17	1.68444	19	0.319903	0.002827	0.613472	0.225535	588.44702	140

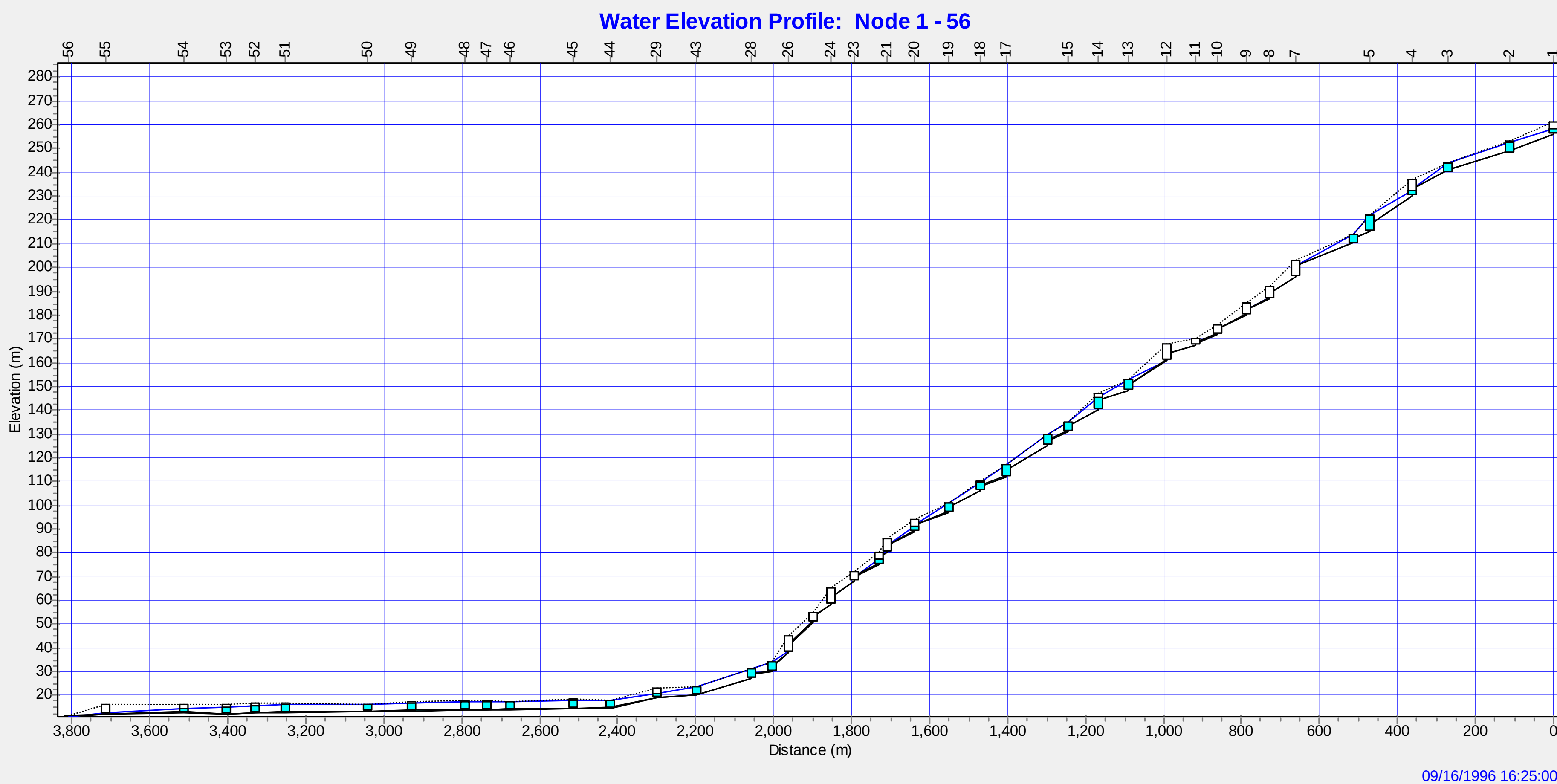
Record: 1 Show: All Selected Records (0 out of 42 Selected) Options

Layout of the System



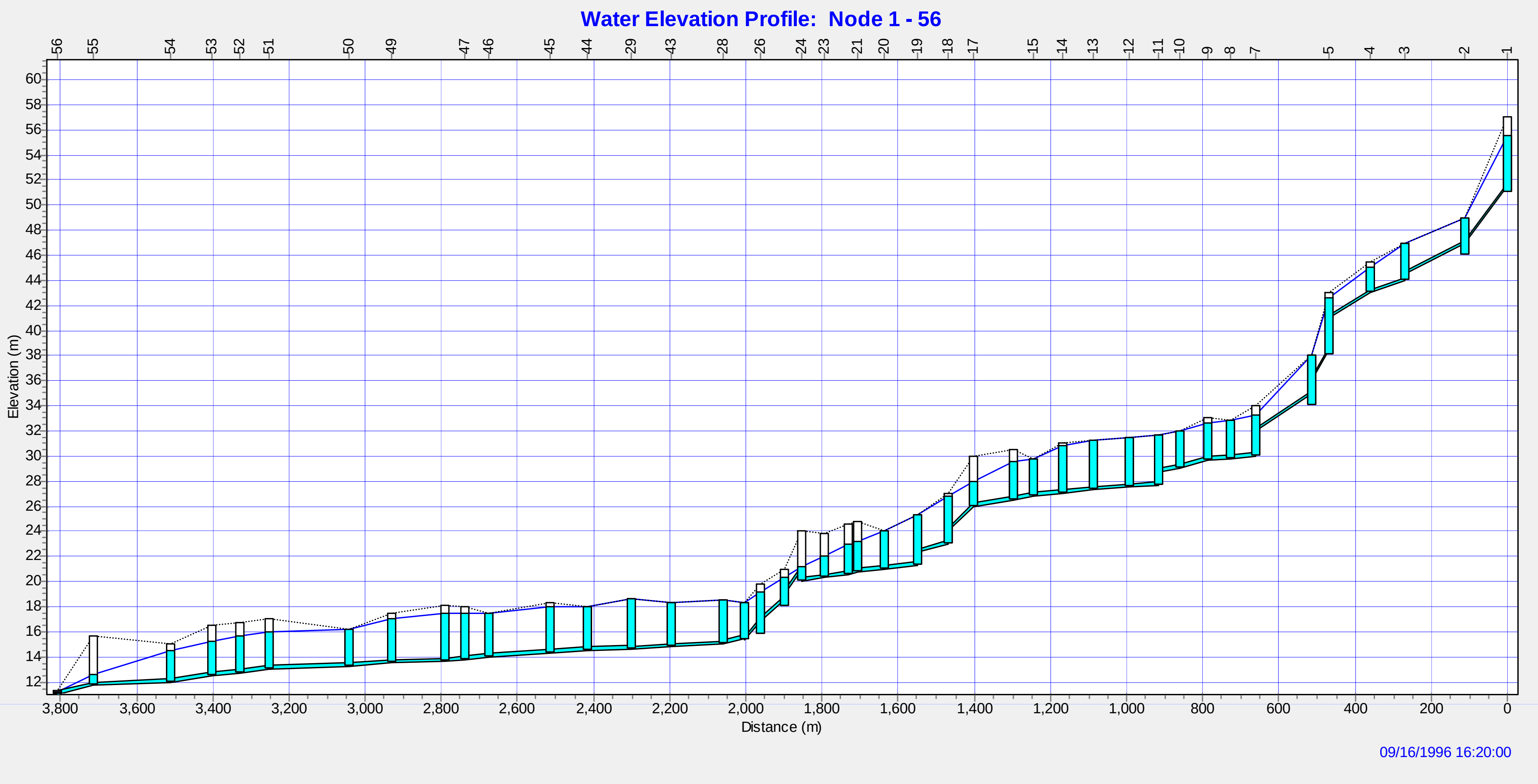
Velocity constraints: 1 to 5 m/s

System profile for a terrain slope of 10%. Steepest part. Maximum calculated velocity in the model was 4.1 m/s



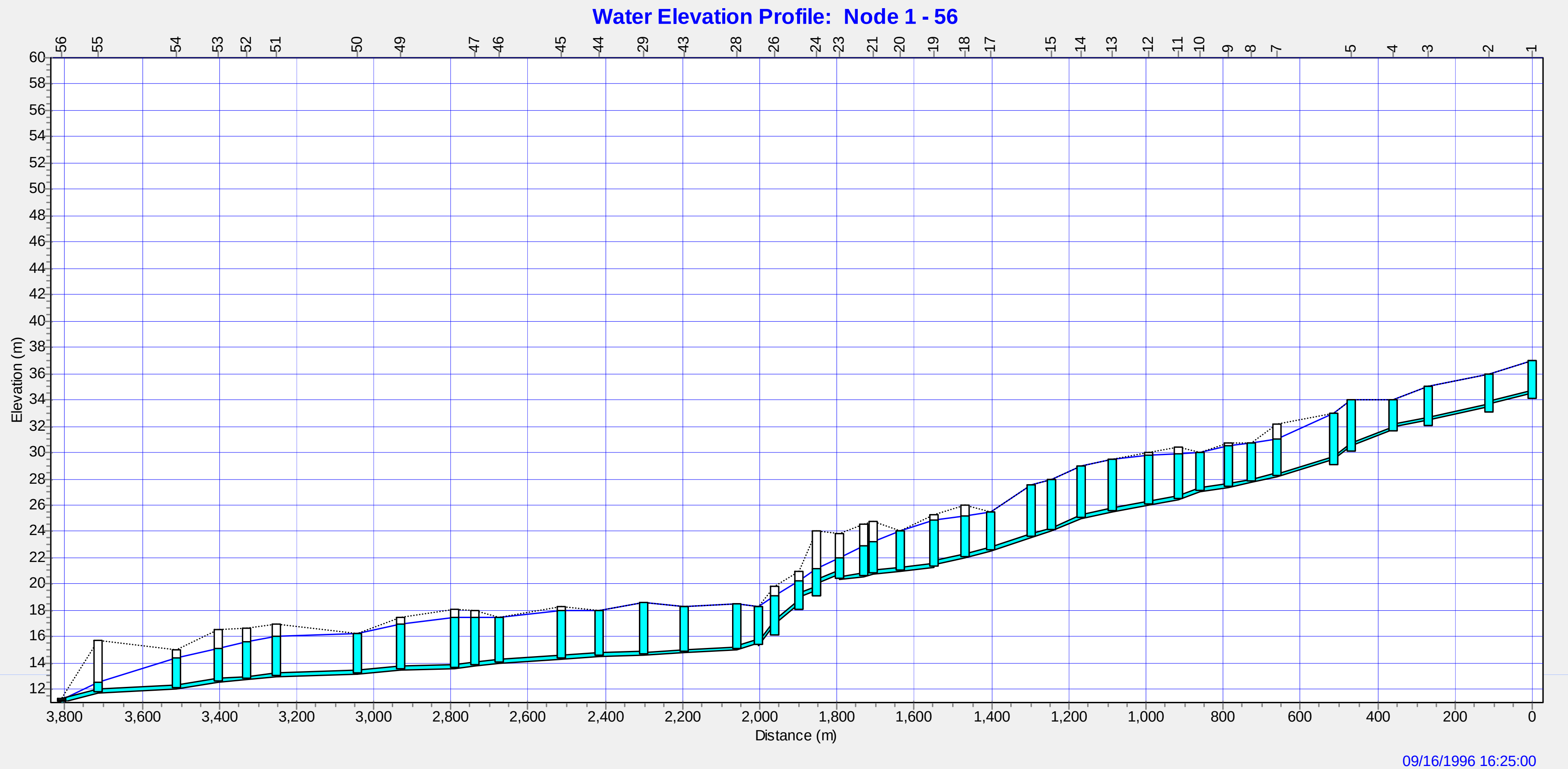
Velocity constraints: 1 to 5 m/s

System profile for an average terrain slope of 3%. Steepest part. Maximum calculated velocity in the model was 2.3 m/s

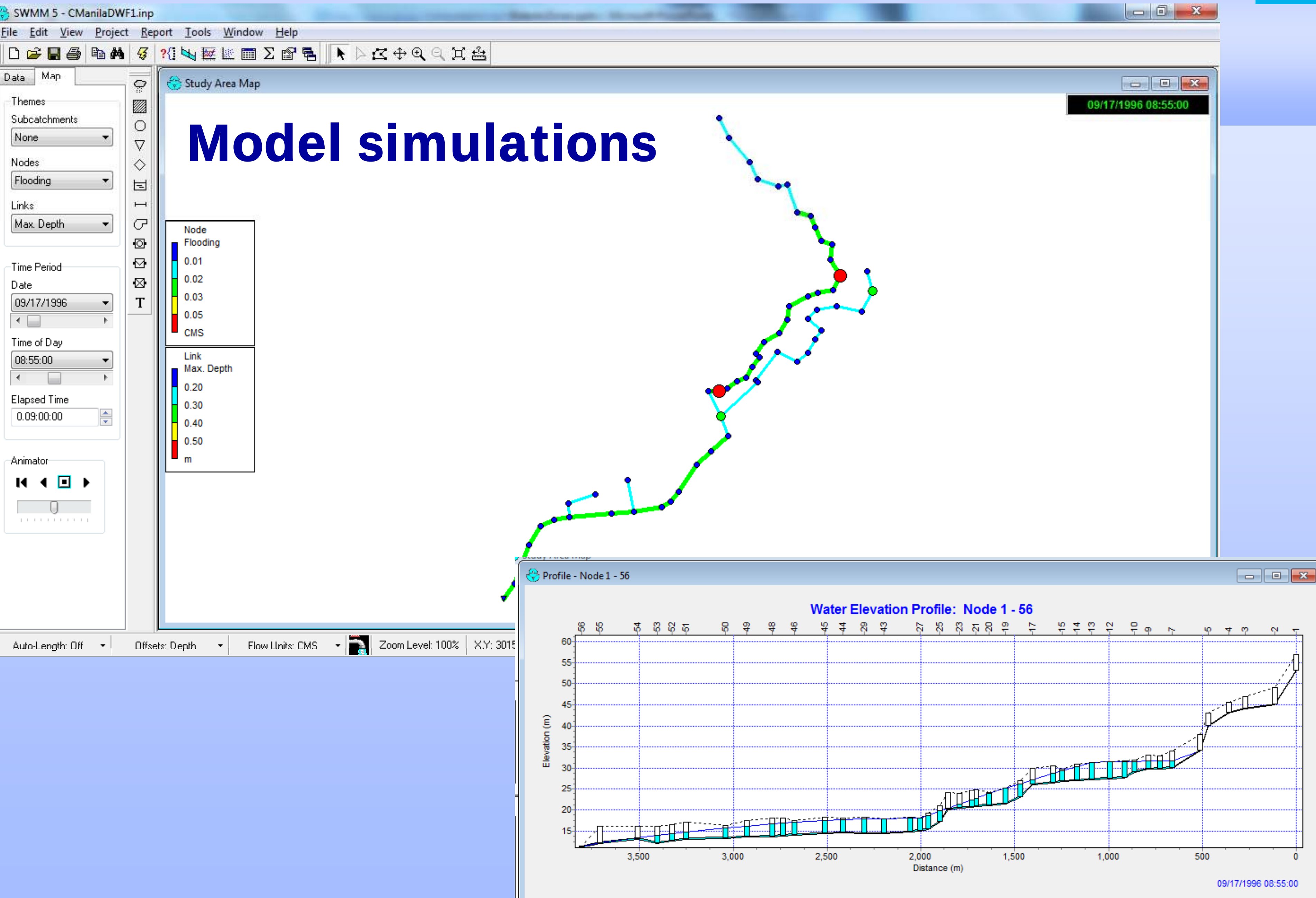


Velocity constraints: 1 to 5 m/s

System profile for an average terrain slope of 1%. Steepest part. Maximum calculated velocity in the model was 1.29 m/s



Model simulations



Summary Table for each model

ombination	Design Criteria							Input Data									OutPut Data						
	Minimum Diamete	Minimum Depth (m)	Velocity Min (m/s)	Velocity Max (m/s)	Per Capita Consum	Design Period (years)	Design Rainfall (yr)	AREA = 50 Ha									Total Flow (Q) (m3/s)	Pipe Distribution (km)			Costs		
								Density 1: 150 inh/Ha			density 2: 500 inh/Ha			Density 3: 1700 inh/Ha									
								S1	S2	S3	s1	s2	s3	s1	s2	s3		< 500 mm	500-1000	>1000 mm	CI	O&M	otal (NP
10	225	2	0.75	10	150	20	5	< 3%									2.903	17.5	2.5	0.1	40.00	6.00	46.00
11	225	2	0.75	10	150	20	5		3-10%								3.313	17.5	2.5	0.1	37.60	5.64	43.24
12	225	2	0.75	10	150	20	5			> 10%							3.713	17.5	2.5	0.1	36.00	5.40	41.40
13	225	2	0.75	10	150	20	5				< 3%						4.173	17.5	2.5	0.1	52.00	7.80	59.80
14	225	2	0.75	10	150	20	5					3-10%					4.583	17.5	2.5	0.1	48.88	7.33	56.21
15	225	2	0.75	10	150	20	5						> 10%				4.993	17.5	2.5	0.1	46.80	7.02	53.82
16	225	2	0.75	10	150	20	5							< 3%			5.928	17.5	2.5	0.1	70.00	10.50	80.50
17	225	2	0.75	10	150	20	5								3-10%		6.338	17.5	2.5	0.1	65.80	9.87	75.67
18	225	2	0.75	10	150	20	5									> 10%	6.748	17.5	2.5	0.1	63.00	9.45	72.45

ombination	Design Criteria							Input Data									OutPut Data						
	Minimum Diamete	Minimum Depth (m)	Velocity Min (m/s)	Velocity Max (m/s)	Per Capita Consum	Design Period (years)	Design Rainfall (yr)	AREA = 100 Ha									Total Flow (Q) (m3/s)	Pipe Distribution (km)			Costs		
								Density 1: 150 inh/Ha			density 2: 500 inh/Ha			Density 3: 1700 inh/Ha									
								S1	S2	S3	s1	s2	s3	s1	s2	s3		< 500 mm	500-1000	>1000 mm	CI	O&M	otal (NP
19	225	2	0.75	10	150	20	5	< 3%									5.816	30	1.6	1.04	75.00	11.25	86.25
20	225	2	0.75	10	150	20	5		3-10%								6.636	30	1.6	1.04	70.50	10.58	81.08
21	225	2	0.75	10	150	20	5			> 10%							7.466	30	1.6	1.04	67.50	10.13	77.63
22	225	2	0.75	10	150	20	5				< 3%						8.347	30	1.6	1.04	90.00	13.50	103.50
23	225	2	0.75	10	150	20	5					3-10%					9.177	30	1.6	1.04	84.60	12.69	97.29
24	225	2	0.75	10	150	20	5						> 10%				10.007	30	1.6	1.04	81.00	12.15	93.15
25	225	2	0.75	10	150	20	5							< 3%			11.865	30	1.6	1.04	110.00	16.50	126.50
26	225	2	0.75	10	150	20	5								3-10%		12.685	30	1.6	1.04	103.40	15.51	118.91
27	225	2	0.75	10	150	20	5									> 10%	13.515	30	1.6	1.04	99.00	14.85	113.85

Estimation of Costs for Pumps

$$C_{Pumps} = \sum_{i=1}^{n} a_i * Q_i^{b_i}$$

The cost depends on the flow or capacity required

The number of pumps required in the system can be estimated according with the topography and the slope. Earle et al, 1999.
http://www.wateronline.com/doc.mvc/Estimating-Sewer-Costs-A-Mathematical-Model-0001

Flat Terrain (<3%): 1 Pump of 12 l/s per 1.6 Km and 2 Pumps of 6 l/s per 1.6 Km.
Rolling Terrain (3-10%) : 1 Pump of 6 l/s per 1.6 Km
Steep Terrain (>10%): 2 Pumps of 12 l/s per 1.6 Km and 2 Pumps of 6 l/s per 1.6 Km

References:
Farrell, R.P., 1992, Two decades of experience with pressure sewer systems, *Journal of the New England Water Pollution Control Association.*
R.S. Means Co., 1996, Site Work and Landscape Cost Data, 16th Kingston, Massachusetts.
Environment One Corporation, 1995, Low-pressure sewer systems using environment one grinder pumps, Schenectady, New York.

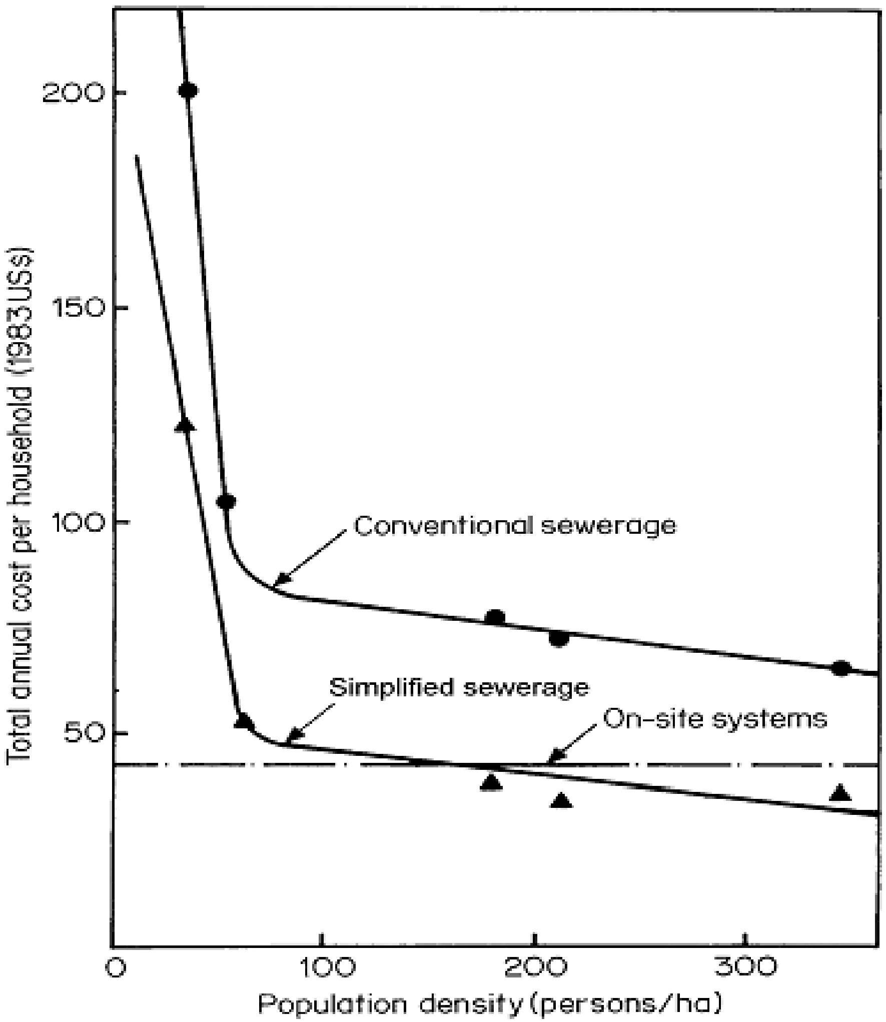
Simplified Sewerage or Condominial Sewerage

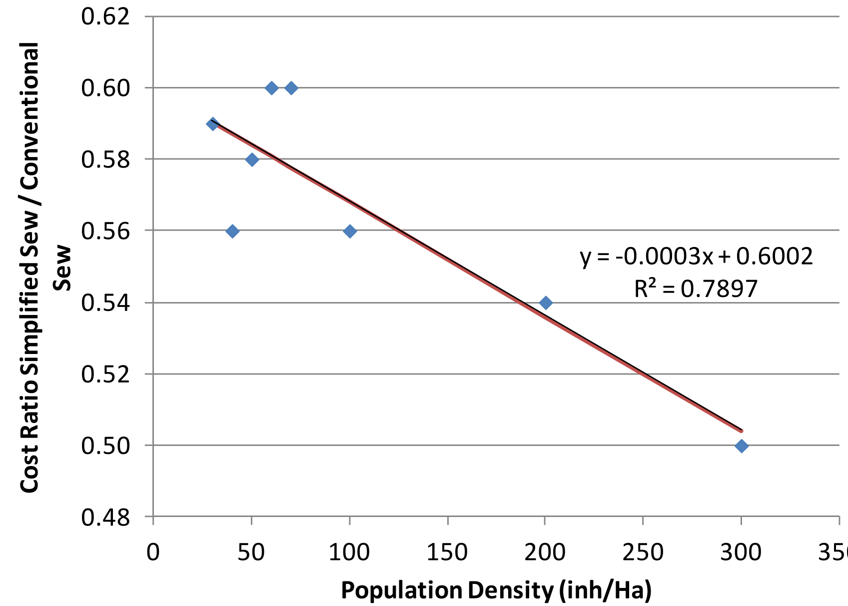
Simplified sewerage is an off-site sanitation technology that removes all wastewater from the household environment. Conceptually it is the same as conventional sewerage, but with conscious efforts made to eliminate unnecessarily conservative design features and to match design standards to the local situation. Mara et all, 2000.

Key Features

Layout: in-block system , routed through private land, either back or front yards.

Depth and diameter: shallow depths, often with covers of 0.4 m. or less. The minimum allowable sewer diameter is 100 mm, rather than the 150 mm or more that is normally required for conventional sewerage. The relatively shallow depth allows small access chambers to be used rather than large expensive manholes/chambers.



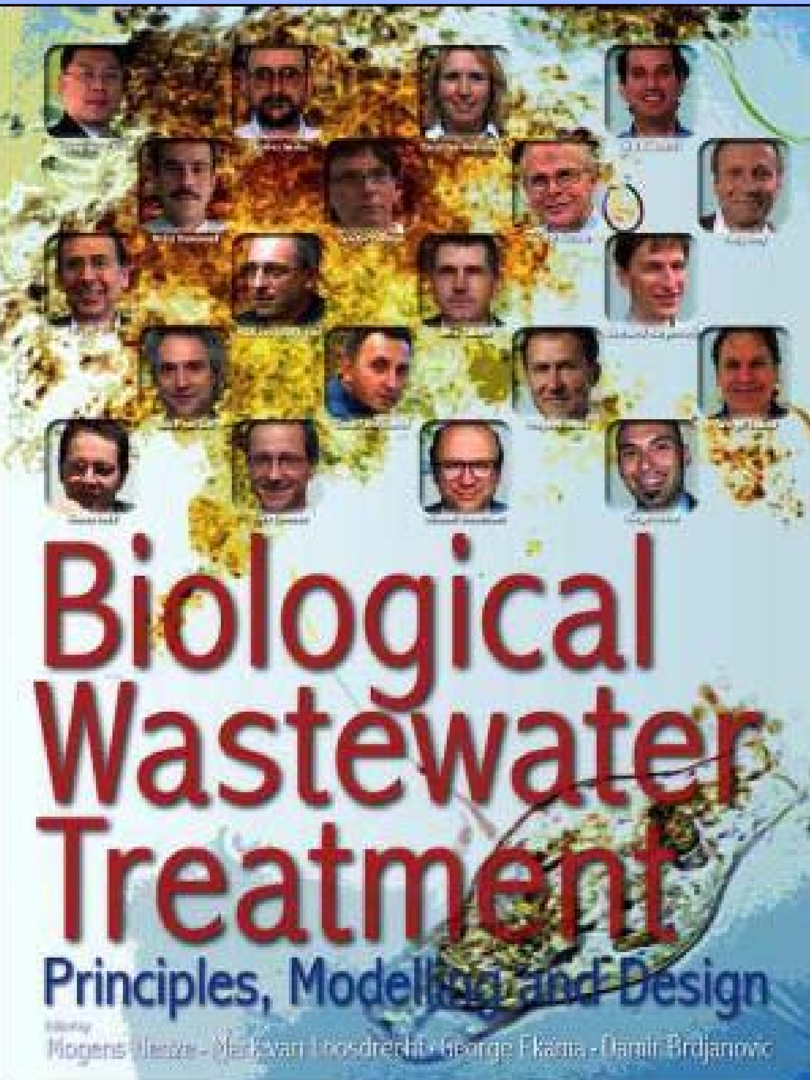


Based on the Brazil Experience. The simplified sewerage alternative is between 40% to 50% cheaper than conventional sanitary sewers.

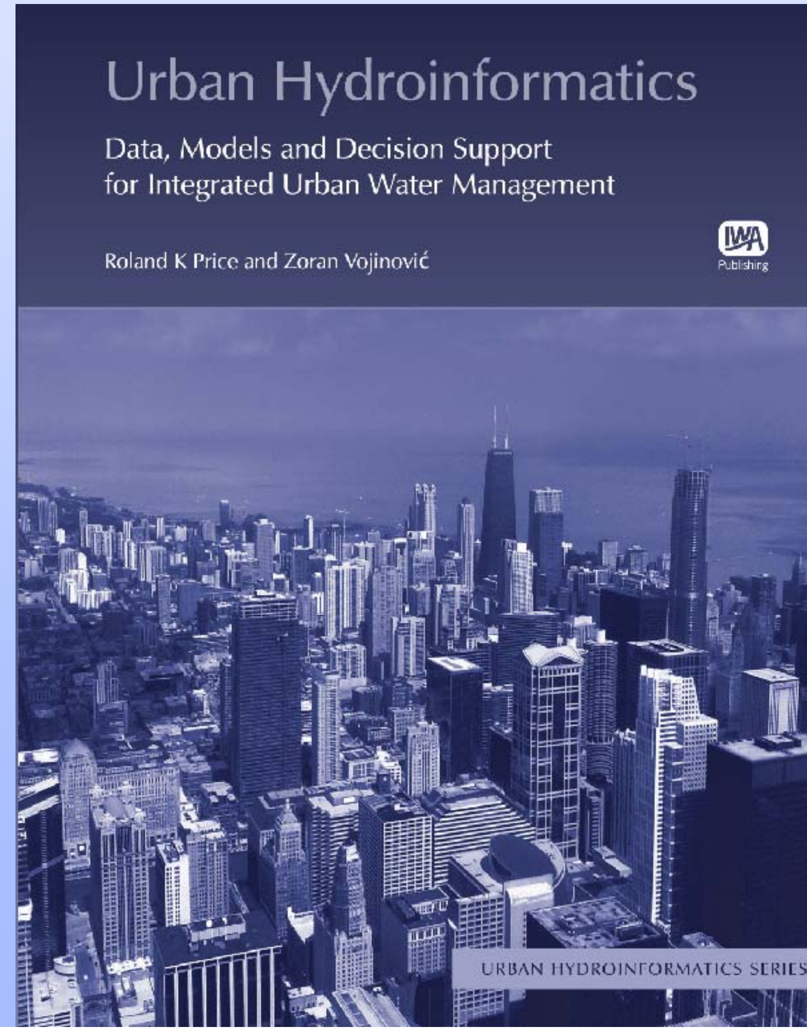
Costs of conventional and simplified sewerage and on-site sanitation in Natal in northeast Brazil in 1983. Source: Sinnatamby, 1983

References

z.vojinovic@unesco-ihe.org



International Water Association



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Thank you for your attention!

DEMONSTRATION

RETICULATION SELECTION MODULE - DEMO

Selection of sewer reticulation network in relation to:

- Different Population Density
- Slope of Terrain

EXERCISE: Wastewater Technology Selection Module

Step 1

Urban area in Malaysia (KL): 30 Hectares
Wastewater production per person per day:
Group a) 100 liters/person/day
Group b) 150 liters/person/day
Group c) 200 liters/person/day

Wastewater source: Group a) Grey water (non-sewer);
Group b) Sanitary Sewage;
Group c) Combined Sewage;

Design Horizon: 20 years;
O&M as % of CI: 3%;
Discount Rate: 5%
Factors for Consideration: Efficiency, Shock Resistance, Economy;

EXERCISE: Wastewater Technologies Selection Module

Typical Values

BOD5:	**54 (15 – 80)**
COD:	**100 (25 - 200)**
TotP:	**2 (1-3)**
TotN:	**5 (2 – 15)**
TSS:	**10**
Vol/C:	**200 (100 – 300)**

EXERCISE: Wastewater Technology Selection Module

Step 2

Government is considering to change to Singaporean Stds

What are the implications?

EXERCISE: Wastewater Technology Selection Module

Step 3

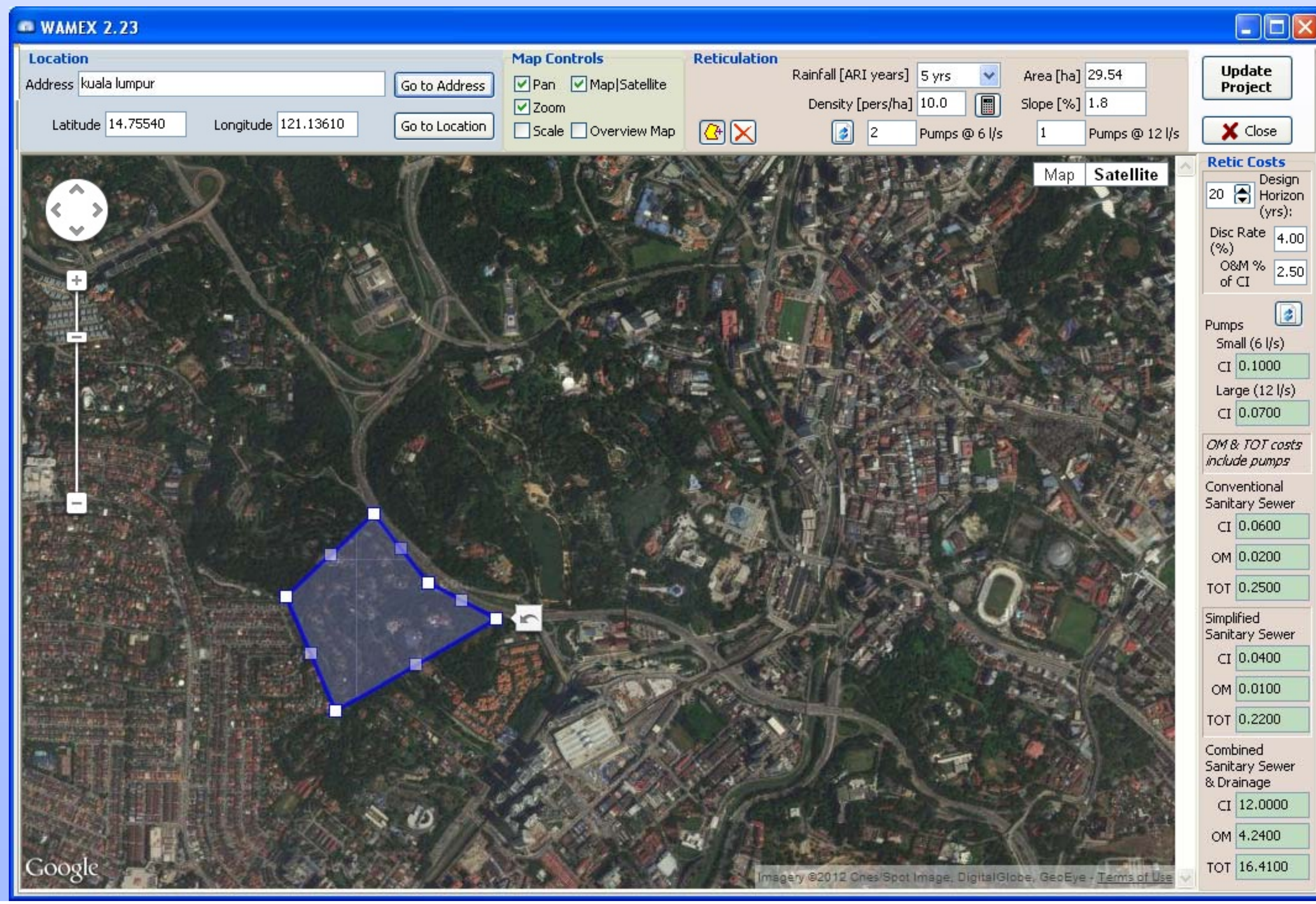
Government is considering to change to European Stds

What are the implications?

EXERCISE: Reticulation Selection Module

Urban area in Malaysia (KL) needs to be sewered:

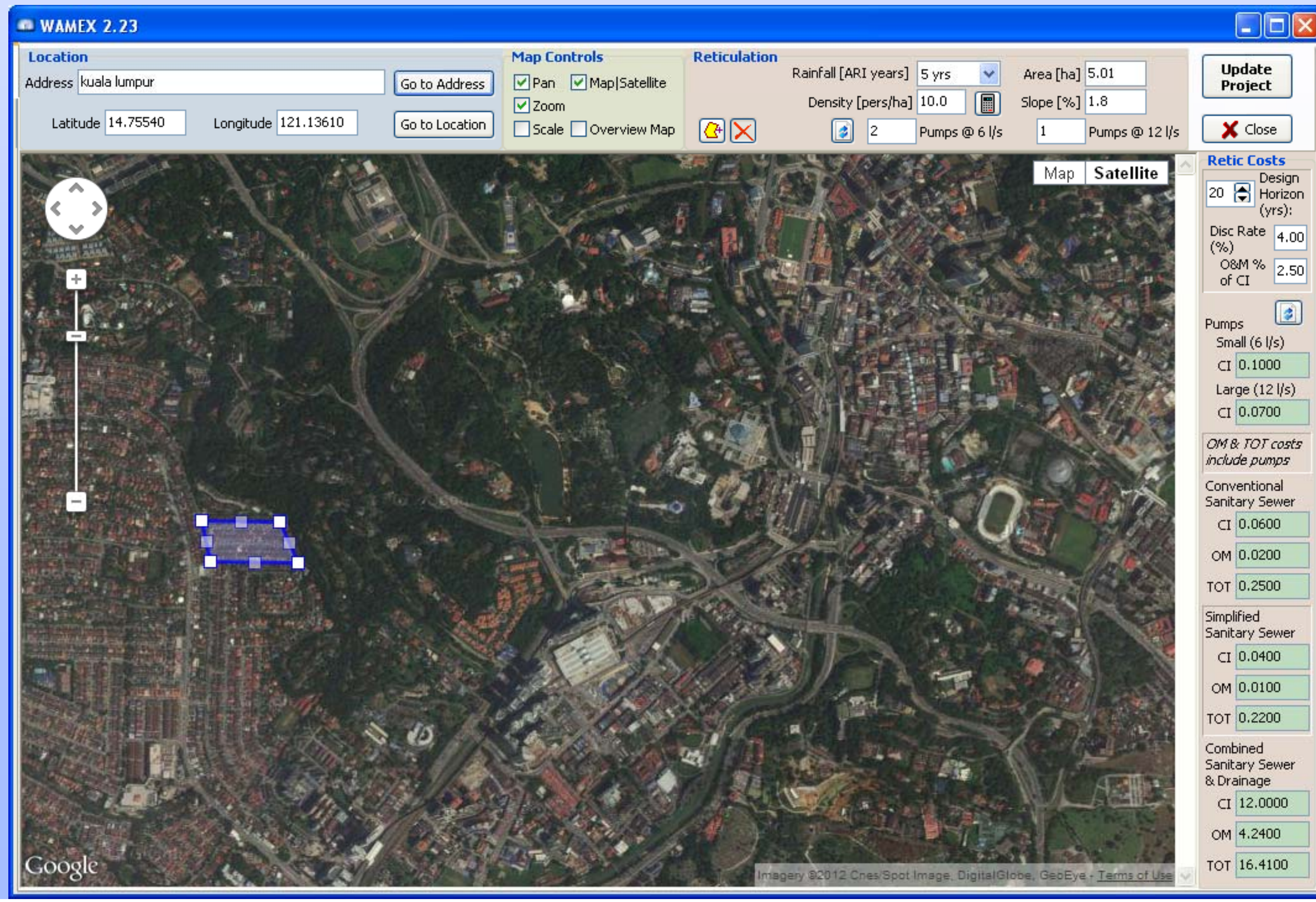
Step 1: Measurements



EXERCISE: Reticulation Selection Module

Approximate development density:

Step 2: Measurements



EXERCISE: Reticulation Selection Module

Terrain slope: 1%
Design Horizon: 50 years;
O&M as % of CI: 2%;
Discount Rate: 5%

Calculate the costs of the following:

- Pumps/pumping stations
- Conventional sanitary sewer
- Simplified sanitary sewer
- Combined Sanitary Sewer and Drainage

EXERCISE: Reticulation Selection Module

Discuss the findings within your group and present the conclusions!