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Environmental Protection
Agency

Municipal Environmental Research
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Research and Development

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Project Summary

EXEC/OP Reference Manual: Version 1.2

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The original version of EXEC/OP, a FORTRAN computer program that synthesizes municipal wastewater treatment system designs from a specified list of unit treatment processes, has been updated. Revisions have been made in several of the unit process performance submodels to produce results that conform more closely to accepted design practices. Modified sets of program input instructions and unit process sub-model descriptions have been prepared. This publication is a summary of the revised program reference manual, which can be purchased from the National Technical Information Service. A computer tape of the FORTRAN source code is also available from NTIS.

EXEC/OP is a FORTRAN computer program that synthesizes municipal wastewater treatment system designs from a specified list of unit treatment processes. It selects the combination of wastewater and sludge treatment processes that approximately best meets a stipulated set of design criteria. The criteria may refer to system cost, energy consumption, land utilization, a subjective index of system desirability, and effluent quality. The program can also identify up to the next 40 best designs relative to the stipulated criteria.

Since the original description of the EXEC/OP computer program (Computer-Aided Synthesis of Wastewater Treatment and Sludge Disposal Systems, EPA-600/2-79-158, December 1979), several changes have been made to the program. Most of these changes have modified several of the subroutines that model the performance of individual unit processes so that the results conform more closely to accepted design practice. The input encoding and output reports for the program have also undergone some minor changes. Here is a brief example of how EXEC/OP can be applied to a waste treatment design problem.

In using EXEC/OP, a multi-option flow diagram of the system being analyzed is first prepared (Figure 1). Each box in the diagram represents an individual unit process option (or design variation of a unit process) for treating wastewater (stages 1 to 5) and sludge (stages 6 to 12). For each unit-process option, the program user supplies values for design parameters related to level of treatment, sludge production, kinetic rate constants, loading rates, etc. As shown in Figure 1, the program pays particular attention to the influence that return sidestreams from sludge processing have on system performance and design.

Additional input data to EXEC/OP consists of influent flow, influent concentration values for 17 wastewater parameters, required effluent discharge standards for 5 parameters, and values for 9 economic parameters (*e.g.*, cost indices, wage rates, energy costs, etc.). The EXEC/OP program can then identify those system designs that best

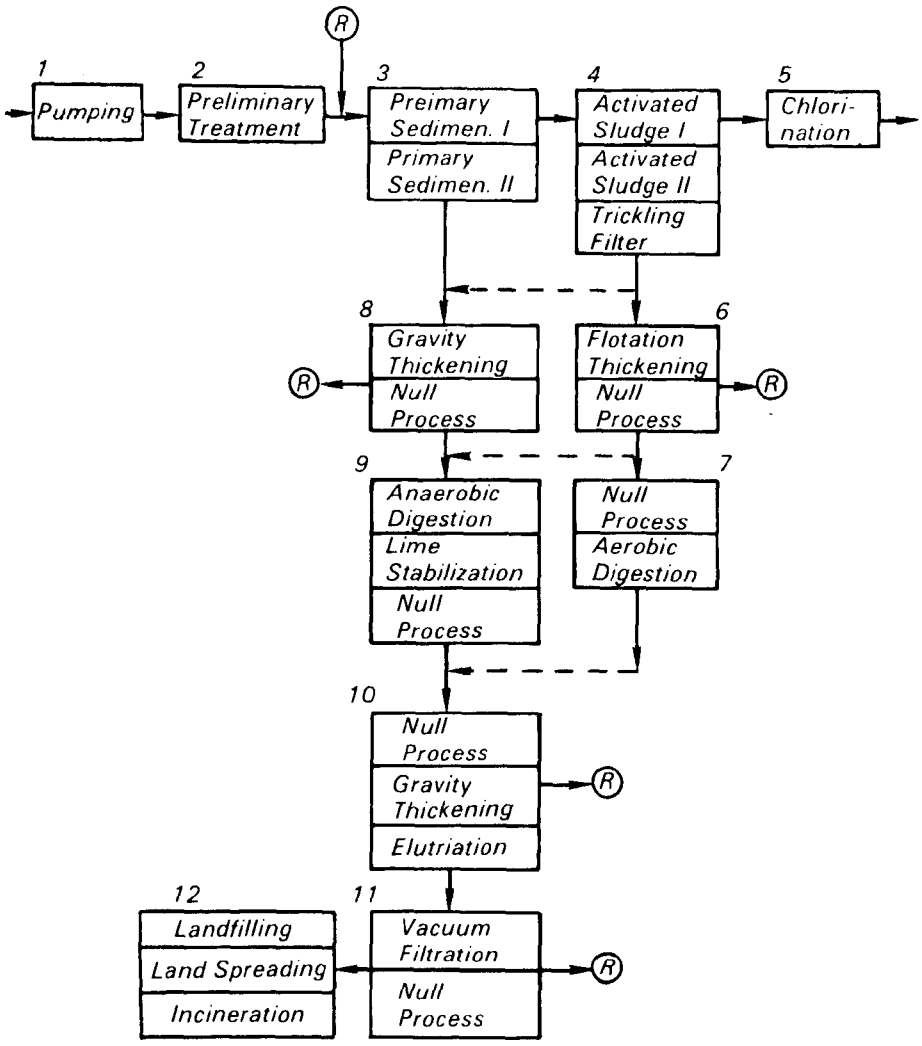

Figure 1. *Multi-option flow diagram for sample design problem.*

meet a stipulated set of criteria. (A "system design" consists of a choice of one of the available process options for each treatment stage of the system.) The individual design criteria included in EXEC/OP are listed in Table 1. These are combined into a weighted, additive objective function whose value is to be minimized. The program user supplies a weighting on the importance of each criterion. The user can also specify upper limits (or a lower limit for energy production) on the individual criteria that cannot be violated by any feasible design

Figure 2 illustrates an abridged output report for an EXEC/OP optimization run. The run analyzes the multi-option flow diagram of Figure 1 for a typical domestic wastewater required to meet effluent standards of 30 mg/l on BOD and suspended solids. For this 10-MGD system, EXEC/OP was instructed to identify the first five least-total annual cost designs whose net energy consumption did not exceed 800 kwh/mil gal. Recovery of usable energy was valued at 0.04 $/kwh. The first table in the Figure 1 printout summarizes the available process options with a subsequent listing of the five best designs. Each design listing contains the following information:

1. The objective function value (exact system value).
2. The option ID number (refer to table of process alternatives) to the process used at each stage of the system.
3. The quantity of sludge either produced or handled by each process.
4. Values for each of the eight design criteria for each unit process and for the total system.

The final line of the printout indicates that the amount of computational resources used by EXEC/OP on this problem was only 5.3% of that required to evaluate each of the 2592 possible system configurations one at a time. The processing time for this example was 55.86 seconds on a DEC PDP-11/70 computer.

EXEC/OP can also be run in another computational mode that will produce a detailed performance report for a particular system design specified by the user. In addition to the information cited above, the detailed output report would include values for those unit process design specifications computed by the program (*e.g.*, equipment size and operating capacity) and the composition of all waste streams in the system.

Table 1. *EXEC/OP Design Criteria*

1. *Total initial construction cost (including equipment, materials, piping, and instrumentation), million dollars.*
2. *Total annual operation and maintenance cost (including labor, materials, supplies, chemicals, and energy), $/million gallons of system influent.*
3. *Total equivalent annual life cycle cost (amortized life cycle construction costs plus annual operation and maintenance costs) $/million gallons of system influent.*
4. *Total gross energy consumption (direct energy consumed by all equipment and operations) kwh/million gallons of system influent.*
5. *Total gross energy production (usable energy extracted from treatment by-products such as digester gas and incinerator waste heat), kwh/million gallons of system influent.*
6. *Total net energy consumption (difference between criteria 4 and 5), kwh/million gallons of system influent.*
7. *Total land area utilization (only considers those processes with significant land requirements such as drying beds, trickling filters, and land disposal of sludges), acres.*
8. *System undesirability index.*

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*            *
*   EXEC/OP  *
*            *
* VERSION 1.2 *
*            *
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EXECUTIVE PROGRAM
(OPTIMIZATION VERSION)
FOR
PRELIMINARY SYNTHESIS OF WASTE TREATMENT SYSTEMS

U.S. ENVIRONMENTAL PROTECTION AGENCY
MUNICIPAL ENVIRONMENTAL RESEARCH LABORATORY
SYSTEMS AND ECONOMIC ANALYSIS SECTION
CINCINNATI, OHIO 45268

*********************************************************************************
*                                                                               *
*   SAMPLE 10 MGD SYSTEM - 30/30 STDS., JUNE 79 PRICES                          *
*                                                                               *
*********************************************************************************

                                PROCESS ALTERNATIVES
                                --------------------

OPTION  PROCESS  STAGE  SIDESTREAM
 NO.     NO.     NO.   DESTINATION                    REMARKS
------  -------  -----  -----------  ------------------------------------------------------------------------
   1       15      1         8      RAW WASTEWATER PUMPING (30 FT. HEAD)
   2        1      2         8      PRELIMINARY TREATMENT
   3        2      3         8      PRIMARY SEDIMENTATION (50% TSS REMOVAL)
   4        2      3         8      PRIMARY SEDIMENTATION (60% TSS REMOVAL)
   5        3      4         6      ACTIVATED SLUDGE ( MLVSS = 2500, 30% RECYCLE,DIFFUSED AERATION)
   6        3      4         6      ACTIVATED SLUDGE ( MLVSS = 2500, 30% RECYCLE,MECHANICAL AERATION)
   7       11      4         6      TRICKLING FILTER (20 MGD/AC LOADING, RECIRC. RATIO = 3)
   8       12      5         6      CHLORINATION (10 MG/L FOR 30 MIN.)
   9       13      6         3      FLOTATION THICKENING (TO 5% SOLIDS)
  20        0      6         3      NULL PROCESS
  24        0      7         3      NULL PROCESS
  10       18      7         3      AEROBIC DIGESTION ( FOR 18 DAYS )
  11        8      8         3      GRAVITY THICKENING (TO 8, 3, OR 6% SOLIDS DEPENDING ON SLUDGE TYPE)
  20        0      8         3      NULL PROCESSS
  12        6      9         3      ANAEROBIC DIGESTION (FOR 15 DAYS WITH GAS RECOVERY BY IC ENGINE)
  13       23      9         3      LIME STABILIZATION (400 LB/TON LIME DOSAGE)
  20        0      9         3      NULL PROCESS
  11        8     10         3      GRAVITY THICKENING (TO 8, 3, OR 6 % DEPENDING ON SLUDGE TYPE)
  20        0     10         3      NULL PROCESS
  14        9     10         3      ELUTRIATION (3:1 WASHWATER RATIO)
  15        7     11         3      VACUUM FILTRATION (DEWATERING RATE = 10 - 17.5 GPH/SQ FT)
  20        0     11         3      NULL PROCESS
  16       22     12         3      LANDFILLING (5 MILE HAUL)
  17       22     12         3      LANDSPREADING (10 MILE HAUL, 600 LB/AC/YR N LIMIT)
  18       14     12         3      INCINERATION (2 UNITS, 2 LB/HR/SQ FT LOADING)

                                    DESIGN   1
                                    ----------

                              EXACT SYSTEM VALUE          236.916

STAGE  PROCESS  SLUDGE     CONSTR     ANN O&M    TOTAL ANN  ENER USE  ENER PROD  NET ENER  LAND REQD  UNDESIRE-
 NO.   OPTION  TONS/DAY   COST M$    COST $/MG  COST $/MG  KWH/MG    KWH/MG     KWH/MG    ACRES      ABILITY
-----  -------  --------  ---------  ---------  ---------  --------  ---------  --------  ---------  ---------
  1        1      0.00     0.8878      9.09      32.05     141.37      0.00     141.37      0.00       0.00
  2        2      0.00     0.2701      8.27      15.26       5.22      0.00       5.22      0.00       0.00
  3        3      5.62     0.4740     10.35      22.61       6.80      0.00       6.80      0.00       0.00
  4        7      2.73     1.7948     20.86      67.27     172.02      0.00     172.02      0.50       3.00
  5        8      0.00     0.2797     19.06      26.29      22.80      0.00      22.80      0.00       0.00
  8       11      8.35     0.1443      1.86       5.59       1.69      0.00       1.69      0.00       0.00
  9       13      7.52     0.0892     11.50      13.81       3.13      0.00       3.13      0.00       2.00
 12       17      9.03     0.6942     29.40      54.04     107.45      0.00     107.45    428.07       8.00
                --------  ---------  ---------  ---------  --------  ---------  --------  ---------  ---------
SYSTEM VALUES    8.35      4.63      110.39     236.92     460.47      0.00     460.47    428.57      13.00

                        PRIMARY AND SECONDARY SLUDGES MIXED AT STAGE  8
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Figure 2. EXEC/OP output for sample design optimization.

DESIGN 2

EXACT SYSTEM VALUE 242.375

STAGE NO.	PROCESS OPTION	SLUDGE TONS/DAY	CONSTR COST M$	ANN O&M COST $/MG	TOTAL ANN COST $/MG	ENER USE KWH/MG	ENER PROD KWH/MG	NET ENER KWH/MG	LAND REQD ACRES	UNDESIRE-ABILITY
1	1	0.00	0.8878	9.09	32.05	141.37	0.00	141.37	0.00	0.00
2	2	0.00	0.2701	8.27	15.26	5.22	0.00	5.22	0.00	0.00
3	4	6.78	0.6042	12.24	27.86	8.69	0.00	8.69	0.00	0.00
4	7	2.15	1.7086	20.21	64.40	156.11	0.00	156.11	0.50	3.00
5	8	0.00	0.2796	19.05	26.28	22.79	0.00	22.79	0.00	0.00
8	11	8.94	0.1494	1.92	5.79	1.75	0.00	1.75	0.00	0.00
9	13	8.04	0.0933	12.05	14.46	3.28	0.00	3.28	0.00	2.00
12	17	9.66	0.7109	31.18	56.28	114.38	0.00	114.38	446.03	8.00
SYSTEM VALUES		8.94	4.70	114.02	242.38	453.60	0.00	453.60	446.53	13.00

PRIMARY AND SECONDARY SLUDGES MIXED AT STAGE 8

DESIGN 3

EXACT SYSTEM VALUE 237.942

STAGE NO.	PROCESS OPTION	SLUDGE TONS/DAY	CONSTR COST M$	ANN O&M COST $/MG	TOTAL ANN COST $/MG	ENER USE KWH/MG	ENER PROD KWH/MG	NET ENER KWH/MG	LAND REQD ACRES	UNDESIRE-ABILITY
1	1	0.00	0.8878	9.09	32.05	141.37	0.00	141.37	0.00	0.00
2	2	0.00	0.2701	8.27	15.26	5.22	0.00	5.22	0.00	0.00
3	3	5.51	0.4724	10.29	22.50	6.80	0.00	6.80	0.00	0.00
4	7	2.78	1.7986	20.89	67.40	172.64	0.00	172.64	0.50	3.00
5	8	0.00	0.2798	19.07	26.31	22.82	0.00	22.82	0.00	0.00
9	12	8.29	1.2358	15.89	47.84	418.54	557.33	-138.78	0.00	7.00
10	11	6.12	0.1242	1.63	4.84	1.42	0.00	1.42	0.00	0.00
12	17	5.51	0.6193	21.43	44.04	80.86	0.00	80.86	345.98	8.00
SYSTEM VALUES		8.29	5.69	106.54	260.23	849.68	557.33	292.35	346.48	18.00

PRIMARY AND SECONDARY SLUDGES MIXED AT STAGE 8

DESIGN 4

EXACT SYSTEM VALUE 240.028

STAGE NO.	PROCESS OPTION	SLUDGE TONS/DAY	CONSTR COST M$	ANN O&M COST $/MG	TOTAL ANN COST $/MG	ENER USE KWH/MG	ENER PROD KWH/MG	NET ENER KWH/MG	LAND REQD ACRES	UNDESIRE-ABILITY
1	1	0.00	0.8878	9.09	32.05	141.37	0.00	141.37	0.00	0.00
2	2	0.00	0.2701	8.27	15.26	5.22	0.00	5.22	0.00	0.00
3	3	5.95	0.4793	10.53	22.93	6.80	0.00	6.80	0.00	0.00
4	7	2.97	1.8147	21.01	67.94	175.61	0.00	175.61	0.50	3.00
5	8	0.00	0.2798	19.07	26.31	22.82	0.00	22.82	0.00	0.00
8	11	8.92	0.1493	1.92	5.78	1.75	0.00	1.75	0.00	0.00
9	12	8.03	1.0752	14.56	42.37	291.21	533.89	-242.68	0.00	7.00
10	11	5.95	0.1226	1.61	4.78	1.40	0.00	1.40	0.00	0.00
12	17	5.35	0.6351	20.93	43.98	78.82	0.00	78.82	372.29	8.00
SYSTEM VALUES		8.92	5.71	106.99	261.38	725.01	533.89	191.12	372.79	18.00

PRIMARY AND SECONDARY SLUDGES MIXED AT STAGE 8

Figure 2. *(cont'd)*

DESIGN 5

EXACT SYSTEM VALUE 240.935

STAGE NO.	PROCESS OPTION	SLUDGE TONS/DAY	CONSTR COST M$	ANN O&M COST $/MG	TOTAL ANN COST $/MG	ENER USE KWH/MG	ENER PROD KWH/MG	NET ENER KWH/MG	LAND REQD ACRES	UNDESIRE-ABILITY
1	1	0.00	0.8878	9.09	32.05	141.37	0.00	141.37	0.00	0.00
2	2	0.00	0.2701	8.27	15.26	5.22	0.00	5.22	0.00	0.00
3	3	5.62	0.4740	10.35	22.61	6.80	0.00	6.80	0.00	0.00
4	7	2.73	1.7948	20.86	67.27	172.02	0.00	172.02	0.50	3.00
5	8	0.00	0.2797	19.06	26.29	22.80	0.00	22.80	0.00	0.00
8	11	8.35	0.1443	1.86	5.59	1.69	0.00	1.69	0.00	0.00
9	12	7.52	1.0618	14.44	41.90	279.95	513.39	-233.44	0.00	7.00
12	17	5.51	0.6942	25.86	50.50	107.45	0.00	107.45	428.07	8.00
SYSTEM VALUES		8.35	5.61	109.79	261.47	737.30	513.39	223.90	428.57	18.00

PRIMARY AND SECONDARY SLUDGES MIXED AT STAGE 8

BEST DESIGN IS NUMBER 1

SEARCH EFFORT WAS 5.2653% OF TOTAL ENUMERATION

Figure 2. *(cont'd)*

The EPA author of this Project Summary was ***Lewis A. Rossman*** *(see below).*
The complete report and/or magnetic tape, entitled "EXEC/OP Reference Manual: Version 1.2," (Report Order No. PB 81 104176; Cost: $11.00; Magnetic Tape Order No. PB 81-104168; Cost: $360.00, costs subject to change) will be available from:

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