

Table 8.4a INITIAL STATISTICS FOR SOURCE 1

Month	Parameter: pH Max Distribution: Normal				Parameter: pH Min Distribution: Normal				Parameter: Lead Distribution: Normal			
	Est. mean	Est. st. dev.	Updated mean	Updated st. dev.	Est. mean	Est. st. dev.	Updated mean	Updated st. dev.	Est. mean, kg	Est. st. dev., kg	Updated mean, kg	Updated st. dev., kg
1	8.5	1.12	-	-	8.5	1.33	-	-	0.41	0.31	-	-
2	7.6	0.73	8.03	1.06	7.6	1.15	8.03	1.33	1.08	0.32	0.76	0.51
3	8.3	0.78	8.12	0.98	8.3	0.97	8.12	1.22	1.09	2.72	0.87	1.62
4	8.1	0.74	8.12	0.92	8.1	0.90	8.12	1.14	0.515	0.67	0.78	1.45

Table 8.4b INITIAL STATISTICS FOR SOURCE 2

Month	Parameter: Chromium Distribution: Normal				Parameter: Copper Distribution: Lognormal				Parameter: Fluoride Distribution: Normal			
	Est. mean, kg	Est. st. dev., kg	Updated mean, kg	Updated st. dev., kg	Est. mean, log kg	Est. st. dev., log kg	Updated mean, log kg	Updated st. dev., log kg	Est. mean, kg	Est. st. dev., kg	Updated mean, kg	Updated st. dev., kg
1	0.216	0.321	-	-	-0.437	0.369	-	-	24.4	3.79	-	-
2	0.313	0.297	0.266	0.308	-0.685	0.474	-0.565	0.443	25.4	3.49	24.9	3.62
3	0.214	0.214	0.247	0.277	-0.570	0.337	-0.567	0.403	24.7	3.29	24.8	3.46
4	0.132	0.070	0.218	0.246	-1.146	0.404	-0.711	0.502	24.0	4.17	24.6	3.61

Table 8.4c INITIAL STATISTICS FOR SOURCE 3

Month	Parameter: SO_2 Distribution: Normal				Parameter: Phosphate Distribution: Lognormal				Parameter: Suspended Solids Distribution: Lognormal				Parameter: Dissolved oxygen	
	Est. mean, kg	Est. st. dev., kg	Updated mean, kg	Updated st. dev., kg	Est. mean, log kg	Est. st. dev., log kg	Updated mean, log kg	Updated st. dev., log kg	Est. mean, log kg	Est. st. dev., log kg	Updated mean, log kg	Updated st. dev., log kg	Est. mean, mg/l	Updated mean, mg/l
1	1165	470	---	---	2.12	0.339	---	---	3.33	0.218	---	---	3.90	---
2	900	598	1030	555	2.20	0.157	2.16	0.265	3.13	0.282	3.23	0.277	3.80	3.85
3	1395	734	1150	648	2.12	0.268	2.16	0.264	3.40	0.312	3.29	0.302	4.20	3.96
4	1080	642	1133	643	1.85	0.286	2.08	0.313	3.30	0.175	3.29	0.274	4.10	4.00

Table 8.4d INITIAL STATISTICS FOR SOURCE 4, PIPE 1

Month	Parameter: Phosphates Distribution: Normal				Parameter: Suspended Solids Distribution: Normal			
	Est. mean, kg	Est. st. dev., kg	Updated mean, kg	Updated st. dev., kg	Est. mean, kg	Est. st. dev., kg	Updated mean, kg	Updated st. dev., kg
1	-	-	-	-	-	-	-	-
2	0.225	0.101	-	-	13.9	4.23	-	-
3	-	-	-	-	-	-	-	-
4	0.755	1.356	0.499	0.925	13.7	5.23	13.5	3.38

Table 8.4e INITIAL STATISTICS FOR SOURCE 4, PIPE 2

Month	Parameter: Phosphates Distribution: Normal				Parameter: Suspended Solids Distribution: Normal			
	Est. mean, kg	Est. st. dev., kg	Updated mean, kg	Updated st. dev., kg	Est. mean, kg	Est. st. dev., kg	Updated mean, kg	Updated st. dev., kg
1	-	-	-	-	-	-	-	-
2	3.20	0.526	-	-	88.0	156.3	-	-
3	-	-	-	-	-	-	-	-
4	4.35	4.096	3.78	2.719	62.0	62.3	75.0	108.2

Table 8.5 EXPECTED DAMAGE AND PROBABILITY OF VIOLATION

Source	Pipe	Est. source flow, MI/day	Stream flow, MI/day	Parameter	Expected damage, D_{ij}	Probability of no violation, $P_{ij}, \%$	Expected damage for source, C_i	Probability of no violation for source, $P_i, \%$
1	1	0.961	100	pH	0.29	80.0	1.60	64.0
				Lead	1.60	80.0		
2	1	0.845	320	Chromium	0.08	82.6	0.12	77.0
				Copper	0.12	96.1		
				Fluoride	0.00	93.1		
3	1	108	525	BOD ₅	3.22	100.0	3.60	35.6
				Phosphate	3.64	97.6		
				Suspended Solids	0.37	87.8		
4	1	0.297	300	Phosphates	-	100.0	0.29	13.0
				Suspended Solids	-	51.8		
	2	1.016	Phosphates	0.29	54.4			
				Suspended Solids	0.03	46.0		

to sample the sources are given in Table 8.6, and the priority list is given in Table 8.7. For the purposes of this example, it was assumed that the sources could be sampled between 0 and 10 times. From the table, one sees that Sources 1 and 3 should be sampled with higher priority than Sources 2 and 4. This is due to the much larger expected damage from the former sources. Source 4 appears relatively early in the list, but most of the samples have low priority. This is because the probability of violation is very large and therefore the chances are that the source will be caught in violation after one or two visits. Further sampling is therefore not necessary. Source 2 has a small expected damage and a fairly large probability of no violation resulting in a low sampling priority. Table 8.7 also gives the marginal return, "cost" of undetected violations and resources used. The marginal returns are decreasing (the list has been ordered in just this manner). The "cost" of undetected violations is decreasing, and the resources required are increasing as more sources are sampled.

If only, say, \$10,000 were available for monitoring, then only the sources with priority 1 through 18 would be monitored. The sampling frequencies for this case are shown in Table 8.8. If, on the other hand, a maximum allowed "cost" of undetected violations of, say, 1.0 were specified, then sources with priorities 1 through 19 would be sampled. The sampling frequencies for this case are shown in Table 8.9. The priority list in Table 8.7 also shows when the return from monitoring (i.e. the marginal return) starts becoming negligible; the return, in this case, for monitoring more than, say, 25 sources is very small.

VIII.3 SENSITIVITY STUDIES

This subsection investigates the effect of various changes in the inputs and design parameters of the example just discussed.

Table 8.6. RESOURCES NEEDED TO SAMPLE

Source	Field and office costs	Laboratory costs	Total Cost r_i
1	\$525	\$10.50	\$535.50
2	\$525	\$23.00	\$548.00
3	\$525	\$38.00	\$563.00
4	\$525	\$30.00	\$555.00

Table 8.7 PRIORITY LIST OF SAMPLES FOR SIMPLIFIED EXAMPLE

PRIORITY	SOURCE SAMPLED	MARGINAL RETURN %/100	COST OF UNDETECTED VIOLATIONS	RESOURCES REQUIRED
1	1	.10774492	5.07571	535.50
2	3	.09326524	4.55342	1095.50
3	3	.07989130	4.10603	1655.50
4	1	.06899248	3.73658	2191.00
5	3	.06843515	3.35334	2751.00
6	3	.05862177	3.02506	3311.00
7	3	.05021559	2.74385	3871.00
8	4	.04526206	2.49264	4426.00
9	1	.04417806	2.25607	4961.50
10	3	.04301484	2.01519	5521.50
11	3	.03684665	1.80285	6081.50
12	3	.03156296	1.63209	6641.50
13	1	.02825461	1.48061	7177.00
14	3	.02703693	1.32920	7737.00
15	3	.02315492	1.19951	8297.00
16	1	.01811409	1.10251	8832.50
17	1	.01159902	1.04039	9368.00
18	1	.00742722	1.00062	9903.50
19	4	.00590254	.96786	10458.50
20	2	.00556719	.93735	11008.50
21	1	.00475588	.91188	11542.00
22	2	.00412025	.88931	12090.00
23	2	.00304938	.87260	12638.00
24	1	.00304534	.85629	13173.50
25	2	.00225683	.84392	13721.50
26	1	.00195003	.83348	14257.00
27	2	.00167027	.82432	14805.00
28	2	.00123616	.81755	15353.00
29	2	.00091488	.81254	15901.00
30	4	.00076974	.80826	16456.00
31	2	.00067710	.80455	17004.00
32	2	.00050112	.80181	17552.00
33	2	.00037087	.79978	18100.00
34	4	.00010038	.79922	18655.00
35	4	.00001309	.79915	19210.00
36	4	.00000171	.79914	19765.00
37	4	.00000022	.79914	20320.00
38	4	.00000003	.79914	20875.00
39	4	.00000000	.79914	21430.00
40	4	.00000000	.79914	21985.00

Table 8.8 FINAL ALLOCATION GIVEN MONETARY BUDGET

FINAL ALLOCATION

BUDGET 10000.00

SOURCE	MIN. NO. SAMPLES REQUIRED	MAX. NO. SAMPLES ALLOWED	TIMES SAMPLED	RESOURCES USED	COST OF UNDETECTED VIOLATIONS
1	0	10	7	3748.50	.07081
2	0	10	0	.00	.11738
3	0	10	10	5600.00	.77476
4	0	10	1	555.00	.03767
TOTAL RESOURCES USED 9903.50					
FINAL COST OF UNDETECTED VIOLATIONS					1.00062

Table 8.9 FINAL ALLOCATION GIVEN MAXIMUM ALLOWED COST OF UNDETECTED VIOLATIONS

FINAL ALLOCATION

MAXIMUM ALLOWED COST OF UNDETECTED VIOLATIONS 1.00000

SOURCE	MIN. NO. SAMPLES REQUIRED	MAX. NO. SAMPLES ALLOWED	TIMES SAMPLED	RESOURCES USED	COST OF UNDETECTED VIOLATIONS
1	0	10	7	3748.50	.07081
2	0	10	0	.00	.11738
3	0	10	10	5600.00	.77476
4	0	10	2	1110.00	.00491
TOTAL RESOURCES USED 10458.50					
FINAL COST OF UNDETECTED VIOLATIONS					.96786