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COST EFFECTIVENESS STUDY OF WASTEWATER MANAGEMENT SYSTEMS FOR SELECTED U.S. COAST GUARD VESSELS,

Volume I. Results of Cost and Effectiveness Analyses and Selection of Optimum Candidate Systems

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16. Abstract

A generalized methodology for quantifying the life-cycle cost and effectiveness of candidate system/vessel combinations, as well as optimum candidate selection procedures for choosing the most cost-effective system, have been developed and documented.

In order to test this analysis methodology in a realistic environment, 18 candidate wastewater management systems (WMS) concepts in configurations suitable for handling black and gray wastewaters on board six U. S. Coast Guard cutters were developed. The 18 WMS concepts were synthesized as hybrid combinations of commercially available MSDs, namely, Jered, GATX, Chrysler, Grumman, and a CHT (Collection, Holding and Transfer) system.

Mission profile data for each vessel were collected and analyzed to determine the mission profile characteristics which affect WMS design and operation.

Detailed life-cycle cost and effectiveness models suitable for analyzing candidate WMS as a function of vessel were developed. Generic MSD cost and effectiveness data were generated.

An installation analysis was performed to establish viable candidate system/vessel combinations and to develop required installation related cost and effectiveness data.

Each viable candidate system/vessel combination was then subjected to a life-cycle cost and an effectiveness analysis. An optimum candidate system for each vessel as a function of holding time objective was determined. The results of these analyses are presented, together with conclusions and recommendations.

17. Key Words
Attribute
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MSD
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COST EFFECTIVENESS STUDY OF WASTEWATER MANAGEMENT SYSTEMS FOR SELECTED U.S. COAST GUARD VESSELS

Volume I - Results of Cost and Effectiveness Analyses and Selection of Optimum Candidate Systems

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April 1977

FINAL REPORT

For

U.S. Dept. of Transportation
U.S. Coast Guard
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This study was conducted under the technical direction of Mr. Thomas S. Scarano of the Office of Research and Development, U.S. Coast Guard. His suggestions for the goals of the study profoundly influenced its course and resulted in a generalization of both the cost effectiveness analysis methodology as well as its application to the candidate system/vessel combinations.

Mr. Scarano and Lt. Ed Magsig of the Office of Engineering, together with Mr. James A. White, of the Office of Research and Development, provided valuable assistance in the formulation of the assumptions and guidelines governing this study and actively participated in the development of the effectiveness model used as the basis for quantifying effectiveness. Mr. Scarano developed the weights for the measures of effectiveness and for the associated factors and subfactors.

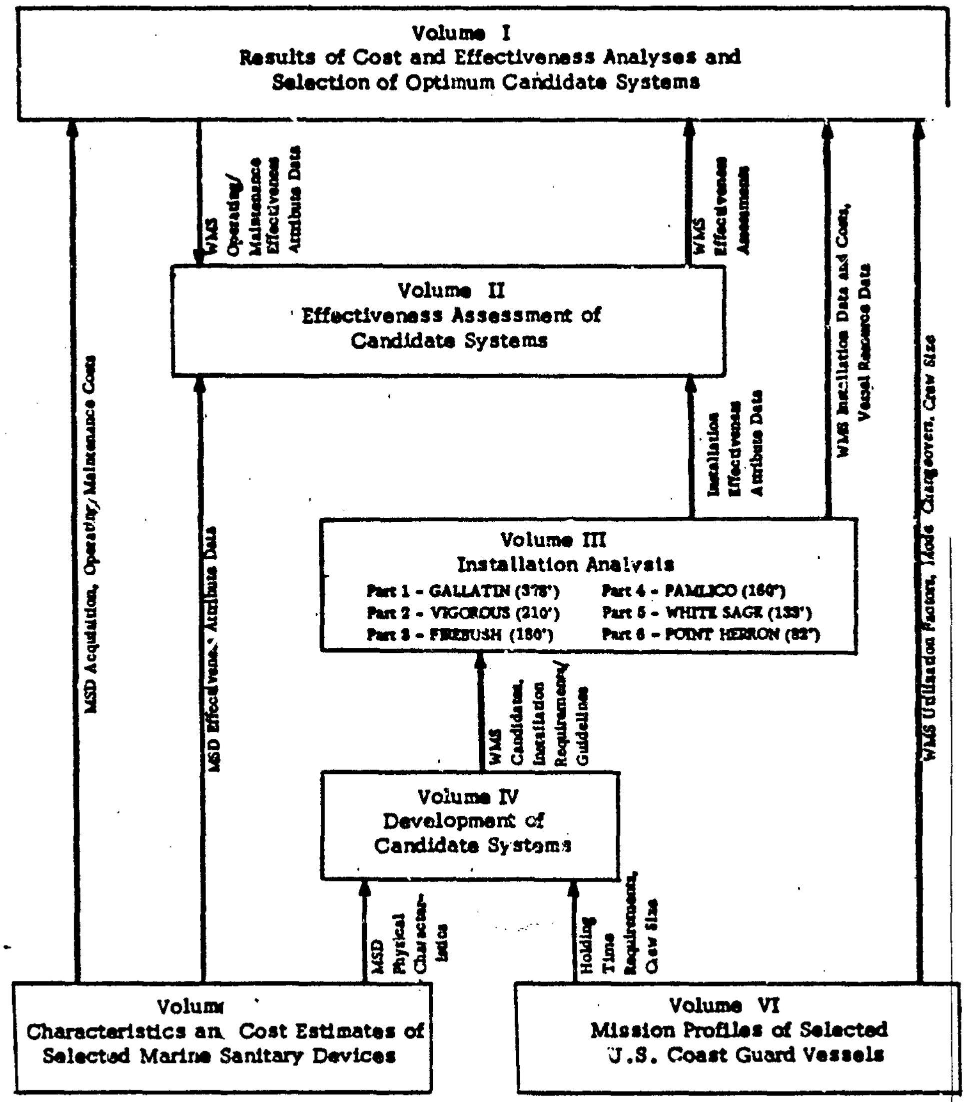
The installation analysis was performed in consultation with George G. Sharp, Inc., 100 Church Street, New York, N.Y. 10007.

The cooperation of the following MSD equipment manufacturers in providing requested product literature, technical data and cost information is greatly appreciated: Chrysler, GATX, Grumman, Jered, and Thiokol.

The cooperation of the officers of U.S. Coast Guard Cutters [GALLATIN (WHEC - 721), VIGOROUS (WHEC - 627), FIREBUSH (WLB - 393), WHITE SAGE (WLM - 544), POINT HERRON (WPB - 82318), PAMLICO (WLIC - 800), CLAMP (WLIC - 75306), and SHADBUSH (WLI - 74287)] in providing the requested vessel data and in making available the ship logs and assisting in the interpretation of the log entries to develop the necessary data for the mission profile analysis is greatly appreciated.

PREFACE

The relationship among the volumes of the report is depicted below. This relationship does not convey all the information contained within each volume.



SUMMARY OF WMS LIFE-CYCLE COST AND EFFECTIVENESS ANALYSES

Vessel GALLATIN (378') Crew Size 152 WMS UTILIZATION FACTOR (%) 11 Sheet 1 of 6

TYPE				HOLDING CAPACITY		WMS LIFE CYCLE COST(1) ESTIMATES												RATIO OF COST(1) TO EFFECTIVENESS RATING		
		TREATMENT/DISPOSAL SUBSYSTEM				FIXED COSTS			RECURRING EXPENDITURES					TOTAL LIFE CYCLE COST(1)						
WMS No.	COLLECTION/TRANSPORT SUBSYSTEM (Black)	BLACK	GRAY	BLACK (%)*	GRAY (%)*	Acquisition $K / % of Total	Installation $K / % of Total	Total Fixed Costs $K / % of Total	Operating $K / % of Total	Preventive Maintenance (PM) $K / % of Total	Corrective Maintenance (CM) $K / % of Total	Overhaul Maintenance $K / % of Total	Total Recurring Costs $K / % of Total	$K	Relative (%) (2)	Cost/Man ($K/Man)	EFFECTIVENESS RATING	PER VESSEL ($K)	PER MAN ($K/Man)	(3) RELATIVE (%)
1	Gravity Collect Oil Recircul. (Chrysler)	Holding Tank	Holding Tank	100	19	-0- -0-	47.260 81	47.260 81	1.942 3	2.876 5	2.636 5	3.669 6	11.123 19	58.383	13	0.384	87	67.107	.441	9
2		Chrysler + Hld Tank	Holding Tank	100	18	27.512 20	42.370 31	69.882 51	26.004 19	3.957 3	21.764 16	14.381 11	66.106 49	135.988	31	0.895	72	188.872	1.243	25
3		Chrysler + Incin.	Holding Tank	100	13	51.960 24	71.220 33	123.180 57	35.153 16	2.654 1	38.557 18	17.039 8	94.303 43	217.483	50	1.431	68	319.828	2.104	42
4	Gravity Collect. (Grumman)	Grum Flow Thru + Hld Tk	Holding Tank	100	17	55.000 48	39.980 35	94.980 83	4.848 4	4.848 4	4.289 4	6.300 5	19.824 17	114.804	26	0.756	77	149.096	.980	20
5		Grumman Flow Thru + Holding Tank		N/A																►
6	Gravity Collect.	Holding Tank	Grum Flow Thru + Hld Tk	N/A																►
7	Gravity Collect. (Grumman)	Grum Flow Thru + Incin.	Holding Tank	100	17	110.000 50	69.060 31	179.060 81	18.612 8	3.724 2	6.108 3	14.492 6	42.936 19	221.996	51	1.461	72	308.328	2.028	40
8		Grumman Flow Thru + Incinerator		N/A																►
9	Vacuum Collect. (Jered)	Holding Tank	Holding Tank	100	21	49.900 22	48.310 21	98.210 43	21.955 10	12.725 6	51.547 23	41.037 18	127.264 57	225.474	52	1.483	64	352.303	2.317	46
10	↓	Incinerator	Holding Tank	100	21	123.400 28	75.900 17	199.300 45	35.239 8	12.762 3	107.542 25	80.160 19	235.703 55	435.003	100	2.862	57	763.163	5.020	100
11	↓	GATX Evaporator	Holding Tank	100	17	150.900 43	47.340 14	198.240 57	31.221 9	21.770 6	54.078 15	44.212 13	151.287 43	349.527	80	2.300	58	602.632	3.964	79
12	↓	Holding Tank	Grum Flow Thru + Hld Tk	N/A																►
13	↓	Incinerator	Grum Flow Thru + Incin.	N/A																►
14	M/T Pump Collect. (GATX)	Holding Tank	Holding Tank	100	30	53.400 21	47.710 20	101.110 41	4.031 1	22.176 9	94.540 38	27.472 11	148.219 59	249.329	57	1.640	72	346.290	2.278	45
15		Incinerator	Holding Tank	100	33	94.650 23	78.120 19	172.770 42	16.805 4	20.996 5	149.884 37	46.500 12	234.185 58	406.995	94	2.677	65	626.084	4.118	82
16	↓	GATX Evaporator	Holding Tank	100	17	163.500 43	41.720 11	205.220 54	13.291 4	31.227 8	97.072 26	30.664 8	172.234 46	377.454	87	2.483	67	563.364	3.706	74
17	↓	Holding Tank	Grum Flow Thru + Hold Tk	N/A																►
18	↓	Incinerator	Grum Flow Thru + Incin.	N/A																►

* Based on the maximum holding time of 97.5 hours. The next smaller holding time of 88.0 hours would satisfy approximately 98% of all holding time requirements.

(1) Based on:

- . WMS utilization factor determined from vessel mission profile study.
- . An effective discount rate of 10%.
- . An assumed WMS useful life of 10 years.

(2) Relative cost (%) based on highest WMS cost for the vessel.

(3) Relative ratio (%) of cost to effectiveness rating based on highest value of such WMS ratios for the vessel.

N/A - Not a viable candidate for this vessel.

SUMMARY OF WMS LIFE-CYCLE COST AND EFFECTIVENESS ANALYSIS

Vessel VIGOROUS (210') Crew Size 60 WMS UTILIZATION FACTOR (%) 5.6 Sheet 2 of 6

WMS No.	TYPE: Collection/Transport Subsystem (Black)	TYPE: Treatment/Disposal Subsystem: Black	TYPE: Treatment/Disposal Subsystem: Gray	Holding Capacity: Black (%) *	Holding Capacity: Gray (%) *	Fixed Costs: Acquisition ($K / % of Total)	Fixed Costs: Installation ($K / % of Total)	Fixed Costs: Total Fixed Costs ($K / % of Total)	Recurring Expenditures: Operating ($K / % of Total)	Recurring Expenditures: Preventive Maintenance (PM) ($K / % of Total)	Recurring Expenditures: Corrective Maintenance (CM) ($K / % of Total)	Recurring Expenditures: Overhaul Maintenance ($K / % of Total)	Recurring Expenditures: Total Recurring Costs ($K / % of Total)	Total Life Cycle Cost (1): $K	Total Life Cycle Cost (1): Relative (%) (2)	Total Life Cycle Cost (1): Cost/Man ($K/Man)	Effectiveness Rating (3)	Ratio of Cost (1) to Effectiveness Rating: Per Vessel ($K)	Ratio of Cost (1) to Effectiveness Rating: Per Man ($K/Man)	Ratio of Cost (1) to Effectiveness Rating: (3) Relative (%)
1	Gravity Collect Oil Recircul. (Chrysler)	Holding Tank	Holding Tank	40	1	-0- -0-	10.200 65	10.200 65	0.645 4	1.438 9	1.221 8	2.203 14	5.509 35	15.709	7	0.262	84	18.701	.312	5
2		Chrysler + Hld Tank	Holding Tank	56	1	9.486 21	13.230 29	22.716 50	8.756 19	1.800 4	7.638 17	5.448 12	43.642 50	46.358	21	0.773	69	67.186	1.120	17
3		Chrysler + Incin.	Holding Tank	N/A																
4	Gravity Collect. (Grumman)	Grum Flow Thru + Hld Tk	Holding Tank	N/A																
5		Grumman Flow Thru + Holding Tank		N/A																
6	Gravity Collect.	Holding Tank	Grum Flow Thru + Hld Tk	N/A																
7	Gravity Collect. (Grumman)	Grum Flow Thru + Incin.	Holding Tank	N/A																
8		Grumman Flow Thru + Incinerator		N/A																
9	Vacuum Collect. (Jered)	Holding Tank	Holding Tank	48	1	29.150 23	16.270 13	45.420 36	11.122 9	7.214 6	34.643 27	28.525 22	81.504 64	126.924	58	2.115	61	208.072	3.468	52
10		Incinerator	Holding Tank	100	1	70.400 32	23.530 11	93.960 43	13.819 6	7.232 3	57.040 26	48.086 22	126.177 57	220.107	100	3.668	55	400.195	6.670	100
11		GATX Evaporator	Holding Tank	N/A																
12		Holding Tank	Grum Flow Thru + Hld Tk	N/A																
13		Incinerator	Grum Flow Thru + Incin.	N/A																
14	M/T Pump Collect. (GATX)	Holding Tank	Holding Tank	100	1	29.530 26	13.650 12	43.180 38	1.512 1	11.318 10	43.798 39	14.074 12	70.702 62	113.882	52	1.898	74	153.895	2.565	38
15		Incinerator	Holding Tank	100	3	70.780 36	20.890 11	91.670 47	4.197 2	11.337 6	55.092 28	33.634 17	104.260 53	195.930	89	3.266	65	301.431	5.024	75
16		GATX Evaporator	Holding Tank	100	1	83.080 48	11.560 7	94.640 55	3.287 2	15.847 9	44.444 25	16.683 9	79.261 45	173.901	79	2.898	69	252.030	4.201	63
17		Holding Tank	Grum Flow Thru + Hold Tk	N/A																
18		Incinerator	Grum Flow Thru + Incin.	N/A																

* Based on the maximum holding time of 172.0 hours. The next smaller holding time of 72.0 hours would satisfy approximately 97% of all holding time requirements.

(1) Based on:
- WMS utilization factor determined from vessel mission profile study.
- An effective discount rate of 10%.
- An assumed WMS useful life of 10 years.

(2) Relative cost (%) based on highest WMS cost for the vessel.

(3) Relative ratio (%) of cost to effectiveness rating based on highest value of such WMS ratios for the vessel.

N/A - Not a viable candidate for this vessel.

SUMMARY OF WMS LIFE-CYCLE COST AND EFFECTIVENESS ANALYSES

Vessel FIREBUSH (180') Crew Size 50 WMS UTILIZATION FACTOR (%) 14.1 Sheet 3 of 6

W M S No.	TYPE			HOLDING CAPACITY		WMS LIFE CYCLE COST(1) ESTIMATES																			EFFECTIVENESS RATING (%)	RATIO OF COST(1) TO EFFECTIVENESS RATING		
	COLLECTION/TRANS-PORT SUBSYSTEM (Black)	TREATMENT/DISPOSAL SUSSYSTEM				FIXED COSTS						RECURRING EXPENDITURES										TOTAL LIFE CYCLE COST(1)				PER VESSEL ($K)	PER MAN ($K/ Man)	(3) RELA-TIVE (%)
		BLACK	GRAY	BLACK (%) *	GRAY (%) *	Acquisition		Installation		Total Fixed Costs		Operating		Preventive Maintenance (PM)		Corrective Maintenance (CM)		Overhaul Maintenance		Total Recurring Costs		$K	Relative (%) (2)	Cost/Man ($K/Man)				
						$K	% of Total	$K	% of Total	$K	% of Total	$K	% of Total	$K	% of Total	$K	% of Total	$K	% of Total	$K	% of Total							
1	Gravity Collect	Holding Tank	Holding Tank	100	0	-0-	-0-	16.850	75	16.850	75	2.378	11	1.198	5	0.664	3	1.384	6	5.624	25	22.474	9	0.449	86	26.133	.523	6
2	Oil Recircul. (Chrysler)	Chrysler + Hld Tank	Holding Tank	100	0	9.486	20	12.060	26	21.546	46	11.718	25	1.561	3	7.342	16	5.161	11	25.782	54	47.328	19	0.947	71	66.659	1.333	14
3		Chrysler + Incin.	Holding Tank	100	12	24.601	23	20.630	20	45.231	43	39.440	37	1.210	1	11.834	11	7.780	7	60.264	57	105.495	43	2.110	69	152.891	3.058	33
4	Gravity Collect. (Grumman)	Grum Flow Thru + Hld Tk	Holding Tank	100	22	27.500	46	18.760	31	46.260	78	5.542	9	2.421	4	2.230	4	3.189	5	13.382	22	59.642	24	1.193	76	78.476	1.570	17
5		Grumman Flow Thru + Holding Tank		100	100	55.000	62	16.070	18	71.070	81	6.624	8	3.171	4	3.330	4	3.950	4	17.075	19	88.145	36	1.763	78	113.006	2.260	24
6	Gravity Collect.	Holding Tank	Grum Flow Thru + Hld Tk	100	100	55.000	58	21.590	23	76.590	81	7.226	8	3.171	3	3.330	4	3.950	4	17.677	19	94.267	39	1.885	78	120.855	2.417	26
7	Gravity Collect. (Grumman)	Grum Flow Thru + Incin.	Holding Tank	100	28	55.000	52	25.640	24	80.640	77	11.766	11	1.862	2	3.392	3	7.289	7	24.309	23	104.949	43	2.099	73	143.766	2.875	31
8		Grumman Flow Thru + Incinerator		100	100	110.00	67	19.250	12	129.250	79	12.916	8	3.250	2	6.212	4	12.681	8	35.059	21	164.309	67	3.286	71	231.421	4.628	49
9	Vacuum Collect. (Jared)	Holding Tank	Holding Tank	100	13	24.350	25	19.710	20	44.060	46	10.587	11	6.059	6	17.948	19	17.851	19	52.445	54	96.505	40	1.930	64	150.789	3.016	32
10		Incinerator	Holding Tank	100	35	65.600	33	33.740	17	99.340	49	16.369	8	6.077	3	41.734	21	37.415	19	101.595	51	200.935	82	4.019	57	352.518	7.050	75
11		GATX Evaporator	Holding Tank	100	35	61.050	40	31.660	21	92.710	60	15.011	10	8.676	6	18.919	12	18.758	12	61.384	40	154.074	63	3.081	58	265.645	5.313	56
12		Holding Tank	Grum Flow Thru + Hld Tk	100	100	79.350	49	21.810	13	101.160	62	13.328	8	8.025	5	20.615	13	20.429	12	62.397	38	163.557	67	3.271	56	292.066	5.841	62
13		Incinerator	Grum Flow Th[illegible]	100	100	134.350	55	29.320	12	163.670	67	17.991	7	7.527	3	23.177	9	31.966	13	80.661	33	244.331	100	4.887	52	469.867	9.397	100
14	M/T Pump Collect. (GATX)	Holding Tank	H[illegible] Tank	100	22	12.660	18	19.420	28	32.080	47	4.959	7	5.598	8	19.613	28	6.642	10	36.812	53	68.812	28	1.378	75	91.856	1.837	20
15		Incinerator	Holding Tank	100	35	53.910	32	29.520	17	83.430	49	10.741	6	5.610	3	43.399	26	26.202	15	85.952	51	169.382	69	3.388	68	249.091	4.982	53
16		GATX Evaporator	Holding Tank	100	35	49.360	42	23.060	20	72.420	62	8.486	7	8.209	7	20.584	18	7.552	6	44.831	38	117.251	48	2.345	70	167.501	3.350	36
17		Holding Tank	Grum Flow Thru + Hold Tk	100	100	67.660	50	21.280	16	88.940	66	7.705	6	7.564	6	22.280	16	9.220	7	46.769	34	135.709	56	2.714	68	199.572	3.991	43
18		Incinerator	Grum Flow Thru + Incin.	100	100	122.660	58	29.590	14	152.250	72	7.005	3	7.060	3	24.842	12	20.754	10	59.661	28	211.911	87	4.238	64	331.111	6.622	70

* Based on the maximum holding time of 277.9 hours. The next smaller holding time of 54.0 hours would satisfy approximately 93% of all holding time requirements.

(1) Based on:
- WMS utilization factor determined from vessel mission profile study.
- An effective discount rate of 10%.
- An assumed WMS useful life of 10 years.

(2) Relative cost (%) based on highest WMS cost for the vessel.

(3) Relative ratio (%) of cost to effectiveness rating based on highest value of such WMS ratios for the vessel.

N/A - Not a viable candidate for this vessel.

SUMMARY OF WMS LIFE-CYCLE COST AND EFFECTIVENESS ANALYSES

Vessel PAMLICO (160') Crew Size 13 WMS UTILIZATION FACTOR (%) 31 Sheet 4 of 6

WMS No.	TYPE			HOLDING CAPACITY*		WMS LIFE CYCLE COST(1) ESTIMATES											EFFECTIVENESS RATING (%)	RATIO OF COST(1) TO EFFECTIVENESS RATING		
	COLLECTION/TRANSPORT SUBSYSTEM (Black)	TREATMENT/DISPOSAL SUBSYSTEM				FIXED COSTS			RECURRING EXPENDITURES					TOTAL LIFE CYCLE COST(1)						
		BLACK	GRAY	BLACK (%)	GRAY (%)	Acquisition	Installation	Total Fixed Costs	Operating	Preventive Maintenance (PM)	Corrective Maintenance (CM)	Overhaul Maintenance	Total Recurring Costs	$K	Relative (%) (2)	Cost/Man ($K/Man)		PER VESSEL ($K)	PER MAN ($K/Man)	(3) RELATIVE (%)
						$K % of Total	$K % of Total	$K % of Total	$K % of Total	$K % of Total	$K % of Total	$K % of Total	$K % of Total							
1	Gravity Collect	Holding Tank	Holding Tank	100	55	1.100 3	28 520 77	29.620 80	2.347 6	1.438 4	1.505 5	1.870 5	7.160 20	36.780	30	2.829	80	45.975	3.537	22
2	Oil Recircul. (Chrysler)	Chrysler + Hld Tank	Holding Tank	100	64	9.642 16	25.290 43	34.932 59	9.395 16	1.800 1	8.006 14	5.027 9	24.228 41	59.160	49	4.551	64	92.438	7.111	44
3		Chrysler + Incin.	Holding Tank	100	64	15.704 21	30.590 41	46.294 62	10.986 15	1.081 1	10.513 14	5.861 8	28.441 38	74.735	62	5.749	61	122.516	9.424	59
4	Gravity Collect. (Grumman)	Grum Flow Thru + Hld Tk	Holding Tank	100	64	28.600 42	24.280 35	52.880 77	5.598 8	2.421 4	4.436 6	3.166 5	15 621 23	68.501	56	5.269	68	100.737	7.749	48
5		Grumman Flow Thru + Holding Tank		100	100	28.600 50	15.220 26	43.820 76	4.866 8	2.187 4	3.926 7	2.633 5	13.612 24	57.432	47	4.418	72	79.767	6.136	38
6	Gravity Collect.	Holding Tank	Grum Flow Thru + Hld Tk	100	100	28.600 45	21.200 33	49.860 78	5.118 8	2.187 4	3.926 6	2.533 4	13.864 22	63.664	52	4.897	72	88.422	6.802	42
7	Gravity Collect. (Grumman)	Grum Flow Thru + Incin.	Holding Tank	100	64	56.100 51	29.230 26	85.330 77	8.793 8	1.862 2	6.999 6	7.265 7	24.919 23	110.249	91	8.481	63	174.908	13.461	84
8		Grumman Flow Thru + Incinerator		100	100	56.100 58	18.030 18	74.130 76	7.988 8	1.622 2	6.495 7	6.733 7	22.838 24	96.968	80	7.459	65	149.182	11.476	71
9	Vacuum Collect. (Jered)	Holding Tank	Holding Tank	100	64	-0- -0-	19.890 45	19.890 45	5.229 12	4.756 11	8.430 19	5.697 13	24.112 55	44.002	36	3.385	64	68.753	5.289	33
10		Incinerator	Holding Tank	100	64	27.530 29	21.370 23	48.870 52	8.332 9	4.197 5	22.870 24	9.796 10	45.195 48	94.065	77	7.236	55	171.027	13.156	82
11		GATX Evaporator	Holding Tank	100	64	17.250 29	15.830 27	33.080 56	5.567 9	5.469 9	9.149 16	5.908 10	26.093 44	59.173	48	4.552	60	98.622	7.586	47
12		Holding Tank	Grum Flow Thru + Hld Tk	100	100	27.500 38	12.760 18	40.260 56	8.252 11	5.745 8	11.361 15	6.987 10	32.345 44	72.605	60	5.585	56	129.652	9.973	62
13		Incinerator	Grum Flow Thru + Incin.	100	100	55.000 51	14.470 13	69.470 64	10.569 10	4.946 4	13.420 12	10.554 10	39.489 36	108.959	90	8.381	52	209.537	16.118	100
14	M/T Pump Collect. (GATX)	Holding Tank	Holding Tank	100	64	9.510 16	20.490 35	30.000 52	2.802 5	4.510 8	15.472 27	5.191 9	27.975 48	57.975	48	4.460	71	81.65	6.282	39
15		Incinerator	Holding Tank	100	64	37.010 34	22.940 21	59.950 55	5.899 5	3.951 4	29.912 27	9.284 9	49.046 45	108.996	90	8.384	61	178.682	13.745	85
16		GATX Evaporator	Holding Tank	100	64	26.760 35	17.770 24	44.530 59	4.301 6	5.217 7	16.191 21	5.401 7	31.110 41	75.640	62	5.818	66	114.606	8.816	55
17		Holding Tank	Grum Flow Thru + Hold Tk	100	100	37.510 43	13.480 15	50.490 58	5.825 7	5.493 6	18.403 21	6.478 8	36.119 42	86.689	71	6.668	63	137.602	10.585	66
18		Incinerator	Grum Flow Thru + Incin.	100	100	64.510 53	13.080 11	77.590 64	3.135 7	4.694 4	20.461 17	10.045 8	43.335 36	120.925	100	9.302	58	208.491	16.038	100

* Based on the maximum holding time of 510.0 hours. The next smaller holding time of 228.0 hours would satisfy approximately 98% of all holding time requirements.

(1) Based on:

- WMS utilization factor determined from vessel mission profile study.
- An effective discount rate of 10%.
- An assumed WMS useful life of 10 years.

(2) Relative cost (%) based on highest WMS cost for the vessel.

(3) Relative ratio (%) of cost to effectiveness rating based on highest value of such WMS ratios for the vessel.

N/A - Not a viable candidate for this vessel.

SUMMARY OF WMS LIFE-CYCLE COST AND EFFECTIVENESS ANALYSES

Vessel WHITE SAGE (133') Crew Size 21 WMS UTILIZATION FACTOR (%) 11.1 Sheet 5 of 6

WMS No.	TYPE: Collection/Transport Subsystem (Black)	TYPE: Treatment/Disposal Subsystem: Black	TYPE: Treatment/Disposal Subsystem: Gray	Holding Capacity: Black (%) *	Holding Capacity: Gray (%) *	Fixed Costs: Acquisition ($K / % of Total)	Fixed Costs: Installation ($K / % of Total)	Fixed Costs: Total Fixed Costs ($K / % of Total)	Recurring Expenditures: Operating ($K / % of Total)	Recurring Expenditures: Preventive Maintenance (PM) ($K / % of Total)	Recurring Expenditures: Corrective Maintenance (CM) ($K / % of Total)	Recurring Expenditures: Overhaul Maintenance ($K / % of Total)	Recurring Expenditures: Total Recurring Costs ($K / % of Total)	Total Life Cycle Cost (1): $K	Total Life Cycle Cost (1): Relative (%) (2)	Total Life Cycle Cost (1): Cost/Man ($K/Man)	Effectiveness Rating (%)	Ratio of Cost (1) to Effectiveness Rating: Per Vessel ($K)	Ratio of Cost (1) to Effectiveness Rating: Per Man ($K/Man)	Ratio of Cost (1) to Effectiveness Rating: (3) Relative (%)
1	Gravity Collect	Holding Tank	Holding Tank	100	100	-0- -0-	13.190 70	13.190 70	1.751 9	1.438 8	0.725 4	1.870 9	5.784 30	18.974	15	.904	86	22.063	1.051	9
2	Oil Recircul. (Chrysler)	Chrysler + Hld Tank	Holding Tank	100	100	8.542 18	13.800 30	22.342 48	9.966 21	1.800 4	7.308 16	5.027 11	24.191 52	46.333	36	2.216	68	68.431	3.259	29
3		Chrysler + Incin.	Holding Tank	100	100	14.604 25	16.800 29	31.404 54	10.999 19	1.081 2	8.695 15	5.861 10	26.536 46	58.040	45	2.764	65	89.292	4.252	37
4	Gravity Collect. (Grumman)	Grum Flow Thru + Hld Tk	Holding Tank	100	100	27.500 49	17.800 32	44.500 79	4.215 7	2.421 4	2.132 4	3.166 6	11.934 21	56.434	44	2.687	74	76.262	3.632	32
5		Grumman Flow Thru + Holding Tank		100	100	27.500 54	12.890 25	40.390 79	3.939 7	2.187 4	1.954 4	2.633 5	10.713 21	51.10	40	2.433	76	67.237	3.202	28
6	Gravity Collect.	Holding Tank	Grum Flow Thru + Hld Tk	100	100	27.500 56	15.460 28	42.960 79	4.240 8	2.187 4	2.132 4	3.166 6	11.725 21	54.685	42	2.604	76	71.954	3.426	30
7	Gravity Collect. (Grumman)	Grum Flow Thru + Incin.	Holding Tank	100	100	55.000 57	23.080 24	78.080 81	5.917 6	1.862 2	3.121 3	7.262 8	18.162 19	96.242	75	4.583	68	141.532	5.740	59
8		Grumman Flow Thru + Incinerator		100	100	55.000 64	13.100 15	68.100 80	5.899 7	1.622 2	2.931 3	6.733 8	17.185 20	85.285	66	4.061	69	123.601	5.886	52
9	Vacuum Collect. (Jered)	Holding Tank	Holding Tank	100	100	7.650 17	12.730 29	20.380 46	6.286 14	4.756 11	7.226 16	5.697 13	23.965 54	44.345	34	2.112	64	69.289	3.299	29
10		Incinerator	Holding Tank	100	100	36.250 40	16.300 18	52.550 58	8.116 9	4.197 5	15.331 17	9.796 11	37.440 42	89.990	70	4.285	56	160.696	7.652	67
11		GATX Evaporator	Holding Tank	100	100	26.000 41	12.220 19	38.220 59	7.189 11	5.469 9	7.472 12	5.908 9	26.038 41	64.258	50	3.060	59	108.912	5.186	46
12		Holding Tank	Grum Flow Thru + Hld Tk	100	100	35.150 48	10.600 14	45.750 62	7.232 10	5.745 8	8.277 11	6.987 9	28.241 38	73.991	57	3.523	56	132.127	6.292	55
13		Incinerator	Grum Flow Thru + Incin.	100	100	62.650 57	13.640 12	76.290 70	8.756 8	4.946 5	9.014 8	10.554 10	33.270 30	109.560	85	5.217	51	214.824	10.230	90
14	M/T Pump Collect. (GATX)	Holding Tank	Holding Tank	100	100	9.510 18	11.990 22	21.500 40	4.165 8	4.510 8	18.096 34	5.191 10	31.902 60	53.402	41	2.543	70	76.289	3.633	32
15		Incinerator	Holding Tank	100	100	37.010 38	15.790 16	52.800 54	5.536 6	3.951 4	26.200 27	9.284 9	44.971 46	97.771	76	4.656	62	157.695	7.509	66
16		GATX Evaporator	Holding Tank	100	100	27.860 38	10.930 15	38.790 54	4.608 6	5.216 7	18.360 25	5.401 7	33.585 46	72.375	56	3.446	66	109.659	5.222	46
17		Holding Tank	Grum Flow Thru + Hold Tk	100	100	44.660 49	10.970 12	55.630 61	4.756 5	5.499 6	19.146 21	6.478 7	35.879 39	91.509	71	4.358	62	147.595	7.028	62
18		Incinerator	Grum Flow Thru + Incin.	100	100	72.160 56	15.640 12	87.800 68	6.519 5	4.694 4	19.884 15	10.045 8	41.142 32	128.942	100	6.140	54	238.781	11.371	100

* Based on the maximum holding time of 65.5 hours. The next smaller holding time of 62.0 hours would satisfy approximately 97% of all holding time requirements.

(1) Based on:

- . WMS utilization factor determined from vessel mission profile study.
- . An effective discount rate of 10%.
- . An assumed WMS useful life of 10 years.

(2) Relative cost (%) based on highest WMS cost for the vessel.

(3) Relative ratio (%) of cost to effectiveness rating based on highest value of such WMS ratios for the vessel.

N/A - Not a viable candidate for this vessel.

SUMMARY OF WMS LIFE-CYCLE COST AND EFFECTIVENESS ANALYSES

Vessel POINT HERRON (82') Crew Size 8 WMS UTILIZATION FACTOR (%) 1.8 Sheet 6 of 6

W M S No.	TYPE: COLLECTION TRANS-PORT SUBSYSTEM (Black)	TYPE: TREATMENT/DISPOSAL SUBSYSTEM: BLACK	TYPE: TREATMENT/DISPOSAL SUBSYSTEM: GRAY	HOLDING CAPACITY: BLACK (%) *	HOLDING CAPACITY: GRAY (%) *	WMS LIFE CYCLE COST(1) ESTIMATES: FIXED COSTS ($K / % of Total): Acquisition	Installation	Total Fixed Costs	RECURRING EXPENDITURES ($K / % of Total): Operating	Preventive Maintenance (PM)	Corrective Maintenance (CM)	Overhaul Maintenance	Total Recurring Costs	TOTAL LIFE CYCLE COST(1): $K	Relative (%) (2)	Cost/Man ($K/Man)	EFFECTIVENESS RATING (%)	RATIO OF COST(1) TO EFFECTIVENESS RATING: PER VESSEL ($K)	PER MAN ($K/Man)	(3) RELATIVE (%)
1	Gravity Collect	Holding Tank	Holding Tank	58	0	-0- / -0-	2.410 / 40	2.410 / 40	0.028 / 15	1.198 / 20	0.264 / 4	1.270 / 21	3.660 / 60	6.070	13	.759	82	7.402	.925	9
2	Oil Recircul. (Chrysler)	Chrysler + Hld Tank	Holding Tank	N/A																▶
3		Chrysler + Incin.	Holding Tank	N/A																▶
4	Gravity Collect. (Grumman)	Grum Flow Thru + Hld Tk	Holding Tank	N/A																▶
5		Grumman Flow Thru + Holding Tank		N/A																▶
6	Gravity Collect.	Holding Tank	Grum Flow Thru + Hld Tk	N/A																▶
7	Gravity Collect. (Grumman)	Grum Flow Thru + Incin.	Holding Tank	N/A																▶
8		Grumman Flow Thru + Incinerator		N/A																▶
9	Vacuum Collect. - (Jered)	Holding Tank	Holding Tank	100	20	6.750 / 24	5.460 / 19	12.210 / 44	3.232 / 18	4.436 / 16	4.215 / 15	3.965 / 14	15.848 / 56	28.058	59	3.507	60	46.760	5.845	57
10		Incinerator	Holding Tank	N/A																▶
11	↓	GATX Evaporator	Holding Tank	100	20	24.000 / 53	4.690 / 10	28.690 / 63	3.281 / 7	5.149 / 11	4.264 / 9	4.175 / 9	16.869 / 37	45.559	96	5.695	56	81.355	10.170	100
12	↓	Holding Tank	Grum Flow Thru + Hld Tk	N/A																▶
13	↓	Incinerator	Grum Flow Thru + Incin.	N/A																▶
14	M/T Pump Collect. (GATX)	Holding Tank	Holding Tank	100	20	6.200 / 21	4.200 / 14	10.400 / 36	2.462 / 8	3.342 / 11	9.352 / 32	3.713 / 13	18.889 / 64	29.289	62	3.661	71	41.252	5.156	51
15		Incinerator	Holding Tank	N/A																▶
16	↓	GATX Evaporator	Holding Tank	100	20	23.450 / 49	4.220 / 9	27.670 / 58	2.532 / 5	4.049 / 9	9.401 / 20	3.927 / 8	19.909 / 42	47.579	100	5.947	66	72.089	9.011	87
17	↓	Holding Tank	Grum Flow Thru + Hold Tk	N/A																▶
18	↓	Incinerator	Grum Flow Thru + Incin.	N/A																▶

* Based on the maximum holding time of 99.0 hours. The next smaller holding time of 21.5 hours would satisfy approximately 99% of all holding time requirements.

(1) Based on:
- WMS utilization factor determined from vessel mission profile s'udy.
- An effective discount rate of 10%.
- An assumed WMS useful life of 10 years.

(2) Relative cost (%) based on highest WMS cost for the vessel.

(3) Relative ratio (%) of cost to effectiveness rating based on highest value of such WMS ratios for the vessel.

N/A - Not a viable candidate for this vessel.

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

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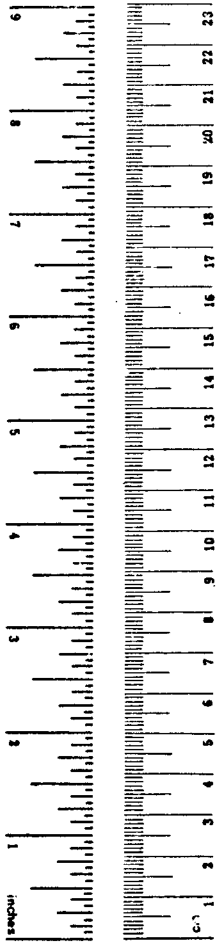
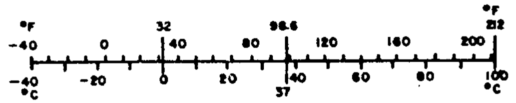
*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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INTRODUCTION

BACKGROUND

Few people have not been exposed to terminology such as: systems analysis, life-cycle cost, system effectiveness, measures of effectiveness, models, cost benefit, input, output, data, etc. Although these words are in daily usage, they often have different meanings for different people. Their use evokes a wide range of varied reactions.

At one extreme is the viewpoint that such analyses are modern types of witchcraft, or numerology, practiced by a priestly cast. Results and conclusions obtained are suspect and these procedures are viewed as a means of spoiling (or soiling) or obscuring otherwise valid engineering analyses.

At the other extreme is the viewpoint that any solution to a problem which does not employ such techniques (or at least is liberally sprinkled with such terminology) is not "modern" or authoritative. A third type of reaction may be that of individuals who are familiar with the underlying concepts associated with such terminology but are unsure whether or not they have any relevance to the problem at hand. To paraphrase a popular comment about the weather, one may wonder whether these techniques, (granted that they are popular and everyone talks about them) can do anything about the necessary decisions with which one is faced.

This study does not purport to address all of the above issues but only those which are relevant to the general problem of comparing competing candidates and choosing an optimum wastewater management system for selected U.S. Coast Guard cutters. The following discussion is related to some of the issues which led to this study.

Complex Problems and Simplistic Approaches

The aforementioned terminology is symptomatic of the complex society we live in and the concomitant and increasing complexity of the systems we use to support it. The two extreme viewpoints are also symptomatic of the various analytic techniques which are used, and sometimes abused, in an effort to cope with this complexity. They are, in effect, reactions to two types of extremes. One extreme is the use of oversophisticated analytic techniques for relatively simple problems which do not warrant such powerful machinery. The other extreme is the attempt to use simplistic approaches to solve complex problems. Ideally, the analytic technique should match the problem. Just as overkill is undersirable, so is it important to recognize that generally there are no simple solutions or shortcuts to complicated problems.

What are simplistic approaches? Briefly stated, simplistic approaches are those which do not address all the relevant considerations and, at the same time, ignore the interrelationships between them. Such an approach focuses on a few issues to the exclusion of the others, without attempting to assess the effects of such exclusions. But considerations which are ignored do not go away or disappear. They sometimes have an unpleasant way of returning.

Characteristic of simplistic approaches is the search for and discovery of a "formula" which requires the substitution of a few easily determined parameters associated with the systems. Among the simplistic approaches must also be included those which, in effect, attempt to provide answers without fully exploring what the questions are, i.e., without relating to the specifics of the candidate systems and their associated context. Such an approach purports to provide solutions and conclusions without requiring as an input (in addition to data) the structure and a configuration of the candidate systems, i.e., how the subsystems/equipments interrelate to accomplish the intended function. This type of approach should be carefully reviewed for the ability to provide meaningful results.*

Simplistic approaches are popular because they promise to solve complex problems the easy way. Although this is never stated explicitly, simplistic approaches carry with them the implied assumption (or belief) that they automate, or at least greatly simplify, the decision-making process. Thus, they provide a false sense of security.

What then is a "sophisticated" approach which is suitable for complex problems? Some characteristics of such an approach are the ability to take into account all the relevant considerations, thus allowing a full examination of all issues which are of interest to the decision maker; it accommodates the dependencies which are inherent in the problem; and it is based on the use of relevant, valid and accurate data. However, this is not any more specific than the suggestion that the design of a bridge should be based on Newton's laws of motion. It is for this reason that a specific analysis methodology with clearly defined procedural steps is required.

Why Cost Effectiveness?

Cost effectiveness has to do with the strategy one uses to acquire a system, a service, or process when more than one legitimate competing candidate exists. To a large extent, cost effectiveness concepts and associated analytic techniques owe their origins to agencies of the Department of Defense.

These concepts are a reaction to the fallacy of attempting to acquire a complex military system simply on the basis of initial cost (i.e., acquisition cost) and performance (i.e., performance at the time of purchase).

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*It is noted that the use of this type of simplistic approach is often responsible for imparting a bad reputation to an entire field of analysis - and deserves the label of witchcraft or numerology.

Although such a simple buying strategy may be adequate for products which are used or consumed at the time of purchase or soon thereafter (certain foods, services, etc., in which the purchase price and the initial quality are the prime considerations), there is more to acquiring a complex system. The element of time becomes an important issue and it has implications for both cost and performance (as well as for numerous other considerations). Complex systems break down and their performance degrades with time. Repairs cost money, they make the system unavailable, etc. Complicating the situation is the fact that many of these events are random; hence, one cannot plan for them in advance on the basis of deterministic procedures.

In practice, it has been found that the real cost of a complex system, such as a weapon system, often exceeds the initial acquisition cost by one or several orders of magnitude. In addition, the performance, as well as other characteristics, often changes considerably as the system ages. These realities gave rise to concepts of cost effectiveness, namely that all costs incurred should be tracked over time and accounted for, and that the the degradation in performance as a function of time should be fully addressed, including all the implications which follow from this.

Although the aim of cost effectiveness analysis is laudable, its practice has not always been up to par with its principles and ideals. Rarely are all relevant considerations taken into account in a direct, explicit, systematic, and comprehensive manner. The attempt to take into account the dependencies of both cost and effectiveness on the time element has resulted in an interest and intensive activity in the field of reliability. Thus, "effectiveness analysis" (or "effectiveness assurance") became synonomous with "reliability/maintainability/availability analysis".

This study was undertaken in an effort to develop and apply a systematic and well defined cost effectiveness analysis methodology which would be suitable for candidate wastewater management systems. In general, any choice of a candidate is made on the basis of information about the candidates and the use of subjective judgements by the decision maker. However, information about complex systems includes a wide range of different considerations and issues. The objectives of this cost effectiveness analysis methodology is the development of procedural steps for methodically accommodating and integrating all considerations of interest, including technical data and such intangibles as objectives, constraints, guidelines, assumptions, and the subjective judgements of the decision maker.

This approach is based on viewing all considerations of interest as falling into two categories, namely economic and non-economic. The economic considerations are all those which affect life-cycle cost and are taken to be the penalty aspect of a candidate. The remaining considerations of interest represent effectiveness and are associated with the overall quality of a candidate (performance, safety, habitability, etc.). However, a given system consideration may have an effect on both categories. As an example, the number of man-hours required for operation and maintenance affects the penalty aspect (i.e., the cost of labor) as well as overall quality (i.e., the extent of the burden on the crew). The overall problem of choosing an optimum candidate is thus viewed as a two-dimensional problem requiring a trade-off between life-cycle cost (penalty) and effectiveness (overall quality).* Notions of "worth" are used in the context of such a trade-off. However, unlike other approaches, this approach does not attempt to use notions of worth to make a direct conversion of effectiveness into cost or vice versa.

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*This approach is valid for non-revenue producing systems. For revenue producing candidate systems, a third and vital issue (namely its revenue producing or income potential) must be taken into account and the problem is then studied in three dimensions.

Interfacing With the Real World

What was definitely not wanted (in accordance with the objectives and intent of this study) is a theoretical analyses approach, applied to a hypothetical problem, using assumed data, and the development of results and conclusions intended for an imaginary decision-maker. Instead, the goal was the development and application of a viable methodology which can address the real world. Such a requirement has a number of implications.

No elaborate arguments are required to convey the idea that meaningful and valid results and conclusions cannot be obtained unless relevant and accurate data are made available. Since the cost-effectiveness analysis methodology per-se does not generate the required data, or for that matter the candidate systems to be analyzed, such information has to be obtained as an input to this methodology. In the overall scheme of things this type of information is obtained via other supporting analyses which are coordinated with the cost-effectiveness analysis procedure. However, a viable methodology must address a number of other issues in addition to the question of data. It must be capable of interfacing not only with real systems but with real people as well.

First and foremost, the methodology must interface with the decision-maker who must have a clear understanding of the principles of the approach as well as the procedural steps and feel comfortable with them. Furthermore, the approach must be capable of being integrated into the decision-makers routines and his overall scheme of operation. Expecting a radical departure in normal operating procedure is unrealistic.

Another type of interface is that between the decision-maker and specialists in other disciplines. This interface is especially important in a large scale project or study effort in which the necessary data for quantifying both cost and effectiveness may require inputs from experts in several different disciplines. One cannot realistically expect to address oneself to individuals in other disciplines and ask for an effectiveness analysis or even for effectiveness attribute data. Attempting to do this may, at best, result in a blank stare and at worst, in a hostile reaction. Instead, what must be done is to formulate specific questions in terms which are meaningful within these disciplines. This can be accomplished by formalizing the process, at least to the extent that it can be carefully documented. Questions must be specific and they must be clearly stated. Thus, one might say that this approach abhors vagueness and ambiguity.

Testing the Approach

The candidate wastewater management systems and vessels included in this study provided ample opportunities for testing and validating the entire range of aspects associated with this approach. These systems also provided additional problems which may not be present in other types of candidates, hence the ability of the approach to cope with these systems represents a demonstration of its validity, versatility, and practicality.

The additional problems resulted from the requirement to handle two separate waste streams (namely, black as well as gray wastewaters) and the fact that these systems are synthesized as hybrid combinations of the subsystems/equipments of different MSDs. This presented special problems for both the cost and the effectiveness analyses. Specifically, all data had to be developed and documented on an MSD subsystem/equipment basis rather than on an overall MSD basis as it is ordinarily presented. Furthermore, each candidate system had to be viewed as consisting of three subsystems (often containing common subsystems/equipments) and both the cost as well as the effectiveness related data on an overall WMS level had to be synthesized from its constituent MSD subsystem/equipment data. Procedures for doing this had to be developed.

A further complication was the requirement to include candidate system/vessel combinations (based on the use of holding tanks) which do not provide full holding capacity for black and/or gray wastewaters. This requirement necessitated special procedures and extra precautions in the presentation and interpretation of results and conclusions.

The ability of the cost effectiveness analysis methodology to interface with supporting analyses used to develop the necessary input data was demonstrated via the MSD analysis and the WMS installation analysis. The effectiveness model served as a medium of communication for guiding these analyses. All aspects relating to the procedural steps of the methodology as well as the data development have been carefully documented. An attempt has been made to maintain a clear distinction between the model, its associated input data, its outputs, and the governing assumptions. Where a conflict arose, preference was given to the modeling and procedural aspects over data accuracies, since the latter are more readily corrected than the former. This aspect of the application served to verify the feasibility of managing the details of the entire approach, including the data handling "mechanics" in a realistic environment.

The practicality of the interface with the decision-maker was validated through extensive participation by Coast Guard technical personnel in the development of the effectiveness model.

A final test of the approach concerns another interface with the decision-maker. Many numbers have been developed in the course of this study. This report abounds with tables, charts and figures presenting information and results at different levels of detail. Although much of the effort associated with this study was consumed in the development of these numbers, they do not represent the ultimate objective of the study. The full purpose of the analysis would not be served if these numbers could not ultimately be reinterpreted by the decision-maker in terms of candidate system properties, trends, inferences, and decisions.

OBJECTIVES

The overall objective of this study is twofold.

Development of a Cost-Effectiveness Analysis Methodology

The first objective is the development of a conceptual basis as well as a practical approach for quantifying the life-cycle cost and effectiveness of candidate system/vessel combinations and using these for selecting an optimum system for each vessel.

The approach for quantifying effectiveness should be capable of addressing all considerations of interest and be consistent with the data which are available or can be obtained with reasonable effort. It should also be capable of accommodating all specifics of the problem and its context, including such intangibles as objectives, requirements, constraints, policies, guidelines, assumptions, and subjective judgements of the decision maker.

The approach for quantifying life-cycle cost should address all cost elements and all variables which affect the life-cycle cost of wastewater management systems. The approach should take into account all dependencies between the variables and parameters of life-cycle cost and it should be consistent with the data which are either available or can be obtained with reasonable effort.

Application of Methodology

The second objective is the development and analysis of candidate wastewater management systems (WMS) for six U.S. Coast Guard cutters. The objective of these systems is to manage both the black and gray wastewaters aboard the selected vessels. The candidate systems are to be developed as hybrid combinations of subsystems from commercially available marine sanitary devices (MSDs) using engineering judgement to select those which have a good chance of meeting performance requirements.

The objective of the application includes generation of all data necessary for the development of the candidate systems, the life-cycle cost estimates and the effectiveness assessment. A specific objective and guideline in this connection is that, to the extent possible, data used should be realistic and obtained directly from the source, rather than projected or derived indirectly. Following are specific requirements in keeping with this objective:

- Visits to inspect the MSDs included in this study on operational vessels.
- Scaling of MSDs included in this study, for use in the development of the candidate WMS, should be considered only to the extent that the various capacities and model types are either commercially available or engineering data for them are available from the manufacturer.
- Hybrid systems should be considered only to the extent that successful operation can be expected without significant equipment modifications.
- The development of candidate systems for each vessel (as well as the subsequent analysis) should be based on vessel operational requirements as determined from actual vessel mission profiles obtained from the ship logs of each vessel.
- The installation analysis to determine feasibility of installation as well as the subsequent analysis to develop installation cost estimates, drawings, and installation dependent effectiveness attribute data are to be based on actual vessel shipcheck inspections and are to be performed in consultation with naval architects and marine engineers.

SCOPE

This study consists of efforts directed at the fulfillment of two main objectives, namely, the development of a generalized methodology for analyzing alternative systems in order to select an optimum (i.e., most cost effective) candidate; and the testing and validation of the entire approach through its application to a real-world problem. The original scope of the developmental effort was limited to the approach for quantifying life-cycle cost and effectiveness and procedures for using these numbers to select an optimum candidate system as a function of platform (i.e., vessel). However, in the course of developing the necessary data for the candidate systems as part of the verification of the approach, additional supporting analyses were introduced and generalized. These include the following:

- The vessel mission profile analysis.
- The MSD analysis.
- The WMS engineering analysis.
- The WMS installation analysis.

The development and incorporation of these analyses as part of this study resulted from conformance to the basic intent of developing an approach which is capable of interfacing with the real world and can realistically cope with the problem of developing and using the data required as an input. What resulted is more than merely a conceptual framework for a cost-effectiveness analysis approach with a sample application.

The approaches for quantifying life-cycle cost and effectiveness, and these supporting analyses complement each other. The approach for quantifying cost and effectiveness provides structure and orientation to these analyses (which would have to be performed anyway in order to generate realistic inputs) so that they become well directed, rather than disorganized, efforts. On the other hand, these supporting analyses serve two important functions. First, they provide the required inputs for the cost-effectiveness analysis. Second, these supporting analyses act to halt the demand for types and forms of data which cannot be realistically expected within the confines of a given study. Thus, the result is a generalized and systematic methodology for solving problems, at least those in the context of comparing competing candiates and selecting an optimum.

The scope of each specific effort is described briefly in the following paragraphs. The applicability and limitations of both the results and the methodology are also discussed. The results of this study appear in this volume as well as in the others. The relationships and dependencies between the information in the various volumes of this report are indicated in the diagram presented in the Preface to the report.

Development and Application of the Effectiveness Assessment Methodology

The effort under this portion of the study includes the following:

- Development and documentation of a generalized effectiveness modeling and assessment methodology (see Volume II).
- Development and documentation of a generalized computer program for quantifying the effectiveness of candidate system/vessel combinations (see Volume II).
- Development of an effectiveness model suitable for analyzing candidate wastewater management systems (WMS) for selected U.S. Coast Guard vessels. The candidate systems are intended for managing the black (output from commodes, urinals and garbage grinder) and gray (galley and turbid, i.e., output from sinks, showers, laundry, deck, drains) wastewaters aboard the vessels (see Volume II).
- Development and documentation of the effectiveness attribute data required as input to the effectiveness model (see Volumes III and V).
- Exercise the effectiveness model by substituting the data and developing quantitative effectiveness assessments for all viable candidate system/vessel combinations (see Volume II).

The emphasis in the effectiveness modeling area was on the development of the procedural aspects of the approach, leading to a general and well defined methodology with clearly identifiable steps. Guidelines for executing each step have been developed and are documented.

An important aspect of the development of the effectiveness model for wastewater management systems was the verification of the feasibility and practicality of decision-maker participation in its development, which is a specific requirement of the approach.

Development and Application of the Life-Cycle Cost Model

The effort under this portion of the study included the following:

- Development and documentation of a life-cycle cost model for candidate wastewater management system concepts as a function of vessel on which they are implemented (presented in this volume).
- Development and documentation of cost-related data required as input to the life-cycle cost model (see Volumes III and V).
- Exercise the life-cycle cost model by substituting the data and developing life-cycle cost estimates (including intermediate results) for all viable system/vessel combinations (presented in this volume).
- Perform a sensitivity analysis on the life-cycle cost estimates (presented in this volume).

The emphasis in the development of the life-cycle cost model was on including all cost elements and cost related parameters as well as addressing all the dependencies among them.

Automation of the life-cycle cost model was not within the scope of this study.

MSDs, Candidate Systems and Vessels Considered

The MSDs to be included in this study were specified by the U.S. Coast Guard. The selection of specific MSDs was based on two considerations. First, inclusions of representatives of the different MSD concepts currently in use or under evaluation, namely, reduced volume vacuum and pumped collection; recirculation; flow through; and CHT (collection, holding and transfer). Second, inclusion of a representative from each of the above concepts which has the most extensive history of actual use and/or development and testing. In order to accommodate the need for systems of various capacities for which the cited MSDs are not particularly appropriate, other selected sizes and types of equipment from the same manufacturers were included, even though the development or testing was not as extensive as for the MSDs originally selected.

The following five MSDs were considered for this study:

- JERED reduced volume vacuum flush collection/incineration, Model V85003 as installed on the USS Kraus (DD 848). For reduced capacity requirements, JERED's Small Boat Sewage Collection System was considered.
- GATX reduced volume flush pumped transfer collection/evaporation, as installed on the Navy service craft MONOB (YAG-61). For reduced capacity requirements, smaller evaporators which are catalog items from the evaporator supplier, but which have not yet had the GATX modifications designed for them, were considered.
- Chrysler recirculating oil full volume flush collection/incineration, Aqua-Sans Models A, A/B an[illegible] plus waste Holding Tank and Incinerator for Model C.
- Grumman flow through/incineration, modified version of prototype installed on USCGC Red Beech (WLM-686). The major modification

is the substitution of a Thiokol Corporation incinerator subsystem in place of the Grumman incinerator. Other modifications are described in Volume V.

- Collection, Holding and Transfer (CHT) system. The CHT System is not proprietary to any one manufacturer, and is generally custom-fitted in each installation.

The systems considered for this study are the 18 WMS concepts in configurations suitable for each of the six vessels included in this study (see Volume IV). Of these, data were developed and results obtained only for those system/vessel combinations which were judged to be viable candidates on the basis of the installation analysis (see Volume III).

The six vessels to be included in this study were specified by the Coast Guard and are as indicated below.

VESSEL	CLASS	TYPE	CREW SIZE	HOME PORT
GALLATIN (378')	WHEC-721 Hamilton (378') Class	High Endurance Cutter	152	Governor's Island, New York
VIGOROUS (210')	WMEC-627 Resolute (210') B Class	Medium Endurance Cutter	60	New London, Conn.
FIREBUSH (180')	WLB-393 Basswood (180') C Class	Buoy Tendor (Seagoing)	50	Governor's Island, New York
PAMLICO (160') New Contruction Based on Data from	WLIC - 800	Buoy and Construction Tender (Inland)	13	New Construction (Intended for Operation in Depot Corpus, Texas)
SHADBUSH (74')	WLI-74287 Clematis (74') Class	Buoy Tender (Inland)	9	New Orleans, La. (Transferred to Galveston, Texas)
CLAMP (75')	WLIC-75306 Clamp (75') Class	Construction Tender (Inland)	9	Galveston, Texas (Transferred to New Orleans, La.)
WHITE SAGE (133')	WLM-544 White Summac (133') Class	Buoy Tender (Coastal)	21	Woods Hole. Mass.
POINT HERRON (82')	WPB-82318 Point (82') C Class	Patrol Boat (Small)	8	Bay Shore, New York (Fire Island)

Vessel Mission Profile Study

The vessel mission profile analysis is one of the supporting analyses for the application. This effort was directed at the development of those vessel mission profile characteristics necessary for the development of the candidate system configurations as a function of vessel, and for estimating life-cycle cost. This resulted in a generalized procedure for collecting and analyzing vessel mission profile data. The results of this effort are presented in Volume VI.

MSD Analysis

The MSD analysis is one of the supporting analyses for the application. The effort was directed at developing a full characterization of the five Marine Sanitary Devices (MSDs) which were hybridized to form the subsystems of the 18 candidate Wastewater Management System (WMS) configurations included in this study. The purpose of this characterization is to develop the various types of generic MSD data necessary for the following phases of this study:

- Development of the 18 candidate WMS concepts and the corresponding configurations suitable for each vessel included in this study, as well as the associated installation requirements.
- Quantification of the effectiveness of each viable candidate system/vessel combination.
- Development of life-cycle cost estimates for each viable candidate system/vessel combination.

The specific types of MSD data developed, on a subsystem level, include the following:

- MSD description, including the following:
  - .. Principle of operation
  - .. Method of implementing principle of operation

- Physical characteristics including:
    - Weights
    - Volumes
    - Dimensions (including maximum height)
    - Pipe connection specifications
- Vessel resource hook up requirements (e.g., fuel, electric power, fresh water, compressed air, cooling water, ventilation, and ambient air).

- MSD related effectiveness attribute data, including the following types of information:
  - Installation characteristics
  - Performance characteristics
  - Operability characteristics
  - Personnel safety characteristics
  - Habitability characteristics
  - Reliability characteristics
  - Maintainability characteristics
- MSD costs, including the following:
  - Acquisition (including initial spare parts)
  - Operation and maintenance, including the following:
    - Consumables
    - Repair parts
    - Labor (number of men, man-hours, skills, frequency of tasks)
    - Vessel resources (fuel, electric power, fresh water, compressed air, etc.)

This effort resulted in a generalized procedure for developing and documenting data on a subsystem level tailored to the requirements of both the life-cycle cost and the effectiveness models. The results of this effort are presented in Volume V.

WMS Engineering Analysis

The WMS engineering analysis is one of the supporting analyses for the application. This effort was directed at the development of both system concepts, as well as specific configurations suitable for implementing these system concepts on each of the vessels included in this study. This effort resulted in a systematic procedure for developing candidate systems, taking into account the parameters which determine system configuration and component sizing, as well as the relevant guidelines and assumptions. The results of this effort are presented in Volume IV.

WMS Installation Analysis

The WMS installation analysis is one of the supporting analyses for the application. This effort was directed at developing the following information:

- Development of pertinent vessel information necessary for the cost and effectiveness analyses, including the following:
  - Existing physical conditions aboard the vessel, especially in compartments where wastewater management system equipments may be installed.
  - Existing wastewater management equipments/systems aboard the vessel (holding tanks, garbage grinders, sewage treatment systems, etc.).
  - Location of black and gray wastewater sources aboard the vessel.
  - Vessel resource capacities and estimated usage rates (prior to system installation).

Selection of the viable candidate systems as determined on the basis of the feasibility of installation, using the governing installation guidelines and assumptions.

- Determination of the black/gray wastewater (or sludge) holding tank capacities which can be fitted.
- Development of installation cost estimates for each viable candidate system.
- Development of drawings showing the proposed arrangement of the wastewater management system equipments for each viable candidate as well as the arrangement of the black and gray wastewater sources on board the vessel.
- Development of installation related effectiveness attribute data.
- This effort resulted in a systematic procedure for developing and documenting installation related data tailored to the requirements of both the life-cycle cost and effectiveness models. The results of this effort are presented in Volume III.

General Applicability of the Approach

Both the concepts and the procedural steps of the life-cycle cost and effectiveness modeling and quantification methodology developed as part of this study are general and have wide applicability.

Specifically, this methodology is applicable to any type of problem which can be cast in the context of choosing an optimum (i.e., most cost-effective) candidate from a number of available legitimate alternatives. These alternative candidates do not necessarily have to be systems. Thus, the candidates may be alternative choices of processes or (e.g., chemical), alternative approaches to solving a problem, etc.

The computer program for quantifying effectiveness was not written for any one specific effectiveness model. Instead, the effectiveness model (and its associated data) is part of the input. As a result, this computer program is capable of handling any type of problem as soon as the necessary inputs have been developed.

Limitations of Results and Approach

Some of the limitations of both the results of this study as well as the cost-effectiveness analysis methodology are presented below.

a. Results of Study

Both the effectiveness ratings and the life-cycle cost estimates presented here are applicable to the specific systems and vessels included in this study. Furthermore, these results reflect the assumptions, objectives, requirements and constraints which are part of the context of this study. Hence, caution is advised in attempting to use these results directly for systems and/or vessels others than those specifically analyzed or in a different context.

All cost estimates, as well as inferences, comparisons and conclusions regarding life-cycle costs and/or optimum (i.e., most cost-effective) candidate system selection are based on the individual vessels included in this study. Economies (and other differences) which may result from implementation of these systems on a fleet-wide basis have not been considered.

The effectiveness ratings are subject to the following considerations. The effectiveness attributes used as the basis for the ratings are a mixture of objectively determined system/vessel characteristics as well as subjectively determined qualitative system/vessel characteristics based on the analysis of the marine sanitary devices (MSDs) and the candidate WMS systems which we hybridized from these MSD subsystem (see data in Volumes III and V).

In addition, the elements of the effectiveness model, especially the weight assignment and the effectiveness rating functions are based on subjective judgements. As a result, if one agrees with these judgements as well as the data used, then one may also accept the validity of the results. On the other hand, if one has reservations about the accuracy of the data and/or strongly disagrees with the subjective judgements inherent in the effectiveness model, then one may question the validity of the results. In such cases, one can substitute different data and/or subjective judgements, assumptions, etc., and obtain a new set of results (at least in principle, even if one may not actually wish to do this). In either case, the data, the subjective judgements, the assumptions, etc., used are all documented and are accessible. Another relevant point to keep in mind is that the effectiveness ratings are not to be used in an absolute sense but rather as a means of comparing candidate systems for the purpose of discerning differences among the alternatives available. In this connection, it is noted that since the same effectiveness model is used to assess the candidate systems and the same generic MSD subsystem/equipment data is used for all system/vessel combinations, all candidates are treated equally. Hence, bias (to be distinguished from subjective judgement) in the results is avoided.

The life cycle cost estimates should be interpreted in the light of the relevant assumption used. These cost estimates are more meaningful in a comparative sense than in an absolute sense. Some of the data (especially equipment failure notes) represent estimates. There are differences in the amount of testing, operational experience, and the availability of documentation for the MSDs included in this study. As a result, not only are there differences in the reliability of the data, but those MSD's for which the documentation is less detailed may unfairly have been made to appear better than they actually are by including a disproportionately small number of operating and maintenance activities. As with the effectiveness ratings, if one disagrees with some of the data and/or the assumptions used, these can be replaced and new results obtained (although this may be a tedious effort). An effort has been made to keep a clear separation between the model, the relevant assumptions, and the data used. This facilitates pinpointing those areas with which one does not agree.

Two final cautions are advised in using and interpreting the results. First, before final acceptance of any candidate system for a given vessel, the discussion relating to its installation (presented in Volume III) should be reviewed. Second, an effectiveness rating or a cost estimate does not necessarily represent an assessment of a given MSD but rather of a given WMS configuration which uses a given MSD or a portion thereof, sometimes in combination with other MSD subsystems.

A specific limitation in connection with the life-cycle cost model concerns the effort required to manually execute the necessary computations. This puts a severe restriction on the number of repetitions of such computations to reflect changes in data, assumptions, systems, etc. Automation of the life-cycle cost model would remove this objection.

General limitations in connection with this cost effectiveness analysis methodology can best be discussed in the context of what it does not do and should not be expected to do.

It does not develop candidate systems. These have to be developed prior to application of the cost effectiveness analysis methodology. The WMS engineering analysis served this purpose in this study. The installation analysis was used to determine viability of candidate system/vessel combinations.

It does not generate the necessary data. Instead, it requires such data as an input. In fact, the validity of the final results are directly dependent on the quality of such data. However, the cost effectiveness analysis methodology can interface with supporting analyses used to develop this required data to give direction to these analyses and to accept the results as an input. In this study, the MSD analysis, the WMS installation analysis and the WMS life-cycle cost analysis represent such supporting analyses which developed the necessary data.

It does not serve as a substitute for a decision maker, reduce the number of decisions required, or produced meaningful results without the participation of a cognizant and knowledgeable decision-maker. The need for a decision-maker is emphasized by his involvement throughout the entire process, from the development of the effectiveness model to the interpretation of the results. However, this methodology provides a systematic procedure for quantifying life-cycle cost and effectiveness and for using the results of this quantification to make inferences, and arrive at conclusions and courses of action. In this connection, it should be remembered that the cost-effectiveness analysis methodology is merely a tool, and a tool implies a user - in this case the decision-maker.

ASSUMPTIONS

The assumptions and guidelines applicable to each one of the various analyses performed as part of this study are presented in the other volumes of this report. Some of them are briefly summarized below.

Vessel Mission Profile Characteristics

The assumptions relating to vessel mission profile data collection and analysis are presented in greater detail in Volume IV of this report. Those assumptions which affect WMS design and operation are as follows:

- Restricted Waters

  Restricted waters are defined as the coastal waters within three (3) miles of any shoreline of the continental United States, as well as all inland waters (e.g., lakes, rivers, bays, streams, estuaries, etc.)

- Waste Receiving Facilities

  Wastewater receiving facilities are assumed to be available at the vessel's home port and at a yard only. Waste off-loading facilities are assumed to be unavailable for the vessel at all other non-home ports regardless of type, i.e., Coast Guard, Navy, municipal, etc.

- WMS Operation Within and Beyond Restricted Waters

  All results are computed on the basis of the following assumptions with respect to WMS operation:

  .. Operation of WMS subsystems which are necessary to avoid discharge of wastewaters (i.e., the primary mode) is initiated as soon as the vessel enters restricted waters or leaves its home port and continues until the vessel either leaves restricted waters or arrives at its own home port or at a yard. WMS operation in the primary mode continues if the vessel is at any non-home port except a yard.

- - As soon as the vessel arrives at its own home port or at a yard, it is connected to a pierside waste receiving facility and WMS subsystem operation is changed to the pierside discharge mode.
  - WMS operation in the overboard discharge mode is initiated as soon as the vessel leaves restricted waters and continues until it reenters restricted waters.
  - Any effects that an installed WMS may have on vessel mission profiles have not been considered. Examples of such effects include remaining longer beyond restricted waters to empty a holding tank, transiting out of restricted waters in order to empty a full holding tank, transiting out of restricted waters more frequently (therefore, affecting the number of mode change-overs) due to the installation of a holding tank which does not provide full capacity, etc.

- Vessel Holding Time Requirements

  For purposes of this study, the holding time goal for a given vessel is based on the largest holding time recorded for that vessel, regardless of its frequency or magnitude in relation to the other holding times in the data obtained, i.e., even if the maximum holding time occurred only once and is considerably higher than all other holding times.

Candidate System Development

The assumptions and guidelines relating to the development of the candidate WMS concepts and their associated WMS equipment configurations as a function of vessel and the guidelines for determining viable system/ vessel combinations are presented in Volume IV of this report. Those relating to the installation analysis of these candidates are presented in Volume III. Some of these assumptions and guidelines are:

- Wastes to be Managed

  The candidate systems are intended for managing black and gray wastewaters on board the six U.S. Coast Guard cutters selected for this study. These wastewaters are defined as follows:

  - Black water includes sewage, i.e., the output from commodes and urinals, and garbage grinder slurry.*
  - Gray water includes: galley wastewater from sinks and kettles (excluding garbage grinder output); turbid water from lavatories, showers, and laundry; drainage from air conditioners, drinking fountains and interior deck drains (including those in head spaces).

  WMS Concept Preferences

  It is assumed that there is no a priori preference of WMS concept with respect to no-discharge versus flow through, as long as existing emission standards are met.

  WMS Acceptability Criteria

  The determination of the viability of a candidate WMS configuration on a given vessel is based on the feasibility of installation within specified guidelines for compartment availability. The WMS acceptability and installation criteria are:

  - All specified sizes and required number of duplicate WMS equipment, except for holding tanks, must be accommodated, based on the established vessel space utilization guidelines.

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* U.S. Coast Guard legal opinion considers garbage grinder output as sewage.

.. Inability to accommodate the required black and/or gray water holding tank size, based on the vessel space availability guidelines below, shall not be deemed sufficient reason for rejecting a candidate WMS configuration. The maximum black and/or gray water holding tank size which can be accommodated shall be specified, using the guidelines for black/gray water holding capacity apportionment and the minimum gray water holding tank requirements.

.. Where limited holding tank capacity exists, black water storage capacity shall have priority. Remaining storage capacity shall be used for gray water, ensuring that the minimum gray water requirements are met.

.. A minimum gray water handling capability must be provided for each vessel. In a system where gray water is dumped as and when received, and the manifold is below the waterline, an overboard discharge pump is required with a feed tank. If the manifold is above the waterline, neither pump nor feed tank is required since overboard discharge can be achieved by gravity. In either case, provisions have to be made for transferring the gray water to the pier connection (which may be accomplished via a black water holding tank).

Holding Tank Aeration

Black water holding tanks must be aerated at a rate of 16.3 SCFM per 1,000 gallons of liquid. Gray water tanks are not aerated. Aeration rates are based on requirements for a full tank. The same aeration rate is assumed regardless of the type of black water held, i.e., full volume flush, reduced volume flush (from Jered or GATX collection subsystem), or sludge (from Chrysler or Grumman treatment subsystem).

Hybrid Systems

The following assumptions have been made with respect to WMS concepts hybridized by combining subsystems/equipments from different MSDs:

.. The effects on cost, effectiveness, and installation of any interface equipment or prime equipment modifications which may be required have been neglected.

.. It is assumed that data (relating to the cost and/or effectiveness analyses) developed on an MSD subsystem/equipment basis are valid even when such data were derived from operational information or observations of the entire MSD and not just the given subsystem/equipment. This does not apply to acquisition costs, which were obtained from MSD manufacturers on a subsystem/equipment basis.

.. It is assumed that overall WMS data (relating to the cost and/or effectiveness analyses) synthesized from MSD subsystem/equipment data are valid, i.e., any changes to such data due to possible interface problems or dependencies have been neglected.

Life-Cycle Cost Estimates

The assumptions and guidelines relating to the development of MSD acquisition, operating and maintenance costs are presented in Volume V of this report and those relating to WMS installation costs are presented in Volume III. Some of these assumptions and guidelines, as well as additional ones affecting the WMS life cycle cost estimates are as follows:

- Labor Rates

The cost of labor for WMS operation and maintenance on board U.S. Coast Guard cutters is based on hourly labor rates derived from the annual billet costs for U.S. Coast Guard military and civilian personnel. Hourly labor rates were obtained by dividing the annual billet costs by the number of working hours per year, assumed for the purposes of this study to be 2,080 hours (i.e., a 40 hour work week). The hourly labor rates thus obtained, as a function of pay grade are given below.

LABOR RATES*

Pay Grade	Electricians Mate (EM)		Machinery Technician (MK)	
	Annual ($)	Hourly Rate ($/hour)	Annual** ($)	Hourly Rate ($/hour)
E-2	11,332	5.45	13,038	6.27
E-3	12,396	5.96	14,235	6.84
E-4	13,522	6.50	15,425	7.42
E-5	15,023	7.22	16,911	8.13
E-6	20,240	9.73	23,215	11.16

* Hourly rate base on annual billet costs and assumed 2080 hours per year

** Source of annual billet costs - USCG Military and Civilian Manpower Billet and Life Cycle Costing, July 1975.

Cost of Vessel Resources

For purposes of this study the cost of vessel resources is assumed to be as follows:

.. 39¢/gallon of fuel oil

.. 3¢/kwh of electric power

.. 70¢/1,000 gallons of fresh water, if taken from shore supply

.. $20/1,000 gallons (2¢/gallon) of fresh water, if generated on board vessel by an evaporator

- 1.83¢/1,000 gallons for the cost of electric power to pump flushing fluid
- $[6.1227\ (14.7 + p)^{0.1419} - 8.9898]\ [V]$ is the annual cost of compressed air in cents, where p is pressure in psig and V is the flow in standard cubic feet per day.

- Preventive Maintenance

  It is assumed that preventive maintenance of WMS subsystems/equipments is unaffected by vessel mission profiles, i.e., scheduled maintenance activities will not be adjusted to reflect differences in WMS utilization factors.

- Overhaul Intervals

  In lieu of available information on overhaul requirements from manufacturers on all MSD subsystems/equipments included in this study, a two (2) year overhaul interval was assumed for all WMS equipment for purposes of estimating life-cycle overhaul costs.

- System Economic Life

  The useful life of each candidate WMS was assumed to be ten (10) years, i.e., life-cycle costs were computed on the basis of adding the fixed costs (capital investment) to the present value of the recurring expenditures (operating and maintenance costs) computed for a 10 year interval.

- Effective Discount Rate

  An effective discount rate (to include the effects of interest and inflation rates) of 10% was used in deriving present value factors for estimating the present value of WMS life-cycle operating and maintenance costs.

APPROACH

A summary of the overall approach used for developing and analyzing the candidate system/vessel combinations is presented in Figure 1. A description of the various steps in this figure is presented in the body of this report, together with the results obtained after executing each step. Further details of the procedural aspects of the approach are presented in the other volumes of this report. The diagram which appears in the "Preface" complements Figure 1 by indicating the flow of information between the various analyses which are part of this study, and which are presented in this as well as in the other volumes of the report.

The discussion below is presented as a means of clarifying some of the issues pertaining to the concepts, principles, philosophy and to a lesser extent, some of the procedural aspects of the approach.

Who Determines What Effectiveness Is and How?

This approach for assessing effectiveness can be characterized as being decision-maker intensive.* The essence of the approach is the notion that an effective system is one that fulfills intended objectives satisfactorily -- in the decision-maker's opinion. Some of the implications of this are:

- Nobody can tell the decision-maker what effectiveness is. Instead, he must make this determination on the basis of the specific problem and its context.
- There is no such thing as a universal formula or model for effectiveness which is suitable for all different types of candidate systems.

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* This is to be interpreted qualitatively rather than a quantitatively, i.e., most of the effort consists of developing the necessary data rather than involvement by the decision-maker.

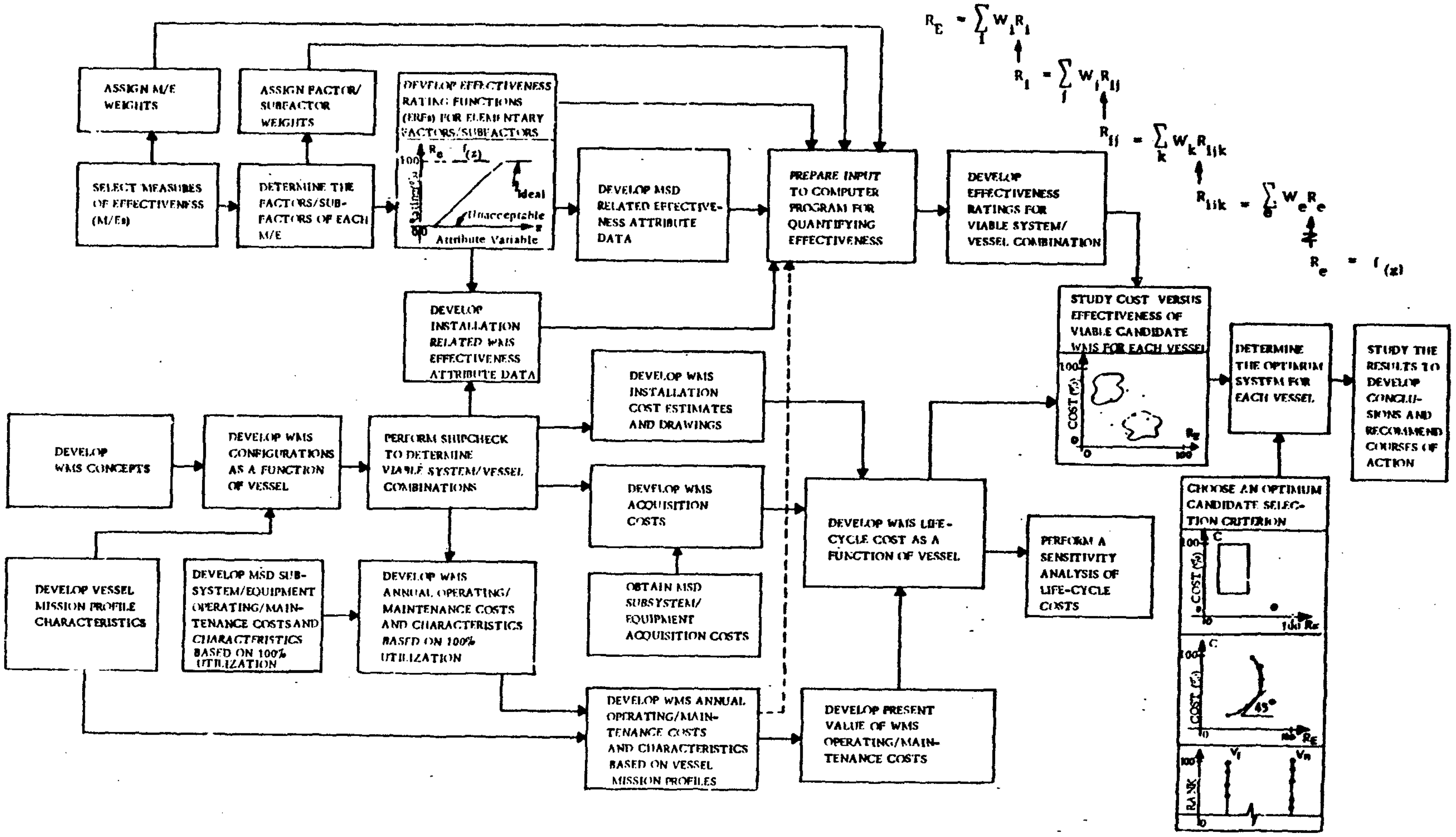
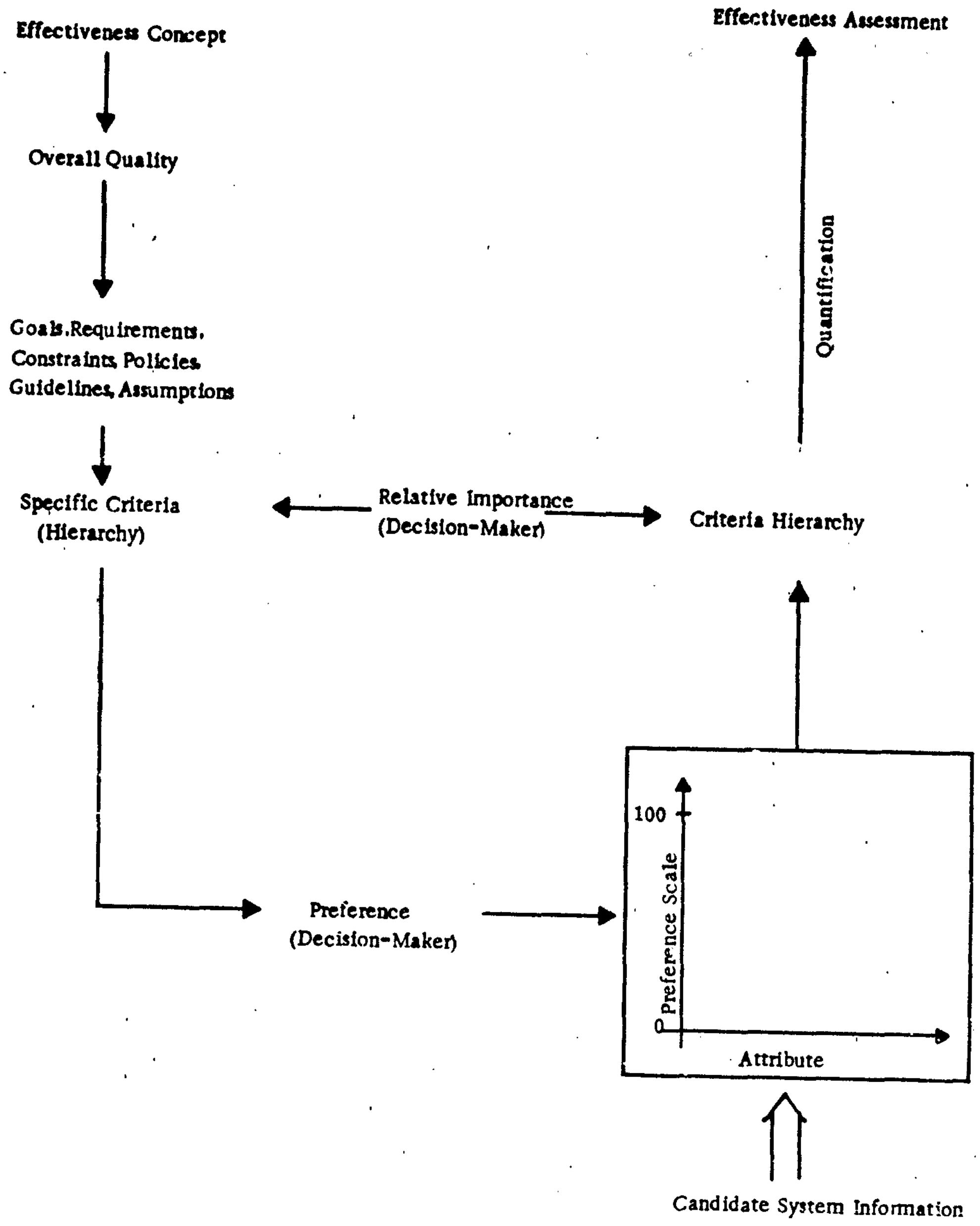


Figure 1

SUMMARY OF APPROACH FOR CANDIDATE SYSTEM DEVELOPMENT AND ANALYSIS

- The model for effectiveness must be adapted and tailored to the candidate systems as well as the context of the problem, and not the other way around.
- The only thing which is universal about effectiveness is its concept as the overall quality of a candidate. What can be generalized is not a specific model for effectiveness but rather the steps for developing such a model, how to use it for quantifying effectiveness, and how to interpret the results for the purpose of arriving at decisions. This generalization takes the form of defining a basic structure and specific elements of an effectiveness model.
- Effectiveness is always directly related to the objectives, requirements, constraints of the problem and the subjective judgements of the decision-maker, in addition to the data for the candidates.
- The decision-maker's involvement in the process of assessing the effectiveness of candidates consists of the following:
  - Stipulation of specific standards (i.e., criteria) for judging the candidates.
  - Indication of the relative importance of these criteria.
  - Specification of the degree of preference for judging candidate characteristics in relation to the established standards.
  - Interpretation of the quantitative results.

These ideas relating to effectiveness and its quantification are summarized on the following page.


Effectiveness Concept
Overall Quality
Goals,Requirements,
Constraints, Policies,
Guidelines, Assumptions
Specific Criteria
(Hierarchy)
Relative Importance
(Decision-Maker)
Criteria Hierarchy
Effectiveness Assessment
Quantification
Preference
(Decision-Maker)
100
0
Preference Scale
Attribute
Candidate System Information

It is noted that what has been suggested for quantifying effectiveness is a methodology as opposed to a model. The difference is that in a methodology, the effectiveness model for a specific set of problems becomes an input, together with its associated data.

The above is in sharp contrast to approaches for quantifying effectiveness which are based on a fixed and preformulated expression for effectiveness (or for cost-effectiveness). Such an approach defines effectiveness in terms of the product of several specific variables (usually performance, availability, and either "utility" or "worth"). This may appear as a simple solution to the problem of quantifying effectiveness since it may seem that all that needs to be done is to determine the values of these variables for the candidate systems and then the answers to all questions will become available. However, this is not quite the case. An attempt to use this method brings up a number of both conceptual and procedural problems.

Since this approach requires that the candidate systems be fitted to the model, rather than the other way around, one immediately faces the problem of how to accomplish this. For instance, one must decide how to examine the systems in question and from that examination derive a single number which is an objective measure of system performance. The difficulty in doing this becomes apparent when one considers the multiplicity of considerations which enter into the overall assessment of system performance.

Another major problem with such an approach is the question of what to do with all the other considerations which are pertinent to the systems of interest but which do not appear in the formulation of effectiveness (e.g., safety and habitability problems, burden on crew). Thus, attempting to use such an approach will inevitably mean omitting large chunks of considerations and will result in a decision arrived at on the basis of a small fraction of the original set of issues which are of interest to the decision-maker.

There is often the belief (or hope) that such an approach for quantifying effectiveness is "objective" (or at least more objective than the approach used in this study). The argument (or belief) for this is that the approach is based on an explicit formula into which are substituted quantitative and "technical" data. Hence, since only this type of information is used in the quantification of effectiveness, the results and conclusions must therefore be (so it is believed) "objective" and perhaps even "scientific".

What such reasoning fails to recognize is that as soon as one confines oneself to a fixed expression for effectiveness (or for cost effectiveness) in terms of several specific variables only, one has immediately made a very subjective decision. One has decided that the entire realm of effectiveness (or cost effectiveness) is encompassed by the few specific variables, i.e., that these variables adequately account for all considerations of interest. Furthermore, such a decision is irrevokable, i.e., one has lost control of the ability to modify ones subjective judgements and examine the effects of such changes.

One may wonder about the origin of such approaches for quantifying effectiveness and under what circumstances they may be adequate. Such approaches are popular in the weapon system mission analysis community in which practically the entire context of the problem is that of determining the probability of mission success. For such purposes, effectiveness is formulated for a specific purpose, namely to serve as a figure of merit or indicator for measuring how well a weapon system can hit a target. In such a formulation, the miss distance is a good indicator of performance.

Thus, a fixed expression for effectiveness may be adequate for systems in which performance is the overriding criterion and furthermore, performance can be adequately characterized by a single parameter. Applications of such approaches to candidate systems in other types of contexts may very well constitute a fallacy resulting from an invalid attempt at a transfer of technology.

Life-Cycle Cost

Estimation of life-cycle cost can be aptly characterized as a complex problem disguised as a simple concept. That is, most of the problems associated with the quantification of this cost are conceptually simple but procedurally difficult.

This is not to say that life-cycle cost is devoid of conceptual problems. One such problem relates to the question of who pays for what? A specific example of this is the issue of the costs associated with the labor required to operate and maintain a system, such as a WMS, installed on board a vessel. It is sometimes argued that since such labor comes from the crew already on board the vessel (assuming that the introduction of the system will not require an increase in the manning complement), its cost should not be charged to the system as an element of the overall life-cycle cost. A similar argument might be advanced with respect to the cost of vessel resources used by the system. Such reasoning is especially appealing when the costs involved come from another department's budget. One fallacy in such views is that if, for instance, the argument about the cost of labor is pursued to its ultimate conclusion, i.e., it is applied in turn to every individual piece of equipment, the result might be a vessel without a crew.

The approach used in this study for estimating life-cycle cost is based on including all items and parameters which affect cost. Regardless of specific budgetary subdivisions and allocations, all costs must eventually be accounted for.

Although the notion of cost is certainly a familiar one and it is even easy to agree with the basic idea of life-cycle cost, namely that all, not only some of the costs, ought to be included, the execution of this objective is by no means simple. The reason for this is twofold. First, the large amount of data which must be dealt with in order to include all cost elements. Second, the numerous dependencies which are inherent in these data elements.

Some of the system/vessel parameters on which life-cycle cost depends may not immediately be obvious as being associated with cost, since they are often considered in other contexts. Thus, performance requirements for a vessel as determined from mission profile data (i.e., the holding time requirements) affect both acquisition and installation costs. System reliability (actually the lack of it) has economic (as well as other) implications, and system maintainability affects life-cycle costs.

Other types of dependencies which must be addressed relate to differences in cost for the equipment operating on board different vessels. Examples of this include the different costs for fresh water depending on its source (i.e., whether taken from shore and stored or whether generated on board the vessel by an evaporator), the dependence of vessel resource usage rates on crew size and mission profiles, etc. Superimposed on this are additional dependencies on assumptions or estimates which affect life-cycle cost, such as how long the system will last, interest and inflation rates in the future, etc.

In the approach adapted for estimating life-cycle cost, the key to addressing these dependencies successfully is to break up life-cycle cost into constituent elements. This, in effect,results in a life-cycle cost model which takes the form of a hierarchy. The various dependencies are addressed by introducing them at strategic points in this hierarchy (see "The Life-Cycle Cost Model" further in this report).

In contrast with the effectiveness model, the life-cycle cost model is considerably more universal. That is, the same types of cost categories are applicable to a large range of different system types. What varies from system to system is the specific data associated with the life-cycle cost model and perhaps some of the dependencies. The advantages of this is that it makes this model amenable to automation and thus alleviates the computational burden associated with developing cost estimates.

Cost Versus Effectiveness - A Priori and A Posteriori

This cost effectiveness analysis approach starts with the premise that there is no a priori relationship between cost (penalty) and effectiveness (quality). The validity of this is generally confirmed by evidence from most types of market places. Such a relationship is provided a posteriori by application of the cost effectiveness analysis methodology.

This is to be contrasted with approaches (in other contexts) which attempt to estimate system cost on the basis of one or more system characteristics. Such approaches are based on the assumption (or belief) that there is an a priori relationship between cost and quality. Such relationships are generally derived by regression analysis techniques applied to historical data for system cost and the value of one or more system characteristics. The cost of any other system is then obtained by substituting the value of the desired characteristic(s) into this relationship. When such approaches are used to estimate the cost of new types of systems, i.e., based on designs different from those used to derive the relationship, then what is being engaged in (perhaps without conscious realization) is technological forecasting.

Some cost effectiveness analysis approaches are based on eventual elimination of a cost versus effectiveness relationship by converting effectiveness into cost so that the final number or figure of merit used is all cost (the purely economic approach). Such a procedure may be appropriate for problems in which the context is one of achieving a specific objective and the overriding consideration is the reduction of cost.

The approach used in this study does not attempt to convert effectiveness into cost or vice versa. Although one of the optimum candidate selection criteria is based on the ratio of cost to effectiveness rating, which results in a number having the units of cost, this is done only for the purpose of ranking the candidates rather than as an attempt to obtain an actual cost equivalent for an effectiveness rating. In the approach used, the problem is formulated in two dimensions in the context of effectiveness (quality) vs. cost (penalty). To put it another way, one can answer the question: what is the most economic approach under different consequences. The question of how and to what extent to trade-off consequences (quality) for economy (or cost penalty) is left to be resolved by the decision-maker.

Another issue concerning the relationship between cost and effectiveness is related to the question of which system aspects belong in the cost category and which ones belong in the effectiveness category. This approach is based on the principle that all candidate system aspects which affect life-cycle cost must be included in the cost estimate and all candidate system aspects which have an impact on effectiveness must be included in the effectiveness assessment, whether or not there is any commonality. In fact, ideally the two analyses (cost and effectiveness) should be performed by different groups of individuals who do not communicate with each other in order to avoid bias in the results. Thus, this principle implies that certain candidate system features will exert an influence on both cost and effectiveness. As an example of this, the number of man-hours required for operation and maintenance has economic implications (i.e., the cost of labor) as well as an impact on overall system quality or effectiveness (i.e., the extent to which it burdens the crew).

The Objectives of Quantification

There are two main and related reasons for quantifying cost and effectiveness. Although the reason for quantifying cost is obvious, the reasons for quantifying effectiveness may not be apparent.

One motivation for attempting to quantify effectiveness relates to the different types of information which must be dealt with in an effectiveness assessment. Some of this information is inherently qualitative and converting such information to numbers reduces the different types of information to a common basis. Qualitative information may, in turn, be objective (e.g., the system has or does not have a given feature, it can or cannot do a given thing) or subjective (e.g., levels of difficulty to perform a given task, odor levels).

The second reason for quantification is directly related to the first one. Once all the types of information have been converted to numbers, it becomes much easier to use and combine the information for the purpose of identifying trends and making inferences. Specifically, it is much easier to manipulate numbers than it is to manipulate such things as system features and characteristics, goals, assumptions, requirements, and subjective judgements. Thus, the resulting effectiveness and cost numbers become the indicators or representatives of system attributes. Often, important system properties, trends, conclusions, etc., not otherwise apparent, can be discerned by manipulating these numbers*.

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* This is analogous to the introduction of the notion of a random variable in probability theory. The basic concepts of probability theory are stated in terms of events (outcomes of an experiment) which are not necessarily quantitative in nature (e.g., heads or tails when a coin is flipped, the color or suit or identification of a card drawn from a deck). The introduction of the notion of a random variable serves to quantify non-numerical events. This, in turn, facilitates analysis on the resulting numbers. Such analyses sometime lead to the discovery of important properties which can then be reinterpreted in terms of the original events.

The cost effectiveness analysis methodology developed and used in this study relies heavily on the use of cost and effectiveness numbers. The purpose of these numbers is to provide the decision-maker with as much visibility as possible of the candidate system properties in relation to the overall context of the problem, so that the important implications become apparent.

In order to facilitate such visibility, this methodology makes available results for both cost estimates as well as effectiveness ratings at several levels of detail. This enhances the decision-maker's ability to interpret the numbers in terms of system features and characteristics.

Although the quantification of life-cycle cost and effectiveness is one of the major aims of this methodology, caution is advised against putting undue emphasis on these numbers. An overemphasis of these numbers, to the exclusion of other considerations, or their use out of context, carries with it the danger of mistaking or substituting form for substance.

It must be remembered that the ultimate objective of the analysis is not to generate these numbers. They are merely a stepping stone toward the higher objective of gaining a better insight into the candidate systems, making inferences and drawing conclusions, so that the best course of action can be identified.* Thus, it is important for a decision-maker using this cost effectiveness analysis methodology to develop a skill in interpreting these numbers in terms of the original goals and requirements associated with the problem.

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* This is analogous to the modulation of a signal to facilitate its transmission over great distances. The ultimate aim of the effort is not to transmit the signal but rather to facilitate communication.

Scales for Relative Importance, Degree of Acceptability and Effectiveness

The effectiveness model requires two types of quantitative inputs from the decision - maker and it provides one type of quantitative output.

One of these inputs is the importance of each criterion in relation to the others at the same level in the criteria hierarchy. This relative importance is expressed as a quantitative weight in terms of a percentage in the range from 0 to 100%, such that the sum of the weights is 100% for all criteria at the same level of subordination (i.e., M/E weights, factor weights, or subfactor weights). On this scale a weight of 0% assigned to a criterion means no importance at all, i.e., the given criterion is in fact ignored. On the other hand, a weight of 100% assigned to a given criterion means overriding importance to the exclusion of all the others, i.e., all the other criteria at the same level of subordination in the effectiveness model will be ignored, and hence will not exert any influence on the overall assessment of the candidates.

The other quantitative input to the effectiveness model is the degree of preference for the various quantitative and qualitative attributes of the candidates being evaluated by the lowest level criteria in the effectiveness model (i.e., the elementary factors/subfactors). These preference assignments are made via the effectiveness rating functions (ERFs) which relate the qualitative or quantitative candidate characteristic or feature to an effectiveness rating as a percentage on a scale of 0 to 100% which represents the degree of acceptability of various possible attribute values or choices. On this scale, a rating of 0% means completely unacceptable, i.e., worthless. A rating of 100% means complete satisfaction of the given criterion, i.e, the candidate attribute is ideal.

Candidate effectiveness assessments are the outputs from the effectiveness model which are expressed quantitatively as effectiveness ratings. Effectiveness ratings are expressed as a percentage on a scale of 0 to 100%. An effectiveness rating of 0% means that the candidate does not satisfy any of the established criteria. An effectiveness rating of 100% means an ideal candidate, i.e., it fully satisfies all of the established criteria.

These quantitative scales associated with the effectiveness assessment methodology are all in terms of percentages. For purposes of the mathematical operations in connection with the quantification of effectiveness, the numerical values for the relative importance (weights), the degrees of preference (elementary factors/subfactor ratings), and the overall effectiveness ratings should be expressed as a fraction in the range from 0 to 1.0 rather than as a percentage. This conversion is done by the computer program for quantifying effectiveness.

For purposes of communicating with the decision-maker, a percentage scale was adapted in this study since it is more user-oriented. Most people are used to thinking in terms of percentages and hence can visualize a percentage and relate to it better than to a fraction.

It is noted that the above three quantitative scales are continuous rather than discrete. Another continuous scale used in connection with this cost effectiveness analysis approach is the ranking of candidates on the basis of the ratio of cost to effectiveness rating (see "Optimum Candidate Selection Criteria" further in this volume). If these rankings are normalized by dividing each by the maximum value, then the resulting relative rankings are percentages in the range of 0 to 100%. The above are in contrast with approaches in which the inputs and/or the outputs are discrete rankings.*

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*For a discussion on the difference between a ranking and a rating see "Simplified ERFs Based on Ranking" in the section on the development of ERFs in Volume II.

ANALYSIS OF VESSELS

VESSELS CONSIDERED

The six vessels selected by the U.S. Coast Guard for inclusion in this study are listed in Table 1. Mission Profile data for the new construction vessel was simulated with data from the SHADBUSH (74') and CLAMP (75') which have similar missions. These vessels were analyzed on the basis of the following:

- Study of various vessel plans and drawings.
- Visits to vessels to obtain mission profile data (see Volume VI).
- Shipcheck inspections of the vessels for the following purposes (see Volume III):
  - Observe physical conditions aboard the vessel.
  - Determine deviations from plans.
  - Ascertain locations of black and gray wastewater sources.
  - Determine the feasibility of installing each candidate system.
  - Obtain information required for developing WMS equipment drawings, installation cost estimates and installation related effectiveness attribute data.

MISSION PROFILE CHARACTERISTICS

Vessel mission data was recorded on the form shown in Figure 2. The results of a statistical analysis of these data are shown in Table 2. Vessel mission profile characteristics which are of particular interest in the development of the candidate systems and the life cycle cost estimates are the following:

- The holding time requirements (assumed to correspond to the maximum holding time), which will determine WMS equipment requirements and sizing.

Table 1

VESSELS INCLUDED IN MISSION PROFILE STUDY

VESSEL	CLASS	TYPE	CREW SIZE	HOME PORT	MISSION PROFILE DATA	
					Time Interval Studied	Source of Data
GALLATIN (378')	WHEC-721 Hamilton (378') Class	High Endurance Cutter	152	Governor's Island, New York	12 Months 7/1/74 - 6/30/75	Ship's Log
VIGOROUS (210')	WMEC-627 Resolute (210') B Class	Medium Endurance Cutter	60	New London, Conn.	12 Months 8/1/74 - 7/31/75	Summary Log
FIREBUSH (180')	WLB-393 Basswood (180') C Class	Buoy Tendor (Seagoing)	50	Governor's Island, New York	12 Months 8/1/74 - 7/31/75	Summary Log
PAMLICO (160') New Contruction Based on Data from	WLIC	Buoy and Construction Tender (Inland)	13	New Construction (Intended for Operation in Depot Corpus, Texas)	Represented by data from SHADBUSH and CLAMP 7 Months 6/1/74-10/31/75	
SHADBUSH (74')	WLI-74287 Clematis (74') Class	Buoy Tender (Inland)	9	New Orleans, La. (Transferred to Galveston, Taxas)	18 Months 6/1/74 - 8/21/75	Summary Log
CLAMP (75')	WLIC - 75306 Clamp (75') Class	Construction Tender (inland)	9	Galveston, Taxas (Transferred to New Orleans, La.)	2 Months 8/22/75 - 10/31/75	Summary Log
WHITE SAGE (133')	WLM-544 White Summac (133') Class	Buoy Tender (Coastal)	21	Woods Hole, Mass.	8 Months 8/1/74 - 7/31/75	Ship's Log
POINT HERRON (82')	WPB-82318 Point (82') C Class	Patrol Boat (Small)	8	Bay Shore, New York (Fire Island)	15 Months 5/1/73 - 7/31/74	Summary Log

DETAILED VESSEL MISSION PROFILE DATA

Vessel ____________________

Sheet of

DATE Month____ Year____	DOCKINGS				HOURS IN HOME PORT	HOURS IN NON-HOME PORT	TOTAL HOURS UNDER-WAY	HOURS UNDER-WAY WITHIN 3-MILE LIMIT	NUMBER OF 3-MILE CROSSINGS
	Home		Non-Home						
	Arrival	Departure	Arrival	Departure					

SORTIE CHARACTERISTICS (Estimated)			
TYPE	HOLDING TIME INTERVALS (Hours)		TIME INTERVALS BEYOND RESTRICTED WATERS (Hours)
	MAX	OTHERS	
	⋮	Initiation of a sortie Completion of a sortie	

Figure 2

DATA FORM FOR RECORDING MISSION PROFILE DATA

Table 2

SUMMARY OF MISSION PROFILE CHARACTERISTICS

VESSEL	ANNUAL TIME SPENT IN PORTS				ANNUAL NUMBER OF DOCKINGS (6)		ANNUAL TIME SPENT IN YARD		ANNUAL TIME UNDERWAY			TIME WITHIN 0-3 MILE LIMIT AND/OR IN NON-HOME PORT (Excluding Yards)									TIME BEYOND RESTRICTED WATERS						
	HOME		NON-HOME									TIME WITHIN 3-MILE LIMIT			HOLDING TIME												
																		N - Sample Size μ - Mean σ - Standard Deviation FREQUENCY							N - Sample Size μ - Mean σ - Standard Deviation FREQUENCY		
	Hours	% of Total	Hours	% of Total	At Home Port (7)	At Non-Home Port	Hours	% of Total	Hours	% of Total	Annual # of 3-Mile Limit Crossings (8)	Hours (Annual)	% of Total (Annual)	% of Underway Time	Hours (Annual)	% of Total (Annual) (10)	Maximum (Hours)/ Lower Confidence Limit (%) (9)	Time (Hrs.)	No. of Occur.	%	Hours (Annual)	% of Total Annual	% of Underway Time	Maximum (Hours)	Time (Hrs.)	No. of Occur.	%
GALLATIN (378')	4556.5	52.0	768.5	8.8	39	50	864.0 (R)	9.8	2571.0	29.3	72	205.0	2.0	8.0	973.5	11.0	97.5 93.70	N=56, μ=17.4, σ=24.5 0-25 25-50 50-75 75-97.5	 46 2 5 3	 88.12 3.57 8.93 5.36	2366.0	27.0	90.0	430.0	N=36, μ=65.7, σ=102.6 0-100 100-200 200-300 300-430	 30 3 1 2	 83.33 8.34 2.77 6.66
VIGOROUS (210')	4930.0	56.3	334.0	4.1	32	24	992.0 (SYA)	11.0	2504.0	28.6	30	152.2	1.7	6.0	486.2	5.6	172.0 88.80	N=31, μ=15.7, σ=32.7 0-50 50-100 100-150 150-172	 23 2 0 1	 90.32 6.45 0 3.23	2351.0	26.9	94.0	353.0	N=15, μ=156.8, σ=110.8 0-100 100-200 200-300 300-353	 6 4 2 3	 40.00 24.67 13.33 20.00
FIREBUSH (180')	6362.0	72.6	377.2	4.3	205	29	268.0 (SYA)	3.0	1252.0	14.3	68	860.7	9.8	68.7	1237.9	14.1	277.9 97.40	N=135, μ=9.2, σ=24.4 0-75 75-150 150-225 225-278	 134 0 0 1	 99.26 0 0 0.74	392.1	4.5	31.3	99.3	N=34, μ=11.5, σ=16.5 0-25 25-50 50-75 75-100	 33 0 0 1	 97.06 0 0 2.94
(3) WHITE SAGE (133')	7519.4	35.8	280.7	3.2	161	21	216.0 (R)	2.5	743.9	8.5	34	692.2	7.9	93.0	972.9	11.1	65.5 94.50	N=64, μ=10.0, σ=12.4 0-15 15-30 30-45 45-66	 58 2 1 3	 90.63 3.12 1.56 4.69	51.7	0.6	6.9	5.0	N=11, μ=3.0, σ=0.7 0-1.5 1.5-3.0 3.0-4.5 4.5-6.0	 0 10 0 1	 0.0 90.91 0.0 9.09
(4) POINT HERRON (82')	7830.4	89.4	91.5	1.0	91	2	(5) 480.0 (R)	5.5	350.0	4.1	92	70.5	0.8	19.7	162.0	1.8	99.0 96.80	N=113, μ=1.8, σ=9.5 0-25 25-50 50-75 75-99	 112 0 0 1	 99.12 0.0 0.0 0.88	187.5	3.3	80.0	22.5	N=58, μ=6.3, σ=4.6 0-5 5-10 10-15 15-23	 31 17 9 1	 53.45 29.31 15.52 1.72
(1) PAMLICO (160')	5273.3	71.6	0	0	63	0	0	0	2486.7	28.4	0	2486.7	28.4	100	2471.1	28.2	456 92.20	N=45, μ=77.9, σ=86.9 0-100 100-200 200-300 300-456	 33 6 5 1	 73.33 13.34 11.11 2.22	•	•	•	•	•		
New Constr. (2)	6024.7	68.9	0	0	65	0	0	0	2735.3	31.1	0	2735.3	31.1	100	2718.1	31.0	501				•	•	•	•			

(1) Combined data from SHADBUSH and CLAMP (12-month average based on 17 months of data).
(2) Estimated data for PAMLICO (10% increase in underway time).
(3) 12-month average based on 8 months of data.
(4) 12-month average based on 15 months of data.

* No time spent beyond restricted waters.
(R) Refurbishment (SYA - Scheduled Yard Availability)

(5) Weighted average of 384 and 216 hours over 15-month period. Weighted difference of 120 hours added to Col. 1.
(6) Arrivals or departures.
(7) Includes yard dockings. Used for estimating the number of WMS pierside to overboard discharge mode changeover cycles.
(8) In either direction. Used for estimating the number of WMS primary to overboard mode changeover cycles.
(9) Lower 95% confidence limit on the maximum holding time.
(10) Used for WMS utilization factor.

- The percentage of the total annual time spent within restricted waters (which corresponds to the WMS utilization factor).
- The number of annual crossings of the 3-mile limit and the number of home port (or yard) dockings (which determine the number of WMS mode changeover cycles from primary to overboard mode and pierside to primary mode).

Vessel Holding Time Requirements

The holding time requirement for a vessel is an important mission profile characteristic used to establish WMS equipment configurations and the choice of a given holding time may determine the feasibility of installing a given candidate WMS configuration. By Coast Guard direction, the holding time goal for each vessel was fixed as the maximum holding time recorded for that vessel, without regard to the frequency of occurrence in relation to the other holding times during the interval for which data were collected. Table 3 shows the relationship between the maximum holding time for each vessel, the next smaller holding time and the percentage of all holding times which are equal to,or less than, the next smaller holding time. It is noted from Table 3 that for some vessels, the maximum holding time is several orders of magnitude larger than the next smaller holding time. The implication of this is that a holding time goal based on satisfying P% rather than 100% of all holding times, would result, for some vessels, in drastic reductions in wastewater management equipment requirements and sizing. Possibly this may also result in a reversal of the decision that some system/vessel combinations are not viable candidates based on installation considerations.

However, the implication of a decision to use a holding time goal for a vessel based on satisfying P% of all holding time requirements, is that emission standards will be violated by (100-P) % of the vessel missions. Alternatively, vessel operations may have to be modified in order to avoid violating emission standards.

Table 3

RELATION BETWEEN MAXIMUM AND ALL OTHER HOLDING TIMES

VESSEL	MAXIMUM HOLDING TIME (Hours)	ALL OTHER HOLDING TIMES	
		Next Smaller Holding Time (Hours)	% of All Holding Times Excluding the Maximum
GALLATIN (378')	97.5	88.0	98.21
VIGOROUS (210')	172.0	72.0	96.77
FIREBUSH (180')	277.9	54.0	99.26
PAMLICO (160')* New Construction	456.0**	228.0	97.78
WHITE SAGE (133')	65.5	62.0	96.88
POINT HERRON (82')	99.0	21.5	99.12

* Based on data from SHADBUSH (74') and CLAMP(75')

** Maximum holding time used for WMS design purposes is 501 hours, an increase of 10% to reflect anticipated longer holding time requirements as a result of more available space for stocking supplies.

DEVELOPMENT OF CANDIDATE SYSTEMS

MSDs CONSIDERED

The five Marine Sanitary Devices (MSDs) to be used as the building blocks for the WMS concepts were specified by the Coast Guard. In accordance with the C.G. guidelines, scaled versions of each MSD were considered only if they are commerciallly available, or operational and physical characteristics are available from the manufacturer. An analysis and data for pertinent characteristics of each MSD are presented in Volume V of this report. A brief description of the principles of operation and a functional block diagram of each MSD considered in this study are presented below.

Jered Sewage Disposal System

The Jered MSD is based on the use of vacuum collection of human wastes from proprietary, reduced flush commodes. Wastes from standard urinals are also collected by the vacuum drains by means of a special interface valve. The collected sewage is incinerated in a vortex incinerator. It is the only MSD considered in this study that provides motive power for transport of sewage at the central collection site.

The primary Jered MSD under consideration is the model V85003 that was installed as a test system on the USS KRAUS. The system has the capacity to handle a maximum of 200 men on a 24-hour basis. In order to examine a vacuum collection system that is practical for significantly fewer users, the Jered Small Boat Collection System was included in this study. The small boat system is essentially a collection and holding system; it does not include an incinerator. Available information on this system is much less extensive than for the 200-man system. The small boat system is available in different capacities. In the description below, prospective minor modifications are discussed which would be expected if the system is to be adapted for use with a small incineration subsystem, possibly by another manufacturer. Currently, Jered has only one size incinerator.

The 200-man MSD is an automatic system but requires an operator for periodic ash removal from the incinerator. However, the system is quite complex and requires a fair amount of operator and preventive maintenance actions.

A functional block diagram of the Jered Large Boat Sewage Disposal System is presented in Figure 3. A functional block diagram of the Jered Small Boat Waste Collection System appears in Figure 4.

GATX Evaporative Toilet System (ETS)

The GATX Evaporative Toilet System (ETS) is a "no discharge" system that is characterized by four basic features. It utilizes:

- Reduced volume flush commodes and urinals (also called controlled volume flush (CVF) water closets and urinals).
- Transport of wastes by macerator/transfer (M/T) pumps.
- Evaporation of the water content of the concentrated sewage.
- Holding of residual sludge in evaporator for subsequent disposal, either to pier connection or overboard.

Because the flush fluid requirement is small (about 1.5 gallons per capita per day (gpcd) rather than 8.5 gpcd), this system is practical with fresh water as well as sea water flushing. The penalties involved with the use of fresh water flushing are offset in part by the reduced corrosion and lower residual volumes in the evaporator. Thus, the evaporator can be smaller or be used for longer periods of time without unloading.

The MSD is fully automatic except for periodic servicing of the evaporator, involving pumping out the sludge, and rinsing and refilling the evaporator with the initial charge of fresh water.

The collection subsystem is required to be operational at all times to provide toilet facilities for the crew. Since the sewage transport pumps are decentralized, only one M/T pump and the urinals and commodes that drain

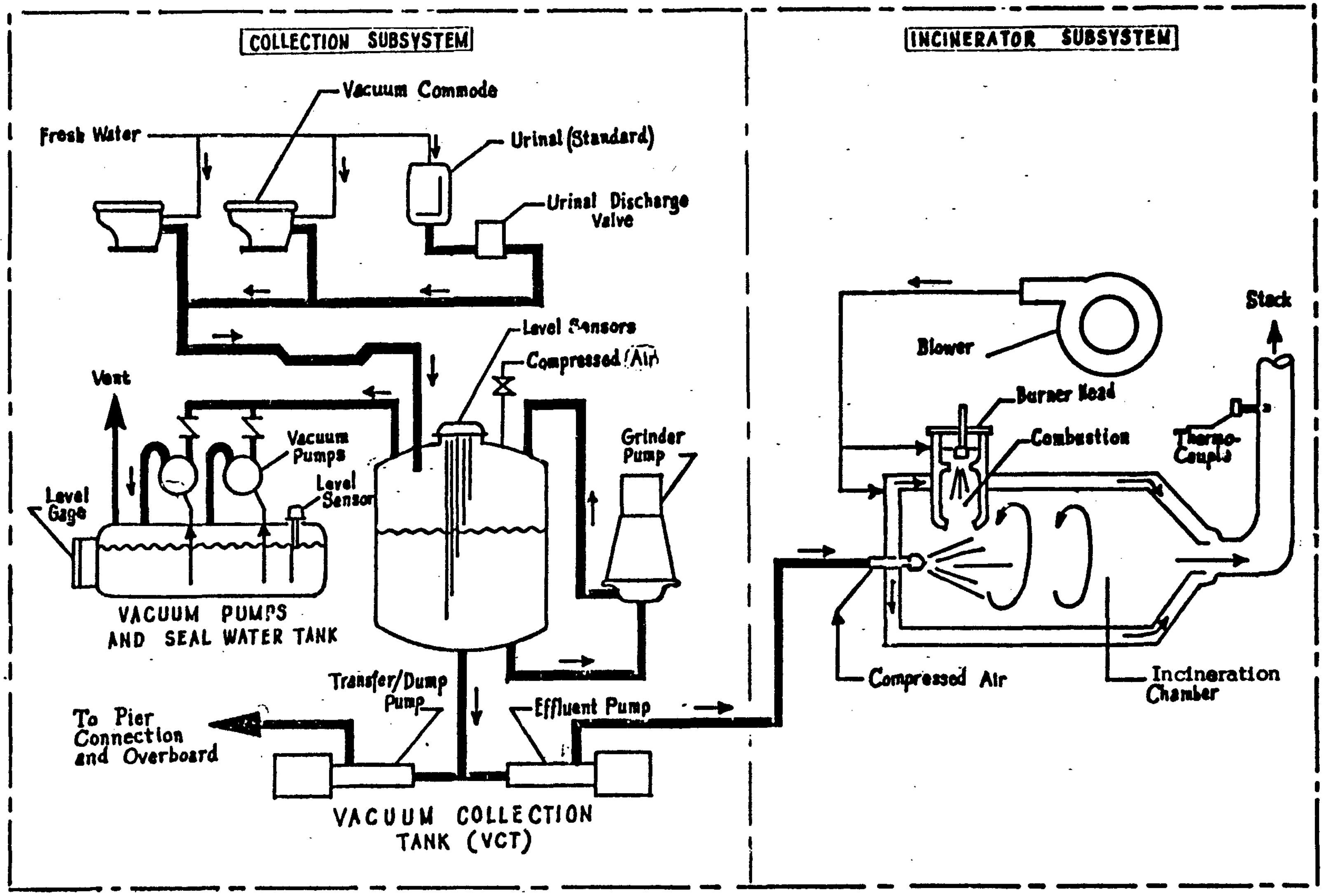

Figure 3

JERED LARGE BOAT SEWAGE DISPOSAL SYSTEM

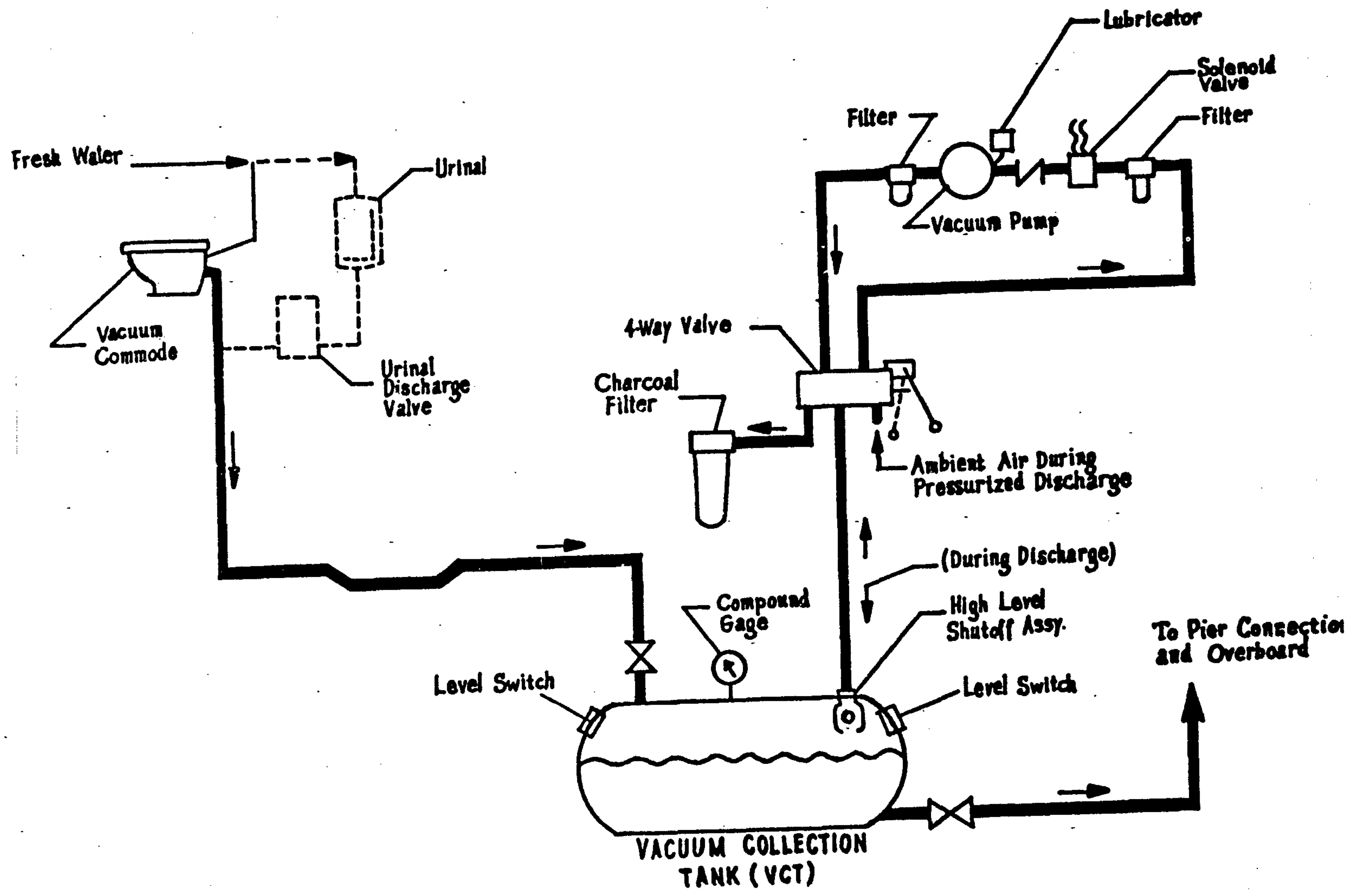

Figure 4

JERED SMALL BOAT WASTE COLLECTION SYSTEM to it need be kept operational, if minimal facilities are required. While at pierside or beyond restricted waters, the M/T pump discharge can be diverted to the pier connection or overboard in a simple MSD system. Where multiple evaporators necessitate an intermediate feed tank, diversion of raw sewage off the vessel is effected by a transfer pump, taking the wastes from the feed tank. functional block diagram of the GATX Evaporative Toilet System appears in Figure 5.

Chrysler "Aqua-Sans" Recirculating Oil System

The Chrysler "Aqua-Sans" is a "no discharge" MSD that differs from most systems in its use of a refined oil to flush wastes from commodes and urinals instead of water. Since the oil is immiscible with, and less dense than, the wastes, gravity separation is effective in disengaging the oil from the wastes to be destroyed. The oil is recirculated as a flush fluid for both urinals and commodes. It is purified by filtration and adsorption and chemically disinfected. The wastes are vaporized and burned in an incinerator.

The equipment is available in predesigned, functional modules of varying sizes or capacities. The modules are:

- Separation tank
- Pressurization and Fluid Maintenance package, which is separated into two modules in the larger size.
- Sludge holding tank, used in larger systems
- Incinerator.

The collection (and recirculation) subsystem, comprised of the Separation Tank and Pressurization and Fluid Maintenance (P & FM) package, is operational at all times, regardless of vessel location (i.e., in or beyond restricted waters or at pierside), in order to provide toilet facilities for the crew. For servicing, or during an emergency, the fluid maintenance portion of the P&FM package can be shut down and remain inoperative until odor becomes too objectionable. While at pierside or beyond restricted

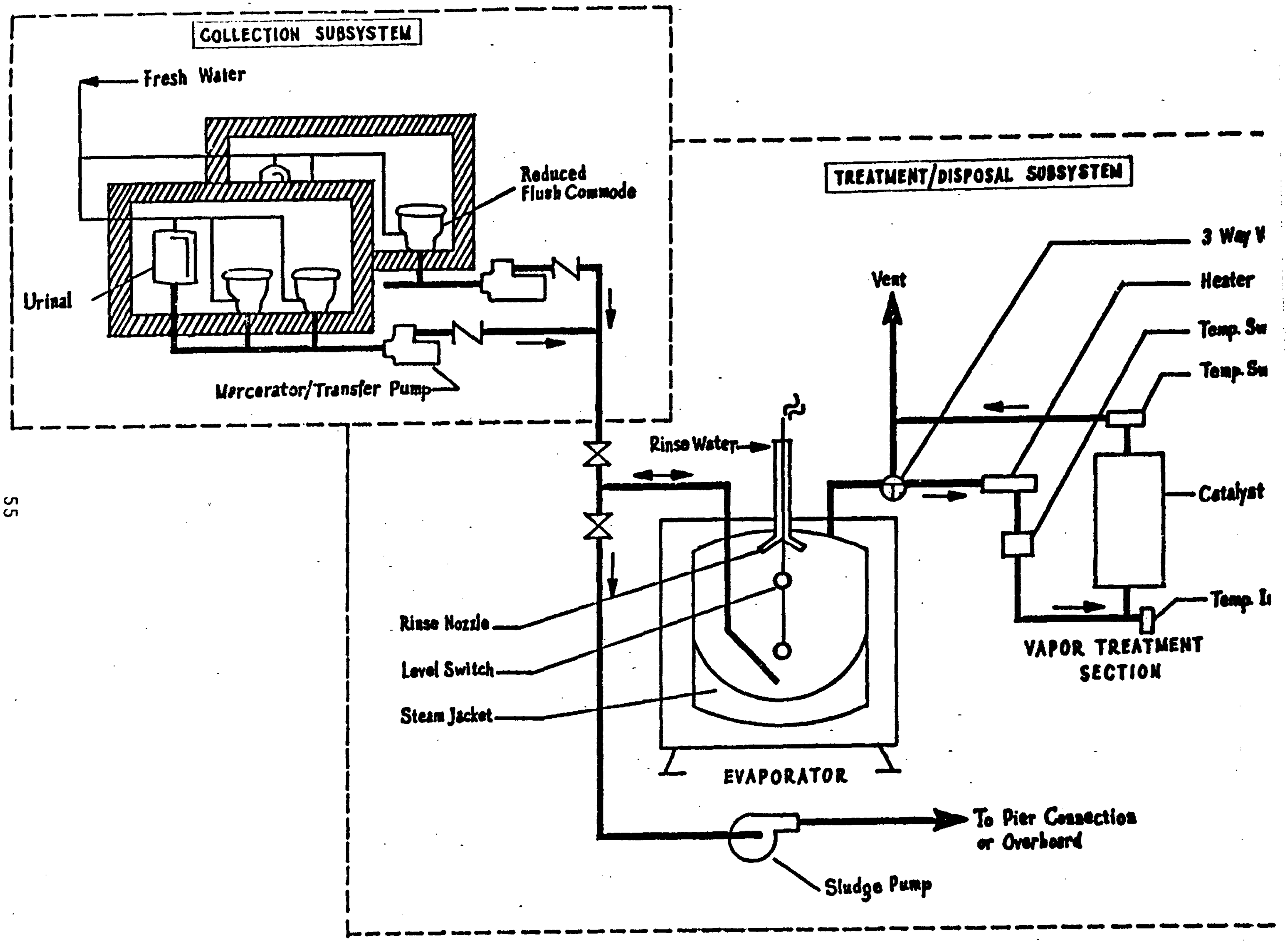

Figure 5

GATX EVAPORATIVE TOILET SYSTEM

waters, collected wastes can be pumped to a pier connection or overboard from the sludge holding tank, permitting the incinerator to be nonoperational In a small system that does not have a sludge holding tank, an ejection tank can be added for just this purpose.

The Chrysler MSD is essentially automatic, requiring supervision of equipment operational status plus the following periodic efforts during normal operating conditions:

- Ash removal from the incinerator
- Addition of chlorine disinfectant tablets
- Replacement of filters (prefilter, charcoal and clay)
- Replacement of filter bag(s) in separator tank
- Addition of make up flush medium (oil)
- Complete replacement of system flush fluid.

A functional block diagram of the Chrysler "Aqua-Sans" Oil Recirculation System is presented in Figure 6.

Grumman Flow Through System

The Grumman MSD is a flow-through system, the only MSD of this type considered for this study. Sewage is treated in a two-stage process consisting of physical separation of liquids and solids by centrifugal force, followed by ozonation treatment. The effluent water is continually discharged overboard. The contaminants removed from the waste stream are dehydrated and burned in an incinerator. The MSD utilizes the standard, existing, full volume flush commodes and urinals, draining by gravity, but it can be adapted for use with reduced flush commodes and urinals.

The Grumman MSD was developed under a U.S. Coast Guard contract, but the version considered for this study eliminates two major items found to be of marginal value: the Hydrasieve and the disk centrifuge. This version also substitutes a Thiokol incinerator, due to operational difficulties with the Grumman unit.

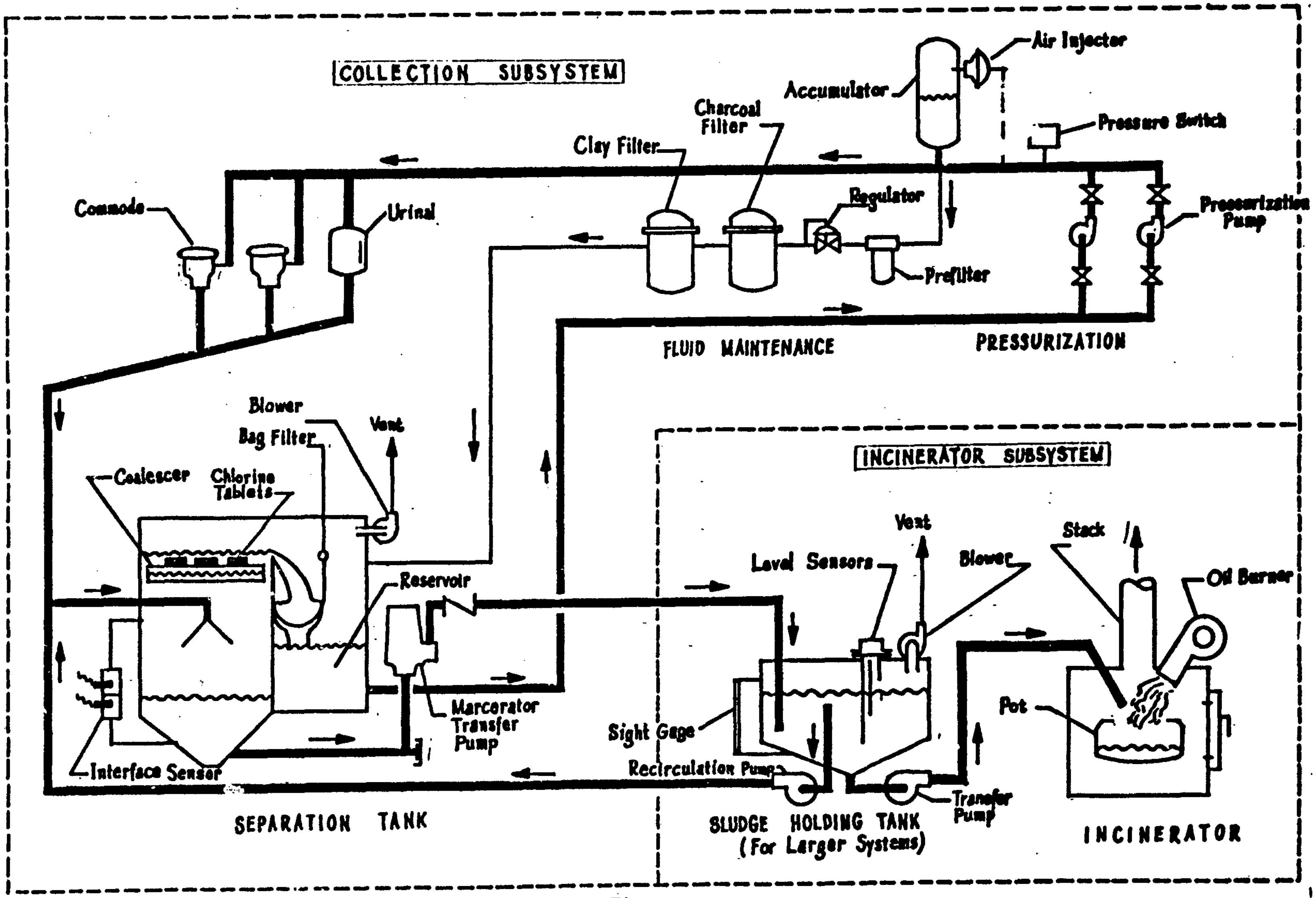

Figure 6
CHRYSLER "AQUA-SANS" RECIRCULATING OIL SYSTEM

It is an automatic system; although complex, it normally requires operator attention mainly for ash removal and filling of the fuel oil day tank. The only expendable that it uses other than fuel oil is ozone, which is made from air (drawn from the atmosphere) by one of the component equipments.

The Grumman MSD, as developed, is unique among the (commercial) MSD's considered for this study in another respect: it receives and treats combined black and gray water. (Although a CHT can also handle black and gray water, it is not a prepackaged commercially available MSD but instead is custom fitted to the vessel.) However, in applying this MSD to a cost-effectiveness analysis, other combinations of input streams are examined: full flush black water only, gray water only and gray water input with reduced flush black water going directly to the incinerator. In all cases, there is a continual discharge overboard of treated water during operation.

When the vessel is at pierside or beyond the restricted zone, the treatment subsystem can be shut off and bypassed. Wastes can be pumped off the vessel from the influent surge tank located at the end of the collection subsystem. The surge tank is normally used for smoothing out peak flows, since the treatment subsystem only accepts a continuous one gallon per minute input.

Only one size of Grumman MSD is available, designed for up to 20 men when receiving combined black and gray wastewaters, using full flush commodes and urinals. For larger capacities, multiple MSD's are required. With some combinations of waste stream inputs on larger vessels, more incinerators may be required than the number of decontamination/disinfection sections. The extra incinerators can be located adjoining or remote from the MSD.

A functional block diagram of the Grumman Flow Through System is presented in Figure 7.

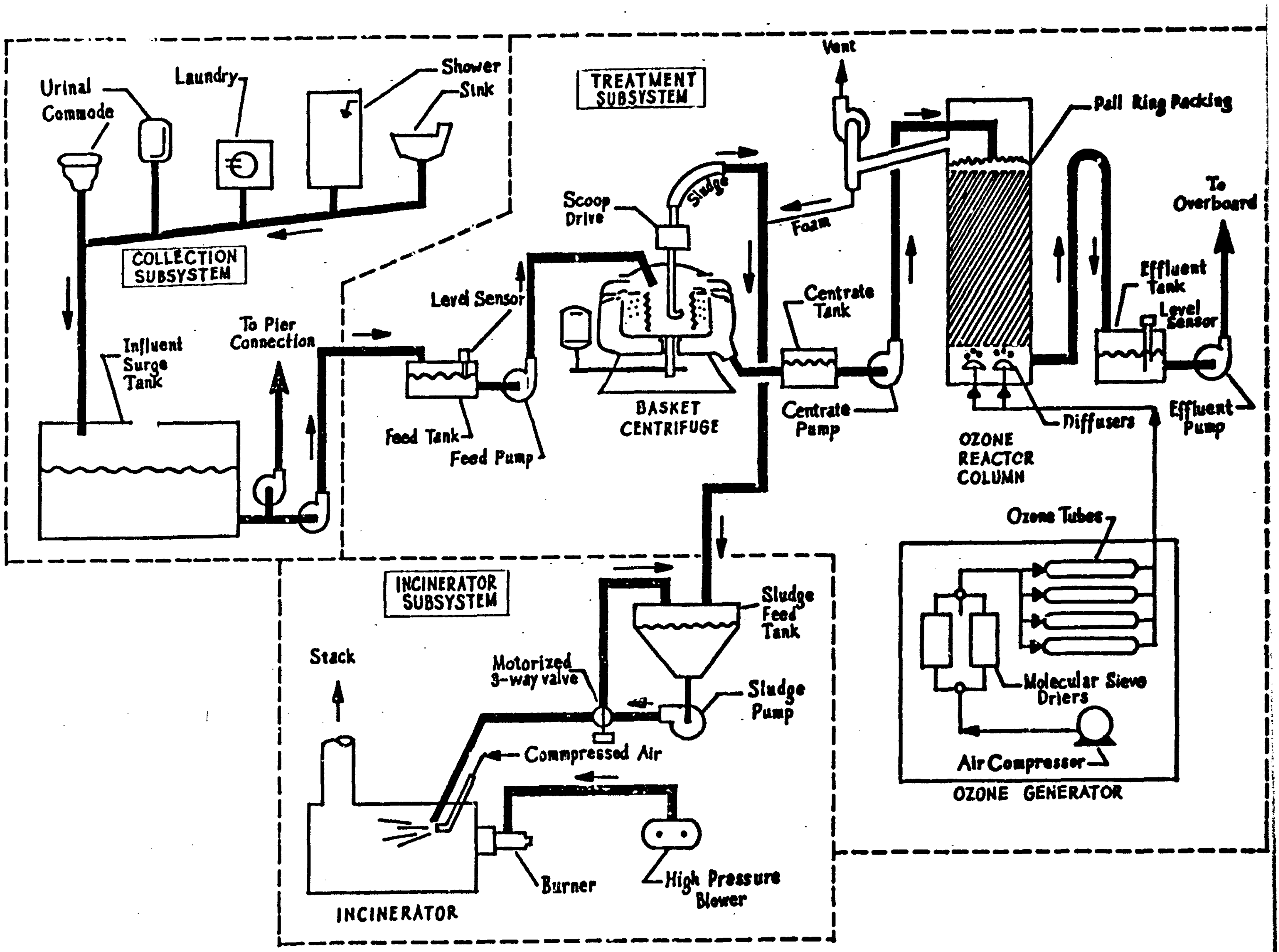

Figure 7

GRUMMAN FLOW THROUGH SYSTEM

Collection, Holding, Transfer (CHT) System

A Collection, Holding, Transfer (CHT) System provides storage volume to receive and hold wastewaters, deferring discharge from the vessel until an appropriate time. It is a "no discharge" system. It is the simplest of the MSD's considered for this study from a processing point of view. Various arrangements of wastewaters and storage tanks are possible and have been considered by others for different applications. These are:

One tank to hold:

.. Black* water only, gray* water not retained

.. Black water, with gray water while in port

.. Black water, with gray water while transiting between open seas and port

Two tanks: One tank for black water and one tank for gray water as follows:

.. Separate and distinct pump-out facilities

.. Common pump-out facilities

.. Serial pump-out, i.e., gray water is pumped into black water tank, from which both wastewaters are discharged.

CHT systems are usually thought of in connection with standard flush volumes of sea water. Supply limitations on board vessels preclude the use of fresh water with standard flush commodes and urinals. However, a CHT tank can be used with fresh or sea water flush medium in a system containing

---

* Black water is synonymous with sewage and soil wastes. It is comprised of human wastes, flush water and, if collected separately, wastewater from a garbage grinder (Coast Guard policy). Gray water is comprised of wastewater from lavatories, sinks, showers, laundry, galley, scullery and inside deck drains.

reduced volume flush commodes and urinals. One reduced volume flush system, using vacuum transport (Jered), requires a separate vacuum tank for collection, in addition to the vented holding tank. Alternately, the CHT tank can be designed as a vacuum tank which may be practical where the total retention volume is small.

A functional block diagram of a Collection, Holding, and Transfer (CHT) System is presented in Figure 8.

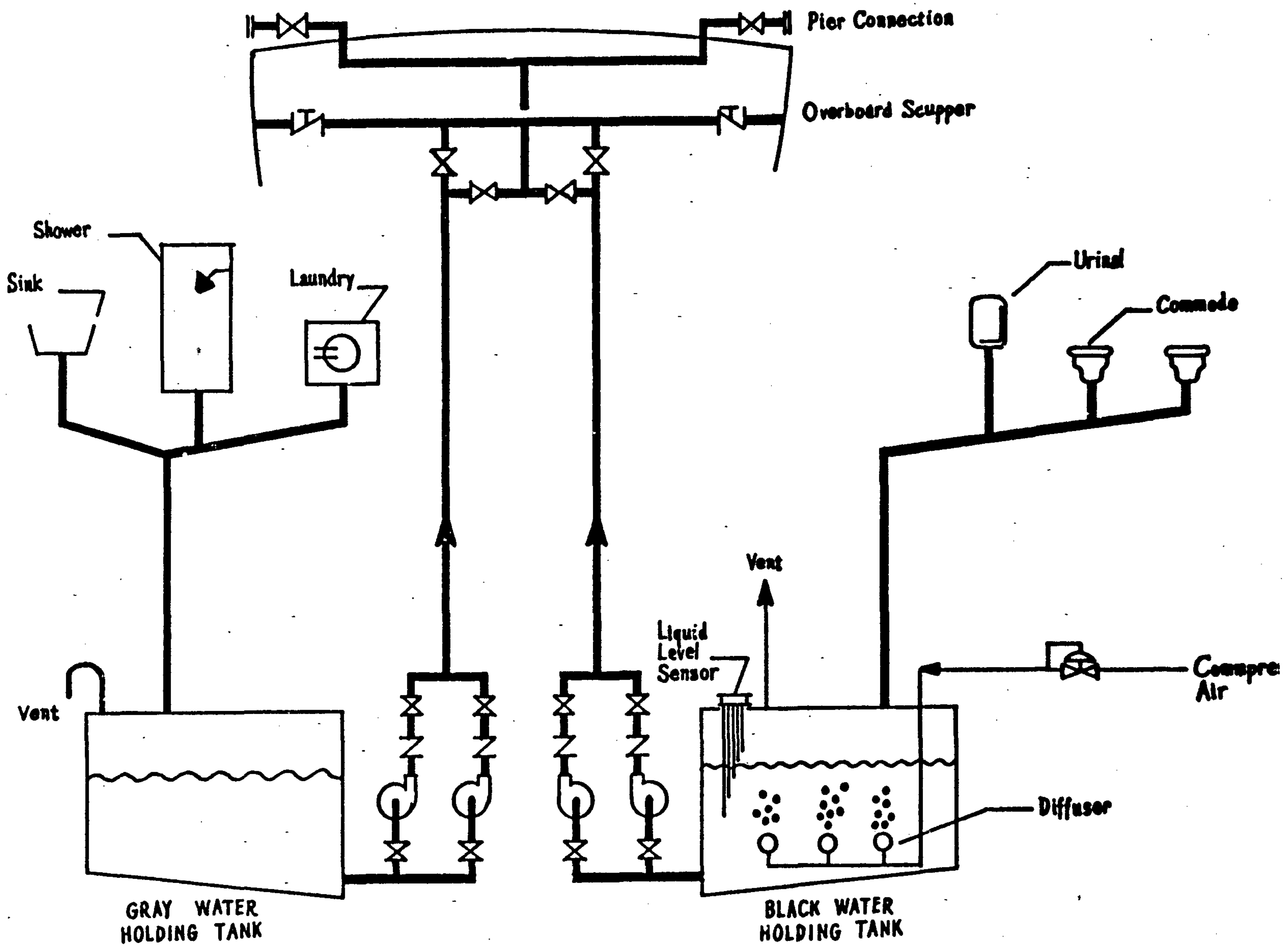

Figure 11

COLLECTION, HOLDING, TRANSFER (CHT) SYSTEM

WMS CONCEPTS

WMS concepts for managing shipboard black and gray wastewaters were developed as hybrid combinations of the subsystems of each MSD included in this study. In general, each MSD was viewed as consisting of two subsystems, namely a Collection/Transport subsystem for black wastewater and a Treatment/Disposal subsystem for either black wastewater or for black and/or gray wastewater(i.e., Grumman and CHT). MSDs whose treatment disposal subsystems included waste treatment equipment and a sludge incinerator, were further subdivided for purposes of forming the hybrid WMS concepts. Of all possible concepts which result from various combinations of these MSD subsystems/equipments, only certain ones were selected for this study. Eliminations were based on the following considerations:

- Hybrid WMS concepts whose successful operation was doubtful on the basis of engineering judgments or operational data.
- Hybrid WMS concepts which were considered to require redesign, elaborate interface equipment, and/or extensive testing for successful operation.
- Hybrid WMS concepts which were considered to be unreasonable on the basis of the overall operational objectives or preliminary economic and/or installation considerations.

Examples of WMS concepts eliminated on the bases cited above, include oil recirculation in conjunction with reduced volume flush due to uncertain successful operation; a holding tank for the full volume flush black water in conjunction with Grumman flow through treatment including a sludge incinerator (the latter on the basis of being contrary to the primary objective, that of giving preference to the management of black water).

The resulting 18 WMS concepts included in this study are shown in Figure 9. Schematic diagrams of these WMS concepts are presented in Appendix A. A summary of the installation requirements for each WMS concept is presented in Figure 10.

- Management of shipboard black (sewage and garbage grinder output) and gray (galley and turbid) wastewater streams
- Separate drain lines for sewage, galley, and turbid wastewaters
- Garbage grinder output is considered sewage (black water) and is assumed to be operationally separable from galley wastewater
- Deck drains are connected to galley and turbid drain lines
- Galley and turbid drain lines are always gravity operated

	Treatment/ Disposal (Bk & Gr.) / Sewage Collection	NO DISCHARGE					FLOW THROUGH (Grumman)					
		HOLDING TANKS	INCINERATOR	EVAPORATOR	OIL RECIRCULATION (Chrysler)		WITH SLUDGE HOLDING TANK			WITH SLUDGE INCINERATOR (Thiokol)		
							CENTRIFUGE FEED			CENTRIFUGE FEED		
					With Hold Tank	With Incinerator	Black Only	Black & Gray	Gray Only	Black Only	Black & Gray	Gray Only
FULL VOLUME FLUSH COLLECTION	GRAVITY DRAINAGE	BLACK Sewage and garbage grinder output to Holding Tank GRAY Galley/Turbid to separate Holding Tank 1			BLACK Chrysler oil recirculation system for sewage Settled sewage & garbage grinder output to Sludge Holding Tank GRAY Galley/Turbid to separate Holding Tank 2	BLACK Chrysler oil recirculation system for sewage Settled sewage and garbage grinder output to Incinerator (Chrysler) GRAY Galley/Turbid to Holding Tank 3	BLACK Sewage and garbage grinder output to Grumman via influent surge tank Sludge to Holding Tank GRAY Galley/Turbid to separate Holding Tank 4	BLACK&GRAY Sewage, garbage grinder output, Galley/Turbid to Grumman via influent surge tank Sludge to Holding Tank 5	BLACK Sewage and garbage grinder output to Holding Tank GRAY Galley/Turbid to Grumman via influent surge tank Sludge to (either separate or sewage) Holding Tank 6	BLACK Sewage and garbage grinder output to Grumman via influent surge tank Sludge to Incinerator (Thiokol) GRAY Galley/Turbid to Holding Tank 7	BLACK & GRAY Sewage, garbage grinder output, Galley/Turbid to Grumman via influent surge tank Sludge to Incinerator (Thiokol) 8	
REDUCED VOLUME FLUSH COLLECTION	VACUUM COLLECTION (JERED)	BLACK Vacuum collection of sewage in VCT Sewage transfer to Holding Tank or held in large VCT Garbage grinder output to VCT or directly to Holding Tank by gravity GRAY Galley/Turbid to separate Holding Tank 9	BLACK Vacuum collection of sewage in VCT Sewage and garbage grinder output to Incin. (Jered or Thiokol GRAY Galley/Turbid to Holding Tank 10	BLACK Vacuum collection of sewage in VCT Sewage and garbage grinder output to GATX Evaporator GRAY Galley/Turbid to Holding Tank 11					BLACK Vacuum collection of sewage in VCT Sewage transfer to Holding Tank or held in large VCT Garbage grinder output to VCT or directly to Holding Tank by gravity GRAY Galley/Turbid to Grumman via influent surge tank Sludge to (separate or sewage) Holding Tank 12			BLACK Vacuum collection of sewage in VCT Sewage & garbage grinder output to Incin. (Thiokol) GRAY Galley/Turbid to Grumman via influent surge tank Sludge to Incin. (Thiokol) 13
	MACERATOR/ TRANSFER PUMP COLLECTION (GATX)	BLACK M/T Pump collection of sewage Sewage and garbage grinder output to Holding Tank GRAY Galley/Turbid to separate Holding Tank 14	BLACK M/T Pump collection of sewage Sewage and garbage grinder output to Incin. (Jered or Thiokol GRAY Galley/Turbid to Holding Tank 15	BLACK M/T Pump collection of sewage Sewage and garbage grinder output to GATX Evaporator GRAY Galley/Turbid to Holding Tank 16					BLACK M/T Pump collection of sewage Sewage and garbage grinder output to Holding Tank GRAY Galley/Turbid to Grumman via influent surge tank Sludge to (separate or sewage) Holding Tank 17			BLACK M/T collection of sewage Sewage and garbage grinder output to Incin. (Thiokol) via surge tank GRAY Galley/Turbid to Grumman via influent surge tank Sludge to Incin. (Thiokol) 18

Figure 9

WMS CONCEPTS FOR SHIPBOARD BLACK AND GRAY WASTEWATERS

WMS No.	FIXTURES				Flush Medium	Holding Tank	Vent Line(s)* from	Incinerator Stack	VESSEL RESOURCES REQUIRED				
	Commodes	Urinals	Urinal Valves	Sewer Lines					Fuel Oil	Electricity	Compressed Air to	Excess Ambient Air for	Cooling Water
1	Standard (Existing)	Standard (Existing)	Standard (Existing)	Standard Gravity Drains (Existing)	Sea Water	B & G	BHT	No	No	Centralized	BHT		No
2					Recirc. Oil	S & G	MSD & SHT	No	No		SHT		No
3					Recirc. Oil	G	MSD	Yes	Yes		Incinerator	Incinerator	No
4					Sea Water	S & G	A/SHT/O_3	No	No		A & SHT		Yes
5						S	A/SHT/O_3	No	No		A & SHT		Yes
6						B & S	BHT & O_3	No	No		BHT		Yes
7						G	A & O_3	Yes	Yes		A & Incin.	Incinerator	Yes
8						-	A & O_3	Yes	Yes		A & Incin.	Incinerator	Yes
9	Special Vacuum Operated (Jered)		Standard (Existing) Valves Plus Urinal Discharge Valves	Vacuum Sewer 1-1/2 & 2" lines	Fresh Water	B & G	VCT & BHT	No	No		BHT		No
10						G	VCT	Yes	Yes		Incinerator	Incinerator	No
11						G	VCT & CO	No	No		CO		No
12						B & S	VCT/BHT/O_3	No	No		BHT		Yes
13						-	VCT & O_3	Yes	Yes		Incinerator	Incinerator	Yes
14	Special Operated with M/T Pump (GATX)		Push Button Operated Solenoid Valve	Pressure Sewer 1-1/4" Line		B & G	BHT	No	No	Dispersed (Electrical) Connection to Every Commode, Urinal and M/T pump	BHT		No
15						G	A	Yes	Yes		A & Incin.	Incinerator	No
16						G	A & CO	No	No		A & CO		No
17						B & S	BHT & O_3	No	No		BHT		Yes
18						-	A & O_3	Yes	Yes		A & Incin.	Incinerator	Yes

* To weather deck
A = Surge Tank
B = Black Water
C = Gray Water
S = Sludge

CO = Catalytic Oxidizer
O_3 = Ozone Reactor
Incin. = Incinerator

BHT = Black water holding tank
GHT = Gray water holding tank
SHT = Sludge holding tank
VCT = Vacuum collection tank
MSD = Marine sanitary device

Figure 10

SUMMARY OF WMS INSTALLATION REQUIREMENTS

For purposes of determining and interpreting the various analyses of this study, it is convenient to think of each WMS concept as consisting of three subsystems, namely: a black water Collection/Transport subsystem, a black water Treatment/Disposal subsystem, and a gray water Treatment/Disposal subsystem. A summary of the 18 WMS concepts in accordance with such a subsystem breakdown is shown in Table 4. Also indicated is the manner in which each WMS subsystem has been synthesized from the available MSD subsystems/equipments. It is noted that in some WMS concepts (5 and 8) the black and gray wastewater Treatment/Disposal subsystems are combined into one, and in others (13 and 18), these two subsystems share the same equipment, namely, an incinerator. As an aid in interpreting the results of this study, the breakdown of each WMS concept in terms of its subsystems, appears on the left side of some tables in this report.

CANDIDATE WMS CONFIGURATIONS AS A FUNCTION OF VESSEL

Specific MSD equipment configurations necessary in order to implement each WMS concept on each vessel were determined on the basis of the following considerations:

- Waste generation rates (for black and gray wastewaters).
- Holding time requirements for each vessel .
- The manning complement for each vessel (crew size).

The waste generation rates used in this study for the purpose of designing the WMS configurations as well as for estimating WMS operating costs are shown in Figure 11. The holding time goal and the crew size for each vessel are shown in Tables 1, 2 and 3. The details of this analysis as well as the resulting candidate WMS equipment configurations for each vessel are presented in Volume IV of this report.

Table 4
SUMMARY OF WASTEWATER MANAGEMENT SYSTEM CONCEPTS
(For Handling Shipboard Black and Gray Wastewaters)

WMS No.	TYPE			ABBREVIATED NAME(1)
	Coll/Trans Subsys (Black)	Treatment/Disposal Subsystem		
		Black	Gray	
1	Gravity Collect.	Holding Tank	Holding Tank	GRV COL/B(HLT)/G(HLT)
2	Oil Recircul. (Chrysler)	Chrysler + Hld Tnk	Holding Tank	RECIRC/B(CHLR+HLT)/G(HLT)
3		Chrysler + Incin.	Holding Tank.	RECIRC/B(CHLR+INC)/G(HLT)
4	Gravity Collect. (Grumman)	Grum Flow Thru+HldTk	Holding Tank	GRV COL/B(GRM+HLT)/G(HLT)
5		Grumman Flow Thru + Holding Tank		GRV COL//B+G(GRM+HLT)
6	Gravity Collect.	Holding Tank	Grum Flow Thru+HldTnk	GRV COL/B(HLT)/G(GRM+HLT)
7	Gravity Collect. (Grumman)	Grum Flow Thru+Incin.	Holding Tank	GRV COL/B(GRM+INC)/G(HLT)
8		Grumman Flow Thru + Incinerator		GRV COL//B+G(GRM+INC)
9	Vacuum Collect. (Jered)	Holding Tank(2)	Holding Tank	VAC COL/B(HLT)/G(HLT)
10		Incinerator	Holding Tank	VAC COL/B(INC)/G(HLT)
11		GATX Evap.	Holding Tank	VAC COL/B(EVAP)/G(HLT)
12		Holding Tank(3)	Grum Flow Thru+ Hld Tnk	VAC COL/B(HLT)/G(GRM+HLT)
13		Incinerator	Grum Flow Thru + Incin.	VAC COL/G(GRM)/B+GS(INC)
14	M/T Pump Collect. (GATX)	Holding Tank	Holding Tank	PMP COL/B(HLT)/G(HLT)
15		Incinerator	Holding Tank	PMP COL/B(INC)/G(HLT)
16		GATX Evap.	Holding Tank	PMP COL/B(EVAP)/G(HLT)
17		Holding Tank	Grum Flow Thru+Hld Tnk	PMP COL/B(HLT)/G(GRM+HLT)
18		Incinerator	Grum Flow Thru + Incin.	PMP COL/G(GRM)/B+GS(INC)

(1) Used to identify system in output of computer program for quantifying effectiveness.

(2) Two subchoices available for WMS No. 9 as follows:
- 9a - Concentrated black water transferred from VCT to holding tank.
- 9b - Concentrated black water held in VCT.

(3) Two subchoices available for WMS No. 12 as follows:
- 12a - Concentrated black water transferred from VCT to holding tank.
- 12b - Concentrated black water held in VCT.

Type/Source		gpcd	Derivation/Reference
Commodes and Urinals	Standard fixtures	9	Ships Waste Management Study, NSRDC/A Rept 28-999, Nov. 1973 average of officers and crew at sea (9.13 gpcd), weighted by numbers of officers and crew
	Chrysler	0.46	Bioastronautics Data Book NASA SP-3006 Urine value - 2nd edition Fecal value - 1st edition
	GATX and JERED	1.875	5 urinal flushes/day @ 1 pint/flush 2 commode flushes/day @ 3 pint/flush plus human waste (Chrysler value)
Galley		8	USCG. Polab Program Phase II presentation. Weighted waste generation rates for officers and crew from NSRDC/A Report cited above yields a value of 7.5 gpcd.
Turbid		22	Average of NSRDC/A Report and USCG presentation values (19.5 and 25, respectively)
Garbage Grinder		1.5	USCG presentation value
Sludge generation rate in Grumman WMS		1/12 of influent	Grumman: 5 gal/hr sludge from 60 gal/hr input

Note: Waste generation rates were assumed in lieu of actual data from the vessels under study or similar ones. The values in terms of gallons per capita per day (gpcd) are indicated above.

Figure 11

WASTE GENERATION RATES ASSUMED

VIABLE CANDIDATE SYSTEM/VESSEL COMBINATIONS

The WMS configurations for each system concept as a function of vessel were developed without regard to the feasibility of installation. Installation considerations were brought to bear in order to establish viable candidate system/vessel combinations. This installation analysis was performed in two steps.

Preliminary Installation Analysis

The preliminary installation analysis was performed on the basis of the vessel compartment arrangement drawings, the known physical dimensions of the candidate WMS equipments and previously established installation guidelines. As an aid in determining the feasibility of installation, vessel compartments which were potential locations for WMS equipment were drawn to scale and paper cutouts of the various WMS equipments, also drawn to scale, were made. These were manipulated in order to test various arrangements of the WMS equipments within the vessel compartments. A summary of the results of this preliminary installation analysis or "paper shipcheck" are shown in Table 5. The details of the preliminary installation analysis are given in the appendices of Volume III of the report.

Shipchecks to Determine Viable System Vessel Combinations

Following the preliminary installation analysis, physical shipcheck inspections were made on each vessel included in this study (except for the PAMLICO new construction vessel which was not available for inspection at the time of the analysis). The purpose of this shipcheck inspection, in addition to obtaining other relevant vessel information, was to confirm and modify the results of the preliminary installation analysis and make a final determination as to the feasibility of installing each candidate WMS configuration on each vessel. For the PAMLICO, this determination was made on the basis of the "As Built" drawings obtained from the Coast Guard.

Table 5
SUMMARY OF PRELIMINARY INSTALLATION ANALYSIS RESULTS

WMS No.	TYPE			SYSTEM ACCEPTABILITY FOR INSTALLATION (1)					
	Coll/Trans Subsys (Black)	Treatment/Disposal Subsystem		GALLATIN (378')	VIGOROUS (210')	FIREBUSH (180')	PAMLICO (160')	WHITE SAGE (133')	POINT HERRON (82')
		Black	Gray						
1	Gravity Collect.	Holding Tank	Holding Tank	Yes	Yes	Yes	Yes	Yes	Yes
2	Oil Recircul. (Chrysler)	Chrysler + Hld Tnk	Holding Tank	Yes	Yes	Yes	Yes	Yes	No
3		Chrysler + Incin.	Holding Tank	Yes	No	Yes	Yes	Yes	No
4	Gravity Collect. (Grumman)	Grum Flow Thru+HldTk	Holding Tank	Yes	No	Yes	Yes	Yes	Yes
5		Grumman Flow Thru + Holding Tank		No	No	Yes	Yes	Yes	Yes
6	Gravity Collect.	Holding Tank	Grum Flow Thru+HldTnk	Yes	No	Yes	Yes	Yes	Yes
7	Gravity Collect. (Grumman)	Grum Flow Thru+Incin.	Holding Tank	Yes	No	Yes	Yes	Yes	Yes
8		Grumman Flow Thru + Incinerator		No	No	Yes	Yes	Yes	Yes
9	Vacuum Collect. (Jered)	Holding Tank (2)	Holding Tank	Yes	Yes	Yes	Yes	Yes	Yes
10		Incinerator	Holding Tank	Yes	Yes	Yes	Yes	Yes	Yes
11		GATX Evap.	Holding Tank	Yes	No	Yes	Yes	Yes	Yes
12		Holding Tank (3)	Grum Flow Thru+Hld Tnk	No	No	Yes	Yes	Yes	Yes
13		Incinerator	Grum Flow Thru + Incin.	No	No	Yes	Yes	Yes	Yes
14	M/T Pump Collect. (GATX)	Holding Tank	Holding Tank	Yes	Yes	Yes	Yes	Yes	Yes
15		Incinerator	Holding Tank	Yes	Yes	Yes	Yes	Yes	Yes
16		GATX Evap.	Holding Tank	Yes	Yes	Yes	Yes	Yes	Yes
17		Holding Tank	Grum Flow Thru+Hld Tnk	Yes	No	Yes	Yes	Yes	Yes
18		Incinerator	Grum Flow Thru + Incin.	No	No	Yes	Yes	Yes	Yes

(1) Based on:
- Information contained in available vessel plans.
- WMS installation requirements.
- WMS installation criteria and guidelines.

(2) Two subchoices available for WMS No. 9 as follows:
- 9a - Concentrated black water transferred from VCT to holding tank (acceptable for all vessels).
- 9b - Concentrated black water held in VCT (acceptable for Point Herron only).

(3) Two subchoices available for WMS No. 12 as follows:
- Concentrated black water transferred from VCT to holding tank (acceptable for all vessels).

The results of this shipcheck analysis are shown in Table 6, which also indicates the percentage of the required holding time goal for black and gray wastewater which can be met by each viable system on each vessel. These holding time percentages result from the Coast Guard installation guidelines which specified that except for the case of holding tanks, the viability of a candidate system is determined on the basis of the feasibility of installing all of the required candidate WMS equipments (within the installation guidelines regarding compartment space availabilities).

In the case of holding tanks (for either black or gray wastewaters and for black or gray wastewater sludge), a candidate WMS configuration was not to be rejected because of the inability to provide 100 % holding capacity, i.e., the inability to install the required holding tank size. Instead, the maximum possible tank size is to be installed, giving preference to black water (or sludge) holding tank capacity, with the remaining capacity being designated for gray water (or sludge). The percentages for holding capacity in Table 6 show the holding tank capacities which could be fitted within the vessel compartments (based on the installation guidelines) as a percentage of the required tank capacities.

WMS Equipment Requirements

The results of the shipcheck were used not only to establish the viable system/vessel combinations but also to determine the actual WMS equipment configurations required to implement each of the viable WMS concepts on each candidate vessel. The equipment configurations for each viable system/vessel combination are shown in Table 7, which also incorporates the results of the tank capacities which could be accomodated by each installation as discussed earlier. Table 7 served as the basis for the remainder of the analysis, i.e., the cost and effectiveness analyses of each viable candidate system/vessel combination.

A discussion of the installation of each viable system as well as drawings showing the locations of waste sources aboard each vessel and the location of WMS equipments within vessel compartments are presented in Volume III of this report.

Table 6

SUMMARY OF VESSEL SHIPCHECK RESULTS

(To Determine Viable Candidate System/Vessel Combinations)

WMS No.	TYPE			PERCENTAGE OF REQUIRED BLACK AND GRAY WATER HOLDING CAPACITY PROVIDED BY INSTALLATION (1)											
	Coll/Trans Subsys (Black)	Treatment/Disposal Subsystem		GALLATIN (378')		VIGOROUS (210')		FIREBUSH (180')		PAMLICO (160')		WHITE SAGE (133')		POINT HERRON (82')	
		Black	Gray	Black (%)	Gray (%)	Black (%)	Gray (%)	Black (%)	Gray (%)	Black (%)	Gray (%)	Black (%)	Gray (%)	Black (%)	Gray (%)
1	Gravity Collect.	Holding Tank	Holding Tank	100	19	40	1	100	0	100	55	100	100	58	0
2	Oil Recircul. (Chrysler)	Chrysler + Hld Tnk	Holding Tank	100	18	33	1	100	0	100	64	100	100	N/A	N/A
3		Chrysler + Incin.	Holding Tank	100	13	N/A	N/A	100	12	100	64	100	100	N/A	N/A
4	Gravity Collect. (Grumman)	Grum Flow Thru+HldTk	Holding Tank	100	17	N/A	N/A	100	22	100	64	100	100	N/A	N/A
5		Grumman Flow Thru + Holding Tank		N/A	N/A	N/A	N/A	100	100	100	100	100	100	N/A	N/A
6	Gravity Collect.	Holding Tank	Grum Flow Thru+HldTnk	N/A	N/A	N/A	N/A	100	100	100	100	100	100	N/A	N/A
7	Gravity Collect. (Grumman)	Grum Flow Thru+Incin.	Holding Tank	100	17	N/A	N/A	100	29	100	64	100	100	N/A	N/A
8		Grumman Flow Thru + Incinerator		N/A	N/A	N/A	N/A	100	100	100	100	100	100	N/A	N/A
9	Vacuum Collect. (Jered)	Holding Tank (2)	Holding Tank	100	21	48	1	100	13	100	64	100	100	100	20
10		Incinerator	Holding Tank	100	21	100	1	100	35	100	64	100	100	N/A	N/A
11		GATX Evap.	Holding Tank	100	17	N/A	N/A	100	35	100	64	100	100	100	20
12		Holding Tank (3)	Grum Flow Thru+ Hld Tnk	N/A	N/A	N/A	N/A	100	100	100	100	100	100	N/A	N/A
13		Incinerator	Grum Flow Thru + Incin.	N/A	N/A	N/A	N/A	100	100	100	100	100	100	N/A	N/A
14	M/T Pump Collect. (GATX)	Holding Tank	Holding Tank	100	30	100	1	100	13	100	64	100	100	100	20
15		Incinerator	Holding Tank	100	33	100	3	100	35	100	64	100	100	N/A	N/A
16		GATX Evap.	Holding Tank	100	17	100	1	100	35	100	64	100	100	100	20
17		Holding Tank	Grum Flow Thru+Hld Tnk	N/A	N/A	N/A	N/A	100	100	100	100	100	100	N/A	N/A
18		Incinerator	Grum Flow Thru + Incin.	N/A	N/A	N/A	N/A	100	100	100	100	100	100	N/A	N/A

N/A - Not a viable candidate

(1) Based on:
- Preliminary installation analysis
- Physical inspection of vessels to verify/modify the results of the preliminary installation analysis.
- Since the PAMLICO (160') New Construction could not be scheduled for a physical inspection during the time of this analysis, results for this vessel are based on the available plans and As Built drawings.

(2) Two subchoices available for WMS No. 9 as follows:
- 9a - Concentrated black water transferred from VCT to holding tank (considered for all vessels).
- 9b - Concentrated black water held in VCT (rejected for all vessels).

(3) Two subchoices available for WMS No. 12 as follows:
- 12a - Concentrated black water transferred from VCT to holding tank (considered for all vessels).
- 12b - Concentrated black water held in VCT (rejected for all vessels).

Table 7

WMS EQUIPMENT REQUIREMENTS

Vessel GALLATIN (378')

Sheet 1 of 6

WMS NUMBER	WMS ACCEPTABILITY				NUMBER OF FIXTURES		JERED							GATX							GRUMMAN	CHRYSLER									TANKS(4)			
							NUMBER OF VCT's (Sized By Gallons)					NUMBER OF INCINERATORS		Number of M/T Pumps	NUMBER OF EVAPORATORS (Sized By Gallons)				Number of Vapor Treatment Sections	Number of Treatment Subsystems	Number of Thiokol Incinerators	COLLECTION AND RECIRCUL. SUBSYSTEM					INCINERATOR SUBSYSTEM				BLACK (Gallons Each Tank)		GRAY (Gallons Each Tank)	
	For Installation (Yes/No)	Holding Time (%)		Safety (Yes/No) (1)	Commodes (2)	Urinals (3)	Small Boat			Large Boat		Jered	Thiokol									Number of Separator Tanks			Number of P&FM Packages		Number of Sludge Surge Tanks		Number of Incinerators					
		Black	Gray				30	60	120	200	250				20	40	60	80				Model			Model		Model		Model		FWD	AFT	FWD	AFT
																						A	A/D	B	A	B	B	C	A	C				
1	Yes	100	19	Yes	28S	10S																									5184B	2596B	1750B	2424B
2	Yes	100	18	Yes	28S	10S																	3		3						965C	487C	1571B	2424B
3	Yes	100	13	Yes	28S	10S																	3		3			1		2			539B	2424B
4	Yes	100	17	Yes	28S	10S														2											528A, 434C	265A, 217C	1750B	2020B
5	No																																	
6	No																																	
7	Yes	100	17	Yes	28S	10S														2	2										258A	265A	1750B	2020B
8	No																																	
9	Yes	100	21	Yes	28J	10S/9J			1	1																					1533B	763B	2244B	2424B
10	Yes	100	21	Yes	28J	10S/9J			1	1.		2																					2244B	2424B
11	Yes	100	17	Yes	28J	10S/9J			1	1								6															1346B	2424B
12	No																																	
13	No																																	
14	Yes	100	30	Yes	28G	10S/10G								18																	1668B	830B	2693B	3994B
15	Yes	100	33	Yes	28G	10S/10G						1		18																			2693B	4668B
16	Yes	100	17	Yes	28G	10S/10G								18				6	6														1346B	2424B
17	No																																	
18	No																																	

WMS = Wastewater Management System

P&FM = Pressurization and Fluid Maintenance

(1) Does WMS meet all applicable safety standards?

(2) Letter following entered number means: S = Standard, J = JERED, G = GATX

(3) Letters following entered numbers mean: S = Standard urinal only, S/J = Standard urinals with indicated number of Jered urinal discharge valves, S/G = Standard urinals with indicated number of GATX flushometers.

(4) Letter following entered gallonage denotes tank usage: A = Influent Surge, B = Wastewater holding, C = Sludge holding, D = Intermediate tank not supplied with MSD.

WMS No.	1, 2	4, 14	9
Tank Height	6'0" (FWD and AFT)	5'-0" (FWD and AFT)	6'-0" (FWD) and 5'-6" (AFT)

Table 7

WMS EQUIPMENT REQUIREMENTS

Vessel VIGOROUS (210')

Sheet 2 of 6

WMS NUMBER	WMS ACCEPTABILITY				NUMBER OF FIXTURES		JERED								GATX						GRUMMAN	CHRYSLER									TANKS(4)	
	For Installation (Yes/No)	Holding Time (%)		Safety (Yes/No) (1)	Commodes (2)	Urinals (3)	NUMBER OF VCT's (Sized By Gallons)					NUMBER OF INCINERATORS		Number of M/T Pumps	NUMBER OF EVAPORATORS (Sized By Gallons)				Number of Vapor Treatment Sections	Number of Treatment Subsystems	Number of Thiokol Incinerators	COLLECTION AND RECIRCUL. SUBSYSTEM					INCINERATOR SUBSYSTEM				BLACK (Gallons Each Tank)	GRAY (Gallons Each Tank)
		Black	Gray				Small Boat			Large Boat		Jered	Thiokol									Number of Separator Tanks			Number of P&FM Packages		Number of Sludge Surge Tanks		Number of Incinerators			
																						Model			Model		Model		Model			
							30	60	120	200	250				20	40	60	80				A	A/B	B	A	B	B	C	A	C		
1	Yes	40	1	Yes	17S	3S																									2154B	120B
2	Yes	53	1	Yes	17S	3S																	1		1						538C	120B
3	No																															
4	No																															
5	No																															
6	No																															
7	No																															
8	No																															
9	Yes	48	1	Yes	17J	3S/5J					1																				740B	120B
10	Yes	100	1	Yes	17J	3S/5J					1	1																				120B
11	No																															
12	No																															
13	No																															
14	Yes	100	1	Yes	17G	3S/3G								9																	1742B	120B
15	Yes	100	3	Yes	17G	3S/3G						1		9																		538B
16	Yes	100	1	Yes	17G	3S/3G								9			3		3													123B
17	No																															
18	No																															

WMS = Wastewater Management System
P&FM = Pressurization and Fluid Maintenance
(1) Does WMS meet all applicable safety standards?
(2) Letter following entered number means: S = Standard, J = JERED, G = GATX
(3) Letters following entered numbers mean: S = Standard urinal only, S/J = Standard urinals with indicated number of Jered urinal discharge valves, S/G = Standard urinals with indicated number of GATX flushometors.
(4) Letter following entered gallonage denotes tank usage: A = Influent Surge, B = Wastewater holding, C = Sludge holding, D = Intermediate tank not supplied with MSD.

WMS No.	1, 2, 9	14
Tank Height	6'-0"	5'-0"

Table 7

WMS EQUIPMENT REQUIREMENTS

Vessel FIREBUSH (180')

Sheet 3 of 6

WMS NUMBER	WMS ACCEPTABILITY				NUMBER OF FIXTURES		JERED							GATX						GRUMMAN		CHRYSLER									TANKS(4)	
	For Installation (Yes/No)	Holding Time (%)		Safety (Yes/No) (1)	Commodes (2)	Urinals (3)	NUMBER OF VCT's (Sized By Gallons)					NUMBER OF INCINERATORS		Number of M/T Pumps	NUMBER OF EVAPORATORS (Sized By Gallons)				Number of Vapor Treatment Sections	Number of Treatment Subsystems	Number of Thiokol Incinerators	COLLECTION AND RECIRCUL. SUBSYSTEM					INCINERATOR SUBSYSTEM				BLACK (Gallons Each Tank)	GRAY (Gallons Each Tank)
		Black	Gray				Small Boat			Large Boat		Jered	Thiokol									Number of Separator Tanks Model			Number of P&FM Packages Model		Number of Sludge Surge Tanks Model		Number of Incinerators Model			
							30	60	120	200	250				20	40	60	80				A	N/U	B	A	B	B	C	A	C		
1	Yes	100	0	Yes	6S	1S																									7295B	0
2	Yes	100	0	Yes	6S	1S																	1		1						1361C	0
3	Yes	100	12	Yes	6S	1S																	1		1		1			1		2395B
4	Yes	100	22	Yes	6S	1S														1											261A, 680C	4495B
5	Yes	100	100	Yes	6S	1S														2											1029A, 2545C	
6	Yes	100	100	Yes	6S	1S														2											9032B	768A
7	Yes	100	29	Yes	6S	1S														1	1										261A	6109B
8	Yes	100	100	Yes	6S	1S														2	2										1029A	
9	Yes	100	13	Yes	6J	1S/2J					1																				2145B	2737B
10	Yes	100	35	Yes	6J	1S/2J					1	1																				7295B
11	Yes	100	35	Yes	6J	1S/2J					1							2	2													7295B
12	Yes	100	100	Yes	6J	1S/2J					1									2											2145B	768A, 1737C
13	Yes	100	100	Yes	6J	1S/2J					1									1	3											768A
14	Yes	100	13	Yes	6G	1S/1G								4																	2345B	2693B
15	Yes	100	35	Yes	6G	1S/1G						1		4																		7295B
16	Yes	100	35	Yes	6G	1S/1G								4				2	2													7295B
17	Yes	100	100	Yes	6G	1S/1G								4						2											2345B	768A, 1737C
18	Yes	100	100	Yes	6G	1S/1G								4						1	3										101D	768A

WMS = Wastewater Management System

P&FM = Pressurization and Fluid Maintenance

(1) Does WMS meet all applicable safety standards?

(2) Letter following entered number means: S = Standard, J = JERED, G = GATX

(3) Letters following entered numbers mean: S = Standard urinal only, S/J = Standard urinals with indicated number of Jered urinal discharge valves, S/G = Standard urinals with indicated number of GATX flushometers.

(4) Letter following entered gallonage denotes tank usage: A = Influent Surge, B = Wastewater holding, C = Sludge holding, D = Intermediate tank not supplied with MSD.

WMS No.	1	2, 5	4	6	9, 12	14, 17
Tank Height	8'-3"	5'-0"	4'-0"	11'-1"	7'-6"	6'-9"

NOTES: (a) WMS No. 6 = Combined sewage/sludge holding tank.
(b) WMS No. 18 - Intermediate tank used as influent surge tank.

Table 7

Vessel PAMLICO (160')(5) - New Construction

WMS EQUIPMENT REQUIREMENTS

Sheet 4 of 6

WMS NUMBER	WMS ACCEPTABILITY				NUMBER OF FIXTURES		JERED							GATX						GRUMMAN		CHRYSLER									TANKS(4)	
	For Installation (Yes/No)	Holding Time (%)		Safety (Yes/No) (1)	Commodes (2)	Urinals (3)	NUMBER OF VCT's (Sized By Gallons)					NUMBER OF INCINERATORS		Number of W/T Pumps	NUMBER OF EVAPORATORS (Sized By Gallons)				Number of Vapor Treatment Sections	Number of Treatment Subsystems	Number of Thiokol Incinerators	COLLECTION AND RECIRCUL. SUBSYSTEM					INCINERATOR SUBSYSTEM				BLACK (Gallons Each Tank)	GRAY (Gallons Each Tank)
		Black	Gray				Small Boat			Large Boat		Jered	Thiokol									Number of Separator Tanks Model			Number of P&FM Packages Model		Number of Sludge Surge Tanks Model		Number of Incinerators Model			
							30	60	120	200	250				20	40	60	80				A	A/B	B	A	B	B	C	A	C		
1	Yes	100	55	Yes	4S	1S																									3419B	5385B
2	Yes	100	64	Yes	4S	1S																1			1						638C	6283B
3	Yes	100	64	Yes	4S	1S																1			1				1			6283B
4	Yes	100	64	Yes	4S	1S														1											268A, 285C	6283B
5	Yes	100	100	Yes	4S	1S														1											268A, 1090C	
6	Yes	100	100	Yes	4S	1S														1											4233B	200A
7	Yes	100	64	Yes	4S	1S														1	1										68A	6283B
8	Yes	100	100	Yes	4S	1S														1	1										268A	
9	Yes	100	64	Yes	4J	1S/2J	1																								1070B	6283B
10	Yes	100	64	Yes	4J	1S/2J			1				1																			6283B
11	Yes	100	64	Yes	4J	1S/2J	1									1			1													6283B
12	Yes	100	100	Yes	4J	1S/2J	1													1											1070B	200A, 814C
13	Yes	100	100	Yes	4J	1S/2J	1													1	1											200A
14	Yes	100	64	Yes	4G	1S/1G								3																	1099B	6283B
15	Yes	100	64	Yes	4G	1S/1G							1	3																		6283B
16	Yes	100	64	Yes	4G	1S/1G								3		1			1													6283B
17	Yes	100	100	Yes	4G	1S/1G								3						1											1099B	200A, 814C
18	Yes	100	100	Yes	4G	1S/1G								3						1	1										26D	200A

WMS = Wastewater Management System

P&FM = Pressurization and Fluid Maintenance

(1) Does WMS meet all applicable safety standards?

(2) Letter following entered number means: S = Standard, J = JERED, G = GATX

(3) Letters following entered numbers mean: S = Standard urinal only, S/J = Standard urinals with indicated number of Jered urinal discharge valves, S/G = Standard urinals with indicated number of GATX flushometers.

(4) Letter following entered gallonage denotes tank usage: A = Influent Surge, B = Wastewater holding, C = Sludge holding, D = Intermediate tank not supplied with MSD.

(5) Pamlico is currently outfitted with a Colt Industries 450-gallon VCT and no wastewater holding tank. Systems 9, 10, 11, 12 and 13 are configured with smaller VCT's and associated treatment/holding tank arrangements in accordance with the guidelines established for this study. It will be assumed, however, that these systems would be adequately served by the existing 450-gallon VCT plus appropriate treatment subsystems (i.e., incinerator/evaporator) with cost/effectiveness assessments treated accordingly.

WMS No.	1, 9, 12, 14, 17	2, 4	5, 6
Tank Height	6'-0"	4'-3"	5'0"

NOTES: (a) WMS No. 6 - Combined sewage/sludge holding tank.
(b) WMS No. 18 - Intermediate tank used as influent surge tank.

Table 7

WMS EQUIPMENT REQUIREMENTS

Vessel WHITE SAGE (133')

Sheet 5 of 6

WMS NUMBER	WMS ACCEPTABILITY				NUMBER OF FIXTURES		JERED							GATX						GRUMMAN		CHRYSLER									TANKS(4)	
	For Installation (Yes/No)	Holding Time (%)		Safety (Yes/No) (1)	Commodes (2)	Urinals (3)	NUMBER OF VCT's (Sized By Gallons)					NUMBER OF INCINERATORS		Number of W/T Pumps	NUMBER OF EVAPORATORS (Sized By Gallons)				Number of Vapor Treatment Sections	Number of Treatment Subsystems	Number of Thiokol Incinerators	COLLECTION AND RECIRCUL. SUBSYSTEM					INCINERATOR SUBSYSTEM				BLACK (Gallons Each Tank)	GRAY (Gallons Each Tank)
		Black	Gray				Small Boat			Large Boat		Jered	Thiokol									Number of Separator Tanks Model			Number of P&FM Packages Model		Number of Sludge Surge Tanks Model		Number of Incinerators Model			
							30	60	120	200	250				20	40	60	80				A	A/B	B	A	B	B	C	A	C		
1	Yes	100	100	Yes	4S	1S																									722B	2063B
2	Yes	100	100	Yes	4S	1S																1			1						135C	2063B
3	Yes	100	100	Yes	4S	1S																1			1				1			2063B
4	Yes	100	100	Yes	4S	1S														1											110A,60C	2063B
5	Yes	100	100	Yes	4S	1S														1											432A, 232C	
6	Yes	100	100	Yes	4S	1S														1											722B	323A,172C
7	Yes	100	100	Yes	4S	1S														1	1										110A	2063B
8	Yes	100	100	Yes	4S	1S														1	1										432A	
9	Yes	100	100	Yes	4J	1S/2J	1																								200B	2063B
10	Yes	100	100	Yes	4J	1S/2J			1				1																			2063B
11	Yes	100	100	Yes	4J	1S/2J	1											1	1													2063B
12	Yes	100	100	Yes	4J	1S/2J	1													1											200B	172C, 323A
13	Yes	100	100	Yes	4J	1S/2J	1													1	1											323A
14	Yes	100	100	Yes	4G	1S/1G								3																	232B	2063B
15	Yes	100	100	Yes	4G	1S/1G							1	3																		2063B
16	Yes	100	100	Yes	4G	1S/1G								3				1	1													2063B
17	Yes	100	100	Yes	4G	1S/1G								3						1											232B	323A, 172C
18	Yes	100	100	Yes	4G	1S/1G								3						1	1										43D	323A

WMS = Wastewater Management System

P&FM = Pressurization and Fluid Maintenance

(1) Does WMS meet all applicable safety standards?

(2) Letter following entered number means: S = Standard, J = JERED, G = GATX

(3) Letters following entered numbers mean: S = Standard urinal only, S/J = Standard urinals with indicated number of Jered urinal discharge valves, S/G = Standard urinals with indicated number of GATX flushometers.

(4) Letter following entered gallonage denotes tank usage: A = Influent Surge, B = Wastewater holding, C = Sludge holding, D = Intermediate tank not supplied with MSD.

WMS No.	1, 5, 14	2, 9, 12	4	6	17
Tank Height	5'-0"	3'-0"	2'-0"	6'-0"	5'-0"

NOTE: WMS No. 18 - Intermediate tank used as influent surge tank.

Table 7

WMS EQUIPMENT REQUIREMENTS

Vessel POINT HERRON (82')

Sheet 6 of 6

WMS NUMBER	WMS ACCEPTABILITY				NUMBER OF FIXTURES		JERED								GATX					GRUMMAN		CHRYSLER									TANKS(4)	
	For installation (Yes/No)	Holding Time (%)		Safety (Yes/No) (1)	Commodes (2)	Urinals (3)	NUMBER OF VCT's (Sized By Gallons)					NUMBER OF INCINERATORS		Number of M/T Pumps	NUMBER OF EVAPORATORS (Sized By Gallons)				Number of Vapor Treatment Sections	Number of Treatment Subsystems	Number of Thiokol Incinerators	COLLECTION AND RECIRCUL. SUBSYSTEM					INCINERATOR SUBSYSTEM				BLACK (Gallons Each Tank)	GRAY (Gallons Each Tank)
							Small Boat			Large Boat												Number of Separator Tanks Model			Number of P&FM Packages Model		Number of Sludge Surge Tanks Model		Number of Incinerators Model			
		Black	Gray				30	60	120	200	250	Jered	Thiokol		20	40	60	80				A	A/B	B	A	B	B	C	A	C		
1	Yes	58	0	Yes	2S	0																									242B	0
2	No																															
3	No																															
4	No																															
5	No																															
6	No																															
7	No																															
8	No																															
9	Yes	100	20	Yes	2J	0S/1J	1																								105B	242B
10	No																															
11	Yes	100	20	Yes	2J	0S/1J	1									1			1												0	242B
12	No																															
13	No																															
14	Yes	100	20	Yes	2G	0								2																	134B	242B
15	No																															
16	Yes	100	20	Yes	2G	0								2		1			1												0	242B
17	No																															
18	No																															

WMS = Wastewater Management System

P&FM = Pressurization and Fluid Maintenance

(1) Does WMS meet all applicable safety standards?

(2) Letter following entered number means: S = Standard, J = JERED, G = GATX

(3) Letters following entered numbers mean: S = Standard urinal only, S/J = Standard urinals with indicated number of Jered urinal discharge valves, S/G = Standard urinals with indicated number of GATX flushometers.

(4) Letter following entered gallonage denotes tank usage: A = Influent Surge, B = Wastewater holding, C = Sludge holding, D = Intermediate tank not supplied with MSD.

WMS No.	1	9	1
Tank Height	2'-10"	2'-6"	3'-0"

LIFE-CYCLE COST ANALYSIS

THE LIFE-CYCLE COST MODEL

For purposes of the life-cycle cost analysis (a similar approach was used for the effectiveness analysis), the physical system configuration will be viewed as a hierarchy of four levels, namely, system, functions, subsystem and equipments, as shown in Figure12. In the case of the Wastewater Management Systems (WMS) analyzed, the overall system level is the WMS; the function levels correspond to the black and gray wastewater handling functions of the WMS; the subsystem levels correspond to the black water Collection/Transport subsystem, the black water Treatment/Disposal subsystem, and the gray water Treatment/Disposal subsystem; the equipment level corresponds to items such as fixtures, Macerator/Transfer (M/T) pumps, Vacuum Collection Tanks (VCT), incinerators, etc. It is noted from Figure12 that equipments and subsystems are not necessarily unique with respect to function, i.e., the same equipment or subsystem may perform more than one function. Two examples of this are the Grumman treatment system which treats both black and gray wastewaters, or a Thiokol incinerator which receives both the sludge from a Grumman treatment system which treats gray water only and the black water stream from a reduced volume Collection/Transport subsystem (Jered or GATX).

The life-cycle cost model is depicted in Figure 13 which shows both the "horizontal" and "vertical" breakdown of the cost. The "horizontal" breakdown is in terms of the various cost elements into which the overall life-cycle cost is subdivided. The "vertical" breakdown [illegible] in terms of the various stages of calculations which are necessary to perform in order to arrive at the overall system life-cycle cost. The computations are performed essentially in three stages. The first stage relates equipment/subsystem characteristics and cost estimates to overall system (or subsystem) costs (and characteristics) on the basis of 100% utilization factor. The second stage of the calculations relates the system/subsystem costs and characteristics based on 100% utilization factor to the overall system (or subsystem) costs and characteristics based on vessel mission profiles

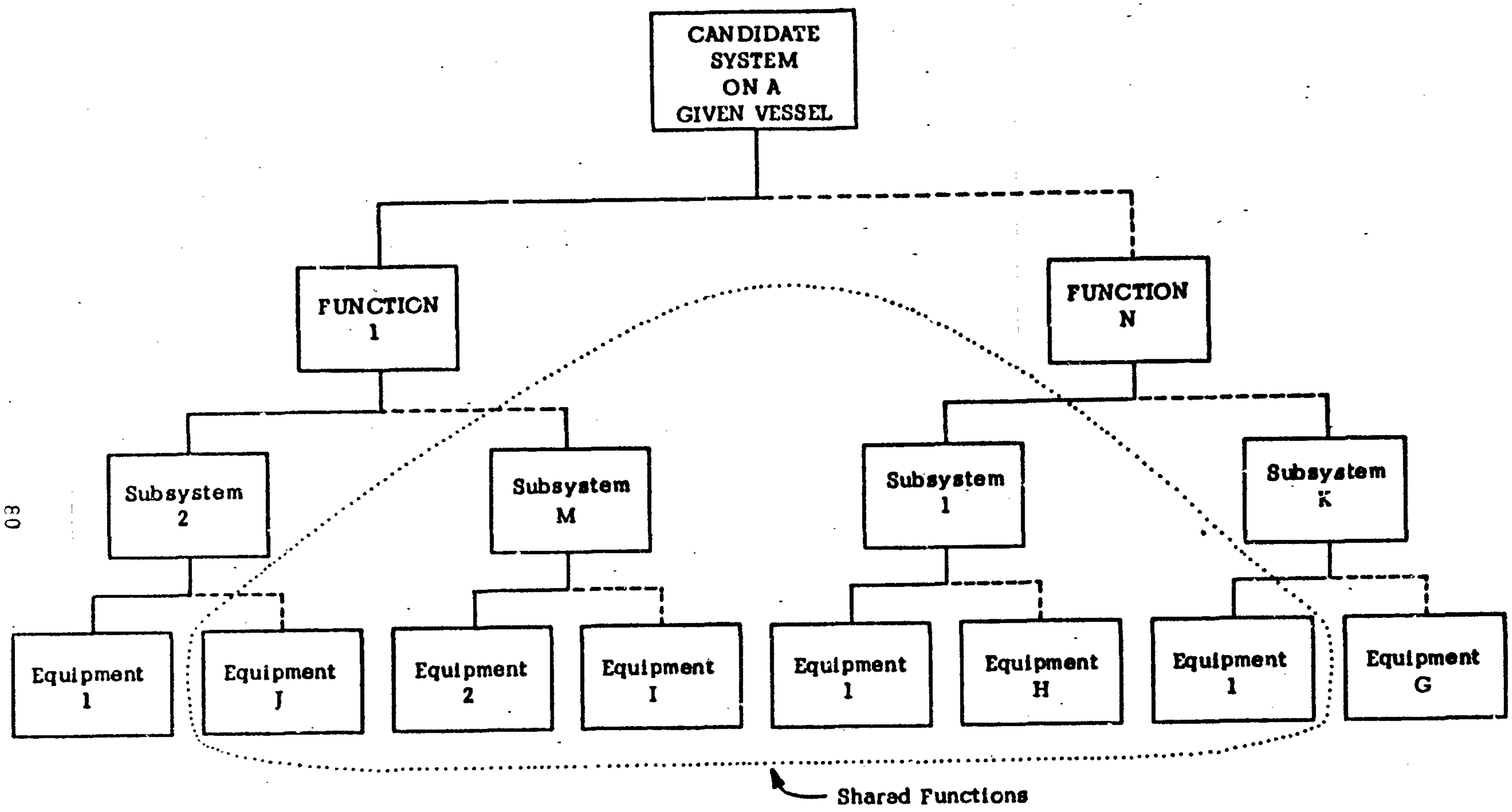

Figure 12

PHYSICAL SYSTEM/EQUIPMENT CONFIGURATION HIERARCHY

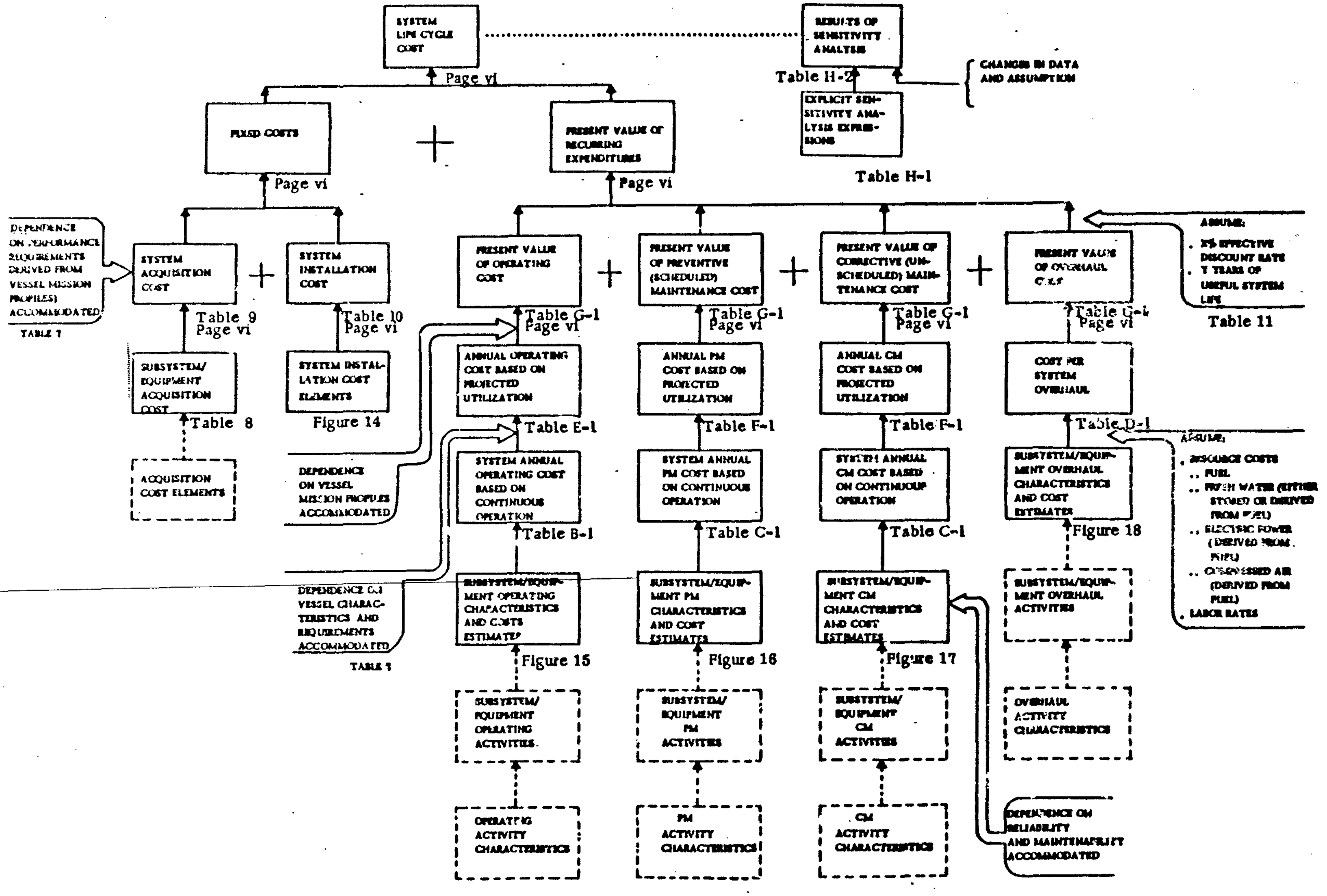

Figure 13

LIFE CYCLE COST MODEL FOR CANDIDATE SYSTEM/VESSEL COMBINATIONS (i.e., utilization factor for each subsystem, the number of mode changeovers, etc.). The third stage of the calculations relates the overall system cost based on vessel mission profiles to the life-cycle cost based on the useful life of the system and an assumed effective discount rate.

The main purpose of the above breakdown of the costs into different cost elements and each cost element into three different stages of calculations is to facilitate the introduction of the various dependencies which affect the overall system life-cycle cost. It is this breakdown which enables the life-cycle cost to be accurately and consistently estimated. This breakdown also facilitates the analysis of system costs and characteristics in such a way as to yield useful information for system modifications, management, and for trade-off studies and decision-making. In addition, this breakdown provides an opportunity for incorporating an extensive sensitivity analysis capability.

Figure 12 indicates the various tables which represent the inputs and outputs associated with the life-cycle cost model. Tables 8 and 14 through 18 are the basic data inputs for acquisition, installation, operation and maintenance (PM, CM and Overhaul) characteristics and cost estimates. Table 7 lists the equipment requirements for each system configuration on each vessel. Table H-1 lists the sensitivity analysis relationships used. The other listed tables represent the various outputs from the life-cycle cost model.

FIXED COSTS

The fixed costs include WMS acquisition and installation costs. The development of these costs is discussed below.

Acquisition Costs

The basis for estimating WMS acquisition costs was data on MSD subsystem/equipment costs obtained from MSD manufacturers. MSD costs were solicited from manufacturers not on an overall system level but rather on a subsystem/equipment level corresponding to the manner in which the MSDs were hybridized to form the candidate WMS concepts. Acquisition cost was broken down into equipment costs and associated initial spares costs. A form showing the breakdown of each MSD into the subsystems/equipments and different pertinent model types was sent to each manufacturer requesting equipment and spares costs as well as suggestions for initial spares stocking requirements. The results of such inquiries are shown in Table 8. Acquisition cost estimates for Grumman were supplied by the Coast Guard.

The results in Table 8, in conjunction with the equipment requirements in Table 7, were used to estimate the WMS acquisition costs shown in Table 9. It is noted that holding tanks were considered to have zero acquisition cost, and the installation cost of holding tanks includes the cost of materials required to fabricate the tanks.

Installation Costs

Installation cost estimates were obtained as part of the WMS installation analysis. Such installation cost estimates were made by first defining a number of installation cost elements with associated unit costs and then viewing each WMS installation in terms of these elements, taking existing vessel conditions into account. The form used for estimating installation costs is shown in Figure 14. The completed forms for each viable system/vessel combination appear in Volume III of this report. A summary of the results of the WMS installation cost estimates is shown in Table 10.

Table 8

SUMMARY OF MSD ACQUISITION AND INITIAL SPARES COSTS

MSD	Equipment		Equipment Cost ($)	Cost ($) of Associated Inital Spares Package
JERED	Commode		300	300 (1)
	Urinal Discharge Valve		300	150 (1)
	VCT(with associated equipment and controls)	30 gal. (Small Boat)	5,000	400 (2)
		60 gal. (Small Boat)	5,000	400 (2)
		120 gal. (Small Boat)	6,000	500 (2)
		200 gal. (Large Boat)	20,000	1,200 (2)
		250 gal. (Large Boat)	20,000	1,200 (2)
	Incinerator (including controls)		33,000	8,250 (2), (3)
GATX	Commode		750	50 (2)
	Urinal Flushometer		150	10 (2)
	Macerator/Transfer Pump (Including contactor)	Fresh Water	1,500 (4)	1,500 (4)
		Salt Water	3,000	50 (2)
	Evaporator (With sludge pump and controls	20 gal.	14,100	600 (2)
		40 gal.	14,400	600 (2)
		60 gal.	15,000	600 (2)
		80 gal.	15,500	600 (2)
	Vapor Treatment Section (Including controls)		2,000	250 (2)
CHRYSLER	Separator Tank (Including Controls)	Model A	4,750	275 (5)
		Model A/B	5,694	275 (5)
		Model B	6,647	275 (5)
	Pressurization & Fluid Maint. Package(s) (Including controls)	Model A	3,319 (6)	198 (6)
		Pump Package	1,585	N/R
		Accumulator	512	26
		Fluid Maint. Pkg.	1,664	26
		Total Model B	4,196 (7)	487 (7)
	Sludge Surge Tank Including controls)	Model B	5,041	350
		Model C	5,200	350
	Incinerator (Including controls)	Model A	5,462	600
		Model C	9,174	550
GRUMMAN	Treatment Subsystem (Including Con[illegible])		25,000 (8)	2,500 (8)
	Incinerator Subsystem - Thiokol (Including controls)		25,000 (8)	2,500 (8)

(1) Manufacturer recommends one initial spares package for every 5 associated equipments on board the vessel.

(2) Manufacturer recommends one initial spares package for every associated equipment on board the vessel.

(3) Includes the cost of one incinerator liner (Inconel 601 at $6, 500) which was not included in cost provided by manufacturer. A new incinerator liner (Inconel 671 at $7,800) is currently being evaluated by the Navy.

(4) U.S. Coast Guard policy is to use fresh water flushing and to stock one extra M/T pump per vessel regardless of the number of such pumps installed on the vessel.

(5) Manufacturer recommends one initial spares package for every 4 associated equipments on board the vessel.

(6) Includes the cost of flush fluid and expendables ($145) which was not included in cost provided by manufacturer.

(7) Includes the cost of flush fluid and expendables ($435) which was not included in cost provided by manufacturer.

(8) Estimates provided by U.S. Coast Guard.

Table 9

WMS ACQUISITION COST AS A FUNCTION OF VESSEL

	TYPE			ACQUISITION COST																	
WMS NO.	Collection/Transport Subsystem (Black)	Treatment/Disposal Subsystem		GALLATIN (373')			VIGOROUS (210')			FIREBUSH (180')			PAMLICO (160') (New Constr.)*			WHITE SAGE (133')			POINT HERRON (82')		
		Black	Gray	Equip. ($)	Initial Spares ($)	Total ($)	Equip. ($)	Initial Spares ($)	Total ($)	Equip. ($)	Initial Spares ($)	Total ($)	Equip. ($)	Initial Spares ($)	Total ($)	Equip. ($)	Initial Spares ($)	Total ($)	Equip. ($)	Initial Spares ($)	Total ($)
1	Gravity Collect.	Holding Tank	Holding Tank	-0	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-	1,000	100	1,100	-0-	-0-	-0-	-0-	-0-	-0-
2	Oil Recircul. (Chrysler)	Chrysler +Hld Tnk	Holding Tank	27,039	473	27,512	9,013	473	9,486	9,013	473	9,486	9,069	573	9,642	8,069	473	8,542		N/A	
3		Chrysler +Incin	Holding Tank	50,587	1,373	51,960		N/A		23,228	1,373	24,601	14,531	1,173	15,704	13,531	1,073	14,604		N/A	
4	Gravity Collect. (Grumman)	Grum Flow Thru+HldTk	Holding Tank	50,000	5,000	55,000		N/A		25,000	2,500	27,500	26,000	2,600	28,600	25,000	2,500	27,500		N/A	
5		Grumman Flow Thru + Holding Tank			N/A			N/A		50,000	5,000	55,000	26,000	2,600	28,600	25,000	2,500	27,500		N/A	
6	Gravity Collect.	Holding Tank	Grum Flow Thru+HldTnk		N/A			N/A		50,000	5,000	55,000	26,000	2,600	28,600	25,000	2,500	27,500		N/A	
7	Gravity Collect. (Grumman)	Grum Flow Thru+Incin.	Holding Tank	100,000	10,000	110,000		N/A		50,000	5,000	55,000	51,000	5,100	56,100	50,000	5,000	55,000		N/A	
8		Grumman Flow Thru + Incinerator			N/A			N/A		100,000	10,000	110,000	51,000	5,100	56,100	50,000	5,000	55,000		N/A	
9	Vacuum Collect. (Jered)	Holding Tank	Holding Tank	37,100	3,800	40,900	26,600	2,550	29,150	22,400	1,950	24,350	-0-	-0-	-0-	6,800	850	7,650	5,900	850	6,750
10		Incinerator	Holding Tank	103,100	20,300	123,400	59,600	10,800	70,400	55,400	10,200	65,600	25,000	2,500	27,500	32,800	3,450	36,250		N/A	
11		GATX Evap.	Holding Tank	142,000	8,900	150,900		N/A		57,400	3,650	61,050	16,400	850	17,250	24,300	1,700	26,000	22,300	1,700	24,000
12		Holding Tank	Grum Flow Thru+HldTnk		N/A			N/A		72,400	6,950	79,350	25,000	2,500	27,500	31,800	3,350	35,150		N/A	
13		Incinerator	Grum Flow Thru+Incin.		N/A			N/A		122,400	11,950	134,350	50,000	5,000	55,000	56,800	6,850	62,650		N/A	
14	M/T Pump Collect. (GATX)	Holding Tank	Holding Tank	49,500	3,900	53,400	26,700	2,830	29,530	10,650	2,010	12,660	7,650	1,860	9,510	7,650	1,860	9,510	4,500	1,700	6,200
15		Incinerator	Holding Tank	82,500	12,150	94,650	59,700	11,080	70,780	43,650	10,260	53,910	32,650	4,360	37,010	32,650	4,360	37,010		N/A	
16		GATX Evap.	Holding Tank	154,500	9,000	163,500	77,700	5,380	83,080	45,650	3,710	49,360	24,050	2,710	26,760	25,150	2,710	27,860	20,900	2,550	23,450
17		Holding Tank	Grum Flow Thru+HldTnk		N/A			N/A		60,650	7,010	67,660	32,650	4,360	37,010	32,650	12,010	44,660		N/A	
18		Incinerator	Grum Flow Thru+Incin.		N/A			N/A		110,650	12,010	122,660	57,650	6,860	64,510	57,650	14,510	72,160		N/A	

* PAMLICO is currently outfitted with a Colt Industries vacuum collection system including a 450 gallon vacuum tank, which receives sanitary wastes at all times and galley/turbid wastes (including garbage grinder) in port only. Accordingly:

- For those system configurations utilizing Jered commodes and VCT's (systems 9, 10, 11, 12, 13) - no acquisition cost for such is included and only those costs associated with incinerators, evaporators, vapor treatment sections, and treatment subsystems are included.
- For those system configurations utilizing standard commodes (systems 1 thru 8), an acquisition cost of $250 per commode (and $25 spares) are included.
- For those system configurations utilizing GATX commodes (systems 14 thru 18), an acquisition cost of $750 per commode (and $50 spares) are included.

Vessel________________________

WMS No._______

<table>
<tr><th colspan="2">Installation Cost Element</th><th>Unit</th><th>Assumed Unit Cost</th><th>Quantity Required (estimated number of units)</th><th>Cost ($)</th></tr>
<tr><td colspan="2">Piping (1)</td><td>Pounds</td><td>$ 4.50/Lb.
(Materials and Labor)</td><td>(2)</td><td></td></tr>
<tr><td colspan="2">Tank Steel (3)</td><td>Pounds</td><td>$ .55/Lb.
(Materials and Labor)</td><td>(4)</td><td></td></tr>
<tr><td colspan="2">Foundations</td><td>Pounds</td><td>$ .92/Lb.
(Materials and Labor)</td><td>(5)</td><td></td></tr>
<tr><td colspan="2">Electric Cables</td><td>Feet</td><td>$ 2.00/Ft.
(Materials and Labor)</td><td></td><td></td></tr>
<tr><td colspan="2">Miscellaneous Installations (pumps, motors, skid-mounted components, etc.)</td><td>Man-Hours</td><td>$15.00/MH
(Labor)</td><td></td><td></td></tr>
<tr><td colspan="2">Access Cuts (in hull, deck plating or bulkhead to provide passageway)</td><td>Feet</td><td>$ 1.00/Ft.
(Labor)</td><td></td><td></td></tr>
<tr><td colspan="2">Welding</td><td>Feet</td><td>$ 6.00/Ft.
(Materials and Labor)</td><td></td><td></td></tr>
<tr><td rowspan="2">Removals</td><td>Cutting</td><td>Hours</td><td>$50.00/Hr. (6)
(Labor)</td><td></td><td></td></tr>
<tr><td>Other (miscellaneous handling)</td><td>Man-Hours</td><td>$15.00/MH
(Labor)</td><td></td><td></td></tr>
<tr><td colspan="5">Total Installation Cost ($)</td><td></td></tr>
</table>

(1) Copper-nickel assumed.
(2) Estimate includes a factor of 50% added to allow for valves, flanges, fittings, take-down joints, etc.
(3) One-quarter inch plate assumed.
(4) Estimate includes a factor of 30% added to allow for requ [illegible]d structural stiffening for proper support.
(5) Estimated on the basis of 10% of the weight which has to [illegible] supported.
(6) Based on an assumed cutting rate of 50 ft./hr.

Figure 14

INSTALLATION COST ESTIMATE FORM

Table 10
SUMMARY OF WMS INSTALLATION COSTS

WMS No.	TYPE			INSTALLATION COST ($)					
	Col/Trans Subsys (Black)	Treatment/Disposal Subsystem							
		Black	Gray	GALLATIN (378')	VIGOROUS (210')	FIREBUSH (180')	PAMLICO(160') (New Constr.)	WHITE SAGE (133')	POINT HERRON (82')*
1	Gravity Collect.	Holding Tank	Holding Tank	47,260	10,200	16,850	28,520	13,190	2,410
2	Oil Recircul. (Chrysler)	Chrysler + Hld Tnk	Holding Tank	12,370	13,230	12,060	25,290	13,800	N/A
3		Chrysler + Incin.	Holding Tank	71,220	N/A	20,630	30,590	16,800	N/A
4	Gravity Collect. (Grumman)	Grum Flow Thru+HldTk	Holding Tank	39.980	N/A	18,760	24,280	17,000	N/A
5		Grumman Flow Thru + Holding Tank		N/A	N/A	16,079	15,220	12,890	N/A
6	Gravity Collect.	Holding Tank	Grum Flow Thru+ HldTnk	N/A	N/A	21,590	21,200	15,460	N/A
7	Gravity Collect. (Grumman)	Grum Flow Thru+Incin.	Holding Tank	69,060	N/A	25,640	29,230	23,080	N/A
8		Grumman Flow Thru + Incinerator		N/A	N/A	19,250	18,030	13,100	N/A
9	Vacuum Collect. (Jered)	Holding Tank	Holding Tank	48,310	16,270	19,710	19,890	12,730	5,460
10		Incinerator	Holding Tank	75,900	23,530	33,740	21,370	16,300	N/A
11		GATX Evap.	Holding Tank	47,340	N/A	31,660	15,830	12,220	4,690
12		Holding Tank	Grum Flow Thru+ Hld Tnk	N/A	N/A	21,810	12,760	10,600	N/A
13		Incinerator	Grum Flow Thru + Incin.	N/A	N/A	29,320	14,470	13,640	4,200
14	M/T Pump Collect. (GATX)	Holding Tank	Holding Tank	47,710	13,650	19,420	20,490	11,990	N/A
15		Incinerator	Holding Tank	78,120	20,890	29,520	22,540	15,790	N/A
16		GATX Evap.	Holding Tank	41,720	11,560	23,050	17,770	10,930	4,220
17		Holding Tank	Grum Flow Thru+Hld Tnk	N/A	N/A	21,280	13,480	10,970	N/A
18		Incinerator	Grum Flow Thru + Incin.	N/A	N/A	29,590	13,080	15,640	N/A

* Installation costs proceed from the assumption that a holding tank (currently planned but not yet on board) will be installed on the Point Herron.

N/A - Not a viable candidate system/vessel combination.

RECURRING EXPENDITURES

Recurring expenditures include WMS operating and maintenance costs. For purposes of this analysis, and in accordance with the life-cycle cost model, maintenance costs are broken down into three categories, namely preventive (scheduled) maintenance, corrective (unscheduled) maintenance resulting from random failures of equipment, and overhaul.

A fuller discussion of these operating and maintenance activities, including definitions and rules for classifying tasks into each of the above categories are presented in Volume V of this report. Highlights of operating/maintenance cost analysis are presented below.

Operating and Maintenance Costs Based On Continuous Operation

As a first step in estimating WMS recurring expenditures, MSD operating and maintenance cost data were developed on a subsystem/equipment basis corresponding to the manner in which the MSDs were hybridized to form the candidate WMS concepts. MSD data for each of the four operating and maintenance cost elements were recorded on the forms shown in Figures 15 through 18 and are presented in Volume V of this report.

The data in Figure 15 through 17 are based on the assumption of continuous operation or 100% utilization factor, and the data in Figure 18 are given on a per overhaul basis. It is noted that data based on continuous operation do not imply that the subsystem or equipment for which such data are given actually operates continuously. Instead, it means that the data are developed on the basis of the assumption that the vessel is continuously within restricted waters, and the data represent estimates of the subsystem/equipment operation (and maintenance) under such conditions (e.g., percentage of time an incinerator is operating if the vessel were continuously within restricted waters). The assumption of continuous operation or 100% utilization factor was made in order to facilitate the development of generic MSD data which could then be used for all candidate system/vessel combinations of interest.

MSD OPERATING CHARACTERISTICS AND COST ESTIMATES
(Based on 100% Utilization Factor)
MSD ________________

Page ___ of ___

	LABOR						VESSEL RESOURCES USED										MATERIALS CONSUMED				TOTAL
							Resource Usage Rate					Annual Cost of Resource Consumed									
Operational Requirement	Scheduled Interval for Operational Activity (Hrs)	Time Required (Hrs-Min)	Number Operators/ Skill Level	Assumed Labor Rate ($/Hr)	Annual Labor Required (Man-Hrs)	Annual Cost of Labor ($)	Electric Power (kwh/day)*	Fuel Oil (gpd)	Fresh Water (gpd)	Power for Flushing water (kwh/day)	Compressed Air (SCF/day @ P)	Electric Power (@ 3¢/kwh)	Fuel Oil (@ 38¢/gal)	Fresh Water (@2¢ & 0.07¢/gal)*	Power for Flushing Water (@ 1.83¢/1000 gal)	Compressed Air (see footnote)	Materials Required	Rate of Usage	Cost of Material	Annual Cost of Corsv and Materials	Annual Operating Cost ($)

* 2¢/gal for vessel generated fresh water and 0.07¢/gal for stored fresh water.

Compressed Air Cost in ¢/Year = $\left(6.12268\ (14.7+p)^{0.1429} - 8.9898\right)$ (SCF/day) where p is in psig

SCF = standard cubic feet at 14.7 psi and 70°F

Figure 15

DATA SHEET FOR MSD OPERATION

MSD PREVENTIVE (SCHEDULED) MAINTENANCE CHARACTERISTICS AND COST ESTIMATES
(Based on 100% Utilization Factor)

MSD ____________________ Page______of______

LABOR							PARTS CONSUMED				TOTAL
Preventive Maintenance Requirement	Scheduled Interval for Maintenance Action (Hrs)	Estimated Time Required (Hrs-Min)	No. Maintainers/ Skill Level	Assumed Labor Rate ($/Hr)	Annual Labor Required (Man-Hrs)	Annual Cost of Labor ($)	Spare Part Required	No. of Parts Used/Year	Cost of Each Part ($)	Annual Cost of Parts ($)	Annual Preventive Maintenance Cost ($)

Figure 16

DATA SHEET FOR MSD PREVENTIVE MAINTENANCE

MSD CORRECTIVE (UNSCHEDULED) MAINTENANCE CHARACTERISTICS AND COST ESTIMATES
(Based on 100% Utilization Factor)

MSD ____________

Page ______ of ______

LABOR							PARTS CONSUMED				TOTAL
Corrective Maintenance Requirement	Estimated Time Between Failures (Hrs)	Estimated Time Required (Hrs-Min)	No. Maintainers/ Skill Level	Assumed Labor Rate ($/Hr)	Annual Labor Required (Man-Hrs)	Annual Cost of Labor ($)	Spare Part Required	Estimated No. of Parts Used/Year	Cost of Each Part ($)	Annual Cost of Parts ($)	Annual Corrective Maintenance Cost ($)

Figure 17
DATA SHEET FOR MSD CORRECTIVE MAINTENANCE

MSD MAJOR OVERHAUL CHARACTERISTICS AND COST ESTIMATES

MSD ______________

Page ______ of ______

LABOR							PARTS CONSUMED				TOTAL
Overhaul Requirement	Time Between Overhauls (Yrs)*	Estimated Time Required (Hrs-Min)	No. Maintainers/ Skill Level	Assumed Labor Rate ($/Hr)	Total Labor Required (Man-Hrs)	Total Cost of Labor ($)	Part Required	No. of Parts Required for Overhaul	Cost of Each Part ($)	Cost of Parts for Overhaul ($)	Major Overhaul Cost ($)

* Since overhaul information was not available from manufacturer for all subsystems and capacities, a 2-year overhaul interval is assumed for all subsystems.

Figure 18

DATA SHEET FOR MSD OVERHAUL

It is noted from Figure 15 that operating costs have been broken down into the following elements:

- Labor, including:
  - The periodicity
  - Time required
  - Number and skill level of operator
- Vessel resources used, including:
  - Electric power (including power for pumping flush medium and cooling water)
  - Fuel oil
  - Fresh water
  - Compressed air
- Materials consumed (filters, chemicals, etc .)

Since the data in Figure 15 have to be generic and on a subsystem/equipment basis, development and subsequent use of these data are not a trivial matter. The reason for this is that not all operational characteristics are on a per unit basis, independent of the vessel on which the subsystem/equipment will be operated. As a result of such dependencies, some of the data cannot be explicitly stated but instead have to be given implicitly in a form which indicate the parameters on which the data are dependent. Some examples of such dependencies are as follows:

- Fuel consumption (and electric power) for an incinerator depends on the vessel crew size. As a result, fuel consumption rates have to be given on a per capita basis.
- The frequency of emptying an evaporator depends on the crew size. As a result, the periodicity for this activity is given in man-days rather than in hours.

- The consumption of compressed air for aerating a black water holding tank depends on the size as well as the maximum height of the tank. As a result, compressed air consumption must be given in terms of an expression which can be quantified only when the physical characteristics of the tank become known.
- The cost of fresh water is vessel dependent since the cost is different depending on whether the fresh water is taken from shore and stored (70¢/1000 gallons) or whether it is generated aboard the vessel by an evaporator ($20/1000 gallons).

Note that in addition to the above, vessel dependencies such as crew size, some of the operating cost elements (e.g. fuel consumption) also depend on vessel mission profiles, but this is another type of dependency which will be treated in the ensuing discussion. This also includes the number of WMS mode changeover cycles from primary to overboard mode and from pierside to primary mode.

Using the data in Figure 15 in conjunction with the equipment requirements information provided in Table 7, the annual operating costs and characteristics for each viable candidate system/vessel combination were computed. In making these computations, all pertinent vessel characteristics on which these cost elements depend have been accounted for. In order to facilitate the use of this information in the next stage of the calculations (which take mission profiles into acccunt) it was necessary to determine these cost elements not on an overall WMS basis, but rather on a WMS subsystem basis. Thus, results for WMS operating costs and characteristics based on continuous operation have been derived and are given separately for each of two major WMS subsystems. For purposes of these calculations, each WMS concept was subdivided into a black water waste Collection/Transport subsystem and a combined black and gray waste Treatment/Disposal subsystem. The results of the above described computations for each viable candidate WMS on each vessel are presented in Appendix B.

The results in Appendix B indicate that the operating costs for the Treatment/ Disposal subsystem are generally much larger than those for the Collection/ Transport subsystem (except for WMS Nos. 2 and 9). Treatment/Disposal subsystem operating costs are especially high for systems with evaporators and even higher for systems with incinerators. Most of the costs are for vessel resources (fuel and electric power). The largest Collection/Transport subsystem operating cost is associated with systems which utilize vacuum collection and oil recirculation* (WMS Nos. 2, 3 and 9 through13). Operating costs are also a function of crew size.

It is noted from Figure 16 that preventive (scheduled) maintenance costs have been broken down into the following elements:

- Labor, including:
  - Periodicity
  - Time required
  - Number and skill level of maintainer
- Parts (or materials) required

Using the results in Figure 16 in conjunction with the equipment requirements information in Table 7, annual preventive maintenance costs and characteristics for each viable candidate WMS configuration on each vessel were computed. The results of these computations are given in the left side of the tables in Appendix C. It is noted from Appendix C that the results for preventive maintenance based on continuous operation are given on an overall WMS basis rather than on a WMS subsystem basis. The reason for this is that due to the limited experience with these systems, a good basis for reducing the amount of preventive maintenance as function of use (i.e., vessel mission profiles) could not be determined and it was assumed that the same amount of preventive maintenance would be performed on these WMS subsystems/equipments independent of the vessel on which they will be installed. The left-hand portion of Appendix C indicates that most of the preventive maintenance cost is due to labor.

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* Note that in an oil recirculation system the Collection/Transport subsystem operating cost includes the cost of the treatment portion as well (except for the holding or incineration function).

It is noted from Figure 17 that corrective (unscheduled) maintenance costs have been broken down into the following elements:

- Labor, including:
    - Frequency
    - Time required
    - Number and skill level of maintainer
- Replacement part requirements

It is noted that, as in the case of operating activities, corrective maintenance activities could also have dependencies. An example of such a dependency is the replacement rate for the Jered incinerator liner. It is estimated that this liner has a life expectancy of approximately 500 burn-hours. However, the annual number of burn hours for an incinerator on a given vessel depends on the crew size. As a result, the failure rate of the liner is given in terms of man-days rather than in hours.

Using the data in Figure 17 in conjunction with the equipment requirements information in Table 7, annual corrective maintenance costs and characteristics based on continuous operation for each viable candidate WMS configuration on each vessel were computed and are presented on the right side of the tables in Appendix C. As in the case of WMS operation, the results for corrective maintenance are given on the basis of the two major WMS subsystems in order to facilitate modification of these data as a function of vessel mission profiles. The right hand portion of Appendix C shows that in most cases, the corrective maintenance cost for the Treatment/Disposal subsystem is much greater than that for the Collection/Transport subsystem. Exceptions are systems based on reduced volume collection in conjunction with a holding tank or evaporator (WMS Nos. 9, 11, 14, 16 and 17) and for oil recirculation with a holding tank (WMS No. 2). This pattern is not followed by WMS No. 11 on the POINT HERRON due to the small number of fixtures on board this vessel and by WMS No. 17 on the FIREBUSH. Also noted is the fact that most of the corrective maintenance costs are due to the cost of parts.

From Figure 18, it is noted that overhaul costs are broken down into the following elements:

- Labor, including:
  - Overhaul interval (assumed to be two years for purposes of this study)
  - Time required
  - Number and skill level of maintainer
- Parts and material requirements

Using the data in Figure 18, in conjunction with the equipment requirements information in Table 7, overhaul costs and characteristics for each viable candidate WMS configuration on each vessel have been computed and are presented in Appendix D. The data in Appendix D are given on an overall WMS basis rather than on a subsystem/equipment basis. Inherent in this is the assumption that the entire WMS will be overhauled at the same time rather than on a subsystem/equipment basis.

It is noted from Appendix D that for systems with complex equipment (i.e., reduced volume collection, incinerators, evaporators, etc.), the overhaul costs are higher and are due mainly to the cost of parts, whereas for less complex systems (e.g., gravity drain with holding tanks) the overhaul costs are lower and are due mainly to the cost of labor.

Operating and Maintenance Costs Based on Vessel Mission Profiles

The second step in estimating WMS recurring expenditures involves modifying the results based on continuous operation by vessel mission profile characteristics. The specific mission profile characteristics which are of interest for this purpose are the percentage of total annual time that the vessel is within restricted waters (or in a non-home port) as well as the annual number of three mile limit crossings and the number of shore dockings at home port and at yards. The percentage of time within restricted waters (or non-home port) is directly translatable into WMS utilization factors, whereas the number of limit crossings and shore dockings are translatable into the annual number of WMS mode changeovers. From Table 2 these mission profile parameters for each vessel are as shown below.

VESSEL	Crew Size	WMS Utilization Factor (%)	Annual Number of Mode Changeover Cycles	
			Primary/ Overboard	Pierside/ Primary
GALLATIN (378')	152	11	36	20
VIGOROUS (210')	60	5.6	15	16
FIREBUSH (180')	50	14.1	34	103
PAMLICO (160')	13	31	0	33
WHITE SAGE (133')	21	11.1	17	81
POINT HERRON (82')	8	1.8	46	46

In using vessel mission profile characteristics to modify the operating and maintenance costs based on continuous operation, it is important to recognize which WMS subsystems/equipments are affected and which ones are not. Thus, the WMS waste Collection/Transport subsystem has a utilization factor of 100% and therefore the data for this subsystem should not be modified by mission profile characteristics. On the other hand, the WMS waste Treatment/Disposal subsystem is operated only when the vessel is within restricted waters or in a non-home port, and it is turned off when the vessel is beyond restricted waters or connected to a shore waste receiving facility. Consequently, the data for this subsystem must be modified by the vessel mission profile characteristics. An exception to this is the treatment portion of an oil recirculation system which has a utilization factor of 100% (this does not apply to the holding or incineration function).

Generally, the modification consists of multiplying the data for the Treatment/Disposal subsystem based on continuous operation by the WMS utilization facotr. When this product is added to the corresponding cost element for the Treatment/Disposal subsystem data based on continuous operation, the resulting numbers are the desired costs.

The results of modifying the WMS operating characteristics and costs based on continuous operation (given in Appendix B) by vessel mission profile characteristics are presented in Appendix E. These results include the effect of accounting for mode changeovers. It is noted that the distribution of operating task frequencies given in the left hand portion of the tables in Appendix B were not modified by vessel mission profile characteristics since a valid basis for such modifications could be determined. The results in Appendix E indicate that the operating costs increase with an increasing WMS utilization factor.

WMS maintenance costs and characteristics based on continuous operation (given in Appendix C) as modified by vessel mission profile characteristics are presented in Appendix F. It is noted that, as discussed earlier, the preventive maintenance results were not modified by the WMS utilization factors for the reason stated. However, corrective maintenance data for the Treatment/Disposal subsystems were multiplied by the WMS utilization factors and added to the Collection/Transport subsystem. As a result, corrective maintenance costs increase with increasing WMS utilization factor.

Present Value of Operating and Maintenance Costs

The last step in estimating the life-cycle cost of WMS recurring expenditures consists of modifying the annual operating and maintenance costs based on WMS utilization factor by suitable present value factors. Present value factors take into account the expected life of the system and the assumed effective discount rate, which depends on prevailing interest and inflation rates and accounts for the time value of money. Present value factors applicable to operating, preventive maintenance and corrective maintenance costs (F_1) and to overhaul costs (F_2) are given in Table 11. The present value factors in Table 11 are based on the following assumptions:

- A 10-year useful system life
- A 10% effective discount rate
- A two-year overhaul interval

Table 11

PRESENT VALUE FACTORS BASED ON A 10% EFFECTIVE DISCOUNT RATE*

PROJECT YEAR	PRESENT VALUE FACTORS			
	Applicable to Each Individual Project Year**	Cumulative (Applicable to Operation, PM and CM)	For WMS Overhauls (Based on a two-year overhaul cycle)	
			Overhaul Status	Cumulative
1	0.909091	0.909091	WMS Installation	
2	0.826446	1.735537	Overhaul	0.826446
3	0.751315	2.486852		
4	0.683013	3.169865	Overhaul	1.509459
5	0.620921	3.790786		
6	0.564474	4.35526	Overhaul	2.073933
7	0.513158	4.868418		
8	0.466507	5.334925	Overhaul	2.54044
9	0.424098	5.759023		
10	0.385543	F_1= 6.144566	Overhaul	F_2= 2.925983

* OM&B Circular No. A-94, dated 3/22/72, "Discount Rates to be used in evaluating time-distributed costs and benefits.

** The discount factors presented in the table above implicitly assume end-of-year lump-sum costs and returns. When costs and returns occur in a steady stream, applying mid-year discount factors may be more appropriate. Present value cost and benefit computed from this table can be converted to a mid-year discounting basis by multiplying them by the factor 1.048809. For example, if the present value cost of a series of annual expenditures computed from the above table is $1,200.00, the present value cost on a mid-year discounting basis is $1,200.00 x 1.048809 or $1,258.57.

The present value factor F_1 can be obtained from the effective discount rate (I) and the assumed useful system life (n) by the expression

$$F_1 = \frac{(1+I)^n - 1}{I(1+I)^n}$$

It is noted that the above expression as well as the results in Table 11 are based on the assumption that the operating and maintenance costs are identical during each year throughout the life of the system, i.e., any differences in costs which may occur during overhaul years are neglected.

The operating and maintenance costs based on vessel mission profiles (presented in Appendices E and F) are multiplied by the appropriate present value factors F_1 or F_2 to obtain the present values of operating and maintenance life-cycle costs. The results of this multiplication are presented in Appendix G. Since these recurring expenditures represent the costs for the entire assumed economic life of the system, these can be added to the fixed costs (acquisition and installation) in order to obtain the total life-cycle cost of each viable candidate system/vessel combination.

SENSITIVITY ANALYSIS OF LIFE-CYCLE COSTS

The sensitivity of the overall life-cycle cost to changes in the data and/or assumptions relating to the individual cost elements is indicated in two ways. First, the summary table at the beginning of this report shows each cost element and in addition indicates its relative contribution (expressed as a percentage) to overall life-cycle cost. These percentages serve as indications of the relative importance of changes in the data for each cost element. Second, expressions were derived relating the overall WMS life-cycle cost to the various cost elements, the assumptions, and the other parameters which affect the cost. These expressions indicate the amount by which any one cost element (or other cost dependent parameter) has to vary in order to effect a given change in the overall life cycle cost, assuming that all other cost factors are held constant. Ideally, for this type of sensitivity analysis, the overall life cycle cost should be related to the actual data at the lowest level of each cost element. However, in view of the computational burden involved when this is done manually, this was not practical. Instead, the sensitivity analysis formulas developed relate the overall life cycle cost to individual cost elements at either the overall WMS level (for fixed costs) or the WMS Collection/Transport and Treatment/Disposal subsystem level (for operating and corrective maintenance costs). In addition to the fixed cost elements (acquisition and installation) and the operating and maintenance cost elements based on continuous operation (or per overhaul), sensitivity analysis expressions were also derived for the WMS utilization factor and the present value factors. The results of this sensitivity analysis are presented in Appendix H. Appendix H includes the derivation of the formulas for sensitivity analysis as well as tables showing the results of this analysis. The entries in these tables indicate the percentage by which the given cost element or other parameter has to change in order to effect a 10% change in the overall life cycle cost.

These results indicate that the sensitivity of a cost element depends on its relative contribution to the overall life cycle cost. As the WMS utilization factor increases, its sensitivity also increases, since this results in a larger contribution of the corresponding cost elements to the total life cycle cost. Comparison of the results for F_1 and F_2 shows greater sensitivity to F_2, indicating that the life cycle cost is sensitive to the overhaul interval.

EFFECTIVENESS ANALYSIS

THE EFFECTIVENESS ASSESSMENT METHODOLOGY

The effectiveness of candidate systems is determined on the basis of numerous considerations, such as system characteristics and features, assumptions, etc. It is very difficult to make sound decisions based on the simultaneous judgment of a multitude of considerations, many of which may be unrelated. On the other hand, it is fairly easy to make individual decisions on a small scale. The approach used for assessing the effectiveness of candidates is based on converting the relatively difficult problem of trying to arrive at a major decision by simultaneously juggling numerous and often unrelated considerations, into the relatively easy problem of systematically making many "small" decisions. The approach also addresses the necessity of combining the decision-maker's subjective judgments with technical data and relevant assumptions in arriving at an overall effectiveness assessment of each candidate system.

The approach for assessing the effectiveness of candidates and the development of the effectiveness model which forms the basis for this assessment are closely related to the definition of effectiveness. In the context of this study, effectiveness is not to be viewed as a fixed and preformulated expression in terms of some specific variables. Instead, the following definition of effectiveness is used:

- The effectiveness of a candidate is broadly defined as its overall quality. This quality is determined on the basis of how well the candidate fulfills specified objectives, requirements and constraints. Furthermore, this overall quality can be quantified and the resulting number is the effectiveness rating of the candidate. The effectiveness rating is a quantitative measure of the degree to which the candidate has satisfied the aggregate of all the individual criteria for determining conformance with objectives and requirements as well as their relative importance.

It is noted that the above definition of effectiveness implies the following:

- It is necessary to specify objectives, requirements and constraints.
- It is necessary to establish criteria for judging how well the candidates fulfill the objectives, requirements and constraints.
- It is necessary to indicate the importance of the established criteria relative to one another.
- It is necessary to quantify each individual criterion as well as the aggregate of all criteria and their relative importance. This quantification must be based on candidate attribute data (i.e., characteristics).

The effectiveness assessment methodology is the system of analysis techniques and associated computational procedures which start with the relevant information concerning the candidates and their associated context as an input, and generates quantitative effectiveness ratings as an output. This methodology consists of procedures, guidelines and computational aids for executing the following three main steps of the effectiveness assessment.

- Development of the effectiveness model.
- Development of effectiveness attribute data geared to the effectiveness model.
- Quantification of effectiveness.

The effectiveness model is, in effect, a framework of criteria for judging the degree of acceptability of each candidate system. This framework is in the form of a hierarchy which structures the effectiveness assessment criteria in successive levels of detail and specificity. A set of weights are then associated with this criterion hierarchy to indicate the importance of each criterion in relation to the others.

The development of the effectiveness model consists of the following identifiable steps:

- Selection of a set of measures of effectiveness (M/E_i). The M/Es constitute a set of highest level overall criteria which will be the basis for assessing the effectiveness of the candidates.
- Assignment of M/E weights (W_i). These M/E weights are used to indicate the importance of each M/E in relation to the others.
- Determination of the factors (F_j) and subfactors (SF_k) of each M/E. Factors result from a breakdown of an M/E into its constituent lower level subordinate criteria which are implied by the higher level criterion represented by the given M/E. Subfactors result from a breakdown of a factor or another subfactor into its constituent lower level subordinate criteria which are implied by the higher level criterion represented by the given factor or subfactor. Elementary factors (F_e) or subfactors (SF_e) are those which have no subordinate subfactors and which can be directly related to one or more attributes (i.e., characteristic) of the candidates under consideration.
- Assignment of factor weights (W_j) and subfactor weights (W_k). These weights are used to indicate the importance of each factor/subfactor (i.e., criterion) in relation to the others at the same level of subordination.
- Development of an effectiveness rating function (ERF) for every elementary factor/subfactor. An ERF constitutes a functional relationship between the candidate attribute (characteristic) relevant to the given elementary factor/subfactor and an effectiveness rating which is a quantitative measure of the candidate's acceptability, quality, worth, desirability, etc., with respect to the given criterion. The ERFs constitute an important element

of the effectiveness model. They provide a mechanism for systematically bringing together and integrating the essential elements of the effectiveness assessment, namely:

.. Assumptions, goals, requirements and constraints.

.. Technical information.

.. Subjective judgments of the decision maker.

The effectiveness attribute data required is determined by the ERFs. The ERFs also determine the format of these data. A numbering scheme which uniquely identifies each ERF within each M/E is used to associate the data with the corresponding ERF. An important aspect of the development of the ERFs and the associated effectiveness attribute data is its flexibility with respect to the type and level of detail of the required data. This ensures that the data requirements are realistic and are consistent with common practice in the field, i.e., the analyses performed in support of the effectiveness assessment such as MSD analysis, installation analysis, life-cycle cost analysis, etc. Thus, the development of effectiveness attribute data represents another important mechanism for integrating the results of the various analyses which are normally performed in the course of studying the candidates.

The quantification of the effectiveness is summarized in Figure 19. It is accomplished by relating the rating at any level of subordination in the effectiveness model to the next lower level elements of the model as the sum of products of the ratings and associated weights of these elements. Thus, starting with the elementary factors/subfactors, the next higher level subfactor or factor ratings are given as the sum of products of the elementary factors/subfactors. Similarly, the rating for a given M/E is obtained as the sum of products of its factor ratings and their associated weights. Finally, the overall effectiveness rating is obtained as the sum of the products of M/E ratings and their associated weights. Once the effectiveness model and the associated effectiveness attribute data have

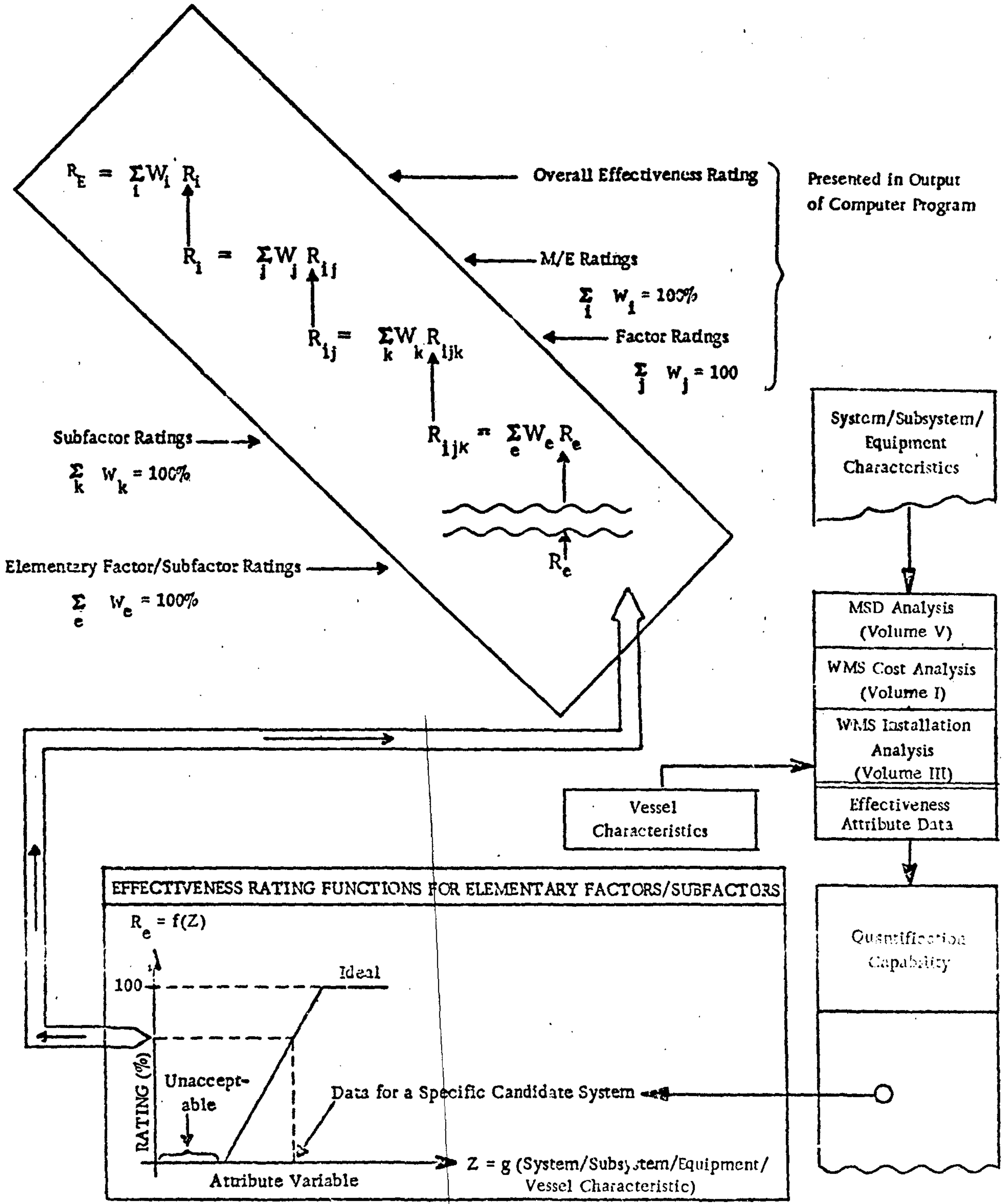


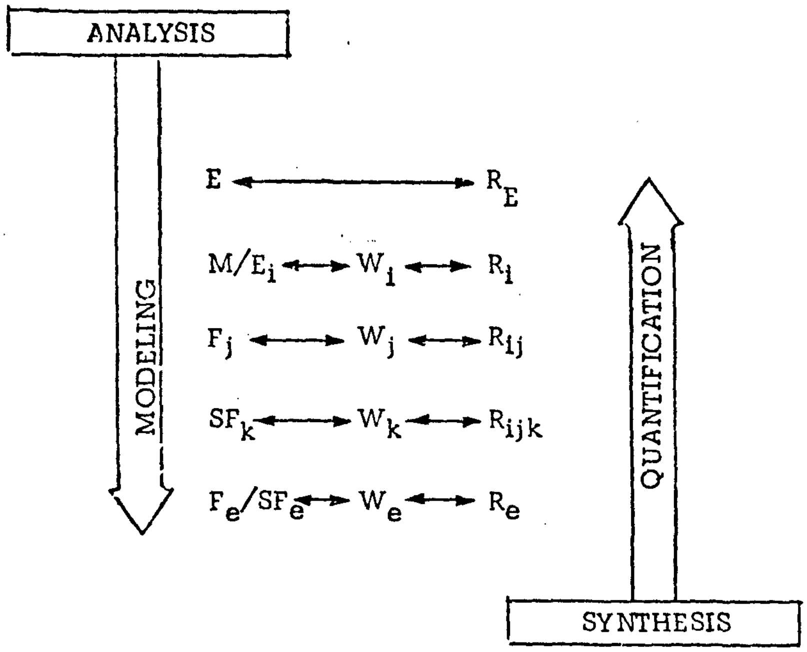
Figure 19

SUMMARY OF THE PROCEDURE FOR QUANTIFYING THE EFFECTIVENESS OF CANDIDATE SYSTEMS/VESSEL COMBINATIONS been developed, the quantification of effectiveness is fairly straightforward and is accomplished by a computer program. The output of the computer program consists of an overall effectiveness rating for each candidate as well as effectiveness ratings with respect to each M/E.

As part of the development of the effectiveness assessment methodology, the above steps have been documented in greater detail and guidelines for executing these steps have been included (see Volume II of this report). It is noted both from the previous discussion of the development of the elements of the effectiveness model and from Figure 19 that the M/Es, the factor/subfactors and their associated levels of subordination constitute a hierarchy. Actually, four types of hierarchies can be discerned in connection with the effectiveness assessment methodology, namely:

- A hierarchy of objectives and requirements.
- A hierarchy of criteria associated with the objectives and requirements.
- A hierarchy indicating the importance of each criterion in relation to the others.
- A hierarchy of effectiveness ratings which are quantitative measures of the degree to which each criterion in the hierarcy is satisfied by each candidate.

The first three hierarchies are associated with the effectiveness model and the last hierarchy is associated with the quantification of effectiveness. However, it is noted from Figure 19 that the quantification of effectiveness includes the use of the weights. Thus, the weights possess a dual character, namely, as indicators of the relative importance of each criterion (related to the effectiveness model), and as numbers used in obtaining the ratings (related to the quantification process). Finally, it is noted that the development of the effectiveness model can be characterized as analysis (top to bottom process), whereas the quantification of effectiveness can be characterized as synthesis (bottom to top process).* The above discussed relationships in connection with the effectiveness assessment methodology are summarized below.



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* It is noted that the life-cycle cost analysis presented in a previous section of this report, is based on a similar approach, consisting of the development of a detailed life cycle cost model appropriate for wastewater management systems (analysis), followed by substitution of data at the lowest level of the model and building up to the overall life-cycle cost (synthesis).

THE EFFECTIVENESS MODEL

One of the tenets of this effectiveness assessment methodology is that in order to produce meaningful results, it is necessary for the decision-maker to participate in the development of the effectiveness model. In conformity with this principle, the effectiveness model was developed in consultation with and the active participation of, cognizant U.S. Coast Guard technical representatives. Such Coast Guard participation was extensive in the development of the structure of the effectiveness model, i.e., the choice of the M/Es and the breakdown of each M/E into its factors/subfactors and the associated levels of subordination. The M/E as well as the factor/subfactor weights assignments were made by the Coast Guard. Finally, the development of the ERFs was carefully coordinated with the Coast Guard technical monitor.

Measures of Effectiveness and Associated Weights

The effectiveness model for the wastewater management systems analyzed in this study is based on the seven measures of effectiveness (M/Es) shown in Table 12. Each M/E in Table 12 is numbered for reference purposes and a brief statement indicates the kinds of considerations which are encompassed by each M/E (and elaborated by its factors and subfactors). A weight is associated with each M/E to indicate its importance in relation to the others, such that the sum of these weights is 100%. It is noted that the overall effectiveness ratings of the viable system/vessel combinations reflect this weight assignment and should be interpreted accordingly.

M/E Factors/S[illegible]actors and Associated Weights

A breakdown of each M/E into its factors and a further breakdown of factors successively into subfactors and associated levels of subordination is indicated in the following pages. Within each M/E, each factor and subfactor is uniquely identified by a numbering scheme which also indicates its level of subordination. The number of bullets appearing in front of each factor and subfactor is intended to provide more convenient visual indication of its level of subordination.

Table 12

MEASURES OF EFFECTIVENESS AND ASSOCIATED WEIGHTS

MEASURE OF EFFECTIVENESS (M/E)	WEIGHT (%)
I - ADAPTABILITY FOR SHIPBOARD INSTALLATION (Suitability for vessel, ease of installing, effects on vessel)	8
II - PERFORMANCE (How well system accomplishes intended functions)	15
III - OPERABILITY (Ease of operation, burden on crew, operational expendables)	12
IV - PERSONNEL SAFETY (Likelihood, severity and ease of correcting hazards)	11
V - HABITABILITY (Noise, odor, heat, user comfort, aesthetics)	17
VI - RELIABILITY (Potential for failure free operation)	23
VII - MAINTAINABILITY (Ease of correcting failures, manpower and logistic requirements)	14

Factor/Subfactors and Associated Weights
for

I - ADAPTABILITY FOR SHIPBOARD INSTALLATION

Sheet 1 of 3

FACTOR/ SUBFACT. IDENT. NO.	M/E FACTORS AND SUBFACTORS (Description and Level of Subordination) / FACTOR/SUBFACTOR WEIGHTS (%) (As a Function of Vessel)	GALLATIN (378')	VIGOROUS (210')	FIREBUSH (180')	PAMLICO (160') (New Constr.)	WHITE SAGE (133')	POINT HERRON (82')
1	. WMS suitability for vessel	20	→	→	→	→	→
11	.. Required capacity for vessel vs. actual capacity of system(s)	55	→	→	→	→	→
111	... Black	90	→	→	→	→	→
112	... Gray	10	→	→	→	→	→
12	.. Materials disallowed or not recommended (as specified in sub-chapter J&F of the Merchant Marine Code and CG MSD regulations)	10	→	→	→	→	→
13	.. Extent of additional support systems/equipment required to accommodate WMS (Compressor, fire fighting equipment, bilge alarm, ozone detector, vents, etc.)	35	→	→	→	→	→
2	. Ease of WMS installation	50	→	→	→	→	→
21	.. Extent of fixture modifications (i.e., existing commodes/urinals/fixtures vs. special commodes/urinals/fixtures, including hook-up requirements)	15	→	→	→	→	→
22	.. Extent of flush medium supply modifications (existing sea water or fresh water, conversion to fresh or sea water, conversion to non-aqueous medium)	15	→	→	→	→	→
23	.. Ease of installation wastewater Collection/Transport subsystem (Note VCT for JERED and M/T pumps for GATX).	15	→	→	→	→	→
231	... Hook-up requirements (e.g., drain piping, electric cables connecting commode, pump and control panel in GATX, but not in JERED)	10	→	→	→	→	→
232	... Routing flexibility for drain piping modifications (e.g., continuous slope and vent requirements for conventional full flush drains vs. JERED and GATX drains)	25	→	→	→	→	→
233	... Space requirements	25	→	→	→	→	→

Factor/Subfactors and Associated Weights
for

I - ADAPTABILITY FOR SHIPBOARD INSTALLATION

Sheet 2 of 3

FACTOR/ SUBFACT. IDENT. NO.	M/E FACTORS AND SUBFACTORS (Description and Level of Subordination) / FACTOR/SUBFACTOR WEIGHTS (%) (As a Function of Vessel)	GALLATIN (378')	VIGOROUS (210')	FIREBUSH (180')	PAMLICO (160') (New Constr.)	WHITE SAGE (133')	POINT HERRON (82')
234	... Modularity of systems (i.e., single package unit vs. decentralization of components)	20	→	→	→	→	→
235	... Vent requirements	20	→	→	→	→	→
24	.. Ease of installing waste Treatment/Disposal subsystem	15	→	→	→	→	→
241	... Space requirements	25	→	→	→	→	→
242	... Hook-up requirements (piping for fuel oil, fresh water cooling cooling water, compressed air, interconnecting remotely located equipment, overboard discharge line, etc.; electric cables for power supply, remote control panels, etc.; ducting for ventilation, etc.)	25	→	→	→	→	→
243	... Modularity of system (single package unit vs. decentralization of components; note that decentralization of components may require additional hook-ups and piping runs).	15	→	→	→	→	→
244	... Vent requirements	10	→	→	→	→	→
245	... Exhaust stack requirements	25	→	→	→	→	→
25	.. Ease of installing WMS support equipment (e.g., compressor, fire fighting, bilge alarm, ozone detector, vents)	10	→	→	→	→	→
26	.. Ease of compensating for added weight of WMS	10	→	→	→	→	→
27	.. Degree of vessel alterations required for WMS installation	20	→	→	→	→	→
271	... SHIPALTS - permanent modifications (e.g., foundations, enlarged doors/hatches, increased capacity requirements for air compressor)	75	→	→	→	→	→
272	... Temporary modifications (e.g., cutting access opening)	25	→	→	→	→	→

Factor/Subfactors and Associated Weights

for

I - ADAPTABILITY FOR SHIPBOARD INSTALLATION

Sheet 3 of 3

FACTOR/ SUBFACT. IDENT. NO.	M/E FACTORS AND SUBFACTORS (Description and Level of Subordination) / FACTOR/SUBFACTOR WEIGHTS (%) (As a Function of Vessel)	GALLATIN (378')	VIGOROUS (210')	FIREBUSH (180')	PAMLICO (160') (New Constr.)	WHITE SAGE (133')	POINT HERRON (82')
3	. Effects of WMS on vessel	30	→	→	→	→	→
31	.. Stability	10	→	→	→	→	→
32	.. Trim and list	10	→	→	→	→	→
33	.. Normal range	15	→	→	→	→	→
34	.. Degree of space trade/off reallocation required	40	→	→	→	→	→
35	.. Vessel resource consumption	25	→	→	→	→	→
351	... Electric power	25	→	→	→	→	→
352	... Fuel oil	20	→	→	→	→	→
353	... Potable water	35	→	→	→	→	→
354	... Compressed air	10	→	→	→	→	→
355	... Cooling water	10	→	→	→	→	→

Factor/Subfactors and Associated Weights
for
II - PERFORMANCE

Sheet 1 of 2

FACTOR/ SUBFACT. IDENT. NO.	FACTOR/SUBFACTOR WEIGHTS (%) (As a Function of Vessel) M/E FACTORS AND SUBFACTORS (Description and Level of Subordination)	GALLATIN (378')	VIGOROUS (210')	FIREBUSH (180')	PAMLICO (160') (New Constr.)	WHITE SAGE (133')	POINT HERRON (82')
1	. WMS figures of merit	15	→	→	→	→	→
11	.. Per capita energy consumption (electric power; power for ventilation, compressed air, pumping flush medium and cooling water; fuel; fuel for fresh water generated aboard vessel)	30	→	→	→	→	→
12	.. Per capita system weight (wet)	25	→	→	→	→	→
13	.. Per capita system volume	45	→	→	→	→	→
2	. Adequacy of WMS holding times	25	→	→	→	→	→
21	.. Black	90	→	→	→	→	→
22	.. Gray	10	→	→	→	→	→
3	. Ability of WMS to handle, and effects on performance, of abnormal hydraulic loads	5	→	→	→	→	→
31	.. Effect of peak loads	50	→	→	→	→	→
311	... Black	90	→	→	→	→	→
312	... Gray	10	→	→	→	→	→
32	.. Effect of low flow conditions and/or long idle items	20	→	→	→	→	→
321	... Black	65	→	→	→	→	→
322	... Gray	35	→	→	→	→	→
33	.. Ability to handle additional personnel	30	→	→	→	→	→
331	... Black	75	→	→	→	→	→
332	... Gray	25	→	→	→	→	→
4	. WMS designed to operate for sustained time periods (e.g., CHT has limited holding capacity vs. JERED, with incinerator, has indefinite capacity)	15	→	→	→	→	→
41	.. Black	90	→	→	→	→	→
42	.. Gray	10	→	→	→	→	→

Factor/Subfactors and Associated Weights
for
II - PERFORMANCE

Sheet 2 of 2

FACTOR/ SUBFACT. IDENT. NO.	M/E FACTORS AND SUBFACTORS (Description and Level of Subordination) / FACTOR/SUBFACTOR WEIGHTS (%) (As a Function of Vessel)	GALLATIN (378')	VIGOROUS (210')	FIREBUSH (180')	PAMLICO (160') (New Constr.)	WHITE SAGE (133')	POINT HERRON (82')
5	. Ability of WMS to handle ground garbage and extraneous materials in black water stream --	15	→	→	→	→	→
51	.. Ground garbage --	65	→	→	→	→	→
52	.. Foreign materials/objects --	15	→	→	→	→	→
53	.. Detergents/surfactants --	10	→	→	→	→	→
54	.. Toxic materials (as it affects performance of biological system) --	10	→	→	→	→	→
6	. Ability of WMS secondary emissions to meet applicable standards ---	15	→	→	→	→	→
61	.. Discharge of significant air pollutants ------------------------	40	→	→	→	→	→
62	.. Disposal of oil contaminated residues at sea -----------------	60	→	→	→	→	→
7	. Performance risk for WMS configuration (i.e., hybrid systems, experience) --	10	→	→	→	→	→
71	.. Black --	75	→	→	→	→	→
72	.. Gray --	25	→	→	→	→	→

Factor/Subfactors and Associated Weights
for
III - OPERABILITY

Sheet 1 of 1

FACTOR/ SUBFACT. IDENT. NO.	M/E FACTORS AND SUBFACTORS (Description and Level of Subordination) / FACTOR/SUBFACTOR WEIGHTS (%) (As a Function of Vessel)	GALLATIN (378')	VIGOROUS (210')	FIREBUSH (180')	PAMLICO (160') (New Constr.)	WHITE SAGE (133')	POINT HERRON (82')
1	. Ease of WMS operation	20	→	→	→	→	→
11	.. Automatic/semi-automatic/manual operation	35	→	→	→	→	→
12	.. Disposal of residue(s)	30	→	→	→	→	→
13	.. Mode changeovers (primary to overboard discharge cycle/pierside to primary cycle)	20	→	→	→	→	→
14	.. Likelihood of violating effluent standards because of procedural errors (discharge of effluent which doesn't meet emission standards, flush oil, evaporator residue, wastewater or sludge from holding tank, stack emissions from incinerator which do not meet standards, etc.)	15	→	→	→	→	→
2	. Burden of WMS on crew's operating personnel	50	→	→	→	→	→
21	.. Frequency of operator involvement	30	→	→	→	→	→
22	.. Man-hour requirements	20	→	→	→	→	→
23	.. Skill level requirements	5	→	→	→	→	→
24	.. Training requirements	5	→	→	→	→	→
25	.. Effect on work routines/schedules	10	→	→	→	→	→
26	.. Additional personnel (billets) required	30	→	→	→	→	→
3	. Operational supplies and support equipment operating requirements for WMS	30	→	→	→	→	→
31	.. Amount of consumables/expendables	50	→	→	→	→	→
32	.. Availability of required specialized or unique consumables/expendables (i.e., vessel inventory, general commercial availability, federal stock system)	30	→	→	→	→	→
33	.. Operating requirements for special or unique WMS support equipment	20	→	→	→	→	→

Factor/Subfactors and Associated Weights

for

IV - PERSONNEL SAFETY

Sheet 1 of 1

FACTOR/ SUBFACT. IDENT. NO.	M/E FACTORS AND SUBFACTORS (Description and Level of Subordination) / FACTOR/SUBFACTOR WEIGHTS (%) (As a Function of Vessel)	GALLATIN (378')	VIGOROUS (210')	FIREBUSH (180')	PAMLICO (160') (New Constr.)	WHITE SAGE (133')	POINT HERRON (82')
1	. Contact with/spillage of toxic/dangerous substance associated with WMS	30	→	→	→	→	→
11	.. Inherent design feature	75	→	→	→	→	→
12	.. Procedural errors/equipment failures (note repair induced hazards)	25	→	→	→	→	→
2	. Explosive potential for operator/maintainer of WMS (e.g., pressurized vessels, vapors)	25	→	→	→	→	→
21	.. Inherent design feature	75	→	→	→	→	→
22	.. Procedural errors/equipment failures	25	→	→	→	→	→
3	. Fire ignition potential of WMS	20	→	→	→	→	→
31	.. Inherent design feature	75	→	→	→	→	→
32	.. Procedural errors/equipment failures	25	→	→	→	→	→
4	. Electric shock potential to operator/maintainer of WMS	15	→	→	→	→	→
5	. Physical hazards associated with WMS	10	→	→	→	→	→
51	.. Sharp edges	20	→	→	→	→	→
52	.. Hot surfaces	30	→	→	→	→	→
53	.. Rotating machinery for maintainer	50	→	→	→	→	→

Factor/Subfactors and Associated Weights

for

V - HABITABILITY

Sheet 1 of 1

FACTOR/ SUBFACT. IDENT. NO.	M/E FACTORS AND SUBFACTORS (Description and Level of Subordination) / FACTOR/SUBFACTOR WEIGHTS (%) (As a Function of Vessel)	GALLATIN (378')	VIGOROUS (210')	FIREBUSH (180')	PAMLICO (160') (New Constr.)	WHITE SAGE (133')	POINT HERRON (82')
1	. Bacterial contamination associated with WMS (user psychological reaction)	15	→	→	→	→	→
11	.. Inherent design feature	75	→	→	→	→	→
12	.. Procedural errors/equipment failures	25	→	→	→	→	→
2	. Fixture efficacy of WMS	10	→	→	→	→	→
21	.. Comfort	15	→	→	→	→	→
22	.. Flushing procedure requirements	15	→	→	→	→	→
23	.. Waste retention in bowl	20	→	→	→	→	→
24	.. Likelihood of user contact with flushing medium	25	→	→	→	→	→
25	.. Flushing medium appearance	20	→	→	→	→	→
26	.. Flushing noise	5	→	→	→	→	→
3	. Odors produced by WMS	25	→	→	→	→	→
31	.. Inherent design feature	75	→	→	→	→	→
32	.. Procedural errors/equipment failures	25	→	→	→	→	→
4	. WMS heat generation for operator/maintainer/adjacent berthing working areas	15	→	→	→	→	→
41	.. Inherent design feature	75	→	→	→	→	→
42	.. Procedural errors/equipment failures	25	→	→	→	→	→
5	. Noise levels in vicinity of WMS for operator/maintainer/adjacent berthing and working areas	15	→	→	→	→	→
6	. Vibration produced by WMS for operator/maintainer/adjacent berthing and working areas	15	→	→	→	→	→
7	. Effect of WMS on user housekeeping routines	5	→	→	→	→	→

Factor/Subfactors and Associated Weights

for

VI - RELIABILITY

Sheet 1 of 1

FACTOR/ SUBFACT. IDENT. NO.	M/E FACTORS AND SUBFACTORS (Description and Level of Subordination) / FACTOR/SUBFACTOR WEIGHTS (%) (As a Function of Vessel)	GALLATIN (378')	VIGOROUS (210')	FIREBUSH (180')	PAMLICO (160') (New Constr.)	WHITE SAGE (133')	POINT HERRON (82')
1	. Failure frequency index for WMS	50	→	→	→	→	→
2	. Reliability index for WMS (system design/configuration)	30	→	→	→	→	→
21	.. System complexity	20	→	→	→	→	→
22	.. Extent of configuration redundancy (e.g., additional head spaces/ fixtures throughout vessel)	25	→	→	→	→	→
23	.. Extent of equipment/component redundancy	25	→	→	→	→	→
24	.. Degree of equipment failure independence (i.e., failure of one item will not cause another item to fail)	15	→	→	→	→	→
25	.. Adequacy of equipment ratings	10	→	→	→	→	→
26	.. Provisions for fault actuated cut-off mechanisms to protect system (i.e., provision for fail safe operation)	5	→	→	→	→	→
3	. Reliability risk for WMS (e.g., hybrid configuration, innovative design, experience)	20	→	→	→	→	→

Factor/Subfactors and Associated Weights

for

VII - MAINTAINABILITY

Sheet 1 of 1

FACTOR/ SUBFACT. IDENT. NO.	M/E FACTORS AND SUBFACTORS (Description and Level of Subordination) / FACTOR/SUBFACTOR WEIGHTS (%) (As a Function of Vessel)	GALLATIN (378')	VIGOROUS (210')	FIREBUSH (180')	PAMLICO (160') (New Constr.)	WHITE SAGE (133')	POINT HERRON (82')
1	. Corrective Maintenance (CM) requirements for WMS	40					
11	.. Frequency of CM actions (failure frequency)	35					
12	.. Man-hour and skill level requirements	25					
13	.. Ease of repair/replace	25					
131	... Accessibility of replaceable components	40					
132	... Extent of system modularization	20					
133	... Degree of repairability on board vessel (repair vs. replace)	30					
134	... Availability of manufacturer field support and training programs	10					
14	.. Spares stockage requirements	15					
141	... Extent of spares stockage requirements	60					
142	... Special/proprietary items vs. standard supply parts	40					
2	. Preventive Maintenance (PM) requirements for WMS	25					
21	.. Frequency of PM actions	35					
22	.. Man-hour requirements	45					
23	.. Effect on watchstander routines	20					
3	. Overhaul Maintenance requirements for WMS	20					
31	.. Frequency of overhauls	40					
32	.. Man-hour and skill level requirements	40					
33	.. Special docking requirements	20					
4	. Logistic requirements for WMS	15					

A weight is associated with each factor and subfactor to indicate its importance in relation to the other factors or subfactors at the same level of subordination such that their sum is equal to 100% (as was done for M/E weights). These weights are assigned to factors and subfactors at a given level of subordination without regard to factor/subfactor weight assignments at higher or lower level of subordination. Factor/subfactor weights may be vessel dependent to reflect individual vessel requirements but for purposes of this study, the same set of weights was used for each vessel. It is noted that the overall effectiveness ratings as well as ratings with respect to each M/E for the viable candidate system/vessel combinations reflect these weight assignments and should be interpreted accordingly.

Effectiveness Rating Functions (ERFs)

An effectiveness rating function (ERF) was developed for each elementary factor/subfactor. Figure 20 shows the form used for documenting these ERFs. This form also facilitates recording the effectiveness attribute data (including its source) and effectiveness ratings for each viable candidate system/vessel combination associated with the given ERF. The effectiveness model used resulted in 111 individual ERFs which are uniquely identified by the numbering scheme for factors and subfactors. Thus, each viable candidate system/vessel combination is evaluated on the basis of 111 individual criteria. These ERFs are presented in Volume II of this report and are numbered to correspond to the numbers associated with each elementary factor/subfactor within each M/E.

EFFECTIVENESS ATTRIBUTE DATA

The effectiveness Attribute Data required as input to the effectiveness model is defined by the ERFs. These data came from three different sources which represent three types of analyses (among others) performed as part of this study, namely:

- The MSD analysis
- The WMS installation analysis
- The WMS life-cycle cost analysis

The manner in which the effectiveness attribute data is used for rating elementary factors/subfactors is documented by the corresponding ERFs. In order to facilitate the quantification of effectiveness, the effectiveness attribute data for each viable candidate system/vessel combination was recorded on the form in Figure 20 in the format specified by the ERF. As noted from Figure 20, this form has a provision for indicating the source of the data and it also lists the non-viable system/vessel combinations for which no effectiveness attribute data (and no ratings) were developed. Some ERFs call for effectiveness attribute data from more than one source, e.g., some elementary factor/subfactor ratings for the M/Es PERSONNEL SAFETY and for HABITABILITY depend on data from both MSD related as well as WMS installation related effectiveness attribute data. In such cases, both sources of data would be indicated on the form in Figure 20. These data, as well as effectiveness ratings, for each viable candidate system/vessel combination with respect to each elementary factor/subfactor are presented in Volume II of this report on the corresponding ERF forms.

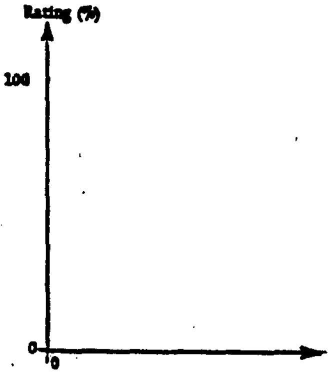
MSD Related Effectiveness Attribute Data

Results of the MSD analysis are presented in Volume V of this report. Figure 21 shows a sample form which was used to document MSD related effectiveness attribute data. It is noted from Figure 21 that the MSD effectiveness attribute data were developed and presented on a subsystem level in accordance with the manner in which the MSDs were hybridized to form the candidate WMS concepts. For ease of reference each MSD subsystem characteristic is keyed to the associated ERF by the unique factor/subfactor identification scheme.

EFFECTIVENESS RATINGS FOR ELEMENTARY FACTORS/SUBFACTORS

M/E____

Effectiveness Rating Function



Source of Data		
MED Anal.	WMS Install. Anal.	WMS Cost Anal.

Effectiveness Attribute Data and Ratings for Viable System/Vessel Combinations

WMS #	GALLATIN (378')		VIGOROUS (210')		FIREBUSH (180')		PAMLICO (160')		WHITE SAGE (133')		POINT HERRON (82')	
1												
2											N	A
3			N	A							N	A
4			N	A							N	A
5	N	A	N	A							N	A
6	N	A	N	A							N	A
7			N	A							N	A
8	N	A	N	A							N	A
9												
10											N	A
11			N	A								
12	N	A	N	A							N	A
13	N	A	N	A							N	A
14												
15											N	A
16												
17	N	A	N	A							N	A
18	N	A	N	A							N	A

Attribute Data ↑ ↑ Rating

N/A - Not a viable system/vessel combination

Figure 20
FORM USED FOR DOCUMENTING EFFECTIVENESS RATING FUNCTIONS AND ASSOCIATED ATTRIBUTE DATA AND RATINGS

MSD EFFECTIVENESS ATTRIBUTE DATA

M/E II - PERFORMANCE

MSD ____________ Sheet 1 of 4

M/E Factor/ Subfactor Ident. No.	PERFORMANCE Characteristics	Attribute Data	
		Collect./Transp. Subsystem	Treat./Disposal Subsystem
311	Effect of peak hydraulic loads in black(1) water stream on MSD performance(2) (a) No significant effect of black water peaks on MSD subsystem performance. (b) Effect of black water peaks is of short duration, with temporary implications for MSD subsystem performance, easy to overcome. (c) Long-term effect of black water peaks, difficult to overcome, with long-term implications for MSD subsystem performance. (d) No ability of MSD subsystem to handle black water peaks.		
312	Effect of peak hydraulic loads in gray(1) water stream on MSD performance (2) (a) No significant effect of gray water peaks on MSD subsystem performance. (b) Effect of gray water peaks is of short duration, with temporary implications for MSD subsystem performance, easy to overcome. (c) Long-term effect of gray water peaks, difficult to overcome with long-term implications for MSD subsystem performance. (d) No ability of MSD subsystem to handle gray water peaks.		
321	Effect of low flow conditions/long idle times in black water stream on MSD performance(3) (a) No significant effect of black water low flow conditions/long idle times on MSD subsystem performance. (b) Effect of black water low flow conditions/long idle times of short duration, with temporary implications for MSD subsystem performance, easy to overcome. (c) Long-term effect of black water low flow conditions/long idle times, difficult to overcome, with long-term implications for MSD subsystem performance. (d) No ability of MSD subsystem to handle black water low flow conditions/long idle times.		

(1) Includes instantaneous, hourly and daily loads.

(2) Peak load handling ability depends on C/T subsystem. The ability of an MSD which employs an influent surge tank to handle peaks usually depends almost entirely on the sizing of this tank.

(3) An example of low flow condition is when 75% of the crew is not on board vessel for a week and usage rate by remaining 25% of crew is normal. Long idle times are on the order of several weeks of virtually no usage of MSD.

Figure 21

SAMPLE DATA FORM USED FOR DOCUMENTING MSD EFFECTIVENESS ATTRIBUTE DATA

WMS Installation Related Effectiveness Attribute Data

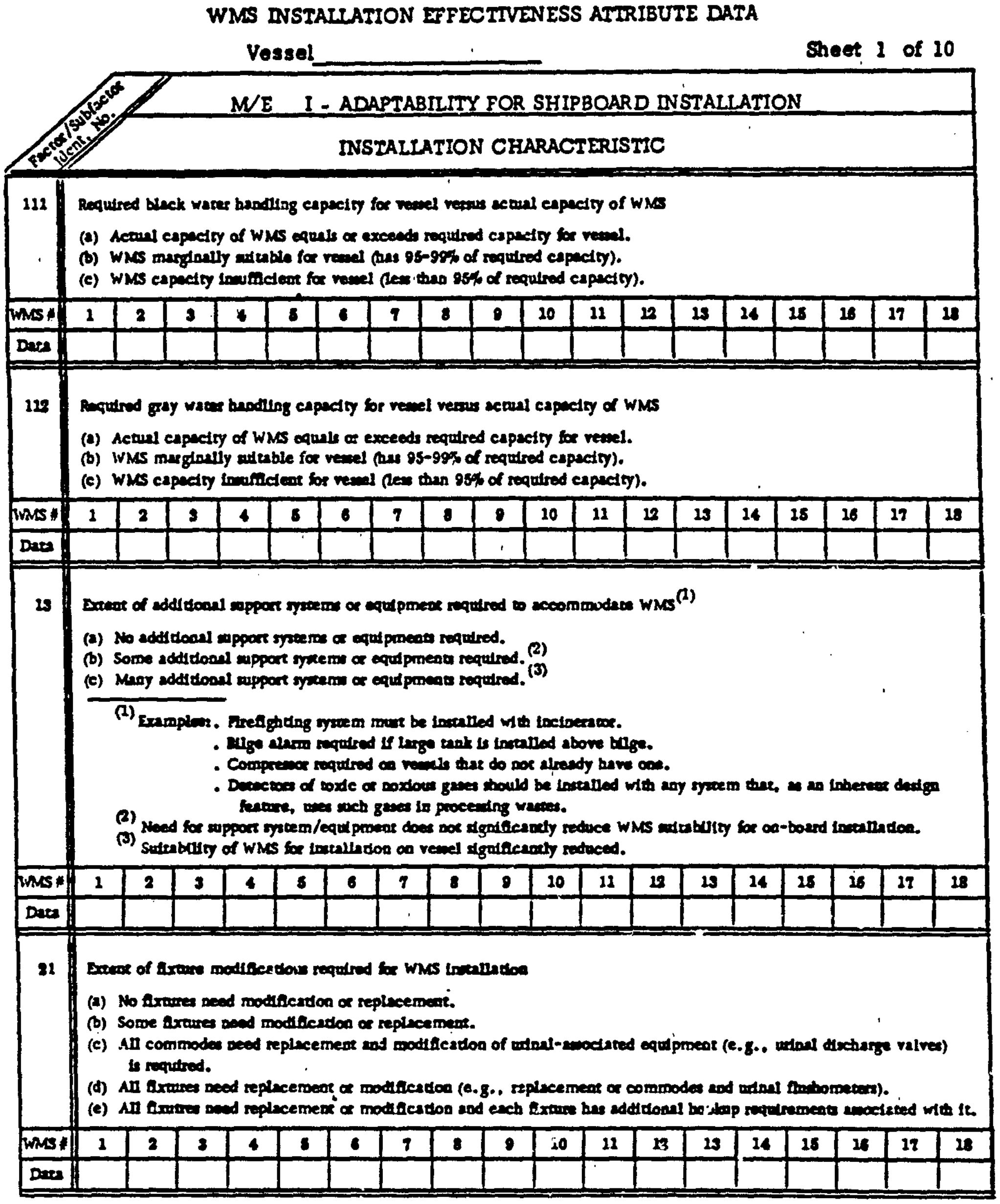
Results of the WMS installation analysis are presented in Volume III of this report. Figure 22 shows a sample form which was used to document WMS installation related effectiveness attribute data. These data were developed and are presented on an overall WMS basis. It is noted from Figure 22 that each WMS installation characteristic is keyed to the associated ERF by the numbering scheme for uniquely identifying each factor and subfactor.

WMS Operating/Maintenance Cost Related Effectiveness Attribute Data

Results of the WMS life-cycle cost analysis are presented in Appendices B through G. Some of the data resulting from this analysis (e.g., vessel resource usage, labor and parts requirements for operation and maintenance), constitute effectiveness attribute data. Most of these data were developed and presented on an overall WMS basis. The WMS cost related information used as effectiveness attribute data came mostly from the WMS overhaul costs and characteristics (Appendix D), the WMS operating costs and characteristics based on vessel mission profiles (Appendix E) and the WMS preventive and corrective maintenance costs and characteristics based on vessel mission profiles (Appendix F).

EFFECTIVENESS RATINGS OF VIABLE CANDIDATE SYSTEM/VESSEL COMBINATIONS

The results of quantifying the effectiveness of each viable system/vessel combination by substituting the effectiveness attribute data into the effectiveness model are presented in Table 13. Results for each viable candidate WMS configuration on each vessel are given at two different levels of detail, namely an overall effectiveness rating and a rating for each M/E of the effectiveness model (including its associated weight). The quantification of effectiveness was performed by a computer program. A description of this computer program as well as the prepared ~~input~~ to the program are presented in Volume II of this report.



WMS INSTALLATION EFFECTIVENESS ATTRIBUTE DATA

Vessel________________ Sheet 1 of 10

Factor/Subfactor Ident. No.

M/E I - ADAPTABILITY FOR SHIPBOARD INSTALLATION

INSTALLATION CHARACTERISTIC

111 Required black water handling capacity for vessel versus actual capacity of WMS

(a) Actual capacity of WMS equals or exceeds required capacity for vessel.
(b) WMS marginally suitable for vessel (has 95-99% of required capacity).
(c) WMS capacity insufficient for vessel (less than 95% of required capacity).

WMS #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Data																		

112 Required gray water handling capacity for vessel versus actual capacity of WMS

(a) Actual capacity of WMS equals or exceeds required capacity for vessel.
(b) WMS marginally suitable for vessel (has 95-99% of required capacity).
(c) WMS capacity insufficient for vessel (less than 95% of required capacity).

WMS #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Data																		

13 Extent of additional support systems or equipment required to accommodate WMS(1)

(a) No additional support systems or equipments required.
(b) Some additional support systems or equipments required.(2)
(c) Many additional support systems or equipments required.(3)

(1) Examples: . Firefighting system must be installed with incinerator.
. Bilge alarm required if large tank is installed above bilge.
. Compressor required on vessels that do not already have one.
. Detectors of toxic or noxious gases should be installed with any system that, as an inherent design feature, uses such gases in processing wastes.

(2) Need for support system/equipment does not significantly reduce WMS suitability for on-board installation.

(3) Suitability of WMS for installation on vessel significantly reduced.

WMS #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Data																		

21 Extent of fixture modifications required for WMS installation

(a) No fixtures need modification or replacement.
(b) Some fixtures need modification or replacement.
(c) All commodes need replacement and modification of urinal-associated equipment (e.g., urinal discharge valves) is required.
(d) All fixtures need replacement or modification (e.g., replacement or commodes and urinal flushometers).
(e) All fixtures need replacement or modification and each fixture has additional backup requirements associated with it.

WMS #	1	2	3	4	5	6	7	8	9	10	11	13	13	14	15	16	17	18
Data																		

Figure 22
SAMPLE FORM USED FOR DOCUMENTING WMS
INSTALLATION EFFECTIVENESS ATTRIBUTE DATA

Table 13

EFFECTIVENESS RATINGS OF VIABLE CANDIDATE SYSTEM/VESSEL COMBINATIONS

Vessel GALLATIN (378') Sheet 1 of 6

WMS No.	TYPE			Holding Capacity		MEASURE OF EFFECTIVENESS RATINGS (AND ASSOCIATED WEIGHTS)							
	Coll/Trans Subsys (Blank)	Treatment/Disposal Subsystem		Black (%)	Gray (%)	Adapt-ability for Ship Inst. (8)	Perfor-mance (15)	Oper-ability (12)	Personnel Safety (11)	Habit-ability (17)	Reli-ability (23)	Maintain-ability (23)	Overall Effectiveness (E) Rating
		Black	Gray										
1	Gravity Collect.	Holding Tank	Holding Tank	100	19	88	72	91	95	75	96	92	87
2	Oil Recircul. (Chrysler)	Chrysler + Hld Tnk	Holding Tank	100	18	81	67	52	88	51	87	78	72
3		Chrysler + Incin.	Holding Tank	100	13	78	76	52	82	36	80	78	68
4	Gravity Collect. (Grumman)	Grum Flow Thru+HldTk	Holding Tank	100	17	77	70	80	94	58	85	79	77
5		Grumman Flow Thru + Holding Tank		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
6	Gravity Collect.	Holding Tank	Grum Flow Thru+ HldTnk	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
7	Gravity Collect. (Grumman)	Grum Flow Thru+Incin.	Holding Tank	100	17	73	72	71	80	43	83	80	72
8		Grumman Flow Thru + Incinerator		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
9	Vacuum Collect. (Jered)	Holding Tank	Holding Tank	100	21	72	69	65	95	71	44	53	64
10		Incinerator	Holding Tank	100	21	69	70	53	92	55	33	53	57
11		GATX Evap.	Holding Tank	100	17	65	58	64	91	65	42	41	58
12		Holding Tank	Grum Flow Thru+ Hld Tnk	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
13		Incinerator	Grum Flow Thru + Incin.	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
14	M/T Pump Collect. (GATX)	Holding Tank	Holding Tank	100	30	71	70	86	93	67	76	49	72
15		Incinerator	Holding Tank	100	33	67	68	74	91	50	64	49	65
16		GATX Evap.	Holding Tank	100	17	64	60	85	89	60	74	41	67
17		Holding Tank	Grum Flow Thru+Hld Tnk	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
18		Incinerator	Grum Flow Thru + Incin.	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not a viable candidate system/vessel combination.

Table 13

EFFECTIVENESS RATINGS OF VIABLE CANDIDATE SYSTEM/VESSEL COMBINATIONS

Vessel VIGOROUS (210') Sheet 2 of 6

WMS No.	TYPE			Holding Capacity		MEASURE OF EFFECTIVENESS RATINGS (AND ASSOCIATED WEIGHTS)							
	Coll/Trans Subsys (Blank)	Treatment/Disposal Subsystem											
		Black	Gray	Black (%)	Gray (%)	Adaptability for Ship Inst. (8)	Performance (15)	Operability (12)	Personnel Safety (11)	Habitability (17)	Reliability (23)	Maintainability (23)	Overall Effectiveness (E) Rating
1	Gravity Collect.	Holding Tank	Holding Tank	40	1	84	58	91	95	75	95	93	84
2	Oil Recircul. (Chrysler)	Chrysler + Hld Tnk	Holding Tank	53	1	69	56	54	88	51	83	81	69
3		Chrysler + Incin.	Holding Tank	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
4	Gravity Collect. (Grumman)	Grum Flow Thru+HldTk	Holding Tank	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
5		Grumman Flow Thru + Holding Tank		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
6	Gravity Collect.	Holding Tank	Grum Flow Thru+ HldTnk	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
7	Gravity Collect. (Grumman)	Grum Flow Thru+Incin.	Holding Tank	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
8		Grumman Flow Thru + Incinerator		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
9	Vacuum Collect. (Jered)	Holding Tank	Holding Tank	48	1	65	57	65	95	71	43	50	61
10		Incinerator	Holding Tank	100	1	63	70	52	88	55	31	50	55
11		GATX Evap.	Holding Tank	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
12		Holding Tank	Grum Flow Thru+ Hld Tnk	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
13		Incinerator	Grum Flow Thru + Incin.	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
14	M/T Pump Collect. (GATX)	Holding Tank	Holding Tank	100	1	76	69	86	93	67	80	53	74
15		Incinerator	Holding Tank	100	3	62	68	74	87	50	67	50	65
16		GATX Evap.	Holding Tank	100	1	69	60	86	89	60	79	44	69
17		Holding Tank	Grum Flow Thru+Hld Tnk	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
18		Incinerator	Grum Flow Thru + Incin.	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not a viable candidate system/vessel combination.

Tabel 13

EFFECTIVENESS RATINGS OF VIABLF CANDIDATE SYSTEM/VESSEL COMBINATIONS

Vessel FIREBUSH (180') Sheet 3 of 6

WMS No.	TYPE			Holding Capacity		MEASURE OF EFFECTIVENESS RATINGS (AND ASSOCIATED WEIGHTS).							
	Coll/Trans Subsys (Blank)	Treatment/Disposal Subsystem		Black (%)	Gray (%)	Adapt-ability for Ship Inst. (8)	Perfor-mance (15)	Oper-ability (12)	Personnel Safety (11)	Habit-ability (17)	Reli-ability (23)	Maintain-ability (23)	Overall Effectiveness (E) Rating
		Black	Gray										
1	Gravity Collect.	Holding Tank	Holding Tank	100	0	82	71	90	95	75	96	93	86
2	Oil Recircul. (Chrysler)	Chrysler + Hld Tnk	Holding Tank	100	0	80	67	51	88	51	82	78	71
3		Chrysler + Incin.	Holding Tank	100	12	77	75	51	82	46	77	76	69
4	Gravity Collect. (Grumman)	Grum Flow Thru+HldTk	Holding Tank	100	22	83	69	76	94	58	84	78	76
5		Grumman Flow Thru + Holding Tank		100	100	83	70	73	94	73	80	76	78
6	Gravity Collect.	Holding Tank	Grum Flow Thru+ HldTnk	100	100	81	71	73	95	60	89	76	78
7	Gravity Collect. (Grumman)	Grum Flow Thru+Incin.	Holding Tank	100	29	79	71	67	80	53	81	79	73
8		Grumman Flow Thru + Incinerator		100	100	78	75	62	72	63	76	74	71
9	Vacuum Collect. (Jered)	Holding Tank	Holding Tank	100	13	70	68	70	95	71	46	48	64
10	↓	Incinerator	Holding Tank	100	35	59	69	59	92	65	31	47	57
11		GATX Evap.	Holding Tank	100	35	61	57	70	91	65	45	35	58
12		Holding Tank	Grum Flow Thru+ Hld Tnk	100	100	62	68	59	95	56	39	36	56
13		Incinerator	Grum Flow Thru + Incin.	100	100	59	67	52	80	63	26	37	52
14	M/T Pump Collect. (GATX)	Holding Tank	Holding Tank	100	13	67	69	82	93	67	86	60	75
15	↓	Incinerator	Holding Tank	100	35	62	67	69	91	60	70	57	68
16		GATX Evap.	Holding Tank	100	35	60	59	82	89	60	84	52	70
17		Holding Tank	Grum Flow Thru+Hld Tnk	100	100	58	68	69	94	52	78	53	68
18		Incinerator	Grum Flow Thru + Incin.	100	100	57	68	63	80	59	66	53	64

N/A - Not a viable candidate system/vessel combination.

Table 13

EFFECTIVENESS RATINGS OF VIABLE CANDIDATE SYSTEM/VESSEL COMBINATIONS

Vessel PAMLICO (160')

Sheet 4 of 6

WMS No.	TYPE			Holding Capacity		MEASURE OF EFFECTIVENESS RATINGS (AND ASSOCIATED WEIGHTS)							
	Coll/Trans Subsys (Blank)	Treatment/Disposal Subsystem		Black (%)	Gray (%)	Adapt-ability for Ship Inst. (8)	Perfor-mance (15)	Oper-ability (12)	Personnel Safety (11)	Habit-ability (17)	Reli-ability (23)	Maintain-ability (23)	Overall Effectiveness (E) Rating
		Black	Gray										
1	Gravity Collect.	Holding Tank	Holding Tank	100	55	55	63	87	95	75	90	84	80
2	Oil Recircul. (Chrysler)	Chrysler + Hld Tnk	Holding Tank	100	64	61	60	46	88	51	74	69	64
3		Chrysler + Incin.	Holding Tank	100	64	58	68	48	82	36	68	71	61
4	Gravity Collect. (Grumman)	Grum Flow Thru+HldTk	Holding Tank	100	64	56	61	71	94	58	73	65	68
5		Grumman Flow Thru + Holding Tank		100	100	57	66	74	94	73	68	70	72
6	Gravity Collect.	Holding Tank	Grum Flow Thru + HldTnk	100	100	57	65	74	95	60	80	70	72
7	Gravity Collect. (Grumman)	Grum Flow Thru+Incin.	Holding Tank	100	64	54	62	63	80	43	71	68	63
8		Grumman F[illegible]ru + Incine[illegible]		100	100	54	71	64	72	58	65	72	65
9	Vacuum Collect. (Jered)	Holding Tank	Holding Tank	100	64	76	62	72	95	71	47	51	64
10		Incinerator	Holding Tank	100	64	73	63	62	92	55	27	50	55
11		GATX Evap.	Holding Tank	100	64	75	54	76	91	65	43	44	60
12		Holding Tank	Grum Flow Thru+ Hld Tnk	100	100	74	63	60	95	56	34	37	56
13		Incinerator	Grum Flow Thru + Incin.	100	100	71	53	53	80	58	22	51	52
14	M/T Pump Collect. (GATX)	Holding Tank	Holding Tank	100	64	67	63	81	93	67	74	53	71
15		Incinerator	Holding Tank	100	64	64	61	72	91	50	54	50	61
16		GATX Evap.	Holding Tank	100	64	66	55	83	89	60	70	49	66
17		Holding Tank	Grum Flow Thru+Hld Tnk	100	100	66	64	69	94	52	61	44	63
18		Incinerator	Grum Flow Thru + Incin.	100	100	63	64	62	80	54	49	49	58

N/A - Not a viable candidate system/vessel combination.

Table 13

EFFECTIVENESS RATINGS OF VIABLE CANDIDATE SYSTEM/VESSEL COMBINATIONS

Vessel WHITE SAGE (133') Sheet 5 of 6

WMS No.	TYPE			Holding Capacity		MEASURE OF EFFECTIVENESS RATINGS (AND ASSOCIATED WEIGHTS)							
	Coll/Trans Subsys (Blank)	Treatment/Disposal Subsystem		Black (%)	Gray (%)	Adapt-ability for Ship Inst. (8)	Perfor-mance (15)	Oper-ability (12)	Personnel Safety (11)	Habit-ability (17)	Reli-ability (23)	Maintain-ability (23)	Overall Effectiveness (E) Rating
		Black	Gray										
1	Gravity Collect.	Holding Tank	Holding Tank	100	100	95	72	87	95	75	94	86	86
2	Oil Recircul. (Chrysler)	Chrysler + Hld Tnk	Holding Tank	100	100	82	68	46	88	51	76	69	68
3		Chrysler + Incin.	Holding Tank	100	100	80	76	47	88	36	70	70	65
4	Gravity Collect. (Grumman)	Grum Flow Thru+HldTk	Holding Tank	100	100	84	70	70	94	58	80	70	74
5		Grumman Flow Thru + Holding Tank		100	100	89	69	72	94	73	74	73	76
6	Gravity Collect.	Holding Tank	Grum Flow Thru+HldTnk	100	100	88	70	71	95	60	85	71	76
7	Gravity Collect. (Grumman)	Grum Flow Thru+Incin.	Holding Tank	100	100	85	72	62	73	43	77	73	68
8		Grumman Flow Thru + Incinerator		100	100	86	74	62	60	58	71	76	69
9	Vacuum Collect. (Jered)	Holding Tank	Holding Tank	100	100	79	69	68	95	71	41	51	64
10		Incinerator	Holding Tank	100	100	72	70	58	94	55	27	50	56
11		GATX Evap.	Holding Tank	100	100	73	58	69	91	65	38	45	59
12		Holding Tank	Grum Flow Thru+ Hld Tnk	100	100	73	68	63	95	56	31	41	56
13		Incinerator	Grum Flow Thru + Incin.	100	100	69	67	49	70	58	19	53	51
14	M/T Pump Collect. (GATX)	Holding Tank	Holding Tank	100	100	76	70	80	93	67	66	49	70
15		Incinerator	Holding Tank	100	100	72	68	69	91	50	52	48	62
16		GATX Evap.	Holding Tank	100	100	74	61	81	90	60	63	47	66
17		Holding Tank	Grum Flow Thru+Hld Tnk	100	100	73	68	68	92	52	58	43	62
18		Incinerator	Grum Flow Thru + Incin.	100	100	67	67	63	69	37	44	47	54

N/A - Not a viable candidate system/vessel combination.

EFFECTIVENESS RATINGS OF VIABLE CANDIDATE SYSTEM/VESSEL COMBINATIONS

Vessel POINT HERRON (82')

Sheet 6 of 6

WMS No.	TYPE			Holding Capacity		MEASURE OF EFFECTIVENESS RATINGS (AND ASSOCIATED WEIGHTS)							
	Coll/Trans Subsys (Blank)	Treatment/Disposal Subsystem Black	Treatment/Disposal Subsystem Gray	Black (%)	Gray (%)	Adapt-ability for Ship Inst. (8)	Perfor-mance (15)	Oper-ability (12)	Personnel Safety (11)	Habit-ability (17)	Reli-ability (23)	Maintain-ability (23)	Overall Effectiveness (E) Rating
1	Gravity Collect.	Holding Tank	Holding Tank	58	0	85	61	83	95	75	91	85	82
2	Oil Recircul. (Chrysler)	Chrysler + Hld Tnk	Holding Tank	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3		Chrysler + Incin.	Holding Tank	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
4	Gravity Collect. (Grumman)	Grum Flow Thru+HldTk	Holding Tank	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
5		Grumman Flow Thru + Holding Tank		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
6	Gravity Collect.	Holding Tank	Grum Flow Thru+HldTnk	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
7	Gravity Collect. (Grumman)	Grum Flow Thru+Incin.	Holding Tank	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
8		Grumman Flow Thru + Incinerator		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
9	Vacuum Collect. (Jered)	Holding Tank	Holding Tank	100	20	62	67	65	95	71	38	44	60
10		Incinerator	Holding Tank	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
11		GATX Evap.	Holding Tank	100	20	61	57	67	90	65	36	38	56
12		Holding Tank	Grum Flow Thru+ Hld Tnk	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
13		Incinerator	Grum Flow Thru + Incin.	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
14	M/T Pump Collect. (GATX)	Holding Tank	Holding Tank	100	20	71	68	74	93	67	75	51	71
15		Incinerator	Holding Tank	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
16		GATX Evap.	Holding Tank	100	20	60	59	76	89	60	72	49	66
17		Holding Tank	Grum Flow Thru+Hld Tnk	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
18		Incinerator	Grum Flow Thru + Incin.	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

N/A - Not a viable candidate system/vessel combination.

OPTIMUM CANDIDATE SELECTION

LIFE-CYCLE COST VERSUS EFFECTIVENESS

The overall effectiveness rating of a candidate is a quantitative indication of its overall quality. The life-cycle cost of the candidate represents its "penalty" in terms of dollar expenditures. One of the tenets of this cost effectiveness analysis methodology is that there is no a priori relationship between cost and effectiveness*, as the evidence from almost any marketplace will confirm. This relationship is provided a posteriori by the cost effectiveness analysis methodology and, in fact, it is one of the purposes for performing such an analysis. The procedure for selecting an optimum (i.e., most cost-effective) wastewater management system for each vessel consists of simultaneously examining the life-cycle cost as well as the effectiveness rating of each viable candidate and applying a systematic selection procedure for making the choice. Thus, due to the a priori independence of cost and effectiveness, the candidates must be studied in two dimensions.

One procedure for studying the (a posteriori) relationship between cost and effectiveness is to visually display this relationship. A convenient way of accomplishing this is to plot each viable candidate system for a given vessel as a point on a set of cartesian coordinates in which one of the axes (the vertical) represents the life-cycle cost (C) of the candidate and the other axis (the horizontal) represents the overall effectiveness rating (R_E) of the candidate. Effectiveness ratings are numbers which are dimensionless and lie in the range of 0 to 100% and hence the effectiveness scale can be so labeled. However, life-cycle costs are expressed in dollars and the range varies from vessel to vessel. In order to express both the life-cycle cost and the effectiveness ratings in the same units, as required by one of the

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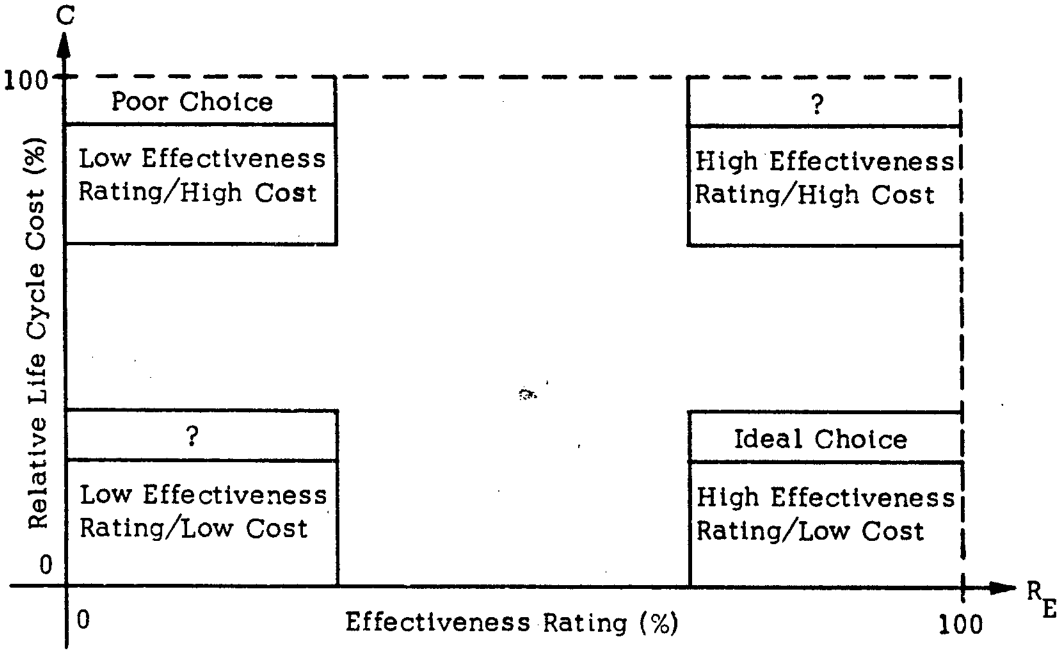
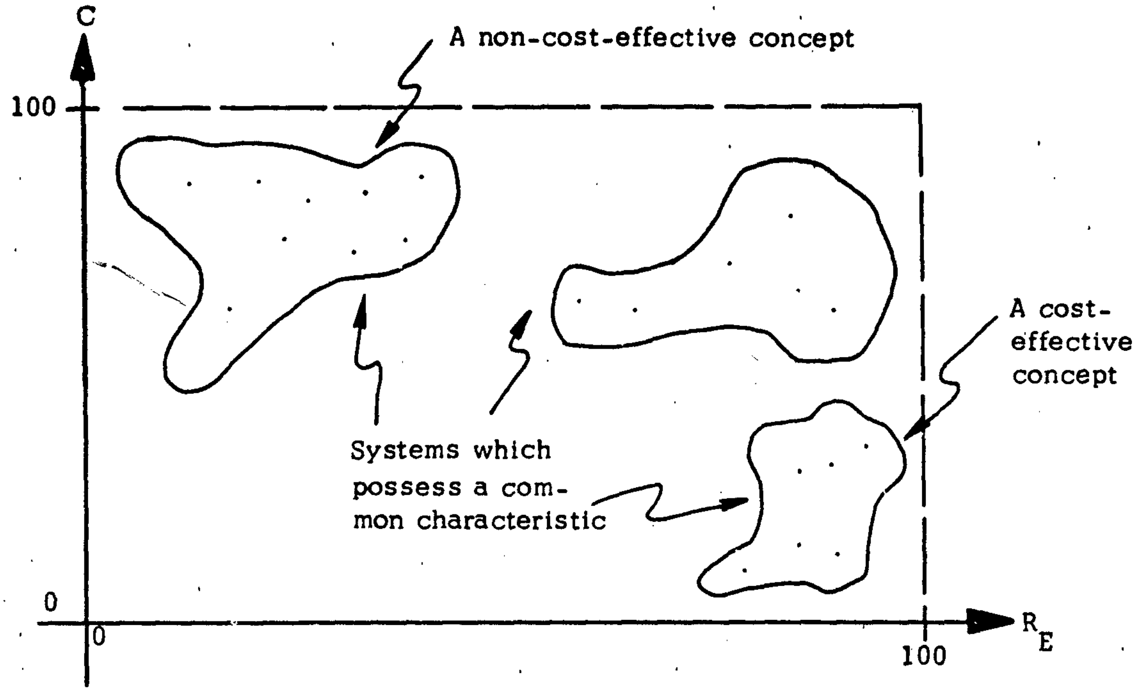
* In order to avoid bias, it is best that the cost and the effectiveness analyses be performed independently of one another, preferably by different individuals or groups of individuals.

optimum candidates selection criteria (to be discussed later), it is necessary to normalize the life-cycle costs so that they are dimensionless and lie in the range of 0 to 100%. This can be readily done by expressing the life-cycle cost of each viable candidate as a percentage of the highest such cost for the given vessel. This procedure yields the relative, rather than the absolute, life-cycle cost of each candidate (resulting in a value of 100% for the candidate possessing the highest cost), and the cost axis can be so labeled.

Such a plot of the cost versus effectiveness relationship of all viable candidate systems for a given vessel is a useful analytic tool which can sometimes be used to discern important properties of the candidates by examining the locations of individual as well as groups of candidates in relation to one another. As shown below, there are "desirable" and



"undesirable" regions in the cost vs. effectiveness plane, which can be thought of as a "decision plane". By encircling all the candidates which have a common characteristic (see below), e.g., incinerator, oil recirculation, reduced volume flush, etc., it may be possible to obtain a visual indication whether or not the given concept is cost-effective.



It is noted that such results imply that the characteristic which is common to the group of systems is the dominant factor and that any other differences between the systems in the group are unimportant. If this is not the case, an attempt to encircle systems possessing a common characteristic will result in a region which is spread out throughout the cost vs. effectiveness plane and conclusions cannot be readily arrived at without further analysis to determine the factors (related to cost and/or effectiveness) which result in such a spread.

The cost vs. effectiveness relationship for the candidate, WMS configurations as a function of vessel are shown in Figure 23. For ease of reference, the table in the left hand portion of Figure 23 indicates the WMS concept (but not the configuration), the holding capacity, the cost (both in dollars and relative) and the effectiveness rating for each candidate. It is noted that WMS No.1, consisting of holding tanks for both black (full volume flush) and gray water, is the most cost effective concept on all vessels. However, as can be seen from the left hand portion of Figure 23, this concept does not result in a full holding capacity on all vessels. It is also noted that the least cost-effective concepts are reduced volume flush in conjunction with an incinerator (WMS No. 10 on GALLATIN and VIGOROUS, WMS No. 13 on FIREBUSH, WMS No. 18 or No. 13 on PAMLICO and WHITE SAGE), or reduced volume flush in conjunction with an evaporator (WMS No. 16 or No. 11 on POINT HERRON).

In order to arrive at conclusions that will pertain to the entire fleet, the cost vs. effectiveness relation was plotted by combining the data for all vessels, as shown in Figure 24. In order to prepare this plot, the cost data used is the per capita life-cycle cost, expressed as a percentage of the maximum value for all vessels. It is noted from Figure 24 that the results for the PAMLICO seem to be in a class by themselves. This is due to the fact that this vessel has a reduced volume (vacuum)collection system (whereas all other vessels have a conventional full volume flush collection system) and an unusual mission profile characteristic (i.e., long holding time and large utilization factor). Except for the PAMLICO, WMS No. 1 is seen to be the most cost-effective candidate on a fleet wide basis.

Sheet 1 of 6

WMS No.	Coll/Trans Subsys (Black)	TYPE Treatment/Disposal Subsystem Black	TYPE Treatment/Disposal Subsystem Gray	Holding Capacity Black (%)*	Holding Capacity Gray (%)*	COST $K	COST Relatv. (%)	R_E (%)
1	Gravity Collect.	Holding Tank	Holding Tank	100	19	58.383	13	87
2	Oil Recircul. (Chrysler)	Chrysler + Hld Tnk	Holding Tank	100	18	135.988	31	72
3		Chrysler + Incin.	Holding Tank	100	13	217.483	50	66
4	Gravity Collect. (Grumman)	Grum Flow Thru+HldTk	Holding Tank	100	17	114.804	26	77
5		Grumman Flow Thru + Holding Tank		N/A				
6	Gravity Collect.	Holding Tank	Grum Flow Thru+HldTnk	N/A				
7	Gravity Collect. (Grumman)	Grum Flow Thru+Incin.	Holding Tank	100	17	221.996	51	72
8		Grumman Flow Thru + Incinerator		N/A				
9	Vacuum Collect. (Jered)	Holding Tank	Holding Tank	100	21	225.474	52	64
10		Incinerator	Holding Tank	100	21	435.003	100	57
11		GATX Evap.	Holding Tank	100	17	349.527	80	58
12		Holding Tank	Grum Flow Thru+ Hld Tnk	N/A				
13		Incinerator	Grum Flow Thru + Incin.	N/A				
14	M/T Pump Collect. (GATX)	Holding Tank	Holding Tank	100	30	249.329	57	72
15		Incinerator	Holding Tank	100	33	406.955	94	65
16		GATX Evap.	Holding Tank	100	17	377.454	87	67
17		Holding Tank	Grum Flow Thru+Hld Tnk	N/A				
18		Incinerator	Grum Flow Thru + Incin.	N/A				

* Based on the maximum holding time of 97.5 hours. The next smaller holding time of 88.0 hours wou satisfy approximately 98% of all holding time requirements.

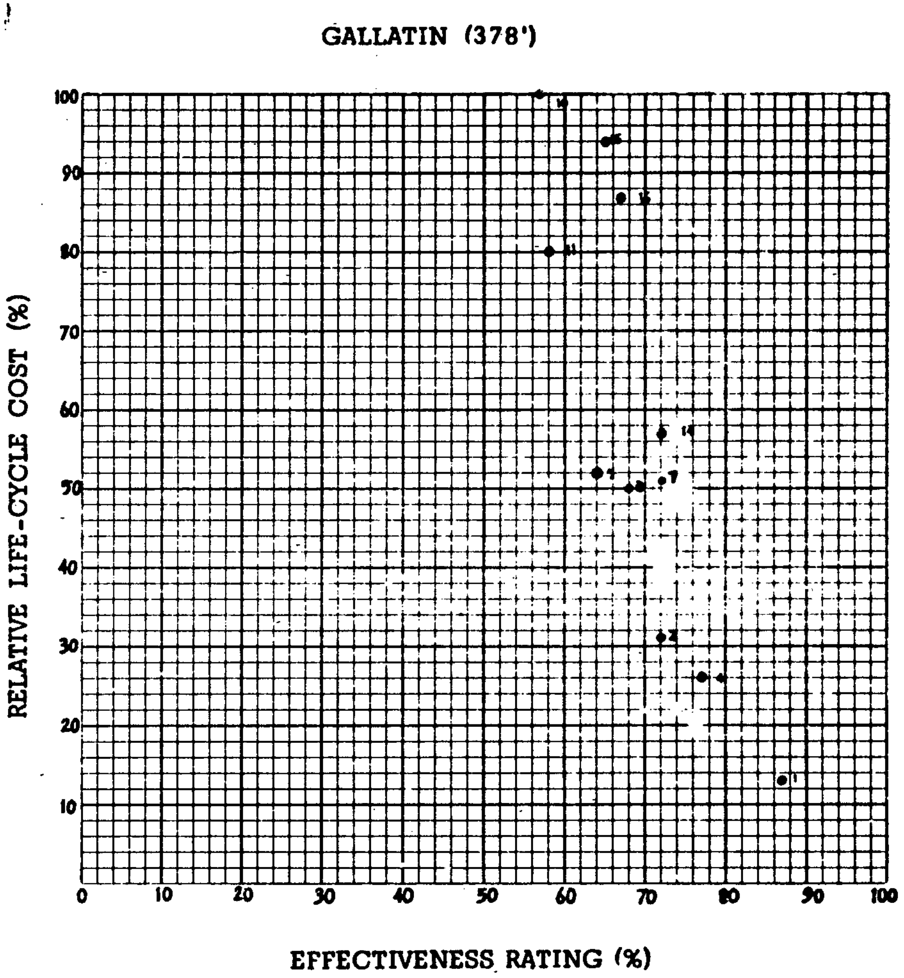


Figure 23

LIFE-CYCLE COST VERSUS EFFECTIVENESS RATING
FOR VIABLE CANDIDATE SYSTEMS

Sheet 2 of 6

WMS No.	TYPE			Holding Capacity		COST		
	Coll/Trans Subsys (Black)	Treatment/Disposal Subsystem		Black* (%)	Gray* (%)	$K	Relatv (%)	R_E (%)
		Black	Gray					
1	Gravity Collect.	Holding Tank	Holding Tank	40	1	15.709	7	84
2	Oil Recircul. (Chrysler)	Chrysler + Hld Tnk	Holding Tank	53	1	46.358	21	69
3		Chrysler + Incin.	Holding Tank	N/A				→
4	Gravity Collect. (Grumman)	Grum Flow Thru+HldTk	Holding Tank	N/A				→
5		Grumman Flow Thru + Holding Tank		N/A				→
6	Gravity Collect.	Holding Tank	Grum Flow Thru+ HldTnk	N/A				→
7	Gravity Collect. (Grumman)	Grum Flow Thru+Incin.	Holding Tank	N/A				→
8		Grumman Flow Thru + Incinerator		N/A				→
9	Vacuum Collect. (Jered)	Holding Tank	Holding Tank	48	1	126.924	58	61
10	↓	Incinerator	Holding Tank	100	1	220.107	100	55
11		GATX Evap.	Holding Tank	N/A				→
12		Holding Tank	Grum Flow Thru+ Hld Tnk	N/A				→
13		Incinerator	Grum Flow Thru + Incin.	N/A				→
14	M/T Pump Collect. (GATX)	Holding Tank	Holding Tank	100	1	113.382	52	74
15	↓	Incinerator	Holding Tank	100	3	195.930	89	65
16		GATX Evap.	Holding Tank	100	1	173.901	79	69
17		Holding Tank	Grum Flow Thru+Hld Tnk	N/A				→
18		Incinerator	Grum Flow Thru + Incin.	N/A				→

* Based on the maximum holding time of 172.0 hours. The next smaller holding time of 72.0 hours would satisfy approximately 97% of all holding time requirements.

VIGOROUS (210')

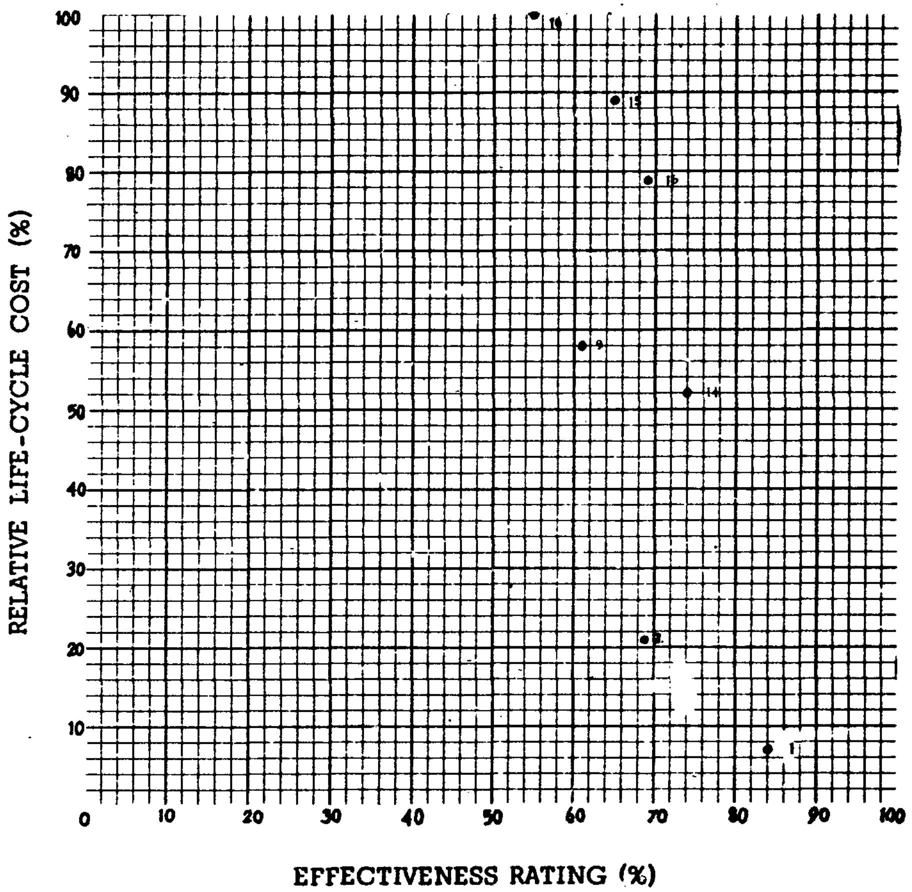


Figure 23

LIFE-CYCLE COST VERSUS EFFECTIVENESS RATING
FOR VIABLE CANDIDATE SYSTEMS

Sheet 3 of 6

WMS No.	TYPE			Holding Capacity		COST		
	Coll/Trans Subsys (Black)	Treatment/Disposal Subsystem Black	Treatment/Disposal Subsystem Gray	Black (%)*	Gray (%)*	$K	Relatv (%)	R_E (%)
1	Gravity Collect.	Holding Tank	Holding Tank	100	0	22.474	9	86
2	Oil Recircul. (Chrysler)	Chrysler + Hld Tnk	Holding Tank	100	0	47.328	19	71
3		Chrysler + Incin.	Holding Tank	100	12	105.495	43	69
4	Gravity Collect. (Grumman)	Grum Flow Thru+HldTk	Holding Tank	100	22	59.642	24	76
5		Grumman Flow Thru + Holding Tank		100	100	88.145	36	78
6	Gravity Collect.	Holding Tank	Grum Flow Thru+HldTnk	100	100	94.267	39	78
7	Gravity Collect. (Grumman)	Grum Flow Thru+Incin.	Holding Tank	100	29	104.949	43	73
8		Grumman Flow Thru + Incinerator		100	100	164.309	67	71
9	Vacuum Collect. (Jered)	Holding Tank	Holding Tank	100	13	96.505	40	64
10		Incinerator	Holding Tank	100	35	200.935	82	57
11		GATX Evap.	Holding Tank	100	35	154.074	63	58
12		Holding Tank	Grum Flow Thru+ Hld Tnk	100	100	163.557	67	56
13		Incinerator	Grum Flow Thru + Incin.	100	100	244.331	100	52
14	M/T Pump Collect. (GATX)	Holding Tank	Holding Tank	100	13	68.892	28	75
15		Incinerator	Holding Tank	100	35	169.382	69	68
16		GATX Evap.	Holding Tank	100	35	117.251	48	70
17		Holding Tank	Grum Flow Thru+Hld Tnk	100	100	135.709	56	68
18		Incinerator	Grum Flow Thru + Incin.	100	100	211.911	87	64

* Based on the maximum holding time of 277.9 hours. The next smaller holding time of 54.0 hours would satisfy approximately 99% of all holding time requirements.

FIREBUSH (180')

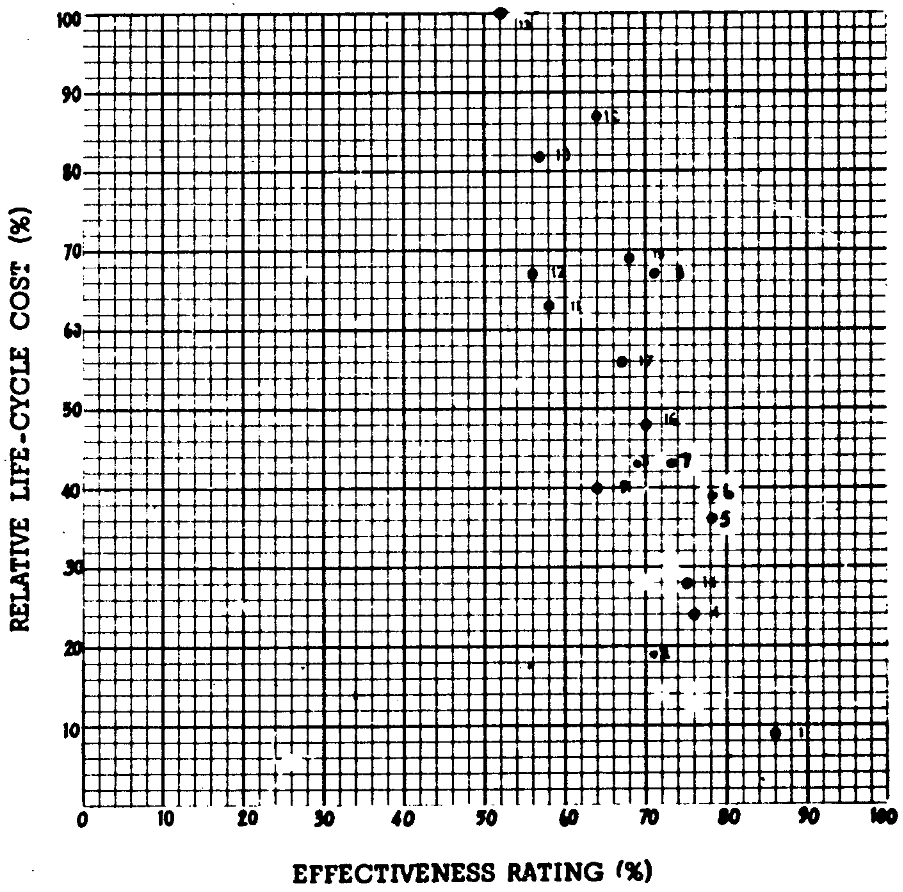


Figure 23

LIFE-CYCLE COST VERSUS EFFETIVENESS RATING FOR VIABLE CANDIDATE SYSTEMS

Sheet 4 of 6

WMS No.	Coll/Trans Subsys (Black)	Treatment/Disposal Subsystem Black	Treatment/Disposal Subsystem Gray	Holding Capacity Black (%)*	Holding Capacity Gray (%)*	COST $K	COST Relatv (%)	R_E (%)
1	Gravity Collect.	Holding Tank	Holding Tank	100	55	36.780	30	80
2	Oil Recircul. (Chrysler)	Chrysler + Hld Tnk	Holding Tank	100	64	59.160	49	64
3		Chrysler + Incin.	Holding Tank	100	64	74.735	62	61
4	Gravity Collect. (Grumman)	Grum Flow Thru+HldTk	Holding Tank	100	64	68.501	56	68
5		Grumman Flow Thru + Holding Tank		100	100	57.432	47	72
6	Gravity Collect.	Holding Tank	Grum Flow Thru+ HldTnk	100	100	63.664	52	72
7	Gravity Collect. (Grumman)	Grum Flow Thru+Incin.	Holding Tank	100	64	110.249	91	63
8		Grumman Flow Thru + Incinerator		100	100	96.968	80	65
9	Vacuum Collect. (Jered)	Holding Tank	Holding Tank	100	64	44.002	36	64
10		Incinerator	Holding Tank	100	64	94.055	77	55
11		GATX Evap.	Holding Tank	100	64	59.173	48	60
12		Holding Tank	Grum Flow Thru+ Hld Tnk	100	100	72.605	60	56
13		Incinerator	Grum Flow Thru + Incin.	100	100	108.959	90	52
14	M/T Pump Collect. (GATX)	Holding Tank	Holding Tank	100	64	57.975	48	71
15		Incinerator	Holding Tank	100	64	108.996	90	61
16		GATX Evap.	Holding Tank	100	64	75.640	62	66
17		Holding Tank	Grum Flow Thru+Hld Tnk	100	100	86.689	71	63
18		Incinerator	Grum Flow Thru + Incin.	100	100	120.925	100	58

* Based on the maximum holding time of 501.0 hours. The next smaller holding time of 228.0 hours would satisfy approximately 98% of all holding time requirements.

PAMLICO (160')

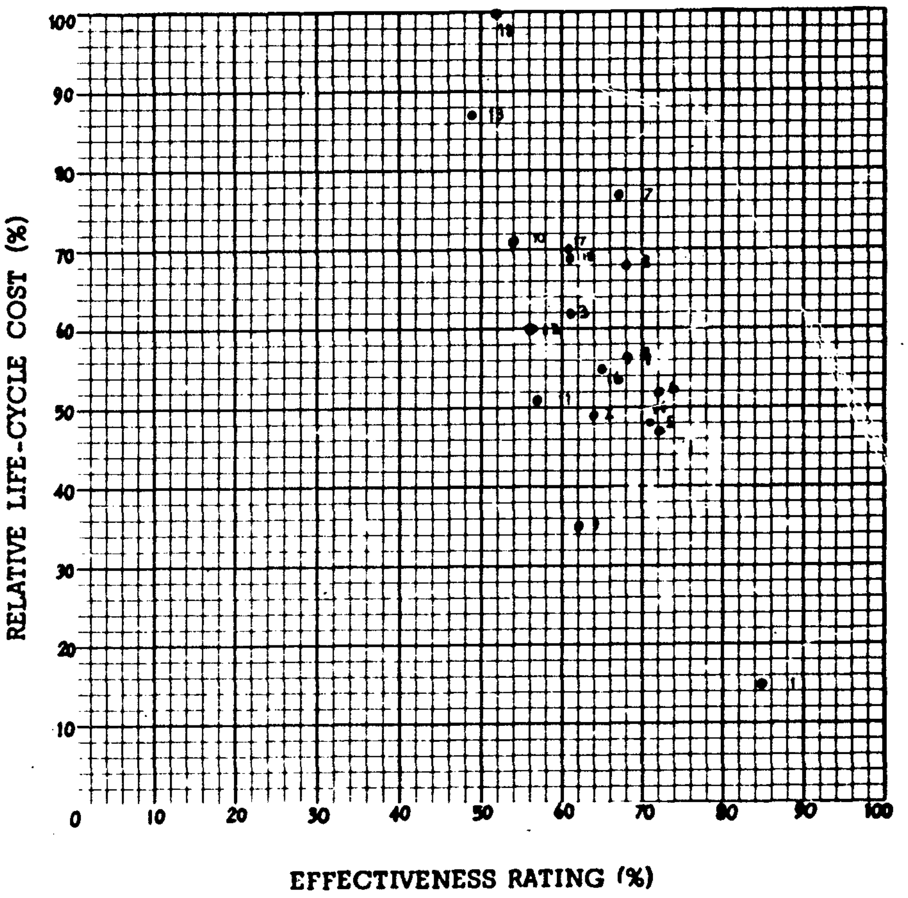


Figure 23

LIFE-CYCLE COST VERSUS EFFECTIVENESS RATING
FOR VIABLE CANDIDATE SYSTEMS

Sheet 5 of 6

WMS No.	TYPE Coll/Trans Subsys (Black)	Treatment/Disposal Subsystem Black	Treatment/Disposal Subsystem Gray	Holding Capacity Black* (%)	Holding Capacity Gray* (%)	COST $K	COST Relatv (%)	R_Σ (%)
1	Gravity Collect.	Holding Tank	Holding Tank	100	100	18.974	15	86
2	Oil Recircul. (Chrysler)	Chrysler + Hld Tnk	Holding Tank	100	100	46.533	36	68
3		Chrysler + Incin.	Holding Tank	100	100	58.040	45	65
4	Gravity Collect. (Grumman)	Grum Flow Thru+Hld Tk	Holding Tank	100	100	56.434	44	74
5		Grumman Flow Thru + Holding Tank		100	100	51.110	40	76
6	Gravity Collect.	Holding Tank	Grum Flow Thru+HldTnk	100	100	54.685	42	76
7	Gravity Collect. (Grumman)	Grum Flow Thru+Incin.	Holding Tank	100	100	96.242	75	68
8		Grumman Flow Thru + Incinerator		100	100	85.285	66	69
9	Vacuum Collect. (Jared)	Holding Tank	Holding Tank	100	100	44.345	34	64
10	↓	Incinerator	Holding Tank	100	100	89.990	70	56
11		GATX Evap.	Holding Tank	100	100	64.258	50	59
12		Holding Tank	Grum Flow Thru+Hld Tnk	100	100	73.991	57	56
13		Incinerator	Grum Flow Thru + Incin.	100	100	109.560	85	51
14	M/T Pump Collect. (GATX)	Holding Tank	Holding Tank	100	100	53.402	41	70
15	↓	Incinerator	Holding Tank	100	100	97.771	76	62
16		GATX Evap.	Holding Tank	100	100	72.375	56	66
17		Holding Tank	Grum Flow Thru+Hld Tnk	100	100	91.509	71	62
18		Incinerator	Grum Flow Thru + Incin.	100	100	128.942	100	54

* Based on the maximum holding time of 65.5 hours. The next smaller holding time of 62.0 hours would satisfy approximately 97% of all holding time requirements.

WHITE SAGE (133')

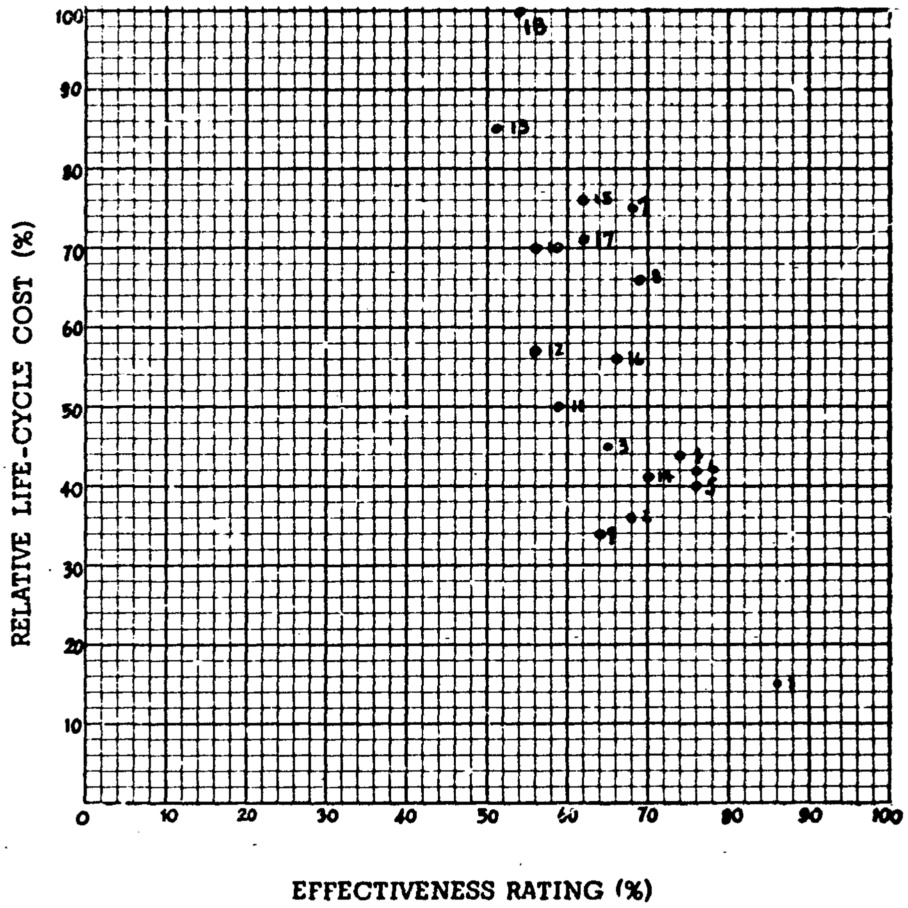


Figure 23

LIFE-CYCLE COST VERSUS EFFECTIVENESS RATING
FOR VIABLE CANDIDATE SYSTEMS

Sheet 6 of 6

WMS No.	Coll/Trans Subsys (Black)	TYPE Treatment/Disposal Subsystem Black	Gray	Holding Capacity Black (%)*	Gray (%)*	COST $K	Relatv (%)	R_E (%)
1	Gravity Collect.	Holding Tank	Holding Tank	58	0	6.070	13	82
2	Oil Recircul. (Chrysler)	Chrysler + Hld Tnk	Holding Tank	N/A				
3		Chrysler + Incin.	Holding Tank	N/A				
4	Gravity Collect. (Grumman)	Grum Flow Thru+HldTk	Holding Tank	N/A				
5		Grumman Flow Thru + Holding Tank		N/A				
6	Gravity Collect.	Holding Tank	Grum Flow Thru+ HldTnk	N/A				
7	Gravity Collect. (Grumman)	Grum Flow Thru+Incin.	Holding Tank	N/A				
8		Grumman Flow Thru + Incinerator		N/A				
9	Vacuum Collect. (Jered)	Holding Tank	Holding Tank	100	20	28.058	59	60
10		Incinerator	Holding Tank	N/A				
11		GATX Evap.	Holding Tank	100	20	45.559	96	56
12		Holding Tank	Grum Flow Thru+ Hld Tnk	N/A				
13		Incinerator	Grum Flow Thru + Incin.	N/A				
14	M/T Pump Collect. (GATX)	Holding Tank	Holding Tank	100	20	29.289	62	71
15		Incinerator	Holding Tank	N/A				
16		GATX Evap.	Holding Tank	100	20	47.579	100	66
17		Holding Tank	Grum Flow Thru+Hld Tnk	N/A				
18		Incinerator	Grum Flow Thru + Incin.	N/A				

* Based on the maximum holding time of 99.0 hours. The next smaller holding time of 21.5 hours would satisfy approximately 99% of all holding time requirements.

POINT HERRON (82')

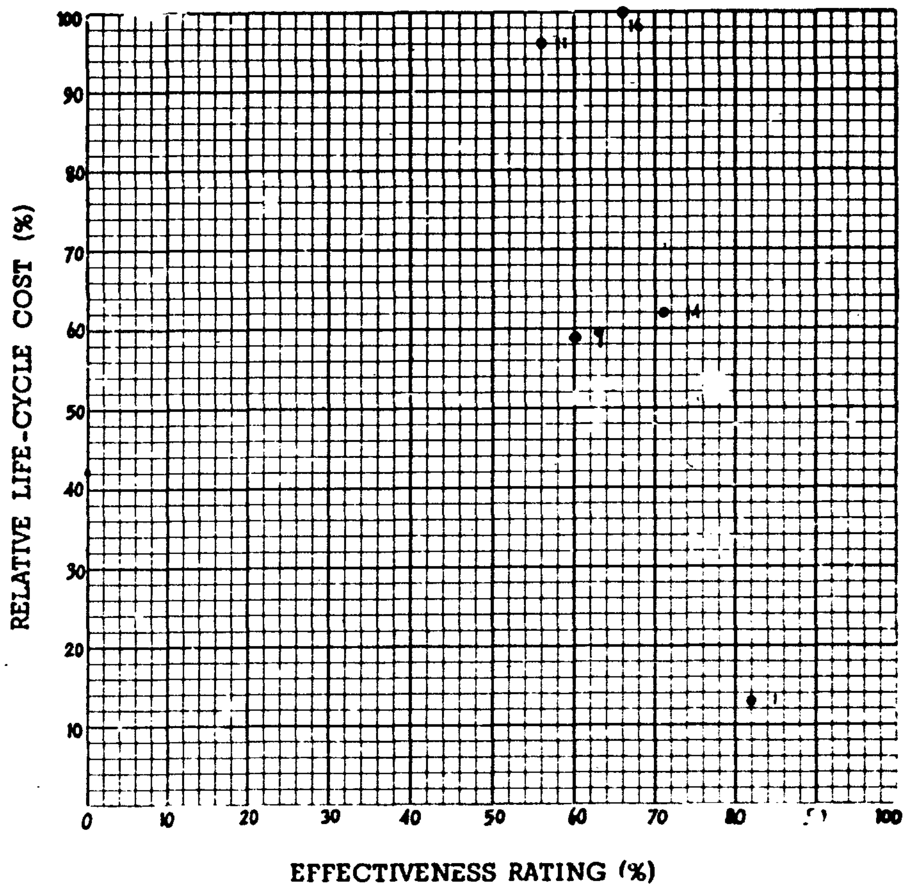
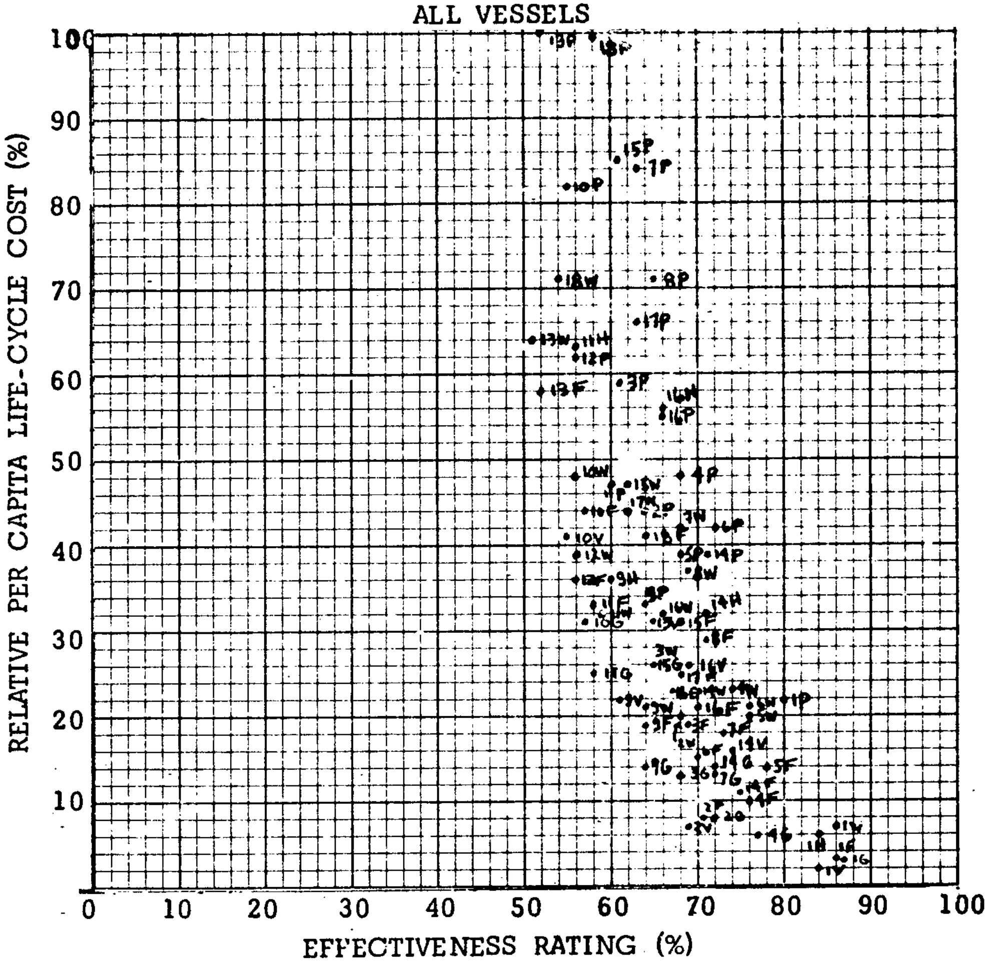


Figure 23

LIFE-CYCLE COST VERSUS EFFETIVENESS RATING
FOR VIABLE CANDIDATE SYSTEMS



LEGEND

G - Gallatin
V - Vigorous
F - Firebush
P - Pamlico
W- White Sage
H - Point Herron

Figure 24

PER CAPITA LIFE-CYCLE COST VERSUS
EFFECTIVENESS RATING FOR VIABLE CANDIDATE SYSTEMS

Sheet 2 of 2

WMS No.	TYPE			COORDINATES OF POINTS FOR EACH VIABLE WMS/VESSEL COMBINATION																	
	Coll/Trans Subsys (Black)	Treatment/Disposal Subsystem		GALLATIN (378')			VIGOROUS (210')			FIREBUSH (180')			PAMLICO (160')			WHITE SAGE (188')			POINT HERRON (82')		
		Black	Gray	Point	C (%)	R_E(%)	Point	C(%)	R_E(%)	Point	C(%)	R_E(%)	Point	C(%)	R_E(%)	Point	C(%)	R_E(%)	Point	C(%)	R_E(%)
1	Gravity Collect.	Holding Tank	Holding Tank	1G	4	87	1V	3	84	1F	5	86	1P	30	80	1W	10	86	1H	8	82
2	Oil Recircul. (Chrysler)	Chrysler + Hld Tnk	Holding Tank	2G	10	72	2V	8	69	2F	10	71	2P	49	64	2W	24	68	N/A	N/A	N/A
3		Chrysler + Incin.	Holding Tank.	3G	15	68	N/A	N/A	N/A	3F	23	69	3P	62	61	3W	30	65	N/A	N/A	N/A
4	Gravity Collect. (Grumman)	Grum Flow Thru+HldTk	Holding Tank	4G	8	77	N/A	N/A	N/A	4F	13	76	4P	57	68	4W	29	74	N/A	N/A	N/A
5		Grumman Flow Thru + Holding Tank		N/A	N/A	N/A	N/A	N/A	N/A	5F	19	78	5P	47	72	5W	26	76	N/A	N/A	N/A
6	Gravity Collect.	Holding Tank	Grum Flow Thru+ HldTnk	N/A	N/A	N/A	N/A	N/A	N/A	6F	20	78	6P	53	72	6W	28	76	N/A	N/A	N/A
7	Gravity Collect. (Grumman)	Grum Flow Thru+Incin.	Holding Tank	7G	16	72	N/A	N/A	N/A	7F	23	73	7P	91	63	7W	49	68	N/A	N/A	N/A
8		Grumman Flow Thru + Incinerator		N/A	N/A	N/A	N/A	N/A	N/A	8F	35	71	8P	80	65	8W	44	69	N/A	N/A	N/A
9	Vacuum Collect. (Jered)	Holding Tank	Holding Tank	9G	15	64	9V	23	61	9F	21	64	9P	36	64	9W	23	64	9H	38	60
10		Incinerator	Holding Tank	10G	31	57	10V	39	55	10F	43	57	10P	78	55	10W	46	56	N/A	N/A	N/A
11		GATX Evap.	Holding Tank	11G	25	58	N/A	N/A	N/A	11F	33	58	11P	49	60	11W	33	59	11H	61	56
12		Holding Tank	Grum Flow Thru+ Hld Tnk	N/A	N/A	N/A	N/A	N/A	N/A	12F	35	56	12P	60	56	12W	38	56	N/A	N/A	N/A
13		Incinerator	Grum Flow Thru + Incin.	N/A	N/A	N/A	N/A	N/A	N/A	13F	53	52	13P	90	52	13W	56	51	N/A	N/A	N/A
14	M/T Pump Collect. (GATX)	Holding Tank	Holding Tank	14G	16	72	14V	20	74	14F	15	75	14P	48	71	14W	27	70	14H	39	71
15		Incinerator	Holding Tank	15G	29	65	15V	35	65	15F	36	68	15P	90	61	15W	50	62	N/A	N/A	N/A
16		GATX Evap.	Holding Tank	16G	26	67	16V	31	69	16F	25	70	16P	63	66	16W	37	66	16H	64	66
17		Holding Tank	Grum Flow Thru+Hld Tnk	N/A	N/A	N/A	N/A	N/A	N/A	17F	29	68	17P	72	63	17W	45	62	N/A	N/A	N/A
18		Incinerator	Grum Flow Thru + Incin.	N/A	N/A	N/A	N/A	N/A	N/A	18F	46	64	18P	100	58	18W	66	54	N/A	N/A	N/A

C(%) - Relative per capita life-cycle cost expressed as a percentage of the largest value for any viable WMS/Vessel combination.

R_E(%) - Effectiveness rating.

N/A - Not a viable candidate system/vessel combination.

Figure 24

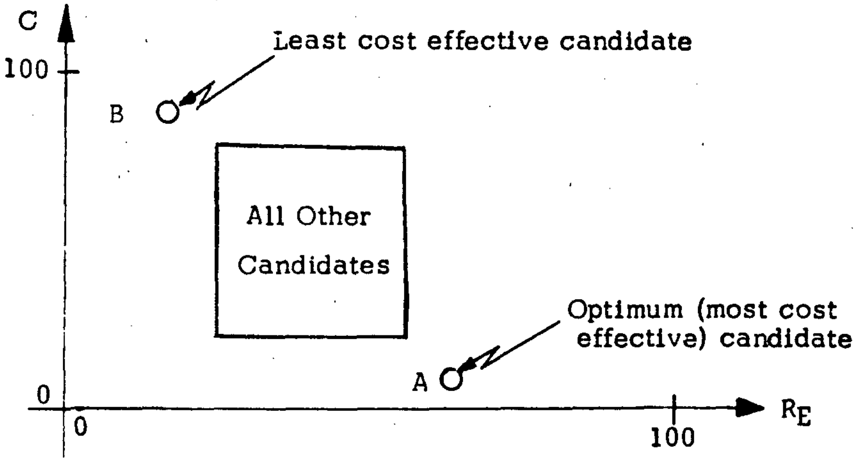
PER CAPITA LIFE-CYCLE COST VERSUS
EFFECTIVENESS RATING FOR VIABLE CANDIDATE SYSTEMS

OPTIMUM CANDIDATE SELECTION CRITERIA

Since cost and effectiveness represent opposing aspects of a candidate (quality vs. cost penalty) and since these two aspects are a priori independent of each other (and hence may result in unpredictable combinations of cost and effectiveness), it is necessary to establish a systematic procedure for choosing an optimum system from among the available candidates. An optimum candidate selection criterion is a rule which can be used consistently for making this type of selection. Such a rule sometimes results in trading off cost (penalty) for effectiveness (quality). Several such optimum candidate selection criteria are discussed below.

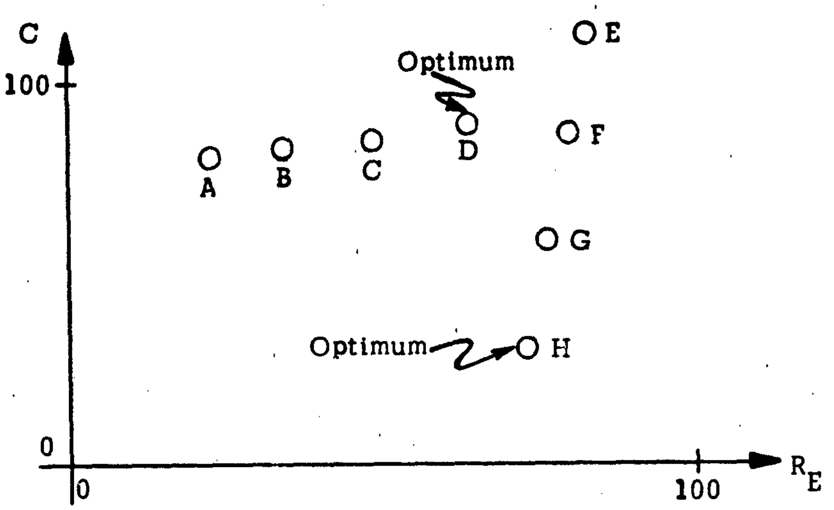
Outliers

Outliers are candidates whose cost vs. effectiveness relationship is drastically different from that of all the other candidates. Identification of outliers is a quick and convenient method of determining the most and/or the least cost effective candidates. Thus, in the cost vs. effectiveness, relationship shown below, candidate A is an obvious optimum because it has the highest effectiveness rating and the lowest cost of all available candidates.



In Figure 23, WMS No. 1 is such an obvious optimum. Candidate B above is the least cost-effective choice since it has the highest cost and lowest effectiveness rating of all available candidates. In Figure 23, depending on vessel, WMS Nos. 10, 11, 13, 16 or 18 are such obvious least cost-effective candidates.

Other less obvious types of outliers are shown below.



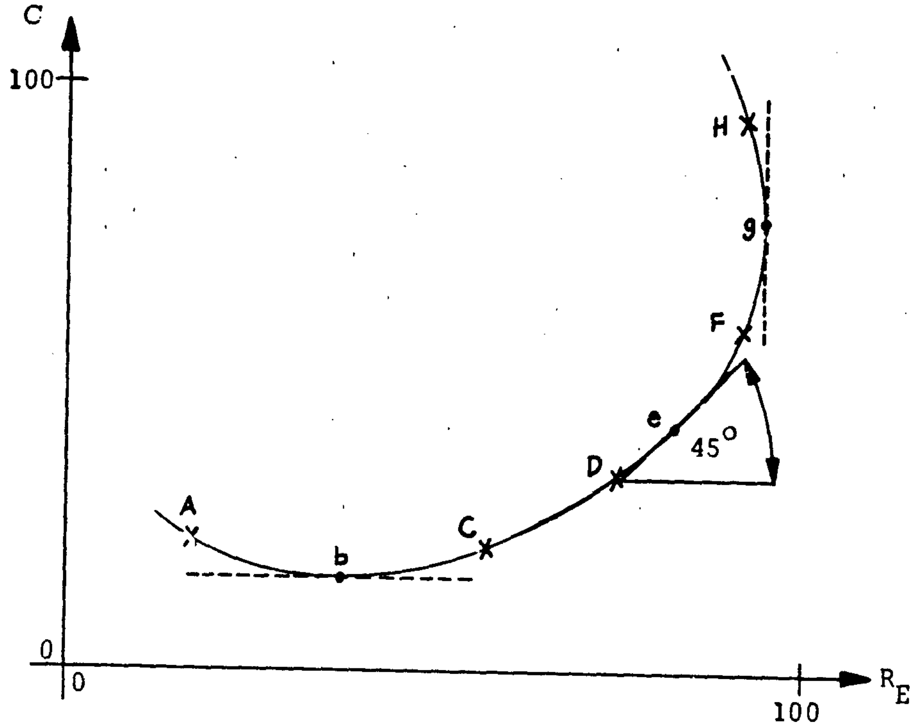
A cost vs. effectiveness relationship represented by the group of candidates A, B, C, D in which cost increases relatively slowly and the corresponding effectiveness ratings increase substantially may result in the choice of the most expensive (and most effective) candidate, since a high gain in effectiveness is obtained for a small increase in cost. In such a situation, one has to decide what constitutes a "large" increase in effectiveness and "small" increase in cost. It is obvious that if all candidates have the same cost but different effectiveness ratings, i.e., lie on a horizontal line, then the optimum is the candidate with the highest effectiveness rating.

A cost vs. effectiveness relationship represented by the group of candidates E, F, G, H in which cost decreases rapidly and the corresponding effectiveness ratings decrease relatively slowly may result in the choice of the least effective (and least costly) candidate, since a substantial decrease in cost is achieved at a relatively small decrease in effectiveness. Again, in such a situation, one has to decide what constitutes a "substantial" decrease in cost and "small" decrease in effectiveness. It is obvious that if all candidates have the same effectiveness rating but different costs (i.e., lie on a vertical line), then the optimum is the candidate with the lowest life-cycle cost.

Marginal Cost-Marginal Utility Principle

If the cost vs. effectiveness relationship does not fall within the category of outliers(in which case the optimum choice is obvious), an alternative procedure based on the economic principle of Marginal Cost-Marginal Utility (or Marginal Value) may sometimes be used as the optimum candidate selection criterion.

To use this selection procedure, a smooth curve is drawn through the points representing the candidates. An example of such a curve is shown below:



In the curve shown above, points A, C, D, F and H represent candidate systems.* The selection of the optimum system (i.e., the most cost effective system) is determined by considering some of the characteristics of the above curve relating cost to effectiveness. It is noted that between points b and g as cost increases, the corresponding effectiveness rating also increases. Between points b and A, since an increase in cost is accompanied by a corresponding decrease in effectiveness rating, this region will not contain the optimum choice. It is noted that the cost is minimum at point b. Similarly, in the region between points g and H, since an increase in cost is also accompanied by a corresponding decrease in effectiveness rating, this portion of the curve will not contain the optimum candidate system. Also, note that the effectiveness rating is highest at point g. The most cost effective system is therefore found in the region between points b and g. The optimum choice is determined by drawing a tangent to the curve at an angle of 45° with the abscissa, as indicated by point e. This point corresponds to the most cost effective system as determined by the principle of Marginal Cost - Marginal Utility.**

At this point, the rate of change of cost with respect to effectiveness rating, i.e., the slope of the curve, is equal to 1.0 because the tangent line was drawn at an angle of 45° to the abscissa. This means that at this point, a single unit of change in relative cost produces a single unit of change in effectiveness rating. This point is considered to be optimum because if the rate of change of cost relative to effectiveness is greater than 1.0, it indicates that a relatively large change in expenditures will result in a relatively small gain in effectiveness rating. On the other hand, if the rate of change of cost with respect to effectiveness rating is less than 1.0, it means that a relatively small change in cost produces

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* It is noted that to obtain such a relationship, it may first be necessary to eliminate outliers as discussed in the previous section.

** William F. Sharpe, The Economics of Computers, (N.Y. and London: Columbia University Press, 1969), pages 13-19.

a relatively large increase in effectiveness. This is an indication that such a point is not the place to end the search because the optimum has not yet been reached. Thus, when the rate of change is equal to 1.0, a change in cost is balanced by an equal change in effectivenss rating and is the optimum choice.

In the above example, since there is no candidate corresponding to point e, the optimum choice corresponds to the candidate which is closest to point e, namely, candidate D.

In order to utilize this approach, it is necessary that both cost and effectiveness be expressed in the same units. This is accomplished by using the relative, instead of the absolute costs of the candidates, as discussed in a previous section.

Ratio of Cost to Effectiveness Rating

Another optimum candidate selection procedure is based on a ranking of candidates on the basis of the ratio of life-cycle cost to effectiveness rating. An advantage of this selection procedure is that it reduces the two dimensional problem into one dimension and results in a ranking of the candidates which makes the choice of the optimum candidate an obvious one, namely the one with the smallest ratio.

Since effectivenss ratings are dimensionless, the ratio of cost to effectiveness rating (C/R_E) has the dimensions of dollars (\$). Thus, this ratio can be thought of as "cost" in terms of "effectiveness dollars". Since the values of effectiveness lie between 0 and 100%, the value of this ratic, when the effectivenss rating is expressed as a fraction rather than as a percentage, will usually be greater than the cost in absolute dollars. Thus, this ratio can be interpreted as the penalty in dollars (\$) for a low effectiveness rating. As an example, if two candidates have the same life-cycle cost but the effectiveness rating of the first is half that of the second, the latter is "worth", half as much in terms of effectiveness dollars. Similarly, if the life-cycle cost of one candidate is one half that of another one, but its effectiveness rating is also one half of the other one, then they are both "worth" the same in terms of effectiveness dollars. Thus, this optimum selection procedure results in an equal trade-off between cost and effectiveness ratings.

The results of applying this optimum selection procedure to the viable candidate wastewater management systems for each vessel are shown in Figure 25. In order to simplify the presentation and facilitate comparison of results for each vessel, the ratio of life-cycle cost to effectiveness rating was plotted as a percentage of the maximum value for each vessel. The results in Figure 25 confirm the conclusions regarding the most and least cost effective systems for each vessel previously determined on the basis of the outlier technique.

In order to obtain results on a fleetwide basis rather than on an individual vessel basis, a similar ranking was obtained by combining the data for all vessels based on the ratio of the per capita life-cycle cost to effectiveness rating. The results of such a ranking are shown in Figure 26. The ranking in Figure 26 is based on expressing each ratio as a percentage of the maximum value for all vessels. The results in Figure 26 also confirm the previously noted observation that the PAMLICO is in a class by itself due to its waste collection system which is different from that of the other vessels and its unusual mission profile characteristics.

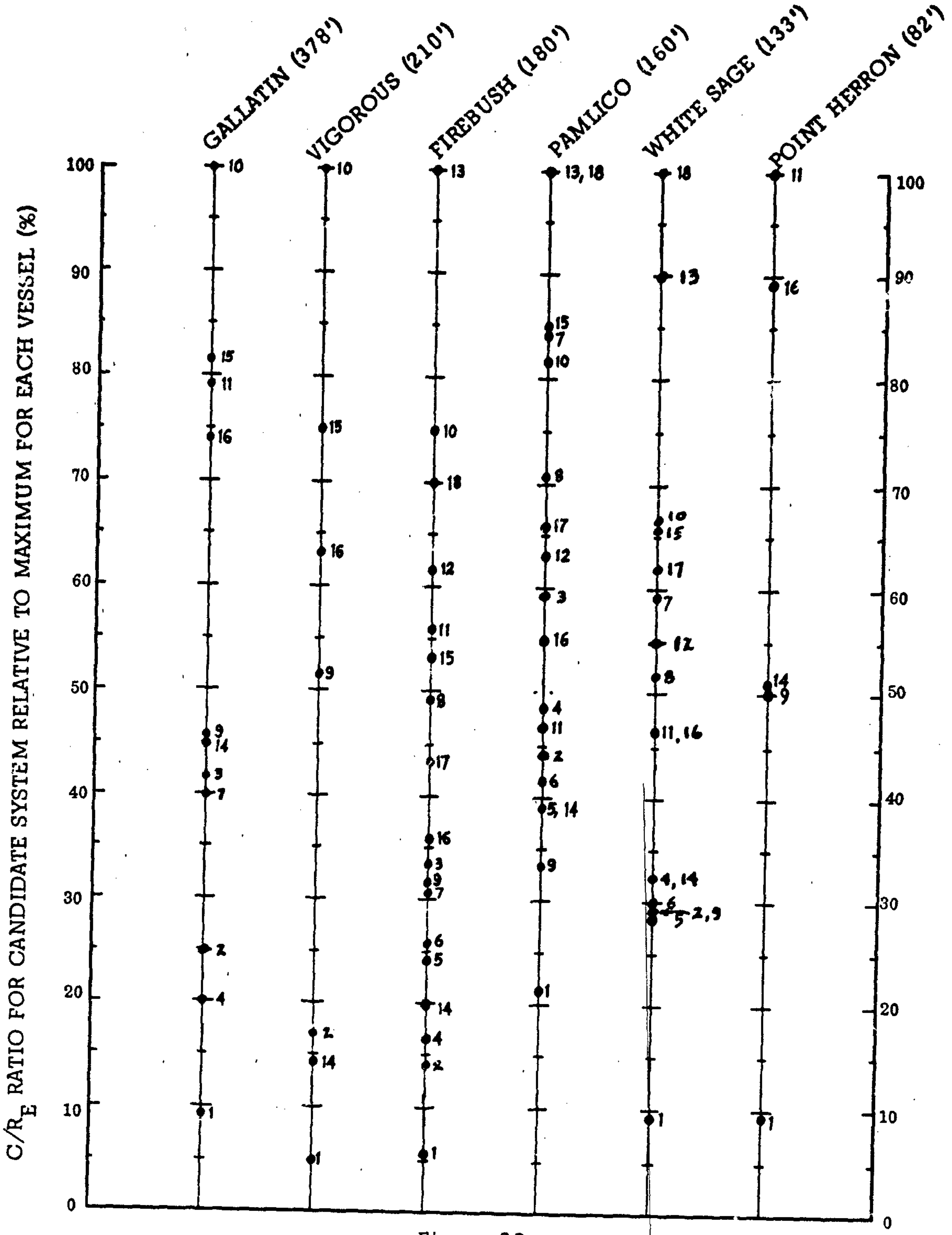

Figure 25

RELATIVE RANKING OF VIABLE CANDIDATE SYSTEMS ON EACH VESSEL BASED ON THE RATIO OF LIFE CYCLE COST (C) TO EFFECTIVENESS RATING (R_E)

Sheet 1 of 2

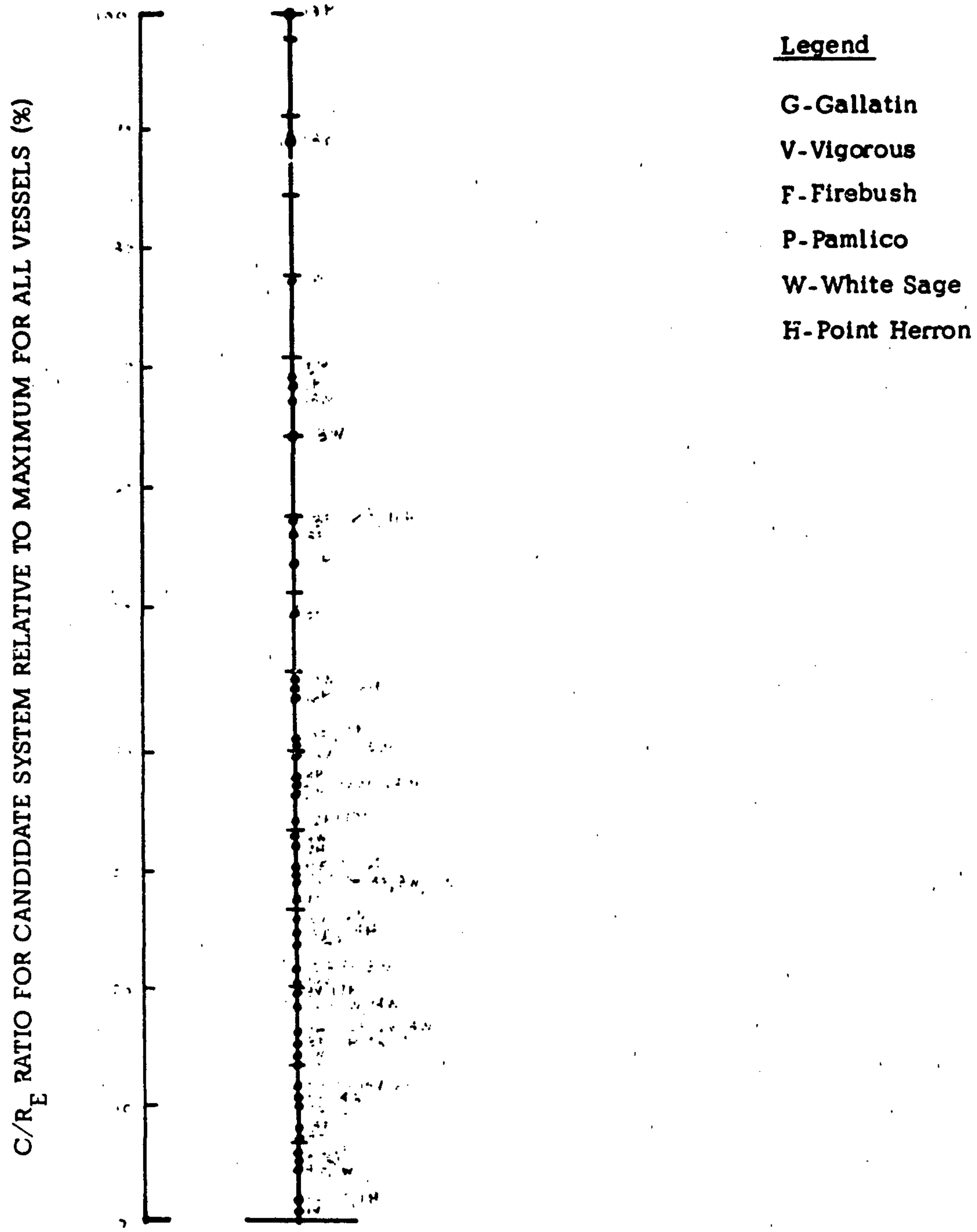

FIGURE 26

RELATIVE RANKING OF VIABLE CANDIDATE SYSTEMS ON ALL VESSELS BASED ON THE RATIO OF PER CAPITA LIFE CYCLE COST (C) TO EFFECTIVENESS RATING (R_E)

Sheet 2 of 2

WMS No.	Coll/Trans Subsys (Black)	TYPE Treatment/Disposal Subsystem		VALUE OF POINTS FOR EACH VIABLE WMS/VESSEL COMBINATION											
				GALLATIN (378')		VIGOROUS (210')		FIREBUSH (180')		PAMLICO (160')		WHITE SAGE (133')		POINT HERRON (82')	
		Black	Gray	Point	$C/R_E(\%)$	Point	$C/R_E(\%)$	Point	$C/R_E(\%)$	Point	$C/R_E(\%)$	Point	$C/R_E(\%)$	Point	$C/R_E(\%)$
1	Gravity Collect.	Holding Tank	Holding Tank	1G	3	1V	2	1F	3	1P	22	1W	7	1H	6
2	Oil Recircul. (Chrysler)	Chrysler + Hld Tnk	Holding Tank	2G	8	2V	7	2F	8	2P	44	2W	20	N/A	N/A
3		Chrysler + Incin.	Holding Tank	3G	13	N/A	N/A	3F	19	3P	58	3W	26	N/A	N/A
4	Gravity Collect. (Grumman)	Grum Flow Thru+HldTk	Holding Tank	4G	6	N/A	N/A	4F	10	4P	48	4W	23	N/A	N/A
5		Grumman Flow Thru + Holding Tank		N/A	N/A	N/A	N/A	5F	14	5P	38	5W	20	N/A	N/A
6	Gravity Collect.	Holding Tank	Grum Flow Thru+ HldTnk	N/A	N/A	N/A	N/A	6F	15	6P	42	6W	21	N/A	N/A
7	Gravity Collect. (Grumman)	Grum Flow Thru+Incin.	Holding Tank	7G	13	N/A	N/A	7F	18	7P	84	7W	42	N/A	N/A
8		Grumman Flow Thru + Incinerator		N/A	N/A	N/A	N/A	8F	29	8P	71	8W	37	N/A	N/A
9	Vacuum Collect. (Jered)	Holding Tank	Holding Tank	9G	14	9V	22	9F	19	9P	33	9W	20	9H	36
10		Incinerator	Holding Tank	10G	31	10V	41	10F	44	10P	82	10W	47	N/A	N/A
11		GATX Evap.	Holding Tank	11G	25	N/A	N/A	11F	33	11P	47	11W	32	11H	63
12		Holding Tank	Grum Flow Thru+ Hld Tnk	N/A	N/A	N/A	N/A	12F	36	12P	62	12W	39	N/A	N/A
13		Incinerator	Grum Flow Thru + Incin.	N/A	N/A	N/A	N/A	13F	58	13P	100	13W	63	N/A	N/A
14	M/T Pump Collect. (GATX)	Holding Tank	Holding Tank	14G	14	14V	16	14F	11	14P	39	14W	23	14H	32
15		Incinerator	Holding Tank	15G	26	15V	31	15F	31	15P	85	15W	47	N/A	N/A
16		GATX Evap.	Holding Tank	16G	23	16V	26	16F	21	16P	55	16W	32	16H	56
17		Holding Tank	Grum Flow Thru+Hld Tnk	N/A	N/A	N/A	N/A	17F	25	17P	66	17W	44	N/A	N/A
18		Incinerator	Grum Flow Thru + Incin.	N/A	N/A	N/A	N/A	18F	41	18P	100	18W	71	N/A	N/A

$C/R_E(\%)$ - Relative ratio of per capita life-cycle cost to effectiveness rating expressed as a percentage of the largest value for any viable WMS/Vessel combination.

N/A - Not a viable candidate system/vessel combination.

FIGURE 26

RELATIVE RANKING OF VIABLE CANDIDATE SYSTEMS ON ALL VESSELS BASED ON THE RATIO OF PER CAPITA LIFE CYCLE COST (C) TO EFFECTIVENESS RATING (R_E)

DISCUSSION

GOALS, POLICIES, GUIDELINES, AND ASSUMPTIONS

The results of this study depend not only on the objective (and subjective) data and characteristics of the systems and vessels analyzed but also on the goals, policies, guidelines, and assumptions used. Hence, the overall as well as specific results should be interpreted accordingly. Although a detailed examination of the consequences of all such objectives, policies, guidelines, and assumptions governing this study will not be attempted here, two important issues are discussed below.

Vessel Holding Time Requirements

The average and maximum holding time requirements for a vessel constitute the most important issues since they affect the following:

- The WMS configuration and equipment sizing.
- The viability of potential system/vessel configurations.
- The life-cycle cost.

Vessel holding time requirements are established on the basis of:

- The definition of restricted waters.
- The guidelines regarding the basis for setting the holding capacity objective for each vessel.
- The policy regarding the availability of pierside waste receiving facilities.

The definition of restricted waters is a matter of law, thus limiting the available options. However, an important concern in this regard is the uncertainty of future changes in the definition of restricted waters (as well as effluent standards). This law has been modified in the last few years. The recent extension of territorial waters to 200 miles is an example of a change in the law which may have significant consequences on the mission profiles of certain classes of vessels. In this study, restricted waters were defined as those within three miles from any shoreline and all inland waters.

For purposes of this study, the guideline regarding vessel holding capacity was that the candidate system must be capable of accommodating the maximum holding time encountered in the vessel mission profile data, regardless of how infrequently such a holding time would be required. For some vessels this policy has important implications for the WMS equipment configuration requirements and viability due to large differences between this maximum and the other holding times. The ratio of the maximum holding time to the next smaller holding time for some of the vessels is as follows:

- VIGOROUS - more than 2 to 1
- FIREBUSH - approximately 5 to 1
- PAMLICO - more than 2 to 1
- POINT HERRON - more than 4 to 1

Thus, for these vessels, if the guideline for holding capacity was based on the objective of satisfying only P% rather than 100% of all holding time requirements, this would profoundly affect the WMS equipment requirements and sizing and, in some cases, system/vessel combinations determined to be non-viable might be judged as viable. However, the consequence of such a decision is that WMS configurations would be accepted which would, with a priori knowledge of the decision maker, result in either the violation of emission standards approximately (100-P)% of the time or the vessel operations (i.e., mission profiles) would have to be modified to avoid this.

Another important issue which affects vessel holding capacity (and is related to the above discussion regarding the maximum holding time) is the U.S. Coast Guard policy of providing pierside waste receiving facilities only at the vessel's home port (and at yards). Provision of shore waste receiving facilities at non-home ports as well, would affect vessel mission profile results and may eliminate the necessity for unusually large holding capacities.

Management of Black and Gray Wastewaters

A list of the systems which can accommodate the maximum holding time for black and gray waste waters on each vessel is presented in Table 14, The systems which do not appear in Table 14 are either non-viable candidates or do not provide the full holding capacity for black or gray wastewater, as the case may be.*

The following observations can be made from the results in Table 14:

- The WHITE SAGE (133') is the only vessel for which all candidate systems are capable of providing the full holding capacity for both black and gray water.
- The objective of providing required gray water holding capacity cannot be met on the following vessels:
  - GALLATIN (378')
  - VIGOROUS (210')
  - POINT HERRON (82')

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* The inclusion in this study of systems which do not provide 100% of the required holding capacity for black and gray wastewaters resulted from a Coast Guard guideline that, if the holding capacity is determined by a tank and full capacity cannot be provided, such systems are not to be eliminated from the study as non-viable candidates. Instead, the maximum available tank capacity is to be provided for black and gray wastewaters, giving preference to the management of black water.

Table 14

CANDIDATE SYSTEMS WHICH PROVIDE FULL HOLDING CAPACITY

VESSEL	CREW SIZE	MAXIMUM HOLDING TIME (Hours)	ALL OTHER HOLDING TIMES		WMS Nos. which provide 100% of the required holding capacity	
			Next Smaller Holding Time (Hours)	% of All Holding Times Excluding the Maximum	Black Wastewater	Gray Wastewater
GALLATIN (378')	152	97.5	88.0	98.21	1, 2, 3, 4, 7, 9, 10, 11, 14, 15, 16	None
VIGOROUS (210')	60	172.0	72.0	96.77	10, 14, 15, 16	None
FIREBUSH (180')	50	277.9	54.0	99.26	All	5, 6, 8, 12, 13, 17, 18
PAMLICO (160') * New Construction	13	456.0**	228.0	97.78	All	5, 6, 8, 12, 13, 17, 18
WHITE SAGE (133')	21	65.5	62.0	96.88	All	All
POINT HERRON (82')	8	99.0	21.5	99.12	9, 11, 14, 16	None

* Based on data from SHADBUSH (74') and CLAMP (75').

** Maximum holding time used for WMS design purposes is 501 hours, an increase of 10% to reflect anticipated longer holding time requirements as a result of more available space for stocking supplies.

- On the two other vessels on which required gray water holding capacity can be provided, namely FIREBUSH (180') and PAMLICO (160'), this can be implemented only by systems which employ flow through treatment (using the Grumman MSD) of the gray water stream (sometimes in combination with the black water stream) in conjunction with either an incinerator or a holding tank for the resulting sludge.

It is noted that the above conclusions are based on the applicable guidelines and assumptions for holding capacity goals, installation, waste generation, mission profiles, etc. Modification of one or more of the above guidelines and assumptions may result in different conclusions.

ANALYSIS OF RESULTS

The various analyses which have been performed as part of this study have generated numerous results and information at several levels of detail. These results can be used to draw conclusions about a number of questions and issues which may be of interest to a decision maker.

The first, and most important step in arriving at conclusions is the formulation of specific questions. The candidate systems analyzed constitute a wide range of different concepts. As a result, caution should be applied to avoid making comparisons between system concepts which differ in more than one respect, in order to avoid confounding the issue or questions being raised.

An exhaustive examination of all possible issues and questions will not be attempted here. However, some of the results are discussed below for the purpose of arriving at some conclusions, and as a means of illustrating the techniques which can be used to answer specific questions. A summary of the reasons why certain results may vary from vessel to vessel is also presented.

Optimum Systems

The determination of the optimum, i.e., most cost-effective, candidate system for each vessel is one of the most important objectives of this study. From the results in Figures 23 and 25 it would seem that this issue is easily resolved since WMS No. 1 is the optimum candidate on all vessels. Furthermore, WMS No. 1 appears to be the optimum not only on the basis of the ratio of cost to effectiveness rating, but it seems to be an obvious optimum since it is an outlier.

However, this issue is not that simple. The reason for this is that, as indicated in Table 14, WMS No. 1 does not provide full holding capacity for both black and gray wastewaters on all vessels. Consequently, the questions regarding the optimum candidate for each vessel must be reformulated in terms of different holding time objectives. Table 15 indicates which WMS viable candidate is the optimum on each vessel as a function of holding time objective. The following observations can be made from the results in Table 15:

- The WHITE SAGE is the only vessel on which WMS No. 1 is both the optimum and provides full holding capacity for black and gray wastewaters.
- No optimum candidate system (based on the candidate WMS concepts investigated as well as the guidelines and assumptions governing this study) is available to meet the full holding capacity for black and gray wastewaters on three vessels, namely GALLATIN, VIGOROUS, and POINT HERRON. On these vessels, optimum candidates for the more limited objective of providing full holding capacity for black water only are WMS No.1 for the GALLATIN, WMS No. 14 for the VIGOROUS and WMS No. 9 or No. 14 for the POINT HERRON. On the latter two vessels, WMS No. 1 is the optimum when the holding time objectives are further reduced by dropping the requirement for

Table 15

OPTIMUM CANDIDATE SYSTEMS AS A FUNCTION OF HOLDING TIME OBJECTIVES

VESSEL	CREW SIZE	MAXIMUM HOLDING TIME (Hours)	ALL OTHER HOLDING TIMES		UTILIZATION FACTOR (%)	WMS Nos.† which are optimum candidates under different holding capacity objectives		
			Next Smaller Holding Time (Hours)	% of All Holding Times Excluding the Maximum		100% Capacity For Black and Gray	100% Capacity For Black Only	Less Than 100% Capacity For Black and Gray
GALLATIN (378')	152	97.5	88.0	98.21	11	None	1 /	–
VIGOROUS (210')	60	172.0	72.0	96.77	5.6	None	14	1 /
FIREBUSH (180')	50	277.9	54.0	99.26	14.1	5	1 /	–
PAMILCO (160') * New Construction	13	456.0**	228.0	97.78	31.0	5	1 /	–
WHITE SAGE (133')	21	65.5	62.0	96.88	11.1	1 /	–	–
POINT HERRON (82')	8	99.0	21.5	99.12	1.8	None	9 or 14	1 /

* Based on data from SHADBUSH (74') and CLAMP (75').

** Maximum holding time used for WMS design purposes is 501 hours, an increase of 10% to reflect anticipated longer holding time requirements as a result of more available space for stocking supplies.

† A check (/) next to the WMS No. designates the most cost effective candidate for the vessel.

managing gray water and accepting less than 100% holding capacity for black water (40% for the VIGOROUS and 58% for the POINT HERRON).

- On the FIREBUSH and PAMLICO, WMS No. 5 is the optimum, under the objective of providing full holding capacity for both black and gray wastewaters. On these vessels, if the requirement for managing gray water is dropped completely (on the FIREBUSH) or limited (to 55% on PAMLICO), then WMS No. 1 is the optimum candidate.

It is emphasized that the above conclusions are all subject to the guideline of setting the holding capacity goals for each vessel on the basis of the maximum holding time, as well as the other guidelines governing this study. Hence, when using the results in Table 15 to study the implications of modifying the guidelines and assumptions of the study, one should not overlook the possibility that such changes may lead to different conclusions. This is so because such changes may affect the installation, the viability, the costs, the effectiveness ratings, and therefore their relative magnitudes.

Comparison of WMS Concepts

Of the 18 WMS concepts, seven include an incinerator which is associated either with the black water stream or with both the black and gray water streams (WMS Nos. 3, 7, 8, 10, 13, 15, and 18). Two of them include an evaporator which is associated with the reduced volume black water stream (WMS Nos. 11 and 16). Some questions which may be of interest to a decision maker, from a cost-effectiveness point of view, are:

- Are incinerators preferable to holding tanks?
- Are evaporators preferable to holding tanks?
- Are incinerators preferable to evaporators?

- Is reduced volume collection preferable to reduced volume macerator/transfer (M/T) pump collection?
- Is oil recirculation preferable to flow through treatment?

As was pointed out earlier, in making comparisons between candidate WMS concepts it is important to compare systems which are similar in all except one respect, i.e., to investigate one variable at a time in order to avoid confounding the issue by other differences which may not be relevant. This principle can be applied by making side-by-side direct comparisons of the candidate WMS concepts on each vessel which are similar in all respects, except for the substitution of a holding tank for an incinerator or evaporator, an incinerator for an evaporator, vacuum collection for pump collection, oil recirculation for flow through treatment, etc.

Such comparisons of WMS concepts are presented in Table 16. The following inferences can be made from the results in this table.

- For all viable system/vessel combinations where such comparisons can be made, a holding tank is more effective and less costly (therefore more cost-effective) than an incinerator.
- For all viable system/vessel combinations where such comparisons can be made, a holding tank is more effective and less costly than an evaporator.
- For all viable system/vessel combinations where such comparisons can be made, an evaporator is more effective and less costly than an incinerator.
- For all viable system/vessel combinations where such comparisons could be made, pump collection is more effective than vacuum collection. However, no pattern is evident with respect to life cycle cost and cost-effectiveness. This indicates that other considerations which are vessel dependent (i.e., WMS equipment configuration differences affecting acquisition cost, differences in vessel conditions affecting installation, etc.) are more important in determining life-cycle cost than the difference between vacuum and pump

Table 16

COMPARISON OF WMS CONCEPTS *

Page 1 of 2

ITEM OF COMPARISON	GALLATIN (378')			VIGOROUS (210')			FIREBUSH (180')			PAMLICO (160')			WHITE SAGE (133')			POINT HUDSON (82')		
	Cost ($K)	Effectiveness Rating (%)	Relative C/R$_E$ Ratio (%)	Cost ($K)	Effectiveness Rating (%)	Relative C/R$_E$ Ratio (%)	Cost ($K)	Effectiveness Rating (%)	Relative C/R$_E$ Ratio (%)	Cost ($K)	Effectiveness Rating (%)	Relative C/R$_E$ Ratio (%)	Cost ($K)	Effectiveness Rating (%)	Relative C/R$_E$ Ratio (%)	Cost ($K)	Effectiveness Rating (%)	Relative C/R$_E$ Ratio (%)
1. Holding tank (WMS No.) vs incinerator (WMS No.) for concentrated waste or sludge																		
. Oil recirculation, gray water holding (2) vs (3)	135.988 vs 217.483	72 vs 68	25 vs 42	46.358 N/A 105.495	69 N/A	17 N/A	47.328 vs 105.495	71 vs 69	14 vs 33	59.160 vs 74.735	64 vs 61	44 vs 59	46.533 vs 58.040	68 vs 65	29 vs 37	N/A	N/A	N/A
. Gravity collection flow through treatment of black water, gray water holding (4) vs (7)	114.804 vs 221.996	77 vs 72	20 vs 40	N/A	N/A	N/A	59.642 vs 104.949	76 vs 72	17 vs 31	68.501 vs 110.249	68 vs 63	48 vs 84	56.434 vs 96.242	74 vs 68	32 vs 59	N/A	N/A	N/A
. Gravity collection, flow through treatment of combined black and gray water (5) vs (8)	N/A	N/A	N/A	N/A	N/A	N/A	88.145 vs 164.309	77 vs 71	24 vs 49	57.432 vs 96.968	71 vs 65	39 vs 71	51.103 vs 85.265	76 vs 69	28 vs 52	N/A	N/A	N/A
. Vacuum collection, gray water holding (9) vs (10)	225.474 vs 435.003	64 vs 57	46 vs 100	** 126.924 vs 220.107	** 61 vs 55	** 52 vs 100	96.505 vs 200.935	64 vs 57	32 vs 75	44.002 vs 94.065	64 vs 55	33 vs 82	44.345 vs 89.990	64 vs 56	29 vs 67	28.058 N/A	60 N/A	57 N/A
. Vacuum collection, gray water flow through treatment (12)vs (13)	N/A	N/A	N/A	N/A	N/A	N/A	163.557 vs 244.331	56 vs 52	62 vs 100	72.605 vs 108.959	56 vs 52	62 vs 100	73.991 vs 109.560	56 vs 51	55 vs 90	N/A	N/A	N/A
. Pump collection, gray water holding (14) vs (15)	249.329 vs 406.995	72 vs 65	45 vs 82	113.882 vs 195.930	74 vs 65	38 vs 75	68.812 vs 169.382	75 vs 68	20 vs 53	57.975 vs 108.996	71 vs 61	39 vs 85	53.402 vs 97.771	70 vs 62	32 vs 66	29.289 N/A	71 N/A	51 N/A
. Pump collection, gray water flow through treatment (17) vs (18)	N/A	N/A	N/A	N/A	N/A	N/A	135.709 vs 211.911	68 vs 64	43 vs 70	86.689 vs 120.925	63 vs 58	66 vs 100	91.509 vs 128.942	62 vs 54	62 vs 100	N/A	N/A	N/A
2. Holding tank (WMS No.) vs evaporator (WMS No.) for concentrated black water.																		
. Vacuum collection, gray water holding (9) vs (11)	225.474 vs 349.527	64 vs 58	46 vs 79	** 126.924 vs N/A	** 61 vs N/A	** 52 vs N/A	96.505 vs 154.074	64 vs 58	32 vs 56	44.002 vs 59.173	64 vs 60	33 vs 47	44.345 vs 64.258	64 vs 59	29 vs 46	28.058 vs 45.559	60 vs 56	57 vs 100
. Pump collection, gray water holding (14) vs (16)	249.329 vs 377.454	72 vs 67	45 vs 74	113.882 vs 173.901	74 vs 69	38 vs 63	68.812 vs 117.251	75 vs 70	20 vs 36	57.975 vs 75.640	71 vs 66	39 vs 55	53.402 vs 72.375	70 vs 66	32 vs 46	29.289 vs 45.579	71 vs 66	51 vs 87

* The system number appears in brackets ( ) and the highest number precedes the lowest number. A lower value of relative C/R$_E$ ratio is more cost effective.

** Only 48% of required black water holding capacity provided.

Table 16

COMPARISON OF WMS CONCEPTS*

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ITEM OF COMPARISON	GALLATIN (378')			VIGOROUS (210')			FIREBUSH (180')			PAMLICO (160')			WHITE SAGE (133')			POINT HERRON (82')		
	Cost ($K)	Effectiveness Rating (%)	Relative C/R_E Ratio (%)	Cost ($K)	Effectiveness Rating (%)	Relative C/R_E Ratio (%)	Cost ($K)	Effectiveness Rating (%)	Relative C/R_E Ratio (%)	Cost ($K)	Effectiveness Rating (%)	Relative C/R_E Ratio (%)	Cost ($K)	Effectiveness Rating (%)	Relative C/R_E Ratio (%)	Cost ($K)	Effectiveness Rating (%)	Relative C/R_E Ratio (%)
3. Incinerator (WMS No.) vs evaporator (WMS No.) for concentrated black water.																		
. Vacuum collection, gray water holding (10) vs (11)	435.003 vs 349.527	57 vs 58	100 vs 79	220.107 vs N/A	55 vs N/A	100 vs N/A	200.935 vs 154.074	57 vs 58	75 vs 56	94.065 vs 59.173	55 vs 60	82 vs 47	89.990 vs 64.258	56 vs 59	67 vs 46	N/A 45.559	N/A 56	N/A 100
. Pump collection, gray water holding (15) vs (16)	406.995 vs 377.454	65 vs 67	82 vs 74	195.930 vs 173.901	65 vs 69	75 vs 63	169.382 vs 117.251	68 vs 70	53 vs 36	108.996 vs 75.640	61 vs 66	85 vs 55	97.771 vs 72.375	62 vs 66	66 vs 46	N/A 45.579	N/A 66	N/A 87
4. Vacuum collection (WMS No.) vs pump collection (WMS No.)																		
. Black and gray water holding (9) vs (14)	225.474 vs 249.329	64 vs 72	46 vs 45	** 126.924 vs 113.882	** 61 vs 74	** 52 vs 38	96.505 vs 68.812	64 vs 75	32 vs 20	44.002 vs 57.975	64 vs 71	33 vs 39	44.345 vs 53.402	64 vs 70	29 vs 32	28.058 vs 29.289	60 vs 71	57 vs 51
. Incineration of concentrated black water, gray water holding (10) vs (15)	435.003 vs 406.995	57 vs 65	100 vs 82	220.107 vs 195.930	55 vs 65	100 vs 75	200.935 vs 169.382	57 vs 68	75 vs 53	94.065 vs 108.996	55 vs 61	82 vs 85	89.990 vs 97.771	56 vs 62	67 vs 66	N/A	N/A	N/A
. Evaporation of concentrated black water, gray water holding (11) vs (16)	349.527 vs 377.454	58 vs 67	79 vs 74	N/A 173.901	N/A 69	N/A 63	154.074 vs 117.251	58 vs 70	56 vs 36	59.173 vs 75.640	60 vs 66	47 vs 55	64.258 vs 72.375	59 vs 66	46 vs 46	45.559 vs 45.579	56 vs 66	100 vs 87
. Holding of concentrated black water and gray water sludge (12) vs (17)	N/A	N/A	N/A	N/A	N/A	N/A	163.557 vs 135.709	56 vs 68	62 vs 43	72.605 vs 86.689	56 vs 63	62 vs 66	73.991 vs 91.509	56 vs 62	55 vs 62	N/A	N/A	N/A
. Incineration of concentrated black water and gray water sludge (13) vs (18)	N/A	N/A	N/A	N/A	N/A	N/A	244.331 vs 211.911	52 vs 64	100 vs 70	108.959 vs 120.925	52 vs 58	100 vs 100	109.560 vs 128.942	51 vs 54	90 vs 100	N/A	N/A	N/A
5. Oil recirculation (WMS No.) vs flow through treatment (WMS No.)																		
. Black water sludge and gray water holding (2) vs (4)	135.988 vs 114.804	72 vs 77	25 vs 20	46.358 N/A	69 N/A	17 N/A	47.328 vs 59.642	71 vs 76	14 vs 17	59.160 vs 68.501	64 vs 68	44 vs 48	46.533 vs 56.434	68 vs 74	29 vs 32	N/A	N/A	N/A
. Black water sludge incineration, gray water holding (3) vs (7)	217.483 vs 221.996	68 vs 72	42 vs 40	N/A	N/A	N/A	105.495 vs 104.949	69 vs 73	33 vs 31	74.735 vs 110.249	61 vs 63	59 vs 84	58.040 vs 96.242	65 vs 68	37 vs 59	N/A	N/A	N/A

* The system number appears in brackets ( ) and the highest precedes the lowest number. A lower value of relative C/R_E ratio is more cost effective.

** Only 48% of required black water holding capacity provided.

collection. The reason for the higher overall effectiveness ratings of pump collection vs vacuum collection can be determined by examining the results of the effectiveness ratings for viable system/vessel combinations presented in Table 13. These results indicate that WMS concepts utilizing pump collection consistently exhibit significantly higher ratings for the M/Es "Operability" and "Reliability" than the WMS concepts utilizing vacuum collection. The higher Reliability ratings for pump collection result from its greater redundancy and lower complexity than for vacuum collection which is centralized.

- For all viable system/vessel combinations where such comparisons can be made, oil recirculation is less effective than flow through treatment, with no pattern apparent for life-cycle cost or cost effectiveness. This indicates that other vessel dependent considerations are more important in determining life-cycle cost. Although the acquisition cost is lower for oil recirculation, the 100% utilization factor for the treatment subsystem tends to neutralize this advantage. The lower overall effectiveness rating for oil recirculation results from its consistently lower ratings for the M/Es "Operability" and "Habitability".

The above inferences regarding a holding tank vs an incinerator or evaporator take on special significance when one takes into account the holding capacities of the WMS concepts being compared. With the exception of WMS No. 9 on the VIGOROUS, all other pairs of WMS concepts comparing a holding tank to an incinerator or evaporator provide full holding capacity for black water (but not for gray water).

One can therefore conclude than an incinerator (besides being less cost-effective) provides no advantage in black water holding capacity, except for the VIGOROUS, on which WMS No. 10 (with incinerator) provides 100% of required black water holding capacity vs 48% for WMS No. 9 (with holding tank). Similarly, one can conclude that an evaporator (besides being less cost-effective) provides no advantage in black water holding capacity over a holding tank. It is noted that even on the

VIGOROUS, the 48% black water holding capacity of WMS No. 1 (with holding tank) could not be offset by WMS No. 11 (with evaporator) since the latter is not a viable candidate. Thus, the improvement in holding time which the evaporator might have provided could not be taken advantage of on this vessel due to the inability to install this configuration. Further examination of the WMS concepts being compared indicates also that incinerators or evaporators offer no advantage in gray water holding capacity.

This lack of advantage in either black or gray water holding capacity of incinerators or evaporators is especially significant in view of the fact that the goals for holding capacity are based on the maximum holding time for each vessel. Thus, the holding time requirements can therefore be only overstated rather than understated. The implication of this is that incinerators and evaporators are either not usable (due to the inability to install the associated configuration) or, when usable, are not required.

In view of the above discussion, the results indicating that evaporators are more cost-effective than incinerators may be academic. The advantages of incinerators over evaporators and holding tanks is the indefinite holding times which they provide. Although this consideration is one of the factors in the M/E "Performance," the overwhelming majority of cost as well as effectiveness considerations tend to favor holding tanks over incinerators and evaporators.

Ranges for Cost and Effectiveness

Ranges of cost and effectiveness values are of interest when comparing candidates, since this brings out differences which are inherent in the systems. In addition, the analysis of extremes (minimum and maximum values) to determine the reasons why the highest and lowest values are associated with certain candidates may provide useful insights into system properties.

Highest and lowest values for a number of cost effectiveness ratings and other properties of viable system/vessel combinations are presented in Table 17. Some observations about the range of values in Table 17 are discussed below.

Table 17

RANGES FOR COST AND EFFECTIVENESS RESULTS*

Sheet 1 of 2

CHARACTERISTIC	GALLATIN (378')	VIGOROUS (210')	FIREBUSH (180')	PAMLICO (160')	WHITE SAGE (133')	POINT HERRON (82')
1. Cost Effectiveness rank determined by relative ratio of cost to effectiveness rating (%). A lower rank is more cost effective.	(10) 100 (1) 9	(10) 100 (1) 5	(13) 100 (1) 6	(13) (18) 100 (1) 22	(18) 100 (1) 9	(11) 100 (1) 9
2. Life cycle costs ($K)						
. Overall WMS cost per vessel.	(10) 435.003 (1) 58.383	(10) 220.107 (1) 15.709	(13) 244.331 (1) 22.474	(18) 120.925 (1) 36.780	(18) 128.942 (1) 18.974	(16) 45.579 (1) 6.070
. Per capita WMS cost.	(10) 2.862 (1) 0.384	(10) 3.668 (1) 0.262	(13) 4.887 (1) 0.449	(18) 9.302 (1) 2.829	(18) 6.140 (1) 0.904	(16) 5.947 (1) 0.759
. Fixed Costs (capital investment)	(16) 205.220 (1) 47.260	(16) 94.640 (1) 10.200	(13) 163.670 (1) 16.850	(7) 85.330 (9) 19.890	(18) 87.800 (1) 13.190	(11) 28.690 (1) 2.410
. Recurring Expenditures (Opera and Maintenance costs)	(10) 235.703 (1) 11.123	(10) 126.177 (1) 5.509	(10) 101.595 (1) 5.624	(15) 49.046 (1) 7.160	(15) 44.971 (1) 5.784	(16) 19.909 (1) 3.660
. Acquisition cost.	(16) 163.500 (1) 0	(16) 83.080 (1) 0	(13) 134.350 (1) 0	(18) 64.510 (9) 0	(18) 72.160 (1) 0	(11) 24.000 (1) 0
. Installation cost.	(15) 78.120 (4) 39.980	(10) 23.530 (1) 10.200	(10) 33.740 (2) 12.060	(3) 30.590 (12) 12.760	(7) 23.080 (12) 10.600	(9) 5.460 (1) 2.410
. Operating cost.	(10) 35.239 (1) 1.942	(10) 13.819 (1) 0.645	(13) 17.991 (1) 2.378	(3) 10.986 (1) 2.347	(3) 10.999 (1) 1.751	(11) 3.281 (1) 0.928
. Preventive maintenance cost.	(16) 31.227 (3) 2.654	(16) 15.847 (1) 1.438	(16) 8.209 (1) 1.198	(12) 5.745 (3) 1.081	(12) 5.745 (3) 1.081	(11) 5.149 (1) 1.198
. Corrective maintenance cost.	(15) 149.884 (1) 2.636	(10) 57.040 (1) 1.223	(15) 43.399 (1) 0.664	(15) 29.912 (1) 1.505	(15) 26.200 (1) 0.725	(16) 9.401 (1) 0.264
. Overhaul cost.	(10) 80.160 (1) 3.669	(10) 48.086 (1) 2.203	(10) 37.415 (1) 1.384	(13) 10.554 (1) 1.870	(13) 10.554 (1) 1.870	(11) 4.175 (1) 1.270

* In each column, the system number appears in brackets ( ) and the highest number precedes the lowest number.

Table 17

RANGES FOR COST AND EFFECTIVENESS RESULTS*

Sheet 2 of 2

CHARACTERISTIC	GALLATIN (378')	VIGOROUS (210')	FIREBUSH (180')	PAMLICO (160')	WHITE SAGE (133')	POINT HERRON (82')
3. Effectiveness Ratings (%)						
. Overall effectiveness rating	(1) 87 (10) 57	(1) 84 (10) 55	(1) 86 (13) 52	(1) 80 (13) 52	(1) 86 (13) 51	(1) 82 (11) 56
. Adaptability for shipboard installation rating.	(1) 88 (16) 64	(1) 84 (15) 62	(4) (5) 83 (18) 57	(12) 74 (7) (8) 54	(1) 95 (18) 67	(1) 85 (16) 50
. Performance rating.	(3) 76 (11) 58	(10) 70 (2) 56	(3) (8) 75 (11) 57	(8) 71 (11) 54	(8) 74 (16) 61	(14) 68 (11) 57
. Operability rating	(1) 91 (2) (3) 52	(1) 91 (10) 52	(1) 90 (2) (3) 51	(1) 87 (2) 46	(1) 87 (2) 46	(1) 83 (9) 65
. Personnel safety rating	(1) (9) 95 (7) 80	(1) (9) 95 (15) 87	(1) (6) (9) (12) 95 (8) 72	(1) (6) (9) (12) 95 (8) 72	(1)(6)(9)(12) 95 (8) 60	(1) (9) 95 (16) 89
. Habitability rating	(1) 75 (3) 36	(1) 75 (15) 50	(1) 75 (3) 46	(1) 75 (3) 36	(1) 75 (3) 36	(1) 75 (16) 60
. Reliability rating.	(1) 96 (10) 33	(1) 95 (10) 31	(1) 96 (10) 31	(1) 90 (13) 22	(1) 94 (13) 19	(1) 91 (11) 36
. Maintainability rating.	(1) 92 (11) (16) 41	(1) 93 (16) 44	(1) 93 (11) 35	(1) 84 (12) 37	(1) 86 (12) 41	(1) 85 (11) 38
4. Figures of merit						
. Per capita WMS weight (lb.).	(1) 1,040 (16) 558	(14) 641 (16) 321	(6) 2,108 (2) 496	(1) 8,585 (13) 1,105	(1) 1,692 (8) 670	(9) 937 (1) 585
. Per capita WMS volume (ft.^{3}).	(3) 31.5 (7) 27.7	(15) 22.0 (1) 20.9	(12) 90.8 (2) 30.2	(3) 289.3 (8) 73.8	(7) 137.3 (16) 71.6	(14) 96.4 (1) 51.3
. Per capita annual energy consumption (Kwh).	(10) 679 (2) 4	(10) 411 (2) 2	(13) 947 (2) 5	(13) 2,514 (2) 31	(13) 847 (2) 3	(11) 116 (1) 1

* In each column, the system number appears in brackets ( ) and the highest number precedes the lowest number.

a. Cost Effectiveness

The cost effectiveness rank varies over a wide range (of more than 10 to 1) except for the PAMLICO, which has a vacuum collection system and significantly different mission profile characteristics. For all vessels, WMS No. 1 is the most cost effective candidate.

b. Life Cycle Costs

The life cycle cost, both on a vessel as well as on a per capita basis, varies over a wide range, the lowest variation being for the PAMLICO due to its specialized collection system and mission profile characteristics. The lowest life cycle cost is associated with WMS No. 1 and the highest cost is associated with systems which employ a specialized collection subsystem and an incinerator (WMS Nos. 10, 13, 18) or evaporator (WMS No. 16) in conjunction with a holding tank (WMS Nos. 10, 16) or a Grumman flow through treatment system (WMS Nos. 13, 18). The reason for the low life cycle cost of WMS No. 1 is its low capital cost (since it requires little additional equipment and installation) and low recurring expenditures (due to the simplicity of the system). Opposed to this is the complex equipment required for the other systems, resulting in expensive acquisition, installation, operation and maintenance.

Capital costs vary over a wide range, being lowest for WMS No. 1 and highest for WMS Nos. 11, 13, 16, 18. The exception is the PAMLICO, in which case the lowest fixed cost is for WMS No. 9 and the highest for WMS No. 7. The large difference in capital costs between the candidates stems largely from the type of collection system aboard the vessel. The original acquisition and installation costs for the existing drain system are not accounted for, resulting in high costs for conversion. The balance of the difference is due to the higher acquisition and installation costs associated with the more complex systems (incinerators, evaporators, waste treatment equipment).

The above is confirmed by an examination of the individual acquisition and installation cost elements in Table 17. The acquisition cost for tanks is zero by definition (the entire cost for tanks being included in the installation cost), resulting in an acquisition cost of zero for WMS No. 1 on all vessels except on the PAMLICO. On this vessel, zero acquisition cost is associated with the existing drain system corresponding to WMS No. 9. It is also noted that installation costs are hightly vessel dependent due to dependence on conditions existing on board the vessel.

Recurring expenditures vary over a wide range being lowest for WMS No. 1 and highest for WMS Nos. 10, 15 and 16. The low values for WMS No. 1 are due to the simplicity of this system, resulting in low operating costs (low labor and vessel resource costs) and low maintenance costs (low labor and parts costs). The high costs of operating and maintaining the other candidates results from their complexity (which increases maintenance costs) and the use of an incinerator or evaporator which results in higher operating costs (due to higher labor and vessel resource costs). The above conclusions regarding this variation in recurring expenditures as a function of system complexity can be confirmed by examining the individual cost elements (i.e., operation, preventive and corrective maintenance, and overhaul) in Table 17.

c. Effectiveness Ratings

In order to facilitate the interpretation of the results for effectiveness ratings, it is necessary to refer to the effectiveness model. Specifically, reference should be made to the measures of effectiveness (M/Es) and their associated weights (Table 12) and the factors/subfactors together with their associated weights (presented in a discussion of the effectiveness model), as well as the individual effectiveness rating functions for each elementary factor/subfactor (presented in Volume II). In general, the rating for each elementary factor/subfactor depends on either the WMS concept alone (independent of the vessel), or on the specific WMS configuration and equipment sizing, in which case such ratings are both system and vessel dependent. The above should be kept in mind when interpreting the effectiveness rating results in Table 13.

The overall effectiveness rating is highest for WMS No. 1 and lowest for WMS Nos. 10, 11 and 13 which consist of a vacuum collection subsystem and either an incinerator or an evaporator in conjunction with a holding tank or a Grumman treatment system. The overall effectiveness ratings range from 87% (WMS No. 1/GALLATIN) to 51% (WMS No. 13/WHITE SAGE).

The ratings for the M/E "Adaptability for Shipboard Installation" vary from 95% (WMS No. 1/WHITE SAGE) to 54% (WMS Nos. 7 or 8/ PAMLICO). No pattern is apparent since these ratings are highly dependent on the specific WMS equipment configuration which differs from vessel to vessel even for the same WMS concept, and on conditions aboard the vessel (as was the case for installation cost estimates).

The ratings for the M/E "Performance" vary from 76% (WMS No. 3/GALLATIN) to 54% (WMS No. 11/PAMLICO) with no pattern being apparent. The vessel dependent considerations (factors/subfactors), resulting from differences in equipment configurations and sizing for the same WMS concept, include: the figures of merit (per capita weight, volume and energy consumption); adequacy of holding times (for systems which utilize black and/or gray water holding tanks); the ability to handle peaks (on systems employing influent surge tanks); and the ability to handle additional personnel. Since the highest "Performance" rating for any system is 76%, this indicates that none of the system/vessel combinations obtained high ratings for all or most of the considerations relevant to this M/E.

The ratings for "Operability" are highest for WMS No. 1 on all vessels and lowest for WMS Nos. 2, 3, 9 and 10. The ratings range from 91% (WMS No. 1/GALLATIN or VIGOROUS) to 46% (WMS No. 2/PAMLICO or WHITE SAGE). Considerations which are vessel dependent and which also account for the high ratings for WMS No. 1 include the burden on operating personnel (labor, etc.), and operational supplies.

Ratings for "Personnel Safety" range from 95% to 60%. Systems rated high are WMS Nos. 1, 6, 9 and 12 (which consist of either a gravity or a vacuum collection subsystem, holding tanks, and may include a Grumman treatment system without an incinerator). Systems rated low include WMS Nos. 7, 8, 15 and 16 (which include an incinerator or an evaporator). Vessel dependent considerations include the proximity of WMS equipment to working and berthing areas or to a fuel tank.

Ratings for "Habitability" range from 75% for WMS No. 1 on all vessels to 36% for WMS No. 3 (Chrysler oil recirculation with an incinerator). Vessel dependent considerations include the proximity of WMS equipment to working and berthing areas. The relatively low maximum rating of 75% indicates that none of the WMS concepts received high ratings for all or most of the considerations relevant to this M/E. Although most of the individual elementary factor/subfactor ratings are 100% for WMS No. 1, it received a rating of 0 for odor production* (due to the holding tanks) which has a weight of 25%, resulting in its overall rating of 75%.

Ratings for the M/E "Reliability" range from 96% (WMS No. 1/ GALLATIN) to 19% (WMS No. 13/WHITE SAGE). The highest ratings are associated with WMS No. 1 and the lowest ratings are associated with WMS Nos. 10, 11 and 13 which employ vacuum collection with either an incinerator or an evaporator in conjunction with a holding tank or a Grumman treatment system. Vessel dependent considerations are due to WMS equipment configuration differences, include the number of equipment failures and configuration redundancy.

Ratings for the M/E "Maintainability" range from 93% (WMS No. 1/ VIGOROUS or FIREBUSH) to 35% (WMS No. 11/FIREBUSH). The highest ratings are associated with WMS No. 1 and lowest ratings are associated with WMS Nos. 11, 12, and 16 which employ reduced volume collection and include either an evaporator or a Grumman treatment system. Vessel dependent considerations,

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*See ERFs in Volume II

due to WMS equipment configuration differences, include labor requirements (frequency and man-hours for PM, CM and overhaul), spares stockage requirements, and differences in clearance around the equipment (for maintenance) provided by each installation.

d. Figures of Merit

No pattern is apparent for the values of per capita weight and volume. Both the highest and the lowest values are highly vessel dependent. These results are due to the following:

- The discrete nature of WMS equipment capacities (which sometimes results in over-capacity relative to the crew size).
- Inclusion of systems which do not provide full holding capacity (i.e., the black and gray water holding tank capacities, in relation to the crew size, varies from vessel to vessel).
- The inherent differences in the drain piping weights and volumes in relation to the crew size from vessel to vessel.
- The inaccuracies in estimating the weight and volume of the existing as well as installed drain piping.

The annual per capita energy consumption (in Kwhr) varies over a very wide range from 1 (WMS No. 1/POINT HERRON) to 2,514 (WMS No. [illegible]/PAMLICO). The lowest values are associated with WMS [illegible]. 1 and WMS No. 2 (Chrysler oil recirculation in conjunction with holding tanks). The highest values are associated with WMS Nos. 10, 11 and 13, indicating that the most energy intensive systems are those which have either an incinerator or an evaporator. It is also noted that the maximum per capita energy consumption varies over a wide range (from 116 to 2,514) and it is vessel dependent. The reason for this is that the per capita energy consumption is highly dependent on the WMS utilization factor. Comparison of the utilization factors associated with each vessel and the maximum per capita energy consumption indicates strong correlation between them, as shown in the tabulation below.

Vessel	WMS Utilization Factor (%)	Maximum Annual Per Capita Energy Consumption	
		Value (Kwh)	WMS No.
PAMLICO (160')	31.0	2,514	13
FIREBUSH (180')	14.1	947	13
WHITE SAGE (133')	11.1	847	13
GALLATIN (378')	11.0	679	11
VIGOROUS (210')	5.6	411	10
POINT HERRON (82')	1.8	116	11

The reason for the strong dependence of the maximum per capita energy consumption on the WMS utilization factor is that most of the energy consumption is due to the waste Treatment/ Disposal subsystem, whose operation is dependent on the vessel mission profiles. It is noted from the above table that although the maximum per capita energy consumption is highly dependent on the WMS utilization factor, it does not seem to be proportional. This is due to the fact that the most energy intensive system, WMS No. 13 (Vacuum collection, a Grumman treatment system for gray water, and an incinerator for the black water and gray water sludge), is not a viable candidate on all vessels. Thus, on the three vessels (FIREBUSH, PAMLICO, WHITE SAGE) on which WMS No. 13 is a viable candidate, the maximum per capita energy consumption and WMS utilization factor are approximately proportional. The greatest discrepancy occurs between the GALLATIN and the WHITE SAGE which have almost identical WMS utilization factors (11% vs 11.1%) but their maximum per capita energy consumptions are considerably different (679 vs 847), since these maximum values are associated with different system concepts (WMS No. 10 vs. WMS No. 13).

Variations in Results Across Vessels

It has been noted in the previous discussions that certain results do not always follow a well defined pattern from vessel to vessel even when comparing similar WMS concepts. Some of the reasons for this seeming lack of consistency have been given in the discussion for specific results. When well defined patterns of results are discerned, it indicates that the characteristic relevant to this pattern is sufficiently dominant to overcome the influence of those considerations which tend to cause a lack of consistency.

A summary of the considerations which result in a lack of uniformity in results across vessels follows.

- The elimination of certain WMS concepts on different vessels tends to distort all results (cost, effectiveness ratings and optimum system selections based on ranking) which are based on normalization (i.e., division of results by the largest number).
- Differences in performance requirements due to vessel mission profiles (i.e., the maximum holding time requirement) results in WMS configuration requirements for similar WMS concepts on different vessels which are disproportionate in relation to the crew sizes. This results in "distortions" not only in acquisition and installation costs but preventive maintenance costs, overhaul costs and effectiveness ratings for elementary factors/subfactors.

- Differences in WMS utilization factors due to vessel mission profiles would result in different operating and maintenance costs as well as in effectiveness ratings of related elementary factors/subfactors, even if any other differences did not exist.
- The discrete capacities of MSD subsystems/equipments sometimes results in mismatches between installed capacity and crew size. This results in distortions in acquisition and installation costs in relation to the crew size. Similarly, the same WMS configuration on vessels which have different crew sizes (which can result from the discrete capacities) would result in different operating and maintenance costs as well as in effectiveness ratings of related elementary factors/subfactors, even if any other differences did not exist.
- Differences in both the physical conditions as well as in the presence of some waste treatment equipment (holding tanks, non-standard drain system, special fixtures, etc.) result in "distortions" in installation and acquisition costs as well as installation related effectiveness ratings even if any other differences did not exist.
- The inclusion of WMS configurations which do not fulfill the full holding capacity for black and/or gray wastewater tends to distort both the installation cost as well as effectiveness ratings for elementary factors/subfactors relevant to installation and to holding capacity.

EFFECTIVENESS ASSESSMENTS

In comparison to the life-cycle cost analysis, the effectiveness assessment methodology developed and used in this study may seem somewhat esoteric and perhaps controversial. The reason for this may very well be due to the differences in the units of measurement which each of these two analyses use and the associated underlying concepts.

The life-cycle cost analysis deals with money, a universal unit and a concept which is familiar to everyone and is part of everyone's daily experience. By contrast, effectiveness deals with quality. But, quality immediately implies two things, namely, subjectivity and a standard (i.e., requirement, objective, constraint), against which the quality is to be measured.

However, there is no such thing as a universal standard of quality, since quality is a function of goals and requirements and these, in turn, depend on the specific set of candidate systems, processes, approaches, etc. being analyzed and compared. As a result, there is no universal measure and associated unit for quality.

The effectiveness assessment methodology used in this study is intended to provide a means for quantifying quality and taking all relevant considerations into account. The effectiveness ratings are the units of quality. The following paragraphs discuss some of the aspects and issues associated with the effectiveness assessment methodology. The nature, use and interpretation of effectiveness ratings are also discussed.

Subjective Judgement, Repeatability and Validity of Results

Subjective judgements* of the analyst play a prominent role in the development of effectiveness rating functions (ERFs) as well as the effectiveness model structure and the associated weights. Thus, such subjective judgements become an integral part of the resulting ERFs and are therefore reflected in the effectiveness ratings of candidate system/vessel combinations for the elementary factors/subfactors (and subsequently the M/E ratings and the overall effectiveness ratings).

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*It is noted that "subjective judgement" is somewhat of a redundancy since it is questionable whether there is such a thing as "objective judgement". Thus, if the judgement were purely objective, it would imply that the same conclusion could be arrived at by logical deduction, in which case, it would not be a judgement but rather a determination and, in fact, could be performed without human intervention - e.g., by a computer.

This raises a potentially serious question regarding the meaning and validity of the results. Thus, if the effectiveness ratings are dependent on the particular analyst conducting the study, then it might be inferred that if different decision makers conducted the analysis, different results might be obtained, i.e., the results are not necessarily repeatable across different analysts. Such an a priori conclusion regarding the seeming lack of "stability" of the results, may be alarming or disturbing and may prompt questions as to the identity and source of the "real" or "true" ERFs. It is noted that a similar issue can be raised regarding the structure of the effectiveness model and the associated weights.

The resolution of this apparent dilemma lies in the nature, definition, and intent of an effectiveness analysis. It will be recalled that effectiveness was defined as inherently being subjective in nature and dependent on the decision-maker, i.e., effectiveness is what the decision-maker says it is, or, effectiveness is in the eyes of the beholder.

Although this may seem like a circuitous and self-serving definition of effectiveness, it is noted that it corresponds to the manner in which decisions are made by individuals whether in their personal lives or in making consequential decisions based on highly technical information. In fact, making a decision, by definition, implies the exercise of a subjective and judgemental faculty, rather than a process of arriving at a conclusion on the basis of some objective set of rules. Thus, for example, it would not be meaningful to ask someone to decide whether system A weighs more than system B. Rather, one can be asked to determine whether system A weighs more than system B. On the other hand, one cannot determine, but rather one would have to decide, whether one system aspect is more important, better, nicer, worthier, preferred, etc., than another.

Another point to keep in mind in connection with the nature of the above dilemma is that a numerical quantity for effectiveness is not meaningful in an absolute sense but only in a relative sense. Thus, regardless of the specific numerical assignments that are made, as long as they are consistent, differences among candidate system/vessel combinations can be brought out. This is the basic purpose of an effectiveness analysis. An effectiveness analysis is not in itself a decision-making process. Instead, effectiveness analysis is a tool which the decision-maker can use to obtain the information he needs in a systematic manner and organize it in a convenient form for use by him in the decision-making process.

Some Characteristics and Features of the Effectiveness Assessment Methodology

The effectiveness assessment methodology developed as part of this study has been found to be applicable for quantifying the effectiveness of candidate system/vessel combinations at several levels of detail. It thus enables a decision-maker to compare candidates with respect to different individual aspects of effectiveness as well as the overall effectiveness. If used properly, this methodology can serve as a useful analytic tool for cost-effectiveness studies, trade-off studies, sensitivity analyses, etc. Some of the relevant characteristics and features of this methodology are as follows:

- It can accommodate all considerations of interest to the decision-maker.
- It synthesizes technical and objectively determined quantitative system/vessel data with qualitative system/vessel information and subjective judgements of the decision-maker.
- It is highly flexible with respect to the range and magnitude of the problems it can accommodate. Thus, the analysis can be either very detailed and comprehensive which may be suitable for large-scale systems, or it can be much smaller in scope and less detailed as warranted by the objectives of the study and the data available.
- It provides results at several levels of detail. Effectiveness ratings for each candidate are provided on three levels as follows:

  - An overall effectiveness rating
  - A rating for each effectiveness measure
  - A rating for each elementary factor/subfactor

- It provides a means of determining the effect of changes in data, assumptions, subjective judgements, etc.

- It has been found that application of the methodology tends to clarify issues, may result in a fresh outlook and often new insights are gained, even by knowledgeable individuals who are familiar with the problem. This is due to the following aspects of the methodology:

  - Effectiveness is defined in terms of, and directly related to, the objectives, requirements and constraints of the problem.

  - Development of the structure of the effectiveness model requires the determination of overall assessment criteria followed by a systematic and successive breakdown of each overall criterion into constituent sub-criteria. This process results in an in-depth examination of the problem. Thus, issues which have either been overlooked or which were vague and ill-defined are identified and resolved.

  - The need to assign a weight to designate the relative importance of each criterion encourages reflection on the basic issues pertaining to the objectives, requirements, etc.

  - Development of effectiveness rating functions results in consideration of the relevant requirements, constraints, the type of data available, the level of detail of the analysis, and identification of the judgements used in deciding what is desirable as well as undesirable.

Properties, Interpretation and Use of Effectiveness Ratings

a. Meaning of Effectiveness Ratings

Although the overall effectiveness rating of a candidate is a number in the range of 0 to 100%, it cannot be legitimately interpreted as a probability. Instead, the rating should be interpreted as a measure of the overall quality or "worth" of the candidate, determined as a weighted average of all considerations, i.e., the extent to which the aggregate of all the individual criteria are satisfied, weighted by the importance of each one relative to the others. Also, overall effectiveness ratings are to be used mainly for comparing candidate systems rather than in an absolute sense.

Similarly, the ratings of candidates with respect to individual M/Es are not to be interpreted as probabilities. It is especially important to keep this in mind when considering M/Es whose attributes or characteristics are usually given as probabilities.

Examples of such M/Es are "RELIABILITY" and "MAINTAINABILITY" whose ratings for a given candidate system do not have the usually used interpretation of being the probability that the system will not fail for a given period of time (Reliability) or the probability that the system will be restored within a given time interval (Maintainability). Instead, the ratings of candidates with respect to these M/Es are to be used for comparing the Reliability and Maintainability of the candidate systems. Furthermore, these M/E ratings may be based either entirely on objectively determined quantitative data, or partially on such data and partially on qualitative system information and subjective judgements. Hence, it is important to be aware of the distinction between the Reliability and Maintainability of a candidate system, which are characteristics or attributes of the system, and the effectiveness ratings of the system for the M/Es "RELIABILITY" and "MAINTAINABILITY" which include subjective judgements pertaining to such issues as what constitutes minimum acceptable and ideal levels as well as the "worth" of intermediate levels of the values for these attributes. It is noted that the Reliability or Maintainability of a candidate system, i.e., the associated probability values, may serve as an input (i.e., the attribute variable in the effectiveness rating function) in rating the system for the M/Es "RELIABILITY" and "MAINTAINABILITY", but the rating may be based on other inputs as well. If these probabilities are used as the attribute variable and a linear relationship is used as the basis for the effectiveness rating function (ERF), then the ratings for these M/Es take on the values of the system Reliability and Maintainability characteristics.

b. The Effect of Weights and Levels of Subordination on Ratings

Variations in overall effectiveness rating (R_E) across candidate systems are generally of smaller magnitude than variations in ratings with respect to any one M/E for different systems. Also, a variation in the value for overall effectiveness rating of a system is much more significant than a variation of the same magnitude in the system rating (R_1) with respect to any one M/E alone. The reason for these two conclusions is that the overall system effectiveness rating is obtained as a sum of the weighted system ratings with respect to the M/Es. Since the weights are all in the range of 0 to 100% (and their sum is 100%), they tend to smooth out (and sometimes swamp) the variations in M/E ratings. Thus, a very large variation in any one M/E rating must occur in order to have any significant effect on the overall effectiveness rating (if everything else is held constant). And, in order to produce a large upward (downward) variation in the overall effectiveness rating, extremely large upward (downward) variations in the ratings with respect to several M/Es must occur simultaneously (if no other variations occur).

The above conclusions can be simply illustrated with some numerical examples. Thus, a 10% change in a system rating with respect to an M/E which has a weight of 10% will result in only a 1% change in the overall effectiveness rating for that system. Similarly, even for an M/E which has a weight of 25%, a 10% change in the system rating with respect to this M/E will result in only a 2.5% change in the overall effectiveness rating for this system.

Since each M/E which is represented in the effectiveness model is generally weighted in such a way that it alone does not dominate the overall effectiveness rating, it is necessary to exercise some caution in using the overall effectiveness rating values for making decisions. This indicates the importance of examining the individual M/E ratings of a candidate in addition to its overall effectiveness rating.

Similar conclusions can be drawn with respect to the effect of factor weights on the corresponding M/E rating and the effect of subfactor weights on the corresponding factor ratings. In addition, this effect is multiplicative when more than one level is considered. It is noted that this is not an unexpected result and it is consistent with the fact that, generally, as the number of considerations determining the outcome of a decision is increased, the influence of any one consideration on the decision must, of necessity, decrease. Thus, the overall effectiveness rating is less sensitive to variations in factor ratings than it is to similar variations in M/E ratings, etc. On the other hand, it should be kept in mind tnat the overall effectiveness of a system is defined in terms of the aggregate of all criteria*rather than in terms of any one criterion, and the weight assignments for relative importance imply the manner in which the decision-maker is willing to trade-off one criterion (consideration) for another one.

c. Use of Effectiveness Ratings

Effectiveness ratings reflect the characteristics and features of the effectiveness assessment methodology discussed earlier and hence the resulting effectiveness ratings should be interpreted accordingly. Following are some guidelines for the use and interpretation of the overall effectiveness ratings as well as the ratings for each M/E.

- The effectiveness assessment methodology does not in itself constitute an automated decision process which eliminates the need for a decision-maker. Instead, the effectiveness assessment methodology is a tool to be used by the decision-maker as an aid in analyzing and evaluating the candidates. As a result, the effectiveness ratings should not be thought of as automatic indicators of the effectiveness of the candidates independently of the decision-maker so that necessity for any further considerations is eliminated. Instead, since effectiveness ratings represent the quantitative result of the synthesis of objective and subjective system information, assumptions, requirements and the subjective judgements of the decision-maker, they should be used as a basis for making comparisons, trade-offs, analyzing the effects of changes in data and/or assumptions, etc.

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* This is analogous to the legal principle of reaching a verdict on the basis of the "preponderance of evidence".

- Effectiveness ratings should not be used as the basis for determining the viability of potential candidates. Such a determination must be made prior to the effectiveness analysis as part of a preliminary analysis on the basis of gross considerations (i.e., minimum requirements), to eliminate non-viable candidates. As indicated in the discussion on the effect of weights on ratings, the effectiveness ratings are not adequate for providing the type of gross differences between candidates which are required for a preliminary analysis.
- The effectiveness ratings are most meaningful when used and interpreted in the context of the effectiveness model. Hence, the more familiar one is with the effectiveness model, the more meaningful are the ratings.
- Although the overall effectiveness ratings of a candidate are the most important and most often used indicator (figure of merit) of the effectiveness assessment, the individual M/E ratings for the candidate should also be examined and the reasons for either poor or high ratings should be understood. These M/E ratings may sometimes provide a rationale for a decision which overrides the importance of either a low or a high overall effectiveness rating.
- The overall effectiveness rating of a candidate is a quantitative indication of its overall quality and hence is a convenient figure of merit which can be used as a basis for comparing and/or ranking the candidates being considered.

Although the effectiveness ratings are most meaningful in a relative sense when comparing candidates against one another, rather than in an absolute sense, the rating for a candidate may be used as a rough indication of how well or how poorly the candidate is likely to fulfill the established goals and requirements. Thus, an overall effectiveness rating of 100% means complete satisfaction of all stated goals and requirements. Hence, if the overall effectiveness ratings for all candidates are low, and especially if the variation among them is small, it may be the basis for a decision that none of the available candidates are acceptable since the objectives and requirements are not likely to be met by either one of them. Prior to forming such a conclusion, one should first reexamine the effectiveness model used to ascertain that it is a reasonable conclusion. The extent to which effectiveness ratings can be used in an absolute sense rather than in a relative sense depends largely on the nature of the elementary factor/subfactor effectiveness rating functions (ERFs) used. Specifically, the important consideration in this regard is whether the rating is based on comparison of the attribute data to an absolute value or it is based on comparing all other candidates to the candidate having the largest (or smallest) value of the attribute variable, i.e., a rating based on scaling. ERFs based on comparison with an absolute value yield an effectiveness model which lends itself more readily for using effectiveness ratings as a basis of direct comparison of candidates with objectives and requirements, than do ERFs which are based on scaling procedures. On the other hand, it is usually more difficult to formulate ERFs based on comparison with an absolute value, since it generally is not obvious or easy to find a basis for establishing the level of such an absolute value.

- The interpretation of effectiveness ratings should be guided by the following considerations:
  - An elementary factor/subfactor rating of zero for any candidate does not imply that the candidate, as a whole, is unacceptable. Instead, this should be interpreted as meaning that a particular aspect of the candidate (among many others being considered) which is represented by the given ERF is not acceptable. This point is best illustrated by an ERF which has two discrete values only, namely, 0 and 100, and which usually arises from a yes or no question.
  - Overall effectiveness ratings as well as individual M/E ratings should be interpreted in the context of a weighted average of multiple considerations. Hence, as was pointed out in the discussion on the effect of weights and levels of subordination on ratings, no one consideration can generally dominate these ratings.
  - Since the overall effectiveness rating (or even individual M/E ratings) will generally not be sufficiently sensitive to variations in ratings for individual considerations (i.e., criteria) which are of special interest to a decision-maker, it is necessary to make special provisions for drawing attention to such individual considerations. An effective way of accomplishing this is the technique of "flagging" the criteria of interest by listing the effectiveness ratings for them in a prominent position

when presenting the results of the analysis. In the candidate system/vessel combinations analyzed as part of this study, the holding capacity of each system for black and gray wastewater was thus flagged by listing the ratings for these two criteria in tables showing the results of the analysis.

CONCLUSIONS

Management of Gray Water

- The objective of managing gray water cannot be fully realized with any of the candidate systems analyzed, and within the guidelines of this study, on the following vessels:
  - GALLATIN (378')
  - VIGOROUS (210')
  - POINT HERRON (82')
- A flow-through treatment system (Grumman) is required in order to provide full gray water holding capacity on the following vessels:
  - FIREBUSH (180')
  - PAMLICO (160')
- Full black and gray water holding capacity can be provided with use of holding tanks and conventional full volume flush gravity drains (WMS No. 1) on the WHITE SAGE (133').

Optimum Systems

- The optimum (most cost-effective) candidate system on each vessel as a function of holding capacity objectives is as follows:

Vessel	Less Than Full Capacity For Black & Gray Water	Full Capacity For Black Water Only	Full Capacity For Black & Gray Water
GALLATIN (378')	-	1	None
VIGOROUS (210')	1	14	None
FIREBUSH (180')	-	1	5
PAMLICO (160')	-	1	5
WHITE SAGE (133')	-	-	1
POINT HERRON (82')	1	9 or 14	None

- The overall life-cycle costs (as well as the individual cost elements) of the candidate systems varied over a large range on each vessel. These variations are greater than those for the overall effectiveness ratings.

Incinerators, Evaporators and Holding Tanks

- Holding tanks are more cost-effective than either incinerators or evaporators.
- Evaporators are more cost-effective than incinerators.
- In all viable candidate system/vessel combinations, except for WMS No. 9 on the VIGOROUS (210'), a holding tank can be substituted for an incinerator or evaporator without sacrificing full holding capacity for black water.

Vacuum Collection Versus Pump Collection

Comparison of WMS concepts based on reduced volume flush collection which are similar except for the use of vacuum collection versus macerator/transfer (M/T) pump collection leads to the following conclusions:

- There are no consistent patterns for life-cycle cost or for cost-effectiveness. This indicates that other considerations, namely differences in WMS equipment configurations and differences in vessel characteristics, are more important.
- Pump collection is more effective than vacuum collection.

Vessel Mission Profile Characteristics

- The holding time goal for a vessel is an important system design parameter which has a strong influence on determining candidate WMS equipment configuration and the feasibility (as well as the cost) of installation. Analysis of vessel holding times leads to the following conclusions:

  - On some vessels, the maximum holding time is much larger than all other holding times. The ratio of the maximum holding time to the next smaller holding time on these vessels is as follows:
    - VIGOROUS (210') - more than 2 to 1
    - FIREBUSH (180') - approximately 5 to 1
    - PAMLICO (160') - more than 2 to 1
    - POINT HERRON (82') - more than 5 to 1
  - The maximum holding time for most vessels is due to the unavailability of waste receiving facilities at non-home ports or operation within inland waters.
- The WMS utilization factor is an important parameter in determining WMS operating and maintenance costs. This vessel mission profile characteristic varied over a wide range, from 1.8 % for the POINT HERRON (82') to 31% for the PAMLICO (160').

The Cost Effectiveness Analysis Methodology

- The cost effectiveness analysis methodology developed and applied as part of this study is a powerful and versatile analytic tool, useful for making decisions in the context of comparing competing candidates. The numbers which result from the quantification of life-cycle cost and effectiveness can be manipulated to reveal important properties of the candidates, determine the presence or absence of trends and the reasons for them, examine issues of interest to the decision maker, make inferences and arrive at conclusions. This methodology can successfully interact with the various supporting studies used to develop the necessary data (e.g., MSD analysis, WMS installation analysis). It does this by providing structure and direction to these studies and then accepts the results of these analyses and integrates them with the other considerations which form the context of the problem.

- Some of the salient properties of the effectiveness assessment methodology are:
  - Effectiveness is directly related and tailored to the goals requirements, and other issues forming the context relevant to the candidates being analyzed. All considerations of interest can be addressed and accommodated.
  - It successfully integrates quantitative objective data, qualitative objective and subjective data, and less tangible information such as goals, requirements, constraints, policies, guidelines, assumptions, and the subjective judgements of the decision-maker.
  - It can handle, in a practical way, the large amounts of data which must be accommodated in order to examine the numerous considerations involved in selecting an optimum candidate.
  - It provides results (effectiveness ratings) at three different levels of detail. These are useful in interpreting the quantitative results in terms of system features and characteristics in the context of the original goals and assumptions.
- Some of the salient properties of the life-cycle cost model are:
  - It accommodates the large amount of data required and addresses the numerous dependencies and assumptions which affect the life-cycle cost of candidate wastewater management systems (vessel characteristics, subsystem/equipment reliability and maintainability, discount rate, etc.).
  - Costs are provided at several different levels of detail. These are useful in studying system properties and making inferences.

.. It provides operating and maintenance characteristics which are of interest in themselves, in addition to their economic implications (man-hour requirements, vessel resource requirements, logistic requirements, etc.).

.. The computations required, when executed manually, are tedious, time consuming, subject to error and must be performed by an individual familiar with the candidate systems, vessels and the underlying assumptions. It is therefore impractical to reevaluate the life-cycle cost manually due to changes in configuration, data, parameters, assumptions, etc. Automation of the life-cycle cost model is necessary in order to provide a flexible and generalized life-cycle cost analysis methodology.

RECOMMENDATIONS

Candidate Systems

- A system employing existing conventional full volume flush gravity drains in conjunction with black and gray water holding tanks (i.e., WMS No. 1) should be specified for vessels on which this WMS concept provides full holding capacity for both black and gray wastewaters. The WHITE SAGE (133') is a candidate for this system concept. In addition, if the Coast Guard policy with respect to gray water management and/or maximum holding time is modified (see ensuing paragraphs), the use of this WMS concept should be considered for other vessels as well.
- A holding tank should be specified in place of an incinerator or evaporator in system/vessel combinations where this is relevant.
- Unless significant breakthroughs in the physical, operational and economic characteristics of incinerators occur, their use should not be considered. A possible exception might be in those cases where their advantage of providing an indefinite holding time becomes an overriding consideration.
- The use of evaporators should not be considered.

Objectives, Policies and Programs

- In view of the consequences (economic, system configuration/ equipment sizing, and feasibility of installation) of long and atypical holding times for some vessels, possibilities for eliminating some of the conditions which give rise to them should be investigated. Two possibilities are as follows:

  - Reexamine the policy of not providing waste receiving facilities at vessel's non-home ports. The possibility of making such pumpout facilities available both at Coast Guard and other ports of interest should be considered.
  - The guideline of using the maximum holding time as the basis for determining the holding capacity objectives for a vessel should be reexamined. As a consequence of this, it will either be necessary to modify vessel operational profiles or emission standards will be violated, albeit infrequently.

- In view of the difficulty of and/or the reduction in cost-effectiveness resulting from the requirement of managing gray water, the following should be considered:
  - Eliminate the objective of managing gray water, at least on some vessels.
  - Consider the possibility of reducing the hydraulic load due to gray water. This might be best done in conjunction with the black water hydraulic load management (perhaps based on reuse concepts) as an integrated waste reduction program for hotel wastes on board U.S. Coast Guard vessels.

- In view of the cost-effectiveness of holding tanks, effective and efficient tank aeration procedures should be devised and implemented to eliminate negative habitability and safety effects of holding tanks.

- The effect of the newly established 200-mile limit for territorial waters on the results and conclusions of this study should be evaluated. Such an evaluation should proceed from an examination of how and to what extent the mission profiles of vessels which are affected by the new limit would be modified. The consequences of modified mission profile characteristics could then be investigated.

- The results and conclusions of this study should be reviewed in the light of the recent Coast Guard survey and analysis of wastewaters aboard the vessels included in this study. Such an evaluation should compare the experimentally established waste generation rates with those assumed for the purposes of this study to determine the effect of candidate WMS configurations and equipment sizing.

The Cost-Effectiveness Analysis Methodology

- Application of the cost effectiveness analysis methodology developed as part of this study should be considered for other problems. Due to the generality of the underlying concepts and the flexibility with respect to the scope of problem and data availability of both the life-cycle cost and the effectiveness modeling approaches, this methodology can be applied to problems of the same, smaller, or larger scope than that of selecting WMS candidates for vessels. Its application to wastewater management systems should not be viewed as a limitation but rather as a demonstration. This methodology is applicable to any problem in the context of studying competing candidates and selecting an optimum. In addition, either the life-cycle cost analysis model alone or the effectiveness assessment methodology alone can sometimes be used to advantage in some situations.
- The life-cycle cost model should be automated in order to make available a flexible and at the same time, practical life-cycle cost analysis methodology. Such automation is essential in order to facilitate reevaluation of results due to: changes in data, system configuration, assumptions and guidelines; application to other systems; and to facilitate sensitivity analyses.

DEFINITIONS AND ABBREVIATIONS

The definitions and abbreviations of certain terms used in conjunction with this study are given below.

ABBREVIATIONS

ERF Effectiveness rating function

M/E - Measure of effectiveness

MSD - Marine sanitary device

WMS - Wastewater management system (for black and gray wastewaters)

DEFINITIONS

Attribute

A quantitative or qualitative characteristic of the candidate systems/subsystems/equipments and/or vessels which is used as the basis for assigning an effectiveness rating to elementary factors/subfactors. Attribute is also used in connection with the following:

- Attribute Data

  The quantitative or qualitative "values" of specific attributes or attribute variables for the candidate system/vessel combinations.

- Attribute Variable

  A variable which is used for quantifying an attribute of candidate system/vessel combinations. Attribute variables are often functions which relate attribute data at the system/subsystem/equipment/vessel level to a numerical or qualitative "value" which is used in conjunction with effectiveness rating functions to obtain an effectiveness rating for elementary factors/subfactors.

Black Water

Wastewaters which includes sewage, i.e., the output from commodes and urinals, and garbage grinder slurry.

Bravo Status

The time allowed for a vessel to get underway.

Charlie Status

The vessel is tied up for maintenance, usually at its own home port.

Effectiveness

The overall quality of a candidate determined on the basis of how well the candidate fulfills specified objective, requirements and constraints. Effectiveness can be quantified and the resulting number is the effectiveness rating of the candidate which is a quantitative measure of the degree to which the candidate has satisfied the aggregate of all established individual criteria and their relative importance.

Effectiveness Rating Function (ERF)

A rule which relates one or more qualitative or quantitative system/ subsystem/equipment / vessel characteristics (attributes) to an effectiveness rating for an elementary factor or subfactor.

Elementary Factor/Subfactor

A factor or subfactor which has no subordinate subfactors and which can be readily related to a single attribute (or a function of one or more attributes) of the candidate system/vessel combinations being analyzed.

Factors

The set of criteria which are implied by a M/E. Factors are characterized (for any candidate system/vessel combination) numerically by two quantities, namely, a rating (which measures how well the candidate satisfies the criterion) and a weight (which indicates how important this factor is in relation to the other factors of the same M/E).

Gray Water

Wastewaters which include: the output from galley drains (sinks, kettles, dishwasher excluding the garbage grinder); turbid waters from lavoratories, showers and laundry; drainage from air conditioners, drinking fountains and interior deck drains including those in head spaces.

Holding Times

The continuous time intervals during which a vessel is in restricted waters and/or in any non-home port, other than a yard. The maximum Holding Time for a given vessel is the longest holding time encountered during the time period over which data was taken. During holding time intervals, wastewaters may not be discharged overboard and therefore have to undergo Treatment/Disposal by the vessel WMS (i.e., it must operate in the primary mode).

Level of Subordination

The indenture of a given factor or subfactor in the hierarchical structure of the effectiveness model. A numbering scheme used to uniquely identify each factor/subfactor with each M/E indicates the level of subordination.

Measures of Effectiveness (M/E)

The set of highest level criteria used as the basis for assessing the overall effectiveness of candidate system/vessel combinations. M/Es are characterized (for any candidate system/vessel combination) numerically by two quantities, namely, a rating (which measures how well the candidate satisfies the criterion) and a weight (which indicates how important this M/E is in relation to the others).

Optimum Candidate

The most cost-effective candidate based on a specified optimum candidate selection criterion.

Rating

A quantity which measures the degree to which a candidate satisfies either a single criterion or the aggregate of a set of criteria and their relative importance. A rating is given as a percentage in the range of 0 to 100% using the convention that the higher the rating the greater the degree acceptability or quality of the candidate and vice versa. Ratings are used in conjunction with the following:

- Overall effectiveness
- M/Es
- Factors
- Subfactors
- Elementary factors/subfactors

Refurbishment

Unscheduled vessel repairs which cannot be made at a vessel's home port and hence are made at a yard.

Scheduled Yard Availability

Time set aside for vessel maintenance and overhaul at a yard.

Sortie

The various vessel movements, i.e., the transits in and out of restricted waters, arrivals at and departures from ports, etc., associated with the normal operations of a vessel. For purposes of this study, a sortie is initiated when a vessel leaves its own home port or a yard (i.e., when it is disconnected from a shore waste receiving facility) and ends when the vessel arrives at its own home port or at a yard (i.e., when it is connected to a shore waste receiving facility).

Sufactors

The set of criteria which are implied by a factor or another higher level subfactor. Subfactors are characterized (for any given candidate system/vessel combination) numerically by two quantities, namely a rating (which measures how well the candidate satisfies the criterion) and a weight (which indicates how important this subfactor is in relation to the other subfactors at the same level of subordination under the corresponding factor/subfactor).

Times Beyond Restricted Waters

The continuous time intervals during which a vessel is beyond restricted waters. When a vessel is beyond restricted waters, it may discharge wastewaters overboard (i.e., the WMS may operate in the overboard discharge mode).

Weight

A quantity which indicates the importance of each criterion in relation to the others, at the same level of subordination in the hierarchical structure of the effectiveness model. A weight is given as a percentage in the range of 0 to 100%, using the convention that the higher the weight the more important the criterion (in relation to the others at the same level) and vice versa. Weights are assigned such that their sum is equal to 100 for all criteria at the same (and every) level of subordination. Weights are used in conjunction with the following:

- M/Es
- Factors
- Subfactors
- Elementary factors/subfactors

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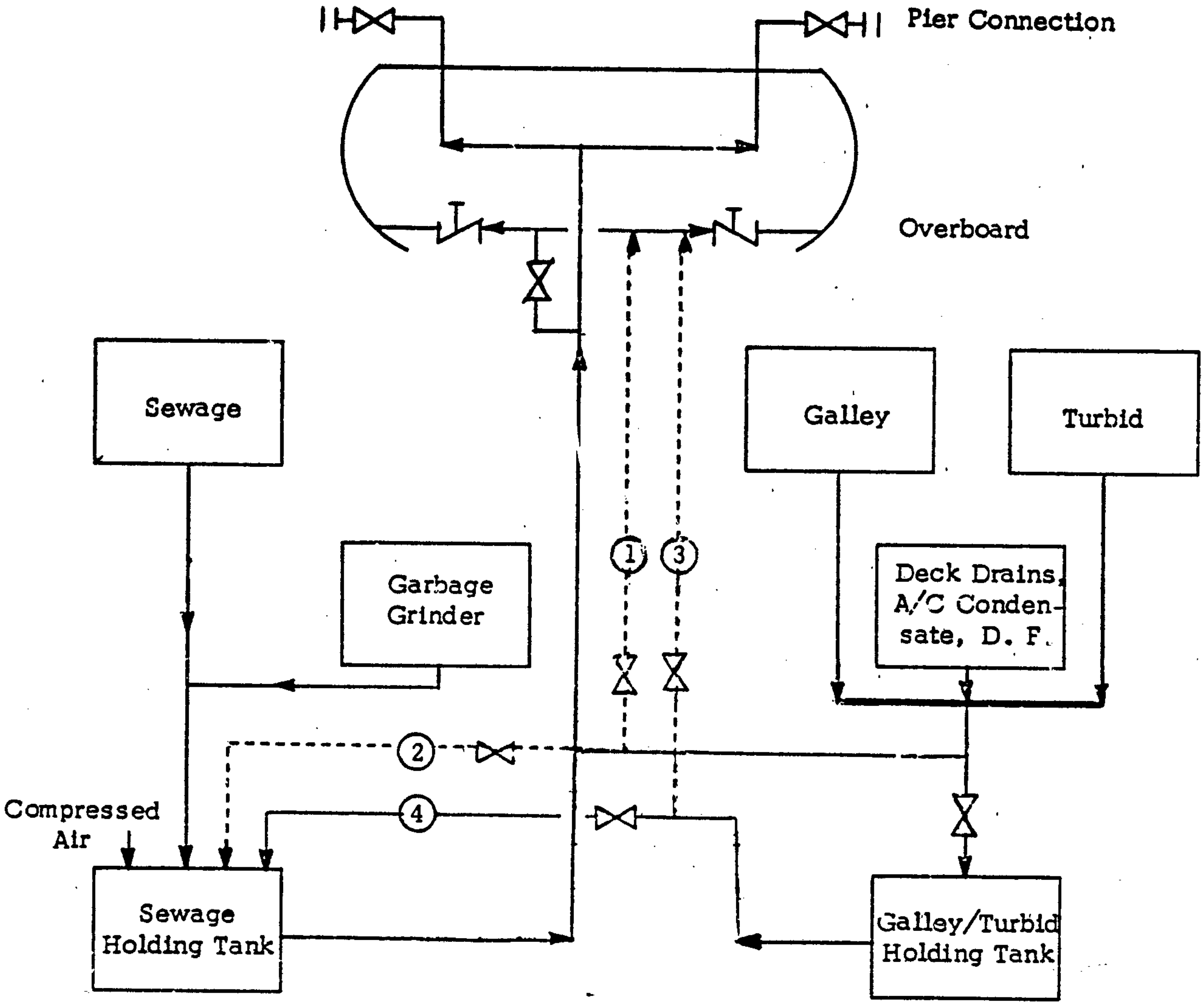
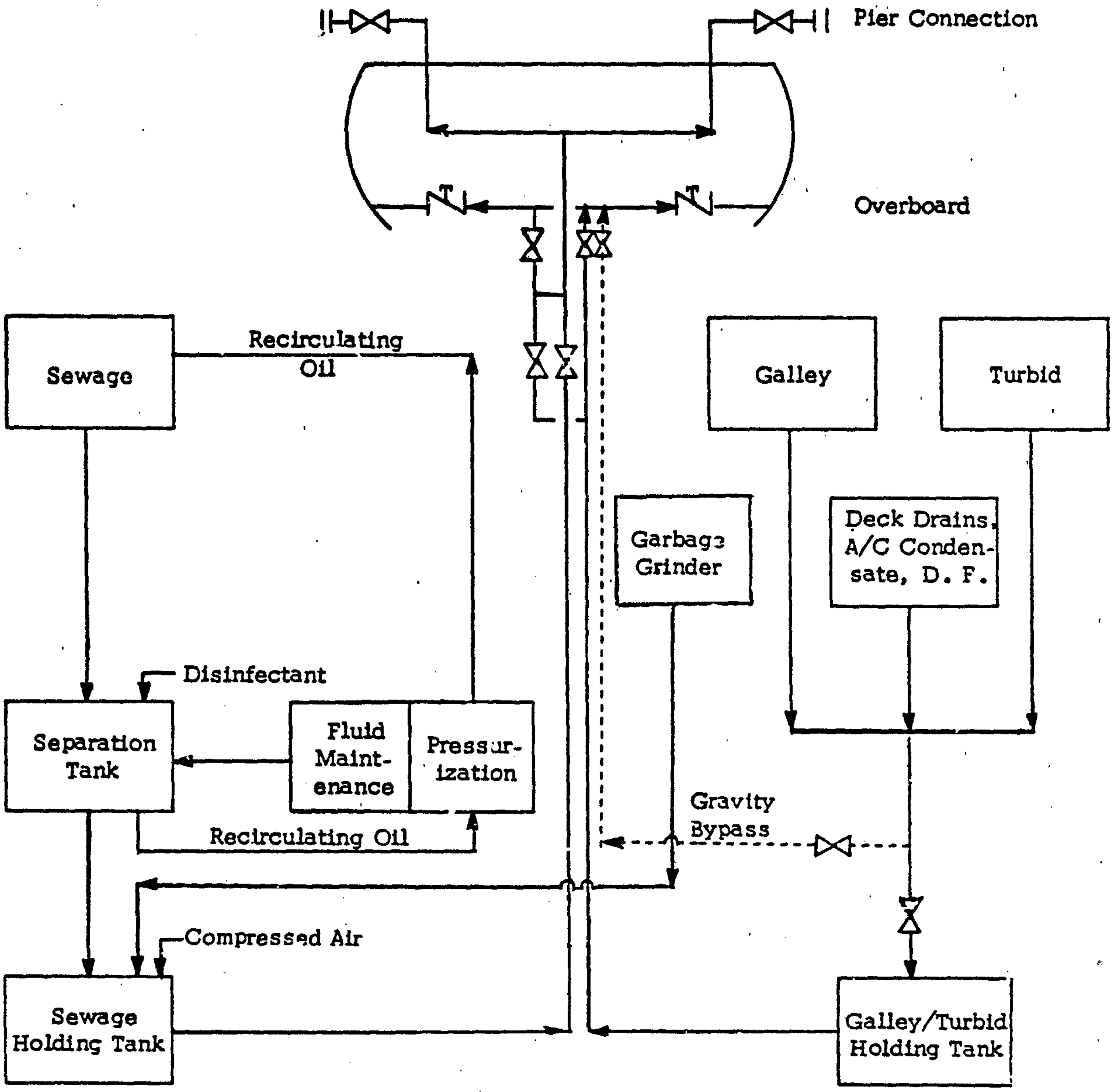
APPENDIX A

SCHEMATIC DIAGRAMS OF WMS CONCEPTS

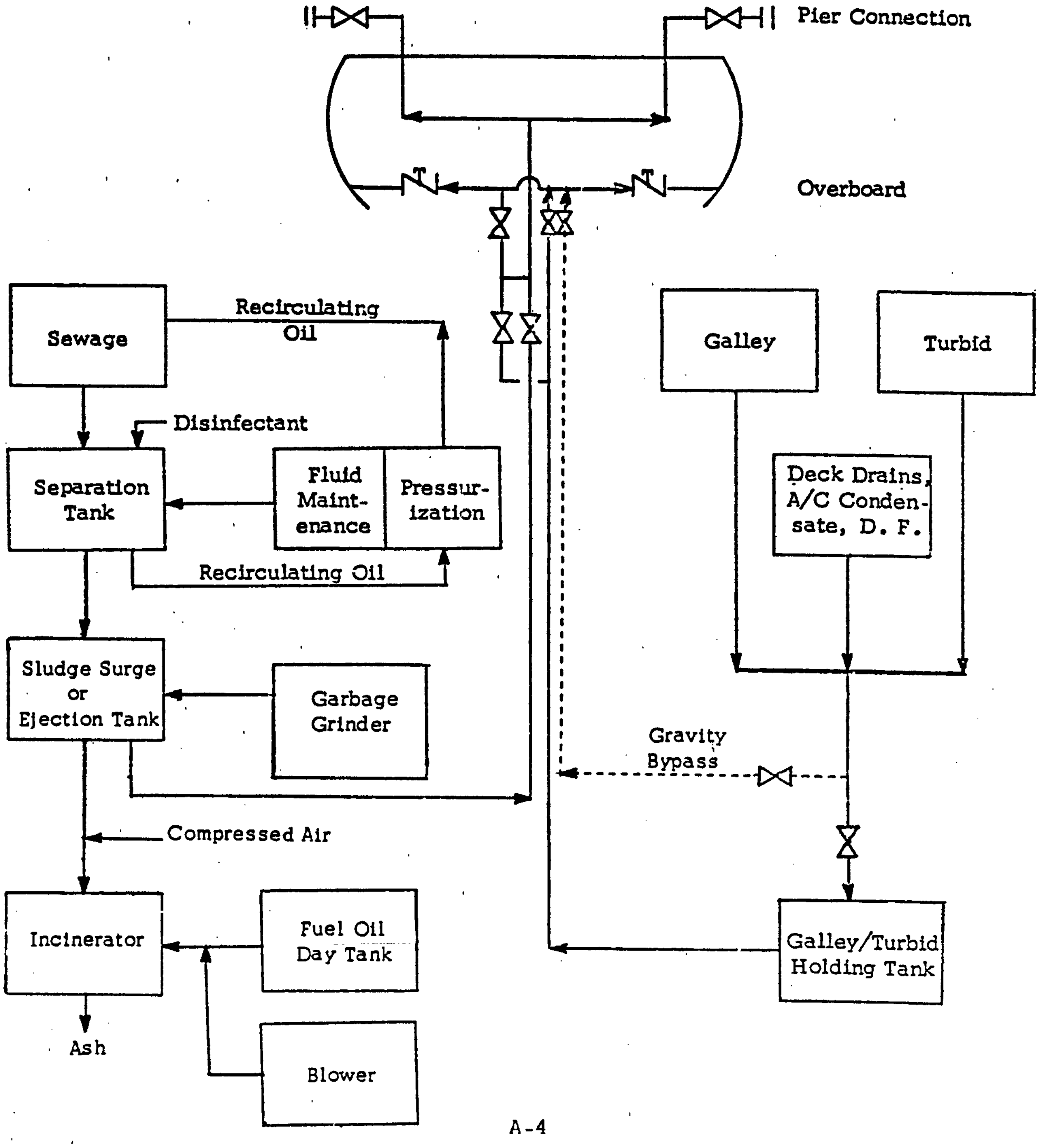
1. Full Volume Flush Gravity Collection/Holding Tank for Black Water/Holding Tank for Gray Water



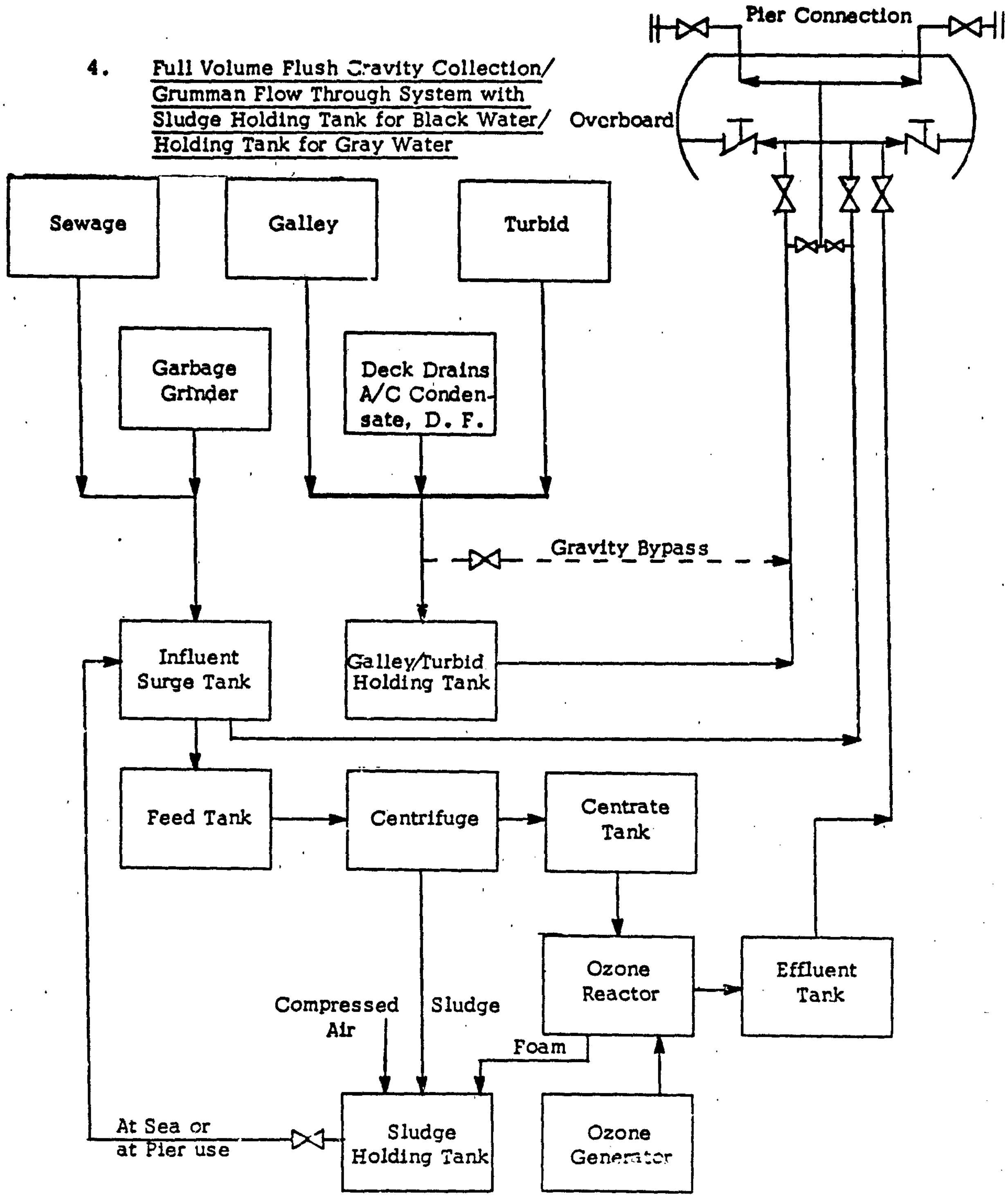
2. Full Volume Flush Oil Recirculation and Gravity Collection/Chrysler System with Sludge Holding Tank for Sewage/Holding Tank for Gray Water



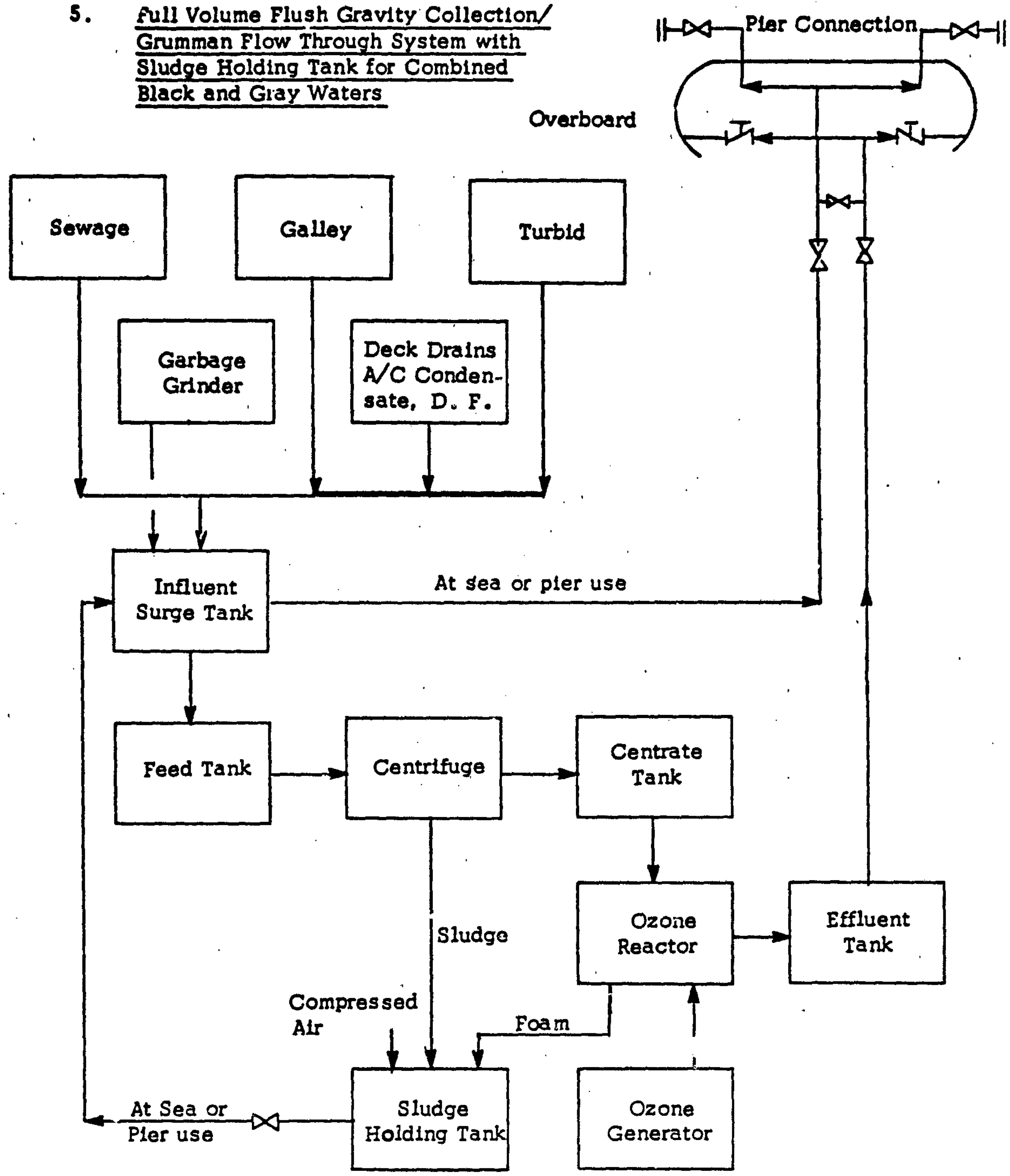
3. Full Volume Flush Oil Recirculation and Gravity Collection/Chrysler System with Incinerator for Sewage/Holding Tank for Gray Water



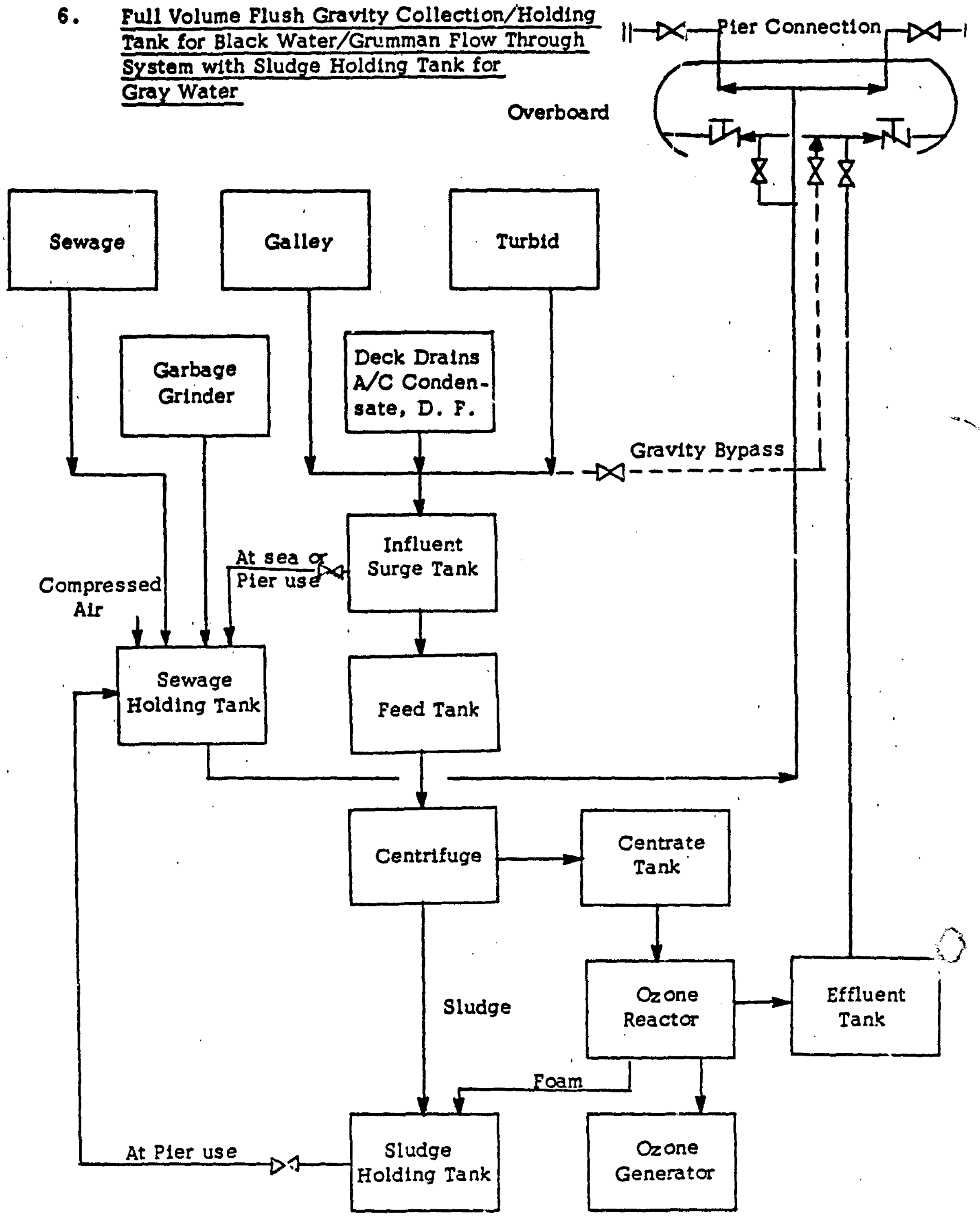
4. Full Volume Flush Gravity Collection/ Grumman Flow Through System with Sludge Holding Tank for Black Water/ Holding Tank for Gray Water



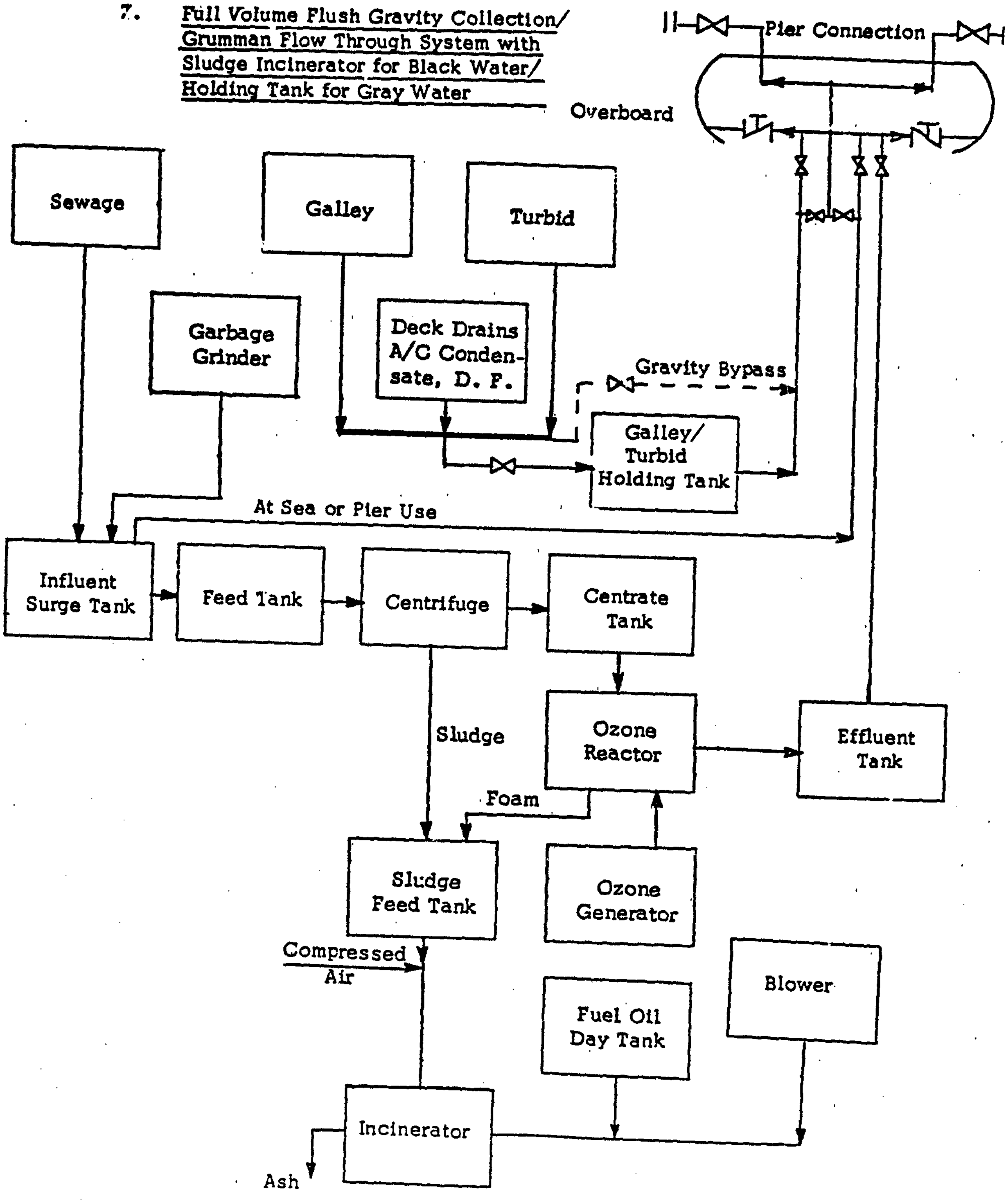
5. Full Volume Flush Gravity Collection/ Grumman Flow Through System with Sludge Holding Tank for Combined Black and Gray Waters



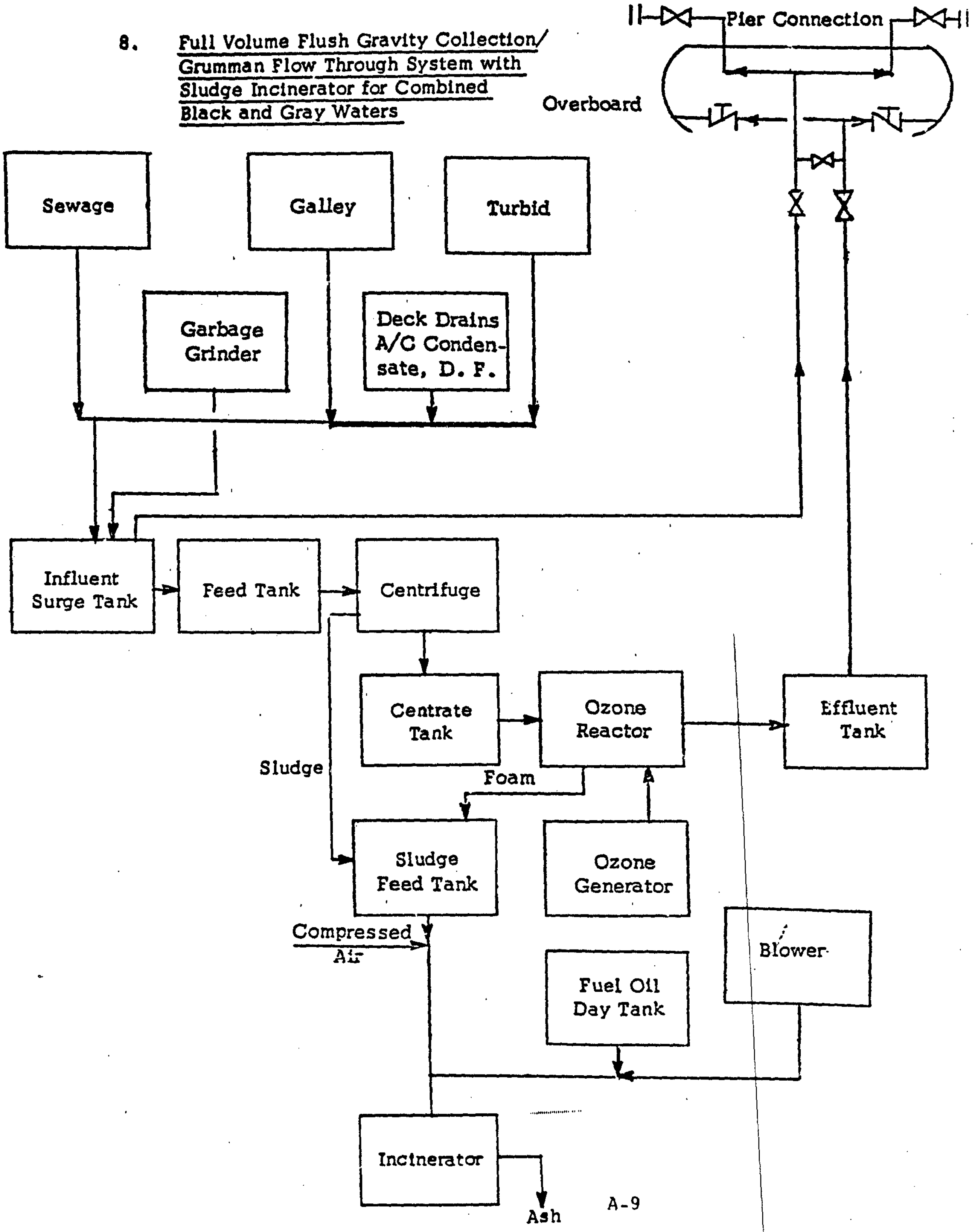
6. Full Volume Flush Gravity Collection/Holding Tank for Black Water/Grumman Flow Through System with Sludge Holding Tank for Gray Water



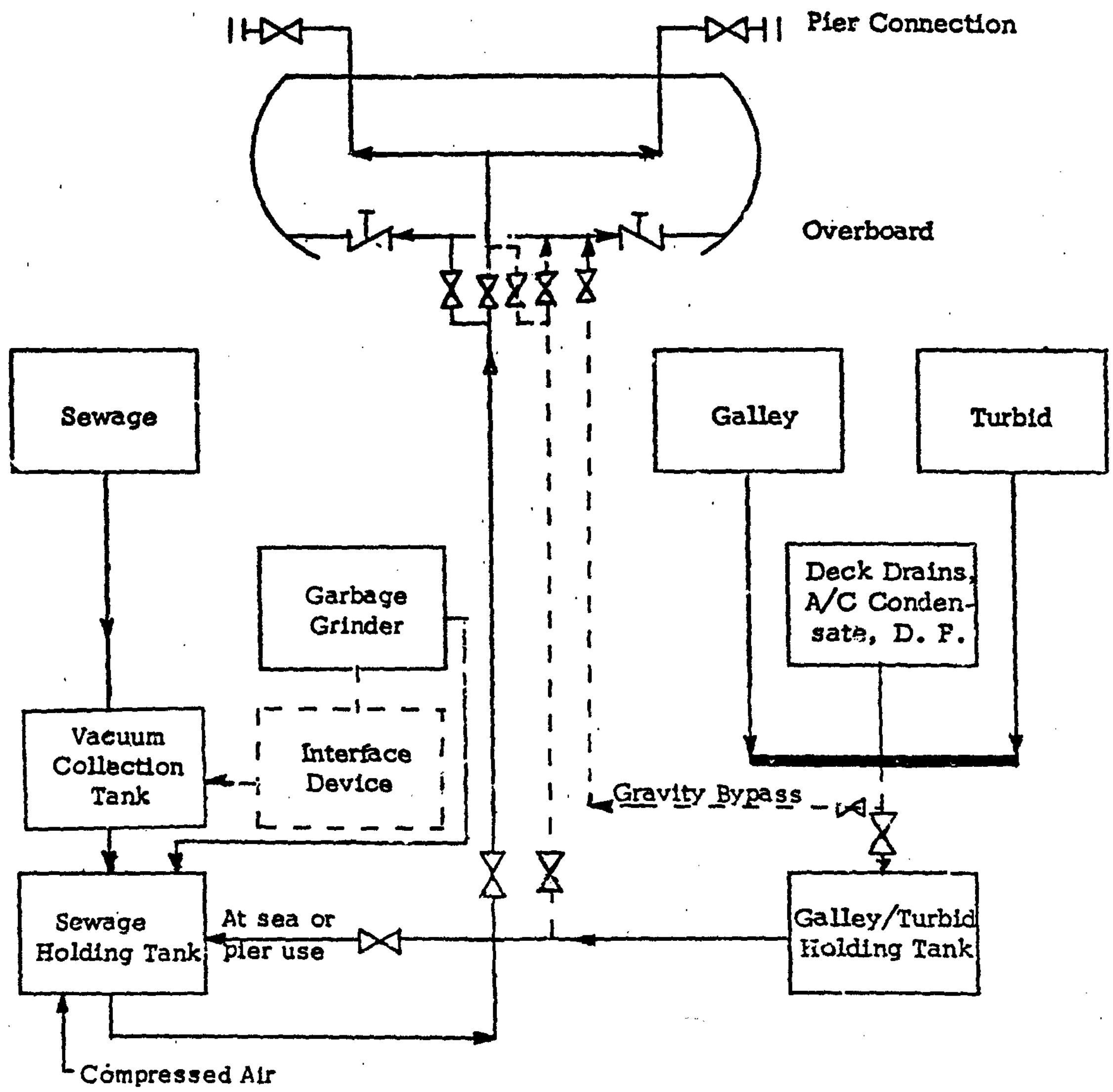
7. Full Volume Flush Gravity Collection/ Grumman Flow Through System with Sludge Incinerator for Black Water/ Holding Tank for Gray Water



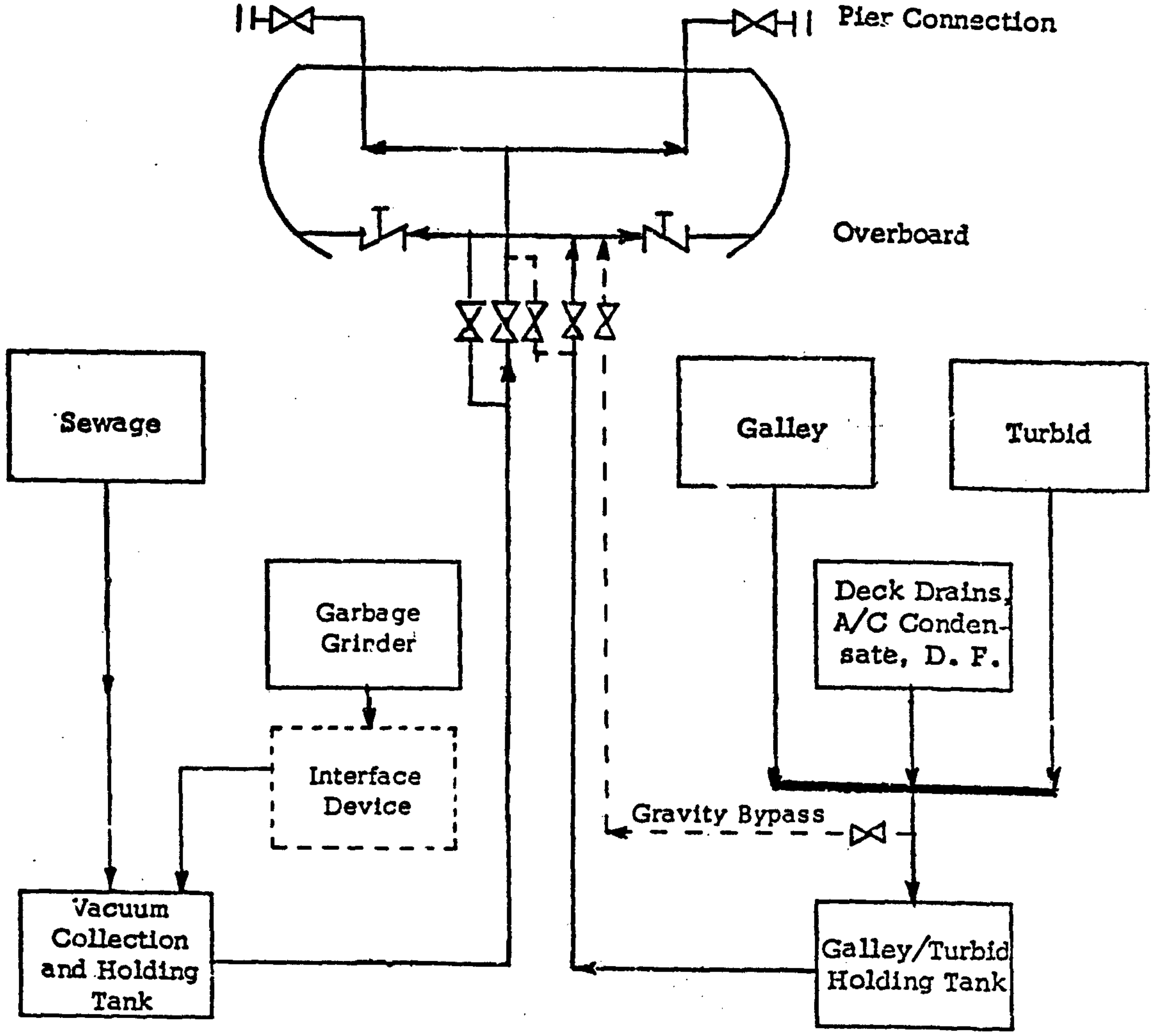
8. Full Volume Flush Gravity Collection/ Grumman Flow Through System with Sludge Incinerator for Combined Black and Gray Waters



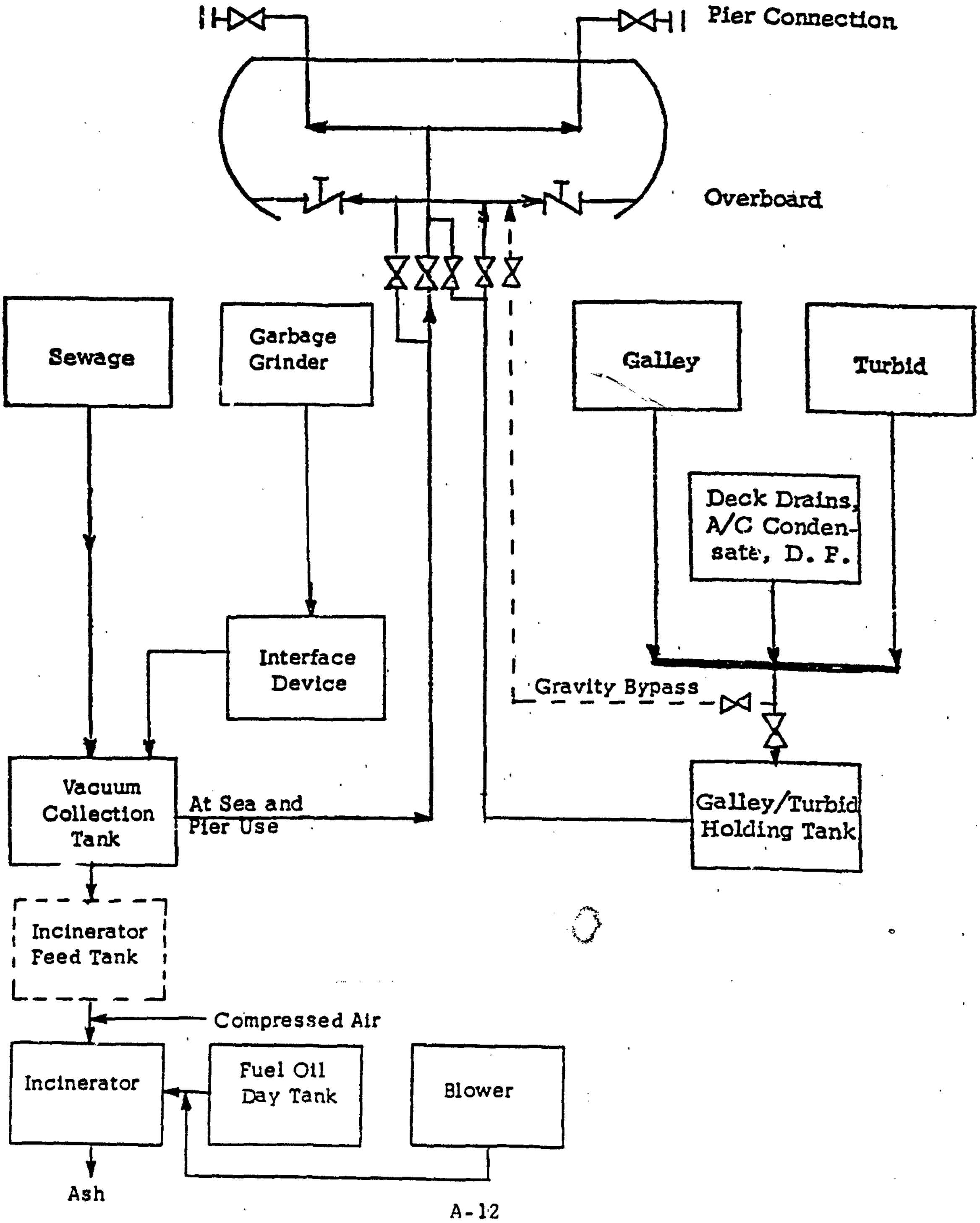
9a. JERED Reduced Volume Flush Vacuum Collection/Holding Tank for Concentrated Black Water/Holding Tank for Gray Water



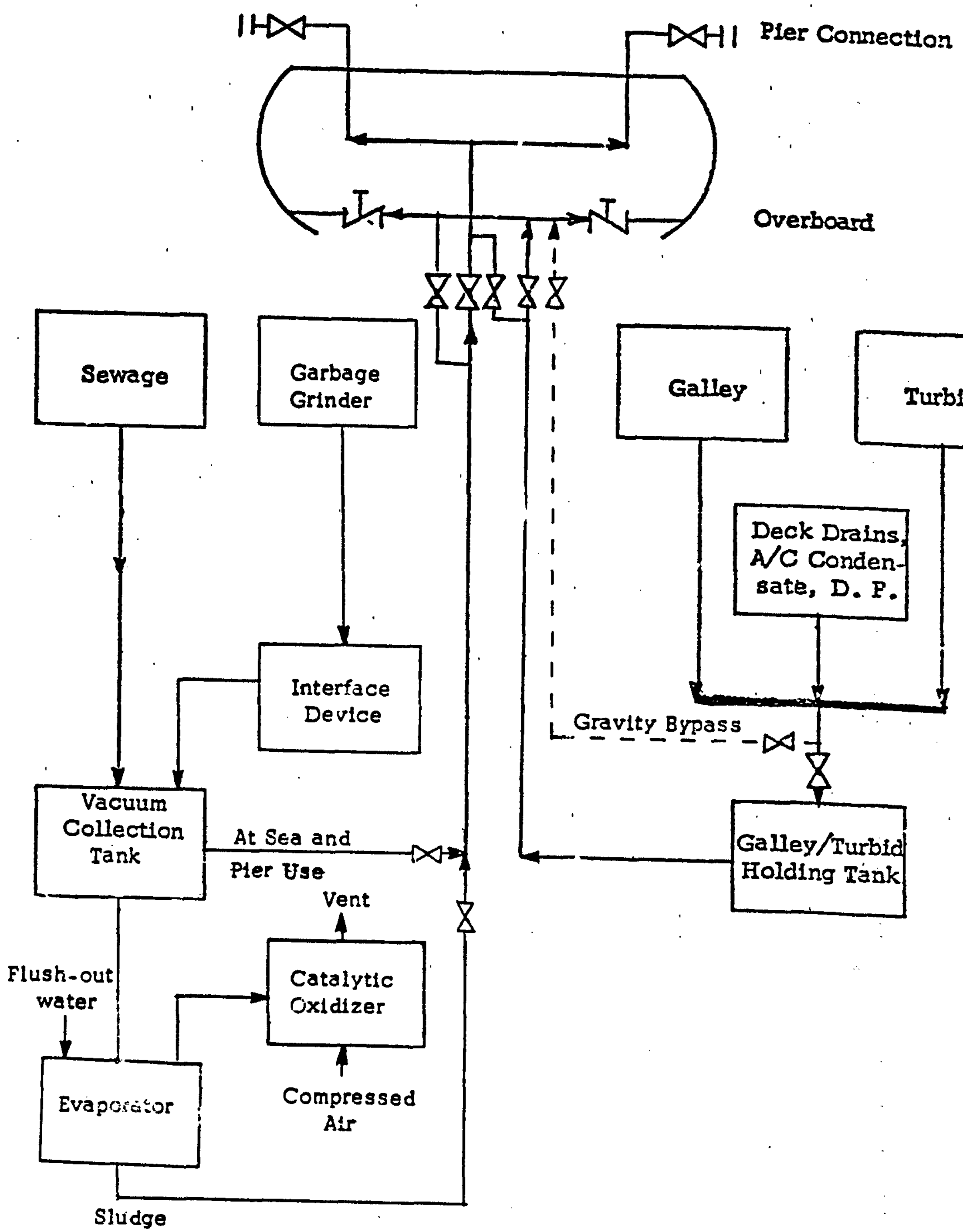
9b. JERED Reduced Volume Flush Vacuum Collection/Concentrated Black Water Held in VCT/Holding Tank for Gray Water



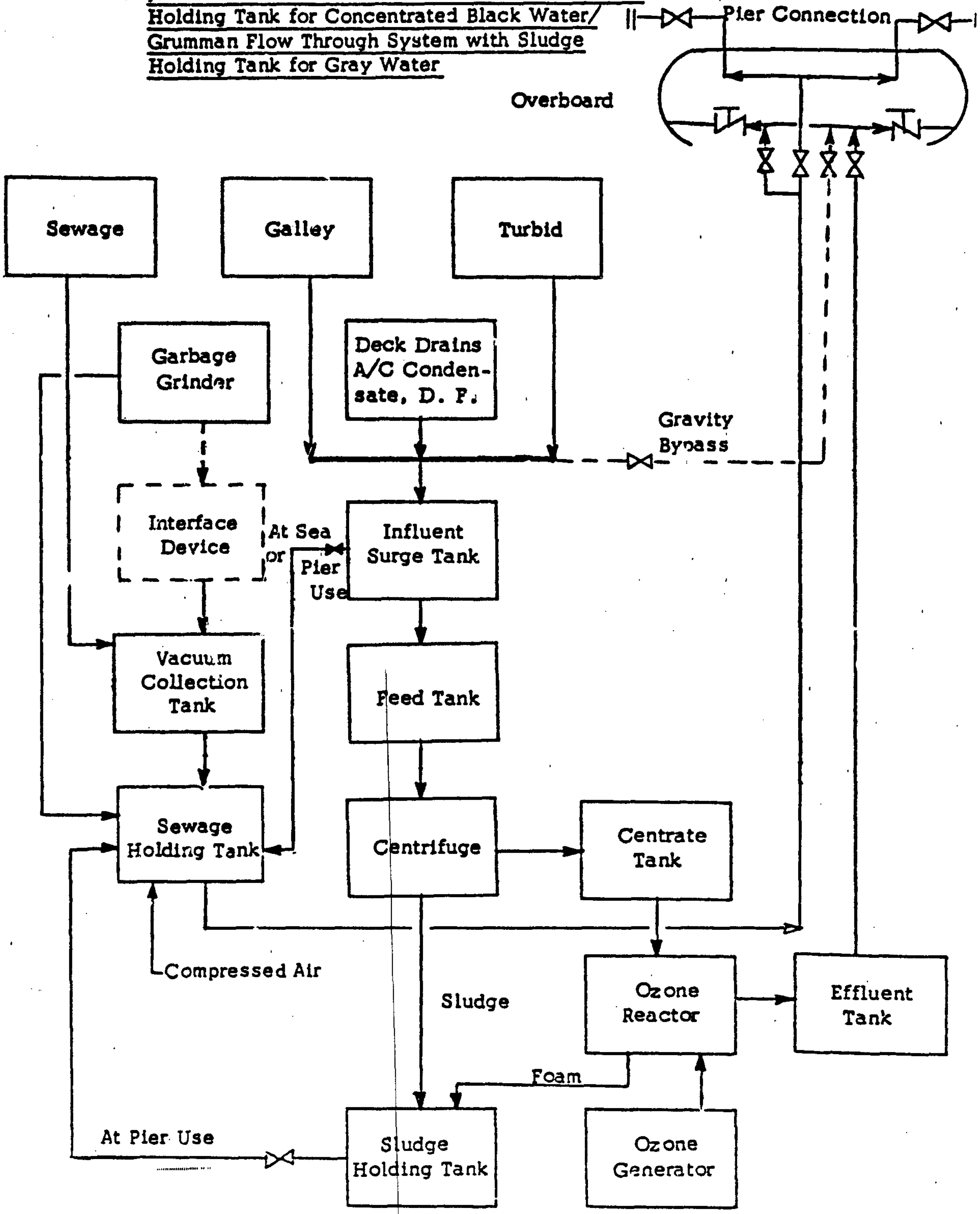
10. JERED Reduced Volume Flush Vacuum Collection/Incinerator for Concentrated Black Water/Holding Tank for Gray Water



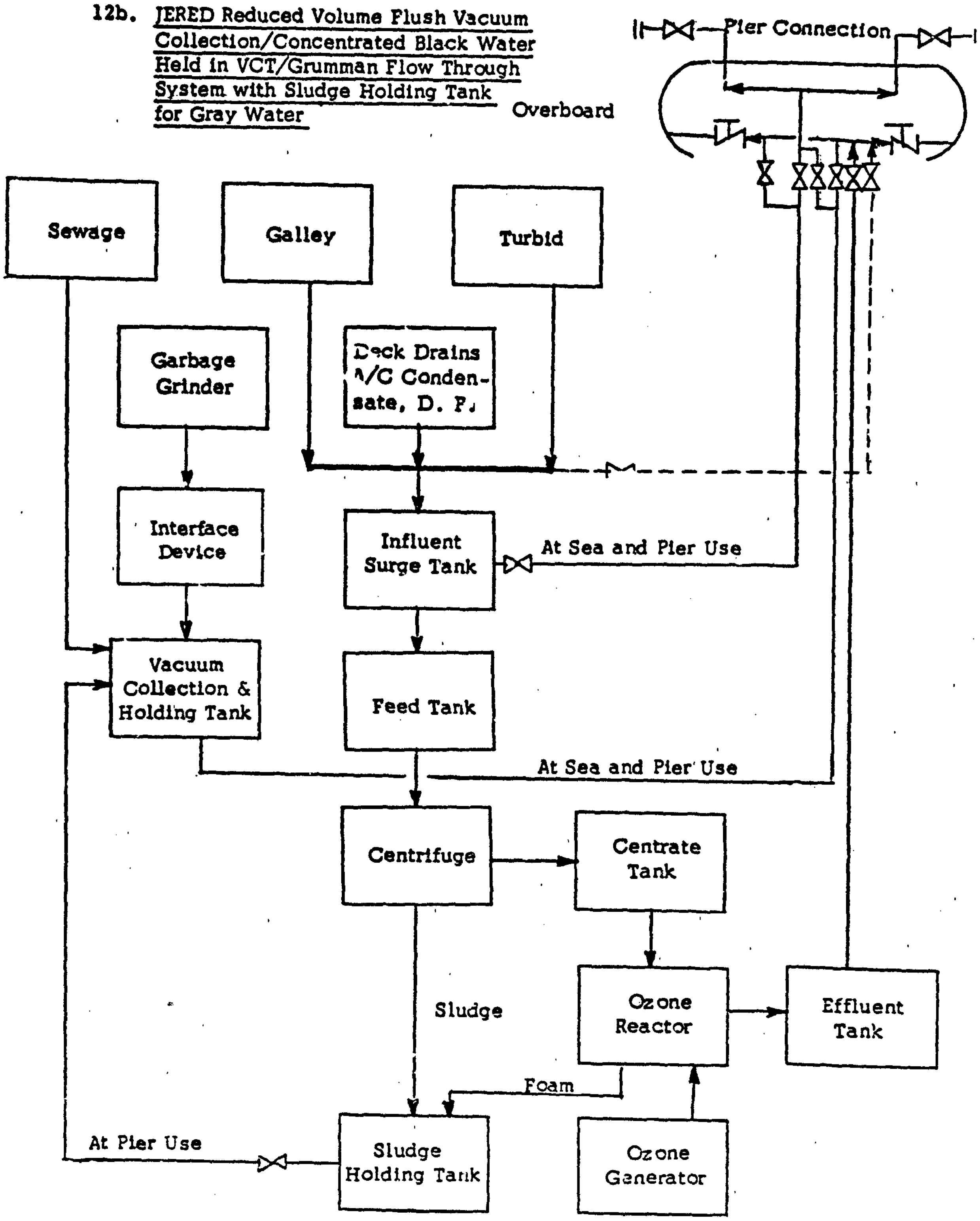
11. JERED Reduced Volume Flush Vacuum Collection/GATX Evaporator for Concentrated Black Water/Holding Tank for Gray Water



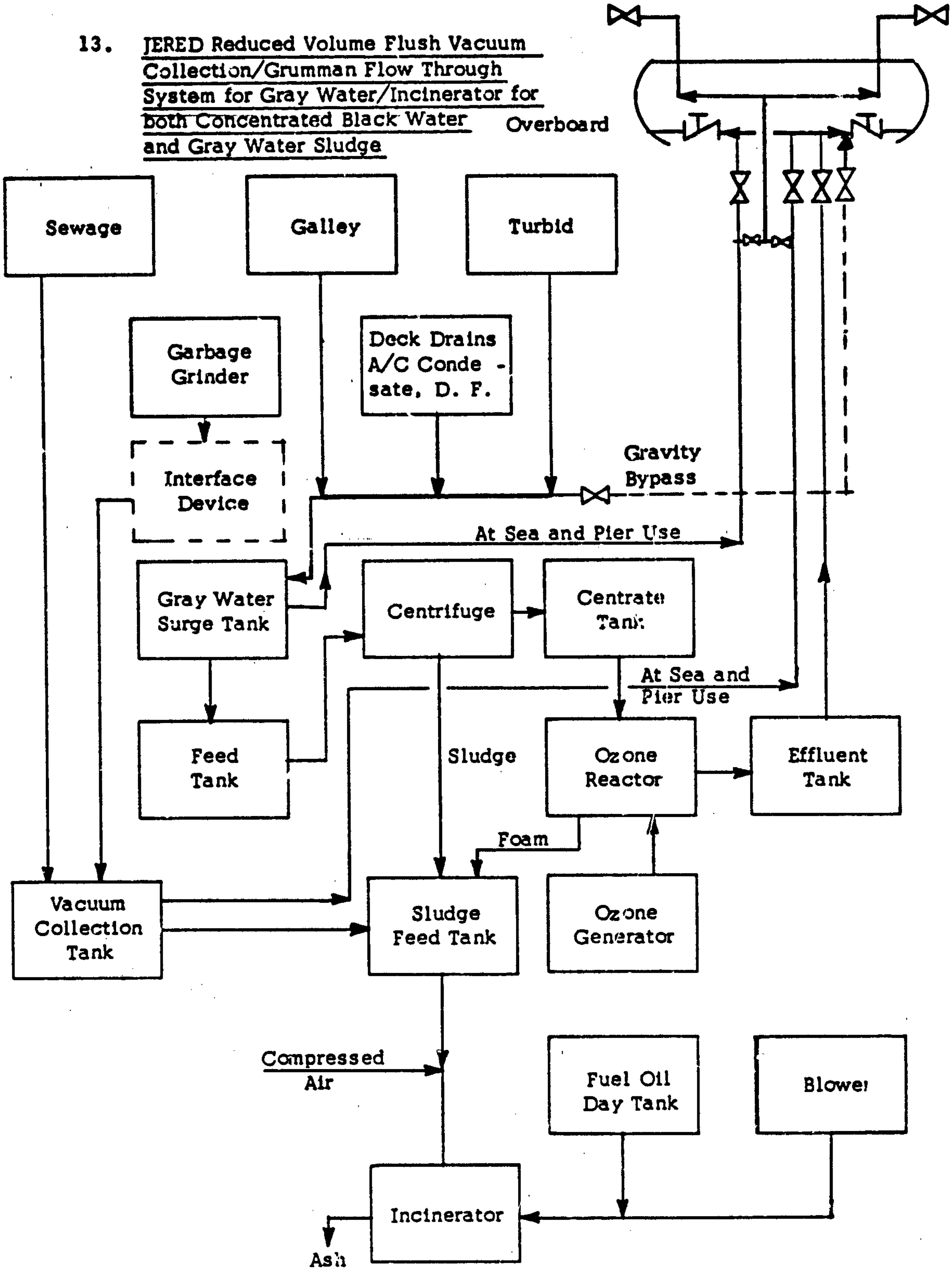
12a. JERED Reduced Volume Flush Vacuum Collection/ Holding Tank for Concentrated Black Water/ Grumman Flow Through System with Sludge Holding Tank for Gray Water



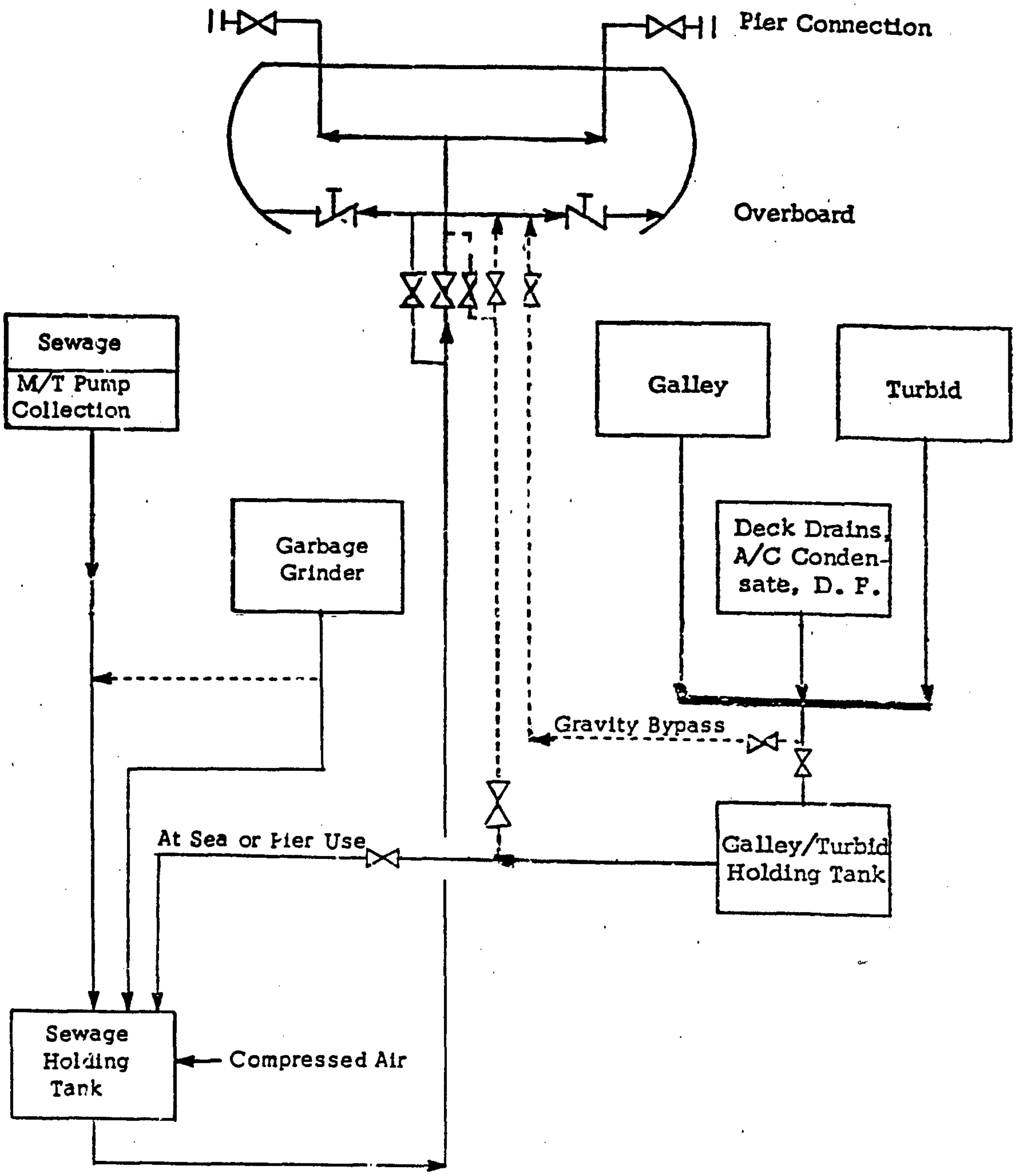
12b. JERED Reduced Volume Flush Vacuum Collection/Concentrated Black Water Held in VCT/Grumman Flow Through System with Sludge Holding Tank for Gray Water



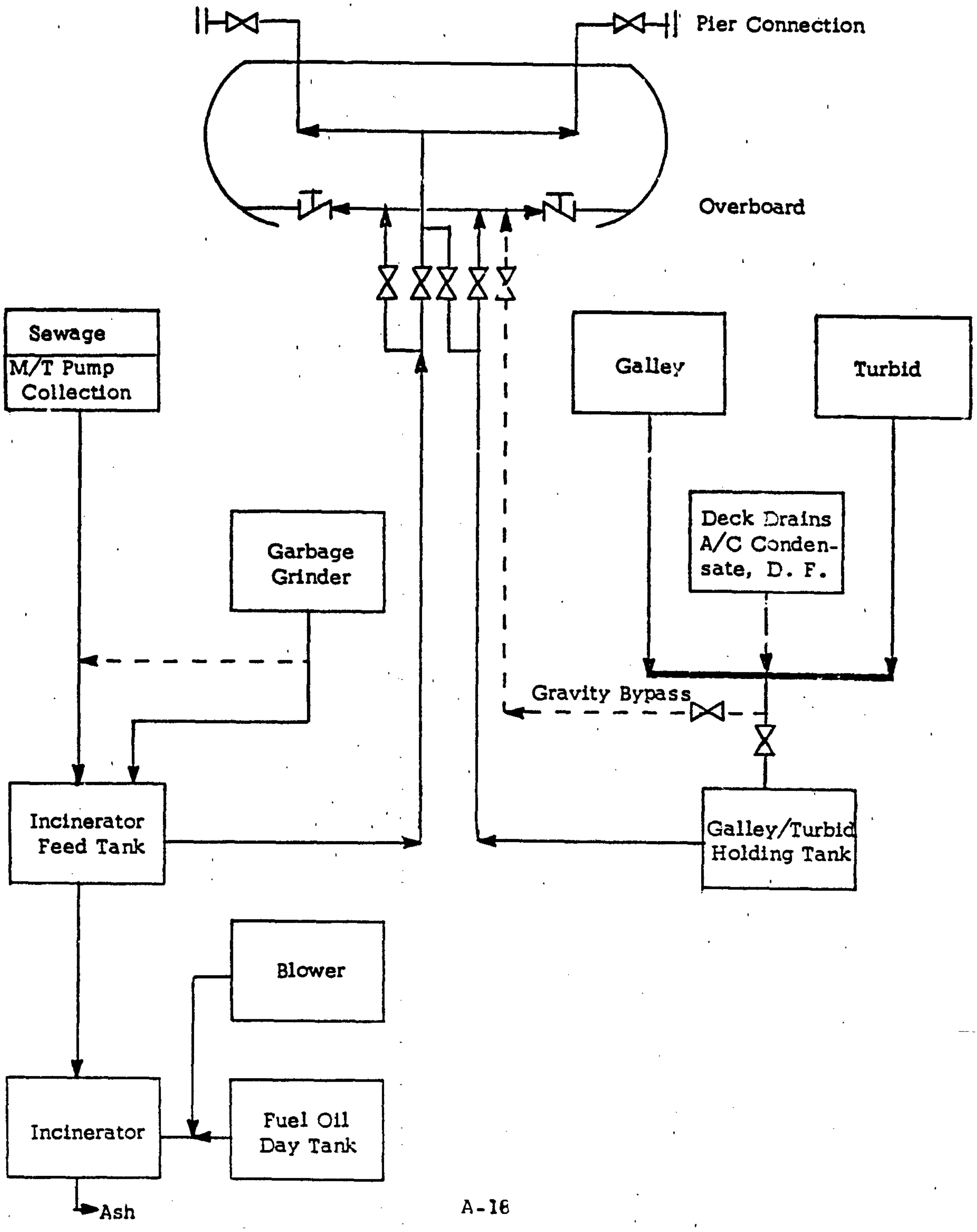
13. JERED Reduced Volume Flush Vacuum Collection/Grumman Flow Through System for Gray Water/Incinerator for both Concentrated Black Water and Gray Water Sludge



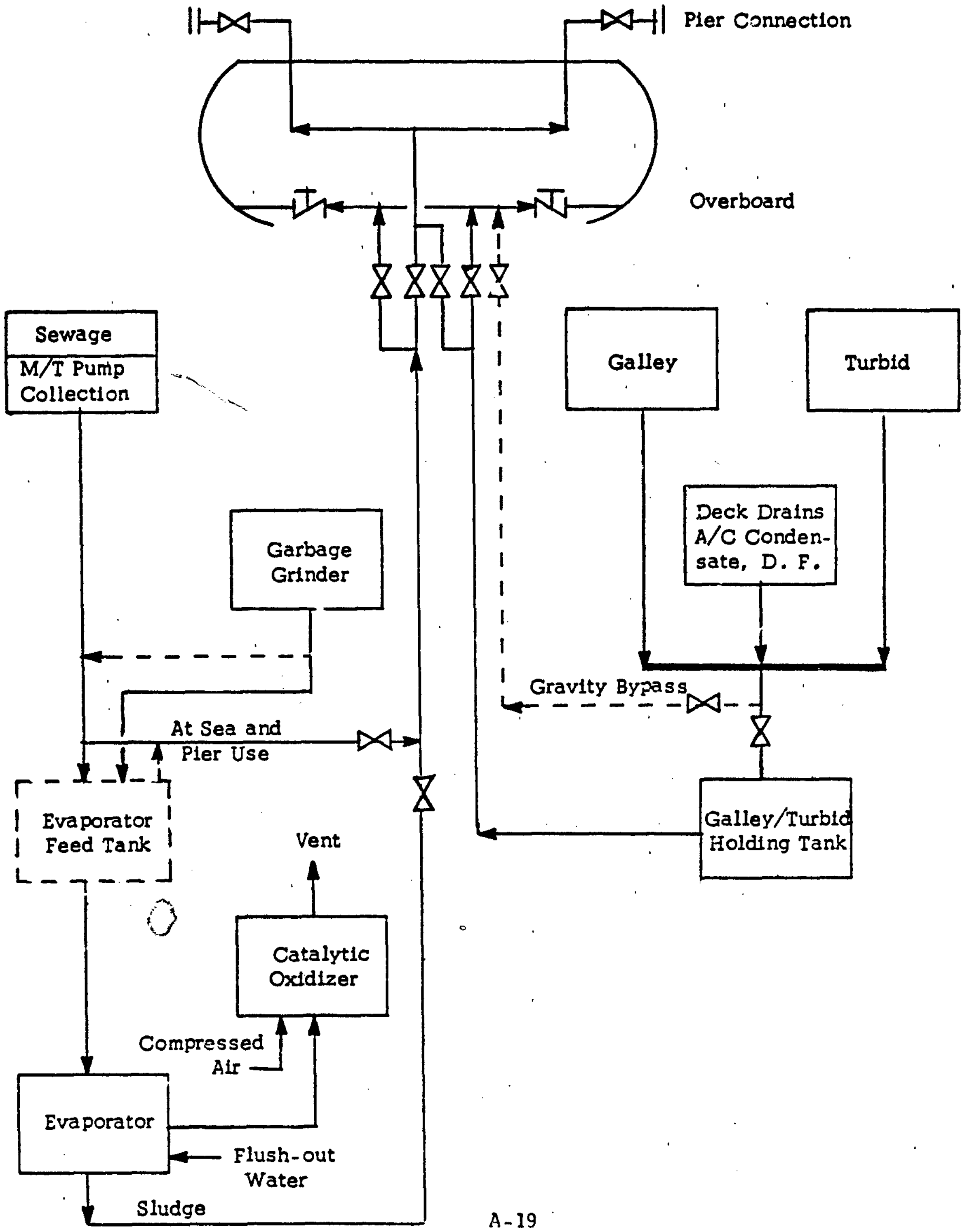
14. GATX Reduced Volume Flush M/T Pump Collection/Holding Tank for Concentrated Black Water/Holding Tank for Gray Water



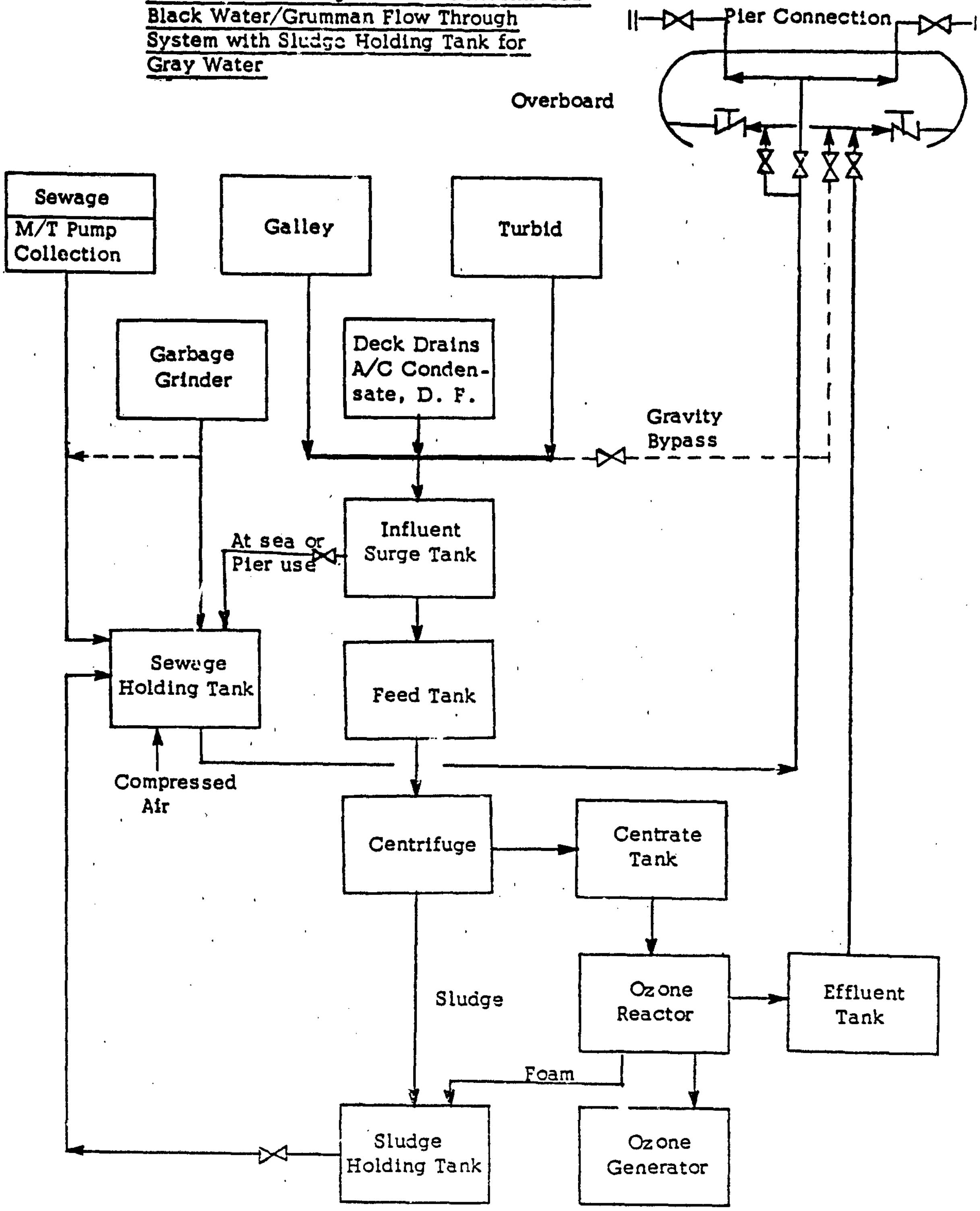
15. GATX Reduced Volume Flush M/T Pump Collection/Incinerator for Concentrated Black Water/Holding Tank for Gray Water



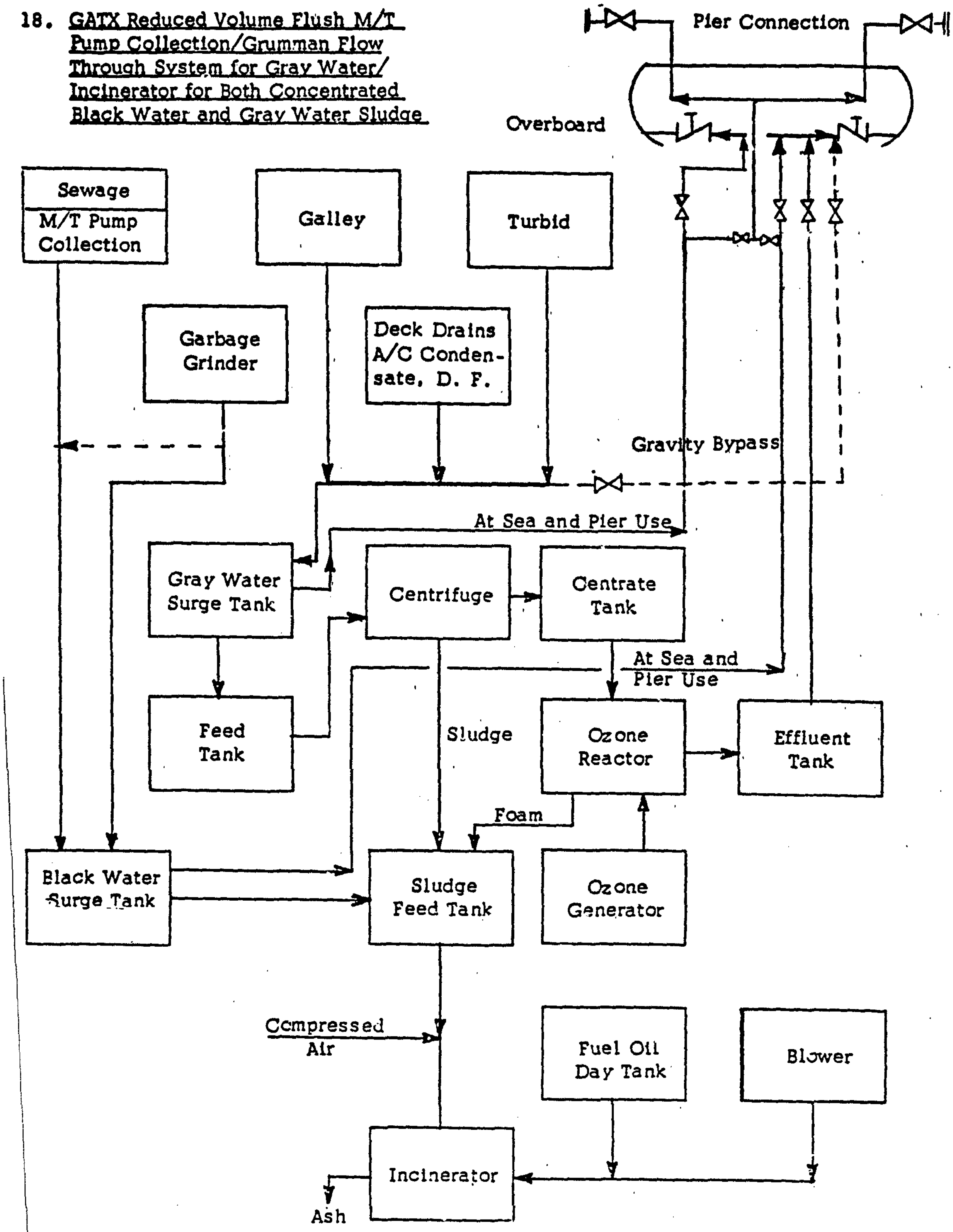
16. GATX Reduced Volume Flush M/T Pump Collection/GATX Evaporator for Concentrated Black Water/Holding Tank for Gray Water



17. GATX Reduced Volume Flush M/T Pump Collection/Holding Tank for Concentrated Black Water/Grumman Flow Through System with Sludge Holding Tank for Gray Water



18. GATX Reduced Volume Flush M/T Pump Collection/Grumman Flow Through System for Gray Water/ Incinerator for Both Concentrated Black Water and Gray Water Sludge



APPENDIX B

ESTIMATED ANNUAL WMS OPERATING CHARACTERISTICS AND COSTS BASED ON CONTINUOUS OPERATION

Table B-1

ESTIMATED ANNUAL WMS OPERATING CHARACTERISTICS AND COSTS BASED ON CONTINUOUS OPERATION

VESSEL GALLATIN (378') CREW SIZE 152

WMS No.	NUMBER OF TASKS AT FREQUENCY INDICATED***				LABOR***		Cost of Materials Consumed ($/Year)	VESSEL RESOURCES USED									Total Annual Operating Cost ($/Year)
								Annual Usage Rate				Cost ($/Year)					
	Daily	Weekly	Monthly	Annually	Man-Hours Per Year	Cost ($/Year)		Electric Power** (Kwh)	Fuel Oil (Gal)	Fresh Water (Gal)	Compressed Air (SCF x 10^6)	Electric Power (@ 3¢/Kwhr)	Fuel Oil (@39¢/Gal)	Fresh* Water (@2¢ or .07¢/Gal)	Compressed Air	Total Vessel Resource Cost	
1	4				243	1,664		199 1,370			67	6 41			388	6 429	6 2,093
**** 2	7	3	21		183 244	1,265 1,669	2,547 0	1,933 427			12	58 12			73	58 85	3,870 1,754
**** 3	5	5	23		183 143	1,265 1,071	2,547 0	1,933 5,127	36,062		.004	58 153	14,064		0	58 14,217	3,870 15,288
4	12	6	2		370	2,493	161	199 73,921			5.6	6 2,217			27	6 2,244	6 4,898
5	N/A																→
6	N/A																→
7	10	12	8		300	1,979	161	199 166,339	48,267		23.1	6 4,990	18,824		1,086	6 24,490	6 26,630
8	N/A																→
9	44	2	1	1	354 243	2,222 1,664		25,632 1,129		79,117	19.6	769 34		224	111	993 145	3,215 1,809
10	44	4	3	1	354 361	2,222 2,342		25,632 20,710	46,825	79,117	5.6	721 621	18,262	224	238	993 19,121	3,215 21,463
11	42	20	7	1	354 441	2,222 2,968		25,632 384,214		79,117	31.9	769 11,526		224	1,028	993 12,554	3,215 15,522
12	N/A																→
13	N/A																→
14	4				243	1,664		724 1,129		76,562	21.4	22 34		217	105	239 139	239 1,803
15	4	1	1		241	1,587		724 20,710	46,825	76,562	5.6	22 621	18,262	217	238	239 19,121	239 20,708
16	2	18	6		441	2,968		724 384,214		76,562	31.9	22 11,526		217	1,028	239 12,554	239 15,522
17	N/A																→
18	N/A																→

* 2¢ per gallon for vessel generated fresh water and 0.07¢ per gallon for stored fresh water.

** Includes energy for pumping flush/cooling fluid.

*** Excluding mode changeovers.

**** Collection/Transport subsystem includes entire Chrysler treatment system, except for holding tank or incinerator, as the case requires.

Collection/Transport subsystem (black only) → [- - -] ← Treatment/Disposal subsystem (black and gray)

Table B-1 (Cont'd)

ESTIMATED ANNUAL WMS OPERATING CHARACTERISTICS AND COSTS BASED ON CONTINUOUS OPERATION

VESSEL °VIGOROUS (210') CREW SIZE 60

WMS No.	NUMBER OF TASKS AT FREQUENCY INDICATED***				LABOR***		Cost of Materials Consumed ($/Year)	VESSEL RESOURCES USED									Total Annual Operating Cost ($/Year)
								Annual Usage Rate				Cost ($/Year)					
	Daily	Weekly	Monthly	Annually	Man-Hours Per Year	Cost ($/Year)		Electric** Power (Kwh)	Fuel Oil (Gal)	Fresh Water (Gal)	Compressed Air (SCF x 10⁶)	Electric Power (@ 3¢/Kwhr)	Fuel Oil (@ 39¢/Gal)	Fresh* Water (@2¢ or .07¢/Gal)	Compressed Air	Total Vessel Resource Cost	
1	2				122	832		77 541			18.4	2 16			107	2 123	2 955
**** 2	3	1	7		61 122	422 832	849 0	466 401			4.61	14 12			27	14 39	1,285 871
**** 3	N/A																
4	N/A																
5	N/A																
6	N/A																
7	N/A																
8	N/A																
9	22	1	1	1	215 122	1,345 832		8,585 445		32,727	6.3	258 13		59	37	317 50	1,662 882
10	23	3	2	1	215 181	1,345 1,171		8,585 8,175	18,483	32,727	2.2	258 245	7,208	59	94	317 7,547	1,662 8,718
11	N/A																
12	N/A																
13	N/A																
14	2				122	832		286 445		30,222	14.9	9 13		54	73	63 86	63 918
15	3	1	1		181	1,171		286 8,175	18,483	30,222	2.2	9 245	7,208	54	94	63 7,547	63 8,718
16	1	6	8		175	1,160		286 151,663		30,222	12.6	9 4,550		54	406	63 4,956	63 6,116
17	N/A																
18	N/A																

* 2¢ per gallon for vessel generated fresh water and 0.07¢ per gallon for stored fresh water.

** Includes energy for pumping flush/cooling fluid.

*** Excluding mode changeovers.

**** Collection/Transport subsystem includes entire Crysler treatment system, except for holding tank or incinerator, as the case requires.

Collection/Transport subsystem (black only) → ┆- - -┆ ← Treatment/Disposal subsystem (black and gray)

Table B-1 (Cont'd)

ESTIMATED ANNUAL WMS OPERATING CHARACTERISTICS AND COSTS BASED ON CONTINUOUS OPERATION

VESSEL FIREBUSH (180') CREW SIZE 50

WMS No.	NUMBER OF TASKS AT FREQUENCY INDICATED ***				LABOR ***		Cost of Materials Consumed ($/Year)	VESSEL RESOURCES USED								Total Vessel Resource Cost	Total Annual Operating Cost ($/Year)
								Annual Usage Rate				Cost ($/Year)					
	Daily	Weekly	Monthly	Annually	Man-Hours Per Year	Cost ($/Year)		Electric ** Power (Kwh)	Fuel Oil (Gal)	Fresh Water (Gal)	Compressed Air (SCF x 10^6)	Electric Power (@ 3¢/Kwhr)	Fuel Oil (@ 39¢/Gal)	Fresh* Water (@2¢ or .07¢/Gal)	Compressed Air		
1	1				61	446		64 450			62.5	2 14			487	2 501	2 947
**** 2	2	1	7		61 61	422 417	849 0	447 335			11.7	13 10			57	13 67	1,284 484
**** 3	2	2	9		61 73	422 497	849 0	447 2,193	11,863		.001	13 66	4,627		0	13 4,693	1,284 5,190
4	6	3	1		185	1,247	80	64 36,787			5.8	2 1,104			23	2 1,127	2 2,354
5	9	6	2		188	1,245	161	64 72,908			20	2 2,187			98	2 2,285	2 3,691
6	9	6	2		188	1,245	161	64 73,025			77.4	2 2,191			788	2 2,979	2 4,385
7	5	5	4		150	990	80	64 67,192	15,878		7.6	2 2,016	6,193		357	2 8,566	2 9,636
8	8	10	8		178	1,147	161	64 103,313	15,878		7.6	2 3,099	6,193		357	2 9,649	2 10,957
9	11	2	1	1	135 122	850 832		7,154 371		27,740	18	215 11		19.42	131	234 142	1,084 974
10	10	3	2	1	135 181	850 1,171		7,154 6,830	15,878	27,440	1.8	215 205	6,193	19.42	78	234 6,476	1,084 7,647
11	10	6	3	3	135 136	850 911		7,154 126,386		27,740	10.5	215 3,792		19.42	338	234 4,130	1,084 5,041
12	17	8	3	1	135 249	850 1,661	161	7,154 72,946		27,740	18	215 2,188		19.42	131	234 2,319	1,084 4,141
13	11	13	8	1	135 140	850 892	80	7,154 66,859	15,878	27,740	7.6	215 2,006	6,193	19.42	357	234 8,556	1,084 9,528
14	2				122	832		238 371		25,185	20	7 11		17.63	130	25 141	25 923
15	3	1	1		181	1,171		238 6,830	15,878	25,185	1.84	7 205	6,193	17.63	78	25 6,476	25 7,647
16	1	4	5		136	911		238 126,386		25,185	10.5	7 3,792		17.63	338	25 4,130	25 5,041
17	10	6	2		249	1,661	161	238 72,946		25,185	20	7 2,188		17.63	130	25 2,319	25 4,140
18	4	9	10		140	892	80	238 66,859	15,878	25,185	7.6	7 2,006	6,193	17.63	352	25 8,556	25 9,528

* 2¢ per gallon for vessel generated fresh water and 0.07¢ per gallon for stored fresh water.

** Includes energy for pumping flush/cooling fluid.

*** Excluding mode changeovers.

**** Collection/Transport subsystem includes entire Chrysler treatment system, except for holding tank or incinerator, as the case requires.

Collection/Transport subsystem (black only) → - - - ← Treatment/Disposal subsystem (black and gray)

Table B-1 (Cont'd)

ESTIMATED ANNUAL WMS OPERATING CHARACTERISTICS AND COSTS BASED ON CONTINUOUS OPERATION

VESSEL PAMLICO (160') CREW SIZE 13

WMS No.	NUMBER OF TASKS AT FREQUENCY INDICATED ***				LABOR ***		Cost of Materials Consumed ($/Year)	VESSEL RESOURCES USED									Total Annual Operating Cost ($/Year)
								Annual Usage Rate				Cost ($/Year)					
	Daily	Weekly	Monthly	Annually	Man-Hours Per Year	Cost ($/Year)		Electric ** Power (Kwh)	Fuel Oil (Gal)	Fresh Water (Gal)	Compressed Air (SCF x 10⁶)	Electric Power (@ 3¢/Kwhr)	Fuel Oil (@ 39¢/Gal)	Fresh* Water (@2¢ or .07¢/Gal)	Compressed Air	Total Vessel Resource Cost	
1	2				122	832		17 117			29.2	1 4			170	1 174	1 1,006
**** 2	3	1	7		61 122	386 833	711 0	376 87			5.46	11 3			23	11 26	1,108 859
**** 3	2	2	7		61 69	386 471	711 0	376 624	3,084		.001	11 19	1,203		0	11 1,222	1,108 1,693
4	6	3	1		185	1,247	80	17 36,542			2.44	1 1,096			10	1 1,105	1 2,433
5	5	3	1		124	830	80	17 36,463			9.41	1 1,094			46	1 1,140	1 2,050
6	5	3	1		124	830	80	17 36,491			36	1 1,094			177	1 1,271	1 2,181
7	5	5	4		150	990	80	17 44,445	4,128		1.98	1 1,338	1,610		93	1 3,036	1 4,106
8	4	5	4		89	574	80	17 44,359	4,128		1.98	1 1,331	1,610		93	1 3,034	1 3,688
9	7	1			74 121	462 832		1,329 97		6,548	9.16	40 3		5	53	45 56	507 888
10	6	4	2		74 86	462 575		1,329 7,992	4,128	6,548	1.98	40 240	1,610	5	93	45 1,943	507 2,518
11	6	3	2	1	43 90	272 608		1,329 32,861		6,548	2.73	40 986		5	88	45 1,074	507 1 682
12	11	4	1		74 185	462 1,247	80	1,329 36,470		6,548	9.16	40 1,094		5	53	45 1,147	507 2,474
13	9	7	3		74 89	462 574	80	1,329 44,359	4,128	6,548	1.98	40 1,331	1,610	5	93	45 3,034	507 3,688
14	2				122	0 832		62 97		6,548	9.41	2 3		5	55	7 58	7 890
15	1	2	3		86	575		62 7,992	4,128	6,548	1.98	2 240	1,610	5	93	7 1,943	7 2,518
16	1	2	1	4	90	608		62 32,861		6,548	2.73	2 986		5	88	7 1,074	7 1,682
17	6	3	1		185	1,247	80	62 36,470		6,548	9.41	2 1,094		5	55	7 1,149	7 2,476
18	4	5	4		89	574	80	62 44,359	4,128	6,548	1.98	2 1,331	1,610	5	93	7 3,034	7 3,688

* 2¢ per gallon for vessel generated fresh water and 0.07¢ per gallon for stored fresh water.

** Includes energy for pumping flush/cooling fluid.

*** Excluding mode changeovers.

**** Collection/Transport subsystem includes entire Chrysler treatment system, except for holding tank or incinerator, as the case requires.

Collection/Transport subsystem (black only) → ⌐- - -¬ ← Treatment/Disposal subsystem (black and gray)

Table B-1 (Cont'd)

ESTIMATED ANNUAL WMS OPERATING CHARACTERISTICS AND COSTS BASED ON CONTINUOUS OPERATION

VESSEL WHITE SAGE (133') CREW SIZE 21

WMS No.	NUMBER OF TASKS AT FREQUENCY INDICATED ***				LABOR ***		Cost of Materials Consumed ($/Year)	VESSEL RESOURCES USED									Total Annual Operating Cost ($/Year)
								Annual Usage Rate				Cost ($/Year)					
	Daily	Weekly	Monthly	Annually	Man-Hours Per Year	Cost ($/Year)		Electric ** Power (Kwh)	Fuel Oil (Gal)	Fresh Water (Gal)	Compressed Air (SCF x 10^6)	Electric Power (@ 3¢/Kwhr)	Fuel Oil (@ 39¢/Gal)	Fresh* Water (@2¢ or .07¢/Gal)	Compressed Air	Total Vessel Resource Cost	
1	2				182	832		27 189			6.19	1 6			33	1 39	1 871
**** 2	3	1	7		61 121	386 834	711 0	391 140			1.16	12 4			4	12 8	1,109 842
**** 3	2	1	7		61 60	386 418	711 0	391 880	4,982		.001	12 26	1,943		0	12 1,969	1,109 2,387
4	6	3	1		185	1,247	80	27 36,594			.51	1 1,094			1	1 1,095	1 2,422
5	5	3	1		124	830	80	27 36,454			1.99	1 1,094			11	1 1,105	1 2,015
6	6	3	1		185	1,247	80	27 36,503			6.19	1 1,094			36	1 1,130	1 2,457
7	5	5	4		150	990	86	27 49,364	6,669		3.204	1 1,481	2,601		150	1 4,232	1 5,302
8	4	5	4		89	574	80	27 49,224	6,669		3.204	1 1,477	2,601		150	1 4,228	1 4,882
9	7	2			74 152	462 1,022		2,146 156		10,578	1.713	64 5		8	5	72 10	534 1,032
10	6	6	2		74 87	462 575		2,146 12,910	6,669	10,578	3.204	64 387	2,601	8	150	72 3,138	534 3,713
11	6	4	1	1	74 92	462 618		2,146 53,065		10,578	4.415	64 1,592		8	142	72 1,734	534 2,352
12	7	3	1		74 185	462 1,247	80	2,145 36,470		10,578	1.713	64 1,094		8	5	72 1,099	534 2,426
13	9	7	4		74 89	462 574	80	2,146 49,224	6,669	10,578	3.204	64 1,477	2,601	8	150	72 4,228	534 4,882
14	2				122	832		100 156		10,578	1.987	3 5		8	11	11 16	11 848
15	1	2	3		87	575		100 12,910	6,669	10,578	3.204	3 387	2,601	8	150	11 3,138	11 3,713
16	1	2	1		92	618		100 53,065		10,578	4.415	3 1,592		8	142	11 1,734	11 2,352
17	6	3	1		185	1,247	80	100 36,470		10,578	6.19	3 1,094		8	160	11 1,254	11 2,581
18	2	5	3		89	574	90	100 49,224	6,669	10,578	3.20	3 1,477	2,601	8	150	11 4,228	11 4,882

* 2¢ per gallon for vessel generated fresh water and 0.07¢ per gallon for stored fresh water.

** Includes energy for pumping flush/cooling fluid.

*** Excluding mode changeovers.

**** Collection/Transport subsystem includes entire Chrysler treatment system, except for holding tank or incinerator, as the case requires.

Collection/Transport subsystem (black only) → ┆- - -┆ ← Treatment/Disposal subsystem (black and gray)

Table B-1 (Cont'd)

ESTIMATED ANNUAL WMS OPERATING CHARACTERISTICS AND COSTS BASED ON CONTINUOUS OPERATION

VESSEL POINT HERRON(82') CREW SIZE 8

WMS No.	NUMBER OF TASKS AT FREQUENCY INDICATED***				LABOR***		Cost of Materials Consumed ($/Year)	VESSEL RESOURCES USED									Total Annual Operating Cost ($/Year)
								Annual Usage Rate				Cost ($/Year)					
	Daily	Weekly	Monthly	Annually	Man-Hours Per Year	Cost ($/Year)		Electric** Power (Kwh)	Fuel Oil (Gal)	Fresh Water (Gal)	Compressed Air (SCF x 10^6)	Electric Power (@ 3¢/Kwhr)	Fuel Oil (@ 39¢/Gal)	Fresh* Water (@2¢ or .07¢/Gal)	Compressed Air	Total Vessel Resource Cost	
1	1				61	416		7 72			2.07	0 2			6	0 8	0 424
**** 2	N/A																→
**** 3	N/A																→
4	N/A																→
5	N/A																→
6	N/A																→
7	N/A																→
8	N/A																→
9	4	2			55 122	347 832		526 59		4,380	.9	16 2		3	2	19 3	366 835
10	N/A																→
11	3	4	1		55 89	347 603		526 20,221		4,380	1.68	16 607		3	54	19 661	366 1,264
12	N/A																→
13	N/A																→
14	2				122	832		37 59		4,380	1.15	1 2		3	3	4 5	4 837
15	N/A																→
16	1	2	1		89	603		37 20,221		4,380	1.68	1 607		3	54	4 661	4 1,264
17	N/A																→
18	N/A																→

* 2¢ per gallon for vessel generated fresh water and 0.07¢ per gallon for stored fresh water.

** Includes energy for pumping flush/cooling fluid.

*** Excluding mode changeovers.

**** Collection/Transport subsystem includes entire Chrysler treatment system, except for holding tank or incinerator, as the case requires.

Collection/Transport subsystem (black only) → [- - -] ← Treatment/Disposal subsystem (black and gray)

APPENDIX C

ESTIMATED ANNUAL WMS MAINTENANCE CHARACTERISTICS AND COSTS BASED ON CONTINUOUS OPERATION

Table C-1

ESTIMATED ANNUAL WMS MAINTENANCE CHARACTERISTICS AND COSTS BASED ON CONTINUOUS OPERATION

VESSEL GALLATIN (378') CREW SIZE 152

WMS No.	PREVENTIVE MAINTENANCE (PM) Number of Tasks at Frequency Indicated: Daily	Weekly	Monthly	Quarterly	Semi-Annually	Annually	Labor: Man-Hours Per Year	Labor Cost ($/Year)	Cost of Parts/Materials ($/Year)	Total PM Cost ($/Year)	CORRECTIVE MAINTENANCE (CM): Number of Repairs/Year	Parts: No. Used Per Year	Parts: Cost ($/Year)	Labor: Man-Hours Per Year	Labor: Labor Cost ($/Year)	Total CM Cost ($/Year)
1	-	2	-	14	4	-	71	452	16	468	16 56	19 56	133 1,108	22 23	156 164	289 1,272
2	-	2	3	20	13	3	98	628	16	644	62 56	59 59	2,788 1,108	106 20	614 164	3,402 1,272
3	-	4	12	14	16	3	62	424	8	432	62 108	59 112	2,738 25,865	106 31	614 254	3,402 26,119
4	-	2	12	22	14	-	106	697	92	789	28 144	19 150	133 3,970	12 50	87 379	220 4,349
5	N/A															
6	N/A															
7	-	2	12	26	16	-	67	482	124	606	28 142	19 149	133 6,426	12 93	87 613	220 7,039
8	N/A															
9	1	16	5	24	44	13	313	1,985	86	2,071	541 56	153 56	6,909 1,108	202 23	1,340 164	8,249 1,272
10	1	16	5	24	48	21	306	1,935	142	2,077	541 188	153 47	6,909 83,209	202 131	1,340 911	8,249 84,120
11	1	32	11	16	54	19	544	3,466	78	3,544	541 190	153 93	6,909 4,304	202 133	1,340 717	8,249 5,021
12	N/A															
13	N/A															
14	-	20	84	32	4	18	476	3,180	429	3,609	191 56	198 56	12,396 1,108	521 23	2,850 164	15,246 1,272
15	-	19	84	28	5	22	442	2,964	453	3,417	191 105	198 55	12,396 82,399	521 107	2,850 757	15,246 83,156
16	-	36	90	24	14	24	707	4,661	421	5,082	191 190	198 93	12,396 4,304	521 133	2,850 717	15,246 5,021
17	N/A															
18	N/A															

Collection/Transport subsystem (black only) → ☐ ← Treatment/Disposal subsystem (black and gray)

Table C-1 (Cont'd)

ESTIMATED ANNUAL WMS MAINTENANCE CHARACTERISTICS AND COSTS BASED ON CONTINUOUS OPERATION

VESSEL VIGOROUS (210') CREW SIZE 60

WMS No.	PREVENTIVE MAINTENANCE (PM)										CORRECTIVE MAINTENANCE (CM)					
	Number of Tasks at Frequency Indicated						Labor					Parts		Labor		
	Daily	Weekly	Monthly	Quarterly	Semi-Annually	Annually	Man-Hours Per Year	Labor Cost ($/Year)	Cost of Parts/Materials ($/Year)	Total PM Cost ($/Year)	Number of Repairs/Year	No. Used Per Year	Cost ($/Year)	Man-Hours Per Year	Labor Cost ($/Year)	Total CM Cost ($/Year)
1	-	1	-	7	2	-	36	226	8	234	22 28	10 28	70 554	13 11	93 82	163 636
2	-	1	1	9	5	1	45	285	8	293	28 28	23 29	955 554	42 11	252 82	1,207 636
3	N/A															
4	N/A															
5	N/A															
6	N/A															
7	N/A															
8	N/A															
9	-	8	4	14	25	13	179	1,134	40	1,174	394 28	97 28	4,628 554	146 11	974 82	5,602 636
10	-	8	4	14	26	17	175	1,109	68	1,177	394 87	97 36	4,628 33,066	146 57	974 398	5,602 33,464
11	N/A															
12	N/A															
13	N/A															
14	-	10	43	16	2	9	244	1,628	214	1,842	108 28	74 28	5,614 554	256 11	1,478 82	7,092 636
15	-	10	43	16	4	13	240	1,603	242	1,845	108 200	74 36	5,614 33,066	256 57	1,478 398	7,092 33,464
16	-	18	46	12	7	12	359	2,369	210	2,579	108 95	74 46	5,614 2,152	256 66	1,478 358	7,052 2,510
17	N/A															
18	N/A															

Collection/Transport subsystem (black only) → ▭ ← Treatment/Disposal subsystem (black and gray)

Table C-1 (Cont'd)

ESTIMATED ANNUAL WMS MAINTENANCE CHARACTERISTICS AND COSTS BASED ON CONTINUOUS OPERATION

VESSEL FIREBUSH (180') CREW SIZE 50

WMS No.	PREVENTIVE MAINTENANCE (PM)										CORRECTIVE MAINTENANCE (CM)					
	Number of Tasks at Frequency Indicated						Labor					Parts		Labor		
	Daily	Weekly	Monthly	Quarterly	Semi-Annually	Annually	Man-Hours Per Year	Labor Cost ($/Year)	Cost of Parts/Materials ($/Year)	Total PM Cost ($/Year)	Number of Repairs/Year	No. Used Per Year	Cost ($/Year)	Man-Hours Per Year	Labor Cost ($/Year)	Total CM Cost ($/Year)
1	-	1	-	4	1	-	30	191	4	195	8 17	4 17	25 317	4 7	31 51	56 368
2	-	1	-	7	4	1	39	250	4	254	18 17	17 18	910 317	35 6	232 54	1,142 371
3	-	2	5	8	7	1	29	193	4	197	18 18	17 41	910 5,431	35 11	232 124	1,142 5,555
4	-	1	6	11	7	-	53	348	46	394	8 72	4 75	25 1,985	4 25	31 189	56 2,174
5	-	1	12	12	11	-	65	436	80	516	6 105	4 111	25 3,179	4 34	31 266	56 3,445
6	-	1	12	12	11	-	65	436	80	516	8 105	4 111	25 3,179	4 34	31 266	56 3,445
7	-	1	6	14	8	-	33	241	62	303	8 71	4 75	25 3,213	4 46	31 306	56 3,519
8	-	2	12	20	14	-	56	413	116	529	8 131	4 139	25 6,189	4 88	31 581	56 6,770
9	-	4	4	14	12	13	150	946	40	986	255 28	46 28	2,232 554	89 11	599 82	2,831 636
10	-	3	4	14	14	17	146	921	68	989	255 180	46 35	2,232 23,730	89 52	599 363	2,831 28,093
11	-	10	6	10	15	15	217	1,376	36	1,412	255 67	46 35	2,232 1,514	89 46	599 249	2,831 1,763
12	-	5	16	22	22	13	184	1,190	116	1,306	255 116	46 122	2,232 3,416	89 38	599 297	2,381 3,713
13	-	7	10	29	21	13	164	1,095	130	1,225	255 92	46 97	2,232 6,065	89 100	599 613	2,831 6,678
14	-	5	17	10	2	4	122	811	100	911	42 28	30 28	2,475 554	110 11	627 82	3,102 636
15	-	5	17	11	4	8	119	786	128	913	42 180	30 35	2,475 27,730	110 52	627 363	3,102 28,093
16	-	10	19	7	5	6	189	1,241	96	1,336	42 67	30 35	2,475 1,514	110 46	627 249	3,102 1,763
17	-	5	29	19	12	4	157	1,055	176	1,231	42 116	30 122	2,475 3,416	110 38	627 297	3,102 3,713
18	-	7	23	26	11	4	137	959	190	1,149	42 92	30 97	2,475 6,065	110 100	627 613	3,102 6,678

Collection/Transport subsystem (black only) → ┌- - - -┐ ← Treatment/Disposal subsystem (black and gray)

Table C-1 (Cont'd)

ESTIMATED ANNUAL WMS MAINTENANCE CHARACTERISTICS AND COSTS BASED ON CONTINUOUS OPERATION

VESSEL PAMLICO (160') CREW SIZE 13

	PREVENTIVE MAINTENANCE (PM)										CORRECTIVE MAINTENANCE (CM)					
	Number of Tasks at Frequency Indicated						Labor					Parts		Labor		
WMS No.	Daily	Weekly	Monthly	Quarterly	Semi-Annually	Annually	Man-Hours Per Year	Labor Cost ($/Year)	Cost of Parts/Materials ($/Year)	Total PM Cost ($/Year)	Number of Repairs/Year	No. Used Per Year	Cost ($/Year)	Man-Hours Per Year	Labor Cost ($/Year)	Total CM Cost ($/Year)
1	-	1	-	7	2	-	36	226	8	234	7 28	3 28	18 554	4 11	30 82	48 636
2	-	1	1	9	5	1	44	285	8	293	17 28	16 29	903 554	35 10	203 82	1,106 636
3	-	2	5	5	6	1	25	172	4	176	17 29	16 23	903 1,856	35 7	203 96	1,106 1,952
4	-	1	6	11	7	-	53	348	46	394	5 72	3 75	18 1,985	4 25	30 189	48 2,174
5	-	1	6	8	6	-	48	314	42	356	5 61	3 64	18 1,748	4 21	30 159	48 1,907
6	-	1	6	8	6	-	48	314	42	356	5 61	3 64	18 1,748	4 21	30 159	48 1,907
7	-	1	6	13	8	-	33	241	62	303	5 71	3 76	18 3,213	4 46	30 306	48 3,519
8	-	1	6	10	7	-	28	206	58	264	5 60	3 65	18 2,976	4 42	30 276	48 3,252
9	1	5	1	10	7	-	115	728	46	774	74 28	27 28	1,011 554	25 11	164 82	1,175 636
10	1	5	1	12	8	-	96	621	62	683	74 83	27 32	1,011 7,985	25 34	164 231	1,175 8,216
11	1	7	2	6	8	1	134	848	42	890	74 39	27 23	1,011 875	25 25	164 140	1,175 1,015
12	1	5	7	14	12	-	132	851	84	935	74 72	27 75	1,011 1,985	25 25	164 189	1,175 2,174
13	-	2	6	10	12	-	108	709	96	805	74 60	27 64	1,011 2,976	25 42	164 276	1,175 3,252
14	-	4	12	10	2	3	100	657	77	734	30 28	22 28	1,859 554	81 11	462 82	2,321 636
15	-	4	12	12	3	3	80	550	93	643	30 83	22 32	1,859 7,985	81 34	462 231	2,321 8,216
16	-	6	13	6	3	4	118	776	73	849	30 39	22 23	1,859 875	81 25	462 140	2,321 1,015
17	-	4	18		7	3	117	779	115	894	30 72	22 75	1,859 1,985	81 25	462 189	2,321 2,174
18	-	4	17	13	7	3	92	637	127	764	30 60	22 64	1,859 2,976	81 42	462 276	2,321 3,252

Collection/Transport subsystem (black only) → ☐ ← Treatment/Disposal subsystem (black and gray)

Table C-1 (Cont'd)
ESTIMATED ANNUAL WMS MAINTENANCE CHARACTERISTICS AND COSTS BASED ON CONTINUOUS OPERATION

VESSEL WHITE SAGE (133') CREW SIZE 21

	PREVENTIVE MAINTENANCE (PM)										CORRECTIVE MAINTENANCE (CM)					
	Number of Tasks at Frequency Indicated						Labor					Parts		Labor		
WMS No.	Daily	Weekly	Monthly	Quarterly	Semi-Annually	Annually	Man-Hours Per Year	Labor Cost ($/Year)	Cost of Parts/Materials ($/Year)	Total PM Cost ($/Year)	Number of Repairs/Year	No. Used Per Year	Cost ($/Year)	Man-Hours Per Year	Labor Cost ($/Year)	Total CM Cost($/Year)
1	-	1	-	7	2	-	36	226	8	234	7 28	3 28	18 554	4 11	30 82	48 636
2	-	1	1	9	5	1	45	285	8	293	21 28	16 29	903 554	35 11	231 82	1,134 636
3	-	2	5	5	6	1	25	172	4	176	21 28	16 23	903 2,429	35 12	231 97	1,134 2,526
4	-	1	6	11	7	-	53	348	46	394	7 72	3 75	18 2,450	4 25	30 245	48 2,695
5	-	1	6	8	6	-	48	314	42	356	7 61	3 64	18 2,213	4 21	30 215	48 2,428
6	-	1	6	11	7	-	48	314	42	356	7 72	3 75	18 2,450	4 25	30 245	48 2,695
7	-	1	6	13	8	-	33	241	62	303	7 77	3 71	18 3,758	4 50	30 383	48 4,141
8	-	1	6	10	7	-	28	206	58	264	7 47	3 60	18 3,521	4 46	30 342	48 3,863
9	1	5	1	10	7	-	115	728	46	774	102 28	27 28	943 554	25 11	163 82	1,106 636
10	1	5	1	12	8	-	96	621	62	683	102 83	27 33	943 12,254	25 38	163 259	1,106 12,513
11	1	7	2	6	8	1	134	848	42	890	102 39	27 23	943 875	25 25	163 140	1,106 1,015
12	1	5	7	14	12	-	132	851	84	935	102 63	27 75	943 1,985	25 25	163 189	1,106 2,174
13	-	2	6	10	12	-	108	709	96	805	102 60	27 63	943 2,976	25 42	163 276	1,106 3,252
14	-	4	12	10	2	3	100	657	77	734	58 28	50 28	2,413 554	93 11	462 82	2,875 636
15	-	4	12	12	3	3	80	550	93	643	58 83	50 33	2,413 12,254	93 38	462 259	2,875 12,513
16	-	6	13	6	3	4	118	776	73	849	58 39	50 23	2,413 875	93 25	462 140	2,875 1,015
17	-	4	18	13	7	3	117	779	115	894	58 63	50 75	2,413 1,985	93 25	462 189	2,875 2,174
18	-	4	17	13	7	3	92	637	127	764	58 60	50 63	2,413 2,976	93 42	462 276	2,875 3,252

Collection/Transport subsystem → (black only) ← Treatment/Disposal subsystem (black and gray)

Table C-1 (Cont'd)

ESTIMATED ANNUAL WMS MAINTENANCE CHARACTERISTICS AND COSTS BASED ON CONTINUOUS OPERATION

VESSEL POINT HERRON (82') CREW SIZE 8

	PREVENTIVE MAINTENANCE (PM)										CORRECTIVE MAINTENANCE (CM)					
	Number of Tasks at Frequency Indicated						Labor					Parts		Labor		
WMS No.	Daily	Weekly	Monthly	Quarterly	Semi-Annually	Annually	Man-Hours Per Year	Labor Cost ($/Year)	Cost of Parts/Materials ($/Year)	Total PM Cost ($/Year)	Number of Repairs/Year	No. Used Per Year	Cost ($/Year)	Man-Hours Per Year	Labor Cost ($/Year)	Total CM Cost ($/Year)
1	-	1	-	4	1	-	30	191	4	195	5 17	1 17	7 317	4 7	29 51	36 368
2	N/A															
3	N/A															
4	N/A															
5	N/A															
6	N/A															
7	N/A															
8	N/A															
9	1	4	1	10	4	-	107	676	46	722	46 28	18 28	579 554	15 12	96 80	675 634
10	N/A															
11	1	6	2	6	5	1	126	796	42	838	46 39	18 23	579 875	15 25	96 140	675 1.015
12	N/A															
13	N/A															
14	-	3	6	9	2	2	75	490	54	544	17 28	13 28	1,217 554	52 11	294 82	1.511 636
15	N/A															
16	-	5	7	5	3	3	93	609	50	659	17 39	13 23	1,217 875	52 25	294 140	1,511 1.015
17	N/A															
18	N/A															

Collection/Transport subsystem (black only) → ⬚ ← Treatment/Disposal subsystem (black and gray)

APPENDIX D

ESTIMATED WMS OVERHAUL COSTS

Table D-1

ESTIMATED WMS OVERHAUL COSTS*

VESSEL GALLATIN (378') CREW SIZE 152

WMS No.	Number of Tasks Required Per Overhaul	Labor			No. of Parts Per Overhaul	Cost of Parts/ Material Used ($/Overhaul)	Total Cost ($/Overhaul)
		Man-Hours Per Overhaul	Cost ($/Overhaul)	** Average Labor Rate ($/Hour)			
1	59	145	988	6.81	38	266	1,254
2	92	159	1,077	6.77	59	3,838	4,915
3	107	117	803	6.86	83	5,328	6,131
4	127	182	1,249	6.86	94	904	2,153
5	N/A						
6	NA						
7	139	145	1,030	7.10	126	3,923	4,953
8	N/A						
9	79	312	2,316	7.42	121	11,709	14,025
10	91	278	2,101	7.56	141	25,295	27,396
11	129	317	2,402	7.58	223	12,708	15,110
12	N/A						
13	N/A						
14	178	301	2,079	6.90	256	7,310	9,389
15	179	257	1,789	6.96	266	14,103	15,892
16	288	306	2,164	7.07	358	8,309	10,473
17	N/A						
18	N/A						

* Assumed Overhaul Frequency of one overhaul every 2 years.

** Average Labor Rate: $\frac{\text{Cost of Labor}}{\text{Total Man-Hrs}} = \$/\text{Hour}$.

Table D-1 (Cont'd)

ESTIMATED WMS OVERHAUL COSTS*

VESSEL VIGOROUS (210') CREW SIZE 60

WMS No.	Number of Tasks Required Per Overhaul	Labor			No. of Parts Per Overhaul	Cost of Parts/ Material Used ($/Overhaul)	Total Cost ($/Overhaul)
		Man-Hours Per Overhaul	Cost ($/ Overhaul)	** Average Labor Rate ($/Hour)			
1	31	88	613	6.97	20	140	753
2	37	76	532	7.00	27	1,331	1,862
3	N/A						
4	N/A						
5	N/A						
6	N/A						
7	N/A						
8	[illegible]/A						
9	47	238	1,823	7.66	94	7,926	9,749
10	53	221	1,715	7.76	104	14,719	16,434
11	N/A						
12	N/A						
13	N/A						
14	99	158	1,091	6.90	135	3,719	4,810
15	105	143	983	6.87	145	10,512	11,495
16	124	162	1,134	7.00	189	4,226	5,360
17	N/A						
18	N/A						

* Assumed Overhaul Frequency of one overhaul every 2 years.

** Average Labor Rate: $\frac{\text{Cost of Labor}}{\text{Total Man-Hrs}}$ = $/Hour.

Table D-1 (Cont'd)

ESTIMATED WMS OVERHAUL COSTS*

VESSEL FIREBUSH (180')   CREW SIZE 50

WMS No.	Number of Tasks Required Per Overhaul	Labor			No. of Parts Per Overhaul	Cost of Parts/ Material Used ($/Overhaul)	Total Cost ($/Overhaul)
		Man-Hours Per Overhaul	Cost ($/ Overhaul)	** Average Labor Rate ($/Hour)			
1	13	60	424	7.07	7	49	473
2	24	74	524	7.08	14	1,240	1,764
3	41	83	591	7.12	29	2,068	2,659
4	52	105	730	6.95	35	360	1,090
5	81	95	671	7.06	63	679	1,350
6	81	95	671	7.06	63	679	1,350
7	58	87	621	7.14	51	1,870	2,491
8	98	85	634	7.46	95	3,700	4,334
9	33	224	1,734	7.74	80	4,367	6,101
10	39	208	1,627	7.82	90	11,160	12,787
11	48	217	1,702	7.84	97	4,709	6,411
12	101	259	1,978	7.64	136	5,004	6,982
13	90	213	1,710	8.03	156	9,215	10,925
14	43	96	656	6.83	55	1,614	2,270
15	49	80	548	6.86	65	8,407	8,955
16	58	89	624	7.01	91	1,957	2,581
17	111	131	899	6.86	111	2,252	3,151
18	100	85	631	7.42	131	6,462	7,093

* Assumed Overhaul Frequency of one overhaul every 2 years.

** Average Labor Rate: $\frac{\text{Cost of Labor}}{\text{Total Man-Hrs}}$ = $/Hour.

Table D-1 (Cont'd)

ESTIMATED WMS OVERHAUL COSTS*

VESSEL PAMLICO (160') CREW SIZE 13

WMS No.	Number of Tasks Required Per Overhaul	Labor			No. of Parts Per Overhaul	Cost of Parts/ Materia: Used ($/Overhaul)	Total Cost ($/Overhaul)
		Man-Hours Per Overhaul	Cost ($/ Overhaul)	** Average Labor Rate ($/Hour)			
1	16	87	604	6.94	5	35	639
2	27	72	492	6.83	12	1,226	1,718
3	30	48	328	6.83	19	1,675	2,003
4	50	105	728	6.93	33	354	1,082
5	45	78	546	7.00	33	354	900
6	45	78	546	7.00	33	354	900
7	56	87	619	7.11	49	1,864	2,483
8	51	59	437	7.41	49	1,864	2,301
9	23	66	436	6.61	18	1,511	1,947
10	29	47	327	6.96	34	3,021	3,348
11	28	48	329	6.86	36	1,690	2,019
12	57	83	558	6.72	46	1,830	2,388
13	58	37	267	7.22	62	3,340	3,607
14	33	84	574	6.83	39	1,200	1,774
15	39	66	464	7.03	55	2,709	3,173
16	38	77	467	6.06	57	1,379	1,846
17	67	102	696	6.82	67	1,518	2,214
18	68	56	405	7.23	83	3,028	3,433

* Assumed Overhaul Frequency of one overhaul every 2 years.

** Average Labor Rate: $\frac{\text{Cost of Labor}}{\text{Total Man-Hrs}}$ = \$/Hour.

Table D-1 (Cont'd)

ESTIMATED WMS OVERHAUL COSTS*

VESSEL WHITE SAGE (133') CREW SIZE 21

WMS No.	Number of Tasks Required Per Overhaul	Labor Man-Hours Per Overhaul	Labor Cost ($/Overhaul)	Labor ** Average Labor Rate ($/Hour)	No. of Parts Per Overhaul	Cost of Parts/Material Used ($/Overhaul)	Total Cost ($/Overhaul)
1	16	87	604	6.94	5	35	639
2	27	72	492	6.83	13	1,226	1,718
3	30	48	328	6.83	19	1,675	2,003
4	50	105	728	6.93	33	354	1,082
5	45	78	546	7.00	33	354	900
6	50	105	728	6.93	33	354	1,082
7	56	87	618	7.10	49	1,854	2,482
8	51	59	437	7.41	49	1,864	2,301
9	23	66	436	6.61	18	1,511	1,947
10	29	47	327	6.96	34	3,021	3,348
11	28	48	329	6.85	36	1,690	2,019
12	57	83	558	6.72	46	1,830	2,388
13	58	37	267	7.22	62	3,340	3,607
14	33	84	574	6.83	39	1,200	1,774
15	39	66	464	7.03	55	2,709	3,173
16	38	77	467	6.06	57	1,379	1,846
17	67	102	696	6.82	67	1,518	2,214
18	68	56	405	7.23	83	3,028	3,433

* Assumed Overhaul Frequency of one overhaul every 2 years.

** Average Labor Rate: $\frac{\text{Cost of Labor}}{\text{Total Man-Hrs}} = \$/\text{Hour}$.

Table D-1 (Cont'd)

ESTIMATED WMS OVERHAUL COSTS*

VESSEL POINT HERRON (82') CREW SIZE 8

WMS No.	Number of Tasks Required Per Overhaul	Labor			No. of Parts Per Overhaul	Cost of Parts/ Material Used ($/Overhaul)	Total Cost ($/Overhaul)
		Man-Hours Per Overhaul	Cost ($/ Overhaul)	** Average Labor Rate ($/Hour)			
1	8	60	420	7.00	2	14	434
2	N/A						
3	N/A						
4	N/A						
5	N/A						
6	N/A						
7	N/A						
8	N/A						
9	20	63	420	6.67	15	935	1,355
10	N/A						
11	25	46	313	6.80	33	1,114	1,427
12	N/A						
13	N/A						
14	22	72	488	6.78	24	781	1,269
15	N/A						
16	27	55	382	6.95	42	960	1,342
17	N/A						
18	N/A						

* Assumed Overhaul Frequency of one overhaul every 2 years.

** Average Labor Rate: $\frac{\text{Cost of Labor}}{\text{Total Man-Hrs}}$ = $/Hour.

APPENDIX E

ESTIMATED ANNUAL WMS OPERATING CHARACTERISTICS AND COSTS BASED ON PROJECTED WMS UTILIZATION

Table E-1

ESTIMATED ANNUAL WMS OPERATING CHARACTERISTICS AND COSTS BASED ON PROJECTED WMS UTILIZATION

VESSEL GALLATIN (378')

CREW SIZE 152

WMS UTILIZATION FACTOR (%) 11

NO. OF MODE CHANGEOVER CYCLES PER YEAR
- Primary - Overboard 36
- Pierside - Primary 20

WMS No.	LABOR					VESSEL RESOURCES USED (Annual)					VESSEL RESOURCE COSTS (Annual)					Consumables Costs ($/Year)	Total Operating Cost ($/Year)
	Mode Changeovers Man-Hours/Year	Mode Changeovers Cost ($/Year)	Total Labor (Man-Hrs/Year) (1)	Total Labor Cost ($/Year) (1)	Average Labor Rate ($/Year) (2)	Electric Power (Kwhr) (3)	Fuel Oil (Gallons)	Fresh Water (Gallons)	Comp. Air (SCF x 106)	Per Capita Energy(5) Consumption (Kwhr) (4)	Electric Power ($/Year)	Fuel Oil ($/Year)	Fresh Water ($/Year)	Comp. Air ($/Year)	All Resources ($/Year)		
1	13	80	40	263	6.58	350	-	-	7.37	12	10	-	-	43	53	-	316
2	27	169	237	1,618	6.83	1,978	-	-	1.32	15	59	-	-	8	67	2,547	4,232
3	27	169	226	1,552	6.87	2,497	3,967	-	0	356	75	1,547	-		1,622	2,547	5,721
4	27	169	67	443	6.62	8,330	-	-	.616	56	250	-	-	3	253	18	714
5	N/A																
6	N/A																
7	27	169	60	387	6.44	18,496	5,309	-	2.54	592	554	2,070	-	119	2,624	18	3,029
8	N/A																
9	25	159	406	2,554	6.32	25,756	-	79,117	2.156	221	773	-	224	12	1,009	-	3,573
10	25	159	419	2,639	6.30	27,910	5,151	79,117	.616	679	837	2,009	224	26	3,096	-	5,735
11	25	159	428	2,708	6.33	67,895	-	79,117	3.509	520	2,036	-	224	113	2,373	-	5,081
12	N/A																
13	N/A																
14	35	218	62	401	6.47	848	-	76,562	2.343	45	26	-	217	12	255	-	656
15	35	218	62	393	6.34	3,002	5,151	76,562	.616	514	90	2,009	217	26	2,342	-	2,735
16	35	218	84	544	6.48	42,987	-	76,562	3.509	344	1,289	-	217	113	1,619	-	2,163
17	N/A																
18	N/A																

(1) Includes mode changeovers.

(2) Average Labor Rate: $\frac{\text{Cost of Labor}}{\text{Total Man-Hrs}} = \$/\text{Hour}$

(3) Includes energy for pumping flush medium and cooling water.

(4) Includes electric power for compressed air, pumping flush medium and cooling water; fuel; power for fresh water if generated aboard vessel.

Per Capita Energy Consumption (Kwhr/Year) = $\frac{\text{Total Annual Resource Cost (less stored water cost, if any)}}{\$0.03/\text{Kwhr}} \times \frac{1}{\text{Crew Size}}$

Stored water cost based on WMS utilization factor.

Table E-1 (Cont'd)

ESTIMATED ANNUAL WMS OPERATING CHARACTERISTICS AND COSTS BASED ON PROJECTED WMS UTILIZATION

VESSEL VICOROUS (210')

CREW SIZE 60

WMS UTILIZATION FACTOR (%) 5.6

NO. OF MODE CHANGEOVER CYCLES PER YEAR
- Primary - Overboard 15
- Pierside - Primary 16

WMS No.	LABOR					VESSEL RESOURCES USED (Annual)					VESSEL RESOURCE COSTS (Annual)					Consumables Costs ($/Year)	Total Operating Cost ($/Year)
	Mode Changeovers																
	Man-Hours/Year	Cost ($/Year)	Total Labor (Man-Hrs/Year) (1)	Total Labor Cost ($/Year) (1)	Average Labor Rate ($/Year) (2)	Electric Power (Kwhr) (3)	Fuel Oil (Gallons)	Fresh Water (Gallons)	Comp. Air (SCF x 106)	Per Capita Energy($) Consumption (Kwhr) (4)	Electric Power ($/Year)	Fuel Oil ($/Year)	Fresh Water ($/Year)	Comp. Air ($/Year)	All Resources ($/Year)		
1	8	49	15	96	6.40	107	-	-	1.03	5	3	-	-	6	9	-	105
2	17	107	85	576	6.77	488	-	-	.25816	9	15	-	-	2	17	849	1,425
3	N/A																
4	N/A																
5	N/A																
6	N/A																
7	N/A																
8	N/A																
9	16	98	237	1,490	6.29	8,609	-	32,777	.3528	178	259	-	59	2	320	-	1,810
10	16	98	241	1,509	6.26	9,043	1,035	32,777	.1232	411	272	404	59	5	740	-	2,249
11	N/A																
12	N/A																
13	N/A																
14	21	131	28	178	6.34	311	-	30,222	.8344	27	10	-	54	4	68	-	246
15	21	131	31	197	6.35	744	1,035	30,222	.12	256	23	404	54	5	486	-	683
16	21	131	31	196	6.32	8,779	-	30,222	.7056	189	263	-	54	23	339	-	535
17	N/A																
18	N/A																

(1) Includes mode changeovers.

(2) Average Labor Rate: $\frac{\text{Cost of Labor}}{\text{Total Man-Hrs}}$ = $/Hour

(3) Includes energy for pumping flush medium and cooling water.

(4) Includes electric power for compressed air, pumping flush medium and cooling water; fuel; power for fresh water if generated aboard vessel.

Per Capita Energy Consumption (Kwhr/Year) = $\frac{\text{Total Annual Resource Cost (less stored water cost, if any)}}{\$0.03/\text{Kwhr}} \times \frac{1}{\text{Crew Size}}$

Stored water cost based on WMS utilization factor.

Table E-1 (Cont'd)

ESTIMATED ANNUAL WMS OPERATING CHARACTERISTICS AND COSTS BASED ON PROJECTED WMS UTILIZATION

VESSEL FIREBUSH (180')

CREW SIZE 50

WMS UTILIZATION FACTOR (%) 14.1

NO. OF MODE CHANGEOVER CYCLES PER YEAR
- Primary - Overboard 34
- Pierside - Primary 103

	LABOR					VESSEL RESOURCES USED (Annual)					VESSEL RESOURCE COSTS (Annual)						
	Mode Changeovers																
WMS No.	Man-Hours/Year	Cost ($/Year)	Total Labor (Man-Hrs/Year) (1)	Total Labor Cost ($/Year) (1)	Average Labor Rate ($/Year) (2)	Electric Power (Kwhr) (3)	Fuel Oil (Gallons)	Fresh Water (Gallons)	Comp. Air (SCF x 106)	Per Capita Energy(5) Consumption (Kwhr) (4)	Electric Power ($/Year)	Fuel Oil ($/Year)	Fresh Water ($/Year)	Comp. Air ($/Year)	All Resources ($/Year)	Consumables Costs ($/Year)	Total Operating Cost ($/Year)
1	40	251	49	314	6.41	127	-	-	8.81	49	4	-	-	69	73	-	387
2	87	555	157	1,036	6.60	494	-	-	1.65	15	14	-	-	8	22	849	1,907
3	87	555	158	1,047	6.63	756	1,673	- -	0	450	23	652	-	0	675	849	2,571
4	87	555	113	731	6.47	5,250	-	-	.8178	107	157	-	-	3	160	11	902
5	87	555	113	731	6.47	10,344	-	-	2.82	217	310	-	-	14	324	23	1,078
6	87	555	113	731	6.47	10,360	-	-	10.91	281	311	-	-	111	422	23	1,176
7	87	555	108	695	6.44	9,538	2,239	-	1.07	805	286	873	-	50	1,209	11	1,915
8	87	555	112	717	6.40	14,631	2,239	-	1.07	908	439	873	-	50	1,362	23	2,102
9	79	502	231	1,469	6.36	7,206	-	27,740	2.54	156	217	-	19.42	18	254	-	1,723
10	79	502	240	1,517	6.32	8,117	2,239	27,740	.25	752	244	873	19.42	11	1,147	-	2,664
11	79	502	233	1,477	6.34	24,974	-	27,740	1.48	531	899	-	19.42	48	966	-	2,443
12	79	502	249	1,586	6.37	17,439	-	27,740	2.54	361	523	-	19.42	18	560	23	2,169
13	79	502	234	1,478	6.32	16,581	2,239	27,740	1.07	947	497	873	19.42	50	1,439	11	2,928
14	102	645	119	762	6.40	690	-	25,185	2.82	18	9	-	17.63	18	45	-	807
15	102	645	128	810	6.33	1,201	2,239	25,185	.25944	613	36	873	17.63	11	938	-	1,748
16	102	645	121	773	6.39	18,058	-	25,185	1.48	393	542	-	17.63	48	608	-	1,381
17	102	645	137	879	6.42	10,523	-	25,185	2.82	223	316	-	17.63	18	352	23	1,254
18	102	645	122	771	6.32	9,665	-	25,185	1.07	809	290	-	17.63	50	358	11	1,140

(1) Includes mode changeovers.

(2) Average Labor Rate: $\frac{\text{Cost of Labor}}{\text{Total Man-Hrs}}$ = \$/Hour

(3) Includes energy for pumping flush medium and cooling water.

(4) Includes electric power for compressed air, pumping flush medium and cooling water; fuel; power for fresh water if generated aboard vessel.

Per Capita Energy Consumption (Kwhr/Year) = $\frac{\text{Total Annual Resource Cost (less stored water cost, if any)}}{\$0.03/\text{Kwhr}} \times \frac{1}{\text{Crew Size}}$

Stored water cost based on WMS utilization factor.

Table E-1 (Cont'd)

ESTIMATED ANNUAL WMS OPERATING CHARACTERISTICS AND COSTS BASED ON PROJECTED WMS UTILIZATION

VESSEL PAMLICO (160')

CREW SIZE 13

WMS UTILIZATION FACTOR (%) 31

NO. OF MODE CHANGEOVER CYCLES PER YEAR
- Primary - Overboard 0
- Pierside - Primary 33

WMS No.	LABOR					VESSEL RESOURCES USED (Annual)					VESSEL RESOURCE COSTS (Annual)					Consumables Costs ($/Year)	Total Operating Cost ($/Year)
	Mode Changeovers		Total Labor (Man-Hrs/Year) (1)	Total Labor Cost ($/Year) (1)	Average Labor Rate ($/Year) (2)	Electric Power (Kwhr) (3)	Fuel Oil (Gallons)	Fresh Water (Gallons)	Comp. Air (SCF x 10^6)	Per Capita Energy ($) Consumption (Kwhr) (4)	Electric Power ($/Year)	Fuel Oil ($/Year)	Fresh Water ($/Year)	Comp. Air ($/Year)	All Resources ($/Year)		
	Man-Hours/Year	Cost ($/Year)															
1	11	69	49	327	6.67	53	-	-	9.05	141	2	-		53	55	-	382
2	24	155	123	799	6.50	403	-	-	1.69	49	12	-		7	19	711	1,529
3	24	155	106	687	6.48	569	956	-	0	1,000	17	373		0	390	711	1,788
4	24	155	81	542	6.69	11,345	-	-	.7564	882	341	-		3	344	25	911
5	24	155	62	412	6.65	11,321	-	-	2.92	910	341	-		14	355	25	792
6	24	155	62	412	6.65	11,329	-	-	11.16	1,015	341	-		55	396	25	833
7	24	155	71	462	6.51	13,795	1,280	-	.6138	2,421	416	499		29	944	25	1,431
8	24	155	52	333	6.40	13,768	1,280	-	.6138	2,415	414	499		29	942	25	1,300
9	11	69	122	789	6.47	1,359		6,548	2.84	147	41	-	5	16	62	-	851
10	11	69	112	709	6.33	3,807	1,280	6,548	.6138	1,647	114	499	5	29	647	-	1,356
11	11	69	82	529	6.45	11,515	-	6,548	.8463	152	345		5	27	377	-	906
12	11	69	142	918	6.46	12,635	-	6,548	2.84	1,014	379	-	5	16	400	25	1,343
13	11	69	113	709	6.27	15,080	1,280	6,548	.6138	2,514	453	499	5	29	986	25	1,720
14	27	173	65	431	6.63	92	-	6,548	2.92	51	3	-	5	17	25	-	456
15	27	173	54	351	6.50	2,540	1,280	6,548	.6138	1,549	76	499	5	29	609	-	960
16	27	173	55	361	6.56	10,248	-	6,548	.8463	859	307	-	5	27	339	-	700
17	27	173	84	560	6.67	11,368	-	6,548	2.92	918	341	-	5	17	363	25	948
18	27	173	55	351	6.38	13,813	1,280	6,548	.6138	2,417	415	499	5	29	948	25	1,324

(1) Includes mode changeovers.

(2) Average Labor Rate: $\frac{\text{Cost of Labor}}{\text{Total Man-Hrs}}$ = \$/Hour

(3) Includes energy for pumping flush medium and cooling water.

(4) Includes electric power for compressed air, pumping flush medium and cooling water; fuel; power for fresh water if generated aboard vessel.

Per Capita Energy Consumption (Kwhr/Year) = $\frac{\text{Total Annual Resource Cost (less stored water cost, if any)}}{\$0.03/\text{Kwhr}} \times \frac{1}{\text{Crew Size}}$

Stored water cost based on WMS utilization factor.

Table E-1 (Cont'd)

ESTIMATED ANNUAL WMS OPERATING CHARACTERISTICS AND COSTS BASED ON PROJECTED WMS UTILIZATION

VESSEL WHITE SAGE (133')
CREW SIZE 21

WMS UTILIZATION FACTOR (%) 11.1

NO. OF MODE CHANGEOVER CYCLES PER YEAR
. Primary - Overboard 17
. . Pierside - Primary 81

WMS No.	LABOR					VESSEL RESOURCES USED (Annual)					VESSEL RESOURCE COSTS (Annual)					Consumables Costs ($/Year)	Total Operating Cost ($/Year)
	Mode Changeovers																
	Man-Hours/Year	Cost ($/Year)	Total Labor (Man-Hrs/Year) (1)	Total Labor Cost ($/Year) (1)	Average Labor Rate ($/Year) (2)	Electric Power (Kwhr) (3)	Fuel Oil (Gallons)	Fresh Water (Gallons)	Comp. Air (SCF x 10⁶)	Per Capita Energy (5) Consumption (Kwhr) (4)	Electric Power ($/Year)	Fuel Oil ($/Year)	Fresh Water ($/Year)	Comp. Air ($/Year)	All Resources ($/Year)		
1	30	187	44	279	6.34	48	-	-	.68598	10	2	-	-	4	6	-	285
2	66	416	129	895	6.94	407	-	-	.12876	25	12	-	-	4	16	711	1,622
3	66	416	134	848	6.33	489	553	-	0	367	15	216	-	0	231	711	1,790
4	66	416	87	554	6.25	4,089	-	-	.06	195	123	-	-	0	123	9	686
5	66	416	79	508	6.43	4,089	-	-	.22089	197	123	-	-	1	124	9	641
6	66	416	87	554	6.25	4,089	-	-	.68598	202	123	-	-	4	127	9	690
7	66	416	83	526	6.34	4,079	740	-	.355644	747	122	289	-	17	428	9	963
8	66	416	76	480	6.32	5,506	740	-	.355644	747	165	289	-	17	471	9	960
9	59	374	150	949	6.33	2,163	-	10,578	.190143	103	65	-	8	1	74	-	1,023
10	59	374	143	900	6.29	3,579	740	10,578	.355644	656	107	289	8	17	421	-	1,321
11	59	374	143	905	6.33	8,038	-	10,578	.490065	408	241	-	8	16	265	-	1,170
12	59	374	154	974	6.32	6,195	-	10,578	.190143	295	185	-	8	1	194	9	1,177
13	59	374	143	900	6.29	7,609	740	10,578	.355644	847	228	289	8	17	525	9	1,425
14	76	477	90	569	6.32	2,987	-	10,578	.220557	8	90	-	8	1	99	-	668
15	76	477	86	541	6.29	1,533	740	10,578	.355644	559	46	289	8	17	360	-	901
16	76	477	86	546	6.35	5,992	-	10,578	.49	310	180	-	8	16	204	-	750
17	76	477	97	615	6.34	4,148	-	10,578	.58	225	124	-	8	18	150	9	774
18	76	477	86	541	6.29	5,564	740	10,578	.36	749	197	289	8	17	511	9	1,061

(2) Average Labor Rate: $\frac{\text{Cost of Labor}}{\text{Total Man-Hrs}}$ = \$/Hour

(3) Includes energy for pumping flush medium and cooling water.

(4) Includes electric power for compressed air, pumping flush medium and cooling water; fuel; power for fresh water if generated aboard vessel.

Per Capita Energy Consumption (Kwhr/Year) = $\frac{\text{Total Annual Resource Cost (less stored water cost, if any)}}{\$0.03/\text{Kwhr}} \times \frac{1}{\text{Crew Size}}$

Stored water cost based on WMS utilization factor.

Table E-1 (Cont'd)

ESTIMATED ANNUAL WMS OPERATING CHARACTERISTICS AND COSTS BASED ON PROJECTED WMS UTILIZATION

VESSEL POINT HERRON (82')

CREW SIZE 8

WMS UTILIZATION FACTOR (%) 1.8

NO. OF MODE CHANGEOVER CYCLES PER YEAR
- Primary - Overboard 46
- Pierside - Primary 46

WMS No.	LABOR					VESSEL RESOURCES USED (Annual)					VESSEL RESOURCE COSTS (Annual)					Consumables Costs ($/Year)	Total Operating Cost ($/Year)
	Mode Changeovers																
	Man-Hours/Year	Cost ($/Year)	Total Labor (Man-Hrs/Year) (1)	Total Labor Cost ($/Year) (1)	Average Labor Rate ($/Year) (2)	Electric Power (Kwhr) (3)	Fuel Oil (Gallons)	Fresh Water (Gallons)	Comp. Air (SCF x 10^6)	Per Capita Energy(5) Consumption (Kwhr) (4)	Electric Power ($/Year)	Fuel Oil ($/Year)	Fresh Water ($/Year)	Comp. Air ($/Year)	All Resources ($/Year)		
1	23	144	24	151	6.29	8	-	-	.03726	.6	0	-		0	-	-	156
2	N/A																→
3	N/A																→
4	N/A																→
5	N/A																→
6	N/A																→
7	N/A																→
8	N/A																→
9	23	145	80	507	6.34	527	-	2,190	.0162	62	16	-	3	0	19	-	526
10	N/A																→
11	23	145	80	503	6.29	889	-	2,190	.03024	116	27	-	3	1	31	-	534
12	N/A																→
13	N/A																→
14	61	385	63	400	6.35	38	-	2,190	.0207	4	1	-	3	0	4	-	404
15	N/A																→
16	61	385	63	396	6.29	403	-	2,190	.03024	54	12	-	3	1	16	-	412
17	N/A																→
18	N/A																→

(1) Includes mode changeovers.

(2) Average Labor Rate: $\frac{\text{Cost of Labor}}{\text{Total Man-Hrs}}$ = \$/Hour

(3) Includes energy for pumping flush medium and cooling water.

(4) Includes electric power for compressed air, pumping flush medium and cooling water; fuel; power for fresh water if generated aboard vessel.

Per Capita Energy Consumption (Kwhr/Year) = $\frac{\text{Total Annual Resource Cost (less stored water cost, if any)}}{\$0.03/\text{Kwhr}} \times \frac{1}{\text{Crew Size}}$

Stored water cost based on WMS utilization factor.

APPENDIX F

ESTIMATED ANNUAL WMS MAINTENANCE CHARACTERISTICS AND COSTS BASED ON PROJECTED WMS UTILIZATION

Table F-1

ESTIMATED ANNUAL WMS MAINTENANCE CHARACTERISTICS AND COSTS BASED ON PROJECTED WMS UTILIZATION

VESSEL GALLATIN (378') CREW SIZE 152 WMS UTILIZATION FACTOR (%) 11

WMS No.	PREVENTIVE MAINTENANCE (PM)					CORRECTIVE MAINTENANCE (CM)							Total P.M. and C.M. Cost ($/Year)
	LABOR						PARTS		LABOR				
	Man-Hours/Year	Labor Cost ($/Year)	Average** Labor Rate ($/Year)	Cost of Materials ($/Year)	Total P.M. Cost ($/Year)	Number of Repairs/Year	Number Used/Year	Cost ($/Year)	Man-Hours/Year	Labor Cost ($/Year)	Average** Labor Rate ($/Year)	Total C.M. Cost ($/Year)	
1	71	452	6.37	16	468	22	25	255	25	174	6.56	429	897
2	98	628	6.41	16	644	68	65	2,910	108	632	5.85	3,542	4,186
3	62	424	6.39	8	432	74	71	5,633	109	642	5.89	6,275	6,707
4	106	697	6.58	92	789	44	35	570	18	129	6.90	698	1,487
5	N/A												
6	N/A												
7	67	482	7.19	124	606	44	35	840	22	154	6.77	994	1,600
8	N/A												
9	313	1,985	6.35	86	2,071	547	159	7,030	205	1,358	6.62	8,389	10,460
10	306	1,935	6.33	142	2,077	562	158	16,062	216	1,440	6.67	17,502	19,579
11	544	3,466	6.38	78	3,544	562	163	7,382	217	1,419	6.54	8,801	12,345
12	N/A												
13	N/A												
14	476	3,180	6.68	429	3,609	197	204	12,518	524	2,868	5.72	15,386	18,995
15	442	2,964	6.59	453	3,417	203	204	21,460	533	2,933	5.75	24,393	27,810
16	707	4,661	6.59	421	5,082	212	208	12,870	536	2,929	5.71	15,798	20,880
17	N/A												
18	N/A												

* Although the treatment/disposal subsystem is not utilized 100% of the time, it will be assumed that preventive maintenance routines will be maintained as if the subsystem were used continuously.

** Average Labor Rate: $\frac{\text{Cost of Labor}}{\text{Total Man-Hrs}}$ = \$/Hour

Table F-1 (Cont'd)

ESTIMATED ANNUAL WMS MAINTENANCE CHARACTERISTICS AND COSTS BASED ON PROJECTED WMS UTILIZATION

VESSEL VIGOROUS (210') CREW SIZE 60 WMS UTILIZATION FACTOR (%) 5.6

WMS No.	PREVENTIVE MAINTENANCE (PM)					CORRECTIVE MAINTENANCE (CM)								
	LABOR						PARTS		LABOR				
	Man-Hours/ Year	Labor Cost ($/Year)	Average** Labor Rate ($/Year)	Cost of Materials ($/Year)	Total P.M. Cost ($/Year)	Number of Repairs/ Year	Number Used/ Year	Cost ($/Year)	Man-Hours/ Year	Labor Cost ($/Year)	Average** Labor Rate ($/Year)	Total C.M. Cost ($/Year)	Total P.M. and C.M. Cost ($/Year)
1	36	226	6.28	8	234	24	12	101	14	98	6.67	199	433
2	45	285	6.33	8	293	30	25	986	43	257	5.98	1,243	1,536
3	N/A												
4	N/A												
5	N/A												
6	N/A												
7	N/A												
8	N/A												
9	179	1,134	6.35	40	1,174	396	99	4,659	147	979	6.68	5,638	6,612
10	175	1,109	6.35	68	1,177	399	99	6,480	149	996	6.70	9,283	10,460
11	N/A												
12	N/A												
13	N/A												
14	244	1,628	6.72	214	1,842	110	76	5,645	257	1,483	5.77	7,128	8,970
15	240	1,603	6.68	242	1,845	119	76	7,466	259	1,500	5.79	8,966	10,811
16	359	2,369	6.60	210	2,579	113	77	5,735	260	1,517	5.76	7,233	9,812
17	N/A												
18	N/A												

*Although the treatment/disposal subsystem is not utilized 100% of the time, it will be assumed that preventive maintenance routines will be maintained as if the subsystem were used continuously.

**Average Labor Rate: $\frac{\text{Cost of Labor}}{\text{Total Man-Hrs}}$ = $/Hour

Table F-1 (Cont'd)

ESTIMATED ANNUAL WMS MAINTENANCE CHARACTERISTICS AND COSTS BASED ON PROJECTED WMS UTILIZATION

VESSEL FIREBUSH (180') CREW SIZE 50 WMS UTILIZATION FACTOR (%) 14.1

WMS No.	PREVENTIVE MAINTENANCE (PM)					CORRECTIVE MAINTENANCE (CM)							Total P.M. and C.M. Cost ($/Year)
	LABOR						PARTS		LABOR				
	Man-Hours/Year	Labor Cost ($/Year)	Average** Labor Rate ($/Year)	Cost of Materials ($/Year)	Total P.M. Cost ($/Year)	Number of Repairs/Year	Number Used/Year	Cost ($/Year)	Man-Hours/Year	Labor Cost ($/Year)	Average** Labor Rate ($/Year)	Total C.M. Cost ($/Year)	
1	30	191	6.37	4	195	10	6	70	5	38	7.60	108	303
2	39	250	6.41	4	254	20	20	955	36	240	6.67	1,195	1,449
3	29	193	6.66	4	197	21	23	1,676	37	250	6.76	1,926	2,123
4	53	348	6.57	46	394	18	14	305	8	58	7.25	363	757
5	65	436	6.71	80	516	23	20	473	9	69	7.67	542	1,058
6	65	431	6.63	80	516	23	20	473	9	69	7.67	542	1,058
7	33	241	7.30	62	303	18	14	478	10	74	7.40	552	855
8	56	413	7.37	116	529	26	24	898	16	113	7.06	1,011	1,540
9	150	946	6.31	40	986	259	50	2,310	91	611	6.71	2,921	3,907
10	146	921	6.31	68	989	280	51	6,142	96	650	6.77	6,792	7,781
11	217	1,376	6.34	36	1,412	264	51	2,445	95	634	6.67	3,079	4,491
12	184	1,190	6.47	116	1,306	271	63	2,714	94	641	6.82	3,355	4,661
13	164	1,0[illegible]5	6.68	130	1,225	268	59	3,087	103	685	6.65	3,772	4,997
14	122	811	6.64	100	911	46	34	2,553	112	639	5.71	3,192	4,103
15	119	786	6.61	128	913	66	35	6,385	117	678	5.79	7,063	7,976
16	189	1,241	6.57	96	1,336	51	35	2,688	116	662	5.71	3,350	4,686
17	157	1,055	6.72	176	1,231	58	47	2,957	115	669	5.82	3,626	4,857
18	137	959	7.00	190	1,149	55	43	3,330	124	713	5.75	4,043	5,192

* Although the treatment/disposal subsystem is not utilized 100% of the time, it will be assumed that preventive maintenance routines will be maintained as if the subsystem were used continuously.

** Average Labor Rate: $\frac{\text{Cost of Labor}}{\text{Total Man-Hrs}}$ = $/Hour

Table F-1 (Cont'd)

ESTIMATED ANNUAL WMS MAINTENANCE CHARACTERISTICS AND COSTS BASED ON PROJECTED WMS UTILIZATION

VESSEL PAMLICO (160') CREW SIZE 13 WMS UTILIZATION FACTOR (%) 31

WMS No.	PREVENTIVE MAINTENANCE (PM)					CORRECTIVE MAINTENANCE (CM)							Total P.M. [illegible]d [illegible] Cost ($/Year)
	LABOR						PARTS		LABOR				
	Man-Hours/Year	Labor Cost ($/Year)	Average** Labor Rate ($/Year)	Cost of Materials ($/Year)	Total P.M. Cost ($/Year)	Number of Repairs/Year	Number Used/Year	Cost ($/Year)	Man-Hours/Year	Labor Cost ($/Year)	Average** Labor Rate ($/Year)	Total C.M. Cost ($/Year)	
1	36	226	6.28	8	234	16	12	190	7	55	7.86	245	4[illegible]
2	44	285	6.48	8	293	26	25	1,075	38	228	6.00	1,303	1,596
3	25	172	6.88	4	176	26	23	1,478	37	233	6.30	1,711	1,887
4	53	348	6.57	46	394	27	26	633	12	89	7.42	722	1,116
5	48	314	6.54	42	356	24	22	560	11	79	7.18	639	995
6	48	314	6.54	42	356	24	22	560	11	79	7.18	639	995
7	33	241	7.30	62	303	27	27	1,014	18	125	6.94	1,139	1,442
8	28	206	7.36	58	264	24	23	941	17	116	6.82	1,057	1,321
9	115	728	6.33	46	774	83	36	1,183	28	189	6.75	1,372	2,146
10	96	621	6.48	62	683	100	37	3,486	36	236	6.56	3,722	4,405
11	134	848	6.33	42	890	86	34	1,282	33	207	6.27	1,489	2,379
12	132	951	6.45	84	935	96	50	1,626	33	223	6.76	1,849	2,784
13	108	709	6.56	96	805	93	46	1,934	38	250	6.58	2,184	2,989
14	100	657	6.57	77	734	39	31	2,031	84	487	5.80	2,518	3,252
15	80	550	6.88	93	643	56	32	4,334	92	534	5.80	4,868	5,511
16	118	776	6.58	73	849	42	42	2,130	89	505	5.67	2,635	3,484
17	117	779	6.66	115	894	52	52	2,474	89	521	5.85	2,995	3,889
18	92	637	6.92	127	764	49	42	2,782	94	548	5.83	3,330	4,094

* Although the treatment/disposal subsystem is not utilized 100% of the time, it will be assumed that preventive maintenance routines will be maintained as if the subsystem were used continuously.

** Average Labor Rate: $\frac{\text{Cost of Labor}}{\text{Total Man-Hrs}} = \$/\text{Hour}$

Table F-1 (Cont'd)

ESTIMATED ANNUAL WMS MAINTENANCE CHARACTERISTICS AND COSTS BASED ON PROJECTED WMS UTILIZATION

VESSEL WHITE SAGE (133') CREW SIZE 21 WMS UTILIZATION FACTOR (%) 11.1

	PREVENTIVE MAINTENANCE (PM)					CORRECTIVE MAINTENANCE (CM)							
	LABOR						PARTS		LABOR				
WMS No.	Man-Hours/Year	Labor Cost ($/Year)	Average** Labor Rate ($/Year)	Cost of Materials ($/Year)	Total P.M. Cost ($/Year)	Number of Repairs/Year	Number Used/Year	Cost ($/Year)	Man-Hours/Year	Labor Cost ($/Year)	Average** Labor Rate ($/Year)	Total C.M. Cost ($/Year)	Total P.M. and C.M. Cost ($/Year)
1	36	226	6.28	8	234	10	6	79	5	39	7.80	118	352
2	45	285	6.33	8	293	24	19	964	36	240	6.67	1,204	1,497
3	25	172	6.88	4	176	24	19	1,173	36	242	6.72	1,415	1,591
4	53	348	6.57	46	394	15	7	290	7	57	8.14	347	741
5	48	314	6.54	42	356	14	10	264	6	54	9.00	318	674
6	48	314	6.54	42	356	15	11	290	7	57	8.14	347	703
7	33	241	7.30	62	303	16	11	435	10	73	7.30	508	811
8	28	206	7.36	58	264	12	10	409	9	68	7.56	477	741
9	115	728	6.33	46	774	105	30	1,004	26	172	6.62	1,176	1,950
10	96	621	6.47	62	683	111	31	2,303	29	192	6.62	2,495	3,178
11	134	848	6.33	42	890	106	30	1,037	28	179	6.39	1,216	2,106
12	132	851	6.43	84	935	109	35	1,163	28	184	6.57	1,347	2,282
13	108	709	6.56	96	805	109	34	1,273	30	194	6.47	1,467	2,272
14	100	657	6.57	77	734	61	53	2,474	94	471	5.01	2,945	3,679
15	80	550	6.88	93	643	67	54	3,773	97	491	5.06	4,264	4,907
16	118	776	6.58	73	849	62	53	2,510	96	478	4.98	2,988	3,837
17	117	779	6.66	115	894	65	58	2,633	96	483	5.03	3,116	4,010
18	92	637	6.92	127	764	65	57	2,743	98	493	5.03	3,236	4,000

* Although the treatment/disposal subsystem is not utilized 100% of the time, it will be assumed that preventive maintenance routines will be maintained as if the subsystem were used continuously.

** Average Labor Rate: $\frac{\text{Cost of Labor}}{\text{Total Man-Hrs}} = \$/\text{Hour}$

Table F-1 (Cont'd)

ESTIMATED ANNUAL WMS MAINTENANCE CHARACTERISTICS AND COSTS BASED ON PROJECTED WMS UTILIZATION

VESSEL POINT HERRON (82') CREW SIZE 8 WMS UTILIZATION FACTOR (%) 1.8

	PREVENTIVE MAINTENANCE (PM)					CORRECTIVE MAINTENANCE (CM)							
	LABOR						PARTS		LABOR				
WMS No.	Man-Hours/ Year	Labor Cost ($/Year)	Average** Labor Rate ($/Year)	Cost of Materials ($/Year)	Total P.M. Cost ($/Year)	Number of Repairs/ Year	Number Used/ Year	Cost ($/Year)	Man-Hours/ Year	Labor Cost ($/Year)	Average** Labor Rate ($/Year)	Total C.M. Cost ($/Year)	Total P.M. and C.M. Cost ($/Year)
1	30	191	6.37	4	195	5	1	13	4	30	7.5	43	238
2	N/A												
3	N/A												
4	N/A												
5	N/A												
6	N/A												
7	N/A												
8	N/A												
9	107	676	6.30	46	722	47	19	589	15	97	6.47	686	1,408
10	N/A												
11	126	796	6.35	42	838	47	18	595	15	99	6.60	694	1,532
12	N/A												
13	N/A												
14	70	490	7.00	54	544	18	14	1,227	52	295	5.67	1,522	2,066
15	N/A												
16	93	609	6.56	50	659	18	13	1,233	52	297	5.71	1,530	2,189
17	N/A												
18	N/A												

* Although the treatment/disposal subsystem is not utilized 100% of the time, it will be assumed that preventive maintenance routines will be maintained as if the subsystem were used continuously.

** Average Labor Rate: $\frac{\text{Cost of Labor}}{\text{Total Man-Hrs}} = \$/\text{Hour}$

APPENDIX G

PRESENT VALUE OF ESTIMATED LIFE-CYCLE WMS OPERATING AND MAINTENANCE COSTS

Table G-1

PRESENT VALUE* OF ESTIMATED LIFE CYCLE WMS OPERATING AND MAINTENANCE COSTS

VESSEL GALLATIN (378')

WMS No.	ANNUAL COSTS** ($/Year)				Overhaul Maintenance Cost ($/Overhaul)	PRESENT VALUE* OF LIFE-CYCLE COST ($)				
	Operating	Preventive Maintenance (PM)	Corrective Maintenance (CM)	Combined Oper. & Maint. (PM & CM)		Operating	Preventive Maintenance	Corrective Maintenance	Overhaul Maintenance	TOTAL
1	316	468	429	1,213	1,254	1,942	2,876	2,636	3,669	11,123
2	4,232	644	3,542	4,186	4,915	26,004	3,957	21,764	14,381	66,106
3	5,721	432	6,275	6,707	6,131	35,153	2,654	38,557	17,939	94,303
4	714	789	698	2,201	2,153	4,387	4,848	4,289	6,300	19,824
5	N/A									
6	N/A									
7	3,029	606	994	4,620	4,953	18,612	3,724	6,108	14,492	42,936
8	N/A									
9	3,573	2,071	8,389	14,033	14,025	21,955	12,725	51,457	41,037	127,264
10	5,735	2,077	17,502	25,314	27,396	35,239	12,762	107,542	80,160	235,703
11	5,081	3,544	8,801	17,426	15,110	31,221	21,776	54,078	44,212	151,287
12	N/A									
13	N/A									
14	656	3,609	15,386	19,658	9,389	4,031	22,176	94,540	27,422	148,219
15	2,735	3,417	24,393	30,545	15,892	16,805	20,996	149,884	46,500	234,185
16	2,163	5,082	15,798	23,043	10,423	13,291	31,227	97,072	30,644	172,234
17	N/A									
18	N/A									

* Based on (1) projected WMS utilization, (2) an assumed 10 year useful life and (3) 10% effective discount rate.

** Based on projected WMS utilization.

Table G-1 (Cont'd)

PRESENT VALUE* OF ESTIMATED LIFE CYCLE WMS OPERATING AND MAINTENANCE COSTS

VESSEL VIGOROUS (210')

WMS No.	ANNUAL COSTS** ($/Year) Operating	Preventive Maintenance (PM)	Corrective Maintenance (CM)	Combined Oper. & Maint. (PM & CM)	Overhaul Maintenance Cost ($/Overhaul)	PRESENT VALUE* OF LIFE-CYCLE COST ($) Operating	Preventive Maintenance	Corrective Maintenance	Overhaul Maintenance	TOTAL
1	105	234	199	538	753	645	1,438	1,223	2,203	5,509
2	1,425	293	1,243	1,536	1,862	8,756	1,800	7,638	5,448	23,642
3	N/A									
4	N/A									
5	N/A									
6	N/A									
7	N/A									
8	N/A									
9	1,810	1,174	5,638	8,622	9,749	11,122	7,214	34,643	28,525	81,504
10	2,249	1,177	9,283	12,709	16,434	13,819	7,232	57,040	48,086	126,177
11	N/A									
12	N/A									
13	N/A									
14	246	1 [illegible]	7,128	11,304	4,810	1,512	11,318	43,798	14,074	70,702
15	683	1,845	8,966	11,494	11,495	4,197	11,337	55,092	33,634	104,260
16	535	2,579	7,233	10,347	5,360	3,287	15,847	44,444	15,683	79,261
17	N/A									
18	N/A									

* Based on (1) projected WMS utilization, (2) an assumed 10 year useful life and (3) 10% effective discount rate.

** Based on projected WMS utilization.

Table G-1 (Cont'd)

PRESENT VALUE* OF ESTIMATED LIFE CYCLE WMS OPERATING AND MAINTENANCE COSTS

VESSEL FIREBUSH (180')

WMS No.	ANNUAL COSTS** ($/Year)				Overhaul Maintenance Cost ($/Overhaul)	PRESENT VALUE* OF LIFE-CYCLE COST ($)				
	Operating	Preventive Maintenance (PM)	Corrective Maintenance (CM)	Combined Oper. & Maint. (PM & CM)		Operating	Preventive Maintenance	Corrective Maintenance	Overhaul Maintenance	TOTAL
1	387	195	108	690	473	2,378	1,198	664	1,384	5,624
2	1,907	254	1,195	1,449	1,764	11,718	1,561	7,342	5,161	25,782
3	2,571	197	1,926	2,123	2,659	39,440	1,210	11,834	7,780	60,264
4	902	394	363	1,659	1,090	5,542	2,421	2,230	3,189	13,382
5	1,078	516	542	2,136	1,350	6,624	3,171	3,330	3,950	17,075
6	1,176	516	542	2,234	1,350	7,226	3,171	3,330	3,950	17,677
7	1,915	303	552	2,770	2,491	11,766	1,862	3,392	7,289	24,309
8	2,102	529	1,011	3,642	4,334	12,916	3,250	6,212	12,681	35,059
9	1,723	986	2,921	3,630	6,101	10,587	6,059	17,948	17,851	52,445
10	2,664	989	6,792	10,445	12,787	16,369	6,077	41,734	37,415	101,595
11	2,443	1,412	3,079	6,934	6,411	15,011	8,676	18,919	18,758	61,364
12	2,169	1,306	3,355	6,830	6,982	13,328	8,025	20,615	20,429	62,397
13	2,928	1,225	3,772	7,925	10,925	17,991	7,527	23,177	31,966	80,661
14	807	911	3,192	4,910	2,270	4,959	5,598	19,613	6,642	36,812
15	1,748	913	7,063	9,724	8,955	10,741	5,610	43,399	26,202	85,952
16	1,381	1,336	3,350	6,067	2,581	8,486	8,209	20,584	7,552	44,831
17	1,254	1,231	3,626	6,111	3,151	7,705	7,564	22,280	9,220	46,769
18	1,140	1,149	4,043	6,332	7,093	7,005	7,060	24,842	20,754	59,661

* Based on (1) projected WMS utilization, (2) an assumed 10 year useful life and (3) 10% effective discount rate.

** Based on projected WMS utilization.

Table G-1 (Cont'd)

PRESENT VALUE* OF ESTIMATED LIFE CYCLE WMS OPERATING AND MAINTENANCE COSTS

VESSEL PAMLICO (160')

WMS No.	ANNUAL COSTS** ($/Year)				Overhaul Maintenance Cost ($/Overhaul)	PRESENT VALUE* OF LIFE-CYCLE COST ($)				
	Operating	Preventive Maintenance (PM)	Corrective Maintenance (CM)	Combined Oper. & Maint. (PM & CM)		Operating	Preventive Maintenance	Corrective Maintenance	Overhaul Maintenance	TOTAL
1	382	234	345	861	639	2,347	1,438	1,505	1,870	7,160
2	1,529	29[illegible]	1,303	1,596	1,718	9,395	1,800	8,006	5,027	24,228
3	1,788	176	1,711	1,887	2,003	10,986	1,081	10,513	5,861	28,441
4	911	394	722	2,027	1,082	5,598	2,421	4,436	3,166	15,621
5	792	356	639	1,787	900	4,866	2,187	3,926	2,633	13,612
6	833	356	639	1,828	900	5,118	2,187	3,926	2,633	13,864
7	1,431	303	1,139	2,873	2,483	8,793	1,862	6,999	7,265	24,919
8	1,300	264	1,057	2,621	2,301	7,988	1,622	6,495	6,733	22,838
9	851	774	1,372	2,997	1,947	5,229	4,756	8,430	5,697	24,112
10	1,356	683	3,722	5,761	3,348	8,332	4,197	22,870	9,796	45,195
11	906	890	1,489	3,285	2,019	5,567	5,469	9,149	5,908	26,093
12	1,343	935	1,849	4,127	2,388	8,252	5,745	11,361	6,987	32,345
13	1,720	805	2,184	4,709	3,607	10,569	4,946	13,420	10,554	39,489
14	456	734	2,518	3,708	1,774	2,802	4,510	15,472	5,191	27,975
15	960	643	4,868	6,471	3,173	5,899	3,951	29,912	9,284	49,046
16	700	849	2,635	4,184	1,846	4,301	5,217	16,191	5,401	31,110
17	948	894	2,995	4,837	2,214	5,825	5,493	18,403	6,478	36,199
18	1,324	764	3,330	5,418	3,433	8,135	4,694	20,461	10,045	43,335

* Based on (1) projected WMS utilization, (2) an assumed 10 year useful life and (3) 10% effective discount rate.

** Based on projected WMS utilization.

Table G-1 (Cont'd)

PRESENT VALUE* OF ESTIMATED LIFE CYCLE WMS OPERATING AND MAINTENANCE COSTS

VESSEL WHITE SAGE (133')

WMS No.	ANNUAL COSTS** ($/Year)				Overhaul Maintenance Cost ($/Overhaul)	PRESENT VALUE* OF LIFE-CYCLE COST ($)				
	Operating	Preventive Maintenance (PM)	Corrective Maintenance (CM)	Combined Oper. & Maint. (PM & CM)		Operating	Preventive Maintenance	Corrective Maintenance	Overhaul Maintenance	TOTAL
1	285	234	118	637	639	1,751	1,438	725	1,870	5,784
2	1,622	293	1,204	1,497	1,718	9,966	1,800	7,398	5,027	24,191
3	1,790	176	1,415	1,591	2,003	10,999	1,081	8,695	5,861	26,636
4	686	394	347	1,427	1,082	4,215	2,421	2,132	3,166	11,934
5	641	356	318	1,315	900	3,939	2,187	1,954	2,633	10,713
6	690	356	347	1,393	1,082	4,240	2,187	2,132	3,166	11,725
7	963	303	508	1,774	2,482	5,917	1,862	3,121	7,262	18,162
8	960	264	477	1,701	2,301	5,899	1,622	2,931	6,733	17,185
9	1,023	774	1,176	2,973	1,947	6,286	4,756	7,226	5,697	23,965
10	1,321	683	2,495	4,499	3,348	8,116	4,197	15,331	9,796	37,440
11	1,170	890	1,216	3,276	2,019	7,189	5,469	7,472	5,908	26,038
12	1,177	935	1,347	3,459	2,388	7,232	5,745	8,277	6,987	28,241
13	1,425	805	1,467	3,697	3,607	8,756	4,946	9,014	10,554	33,270
14	668	734	2,945	4,347	1,774	4,105	4,510	18,096	5,191	31,902
15	901	643	4,264	5,808	3,173	5,536	3,951	26,200	9,284	44,971
16	750	849	2,988	6,087	1,846	4,608	5,216	18,360	5,401	33,585
17	774	894	3,116	4,784	2,214	4,756	5,499	19,146	6,478	35,879
18	1,061	764	3,236	5,061	3,433	6,519	4,694	19,884	10,045	41,142

* Based on (1) projected WMS utilization, (2) an assumed 10 year useful life and (3) 10% effective discount rate.

** Based on projected WMS utilization.

Table G-1 (Cont'd)

PRESENT VALUE* OF ESTIMATED LIFE CYCLE WMS OPERATING AND MAINTENANCE COSTS

VESSEL POINT HERRON (82')

WMS No.	ANNUAL COSTS** ($/Year)				Overhaul Maintenance Cost ($/Overhaul)	PRESENT VALUE* OF LIFE-CYCLE COST ($)				
	Operating	Preventive Maintenance (PM)	Corrective Maintenance (CM)	Combined Oper. & Maint. (PM & CM)		Operating	Preventive Maintenance	Corrective Maintenance	Overhaul Maintenance	TOTAL
1	151	195	43	389	434	928	1,198	264	1,270	3,660
2	N/A									
3	N/A									
4	N/A									
5	N/A									
6	N/A									
7	N/A									
8	N/A									
9	526	722	686	1,934	1,355	3,232	4,436	4,215	3,965	15,848
10	N/A									
11	534	838	694	2,066	1,427	3,281	5,149	4,264	4,175	16,869
12	N/A									
13	N/A									
14	404	544	1,522	2,470	1,269	2,482	3,342	9,352	3,713	18,889
15	N/A									
16	412	659	1,530	2,601	1,342	2,532	4,049	9,401	3,927	19,909
17	N/A									
18	N/A									

* Based on (1) projected WMS utilization, (2) an assumed 10 year useful life and (3) 10% effective discount rate.

** Based on projected WMS utilization.

APPENDIX H

SENSITIVITY ANALYSIS OF LIFE-CYCLE COST

Derivation of Formulas for Sensitivity Analysis

The following definitions are used:

C - Overall WMS life cycle cost

A - WMS acquisition cost

I - WMS installation cost

$O_{C/T}$ - Annual operating cost of WMS (black water) Collection/Transport subsystem based on continuous WMS operation

$O_{T/D}$ - Annual operating cost of WMS Treatment/Disposal subsystem (black and gray) based on continuous WMS operation

PM - Annual WMS preventive maintenance cost for (black water) Collection/Transport subsystem and the Treatment/Disposal subsystem (black and gray) based on continuous WMS operation

$CM_{C/T}$ - Annual corrective maintenance cost of WMS (black water) Collection/Transport subsystem based on continuous WMS operation

$CM_{T/D}$ - Annual corrective maintenance cost of WMS Treatment/Disposal subsystem (black and gray) based on continuous WMS operation

OH - WMS overhaul cost (per overhaul)

U - WMS utilization factor (for black and gray) Treatment/Disposal subsystem for a given vessel

$F_1 = 6.144566$ - Discount factor applicable to operating, preventive and and corrective maintenance costs (based on a 10% effective discount rate and a useful system life of 10 years)

$F_2 = 2.925983$ - Discount factor applicable to overhaul maintenance costs (based on a 2-year overhaul cycle, a 10% effective discount rate and a useful system life of 10 years).

Δ - This symbol, appearing in front of any one of the above symbols, designates a change in the quantity represented by that symbol.

In terms of the above symbols, the overall life cycle cost (C) of any candidate system on a given vessel is related to its various cost elements by the expression

$$C = A + I + F_1\left[O_{C/T} + U\left(O_{T/D}\right) + CM_{C/T} + U\left(CM_{T/D}\right) + PM\right] + F_2\left[OH\right]$$

The sensitivity of the overall cost to a change (error) in any one of the cost elements can be readily determined by introducing a change in that cost element, keeping the other cost elements constant, and deriving the expression for the resulting change in overall cost. Thus, a change in acquisition cost (ΔA) is related to the change in overall cost (ΔC) by the expression

$$C + \Delta C = A + \Delta A + \left\{\text{Remainder of of previous expression}\right\}$$

$$C + \Delta C = \Delta A + \underbrace{A + \left\{ \qquad\qquad\qquad\qquad \right\}}_{C}$$

$$\therefore \quad \Delta A = \Delta C$$

The percentage change in acquisition cost is related to the change in overall cost by the expression

$$\boxed{\frac{\Delta A}{A}\,(\%) = \frac{100\,\Delta C}{A}} \qquad (1)$$

The above expression can be used to determine the percentage change in acquisition cost which will result in a given change in overall life cycle cost. As an example, in order to determine the percentage change in acquisition cost that will result in a 10% change in WMS life-cycle cost, 10% of the life cycle cost (ΔC) and the acquisition cost (A) are substituted in the above expression and the result is the required percentage change in acquisition cost.

Similarly, the percentage change in installation cost (ΔI) is related to the change in overall cost by the expression

$$\boxed{\frac{\Delta I}{I} (\%) = \frac{100 \Delta C}{I}} \qquad (2)$$

The sensitivity of the overall cost to the annual operating cost of the Collection/Transport subsystem ($O_{C/T}$) is obtained from the relation

$$C + \Delta C = I + A + F_1 \left[O_{C/T} + \Delta O_{C/T} + U\left(O_{T/D}\right) + CM_{C/T} + U\left(CM_{T/D}\right) + PM \right] + F_2 \left[OH \right]$$

$$C + \Delta C = \underbrace{I + A + F_1 \left[O_{C/T} + U\left(O_{T/D}\right) + CM_{C/T} + U\left(CM_{T/D}\right) + PM \right] + F_2 \left[OH \right]}_{C} + F_1 \left[\Delta O_{C/T} \right]$$

$$\therefore \; F_1 \left[\Delta O_{C/T} \right] = \Delta C$$

$$\Delta O_{C/T} = \frac{\Delta C}{F_1}$$

Hence,

$$\boxed{\frac{\Delta O_{C/T}}{O_{C/T}} (\%) = \frac{100 \Delta C}{O_{C/T} (F_1)}} \qquad (3)$$

Similarly, the following other relationships are obtained:

$$\boxed{\frac{\Delta CM_{C/T}}{CM_{C/T}} (\%) = \frac{100\,\Delta C}{CM_{C/T}(F_1)}} \qquad (4)$$

and

$$\boxed{\frac{\Delta PM}{PM} (\%) = \frac{100\,\Delta C}{PM\ (F_1)}} \qquad (5)$$

The relationship between $\Delta O_{T/D}$ and ΔC is derived from the expression

$$C + \Delta C = I + A + F_1\left[O_{C/T} + U\left(O_{T/D} + \Delta O_{T/D}\right) + CM_{C/T} + U\left(CM_{T/D}\right) + PM\right] + F_2\left[OH\right]$$

$$C + \Delta C = \underbrace{I + A + F_1\left[O_{C/T} + U\left(O_{T/D}\right) + CM_{C/T} + U\left(CM_{T/D}\right) + PM\right] + F_2\left[OH\right]}_{C} + F_1\left[U\left(\Delta O_{T/D}\right)\right]$$

$$\therefore \quad \Delta C = F_1\left[U\ \left(O_{T/D}\right)\right]$$

$$\Delta O_{T/D} = \frac{\Delta C}{F_1\,(U)}$$

$$\boxed{\frac{\Delta O_{T/D}}{O_{T/D}} (\%) = \frac{100\,\Delta C}{O_{T/D}\,(F_1)\,U}} \qquad (6)$$

Similarly,

$$\boxed{\frac{\Delta CM_{T/D}}{CM_{T/D}} (\%) = \frac{100\Delta C}{CM_{T/D}(F_1)\ U}} \qquad (7)$$

A change in WMS overhaul maintenance cost (ΔOH) is related to a change in overall life cycle cost by the expression:

$$C+\Delta C = A+I+F_1\left[O_{C/T}+U\left(O_{T/D}\right)+CM_{C/T}+U\left(CM_{T/D}\right)+PM\right]+F_2\left[OH+\Delta OH\right]$$

$$C+\Delta C = \underbrace{A+I+F_1\left[O_{C/T}+U\left(O_{T/D}\right)+CM_{C/T}+U\left(CM_{T/D}\right)+PM\right]+F_2\left[OH\right]}_{C}+F_2\left[\Delta OH\right]$$

$$\therefore \quad F_2[\Delta OH] = \Delta C$$

$$\Delta OH = \frac{\Delta C}{F_2}$$

Therefore,

$$\boxed{\frac{\Delta OH}{OH}\ (\%) = \frac{100\Delta C}{OH\ (F_2)}} \qquad (8)$$

The sensitivity of the overall cost to the WMS utilization factor is derived from the relationship:

$$C+\Delta C = I+A+F_1\left[O_{C/T}+\left(U+\Delta U\right)O_{T/D}+CM_{C/T}+\left(U+\Delta U\right)CM_{T/D}+PM\right]+F_2\left[OH\right]$$

$$C+\Delta C = \underbrace{I+A+F_1\left[O_{C/T}+U\left(O_{T/D}\right)+CM_{C/T}+U\left(CM_{T/D}\right)+PM\right]+F_2\left[OH\right]}_{C}+F_1\left[\Delta U\left(O_{T/D}+DM_{T/D}\right)\right]$$

$$\therefore \quad \Delta C = F_1\left[\left(\Delta U\right)\left(O_{T/D}+CM_{T/D}\right)\right]$$

$$\Delta U = \frac{\Delta C}{F_1\left(O_{T/D}+CM_{T/D}\right)}$$

$$\boxed{\frac{\Delta U}{U}\ (\%) = \frac{100\,\Delta C}{U\left(F_1\right)\left(O_{T/D}+CM_{T/D}\right)}} \qquad (9)$$

The sensitivity of the overall life-cycle cost to a change in present value factors (F_1 or F_2) can be investigated by following a procedure similar to that for the cost elements and the utilization factor. The effect of a change (ΔF_1) in the present value factor (F_1) for WMS operating, preventive and corrective maintenance costs is derived from the expression:

$$C+\Delta C = A+I+\left(F_1+\Delta F_1\right)\left[O_{C/T}+U\left(O_{T/D}\right)+CM_{C/T}+U\left(CM_{T/D}\right)+PM\right]+F_2\left[OH\right]$$

$$C+\Delta C = \underbrace{A+I+F_1\left[O_{C/T}+U\left(O_{T/D}\right)+CM_{C/T}+U\left(CM_{T/D}\right)+PM\right]+F_2\left[OH\right]}_{C}+\Delta F_1\left[O_{C/T}+U\left(O_{T/D}\right)+CM_{C/T}+U\left(CM_{T/D}\right)+PM\right]$$

$$\therefore\quad \Delta C = \Delta F_1\left[O_{C/T}+U\left(O_{T/D}\right)+CM_{C/T}+U\left(CM_{T/D}\right)+PM\right]$$

$$\Delta F_1 = \frac{\Delta C}{O_{C/T}+U\left(O_{T/D}\right)+CM_{C/T}+U\left(CM_{T/D}\right)+PM}$$

$$\boxed{\frac{\Delta F_1}{F_1}(\%) = \frac{100\,\Delta C}{F_1\left[O_{C/T}+U\left(O_{T/D}\right)+CM_{C/T}+U\left(CM_{T/D}\right)+PM\right]}} \qquad (10)$$

It is noted that the expression in the denominator is the product of F_1 and the annual cost of operation, preventive maintenance and corrective maintenance based on WMS utilization factor. This product is also equal to the present value of the life cycle cost of operation, preventive maintenance and corrective maintenance.

The sensitivity of the overall life-cycle cost to a change (ΔF_2) in the present value factor (F_2) for WMS overhaul is determined from the relation:

$$C+\Delta C = A+I+F_1\left[O_{C/T}+U\left(O_{T/D}\right)+CM_{C/T}+U\left(CM_{T/D}\right)+PM\right]+\left(F_2+\Delta F_2\right)\left[OH\right]$$

$$C+\Delta C = \underbrace{A+I+F_1\left[O_{C/T}+U\left(O_{T/D}\right)+CM_{C/T}+U\left(CM_{T/D}\right)+PM\right]+F_2\left[OH\right]}_{C}+\Delta F_2\left[OH\right]$$

$$\therefore \quad \Delta C = F_2 (OH)$$

$$\Delta F_2 = \frac{\Delta C}{OH}$$

$$\boxed{\frac{\Delta F_2}{F_2} (\%) = \frac{100 \Delta C}{F_2 (OH)}} \qquad (11)$$

The expression in the denominator is the present value of the life-cycle cost of WMS overhauls.

It is noted that the expressions in (10) and (11) can be used to determine the sensitivity of the overall life-cycle cost to changes in the present value factors F_1 and F_2. However, these present value factors, in turn, are based on a number of assumptions and the above sensitivity relationships do not directly indicate which assumption is the dominant one. The governing assumptions for F_1 are the following:

- An effective discount rate of 10% which includes the combined effects of inflation and interest rates.
- A useful system life of 10 years.

The corresponding assumptions for F_2 are as follows:

- An effective discount rate of 10%.
- A useful system life of 10 years.
- WMS overhaul intervals of two years.

The above result for the present value factor F_1 can be related to the assumed effective discount rate (I) and the useful system life (n) by the following relationship:

$$F_1 = \frac{(1 + I)^n - 1}{I (1 + I)^n}$$

Similarly, an expression for the prevent value factor F_2 can be developed in terms of I, n and the overhaul interval.

Table H-1
Summary of Formulas for Sensitivity Analysis

Cost Element or Cost-Dependent Parameter Being Varied	Formula	Formula No.
Acquisition cost (A)	$\frac{\Delta A}{A}(\%) = \frac{100\Delta C}{A}$	1
Installation cost (I)	$\frac{\Delta I}{I}(\%) = \frac{100\Delta C}{I}$	2
Annual operating cost of the (black water) Collection/Transport subsystem based on continuous operation $(O_{C/T})$	$\frac{\Delta O_{C/T}}{O_{C/T}}(\%) = \frac{100\Delta C}{O_{C/T}(F_1)}$	3
Annual corrective maintenance cost of the (black water) Collection/Transport subsystem based on continuous operation $(CM_{C/T})$	$\frac{\Delta CM_{C/T}}{CM_{C/T}}(\%) = \frac{100\Delta C}{CM_{C/T}(F_1)}$	4
Annual system preventive maintenance cost based on continuous operation (PM)	$\frac{\Delta PM}{PM}(\%) = \frac{100\ C}{PM(F_1)}$	5
Annual operating cost of the Treatment/Disposal subsystem (black and gray) based on continuous operation $(O_{T/D})$	$\frac{\Delta O_{T/D}}{O_{T/D}}(\%) = \frac{100\Delta C}{O_{T/D}(F_1)U}$	6
Annual corrective maintenance cost of the Treatment/Disposal subsystem (black and gray) based on continuous operation $(CM_{T/D})$	$\frac{\Delta CM_{T/D}}{CM_{T/D}}(\%) = \frac{100\Delta C}{CM_{T/D}(F_1)U}$	7
System overhaul cost - per overhaul (OH)	$\frac{\Delta OH}{OH}(\%) = \frac{100\Delta C}{OH(F_2)}$	8
Utilization factor for the Treatment/Disposal subsystem - black and gray (U)	$\frac{\Delta U}{U}(\%) = \frac{100\Delta C}{U(F_1)(O_{T/D}+CM_{T/D})}$	9
Present value factor for operation, preventive maintenance and corrective maintenance (F_1)	$\frac{\Delta F_1}{F_1}(\%) = \frac{100\Delta C}{F_1[O_{C/T} + U(O_{T/D}) + CM_{C/T} + U(CM_{T/D}) + PM]}$	10
Present value factor for overhaul (F_2)	$\frac{\Delta F_2}{F_2}(\%) = \frac{100\Delta C}{F_2(OH)}$	11

Table H-2

RESULTS OF SENSITIVITY ANALYSIS

Vessel GALLATIN (378')

WMS Utilization Factor (%) 11

WMS No.	Coll/ Trans. Subsys. (Black)	TYPE Treatment/Disposal Subsystem		Holding Capacity		% Change in Cost Element (1)								% Change in WMS Utilization Factor (1)	% Change in Present Value Factors (1), (6)	
		Black	Gray	Black (%)	Gray (%)	Acquisition	Installation	Operation (4) C/T (2)	Operation (4) T/D (3)	Preventive Maintenance (PM) (4)	Corrective Maint. (CM) (4) C/T (2)	Corrective Maint. (CM) (4) T/D (3)	Overhaul Maintenance (5)		F_1 (7)	F_2 (8)
1	Gravity Collect.	Holding Tank	Holding Tank	100	19	-	12	15,836	413	203	329	679	159	257	481	159
2	Oil Recircul. (Chrysler)	Chrysler + Hld Tnk	Holding Tank	100	18	49	32	57	1,147	56	65	1,582	32	665	53	32
3		Chrysler + Incin.	Holding Tank	100	13	42	31	91	1,834	133	104	123	40	78	53	40
4	Gravity Collect. (Grumman)	Grum Flow Thru+HldTk	Holding Tank	100	17	21	29	31,140	347	268	849	391	182	496	522	182
5		Grumman Flow Thru + Holding Tank		N/A	N/A											→
6	Gravity Collect.	Holding Tank	Grum Flow Thru+ HldTnk	N/A	N/A											→
7	Gravity Collect. (Grumman)	Grum Flow Thru+Incin	Holding Tank	100	17	20	32	60,215	123	596	1,642	467	153	264	480	153
8		Grumman Flow Thru + Incinerator		N/A	N/A											→
9	Vacuum Collect. (Jered)	Holding Tank	Holding Tank	100	21	45	47	114	1,844	177	44	2,623	55	2,925	161	55
10	↓	Incinerator	Holding Tank	100	21	35	57	220	300	341	86	77	54	165	172	54
11		GATX Evap.	Holding Tank	100	17	23	74	177	333	161	69	1,030	79	680	201	79
12		Holding Tank	Grum Flow Thru+ Hld Tnk	N/A	N/A											→
13		Incinerator	Grum Flow Thru + Incin.	N/A	N/A											→
14	M/T Pump Collect. (GATX)	Holding Tank	Holding Tank	100	30	47	52	1,698	2,046	112	27	2,900	91	3,241	127	91
15		Incinerator	Holding Tank	100	33	43	52	2,771	291	194	43	72	88	157	133	88
16		GATX Evap.	Holding Tank	100	17	23	90	2,570	360	121	40	1,112	123	734	164	123
17		Holding Tank	Grum Flow Thru+Hld Tnk	N/A	N/A											→
18	↓	Incinerator	Grum Flow Thru + Incin.	N/A	N/A											→

(1) Which will result in a 10% change in total WMS life-cycle cost.
(2) Black water Collection/Transport subsystem.
(3) Black and gray water Treatment/Disposal subsystem.
(4) % change in annual cost based on continuous WMS operation.
(5) % change in cost per overhaul.
(6) Based on assumed 10% effective discount rate and a useful system life of 10 years.
(7) F_1 = 6.144566 - Present value factor for operating, preventive and corrective maintenance costs.
(8) F_2 = 2.925983 - Present value factor for overhaul costs (based on a two-year overhaul interval).

Table H.2 (Cont'd)

RESULTS OF SENSITIVITY ANALYSIS

Vessel VIGOROUS (210')

WMS Utilization Factor (%) 5.6%

WMS No.	Coll/ Trans. Subsys. (Black)	TYPE Treatment/Disposal Subsystem		Holding Capacity		% Change in Cost Element (1)								% Change in WMS Utilization Factor (1)	% Change in Present Value Factors (1), (6)	
		Black	Gray	Black (%)	Gray (%)	Acquisition	Installation	Operation (4) C/T (2)	Operation (4) T/D (3)	Preventive Maintenance (PM) (4)	Corrective Maint. (CM) (4) C/T (2)	Corrective Maint. (CM) (4) T/D (3)	Overhaul Maintenance (5)		F_1 (7)	F_2 (8)
1	Gravity Collect.	Holding Tank	Holding Tank	40	1	-	15	12,783	478	109	157	718	71	287	292	71
2	Oil Recircul. (Chrysler)	Chrysler + Hld Tnk	Holding Tank	53	1	49	35	59	1,547	42	63	2,118	29	894	49	29
3		Chrysler + Incin.	Holding Tank	N/A	N/A											→
4	Gravity Collect. (Grumman)	Grum Flow Thru+HldTk	Holding Tank	N/A	N/A											→
5		Grumman Flow Thru + Holding Tank		N/A	N/A											→
6	Gravity Collect.	Holding Tank	Grum Flow Thru+ HldTnk	N/A	N/A											→
7	Gravity Collect. (Grumman)	Grum Flow Thru+Incin.	Holding Tank	N/A	N/A											→
8		Grumman Flow Thru + Incinerator		N/A	N/A											→
9	Vacuum Collect. (Jered)	Holding Tank	Holding Tank	48	1	44	78	127	4,182	176	37	5,800	44	2,430	147	44
10		Incinerator	Holding Tank	100	1	31	94	216	734	304	64	191	46	152	173	46
11		GATX Evap.	Holding Tank	N/A	N/A											
12		Holding Tank	Grum Flow Thru+ Hld Tnk	N/A	N/A											→
13		Incinerator	Grum Flow Thru + Incin.	N/A	N/A											→
14	M/T Pump Collect. (GATX)	Holding Tank	Holding Tank	100	1	39	83	2,942	3,605	101	26	5,204	81	2,130	101	81
15		Incinerator	Holding Tank	100	3	28	94	5,061	653	173	45	170	58	135	170	58
16		GATX Evap.	Holding Tank	100	1	21	150	4,492	826	110	40	2,013	111	586	168	111
17		Holding Tank	Grum Flow Thru+Hld Tnk	N/A	N/A											→
18		Incinerator	Grum Flow Thru + Incin.	N/A	N/A											→

(1) Which will result in a 10% change in total WMS life-cycle cost.
(2) Black water Collection/Transport subsystem.
(3) Black and gray water Treatment/Disposal subsystem.
(4) % change in annual cost based on continuous WMS operation.
(5) % change in cost per overhaul.
(6) Based on assumed 10% effective discount rate and a useful system life of 10 years.
(7) F_1 = 6.144566 - Present value factor for operating, preventive and corrective maintenance costs.
(8) F_2 = 2.925983 - Present value factor for overhaul costs (based on a two-year overhaul interval).

Table H-2 (Cont'd)

RESULTS OF SENSITIVITY ANALYSIS

Vessel FIREBUSH (180')

WMS Utilization Factor (%) 14.1

WMS No.	Coll/ Trans. Subsys. (Black)	TYPE Treatment/Disposal Subsystem		Holding Capacity		% Change in Cost Element (1)								% Change in WMS Utilization Factor (1)	% Change In Present Value Factors (1), (6)	
		Black	Gray	Black (%)	Gray (%)	Acquisition	Installation	Operation (4) C/T (2)	Operation (4) T/D (3)	Preventive Maintenance (PM) (4)	Corrective Maint. (CM) (4) C/T (2)	Corrective Maint. (CM) (4) T/D (3)	Overhaul Maintenance (5)		F_1 (7)	F_2 (8)
1	Gravity Collect.	Holding Tank	Holding Tank	100	0	-	13	18,288	274	188	653	705	162	197	326	162
2	Oil Recircul. (Chrysler)	Chrysler + Hld Tnk	Holding Tank	100	0	50	39	60	2,842	49	67	3,708	31	1,609	53	31
3		Chrysler + Incin.	Holding Tank	100	12	43	51	134	591	142	150	552	46	285	81	46
4	Gravity Collect. (Grumman)	Grum Flow Thru+HldTk	Holding Tank	100	22	22	32	48,532	281	246	1,733	200	187	149	360	187
5		Grumman Flow Thru + Holding Tank		100	100	16	55	71,726	276	278	2,562	295	223	143	413	223
6	Gravity Collect.	Holding Tank	Grum Flow Thru+ HldTnk	100	100	17	44	76,708	248	297	2,740	316	239	139	422	239
7	Gravity Collect. (Grumman)	Grum Flow Thru+Incin.	Holding Tank	100	29	19	41	85,400	126	564	3,050	344	144	92	379	144
8		Grumman Flow Thru + Incinerator		100	100	15	85	133,703	173	506	4,775	280	130	107	451	130
9	Vacuum Collect. (Jered)	Holding Tank	Holding Tank	100	13	40	49	145	1,144	160	55	1,751	54	692	171	54
10		Incinerator	Holding Tank	100	35	31	60	302	303	331	116	83	54	65	192	54
11		GATX Evap.	Holding Tank	100	35	25	49	231	353	178	89	1,009	82	261	222	82
12		Holding Tank	Grum Flow Thru+ Hld Tnk	100	100	21	75	246	456	204	94	508	80	240	239	80
13		Incinerator	Grum Flow Thru + Incin.	100	100	18	83	367	296	325	140	422	76	174	308	76
14	M/T Pump Collect. (GATX)	Holding Tank	Holding Tank	100	13	54	35	4,485	817	123	36	1,250	104	494	140	104
15		Incinerator	Holding Tank	100	35	31	57	11,026	256	302	89	70	65	55	174	65
16		GATX Evap.	Holding Tank	100	35	24	51	7,633	268	143	62	768	155	199	193	155
17		Holding Tank	Grum Flow Thru+Hld Tnk	100	100	20	64	8,834	378	179	71	422	147	199	222	147
18		Incinerator	Grum Flow Thru + Incin.	100	100	17	72	13,795	257	300	111	366	102	151	335	102

(1) Which will result in a 10% change in total WMS life-cycle cost.

(2) Black water Collection/Transport subsystem.

(3) Black and gray water Treatment/Disposal subsystem.

(4) % change in annual cost based on continuous WMS operation.

(5) % change in cost per overhaul.

(6) Based on assumed 10% effective discount rate and a useful system life of 10 years.

(7) $F_1 = 6.144566$ - Present value factor for operating, preventive and corrective maintenance costs.

(8) $F_2 = 2.925983$ - Present value factor for overhaul costs (based on a two-year overhaul interval).

Table H-2 (Cont'd)

RESULTS OF SENSITIVITY ANALYSIS

Vessel PAMLICO (160')

WMS Utilization Factor (%) 31

WMS No.	Coll/ Trans. Subsys. (Black)	TYPE Treatment/Disposal Subsystem		Holding Capacity		% Change in Cost Element (1)							% Change in WMS Utilization Factor (1)	% Change In Present Value Factors (1), (5)	
		Black	Gray	Black (%)	Gray (%)	Acquisition	Installation	Operation (4) C/T (2)	Operation (4) T/D (3)	Preventive Maintenance (PM) (4)	Corrective Maint. (CM) (4) C/T (2)	Corrective Maint. (CM) (4) T/D (3)	Overhaul Maintenance (5)		F_1 (7)	F_2 (8)
1	Gravity Collect.	Holding Tank	Holding Tank	100	55	334	13	59,858	192	256	1,247	304	197	118	427	197
2	Oil Recircul. (Chrysler)	Chrysler + Hld Tnk	Holding Tank	100	64	61	23	87	362	53	87	488	40	208	60	40
3		Chrysler + Incin.	Holding Tank	100	64	48	24	110	232	113	110	201	44	108	64	44
4	Gravity Collect. (Grumman)	Grum Flow Thru+HldTk	Holding Tank	100	64	24	28	111,482	148	283	2,323	165	216	78	338	216
5		Grumman Flow Thru + Holding Tank		100	100	20	38	93,468	147	263	1,947	158	218	76	321	218
6	Gravity Collect.	Holding Tank	Grum Flow Thru+ HldTnk	100	100	22	30	103,610	153	291	2,159	175	242	82	348	242
7	Gravity Collect. (Grumman)	Grum Flow Thru+Incin.	Holding Tank	100	64	20	38	179,425	141	592	3,738	164	152	76	384	152
8		Grumman Flow Thru + Incinerator		100	100	17	54	157,811	138	598	3,288	157	144	73	370	144
9	Vacuum Collect. (Jered)	Holding Tank	Holding Tank	100	64	-	22	141	260	93	61	363	77	152	147	77
10		Incinerator	Holding Tank	100	64	34	44	302	196	224	130	60	96	46	163	96
11		GATX Evap.	Holding Tank	100	64	34	37	190	185	108	82	306	100	115	180	100
12		Holding Tank	Grum Flow Thru+ Hld Tnk	100	100	26	57	233	154	126	101	175	104	82	176	104
13		Incinerator	Grum Flow Thru + Incin.	100	100	20	75	350	155	220	151	176	103	82	231	103
14	M/T Pump Collect. (GATX)	Holding Tank	Holding Tank	100	64	61	28	13,480	342	21	41	479	38	199	25	38
15		Incinerator	Holding Tank	100	64	29	48	25,341	227	276	76	70	117	53	168	117
16		GATX Evap.	Holding Tank	100	64	28	43	17,586	236	145	53	391	140	147	181	140
17		Holding Tank	Grum Flow Thru+Hld Tnk	100	100	23	64	20,155	184	158	61	210	134	98	179	134
18		Incinerator	Grum Flow Thru + Incin.	100	100	19	92	28,114	172	258	85	195	120	91	223	120

(1) Which will result in a 10% change in total WMS life-cycle cost.
(2) Black water Collection/Transport subsystem.
(3) Black and gray water Treatment/Disposal subsystem.
(4) % change in annual cost based on continuous WMS operation.
(5) % change in cost per overhaul.
(6) Based on assumed 10% effective discount rate and a useful system life of 15 years.
(7) F_1 = 6.144566 - Present value factor for operating, preventive and corrective maintenance costs.
(8) F_2 = 2.925983 - Present value factor for overhaul costs (based on a two-year overhaul interval).

Table H-2 (Cont'd)

RESULTS OF SENSITIVITY ANALYSIS

Vessel WHITE SAGE (133')

WMS Utilization Factor (%) 11.1

WMS No.	Coll/ Trans. Subsys. (Black)	TYPE Treatment/Disposal Subsystem Black	Gray	Holding Capacity Black (%)	Gray (%)	% Change in Cost Element (1) Acquisition	Installation	Operation (4) C/T(2)	T/D(3)	Preventive Mainte-nance (PM)(4)	Corrective Mai t. (CM) (4) C/T(2)	T/D(3)	Overhaul Mainte-nance (5)	% Change in WMS Utiliza-tion Factor (1)	% Change in Present Value Factors (1), (6) F1 (7)	F2 (8)
1	Gravity Collect.	Holding Tank	Holding Tank	100	100	-	14	30,879	319	132	643	437	101	185	298	101
2	Oil Recircul. (Chrysler)	Chrysler + Hld Tnk	Holding Tank	100	100	54	34	68	810	42	67	1,073	32	462	51	32
3		Chrysler + Incin.	Holding Tank	100	100	40	35	85	357	87	83	337	34	173	59	34
4	Gravity Collect. (Grumman)	Grum Flow Thru+HldTk	Holding Tank	100	100	21	32	91,837	342	38	1,913	307	61	162	64	61
5		Grumman Flow Thru + Holding Tank		100	100	19	40	83,163	372	38	1,733	309	66	169	63	66
6	Gravity Collect.	Holding Tank	Grum Flow Thru+ HldTnk	100	100	20	35	89,005	326	41	1,854	298	59	156	64	59
7	Gravity Collect. (Grumman)	Grum Flow Thru+Incin	Holding Tank	100	100	17	42	156,626	266	84	3,263	341	45	149	88	45
8		Grumman Flow Thru + Incinerator		100	100	16	65	138,806	256	86	2,892	324	43	143	82	43
9	Vacuum Collect. (Jered)	Holding Tank	Holding Tank	100	100	58	35	135	630	15	65	1,021	27	390	24	27
10		Incinerator	Holding Tank	100	100	25	55	274	355	35	132	105	31	81	33	31
11		GATX Evap.	Holding Tank	100	100	25	53	196	401	19	95	928	37	280	32	37
12		Holding Tank	Grum Flow Thru+ Hld Tnk	100	100	21	70	225	447	21	109	499	36	236	35	36
13		Incinerator	Grum Flow Thru + Incin.	100	100	17	80	334	329	36	161	494	35	197	48	35
14	M/T Pump Collect. (GATX)	Holding Tank	Holding Tank	100	100	56	45	7,901	923	19	30	1,231	35	528	20	35
15		Incinerator	Holding Tank	100	100	26	62	14,465	386	40	55	115	36	88	27	36
16		GATX Evap.	Holding Tank	100	100	26	66	10,709	451	23	41	1,046	46	315	19	46
17		Holding Tank	Grum Flow Thru+Hld Tnk	100	100	20	83	13,539	520	27	52	617	48	282	31	48
18		Incinerator	Grum Flow Thru + Incin.	100	100	18	82	19,077	387	45	73	584	44	232	41	44

(1) Which will result in a 10% change in total WMS life-cycle cost.
(2) Black water Collection/Transport subsystem.
(3) Black and gray water Treatment/Disposal subsystem.
(4) % change in annual cost based on continuous WMS operation.
(5) % change in cost per overhaul.
(6) Based on assumed 10% effective discount rate and a useful system life of 10 years.
(7) F_1 = 6.144566 - Present value factor for operating, preventive and corrective maintenance costs.
(8) F_2 = 2.925983 - Present value factor for overhaul costs (based on a two-year overhaul interval).

Table H-2 (Cont'd)

RESULTS OF SENSITIVITY ANALYSIS

Vessel POINT HERRON (82')

WMS Utilization Factor (%) 1.8

WMS No.	Coll/ Trans. Subsys. (Black)	TYPE Treatment/Disposal Subsystem		Holding Capacity		% Change in Cost Element (1)								% Change in WMS Utilization Factor(1)	% Change In Present Value Factors (1), (6)	
		Black	Gray	Black (%)	Gray (%)	Acquisition	Installation	Operation(4)		Preventive Maintenance (PM)(4)	Corrective Maint. (CM)(4)		Overhaul Maintenance (5)		F1(7)	F2(8)
								C/T(2)	T/D(3)		C/T(2)	T/D(3)				
1	Gravity Collect.	Holding Tank	Holding Tank	58	0	-	25	-	1,294	51	274	1,491	48	693	156	48
2	Oil Recircul. (Chrysler)	Chrysler + Hld Tnk	Holding Tank	N/A	N/A											→
3		Chrysler + Incin.	Holding Tank	N/A	N/A											→
4	Gravity Collect. (Grumman)	Grum Flow Thru+HldTk	Holding Tank	N/A	N/A											→
5		Grumman Flow Thru + Holding Tank		N/A	N/A											→
6	Gravity Collect.	Holding Tank	Grum Flow Thru+HldTnk	N/A	N/A											→
7	Gravity Collect. (Grumman)	Grum Flow Thru+Incin.	Holding Tank	N/A	N/A											→
8		Grumman Flow Thru + Incinerator		N/A	N/A											→
9	Vacuum Collect. (Jered)	Holding Tank	Holding Tank	100	20	42	51	125	3,038	10	68	4,002	24	1,727	24	24
10	↓	Incinerator	Holding Tank	N/A	N/A											→
11	↓	GATX Evap.	Holding Tank	100	20	19	96	200	3,221	93	109	4,011	108	1,787	218	108
12	↓	Holding Tank	Grum Flow Thru+ Hld Tnk	N/A	N/A											→
13	↓	Incinerator	Grum Flow Thru + Incin.	N/A	N/A											→
14	M/T Pump Collect. (GATX)	Holding Tank	Holding Tank	100	20	47	69	11,824	3,139	94	31	4,131	78	1,784	118	78
15	↓	Incinerator	Holding Tank	N/A	N/A											→
16	↓	GATX Evap.	Holding Tank	100	20	20	111	19,136	3,364	133	51	4,190	120	1,866	181	120
17	↓	Holding Tank	Grum Flow Thru+Hld Tnk	N/A	N/A											→
18	↓	Incinerator	Grum Flow Thru + Incin.	N/A	N/A											→

(1) Which will result in a 10% change in total WMS life-cycle cost.
(2) Black water Collection/Transport subsystem.
(3) Black and gray water Treatment/Disposal subsystem.
(4) % change in annual cost based on continuous WMS operation.
(5) % change in cost per overhaul.
(6) Based on assumed 10% effective discount rate and a useful system life of 10 years.
(7) F_1 = 6.144566 - Present value factor for operating, preventive and corrective maintenance costs.
(8) F_2 = 2.925983 - Present value factor for overhaul costs (based on a two-year overhaul interval).

*U.S.G.P.O. 727-105/1302-1661