

Appendix — Supplementary Material

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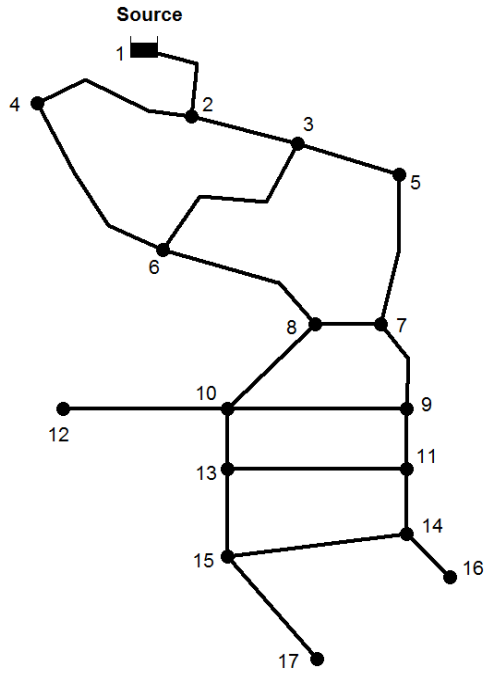
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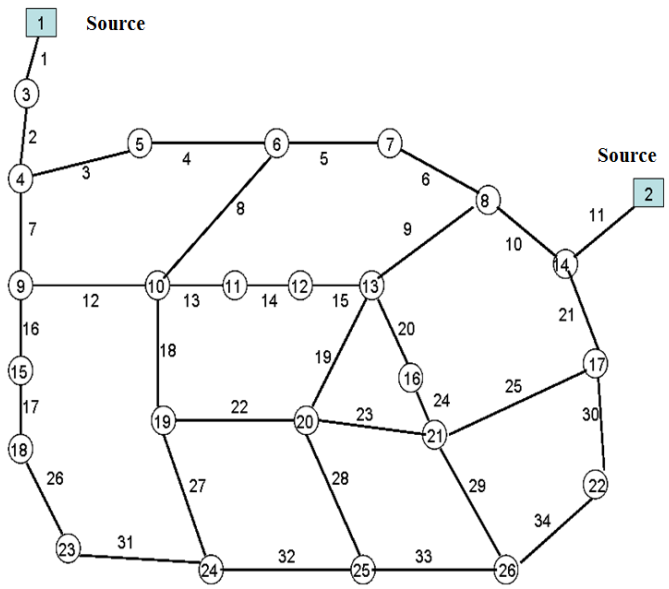
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(a) Wobulenzi network



(b) Kadu network

Figure 4 Layouts of the Wobulenzi (a) and Kadu (b) water distribution networks

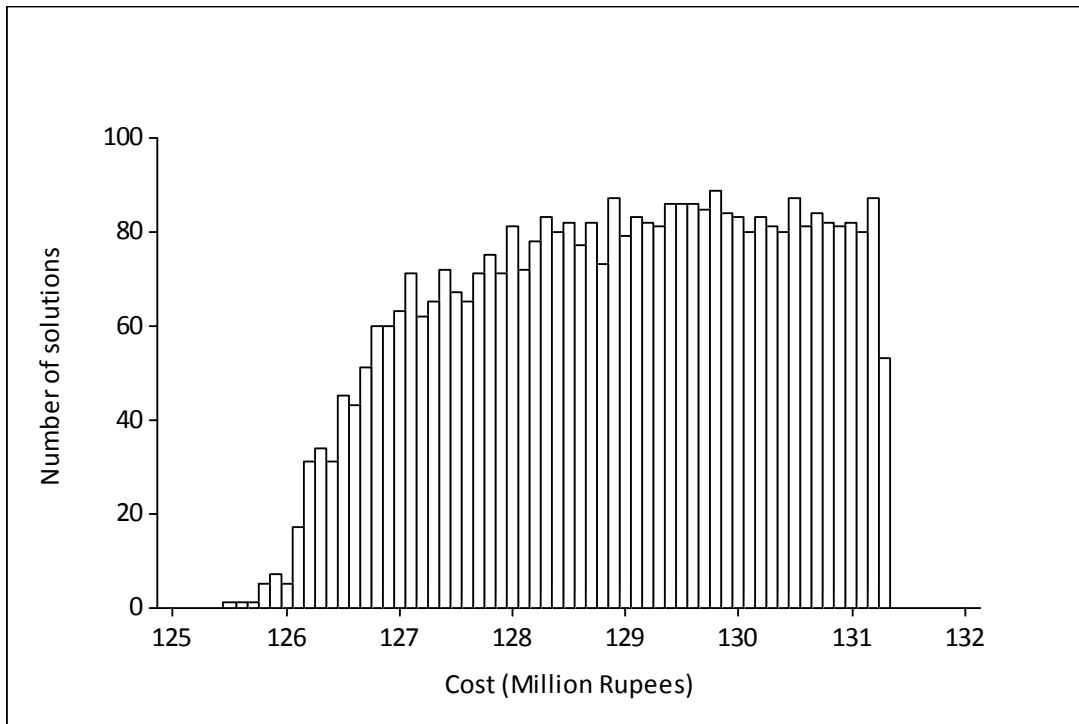


Figure 5 Distribution of the individual solutions found (3834 in total) in 705 optimization runs that are feasible and cheaper than the previous best solution.

The solutions here include the solutions found in the 30 optimization runs with the default values of the coefficients of the Hazen-Williams formula in EPANET 2. Approximately 20-25 solutions in total (out of 3834) may be considered theoretically borderline in terms of feasibility due to modelling and unit conversion errors including minor differences between EPANET 2 and EPANET-PDX. For these theoretically borderline solutions, the shortfall in the residual head at the node with the smallest pressure may be up to about 2 cm approximately.

Table 4 Details of the new solutions for the Wobulenzi network

		Phase I			Phase II					
		Diameter (mm)			Solution 1		Solution 2		Solution 3	
Link	Failure factor ^a	Solution 1	Solution 2	Solution 3	Upgrade option	Dia. (mm)	Upgrade option	Dia. (mm)	Upgrade option	Dia. (mm)
1-2	1.5	250	250	250	Parallel	350	Parallel	250	Parallel	300
2-3	1.5	200	200	250	Parallel	300	Parallel	300	-	-
2-4	1.5	150	150	150	-	-	-	-	-	-
3-5	1.5	200	150	100	Replace	350	-	-	Parallel	300
3-6	1.5	80	200	200	-	-	-	-	-	-
4-6	3.0	80	80	80	-	-	-	-	-	-
5-7	3.0	200	100	80	-	-	-	-	Parallel	250
6-8	3.0	80	150	200	-	-	Replace	300	-	-
7-8	3.0	80	80	80	Replace	300	-	-	Replace	200
7-9	3.0	150	100	100	-	-	-	-	-	-
8-10	3.0	80	150	200	Parallel	200	Replace	250	-	-
9-10	3.0	80	80	80	-	-	-	-	-	-
9-11	5.0	200	80	80	-	-	-	-	-	-
10-12	3.0	80	80	80	-	-	-	-	-	-
10-13	5.0	80	150	150	-	-	-	-	Replace	250
11-13	3.0	80	80	80	-	-	-	-	-	-
11-14	3.0	100	100	150	-	-	-	-	-	-
13-15	3.0	80	100	80	Replace	150	Parallel	150	Replace	200
14-15	3.0	80	80	80	-	-	-	-	-	-
14-16	3.0	80	80	80	-	-	-	-	-	-
15-17	1.0	100	100	80	-	-	-	-	-	-

^aFrom Tanyimboh and Kalungi 2008; failure factors are largely predetermined by land use.

Table 5 Comparison of alternative solutions for the Kadu network

Pipe ID	Diameter (mm)				
	Full Solution Space			Reduced Solution Space	
	Kadu <i>et al.</i> 2008	Haghighi <i>et al.</i> 2011	PF-MOEA	Kadu <i>et al.</i> 2008	PF-MOEA
1	1000	1000	900	1000	900
2	900	900	900	900	900
3	400	400	350	350	400
4	350	350	300	250	250
5	150	150	150	150	150
6	250	250	250	250	200
7	800	800	800	800	800
8	150	150	150	150	150
9	400	400	450	600	600
10	500	500	500	700	600
11	1000	1000	900	900	900
12	700	700	700	700	700
13	800	800	500	500	500
14	400	400	500	450	500
15	150	150	150	150	150
16	500	500	500	450	500
17	350	350	350	350	350
18	350	350	400	400	350
19	150	150	150	450	450
20	200	150	150	150	150
21	700	700	700	600	600
22	150	150	150	150	150
23	400	450	450	150	150
24	400	400	350	400	350
25	700	700	700	500	600
26	250	250	250	200	250
27	250	250	250	350	300
28	200	200	300	250	300
29	300	300	200	150	200
30	300	300	250	300	300
31	200	200	150	150	150
32	150	150	150	150	150
33	250	200	150	150	150
34	150	150	150	200	150
Cost (Rupees)	131,678,935	131,312,815	125,460,980	126,368,865	125,826,425
Evaluations	120,000 ^a	4,440 ^a	436,000	25,200 ^a	82,400

^aInfeasible solutions (based on EPANET 2 with $\alpha = 1.85$; $\beta = 4.87$; $\omega = 10.68$)

Table 6 Comparison of nodal heads from alternative solutions of the Kadu network

Node ID	Required head (m)	Available head (m) (based on EPANET 2 with $\alpha=1.85$; $\beta=4.87$; $\omega=10.68$)				
		Full Solution Space			Reduced Solution Space	
		Kadu <i>et al.</i> 2008 ^a	Haghighi <i>et al.</i> 2011 ^a	PF-MOEA	Kadu <i>et al.</i> 2008 ^a	PF-MOEA
1 ^b	100.00	100.00	100.00	100.00	100.00	100.00
2 ^b	95.00	95.00	95.00	95.00	95.00	95.00
3	85.00	98.95	98.96	98.28	98.98	98.26
4	85.00	95.65	95.66	95.04	95.76	94.98
5	85.00	90.85	90.85	87.47	88.79	90.68
6	85.00	89.40	89.41	85.63	85.28	85.07
7	82.00	87.75	87.73	85.83	87.99	82.95
8	82.00	89.99	89.96	88.82	91.62	89.35
9	85.00	91.77	91.79	91.12	91.83	91.05
10	85.00	89.05	89.08	88.30	88.88	88.22
11	85.00	88.85	88.88	86.42	87.1	86.38
12	85.00	84.98* (0.02)	85.01	85.13	85.13	85.12
13	82.00	82.02	81.88* (0.12)	83.25	86.73	84.85
14	82.00	94.49	94.49	94.14	94.13	94.15
15	85.00	88.44	88.46	87.97	87.11	87.92
16	82.00	84.53	84.81	83.11	82.05	83.04
17	82.00	90.88	90.88	90.69	90.29	90.04
18	85.00	85.46	85.47	85.39	85.24	85.39
19	82.00	85.11	85.24	86.14	85.93	83.82
20	82.00	82.1	83.78	83.15	83.72	82.07
21	82.00	87.39	87.38	87.37	83.98	87.00
22	80.00	86.45	86.55	80.69	84.8	85.50
23	82.00	82.09	82.07	82.96	82.17	83.05
24	80.00	79.94* (0.06)	79.89* (0.11)	80.28	83.63	80.86
25	80.00	79.96* (0.04)	79.77* (0.23)	81.10	80.15	80.54
26	80.00	82.87	84.04	80.04	78.38* (1.62)	80.39
Total shortfall in head (m)		0.12 ^a	0.46 ^a	0.00	1.62 ^a	0.00
Cost (Rupees)		131,678,935	131,312,815	125,460,980	126,368,865	125,826,425
Function evaluations		120,000	4,440	436,000	25,200	82,400

^a Infeasible solutions; the asterisk indicates a shortfall in head (shown in parentheses).

^b Reservoir (i.e. source with constant head).