Wat. Res. Vol. 34, No. 5, pp. 1714–1726, 2000

Printed in Great Britain
PII: S0043-1354(99)00289-4
0043-1354/00/$ - see front matter

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MANAGEMENT ANALYSIS OF WASTEWATER CAPITAL IMPROVEMENT PROGRAMS IN LARGE CITIES

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(First received 1 July 1998; accepted in revised form 1 July 1999)

Abstract—Major environmental engineering programs are typically organized into a large number of individual projects grouped into one or more higher levels of classification. Managing such programs is challenging because of their sizes, long duration, diffuse activities, and vulnerability to change due to unforeseen conditions. Often, individual projects are canceled, delayed, or changed in scope, so that assessing the progress and efficiency of the overall program is not easy with conventional project-oriented software. In many cases current economic trends make raising additional revenues difficult, and regulatory agencies often set deadlines that are not likely to change, so that there is increasing pressure to control the costs and schedule of a program. Also, in many places important facilities are already years past their planned dates for repair or replacement, because of past neglect. This paper describes methods of aggregating, transforming, and displaying information about program progress that potentially have value for managers of a wide range of programs. These methods are demonstrated by a hypothetical example that contains simulated statistics for a major city wastewater system improvement program. The paper also considers some issues of data storage and communication between offices that would increase the convenience of performing such analyses and of other tasks of managing large programs. © 2000 Published by Elsevier Science Ltd. All rights reserved

Key words—management, capital, wastewater program, efficiency, planning, progress

NOMENCLATURE

ACT	also denoted Act, for actual (real) data
CA	canceled, projects terminated before or after incurring any costs
CAT	also denoted Cat, for category
CM	construction management (costs after project award date)
CONS	construction
CP	completed, projects with all phases completed
CTCM	consultant construction management
CTP	consultant plan (consultant design work up to award date)
CUM	cumulative
DES	design
DIFF	differential
DOC	document
EXP	expenditures
FA	force account (design work up to award date)
FAP	force account plan
FACM	force account construction management
FU	future, projects planned to begin in future
FY	fiscal year(s)
IP	in progress, projects in progress under some phase or ready for the next phase
WCIP	Wastewater Capital Improvement Program
OH	on hold
TAE	total actual expenditures
TOT	total
TPEF	total planned expenditures for projects when they first appeared in WCIP documents
TPEL	total planned expenditures for projects when they last appeared in WCIP documents
YRLY	yearly document, referring to a WCIP planning document published in each Fiscal Year.

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INTRODUCTION

Questions about how long a major environmental engineering program or its components will take, and how much they will cost, are easy to ask, but may be hard to answer accurately, because plans must often be made when much important information is not known (Langford and Male, 1995; Retik *et al.*, 1992). Geological conditions may have never been tested in places where construction is desired, equipment that is to be refurbished may be in worse condition than initially known, and regulatory requirements may change years after a program has begun.

Issues of human relationships and organizational deficiencies may also be involved, since such programs employ large numbers of people. Planners, contractors, and engineers each may have their own group biases or institutional pressures to over- or underestimate durations and costs, or to depart from plans and estimates made by others. There may also be organizational deficiencies in communication and integration of information that lead to duplication of efforts and working at cross-purposes.

Nevertheless, it is important that decisions to allocate resources should be made on the best possible information (Wilkinson, 1996; Jergeas *et al.*, 1989). This is because underestimates lead to crises and failures, and overestimates lead to more subtle but not necessarily less significant losses of actions (Ichniowski, 1995) that could have been performed if it had been known that resources for them would be available.

The need for accuracy in estimating durations and costs applies to both public and private entities. Moreover, major environmental engineering programs will be conducted for the foreseeable future. From metropolitan areas in poorer countries with no sewage treatment systems to toxic waste site programs in many countries to the disposal of dangerous relics of the cold war, there is a vast number and range of major engineering programs needed to protect or improve the environment.

For all of these reasons, we anticipate increased needs for analysis methods to aid management. Statistical methods for business management to assess the progress of individual projects are now well established, and have been incorporated into software tools (e.g., Primavera Systems, Inc., 1997; Gottlieb, 1997; ASTA, 1997). However, a large program involves coordinating many projects, with interactions that may not be considered by these methods. Larger questions of putting program performance into the context of comparable programs definitely go beyond the scopes of generally available software, although it is possible that such issues may be addressed to some extent by proprietary systems such as PowrTrak (Denning, 1997) or COMANDS (Coles and Reinschmidt, 1994). The methods in this article are the results of attempts to deal with these lacks.

The present methodology must be regarded as preliminary, since often there is more than one possible reason, positive as well as negative, for values like those shown in the exposition of our approach. Nevertheless, even in their present state these kinds of statistics have the potential to show that management attention should be paid to anomalies. We hope that this discussion stimulates additional development along these lines.

MATERIALS AND METHODS

Progress and efficiency assessment

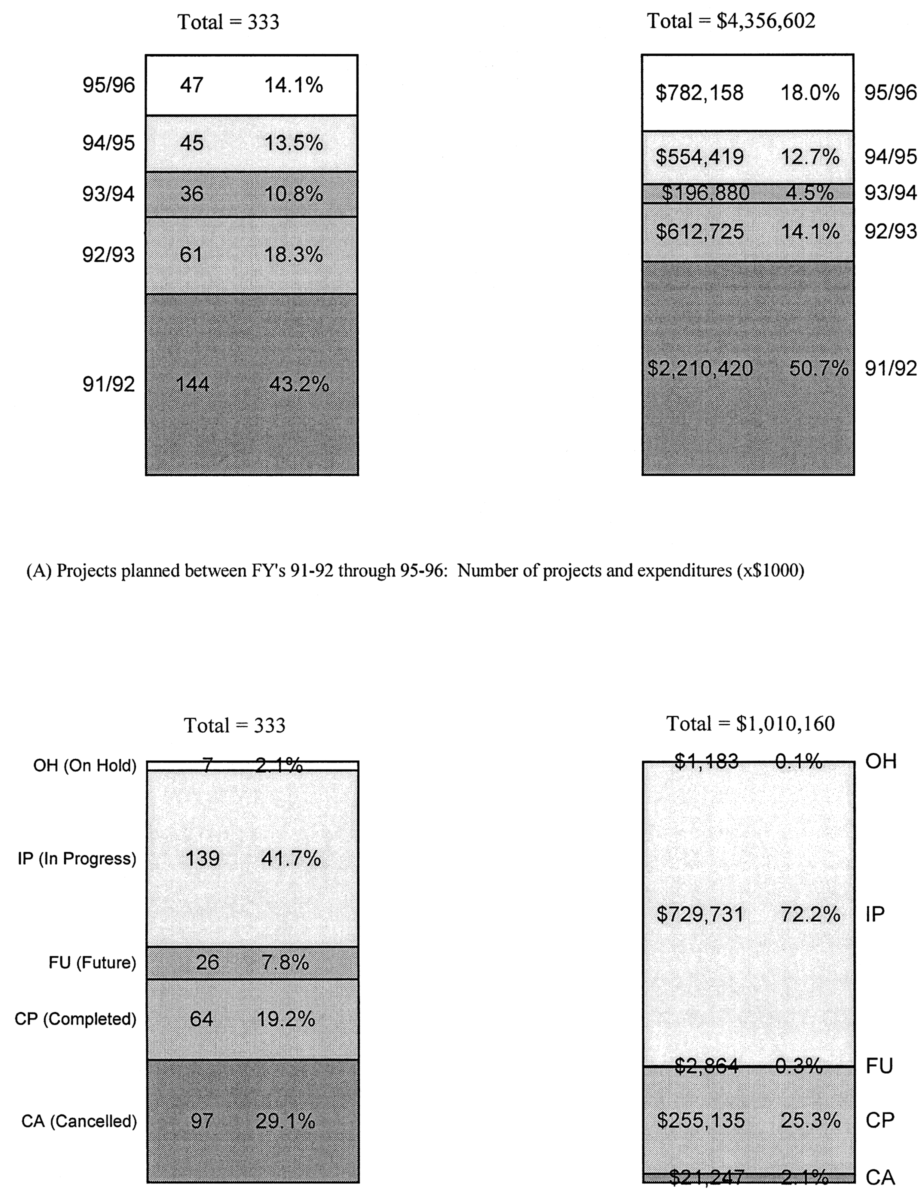
The term *planning* is used here to cover the whole process by which the overall goals of a project are converted into operations performed by engineers, contractors, technicians or laborers. Thus, it includes formulating projects, preliminary work for rough estimates of costs, durations, or other aspects of feasibility, and decisions on whether to commit to proposed projects, as well as specifying schedules and other details to implement projects for which commitments have been made (Galinsky and Hartman, 1996).

The viewpoint in this article is also influenced by experience with wastewater system capital improvement programs (CH2M Hill, 1986–1994). This is a field where most of the technologies are mature in the sense that good practice consists of applying technologies with known capabilities and limitations, and there are reliable methods for accomplishing established types of tasks. Thus, many aspects of uncertainty can be reduced by suitable preliminary examination of facilities and terrain (Alkass and Jergeas, 1992). Hence, in this environment a frequent need to change projects substantially while they are in progress is taken to reflect some deficiency in planning or execution. This assumption does not apply in many other areas of engineering, where technology is changing more rapidly, and the only way to eliminate many uncertainties is by experimentation during projects. However, since it is suited for the wastewater program described in the example, numerous project cancellations and large changes in the scopes or schedules of projects are viewed negatively as instability in the program.

At any time during a program it is reasonable to classify projects according to whether they are being planned or designed, or are being carried out, or have been completed, or perhaps have been delayed or postponed. Projects may even be canceled, or initially proposed, but removed after preliminary consideration, and for program assessment it is valuable to know if this happens. We may say that this approach classifies projects by *status*.

From another viewpoint, grouping projects according to their subject area or geographical location is appropriate in a program that involves coordinated activities in more than one such area. For the present discussion, it is convenient to call such project groups *categories*, and it is common for such groupings to be recognized in the program management structure. Thus, category managers are often designated to take responsibility for coordinating projects in their own categories or for monitoring the progress of relevant projects in other categories. In short, there is a natural two-way classification of the individual projects in a program: by status and by category; and much can be learned about the progress of a program by examining the progress of the projects in each category from one status to another, with comparisons between expected and actual costs.

Tables and figures displaying specific comparisons and progress measures for an extended example appear in the following sections. They show statistics describing large



(A) Projects planned between FY's 91-92 through 95-96: Number of projects and expenditures (x$1000)

(B) Actual status of projects as of January 1, 1996: Number of projects and expenditures (x$1000)

Fig. 1. Overall summary of WCIP 10 year planned projects and the actual status.

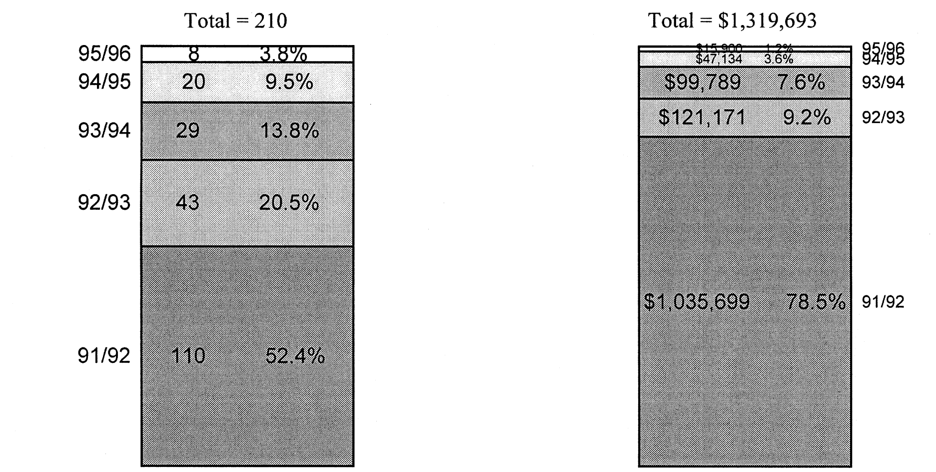
cities in the United States. The dates have been changed, and the absolute numbers have been changed by a relatively simple transformation, but the resulting percentages are little different from actual experience, and hence the example has a substantial degree of realism. The example uses a wastewater program with six status classes and six categories, involving a collection system and treatment plants, but the methods are not specific to a particular number of categories or to wastewater systems.

A few strategies were used in constructing the tables and figures. Results may be aggregated for the whole program, or divided into individual categories. Likewise, some tables or parts of them show simple project counts, and thus treat all projects the same, regardless of size, while others present expenditures, and hence contain many averages that primarily reflect a relatively small number of large projects. Also, some table entries describe events only up to the time of the analysis, and others include planned future values with adjustment for inflation. Still another form of analysis is to compare predictions in planning documents from previous years with the actual developments, both in expenditures (City of LA, 1986–1994) and project completions (City of LA, 1984–1994). In particular, to see whether the program was falling behind schedule, programs planned to be completed by 30 June 1996 (the end of fiscal year 1995/1996) are examined to see how many actually were completed by the report cutoff time of 1 January 1996. The tables and figures are designed to facilitate answering such questions as:

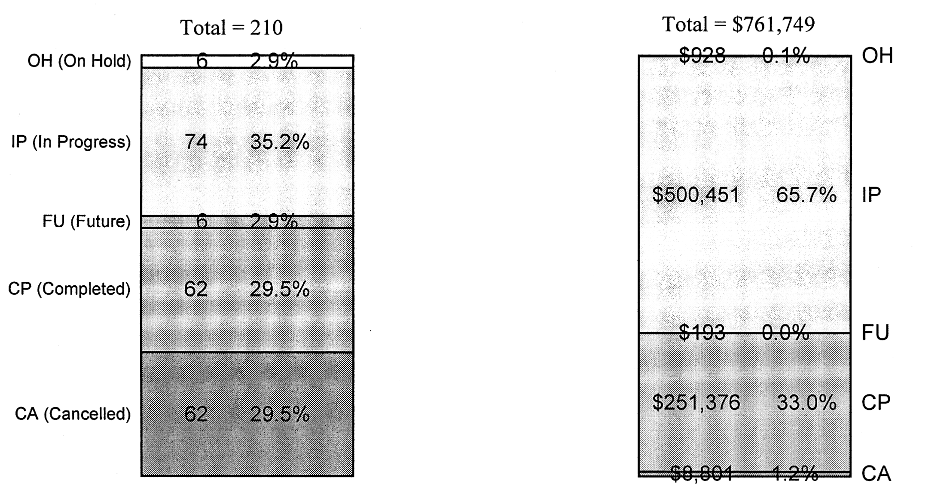
- How do the planned and actual numbers of completed projects compare?
- How do the planned and actual expenditures compare?

- How do the planned and actual completion dates compare?
- Is each category behind or ahead of schedule? over or under budget?
- Is the program as a whole behind or ahead of schedule? over or under budget?
- What is the ratio between design and construction costs?
- How stable is the planning process?

Figures 1 and 2 are aggregate values for the whole program, while Tables 1 and 2 offer breakdowns by categories; conversely, Table 1 and Fig. 1 consider all projects while Table 2 and Fig. 2 consider only projects scheduled for completion by the end of FY 1995/1996. Table 3 shows successive yearly planning documents' projections, from the document dates to the end of the program, of counts and expenditures by category, while Table 4 shows the documents' aggregate projections for future years. Figure 3 compares planned and actual costs and durations for the projects completed by January, 1996, aggregated over the whole program, while Table 5 breaks



(A) Projects planned between FY's 91-92 through 95-96: Number of projects and expenditures (x$1,000).



(B) Actual status of projects as of January 1, 1996: Number of projects and expenditures (x$1000)

Fig. 2. Overall summary of WCIP projects planned for completion by 30 June 1996, compared with actual status as of 1 January 1996.

Table 1. Summary of WCIP 10 year planned projects, by category, and the actual status[a]

Category	Absolute values						Relative values (%)					
	Number of projects			Expenditures (×$1000)			Number of projects			Expenditures		
	CS	SGU	SAP	CS	SGU	SAP	CS	SGU	SAP	CS	SGU	SAP
(A) Projects planned between FYs 1991/1992 and 1995/1996												
Yrly doc												
1991/1992	41	32	10	431,976	1,282,904	171,507	48.2	65.3	14.9	29.5	76.3	25.1
1992/1993	11	6	38	186,083	54,921	343,986	12.9	12.2	56.7	12.7	3.3	50.3
1993/1994	9	3	6	35,208	12,335	32,283	10.6	6.1	9.0	2.4	0.7	4.7
1994/1995	9	7	10	23,515	328,428	135,832	10.6	14.3	14.9	1.6	19.5	19.9
1995/1996	15	1	3	788,570	3,689	350	17.6	2.0	4.5	53.8	0.2	0.1
Total planned	85	49	67	1,465,352	1,682,277	683,958	100.0	100.0	100.0	100.0	100.0	100.0
(B) Actual status of the above projects as of 1 January 1996												
Status												
CA	17	9	22	451	2,124	598	20.0	18.4	32.8	0.2	0.4	0.4
CP	11	9	20	19,721	77,712	69,715	12.9	18.4	29.9	8.9	16.3	43.1
FU	12	2	2	75	0	4	14.1	4.1	3.0	0.0	0.0	0.0
IP	44	29	23	201,361	396,530	91,303	51.8	59.2	34.3	90.8	83.2	56.5
OH	1	0	0	83	0	0	1.2	0.0	0.0	0.0	0.0	0.0
Total actual	85	49	67	221,691	476,366	161,620	100.0	100.0	100.0	100.0	100.0	100.0
(C) Actual expenditures versus total 10 yr planned (%)				(D) Total 10 yr planned expenditures, TPEF (×$1000)								
Status												
CA	0.03	0.13	0.09	203,849	344,905	63,075						
CP	1.35	4.62	10.19	25,563	66,364	184,655						
FU	0.01	0.00	0.00	52,115	26,000	41,350						
IP	13.74	23.57	13.35	1,182,461	1,245,008	394,878						
OH	0.01	0.00	0.00	1,364	0	0						
Total	15.13	28.32	23.63	1,465,352	1,682,277	683,958						

Category	Absolute values						Relative values (%)					
	Number of projects			Expenditures (×$1000)			Number of projects			Expenditures		
	SW	GRP	PP	SW	GRP	PP	SW	GRP	PP	SW	GRP	PP
(A) Projects planned between FYs 1991/1992 and 1995/1996												
Yrly doc												
1991/1992	35	15	11	131,129	122,038	68,166	58.3	50.0	26.2	59.7	70.1	28.6
1992/1993	3	0	3	4,158	0	68,483	5.0	0.0	7.1	1.9	0.0	28.7
1993/1994	6	7	5	6,050	11,590	32,720	10.0	23.3	11.9	2.8	6.7	13.7
1994/1995	12	7	0	58,408	40,445	0	20.0	23.3	0.0	26.6	23.2	0.0
1995/1996	4	1	23	19,895	135	69,062	6.7	3.3	54.8	9.1	0.1	29.0
Total planned	60	30	42	219,640	174,208	238,431	100.0	100.0	100.0	100.0	100.0	100.0
(B) Actual status of the above projects as of 1 January 1996												
Status												
CA	14	12	23	686	2,044	8,904	23.3	40.0	54.8	0.8	10.6	24.1
CP	16	4	4	20,611	11,097	14,240	26.7	13.3	9.5	24.0	57.5	38.5
FU	6	4	0	0	3,085	0	10.0	13.3	0.0	0.0	16.0	0.0
IP	21	7	15	64,644	2,975	13,831	35.0	23.3	35.7	75.2	15.4	37.4
OH	3	3	0	3	104	0	5.0	10.0	0.0	0.0	0.5	0.0
Total actual	60	30	42	85,944	19,303	36,975	100.0	100.0	100.0	100.0	100.0	100.0
(C) Actual expenditures versus total 10 yr planned (%)				(D) Total 10 yr planned expenditures, TPEF (×$1000)								
Status												
CA	0.31	1.17	3.73	37,030	33,375	91,209						
CP	9.38	6.37	5.97	27,833	8,318	44,095						
FU	0.00	1.77	0.00	52,410	114,915	0						
IP	29.43	1.71	5.80	101,301	13,106	103,127						
OH	0.00	0.06	0.00	1,066	4,494	0						
Total	39.13	11.08	15.51	219,640	174,208	238,431						

[a]CA: cancelled; CP: completed; FU: future; FY: fiscal year; IP: in progress; OH: on hold; PID: preliminary integrated database; WCIP: wastewater capital improvement program; Yrly Doc: yearly document. Yrly Doc refers to Yearly WCIP 10 year planning document published for the indicated FY.

Table 2. Summary of WCIP projects, by category, planned for completion by 30 June 1996, compared with the actual status[a]

Category	Absolute values						Relative values (%)					
	Number of projects			Expenditures (×$1000)			Number of projects			Expenditures		
	CS	SGU	SAP	CS	SGU	SAP	CS	SGU	SAP	CS	SGU	SAP
(A) Projects planned to be completed between FYs 1991/1992 and 1995/1996												
Yrly doc												
1991/1992	30	14	10	232,605	259,816	171,507	68.2	56.0	20.0	91.7	79.1	66.0
1992/1993	3	4	32	1,734	46,403	53,786	6.8	16.0	64.0	0.7	14.1	20.7
1993/1994	7	3	5	9,508	12,335	29,972	15.9	12.0	10.0	3.7	3.8	11.5
1994/1995	2	3	1	3,092	6,239	4,460	4.5	12.0	2.0	1.2	1.9	1.7
1995/1996	2	1	2	6,745	3,689	250	4.5	4.0	4.0	2.7	1.1	0.1
Total planned	44	25	50	253,684	328,482	259,975	100.0	100.0	100.0	100.0	100.0	100.0
(B) Actual status of the above projects as of 1 January 1996												
Status												
CA	8	3	20	91	1,285	598	18.2	12.0	40.0	0.0	0.5	0.5
CP	10	8	19	16,930	77,712	69,054	22.7	36.0	38.0	8.9	27.9	56.0
FU	1	0	1	0	0	3	2.3	0.0	2.0	0.0	0.0	0.0
IP	25	13	10	173,930	199,156	53,613	56.8	52.0	20.0	91.1	71.6	43.5
OH	0	0	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0
Total actual	44	25	50	190,951	278,153	123,268	100.0	100.0	100.0	100.0	100.0	100.0
(C) Actual costs versus total planned (%)				(D) Total planned expenditures, TPEF (×$1000)								
Status												
CA	0.04	0.39	0.23	13,774	6,368	47,860						
CP	6.67	23.66	26.56	22,913	66,364	168,155						
FU	0.00	0.00	0.00	919	0	2,300						
IP	68.56	60.63	20.62	261,078	255,750	41,660						
OH	0.00	0.00	0.00	0	0	0						
Total	75.27	84.68	47.42	253,684	328,482	259,975						

Category	Absolute values						Relative values (%)					
	Number of projects			Expenditures (×$1000)			Number of projects			Expenditures		
	SW	GRP	PP	SW	GRP	PP	SW	GRP	PP	SW	GRP	PP
(A) Projects planned to be delivered between FYs 1991/1992 and 1995/1996												
Yrly doc												
1991/1992	33	12	11	107,234	22,490	68,166	64.7	50.0	68.8	85.0	57.3	75.7
1992/1993	3	0	1	4,158	0	858	5.9	0.0	6.3	3.3	0.0	1.0
1993/1994	6	7	1	6,050	11,590	7,860	11.8	29.2	6.3	4.8	29.5	8.7
1994/1995	9	4	1	8,700	5,018	5,840	17.6	16.7	6.3	6.9	12.8	6.5
1995/1996	0	1	2	0	135	7,328	0.0	4.2	12.5	0.0	0.3	8.1
Total planned	51	24	16	126,142	39,233	90,052	100.0	100.0	100.0	100.0	100.0	100.0
(B) Actual status of the above projects as of 1 January 1996												
Status												
CA	13	10	8	686	2,044	3,916	25.5	41.7	50.0	0.9	12.6	15.6
CP	16	4	4	20,611	11,097	14,240	31.4	16.7	25.0	25.6	68.4	56.7
FU	4	0	0	0	0	0	7.8	0.0	0.0	0.0	0.0	0.0
IP	15	7	4	59,300	2,975	6,955	29.4	29.2	25.0	73.6	18.3	27.7
OH	3	3	0	0	104	0	5.9	12.5	0.0	0.0	0.6	0.0
Total actual	51	24	16	80,597	16,220	25,111	100.0	100.0	100.0	100.0	100.0	100.0
(C) Actual costs versus total planned (%)				(D) Total planned expenditures, TPEF (×$1000)								
Status												
CA	0.54	5.21	4.35	23,130	13,315	28,905						
CP	16.34	28.28	15.81	27,833	8,318	44,095						
FU	0.00	0.00	0.00	3,660	0	0						
IP	47.01	7.58	7.72	70,453	13,106	17,052						
OH	0.00	0.27	0.00	1,066	4,494	0						
Total	63.89	41.34	27.88	126,142	39,233	90,052						

[a]CA: cancelled; CP: completed; FU: future; FY: fiscal year; IP: in progress; OH: on hold; PID: preliminary integrated database; WCIP: wastewater capital improvement program; Yrly Doc: yearly document. Yrly Doc refers to Yearly WCIP 10 year planning document published for the indicated FY.

Table 3. Number and estimated expenditures (×$1000) of projects, by category, planned for completion over all planning FYs according to each successive yearly WCIP 10 year planning documents[a]

Yrly Doc	Category		CS	SGU	SAP	SW	GRP	PP	Total
1991/1992	No	Absolute	41	32	10	35	15	11	144
		Relative	28	22	7	24	10	8	100
	Exp	Absolute	431,976	1,282,904	171,507	131,129	122,038	68,166	2,207,720
		Relative	20	58	8	6	6	3	100
1992/1993	No	Absolute	37	22	40	20	11	8	138
		Relative	27	16	29	14	8	6	100
	Exp	Absolute	639,962	1,087,536	403,015	79,541	117,943	127,205	2,455,202
		Relative	26	44	16	3	5	5	100
1993/1994	No	Absolute	40	21	37	17	12	11	138
		Relative	29	15	27	12	9	8	100
	Exp	Absolute	649,146	1,070,818	470,730	74,196	131,720	139,914	2,536,524
		Relative	26	42	19	3	5	6	100
1994/1995	No	Absolute	43	26	21	26	15	10	141
		Relative	30	18	15	18	11	7	100
	Exp	Absolute	1,051,005	1,339,150	820,560	132,494	208,415	177,799	3,729,423
		Relative	28	36	22	4	6	5	100
1995/1996	No	Absolute	40	20	23	18	13	26	140
		Relative	29	14	16	13	9	19	100
	Exp	Absolute	1,519,970	1,302,162	831,316	146,749	228,946	101,035	4,130,178
		Relative	37	32	20	4	6	2	100

[a]Yrly Doc: yearly document; FY: fiscal year; No: number; Exp: expenditure. The data from each yearly document were collected independent of the data from prior FY's documents. Percentages have been rounded off to whole numbers. Yrly Doc refers to the yearly WCIP 10 year planning document published for the indicated fiscal year.

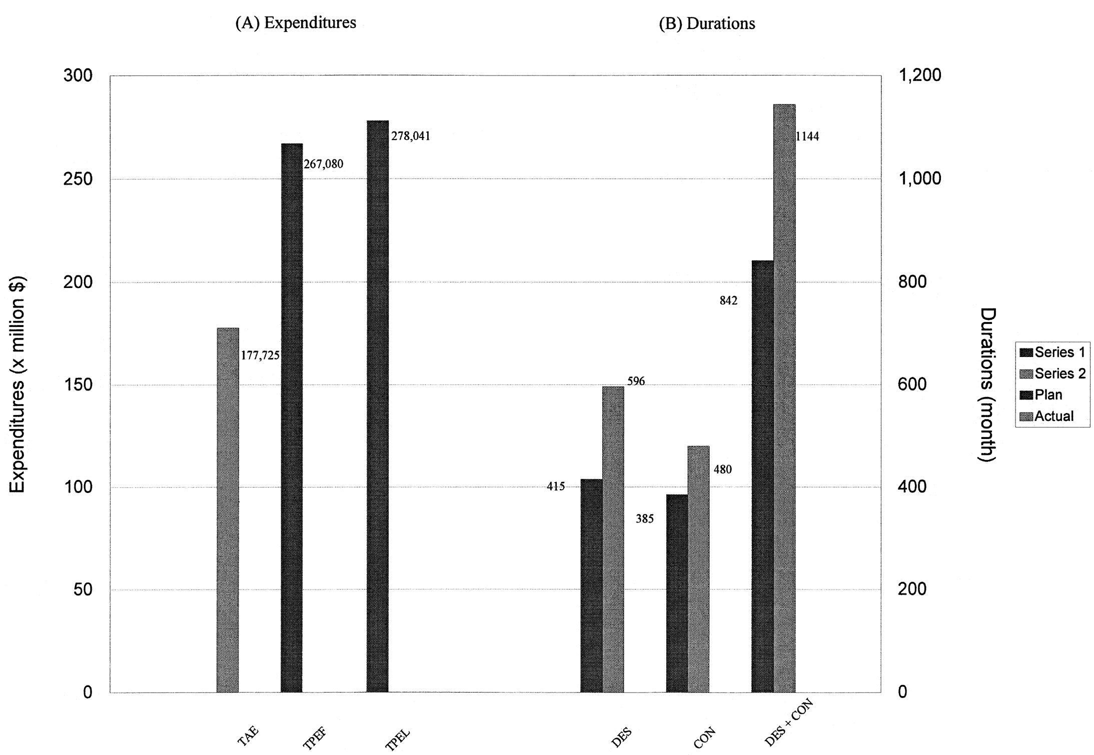


Fig. 3. Overall breakdown and evaluation of expenditures and durations for WCIP projects completed as of 1 January 1996.

Table 4. Number and estimated expenditures (×$1000) of projects by FY planned for completion over all categories according to each successive yearly WCIP 10 year planning documents[a]

Yrly Doc	Fiscal year		1991/1992	1992/1993	1993/1994	1994/1995	1995/1996	1996/1997	1997/1998	1998/1999	1999/2000	2000/2001	2001/2002	2002/2003	2003/2004	2004/2005
1991/1992	Diff	No	28	22	32	18	17					27				
		Exp	162,959	81,387	214,635	157,465	402,703					1,173,272				
	Cum	No		50	82	100	117					144				
		Exp		244,345	458,984	616,445	1,037,148					2,210,420				
1992/1993	Diff	No		23	33	30	18	13					21			
		Exp		96,292	171,504	180,879	333,777	287,773					1,384,956			
	Cum	No			56	86	104	117					138			
		Exp			267,796	448,675	782,472	1,070,246					2,455,202			
1993/1994	Diff	No			31	42	23	19	9					14		
		Exp			160,267	136,209	427,934	282,453	74,615					1,459,143		
	Cum	No				73	96	145	124					138		
		Exp				296,476	724,410	1,006,863	1,081,478					2,540,621		
1994/1995	Diff	No				33	33	22	13	9					31	
		Exp				191,534	281,938	371,925	351,537	173,282					2,359,562	
	Cum	No					66	88	101	110					141	
		Exp					473,472	845,397	1,196,935	1,370,216					3,729,778	
1995/1996	Diff	No					31	34	29	8	9					29
		Exp					250,252	283,646	457,620	72,264	452,011					2,614,386
	Cum	No						65	94	102	111					140
		Exp						533,898	991,577	1,063,781	1,575,792					4,130,178

[a]Yrly Doc: yearly document; FY: fiscal year; No: number; Exp: expenditure. The data from each yearly document were collected independent of the data from prior FY's documents. There are four rows for each Yrly Doc. The first row represents projects to be delivered within a FY. The second row indicates the total number of projects from the year of that document to the indicated FY. The third and fourth rows are corresponded expenditures. Yrly Doc refers to the yearly WCIP 10 year planning document published for the indicated fiscal year.

Table 5. Breakdown and evaluation of expenditures (×$1000), by category, for WCIP projects, completed as of 1 January 1996[a]

	CS	SGU	SAP	SW	GRP	PP	OVERALL
CP	11	9	20	16	4	4	64
BID	12,902	50,651	0	9981	6849	7672	88,055
	(10)	(6)	(0)	(4)	(3)	(2)	(25)
Breakdown of expenditures							
CON	11,527	63,721	0	11,326	7566	9138	103,278
	(10)	(6)	(0)	(4)	(3)	(2)	(25)
CTP	5018	15	800	361	290	555	7039
CTCM	725	1606	17,769	471	385	1424	22,380
FAP	1041	1302	74	804	806	532	4559
FACM	1409	12,227	1636	2468	2050	2034	21,824
TAE	19,720	77,713	35,098	19,877	11,097	14,240	177,725
TPEF	25,563	66,364	99,084	23,656	8318	44,095	267,080
TPEL	23,646	72,931	98,707	23,491	10,667	48,599	278,041
Evaluation of expenditures							
CON/BID	0.89	1.26	na	1.13	1.10	1.19	1.17
	(10)	(6)	(0)	(4)	(3)	(2)	(25)
P/CON	0.09	0.02	na	0.07	0.14	0.01	0.11
	(9)	(5)	(0)	(3)	(3)	(2)	(22)
CM/CON	0.19	0.23	na	0.14	0.29	0.27	0.25
	(10)	(5)	(0)	(3)	(3)	(2)	(23)
TAE/TPEF	0.77	1.17	0.35	0.84	1.33	0.32	0.66
TAE/TPEL	0.83	1.07	0.36	0.85	1.04	0.29	0.64

[a]C or CON: construction (project); CP: completed projects; CTP: consultant plan; CTCM: consultant construction management; FAP: force account plan; FACM: force account construction management; NC or NCON: non construction (project); TAE: total actual expenditures; TPEF: total planned expenditures for projects when they first appeared in WCIP documents; TPEL: total planned expenditures for projects when they last appeared in WCIP documents; CM = CTCM + FACM; P = CTP + FAP. Not all completed projects (CP's) have both bid and construction expenditures. Therefore, the number of projects is shown in () directly below the expenditures and ratios if not all completed projects are included in these evaluations. TPEF and TPEL are identical for a project that appeared only once in WCIP planning documents. TPEL is a combination of actual expenditures in previous years and the planned future expenditures for a project in a WCIP planning document.

down these cost data by categories, and Table 6 does the same for the durations.

The hypothetical situation

Pseud City, Nevazona, is a city of two million people, with another million in suburbs in the metropolitan area. The whole area's wastewater is processed by the Sunset Creek Treatment Plant, which performs primary and secondary treatment and discharges the treated effluent into the Wyomaho River. The Sunset Creek Plant is quite old and has been enlarged a number of times. Now it needs extensive repairs, and has been approaching its capacity as people kept moving to Pseud City to enjoy its great climate. In the middle eighties the Wyomaho River Basin Alliance, a group of governmental units whose citizens use the river in various ways, agreed that the nutrient content of the effluent must be reduced to allow additional use of

Table 6. Breakdown and evaluation of durations (months), by category, for WCIP projects completed as of 1 January 1996[a]

		CS	SGU	SAP	SW	GRP	PP	OVERALL
	CP	11	9	20	16	4	4	64
Project phase durations								
Des	Plan	114.8	95.4	52.7	43.6	50.9	57.9	415
		(5)	(9)	(4)	(7)	(4)	(2)	(31)
	Act	160.4	132.8	69.8	96.4	78.1	57.9	596
		(5)	(9)	(4)	(7)	(4)	(2)	(31)
Con	Plan	28.5	137.1	76.1	89.5	24.3	53.8	385
		(4)	(7)	(8)	(8)	(3)	(2)	(32)
	Act	27.4	171.5	112.5	99.5	47.8	69.1	480
		(4)	(7)	(8)	(8)	(3)	(2)	(32)
Des	Plan	143.3	232.5	128.8	151.3	75.2	111.7	842
+		(5)	(9)	(8)	(10)	(4)	(2)	(38)
Con	Act	187.8	304.3	182.3	224.2	125.8	119.8	1144
		(5)	(9)	(8)	(10)	(4)	(2)	(38)
Evaluation of durations								
Des	Act-Plan	45.6	37.4	17.1	52.7	27.2	0.0	180.2
	Act/Plan	1.4	1.4	1.3	2.2	1.5	1.0	1.5
Con	Act-Plan	−1.1	34.4	36.4	10.0	23.4	8.1	95
	Act/Plan	1.0	1.3	1.5	1.1	2.0	1.1	1.2
Des	Act-Plan	44.5	71.8	53.5	72.9	50.6	8.1	301.5
+								
Con	Act/Plan	1.3	1.3	1.4	1.5	1.7	1.1	1.4

[a]Act: actual; Con: construction; CP: completed projects; Des: design; Plan: planning. Not all completed projects (CP's) have "Plan and Act" durations for a project phase, Des, Con or Des + Con. Therefore, the number of projects is shown in () directly below the durations if all completed projects are not included. The absolute values in the rows include only the projects that have nonzero values for both Plan and Actual durations of each phase, Des or Con or Des + Con.

the river water downstream of Pseud City. Also, the Glenville Reclamation Plant is to be built on a large sewer running from an area of suburbs and factories east of the city, to reclaim water for irrigation and to reduce the flow into the Sunset Creek Plant, The rising population also is forcing an upgrade of the collection system, including new pumping stations and new pumps for many old ones that were established because the city's subdivisions do not follow the natural drainage basins.

In 1991 the Pseud City Sewage Bureau, for a combination of historical and technical reasons, organized the current system of six categories of projects within what it calls the Wastewater Capital Improvement Program (WCIP). These categories are:

1. Sunset advanced processing (SAP) — installing the equipment to reduce nutrients, and also fermenters to get methane from sludge to cut energy costs;
2. Sunset general upgrade (SGU) — many repairs and improvements, including new aeration basins and rebuilding some old ones that have suffered serious corrosion over more than 50 years;
3. Glenville reclamation plant (GRP) — building the plant, including full tertiary treatment and a pipeline to the East Valley Irrigation Network;
4. pumping plants (PP) — not only improved capacity and greater efficiency, but the number of types of pumps is being reduced to cut future maintenance costs;
5. collection system (CS) — rebuilding parts of the system provides an opportunity to deal with the corrosion problems in the area around Alkali Hot Springs;
6. system-wide (SW) — projects that do not fit into any of the other categories, mostly involving measurement, communication, and computer equipment.

RESULTS AND DISCUSSION: ANALYSIS OF THE PROGRAM

Actual projects vs planning

Overall program. Figure 1 shows the overall summary of the WCIP. The projects are assigned to five status classifications. Future projects (FU) are those that were deferred to some later time before they were begun, while projects on hold (OH) are those that have been postponed from their previously planned times after some work had been done. It is hoped that most of the other labeling and titling is self explanatory.

Figure 1 shows that nearly one third of the projects (29.1%) were canceled. Although the more than twenty million dollars spent on them is only a small fraction of the billion dollars spent already, it is likely that nearly all of this expenditure must be considered to have been wasted.

Figure 2 shows that, as of 1 January 1996, only 29.5% of the projects scheduled for completion by 30 June 1996 had actually been completed. As another 29.5% of the projects had been canceled, approximately three sevenths of the projects still included in the program had been completed. This includes all the projects completed in the four previous fiscal years. Thus, with only six months left in the fiscal year to complete more than half the scheduled projects and two thirds of the scheduled expenditures, it appears likely that the schedule has slipped substantially. Not only are the present projects later than expected, but other projects that depend on them will be later, too.

By category. Tables 1 and 2 respectively break down the data in Figs 1 and 2. These tables allow the reader to see the impact of various program changes during the history to the time of the data. Thus, in Table 1, the large number of new projects and new planned expenditures for SAP (corresponding to more than 50% of the total for this category) in the 1992/1993 Fiscal Year (FY) corresponds to the time when the methane processing was added to the Sunset Advanced Processing category. This previously consisted of the installation of the nutrient reduction equipment. Likewise, the various new projects and increased costs in the 1994/1995 FY mark the point when rebuilding old aeration basins was added to the Sunset General Upgrade. The great expense of replacing parts of the collection system and modifying the associated pumping plants in the area where the subsoil contains residues from the alkali hot springs (for which a suburb was named) was not recognized until 1995/1996 FY.

Evidently, the fraction of projects canceled varied greatly, from approximately 18% for SGU to approximately 55% for PP. Except for GRP and PP, a small percentage of the money was spent on canceled projects compared to the expenditures on the other status classes. In part, however, this proportionate expenditure on the canceled projects may be understood because very little of the work in GRP and PP has been completed, or even put in progress. Table 2 shows that these are the categories in which the smallest number of projects were done that had been planned for completion by 30 June 1996. There was also little expenditure in GRP and PP on work in progress as of 1 January 1996. Hence, these are the categories that are making the least progress.

For comparison to Fig. 1(B), adding up the "Total" and "CA" rows for all six categories in Table 1(D) shows that around one fifth of the four and a third billion had been budgeted to carry out these projects that turned out to be unnecessary or unfeasible. This means that the costs of the program were significantly overestimated. As in Table 1(D), Table 2(D) shows that the budget for cancelled projects was a significant fraction of the total budget for the projects analyzed in this table, although it is closer to one tenth than one fifth.

Stability of program planning

By category. Table 3 lists, by category, measures of all the subsequent work specified in each yearly planning document. It shows the substantial change in the fractions of program cost devoted to CS, SGU, and SAP, the three large categories, and the small amount of expenditure in each of the other three categories. This table provides insight into the near doubling of the program's planned costs during the five fiscal years listed, from $2.2 to $4.3 billion. The numbers of projects varied only modestly, so the growth in planned costs was primarily the result of enlarging the existing projects or replacing them with larger new ones.

Fiscal year. Table 4 presents the varying projections of project counts and expenditures in planning documents from successive fiscal years. The last entry in each row is the sum for the last five fiscal years in the ten-year period, an arrangement that mimics some real city planning documents that do not give yearly values for times further in the future. The numbers not only show responses to the program changes described above, but also show that it has always been expected that the greatest activity and expenditure would come in the last half of the program.

Table 4 provides some insight into the magnitude of the management tasks provided by the plans for the future. The planned yearly expenditures in each document for the years up to 1996/1997 have always been below 460 million dollars per year. On the other hand, the average expenditure for the last half of the decade in the 1994/1995 document is over 470 million dollars per year, and the 1995/1996 document raises this to more than 520 million dollars per year. Since the listings in the Differential (Diff) rows for the earlier fiscal years show substantial variation, it is reasonable to expect that one or more of the years later in the decade will actually have planned expenditures above 550 million dollars. Evidently the program will continue to grow, imposing heavier burdens on WCIP staff than those provided by the present level of work.

Analysis of completed projects

Overall program. Figure 3 summarizes the expenditures and schedules of all the completed projects. Total actual expenditures average roughly two-thirds of planned expenditures, but there is a consistent tendency to take longer than planned in both design and construction: 40% longer in design and 20% longer in construction. As the aggregate values obscure the true range of variation among the categories, a subdivision by category is performed in Tables 5 and 6.

Expenditures by category. In Table 5 the expenditure totals in the rightmost columns are the program aggregate numbers, including those corresponding to the bars in Fig. 3, and the other columns are the values by categories; 64 projects were completed out of 333 that were included in all the planning documents from FY 1991/1992 through FY 1995/1996. SAP had not yet incurred any construction costs, but for the other categories except CS, construction costs are higher than bids.

Substantial variations among the categories appear in TAE/TPEF and TAE/TPEL, the ratios of the total actual expenditures to the total planned expenditures when they first and last appeared in the WCIP. Costs were usually underestimated for GRP and SGU, but overestimated for the other categories, especially for PP and SAP. This explains the aggregate TAE/TPEF and TAE/TPEL ratios in Fig. 3; SAP and PP typically overestimated their costs by a factor of three or more. Furthermore, in all the categories but SGU and GRP, the agreement between planned and actual costs does not improve with time.

A more subtle point is that since the average construction management (CM) cost for the public works industry is about 0.15 of the construction (CON) costs, the aggregate CM/CON ratio of 0.25 is high. The data suggest that further investigation might be justified.

Schedules by category. In Table 6 scheduling data for completed projects have been studied both in terms of delays of starting and completion dates of phases of projects and by comparing actual and planned durations. According to this table, there is a high frequency of schedule slippage for the completed projects.

For comparisons between categories, the ratios, which cancel out the greatly differing sizes of the categories, are more informative than the differences. Evidently SW and GRP have the greatest tendencies toward schedule slippage. The overall durations of projects (design and construction) in these categories average 50 and 70%, respectively, longer than planned.

CONCLUSIONS

The example and the analysis

If there really were a Pseud City Wastewater Capital Improvement Program, it would have room for improvement of its management. It is likely that the planners, contractors, and engineers all bear some responsibility for the results, and there also may be a contribution from poor organization.

Probably it is better to overestimate costs than to underestimate them, since overestimation avoids the cost overrun scandals that have erupted from time to time in military procurement, but overestimating costs prompts an unjustified pessimism about what can be accomplished. Everyone involved, including the public at large, would benefit from more accurate scheduling and budgeting.

The forms of data aggregation and presentation in this article seem sufficiently adaptable to be applied to a wide range of large programs. Although the comparisons are simple, they appear useful for detecting patterns of incompatibility between the efforts of various groups that must cooperate to complete such a program. These comparison methods seem relevant for various types of large construction programs, not merely for wastewater systems like those in the example.

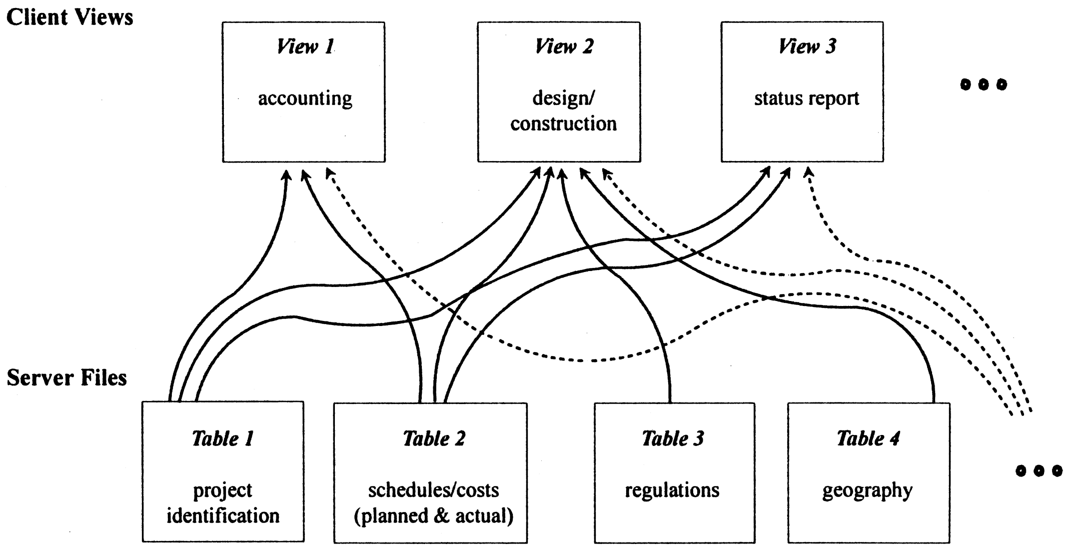


Fig. 4. Client views and server files in a network information system.

Information systems and consistency

These comparisons display patterns of inconsistencies between predicted and actual results, but do not provide explanations for them. We suggest that an information system and office environment could emphasize maintenance of consistency among the activities of the major groups involved in a program. Then it would be expected to detect incompatibilities between planning and reality before they had become as numerous and pervasive as in our example, and might help prevent their development.

The rise of networked office systems, particularly the client-server structure, has greatly changed the situation that existed in the era of paper recordkeeping. Figure 4 is a generic depiction of the relationships that are likely to exist between server files and users' views, with appropriate processing at each client to display the information in the form needed in that office.

For the kind of analysis presented here, it would be convenient if one of the files or views were organized as a program progress database. This would be a table in which the projects were grouped together by category, with columns for actual and planned expenditures, and scheduling information. This would be an easy summary to extract from a unified system incorporating design and accounting information for a program, since classification by project and category would probably be a fundamental feature of the data structure.

It must be acknowledged that it is only recently that computer software has developed to the point of providing the capabilities needed in a unified office system for a large environmental engineering program. For example, development of geographical information systems (GIS) has required adding "middleware" to the client-server structure (Goldstein, 1997; Ilincuta and Hartman, 1996), and three-dimensional graphic software for designers is also a relatively recent innovation (Coles and Reinschmidt, 1994). But now, as described by Coles and Reinschmidt, software has become capable of generating detailed schedules for construction, with calculations of dimensions, cubic feet of concrete, tons of steel, etc. Hence, perhaps some past difficulties caused by relying on the judgment of human planners may be eliminated when this kind of software becomes more widely used.

Methods similar to those in the hypothetical example would allow useful comparisons of management effectiveness and remain useful for improvements in communication and computational support. We hope that the discussion in this article contributes to this development.

Acknowledgements—The authors would like to acknowledge contributions by the Executive Editor and Reviewers of IAWQ Water Research; K. Ludwig, G. Garnas, S. Kharaghani, A. Magallanes, P. Tran, J. Cuny, H. Trejo, R. LaFrance of LA Sanitation; and J. Knoll and D. Borgoygn of CH2M Hill and Montgomery Watson Consultants.

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