TABLE VI-11 ANNUAL CONTROL COSTS - UNSEWERED AREAS

EPA REG	STATE ID	URBANIZED AREA	REF CTY	EQN VI-20 COEFS. k	EQN VI-20 COEFS. β	CONTROL COST ($/ACRE) 25%	50%	75%	85%
5	IL	AURORA	3	2.98	0.037	7.	19.	47.	67.
5	IL	BLOOMINGTON	3	3.36	0.037	8.	21.	53.	77.
5	IL	CHAMPAIGN	3	3.85	0.037	10.	25.	62.	90.
5	IL	CHICAGO	3	3.05	0.037	8.	19.	48.	70.
5	IL	DAVENPORT METRO	3	4.56	0.038	12.	30.	78.	113.
5	IL	DECATUR	3	6.19	0.038	16.	42.	110.	162.
5	IL	JOLIET	3	3.20	0.037	8.	20.	51.	74.
5	IL	PEORIA	3	5.53	0.038	14.	37.	97.	143.
5	IL	ROCKFORD	3	3.17	0.037	8.	20.	50.	72.
5	IL	SPRINGFIELD	3	3.87	0.037	10.	25.	63.	92.
5	IL	OTHER URBAN AREAS		3.35	0.037	8.	21.	54.	78.
5	IL	AVE. FOR STATE		3.35	0.037	8.	21.	54.	78.
5	IN	ANDERSON	3	0.0	0.0	0.	0.	0.	0.
5	IN	CHICAGO METRO	3	2.93	0.037	7.	18.	46.	67.
5	IN	EVANSVILLE	3	0.0	0.0	0.	0.	0.	0.
5	IN	FORT WAYNE	3	2.99	0.037	7.	19.	47.	68.
5	IN	INDIANAPOLIS	3	3.18	0.036	8.	20.	49.	70.
5	IN	LAFAYETTE	3	0.0	0.0	0.	0.	0.	0.
5	IN	MUNCIE	3	5.06	0.038	13.	33.	85.	125.
5	IN	SOUTH BEND	3	5.72	0.038	15.	39.	101.	148.
5	IN	TERRA HAUTE	3	5.57	0.038	14.	37.	98.	139.
5	IN	OTHER URBAN AREAS		3.42	0.037	9.	22.	55.	79.
5	IN	AVE. FOR STATE		3.42	0.037	9.	22.	55.	79.
5	MI	ANN ARBOR	3	3.43	0.037	9.	22.	56.	82.
5	MI	BAY CITY	3	4.85	0.039	13.	33.	87.	128.
5	MI	DETROIT	3	2.86	0.037	7.	18.	45.	65.
5	MI	FLINT	3	3.09	0.037	8.	20.	50.	72.
5	MI	GRAND RAPIDS	3	2.72	0.037	7.	17.	43.	62.
5	MI	JACKSON	3	4.65	0.038	12.	31.	80.	116.
5	MI	KALAMAZOO	3	3.29	0.037	8.	21.	53.	76.
5	MI	LANSING	3	3.23	0.037	8.	21.	52.	76.
5	MI	MUSKEGON	3	2.86	0.037	7.	18.	45.	65.
5	MI	SAGINAW	3	5.12	0.039	13.	35.	93.	137.
5	MI	OTHER URBAN AREAS		3.03	0.037	8.	19.	49.	70.
5	MI	AVE. FOR STATE		3.03	0.037	8.	19.	49.	70.
5	MN	DULUTH	3	2.65	0.037	7.	17.	42.	60.
5	MN	FARGO METRO	3	2.67	0.038	7.	18.	45.	66.
5	MN	MINNEAPOLIS	3	2.18	0.037	5.	14.	34.	49.
5	MN	ROCHESTER	3	3.44	0.037	9.	22.	57.	83.
5	MN	OTHER URBAN AREAS		2.23	0.037	6.	14.	35.	51.
5	MN	AVE. FOR STATE		2.23	0.037	6.	14.	35.	51.
5	OH	AKRON	3	3.36	0.037	8.	21.	53.	76.
5	OH	CANTON	3	3.35	0.037	8.	21.	52.	76.
5	OH	CINCINNATI	3	4.06	0.037	10.	26.	68.	98.
5	OH	CLEVELAND	3	2.25	0.036	6.	14.	34.	48.
5	OH	COLUMBUS	3	2.91	0.036	7.	18.	45.	65.
5	OH	DAYTON	3	3.25	0.037	8.	20.	51.	74.
5	OH	HAMILTON	3	3.22	0.036	8.	20.	50.	71.
5	OH	LIMA	3	0.0	0.0	0.	0.	0.	0.
5	OH	LORAIN	3	3.14	0.037	8.	20.	49.	71.
5	OH	MANSFIELD	3	5.75	0.038	15.	38.	98.	143.
5	OH	SPRINGFIELD	3	5.19	0.038	13.	34.	88.	128.
5	OH	STEUBENVILLE	3	0.0	0.0	0.	0.	0.	0.
5	OH	TOLEDO	3	3.14	0.037	8.	20.	50.	73.
5	OH	YOUNGSTOWN	3	4.15	0.037	10.	26.	66.	96.
5	OH	OTHER URBAN AREAS		3.08	0.037	8.	19.	48.	70.
5	OH	AVE. FOR STATE		3.08	0.037	8.	19.	48.	70.
5	WI	APPLETON	3	2.54	0.037	6.	16.	40.	57.
5	WI	DULUTH METRO	3	2.69	0.037	7.	17.	43.	62.
5	WI	GREEN BAY	3	3.08	0.037	8.	20.	51.	74.
5	WI	KENOSHA	3	0.0	0.0	0.	0.	0.	0.
5	WI	LA CROSSE	3	3.47	0.037	9.	22.	57.	83.
5	WI	MADISON	3	2.75	0.037	7.	17.	43.	62.
5	WI	MILWAUKEE	3	3.36	0.038	9.	22.	56.	82.
5	WI	OSHKOSH	3	0.0	0.0	0.	0.	0.	0.
5	WI	RACINE	3	3.55	0.037	9.	23.	58.	85.
5	WI	OTHER URBAN AREAS		3.21	0.037	8.	21.	53.	77.
5	WI	AVE. FOR STATE		3.21	0.037	8.	21.	53.	77.
5		AVE. FOR REGION 5		3.08	0.037	8.	20.	49.	71.

TABLE VI-11 ANNUAL CONTROL COSTS - UNSEWERED AREAS

EPA REG	STATE ID	URBANIZED AREA	REF CTY	EQN VI-20 COEFS. k	β	CONTROL COST ($/ACRE) 25%	50%	75%	85%
6	AR	FORT SMITH	4	5.52	0.038	14.	37.	96.	141.
6	AR	LITTLE ROCK	4	5.89	0.038	15.	39.	101.	148.
6	AR	PINE BLUFF	4	5.82	0.038	15.	38.	99.	144.
6	AR	OTHER URBAN AREAS		5.80	0.038	15.	39.	100.	146.
6	AR	AVE. FOR STATE		5.80	0.038	15.	39.	100.	146.
6	LA	BATON ROUGE	4	5.84	0.037	15.	38.	96.	140.
6	LA	LAFAYETTE	4	6.62	0.038	17.	44.	112.	163.
6	LA	LAKE CHARLES	4	6.18	0.038	16.	40.	104.	151.
6	LA	MONROE	4	6.10	0.038	16.	41.	105.	154.
6	LA	NEW ORLEANS	4	0.0	0.0	0.	0.	0.	0.
6	LA	SHREVEPORT	4	4.82	0.038	12.	32.	81.	118.
6	LA	OTHER URBAN AREAS		5.64	0.038	14.	37.	95.	138.
6	LA	AVE. FOR STATE		5.64	0.038	14.	37.	95.	138.
6	NM	ALBUQUERQUE	2	1.45	0.036	4.	9.	21.	30.
6	NM	OTHER URBAN AREAS		1.45	0.036	4.	9.	21.	30.
6	NM	AVE. FOR STATE		1.45	0.036	4.	9.	21.	30.
6	OK	LAWTON	3	3.94	0.038	10.	26.	67.	97.
6	OK	OKLAHOMA CITY	3	2.49	0.036	6.	15.	38.	55.
6	OK	TULSA	3	3.32	0.037	8.	21.	52.	75.
6	OK	OTHER URBAN AREAS		2.91	0.037	7.	18.	46.	66.
6	OK	AVE. FOR STATE		2.91	0.037	7.	18.	46.	66.
6	TX	ABILENE	3	1.97	0.037	5.	12.	31.	44.
6	TX	AMARILLO	3	1.74	0.037	4.	11.	27.	40.
6	TX	AUSTIN	3	3.45	0.037	9.	22.	56.	81.
6	TX	BEAUMONT	3	4.45	0.036	11.	28.	69.	99.
6	TX	BROWNSVILLE	3	3.46	0.038	9.	23.	59.	85.
6	TX	BRYAN	3	3.19	0.036	8.	20.	49.	71.
6	TX	CORPUS CHRISTI	3	2.25	0.036	6.	14.	35.	50.
6	TX	DALLAS	3	2.66	0.036	7.	16.	41.	58.
6	TX	EL PASO	3	0.61	0.037	2.	4.	10.	14.
6	TX	FORT WORTH	3	2.41	0.036	6.	15.	37.	53.
6	TX	GALVESTON	3	4.79	0.037	12.	31.	79.	114.
6	TX	HARLINGEN	3	3.53	0.038	9.	23.	60.	88.
6	TX	HOUSTON	3	5.22	0.037	13.	34.	86.	125.
6	TX	LAREDO	3	2.21	0.037	6.	14.	37.	54.
6	TX	LUBBOCK	3	1.98	0.037	5.	13.	33.	47.
6	TX	MCALLEN	3	2.78	0.038	7.	18.	47.	69.
6	TX	MIDLAND	3	1.80	0.038	5.	12.	31.	45.
6	TX	ODESSA	3	1.60	0.037	4.	10.	27.	39.
6	TX	PORT ARTHUR	3	6.29	0.037	16.	41.	104.	151.
6	TX	SAN ANGELO	3	2.48	0.038	6.	16.	42.	62.
6	TX	SAN ANTONIO	3	2.46	0.037	6.	15.	39.	56.
6	TX	SHERMAN	3	5.31	0.038	14.	35.	91.	132.
6	TX	TEXARKANA	3	6.17	0.038	16.	41.	105.	153.
6	TX	TEXAS CITY	3	4.05	0.037	10.	25.	64.	92.
6	TX	TYLER	3	5.11	0.037	13.	33.	84.	122.
6	TX	WACO	3	2.73	0.037	7.	17.	43.	61.
6	TX	WICHITA FALL	3	3.78	0.038	10.	25.	64.	94.
6	TX	OTHER URBAN AREAS		3.22	0.037	8.	20.	52.	75.
6	TX	AVE. FOR STATE		3.22	0.037	8.	20.	52.	75.
6		AVE. FOR REGION 6		3.47	0.037	9.	22.	56.	82.

TABLE VI-11 ANNUAL CONTROL COSTS - UNSEWERED AREAS

EPA REG	STATE ID	URBANIZED AREA	REF CTY	EQN VI-20 COEFS. k	β	CONTROL COST ($/ACRE) 25%	50%	75%	85%
7	IA	CEDAR RAPIDS	3	3.69	0.037	9.	24.	61.	88.
7	IA	DAVENPORT	3	3.15	0.037	8.	20.	50.	72.
7	IA	DES MOINES	3	2.82	0.037	7.	18.	44.	64.
7	IA	DUBUQUE	3	4.26	0.038	11.	28.	72.	105.
7	IA	SIOUX CITY	3	2.07	0.037	5.	13.	32.	46.
7	IA	WATERLOO	3	3.67	0.037	9.	24.	61.	88.
7	IA	OTHER URBAN AREAS		3.13	0.037	8.	20.	50.	73.
7	IA	AVE. FOR STATE		3.13	0.037	8.	20.	50.	73.
7	KS	KANSAS CITY METRO	3	3.56	0.037	9.	23.	58.	84.
7	KS	TOPEKA	3	3.42	0.037	9.	22.	55.	80.
7	KS	WICHITA	3	3.45	0.037	9.	22.	57.	82.
7	KS	OTHER URBAN AREAS		3.48	0.037	9.	22.	57.	82.
7	KS	AVE. FOR STATE		3.48	0.037	9.	22.	57.	82.
7	MO	COLUMBIA	3	3.15	0.037	8.	20.	49.	71.
7	MO	KANSAS CITY	3	3.90	0.037	10.	25.	64.	94.
7	MO	SPRINGFIELD	3	4.01	0.037	10.	25.	64.	93.
7	MO	ST. JOSEPH	3	0.0	0.0	0.	0.	0.	0.
7	MO	ST. LOUIS	3	7.48	0.039	20.	52.	138.	204.
7	MO	OTHER URBAN AREAS		5.64	0.038	15.	38.	100.	147.
7	MO	AVE. FOR STATE		5.64	0.038	15.	38.	100.	147.
7	NE	LINCOLN	3	2.56	0.037	6.	16.	41.	59.
7	NE	OMAHA	3	2.26	0.037	6.	14.	35.	51.
7	NE	OTHER URBAN AREAS		2.33	0.037	6.	15.	37.	53.
7	NE	AVE. FOR STATE		2.33	0.037	6.	15.	37.	53.
7		AVE. FOR REGION 7.		4.12	0.038	11.	27.	70.	103.
8	CO	BOULDER	2	3.44	0.036	8.	21.	50.	72.
8	CO	COLORADO SPRINGS	2	2.58	0.036	6.	16.	38.	55.
8	CO	DENVER	2	2.22	0.036	5.	13.	32.	45.
8	CO	PUEBLO	2	2.40	0.036	6.	14.	35.	51.
8	CO	OTHER URBAN AREAS		2.33	0.036	6.	14.	34.	48.
8	CO	AVE. FOR STATE		2.33	0.036	6.	14.	34.	48.
8	MT	BILLINGS	2	2.61	0.036	6.	16.	38.	55.
8	MT	GREAT FALLS	2	3.39	0.036	8.	21.	51.	73.
8	MT	OTHER URBAN AREAS		2.90	0.036	7.	18.	43.	62.
8	MT	AVE. FOR STATE		2.90	0.036	7.	18.	43.	62.
8	ND	FARGO	3	2.53	0.038	6.	17.	42.	62.
8	ND	OTHER URBAN AREAS		2.53	0.038	6.	17.	42.	62.
8	ND	AVE. FOR STATE		2.53	0.038	6.	17.	42.	62.
8	SD	SIOUX FALLS	3	2.63	0.037	7.	17.	43.	62.
8	SD	OTHER URBAN AREAS		2.63	0.037	7.	17.	43.	62.
8	SD	AVE. FOR STATE		2.63	0.037	7.	17.	43.	62.
8	UT	OGDEN	2	2.89	0.036	7.	17.	42.	60.
8	UT	PROVO	2	1.85	0.035	4.	11.	26.	37.
8	UT	SALT LAKE CITY	2	2.45	0.036	6.	15.	35.	50.
8	UT	OTHER URBAN AREAS		2.44	0.036	6.	14.	35.	50.
8	UT	AVE. FOR STATE		2.44	0.036	6.	14.	35.	50.
8	WY	URBAN AREAS	2	3.04	0.036	7.	18.	45.	64.
8	WY	AVE. FOR STATE		3.04	0.036	7.	18.	45.	64.
8		AVE. FOR REGION 8.		2.49	0.036	6.	15.	37.	53.

TABLE VI-11 ANNUAL CONTROL COSTS - UNSEWERED AREAS

EPA REG	STATE ID	URBANIZED AREA	REF CTY	EQN VI-20 COEFS. k	β	CONTROL COST ($/ACRE) 25%	50%	75%	85%
9	AK	URBAN AREAS	1	2.98	0.037	8.	19.	48.	69.
9	AK	AVE. FOR STATE		2.98	0.037	8.	19.	48.	69.
9	AZ	PHOENIX	2	0.96	0.035	2.	6.	14.	20.
9	AZ	TUCSON	2	2.12	0.036	5.	13.	31.	45.
9	AZ	OTHER URBAN AREAS		1.23	0.036	3.	7.	18.	25.
9	AZ	AVE. FOR STATE		1.23	0.036	3.	7.	18.	25.
9	CA	BAKERSFIELD	1	1.17	0.037	3.	8.	19.	28.
9	CA	FRESNO	1	1.34	0.037	3.	9.	22.	32.
9	CA	LOS ANGELES	1	1.58	0.037	4.	10.	26.	38.
9	CA	MODESTO	1	3.47	0.038	9.	23.	58.	84.
9	CA	OXNARD	1	1.56	0.037	4.	10.	25.	36.
9	CA	SACRAMENTO	1	2.04	0.037	5.	13.	33.	48.
9	CA	SALINAS	1	2.00	0.038	5.	13.	33.	49.
9	CA	SAN BERNANDINO	1	1.69	0.037	4.	11.	27.	39.
9	CA	SAN DIEGO	1	1.19	0.037	3.	8.	19.	28.
9	CA	SAN FRANCISCO	1	1.80	0.037	4.	11.	28.	41.
9	CA	SAN JOSE	1	1.46	0.037	4.	9.	24.	34.
9	CA	SANTA BARBARA	1	2.41	0.038	6.	16.	40.	58.
9	CA	SANTA ROSA	1	5.00	0.038	13.	33.	85.	125.
9	CA	SEASIDE	1	2.52	0.038	6.	17.	43.	63.
9	CA	SIMI VALLEY	1	3.51	0.038	9.	23.	59.	85.
9	CA	STOCKTON	1	1.84	0.038	5.	12.	31.	45.
9	CA	OTHER URBAN AREAS		1.69	0.037	4.	11.	27.	40.
9	CA	AVE. FOR STATE		1.69	0.037	4.	11.	27.	40.
9	HI	HONOLULU	1	2.60	0.037	7.	17.	42.	61.
9	HI	OTHER URBAN AREAS		2.60	0.037	7.	17.	42.	61.
9	HI	AVE. FOR STATE		2.60	0.037	7.	17.	42.	61.
9	NV	LAS VEGAS	2	0.50	0.035	1.	3.	7.	10.
9	NV	RENO	2	1.23	0.036	3.	7.	18.	26.
9	NV	OTHER URBAN AREAS		0.70	0.036	2.	4.	10.	14.
9	NV	AVE. FOR STATE		0.70	0.036	2.	4.	10.	14.
9		AVE. FOR REGION 9		1.66	0.037	4.	11.	27.	38.
10	ID	BOISE	2	2.55	0.036	6.	16.	38.	55.
10	ID	OTHER URBAN AREAS		2.55	0.036	6.	16.	38.	55.
10	ID	AVE. FOR STATE		2.55	0.036	6.	16.	38.	55.
10	OR	EUGENE	1	4.74	0.037	12.	31.	78.	113.
10	OR	PORTLAND	1	4.59	0.037	12.	30.	75.	108.
10	OR	SALEM	1	5.66	0.038	14.	37.	95.	138.
10	OR	OTHER URBAN AREAS		4.72	0.037	12.	30.	77.	112.
10	OR	AVE. FOR STATE		4.72	0.037	12.	30.	77.	112.
10	WA	SEATTLE	1	4.07	0.037	10.	26.	66.	96.
10	WA	SPOKANE	1	3.69	0.038	10.	25.	65.	96.
10	WA	TACOMA	1	4.65	0.037	12.	30.	76.	111.
10	WA	OTHER URBAN AREAS		4.17	0.037	11.	27.	68.	99.
10	WA	AVE. FOR STATE		4.17	0.037	11.	27.	68.	99.
10		AVE. FOR REGION 10		4.21	0.037	11.	27.	69.	100.
		AVERAGE FOR THE U.S.		3.31	0.038	8.	22.	56.	81.

Because of this definition, the number of overflows may increase with an increase in treatment rate as shown in Figure VI-12, Effect of Storage and Treatment Capacity on Number of Overflow Events. If the treatment rate is high enough to deplete storage after the first overflow, then the event is over. When storage is utilized later a new event starts, and any overflow occurring in this event is considered separate from the first overflow. Thus, the number of overflow events was increased from one to two events, even though the treatment rate was increased.

The number of overflow events appears to provide a more meaningful parameter if the event is defined differently than the definition used by STORM. The overflows shown in case 2 in Figure VI-12, should be considered as a single event since they occur so closely together. The event would then be redefined to be a separate overflow event if there was a specified length of time between it and the overflows preceding and following the event.

Determination of a National Precipitation Event Definition

A methodology is presented by which separate precipitation events may be defined on a national scale. Several valid, but totally different, alternate approaches will be briefly discussed and evaluated with regard to each one's usefulness in deriving a national event definition. The main portion will be devoted to the derivation of a precipitation event definition for the five test cities. Each city has precipitation records which are representative of the climatologic region in which it is located. From the results for each region a national precipitation event definition will be formulated for the contiguous United States. Given an event definition the relationship between the number of overflow events and volume of runoff controlled will be presented.

Meteorologic studies are one approach which may provide a useful insight into the definition of a national precipitation event. Since the atmospheric mechanisms for the cooling that creates saturation are of three types -- cyclonic, orographic, and convective -- an event definition could be based upon storm origination (e.g., all precipitation resulting from one frontal movement would be considered a single event even if the front became stationary with extended periods of zero precipitation). This would dictate an event duration range of from an extended period (i.e., 12 to 72 hours) for a cyclonic storm to a short period (i.e., seldom more than one hour) for a convective storm.[17] This causal concept would not be applicable for even a local precipitation event definition since localities are subjected to both cyclonic and convective storms. Even a twofold definition -- one each for cyclonic and convective origination -- is inappropriate as cyclonic storms may be divided into frontal and nonfrontal varieties. Overshadowing the possibly solvable problem of regionalizing cyclonic and convective precipitation events is the problem of identifying all future

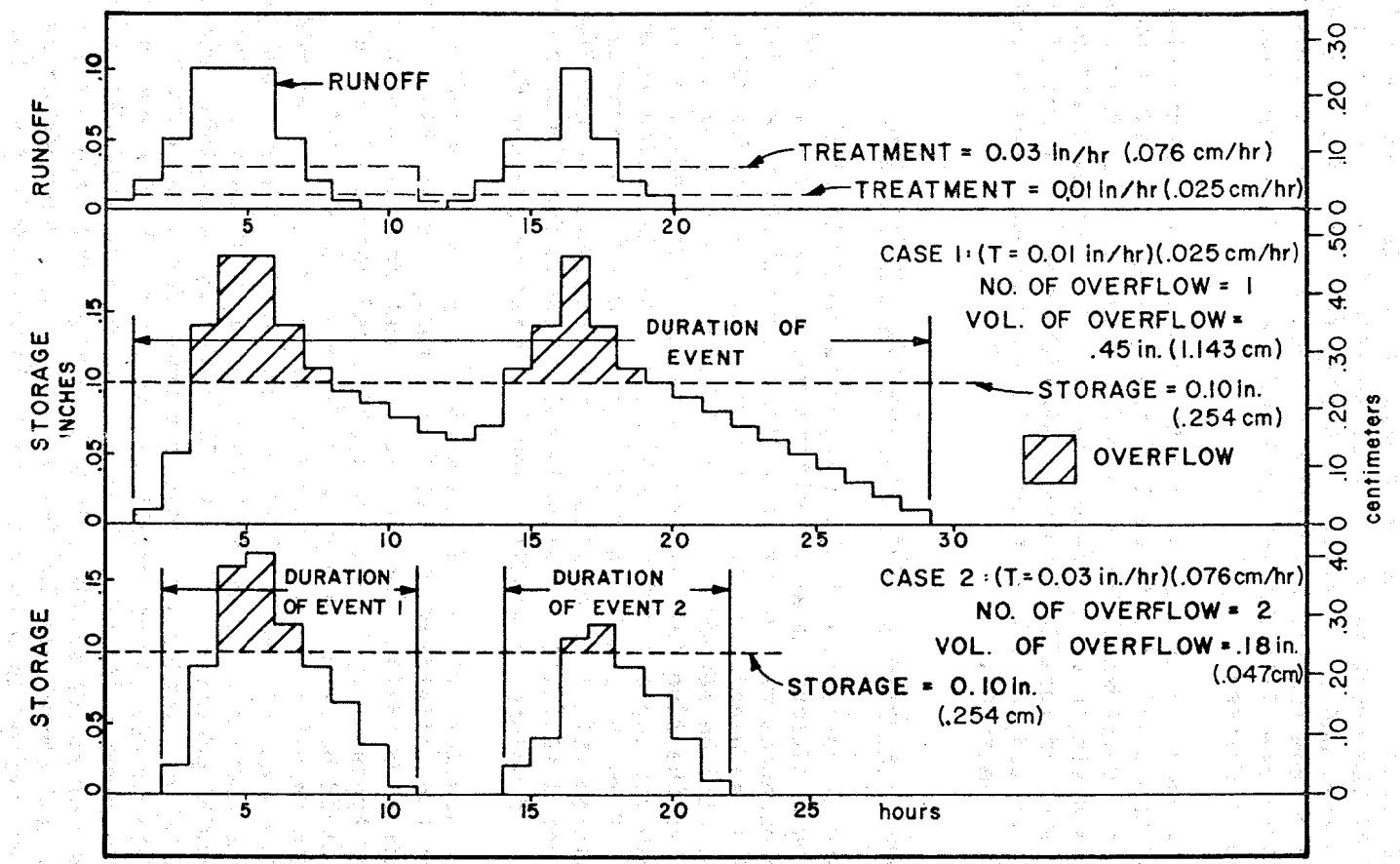

Figure VI-12. Effect of Storage and Treatment Capacity on Number of Overflow Events.

storm types in order to determine the number of events. These difficulties make the envisioned national precipitation event definition an unattainable entity via this approach.

A second approach to this event definition is a statistical one. The examination of the probability distribution of storm characteristics is accomplished first by separating a time-series of point rainfall observations into events which are statistically independent by use of the rank correlation coefficient.[18,19] Then, combination with a significance test allows selection of a limiting time interval (i.e., a minimum interevent time) between nonzero rainfall pulses, such that the hypothesis of independence may be rejected with a chosen level of assurance for nonzero pulses which are closer together. This time between independent precipitation events has been observed to follow closely the Weibull distribution.[18,19] Use of this approach would be applicable for a specific region at best. Extensive studies would be required to determine the parameters of the Weibull distribution. Furthermore, comprehensive validity of this technique is open to question as it was developed through studies of convective storms only in northeastern North America and Tucson, Arizona.[18,19]

A final approach could be one which established a minimum number of consecutive dry (i.e., no measurable precipitation) hours that must precede and follow individual storm events. This rather elementary concept is probably the best current approach to providing a useable event definition that can readily be applied on a national scale. This dry hour or zero precipitation approach is presented next.

In general, the following procedures were utilized to develop the event definition for each of the study cities. A one year precipitation record that approximates the average rainfall distribution was obtained for each city. Precipitation events were tabulated by varying the number of zero rainfall hours necessary to divide two separate events.

A "minimum interevent time" is defined as the minimum number of consecutive zero precipitation hours which must occur between two separate storm events. By varying the "minimum interevent time" the number of separate storm events generated is tabulated. The results are shown in Figure VI-13, Effect of Minimum Interevent Time on the Annual Number of Storm Events. Based on a qualitative analysis, a value of 12 hours is chosen for the national precipitation event definition. Using this event definition and the results of the STORM analysis, one can derive the relationship between percent runoff control and number of overflow events per year. The results, shown in Figure VI-14, Relationship Between Percent Runoff Control and Annual Number of Overflow Events, can be used to transform the final estimates to a base of events per year. The no-first-flush isoquant parameters can be used to estimate the level of runoff control.

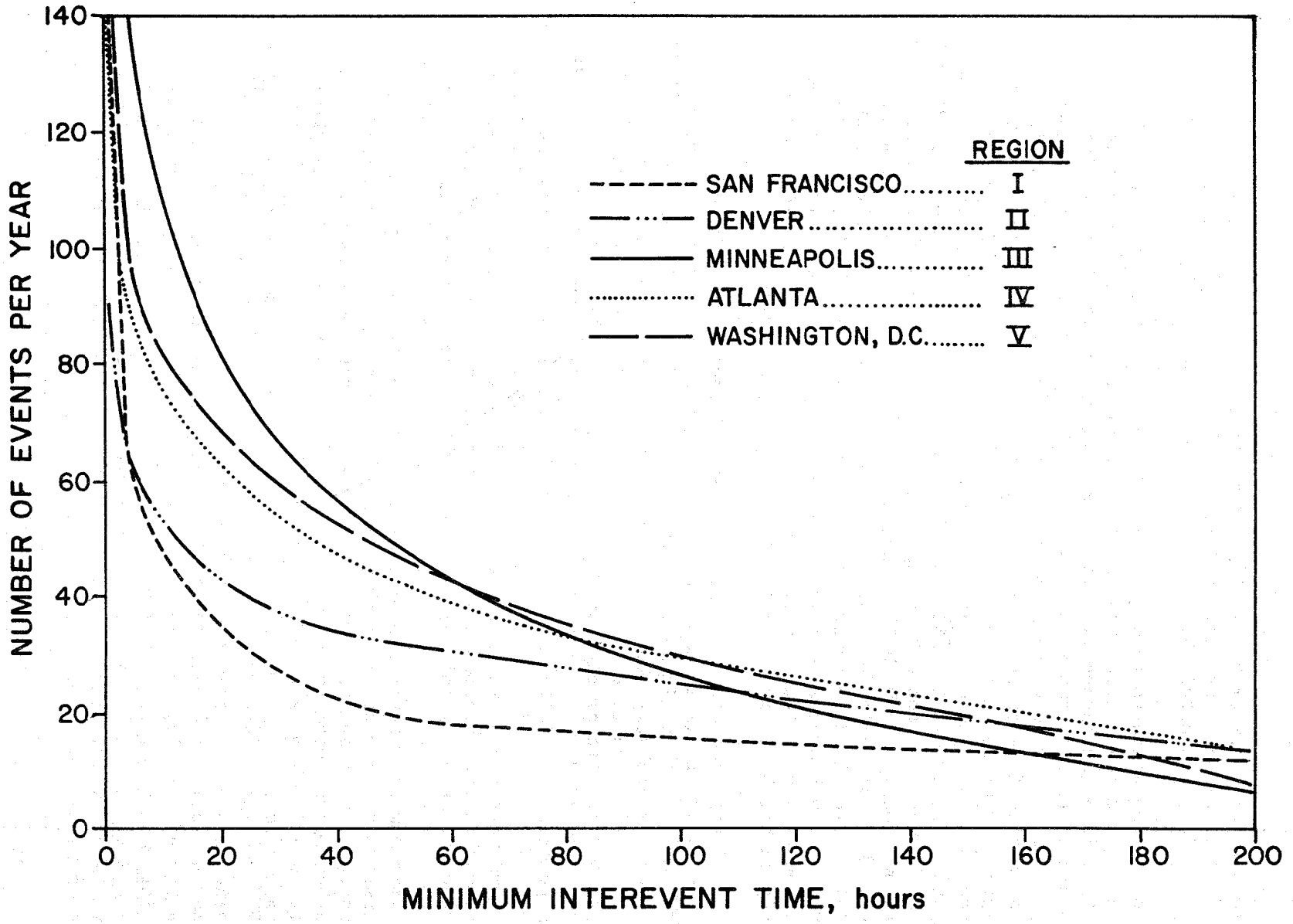

Figure VI-13. Effect of Minimum Interevent Time on the Annual Number of Storm Events

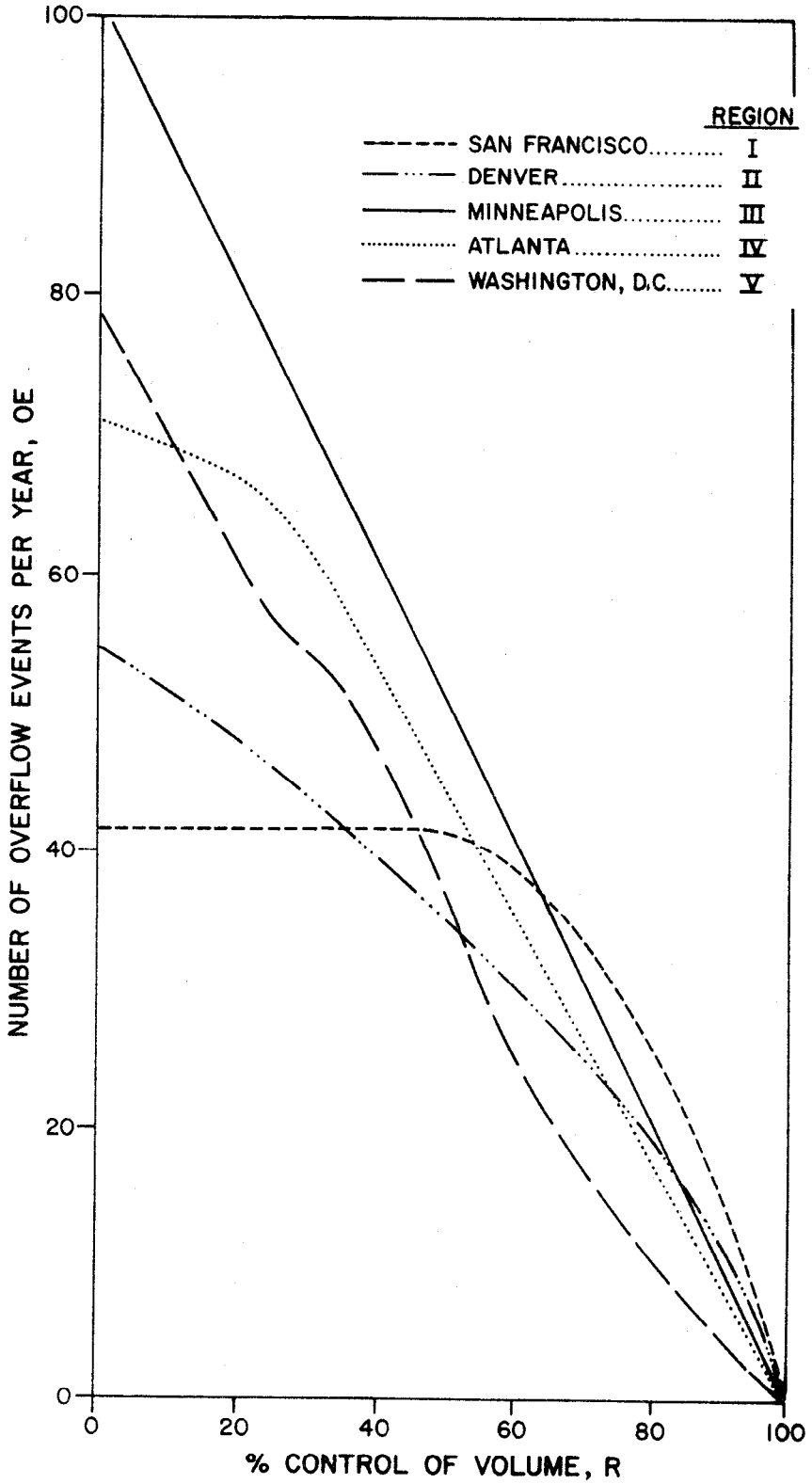

Figure VI-14. Relationship Between Percent Runoff Control and Annual Number of Overflow Events

OVERALL COST ASSESSMENT

Overall Results

General results thus far are summarized in Table VI-12, General Information, Table VI-13, Land Use by Type of Use, Table VI-14, Land Use and Population by Type of Sewerage System, Table VI-15, Quantity and Quality of Sewage and Stormwater Runoff, and Table VI-16, Annual Control Costs per Unit of Developed Urban Area.

The only remaining problem is to estimate the nation-wide costs for 25, 50, 75, and 85 percent control. As a first approximation, assume that an overall 25 percent control level is achieved by 25 percent control on the combined (A_1), storm (A_2) and unsewered (A_3) areas at annual unit costs ($ per acre) of C_1, C_2, and C_3, respectively. Thus, the approximate total annual costs, TAC, are

$$(TAC)_{25} = (C_1)_{25}A_1 + (C_2)_{25}A_2 + (C_3)_{25}A_3. \qquad \text{(VI-21)}$$

From Tables VI-14 and VI-16, we obtain

$$(TAC)_{25} = 47(2.248 \times 10^6) + 32(5.987) \times 10^6) + 8(7.393 \times 10^6)$$
$$= \$356.4 \times 10^6/\text{hr}.$$

Likewise,

$$(TAC)_{50} = \$1{,}065 \times 10^6 \qquad \text{(VI-22)}$$
$$(TAC)_{75} = \$3{,}210 \times 10^6$$
$$(TAC)_{85} = \$5{,}029 \times 10^6.$$

Recall that the cost of wet-weather control using secondary facilities is

$$Z_s^* = ke^{\beta R_1} \qquad \text{(VI-24)}$$

where Z_s^* = annual cost for optimal solution, dollars per acre,

k, β = constants, and

R_1 = percent BOD removal ($0 \leq R_1 \leq 85$).

The cost of wet weather control in terms of pounds of pollutant removed, w, is

$$Z_s^* = ke^{\beta(100)(\frac{w}{M})} \qquad \text{(VI-25)}$$

where w = pollutant removal, lbs/acre-yr, and

M = pollutants available, lbs/acre-yr.

Table VI-12. GENERAL INFORMATION

Total Urbanized Area	=	29.037×10^6 ac (11.751×10^6 ha)
Total Population	=	149.366×10^6 persons
Average Population Density	=	5.14 persons/acre (12.7 persons/ha)
Average Precipitation	=	33.4 inches/year (84.8 cm/year)

Table VI-13. LAND USE BY TYPE OF USE

Use	10^6 Acres (ha)
Undeveloped	13.409 (5.426)
Residential	9.120 (3.691)
Commercial	1.337 (0.541)
Industrial	2.324 (0.941)
Other	2.847 (1.152)
Total	29.037 (11.751)

Table VI-14. LAND USE AND POPULATION BY TYPE OF SEWERAGE SYSTEM

	10^6 Acres (ha)	10^6 Persons	Developed Population Density Persons/ Acre (ha)
Undeveloped	13.409 (5.426)	0	0
Combined	2.248 (0.910)	37.606	16.7 (41.3)
Storm	5.987 (2.423)	77.853	13.0 (32.1)
Unsewered	7.393 (2.992)	33.906	4.6 (11.4)
	29.037 (11.751)	149.366	9.6 (23.7)

Table VI-15. QUANTITY AND QUALITY OF SEWAGE AND STORMWATER RUNOFF

Sewerage System	Flow: in./yr (cm/yr)		Quality: Annual Pounds of BOD/acre (kg/ha)	
	Sanitary Sewage [a]	Storm Runoff [b]	Sanitary Sewage [c]	Storm Runoff [d]
Combined	22.5 (57.2)	16.5 (41.9)	1039 (1167)	136.6 (153.0)
Storm	17.5 (44.5)	14.8 (37.6)	807 (907)	30.5 (35.3)
Unsewered	6.2 (15.7)	10.8 (27.4)	285 (320)	25.9 (26.5)
Weighted Average	12.8 (32.5)	13.4 (34.0)	594 (667)	43.6 (49.0)

[a]Table IV-4 [b]Table IV-3 [c]Table V-11 [d]Table V-10

Table VI-16. ANNUAL CONTROL COSTS PER UNIT OF DEVELOPED URBAN AREA: $/ACRE ($/HA)

Type of Sewerage System	Level of Control, % of Total				Coefficients	
	25	50	75	85	k	β
Combined[a]	47 (116)	151 (373)	501 (1238)	815 (2013)	14.05	0.048
Storm[b]	32 (79.1)	94 (232)	279 (689)	434 (1072)	10.82	0.043
Unsewered[c]	8 (19.8)	22 (54.4)	56 (138)	81 (200)	3.31	0.038

[a]Table VI-9 [b]Table VI-10 [c]Table VI-11

The marginal cost of BOD removal is

$$\frac{dZ_s^*}{dw} = \frac{100\ \beta\ k}{M}\ e^{\frac{100\beta\ w}{M}} \qquad \text{(VI-26)}$$

Given these convex cost functions, the optimal mix of control of storm runoff from combined, storm, and unsewered areas is found by equating marginal costs. Using equation VI-26 with the subscript (1) denoting combined, (2) denoting storm, and (3) denoting unsewered, yields

$$\frac{100\ \beta_1 k_1}{M_1}\ e^{\frac{100\ \beta_1 w_1}{M_1}} = \frac{100\ \beta_2 k_2}{M_2}\ e^{\frac{100\ \beta_2 w_2}{M_2}} = \frac{100\ \beta_3 k_3}{M_3}\ e^{\frac{100\ \beta_3 w_3}{M_3}} \qquad \text{(VI-27)}$$

If marginal costs for, say, 50% BOD removal are compared, one obtains

$$MC_1 = \frac{100(0.048)(14.05)}{136.6}\ e^{100(0.048)(0.5)} = \$5.44/\text{lb BOD}\ (\$11.99/\text{kg BOD}) \qquad \text{(VI-28)}$$

$$MC_2 = \frac{100(0.043)(10.82)}{30.5}\ e^{100(0.043)(0.5)} = \$13.10/\text{lb BOD}\ (\$28.85/\text{kg BOD}) \qquad \text{(VI-29)}$$

$$MC_3 = \frac{100(0.038)(3.31)}{25.9}\ e^{100(0.038)(0.5)} = \$3.25/\text{lb BOD}\ (\$7.15/\text{kg BOD}) \qquad \text{(VI-30)}$$

This result indicates that, to achieve 50 percent control, storm sewered areas should be controlled less intensively due to their relatively high marginal costs and unsewered areas should be controlled more intensively because of their relatively low marginal cost.

The correct solution can be found by solving for w_1 and w_3 as functions of w_2, i.e.,

$$w_1 = a_{12} + b_{12} w_2 \qquad 0 \leq w_1 \leq .85\ M_1 \qquad \text{(VI-31)}$$

$$w_3 = a_{32} + b_{32}w_2 \quad 0 \leq w_3 \leq .85\ M_3 \tag{VI-32}$$

where $$a_{12} = \frac{M_1}{100\ \beta_1} \ln \left[\left(\frac{\beta_2}{\beta_1}\right) \left(\frac{k_2}{k_1}\right) \left(\frac{M_1}{M_2}\right) \right]$$

$$a_{32} = \frac{M_3}{100\ \beta_3} \ln \left[\left(\frac{\beta_2}{\beta_3}\right) \left(\frac{k_2}{k_3}\right) \left(\frac{M_3}{M_2}\right) \right]$$

$$b_{12} = \left(\frac{\beta_2}{\beta_1}\right) \left(\frac{M_1}{M_2}\right)$$

$$b_{32} = \left(\frac{\beta_2}{\beta_3}\right) \left(\frac{M_3}{M_2}\right)$$

M_1, M_2, M_3, β_1, β_2, β_3, k_1, k_2, k_3, w_1, w_2, w_3 are as defined earlier.

The total wet-weather pollution load, WP (pounds/year), is

$$WP = \sum_{i=1}^{3} M_i A_i \tag{VI-33}$$

where M_i = annual pounds per acre from i^{th} area, and

A_i = area of ith area, acres.

Let ρ denote the proportion of WP that one wishes to control. Then, the optimal removal, w_i^*, for a given ρ is found by substituting equations VI-31 and VI-32 into VI-33, or

$$\rho(WP) = w_1A_1 + w_2A_2 + w_3A_3 \tag{VI-34}$$

$$\rho(WP) = (a_{12} + b_{12}w_2)A_1 + w_2A_2 + (a_{32} + b_{32}w_2)A_3 \tag{VI-35}$$

$$w_2^* = \frac{\rho(WP) - a_{12}A_1 - a_{32}A_3}{b_{12}A_1 + A_2 + b_{32}A_3} \tag{VI-36}$$

where w_i^* = optimal annual pounds per acre removed from the ith source area.

Knowing w_2^*, one can find w_1^* and w_3^* by substituting into equations VI-31 and VI-32.

The optimal percent control of the ith source for control level, ρ, in terms of w_i^* is

$$(R_i^*)_\rho = \frac{100(w_i^*)_\rho}{M_i} \qquad 0 \leq (R_i^*)_\rho \leq 85 \qquad \text{(VI-37)}$$

The optimal percent control for 25, 50, 75, and 85 percent is shown in Table VI-17, Optimal Percent Control For Specified Overall Percent Control. Knowing (R_1) , one can find the cost per acre by simply substituting into equation VI-24, i.e.,

$$Z_s^* = ke^{\beta R_1} \qquad \text{(VI-38)}$$

to obtain the optimal annual cost per acre as shown in Table VI-18, Optimal Annual Cost per Acre for Specified Percent Control. Thus, the optimal annual control costs are shown in Table VI-19, Optimal Annual Control Costs. These costs are approximately 17 percent less than the approximate values reported earlier for 25, 50, and 75 percent control, i.e. equations VI-21 and VI-22.

Tertiary Treatment vs Wet-Weather-Treatment

The optimal mix of tertiary treatment and wet-weather control can be found by equating the marginal cost of tertiary treatment with the marginal cost of wet-weather pollution control. The estimated total annual incremental cost of a tertiary treatment plant is:[20]

$$C_{tert} = 87{,}000\ D^{0.787} \qquad \text{(VI-39)}$$

where C_{tert} = total annual incremental cost of tertiary treatment plant, dollars per year, and

D = plant size, mgd.

Assume a 25 mgd plant. Then, C_{tert} = \$1,096,000 per year. The plant is assumed to increase the BOD removal from 85 percent to 95 percent or about 0.017 pounds (7.71 g) per capita-day or 1,550,000 pounds (704,000 kg) per year for the city of 250,000 people. Thus, the unit cost of tertiary treatment, c_{tert}, is \$0.71 per pound (\$1.55 per kg) of BOD removed.

Equating the marginal cost of wet weather control to the unit cost of tertiary treatment yields

$$c_{tert} = \frac{100\beta\ k}{M} e^{\frac{100\beta\ w}{M}} \qquad \text{(VI-40)}$$

TABLE VI-17 OPTIMAL PERCENT CONTROL FOR SPECIFIED OVERALL PERCENT CONTROL

EPA REG	STATE ID	OPTIMAL PERCENT CONTROL 25% COMB	25% STORM	25% UNSEW	50% COMB	50% STORM	50% UNSEW	75% COMB	75% STORM	75% UNSEW	85% COMB	85% STORM	85% UNSEW
1	CT	31.0	3.9	28.6	54.6	29.1	56.1	78.1	54.2	83.5	85.0	85.0	85.0
1	ME	27.9	0.0	3.0	52.8	0.0	28.7	77.7	0.0	54.5	85.0	0.0	85.0
1	MA	34.6	0.0	26.1	60.5	18.4	54.4	84.9	42.2	81.2	85.0	85.0	85.0
1	NH	28.3	0.0	3.7	53.2	0.0	29.5	78.1	0.0	55.3	85.0	0.0	85.0
1	RI	26.5	7.0	32.1	50.5	32.1	59.4	75.1	57.8	85.0	85.0	85.0	85.0
1	VT	32.0	0.0	0.8	56.9	0.0	26.0	81.8	0.0	51.2	85.0	0.0	85.0
2	NJ	29.0	4.0	42.7	48.9	28.1	70.2	77.9	63.0	85.0	85.0	85.0	85.0
2	NY	27.3	2.6	54.8	51.9	27.4	85.0	78.5	54.3	85.0	85.0	85.0	85.0
3	DE	36.7	3.5	27.5	61.1	27.9	54.0	85.0	52.7	81.0	85.0	85.0	85.0
3	DC	25.8	22.9	0.0	48.9	52.8	0.0	72.0	82.8	0.0	85.0	85.0	0.0
3	MD	0.0	16.1	46.2	0.0	40.4	73.0	0.0	70.8	85.0	0.0	85.0	85.0
3	PA	32.2	8.9	42.4	55.7	33.5	70.3	83.3	62.4	85.0	85.0	85.0	85.0
3	VA	44.6	3.3	36.5	69.2	27.8	63.5	85.0	61.5	85.0	85.0	85.0	85.0
3	WV	27.2	0.0	6.5	52.3	9.6	33.1	77.2	33.9	59.3	85.0	85.0	85.0
4	AL	0.0	10.4	36.3	0.0	34.4	62.1	0.0	62.1	85.0	0.0	85.0	85.0
4	FL	40.9	9.9	43.0	64.7	33.9	69.2	85.0	66.6	85.0	85.0	85.0	85.0
4	GA	37.8	0.9	21.4	62.3	25.4	47.4	85.0	51.6	75.1	85.0	85.0	85.0
4	KY	44.0	6.6	37.3	68.4	30.6	64.0	85.0	62.5	85.0	85.0	85.0	85.0
4	MS	0.0	12.1	35.3	0.0	36.2	61.0	0.0	62.5	85.0	0.0	85.0	85.0
4	NC	0.0	11.7	34.7	0.0	35.8	60.4	0.0	61.3	85.0	0.0	85.0	85.0
4	SC	0.0	13.1	33.9	0.0	37.3	59.5	0.0	61.6	85.0	0.0	85.0	85.0
4	TN	39.0	1.2	31.9	63.3	25.2	58.1	85.0	50.9	85.0	85.0	85.0	85.0
5	IL	22.0	24.7	40.8	45.7	52.6	70.4	71.9	83.5	85.0	85.0	85.0	85.0
5	IN	28.4	0.0	19.3	53.7	14.6	46.8	78.3	39.1	73.6	85.0	85.0	85.0
5	MI	28.2	0.8	27.7	52.6	25.9	54.8	77.0	51.0	82.0	85.0	85.0	85.0
5	MN	34.4	0.0	29.5	58.8	23.6	56.2	83.1	47.8	82.7	85.0	85.0	85.0
5	OH	30.6	0.0	28.3	56.3	16.8	56.9	80.7	40.9	84.0	85.0	85.0	85.0
5	WI	18.6	20.4	35.8	39.7	46.7	63.5	63.7	76.6	85.0	85.0	85.0	85.0

TABLE VI-17 OPTIMAL PERCENT CONTROL FOR SPECIFIED OVERALL PERCENT CONTROL

EPA REG	STATE ID	OPTIMAL PERCENT CONTROL 25% COMB	25% STORM	25% UNSEW	50% COMB	50% STORM	50% UNSEW	75% COMB	75% STORM	75% UNSEW	85% COMB	85% STORM	85% UNSEW
6	AR	55.0	1.4	19.3	80.1	25.5	44.6	85.0	56.8	77.5	85.0	85.0	85.0
6	LA	0.0	13.6	54.3	0.0	37.7	81.6	0.0	71.1	85.0	0.0	85.0	85.0
6	NM	0.0	7.4	41.6	0.0	31.5	67.5	0.0	64.4	85.0	0.0	85.0	85.0
6	OK	0.0	5.8	39.5	0.0	29.4	65.5	0.0	61.7	85.0	0.0	85.0	85.0
6	TX	25.7	10.2	39.1	44.9	34.3	65.3	69.2	64.9	85.0	85.0	85.0	85.0
7	IA	12.7	15.7	36.5	30.9	41.4	63.9	53.7	73.5	85.0	85.0	85.0	85.0
7	KS	38.2	4.2	27.1	62.6	28.7	53.3	85.0	54.4	80.8	85.0	85.0	85.0
7	MO	31.4	0.0	4.2	56.3	24.1	29.8	81.2	49.2	55.4	85.0	85.0	85.0
7	NE	27.7	0.0	28.7	53.5	20.3	56.3	76.8	44.8	83.4	85.0	85.0	85.0
8	CO	24.6	9.6	44.7	45.4	34.0	70.9	73.8	67.3	85.0	85.0	85.0	85.0
8	MT	0.0	16.7	36.7	0.0	41.3	62.3	0.0	67.9	85.0	0.0	85.0	85.0
8	ND	51.4	15.5	32.4	76.1	40.1	58.3	85.0	67.6	85.0	85.0	85.0	85.0
8	SD	44.8	9.5	35.5	68.9	33.6	61.4	85.0	61.8	85.0	85.0	85.0	85.0
8	UT	0.0	6.9	41.9	0.0	30.9	67.8	0.0	64.3	85.0	0.0	85.0	85.0
8	WY	0.0	13.0	36.5	0.0	37.4	62.1	0.0	64.6	85.0	0.0	85.0	85.0
9	AK	36.1	0.3	39.0	60.2	24.4	64.9	85.0	56.4	85.0	85.0	85.0	85.0
9	AZ	0.0	3.6	41.6	0.0	32.8	67.4	0.0	65.1	85.0	0.0	85.0	85.0
9	CA	19.7	13.4	47.6	41.7	38.6	74.4	69.9	71.1	85.0	85.0	85.0	85.0
9	HI	0.0	10.6	46.0	0.0	35.0	71.9	0.0	68.2	85.0	0.0	85.0	85.0
9	NV	30.2	2.5	35.6	54.1	27.0	61.7	80.1	53.5	85.0	85.0	85.0	85.0
10	ID	0.0	16.4	33.7	0.0	41.0	59.1	0.0	65.6	84.5	0.0	85.0	85.0
10	OR	31.9	0.0	27.7	57.0	22.6	54.1	81.6	47.2	80.1	85.0	85.0	85.0
10	WA	32.2	0.0	23.8	57.8	19.7	50.7	82.5	44.3	76.6	85.0	85.0	85.0

TABLE VI-18 OPTIMAL ANNUAL COST PER ACRE FOR SPECIFIED PERCENT CONTROL

EPA REG	STATE ID	OPTIMAL ANNUAL COST PER ACRE 25% COMB	25% STORM	25% UNSEW	50% COMB	50% STORM	50% UNSEW	75% COMB	75% STORM	75% UNSEW	85% COMB	85% STORM	85% UNSEW
1	CT	43.	11.	10.	127.	32.	30.	371.	95.	87.	510.	352.	92.
1	ME	18.	0.	4.	50.	0.	11.	139.	0.	32.	187.	0.	107.
1	MA	41.	0.	9.	124.	31.	28.	355.	90.	80.	356.	592.	93.
1	NH	19.	0.	4.	53.	0.	12.	147.	0.	34.	196.	0.	113.
1	RI	46.	11.	10.	133.	32.	29.	396.	94.	77.	614.	297.	77.
1	VT	18.	0.	4.	49.	0.	12.	137.	0.	33.	157.	0.	130.
2	NJ	55.	16.	14.	157.	46.	41.	727.	215.	72.	1068.	565.	72.
2	NY	116.	25.	23.	450.	98.	74.	1955.	425.	74.	2797.	2271.	74.
3	DE	48.	12.	11.	135.	33.	30.	374.	94.	87.	374.	374.	101.
3	DC	125.	32.	0.	460.	118.	0.	1696.	436.	0.	3546.	481.	0.
3	MD	0.	22.	20.	0.	63.	56.	0.	233.	90.	0.	430.	90.
3	PA	62.	17.	14.	183.	49.	41.	656.	175.	73.	711.	474.	73.
3	VA	55.	14.	13.	156.	39.	37.	305.	171.	85.	305.	473.	85.
3	WV	19.	0.	5.	53.	14.	13.	149.	41.	37.	206.	360.	101.
4	AL	0.	23.	21.	0.	59.	54.	0.	178.	127.	0.	445.	127.
4	FL	101.	27.	24.	266.	72.	63.	610.	271.	113.	610.	570.	113.
4	GA	47.	12.	11.	125.	32.	29.	310.	90.	83.	310.	340.	121.
4	KY	61.	15.	13.	172.	41.	37.	350.	164.	84.	350.	435.	84.
4	MS	0.	22.	21.	0.	58.	54.	0.	164.	133.	0.	403.	133.
4	NC	0.	19.	17.	0.	49.	45.	0.	135.	114.	0.	348.	114.
4	SC	0.	19.	18.	0.	50.	46.	0.	131.	121.	0.	332.	121.
4	TN	61.	15.	14.	162.	41.	36.	387.	115.	99.	387.	458.	99.
5	IL	66.	15.	15.	198.	46.	46.	667.	154.	78.	1225.	164.	78.
5	IN	31.	0.	7.	87.	21.	19.	233.	57.	52.	305.	364.	79.
5	MI	38.	9.	8.	105.	25.	23.	285.	69.	63.	396.	270.	70.
5	MN	30.	0.	7.	80.	20.	18.	212.	52.	47.	229.	232.	51.
5	OH	39.	0.	9.	113.	29.	25.	306.	77.	67.	365.	477.	70.
5	WI	50.	13.	12.	142.	36.	34.	459.	117.	77.	1305.	162.	77.

TABLE VI-18 OPTIMAL ANNUAL COST PER ACRE FOR SPECIFIED PERCENT CONTROL

EPA REG	STATE ID	OPTIMAL ANNUAL COST PER ACRE 25% COMB	25% STORM	25% UNSEW	50% COMB	50% STORM	50% UNSEW	75% COMB	75% STORM	75% UNSEW	85% COMB	85% STORM	85% UNSEW
6	AR	45.	13.	12.	117.	35.	31.	141.	121.	110.	141.	372.	146.
6	LA	0.	53.	44.	0.	148.	121.	0.	609.	138.	0.	1096.	138.
6	NM	0.	7.	6.	0.	18.	16.	0.	63.	30.	0.	139.	30.
6	OK	0.	14.	12.	0.	37.	32.	0.	136.	66.	0.	347.	66.
6	TX	82.	15.	14.	217.	41.	36.	743.	139.	75.	1665.	310.	75.
7	IA	49.	13.	12.	134.	36.	33.	472.	126.	73.	2688.	198.	73.
7	KS	44.	10.	10.	118.	27.	25.	287.	75.	70.	287.	254.	82.
7	MO	28.	0.	7.	76.	18.	18.	202.	47.	47.	235.	193.	147.
7	NE	31.	0.	7.	85.	21.	18.	230.	57.	50.	322.	290.	53.
8	CO	45.	13.	11.	115.	33.	29.	412.	119.	48.	684.	236.	48.
8	MT	0.	12.	11.	0.	30.	27.	0.	81.	62.	0.	154.	62.
8	ND	37.	9.	9.	98.	24.	23.	140.	70.	62.	140.	140.	62.
8	SD	44.	11.	10.	116.	28.	26.	221.	87.	62.	221.	221.	62.
8	UT	0.	12.	11.	0.	31.	27.	0.	110.	50.	0.	243.	50.
8	WY	0.	12.	11.	0.	31.	28.	0.	85.	64.	0.	183.	64.
9	AK	62.	15.	13.	160.	39.	33.	426.	138.	69.	426.	426.	69.
9	AZ	0.	6.	5.	0.	15.	14.	0.	53.	25.	0.	112.	25.
9	CA	63.	10.	10.	169.	27.	27.	607.	99.	40.	1201.	170.	40.
9	HI	0.	17.	14.	0.	44.	38.	0.	162.	61.	0.	314.	61.
9	NV	17.	3.	2.	43.	7.	6.	118.	18.	14.	142.	60.	14.
10	ID	0.	9.	9.	0.	23.	22.	0.	57.	54.	0.	119.	55.
10	OR	63.	0.	13.	169.	40.	35.	445.	106.	93.	509.	469.	112.
10	WA	40.	0.	10.	106.	33.	28.	284.	88.	73.	314.	432.	99.

TABLE VI-19 OPTIMAL ANNUAL CONTROL COSTS

EPA REG	STATE ID	OPTIMAL ANNUAL CONTROL COST (MILLIONS OF DOLLARS) 25%	50%	75%	85%
1	CT	4.6	13.5	39.5	68.6
1	ME	0.9	2.5	7.0	11.1
1	MA	6.7	25.4	72.8	157.1
1	NH	0.7	1.9	5.4	8.7
1	RI	1.7	5.0	14.6	24.2
1	VT	0.2	0.5	1.4	2.5
TL REG 1		14.9	49.0	140.8	272.3
2	NJ	12.5	35.8	115.2	229.8
2	NY	37.9	144.9	593.3	1245.2
TL REG 2		50.4	180.7	708.4	1475.1
3	DE	0.7	2.1	5.9	11.0
3	DC	2.4	8.3	32.6	57.2
3	MD	6.1	17.4	53.2	90.7
3	PA	17.4	51.5	159.1	293.2
3	VA	5.2	14.9	45.0	91.8
3	WV	1.2	3.4	9.6	15.5
TL REG 3		33.1	98.2	305.4	559.4
4	AL	5.7	14.8	38.9	66.9
4	FL	16.3	43.1	121.5	214.6
4	GA	6.1	16.2	43.1	75.6
4	KY	3.0	8.5	25.2	49.0
4	MS	2.7	6.9	18.2	30.5
4	NC	5.2	13.6	35.7	59.9
4	SC	2.9	7.5	19.6	32.1
4	TN	5.4	14.3	37.9	71.7
TL REG 4		47.2	124.9	340.0	600.3
5	IL	28.5	85.5	263.6	437.0
5	IN	6.6	19.4	52.1	86.9
5	MI	12.9	33.2	94.1	155.4
5	MN	2.6	8.8	23.3	42.4
5	OH	12.6	42.8	115.8	224.7
5	WI	5.5	15.6	44.5	78.1
TL REG 5		68.7	207.3	595.5	1024.4

TABLE VI-19 OPTIMAL ANNUAL CONTROL COSTS

EPA REG	STATE ID	OPTIMAL ANNUAL CONTROL COST (MILLIONS OF DOLLARS) 25%	50%	75%	85%
6	AR	1.9	5.0	14.3	24.8
6	LA	9.9	27.7	88.7	152.2
6	NM	0.6	1.5	3.9	6.8
6	OK	3.0	7.9	21.5	40.1
6	TX	16.5	43.5	118.3	206.9
TL REG 6		32.0	85.5	246.7	430.7
7	IA	3.0	8.1	23.1	48.3
7	KS	2.5	6.5	17.3	30.2
7	MO	5.9	16.2	43.2	71.5
7	NE	1.3	4.0	10.7	18.1
TL REG 7		12.6	34.8	94.2	168.1
8	CO	2.5	6.2	17.0	28.9
8	MT	0.5	1.3	3.2	5.0
8	ND	0.3	0.8	2.1	3.4
8	SD	0.4	1.0	2.7	4.7
8	UT	1.2	3.1	8.1	14.3
8	WY	0.3	0.7	1.8	2.9
TL REG 8		5.2	13.1	35.0	59.2
9	AK	0.3	0.8	2.1	4.0
9	AZ	1.0	2.6	6.7	11.5
9	CA	21.9	59.2	172.4	287.6
9	HI	1.1	2.8	7.9	13.5
9	NV	0.2	0.4	1.1	1.9
TL REG 9		24.5	65.8	190.1	318.5
10	ID	0.4	1.0	2.5	3.9
10	OR	3.2	10.4	27.5	47.8
10	WA	4.6	14.9	39.2	69.2
TL REG 10		8.2	26.4	69.2	120.9
TL U.S.		296.7	885.7	2725.4	5029.0

or

$$w^* = \frac{M}{100\beta} \ln \left[\frac{c_{tert}(M)}{100\beta\ (k)}\right] \qquad \text{(VI-41)}$$

where w^* = optimal pounds of wet-weather pollution to control prior to using tertiary treatment, pounds/acre-yr.

The optimal percent control in terms of R_1 is

$$R_1^* = \max\left(\frac{1}{\beta} \ln \left[\frac{c_{tert}(\overline{M})}{100\beta\ (k)}\right],\ 0\right). \qquad \text{(VI-42)}$$

The overall average BOD loading per acre, $\overline{M}$ (pounds/acre-yr), is

$$\overline{M} = \frac{WP}{A_{tot}} = \frac{6.81 \times 10^6}{15.63 \times 10^6} \qquad \text{(VI-43)}$$

$$\overline{M} = 43.6 \text{ lb BOD/ac-yr } (34.0 \text{ kg BOD/ha-yr})$$

where A_{tot} = total developed area in US, acres.

The overall cost function for the US is $Z = 5.37e^{0.047R_1}$. Thus,

$$R_1^* = \max\left[\frac{1}{0.047} \ln \frac{0.71(43.6)}{100(0.047)(5.37)};\ 0\right] \qquad \text{(VI-44)}$$

$$R_1^* = 4.3\%.$$

Thus, for these assumed conditions, approximately 4 percent of the wet-weather pollution should be controlled prior to initiating tertiary treatment. While these results are for one specific set of assumptions, they do suggest that it is highly desirable to do this tradeoff analysis before committing a community to tertiary treatment.

Potential Savings Due to Multipurpose Planning

The cost of wet-weather quality control can be reduced by integrating this purpose with dry-weather sewage treatment plants and/or storage facilities for stormwater quantity control. Therefore, it has been suggested that flow equalization be considered as an alternative to conventional design.[21] The storage volume needed for dry-weather flow equalization is estimated to be 10 to 20 percent of the average dry-weather flow.[22] Integration of wet-weather quality control with dry-weather control affords the opportunity for equalization of dry-weather flow since the wet-weather quality, in general, must be

accomplished through a combination of storage and treatment. Therefore, if a sewage treatment facility is designed on the basis of peak flow, equalization would result in some excess capacity at this facility. Utilization of this excess capacity can reduce the treatment capacity needed for wet-weather quality control.

Wet-weather quantity control can be accomplished through storage. Utilization of this storage for accomplishing wet-weather quality control can reduce the storage and treatment requirements for wet-weather quality control. A rough estimate of the potential savings by integrating these three purposes can be made as follows.

Let D denote actual sewage flow, mgd, and E' equal excess capacity through equalization, mgd. Then, using cost data presented by Hasan,[20]

Z_1' = cost of dry-weather control at a secondary plant, dollars per year

= amortized capital costs and annual O & M costs

$$= 118{,}000(D + E')^{0.77} + 55{,}000\ D^{0.83}. \qquad \text{(VI-45)}$$

Assuming D = 10 mgd, E' = 10 mgd and a per capita sewage flow of 100 gallons per day, computing Z_1' and dividing by area $A = D(\text{mgd})/10^{-4}PD_d$ gives

$$Z_1 = 15.6\ PD_d \qquad \text{(VI-46)}$$

where Z_1 = annual cost of dry-weather quality control, dollars per acre, and

PD_d = developed population density, persons per acre.

Also,

Z_2 = annual cost of wet-weather quality control, dollars per acre

$$= c_S S^* + c_T[T_1 + (T_2 - T_1)e^{-KS^*}], \qquad \text{(VI-47)}$$

where all terms are as defined earlier,

and

Z_3 = annual cost of wet-weather quantity control, dollars per acre,

$$= c_S V, \qquad \text{(VI-48)}$$

where V = storage volume required for wet-weather quantity control, inches,

= $CR'(i)$, with

CR' = runoff coefficient in developed state minus runoff coefficient in undeveloped state, and

i = 24-hour rainfall for design frequency, inches.

If dry-weather quality control and wet-weather quality control are integrated, then

Z_{12} = joint annual cost of two purposes, dollars per acre,

$$= 15.6 \; PD_d + c_E E + c_S S^* + c_T[\, T_1 - E + (T_2 - T_1)e^{-KS^*}] \qquad \text{(VI-49)}$$

where E = excess capacity per total area, inches per hour = $1.535 \times 10^{-4} PD_d$ assuming E' = 10 mgd generated using 100 gal/capita-day and converting from mgd to ac-in./hr; and

c_E = annual cost of treating E at dry-weather plant,

= \$1,960 per acre-inch/hour (assumed using \$3,000 per mgd from analysis of treatment costs).

If wet-weather quality control is integrated with wet-weather quantity control, then

Z_{23} = joint annual cost of two purposes, dollars per acre,

$$= c_S S_2^* + c_T[T_1 + (T_2 - T_1)e^{-KS^*_2}] \qquad \text{(VI-50)}$$

where $$S_2^* = \max\left(V, \frac{1}{K} \ln \left[\frac{c_T}{c_S} K(T_2 - T_1)\right], 0\right). \qquad \text{(VI-51)}$$

It is assumed that dry-weather control cannot be integrated with wet-weather quantity control. Therefore,

Z_{13} = joint annual cost of two purposes, dollars per acre,

$$= Z_1 + Z_3 \tag{VI-52}$$

$$= 15.6 \quad PD_d + c_S V. \tag{VI-53}$$

If all three purposes are integrated, then

$$Z_{123} = 15.6 \quad PD_d + c_E E + c_S S_2^* + c_T[\, T_1 - E \; + (T_2 - T_1)e^{-KS_2^*}]. \tag{VI-54}$$

To determine the potential savings in wet-weather quality control due to integrating this purpose with the other two purposes, it is first necessary to apportion the total cost among the three purposes. For cost allocation, the use of facility method, most commonly applied in the wastewater field, cannot be applied in this case because there is no single facility utilization parameter that is common to all three purposes. Hasan has demonstrated that the alternative cost method is appropriate for cost allocation.[20] Briefly, the alternative cost method assigns each purpose its separable cost plus a portion of the joint or non-separable cost on the basis of alternative cost. These costs are defined as follows:

SC_i = separable cost to purpose i

= cost of the total project minus cost of the project with purpose i excluded, and

NSC = non-separable cost

= total project cost minus sum of the separable costs to all purposes.

Then,

$$\phi_i = SC_i + \gamma_i(NSC) \tag{VI-55}$$

where ϕ_i = cost allocation to purpose i, and

γ_i = fraction of the non-separable cost assigned to i.

In light of the above discussion, the cost assigned to stormwater quality control, ϕ_2, (purpose 2) is as follows:

$$\phi_2 = SC_2 + \gamma_2(NSC) \tag{VI-56}$$

where $SC_2 = Z_{123} - Z_{13}$ (VI-57)

$$NSC = Z_{123} - \sum_{i=1}^{3} SC_i \quad \text{(VI-58)}$$

$$= Z_{12} + Z_{13} + Z_{23} - 2Z_{123}, \text{ and}$$

$$\gamma_2 = \frac{Z_2 - SC_2}{(Z_1 + Z_2 + Z_3) - \sum_{i=1}^{3} SC_i} \quad \text{(VI-59)}$$

$$= \frac{Z_2 - (Z_{123} - Z_{13})}{(Z_1 + Z_2 + Z_3) - [(Z_{123} - Z_{23}) + (Z_{123} - Z_{13}) + (Z_{123} - Z_{12})]}. \quad \text{(VI-60)}$$

Then, the potential savings are $Z_2 - \phi_2$.

The above procedure was used to derive Figure VI-15, Cost Allocation Factors for Five Cities, for the two year storm. The sensitivity analysis reflecting the variations in cost allocation relationship for various frequency storms for region III is presented in Figure VI-16, Effect of Design Storm and Number of Purposes on Cost Allocation Factor for Various Levels of Control. Based on the results in Figure VI-15, the following cost allocation proportions can be used for all urbanized areas.

% Pollutant Control	Cost Allocation Factor, ϕ_2/Z_2
25	0.46
50	0.50
75	0.70
85	0.80

Potential Savings Using Best Management Practices

In addition to using storage-treatment devices to control wet-weather pollution, other options, popularly called best management practices (BMP's), are available. In a related study, Heaney and Nix evaluated the savings in control costs if BMP's are used in conjunction with storage-treatment.[24] The procedure was applied to Anytown, U.S.A., a hypothetical city of one million people whose characteristics were determined based on average values

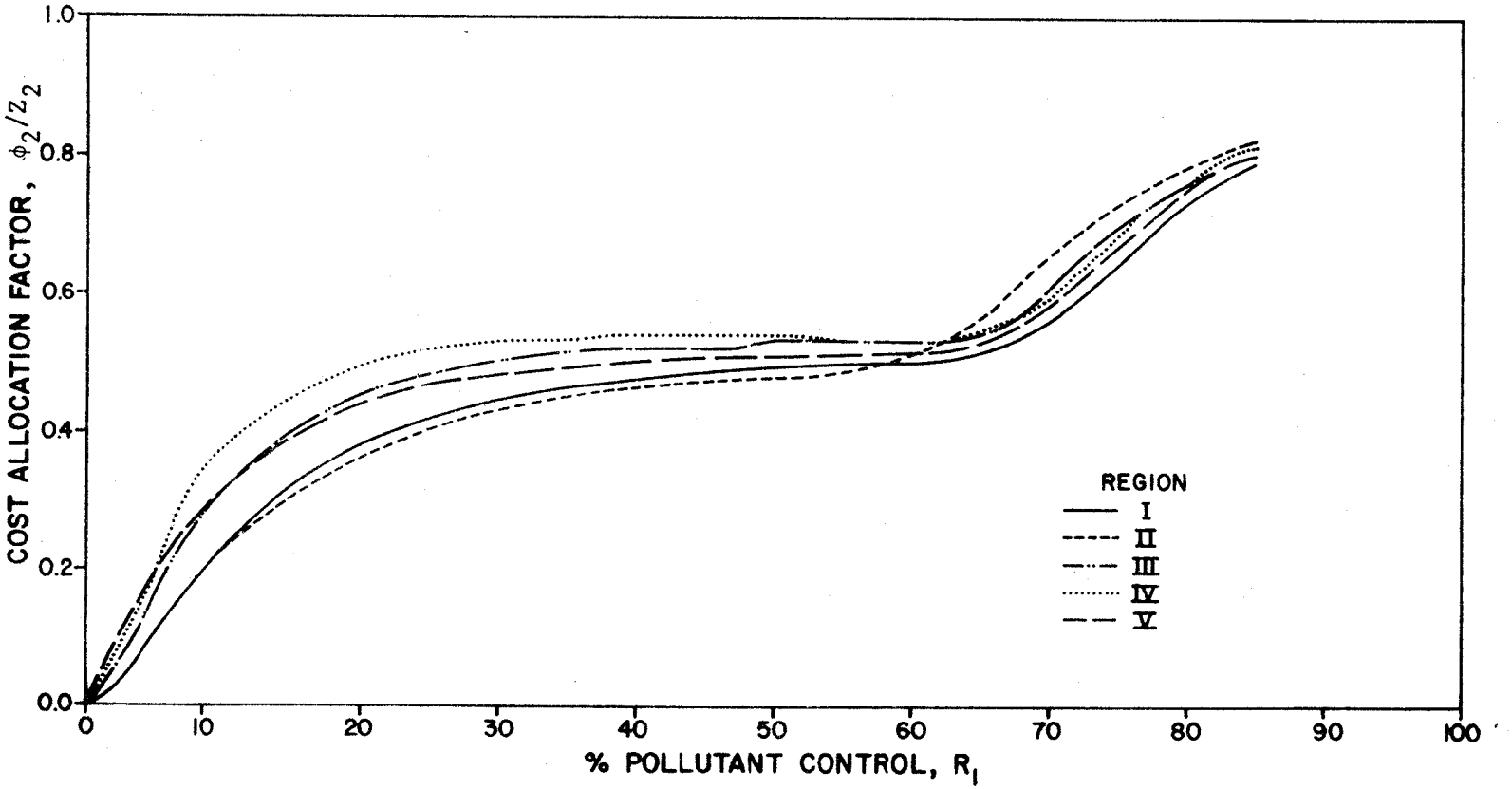

Figure VI-15. Cost Allocation Factors for Five Cities

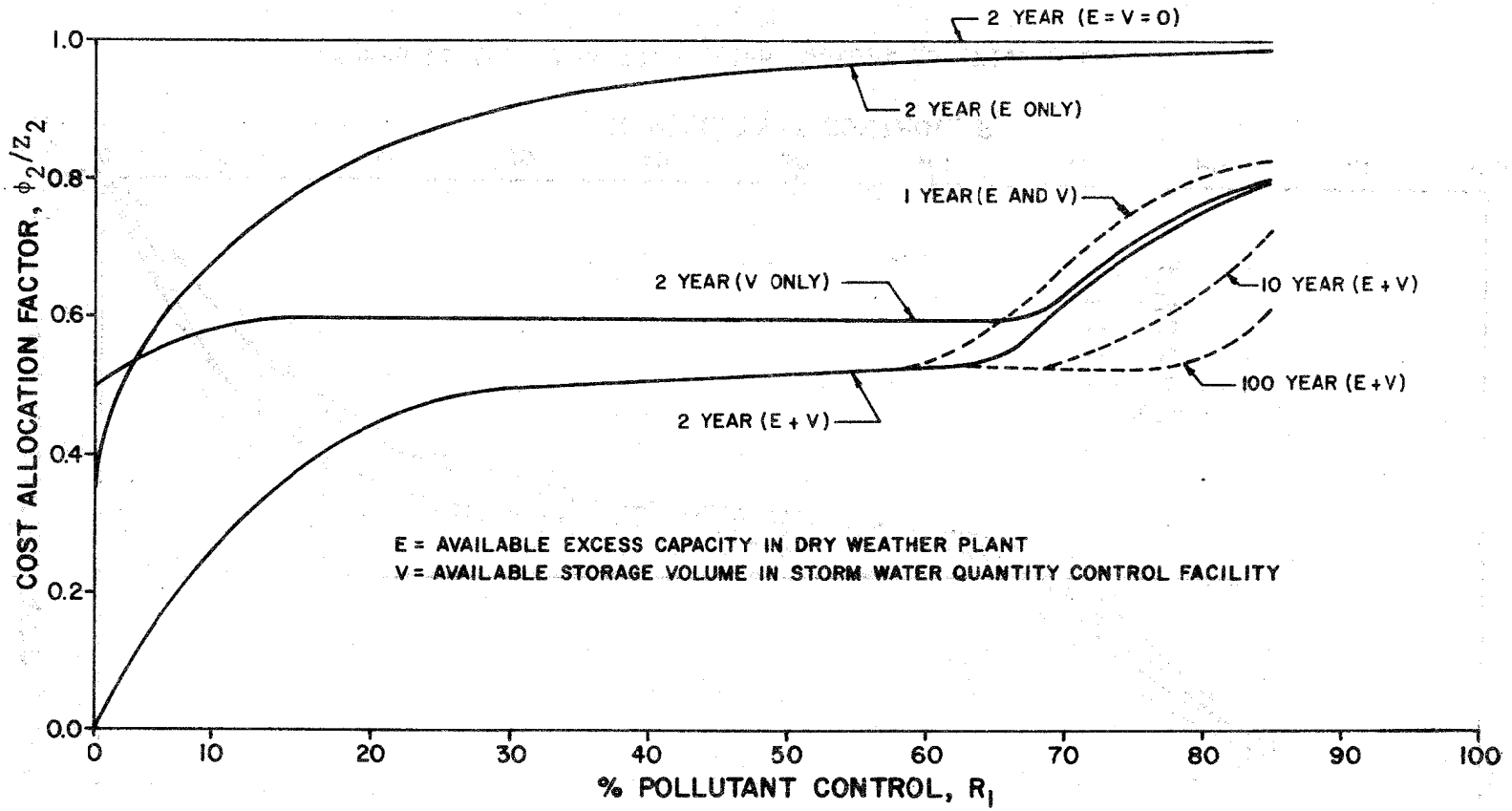

Figure VI-16. Effect of Design Storm and Number of Purposes on Cost Allocation Factor for Various Levels of Control

derived in this study. The results, shown in Table VI-20, Comparison of Annual Cost of Optimal Control Strategy for Anytown, U.S.A. Using Storage-Treatment Alone and in Combination with Best Management Practices, indicate significant savings could be realized by using BMP's in conjunction with storage-treatment devices. These results can be incorporated into the final assessment by multiplying the storage-treatment costs by the % savings shown below.

% Pollutant Control	% Savings Using BMP's
25	54
50	37
75	37
85	39

SUMMARY

The purpose of this assessment is to evaluate the cost of controlling varying levels of wet-weather pollution, emanating from the 149 x 10^6 people living in urban areas in the United States. Reliable procedures for assessing stormwater pollution are not yet available. Thus, a considerable amount of developmental effort was expended in devising such procedures. Major results are presented, by item, in the next paragraphs.

1. Total Single Purpose Control Costs

Relatively detailed studies in five cities provided the basis for evaluating storage-treatment alternatives for wet-weather control. One year of hourly data was simulated to predict the performance of various storage-treatment configurations. These results were put in analytical form to expedite extrapolation to the other 243 urbanized areas and other urban areas. These results are combined with data on the cost of storage and treatment to derive the optimal mix of storage and treatment to use to obtain a given level of control. The final result is shown in Figure VI-17, Storm Water Pollution Control Costs for the United States. A striking feature of curve A is that it bends upward (convex) indicating increasing incremental costs (particularly at higher levels of control). The primary reason the curve has this shape is due to the disproportionately larger amounts of storage and treatment required to control the larger storms.

Table VI-20. Comparison of Annual Cost of Optimal Control Strategy for Anytown, U.S.A. Using Storage-Treatment Alone and in Combination with Best Management Practices

Type of Sewered Area	% BOD Control	Annual Cost ($ X 10^6/yr)		% Savings Over S-T Only
		Storage-Treatment (S-T) Only	Storage-Treatment and BMP's	
Combined	25	0.94	0.42	55
	50	2.46	1.49	39
	75	7.28	4.03	45
	85	9.22	7.03	24
Storm	25	0.60	0.25	58
	50	1.56	1.00	36
	75	4.64	2.62	44
	85	13.19	5.17	61
Unsewered	25	0.68	0.35	49
	50	1.79	1.17	35
	75	3.50	3.12	11
	85	3.50	3.50	0
Total	25	2.22	1.02	54
	50	5.81	3.66	37
	75	15.42	9.77	37
	85	25.91	15.70	39

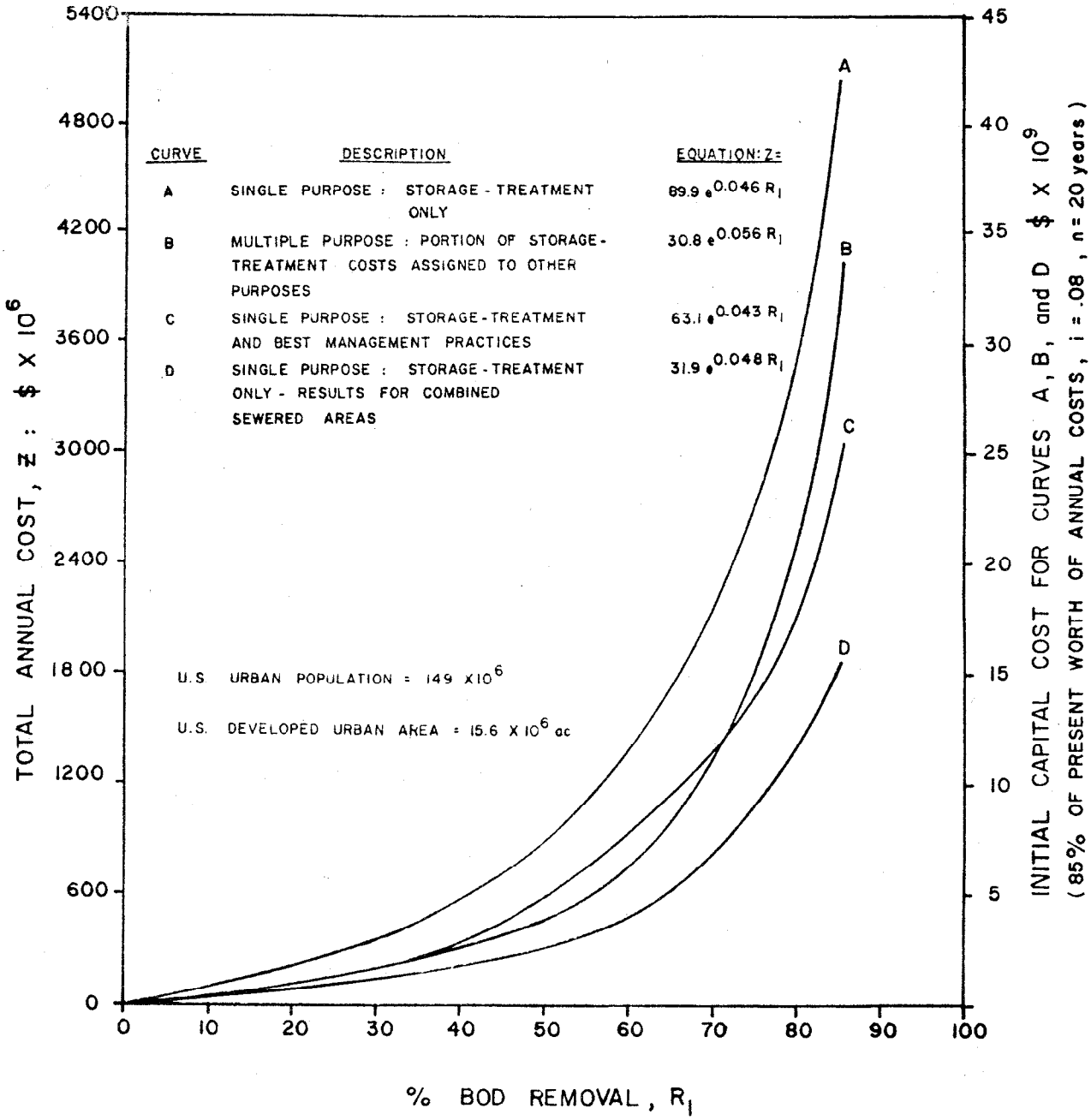

Figure VI-17. Storm Water Pollution Control Costs for the United States

2. Total Multiple Purpose Control Costs

Significant savings can be realized if one integrates dry and wet-weather treatment and storage for quality as well as quantity control. Curve B in Figure VI-17 indicates the cost of stormwater quality control in an integrated system. This result suggests that the potential savings are significant enough to warrant further study in evaluating stormwater systems.

3. Total Costs of Storage-Treatment and Best Management Practices

Potentially significant savings can be achieved by including best management practices (BMP's) in the analysis (curve C). Street sweeping in areas with relatively high pollutant loading rates and sewer flushing where heavy deposition occurs in combined sewers appear to be especially promising as options to storage-treatment. Furthermore, a significant portion of the costs of BMP's could be allocated to other purposes.

4. Tertiary Treatment vs Stormwater Quality Management

A comparison of the marginal costs of tertiary treatment of sewage for further BOD control with initiating control of wet-weather quality indicates that one should initiate some level of wet-weather quality control prior to using tertiary treatment. Of course, a different result would occur if nutrient control is used instead of BOD control. Nevertheless, the relatively low marginal costs of wet-weather control at low levels of control indicate that it should be given serious consideration as an alternative to tertiary treatment.

5. Comparison of Control Costs with Other Studies

Previous studies have indicated that stormwater control is quite expensive. Table VI-21, Control Costs Reported in Other Studies indicates that the 1974 Needs Survey estimated total control costs as $266 billion whereas the more recent National Commission on Water Quality estimate is $278.6 x 10^9.[25, 26] This assessment indicates initial capital costs ranging from 2.5 billion for 25 percent control to 41.9 billion for 85 percent pollutant control, a small fraction of the above estimates. Two reasons why the estimates vary by such a large amount are discussed below.

Table VI-21. CONTROL COSTS REPORTED IN OTHER STUDIES

Study	Cost Item	Capital Cost: $ x 10^9
1974 Needs Survey	Combined Sewers[a]	31.1
	Storm[b] Sewers	235.0
	Total	266.1
National Commission on Water Quality[c]	Combined Sewers[d,e]	79.6
	Storm Sewers[d,f]	199.0
	Total	278.6

[a]States developed estimates using various assumptions regarding design storm, unit costs, etc.
[b]Estimate includes collection sewer costs.
[c]Source: Staff Report to the National Commission on Water Quality, Washington, D.C., U.S.G.P.O., 1976.
[d]Used 2 year, 1 hour design storm.
[e]Cost based on disinfection and in-line and off-line storage with primary treatment in effluent limited receiving waters and secondary treatment in water quality limited receiving waters.
[f]Cost based on removal of sediment, bacteria, and associated pollutants. Includes stormwater collection system costs equal to $84 x 10^9.

A. Collection System Costs -

The NCWQ estimate includes $84 x 10^9 for constructing storm sewers. This study did not view storm sewers as chargeable to pollution control.

B. Choice of a Design Storm -

The NCWQ studies used control of the two year, one hour storm as the basis for their mean estimate of control costs. The concept of a design storm was not used because it was felt that a continuous characterization in terms of percent of the runoff which could be treated (or events per year) was more appropriate since no accepted design event condition exists which also specifies a design antecedent dry-weather period. Also, sizing storm water quality control units to treat runoff from storm intensities associated with less frequent events, e.g., two year - one hour storm, requires relatively large treatment and storage capacities.

Using 25 years of hourly rainfall data for San Francisco, CA, and Atlanta, GA, the relationship between percent of precipitation "treated" and the design storm was determined. Figure VI-18, Percent of Total Precipitation Volume vs Rainfall Intensity - Atlanta, GA (1948-1972), indicates the percentage of total volume less than or equal to a given value. For example, approximately 65 percent of the total precipitation volume occurs from rainfall rates of 0.30 inch per hour (0.76 cm/hour) or less. Thus, a treatment unit of this capacity could treat the entire precipitation during those hours. It could also treat a portion of the remaining more intense storms. The additional volume treated equals the number of hours during which the precipitation was greater than the indicated treatment rate times the treatment. From Figure VI-19, Percent of Total Precipitation Hours vs Rainfall Intensity - Atlanta, GA (1948-1972), approximately five percent of the rainfall hours exceed 0.30 inch per hour (0.76 cm/hour). The average precipitation in Atlanta is 47.1 inches per year (120 cm/year) occurring during an average

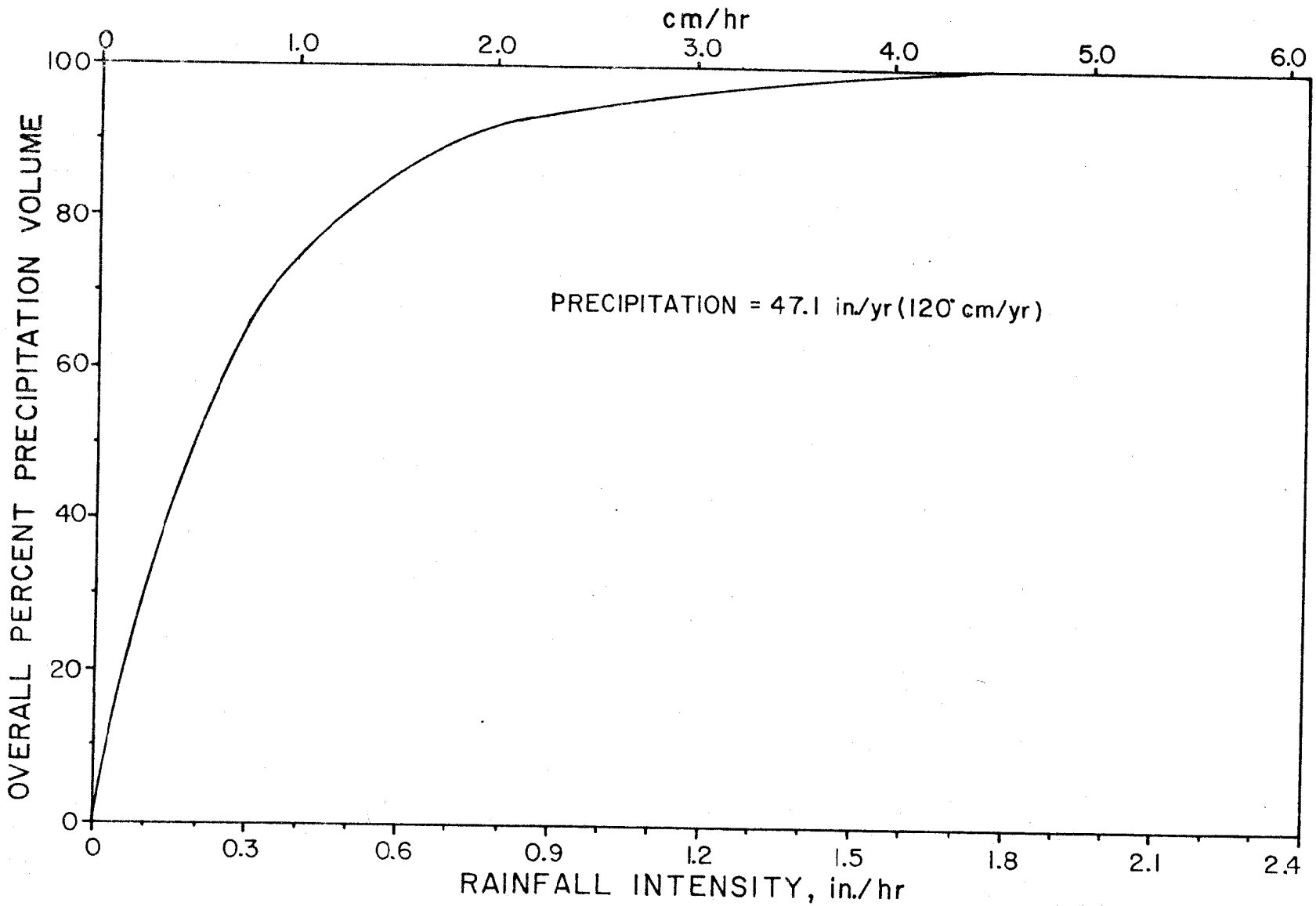

Figure VI-18. Percent of Total Precipitation Volume vs Rainfall Intensity - Atlanta, GA (1948-1972)

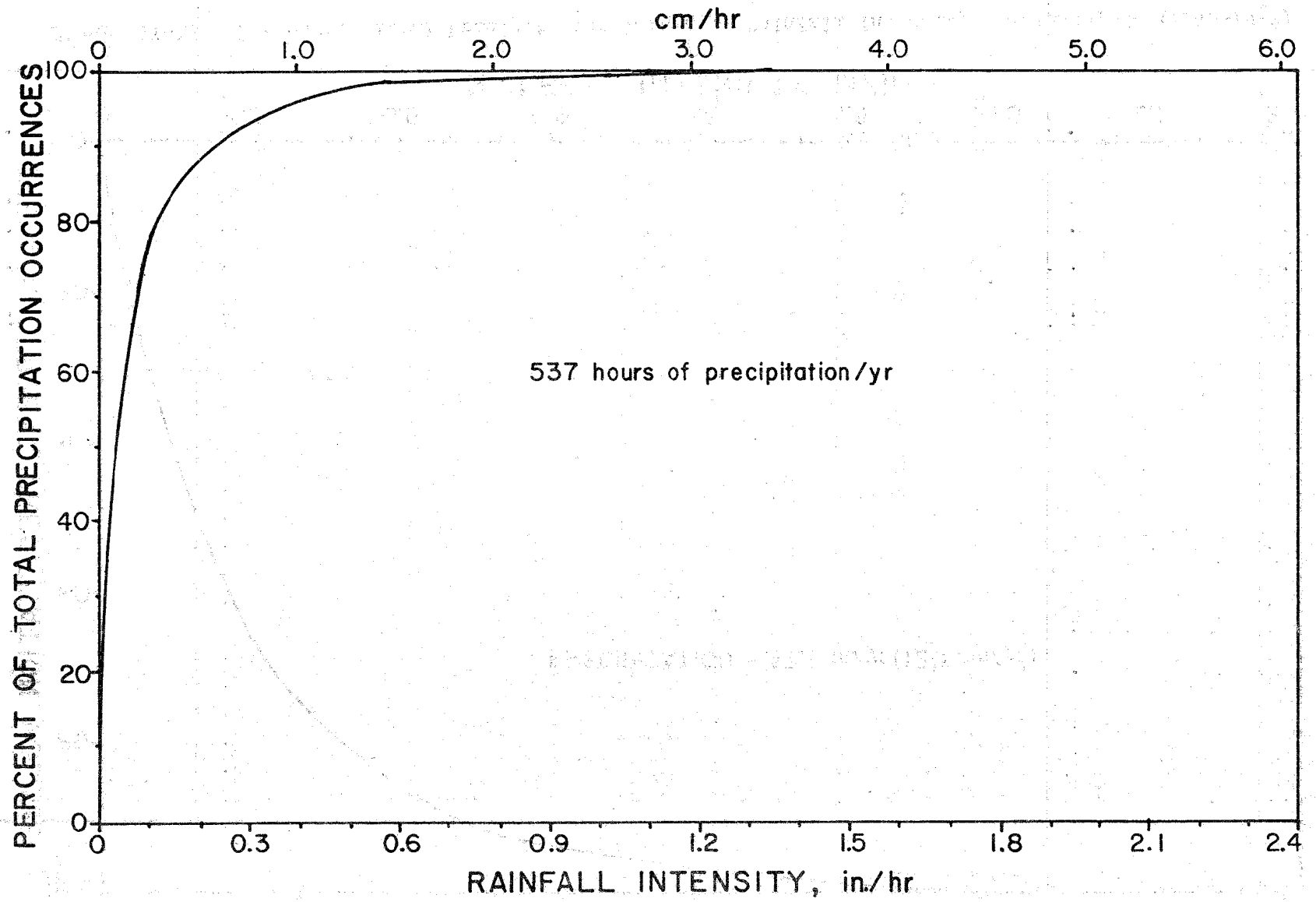

Figure VI-19. Percent of Total Precipitation Hours vs Rainfall Intensity - Atlanta, GA (1948-1972)

of 537 hours per year. Thus, the additional percent volume treated during intensities greater than 0.30 inch per hour (0.76 cm/hour) is 100[0.05(0.30 in./hr)(537 hr/yr)/47.1 in./yr], or 17.1 percent.

Thus, the total percent of volume treated with a unit capable of handling precipitation of 0.30 inch per hour (0.76 cm/hour) is about 65 + 17 = 82 percent. In general, to find percent treated use:

$$PT = F_B + (100 - F_C)(I_T)(N_{TOTAL})/P \qquad \text{(VI-61)}$$

where PT = annual overall percent of precipitation treated,

I_R = rainfall intensity, in./hr,

I_T = design treatment rate, in./hr,

F_B = percent volume for all $I_R \leq I_T$,

F_C = percent of total rainfall hours with $I_R \leq I_T$,

N_{TOTAL} = total number of rainfall hours per year, and

P = average annual precipitation, in./yr.

Note that the result is conservative (the estimate of PT is slightly low) since the frequency analysis has been performed using precipitation volumes and hours rather than runoff volumes and hours. This was done to insure comparison with the NCWQ study in which only precipitation frequencies are reported.

The general results for Atlanta, GA, are shown in Figure VI-20, Overall Percent Precipitation Control vs Rainfall Intensity - Atlanta, GA (1948-1972). Also shown on Figure VI-20 are the intensities for storms ranging in frequency from two weeks to 25 years. Treating at the intensity equal to the two week storm would process over 80 percent of the rainfall volume.

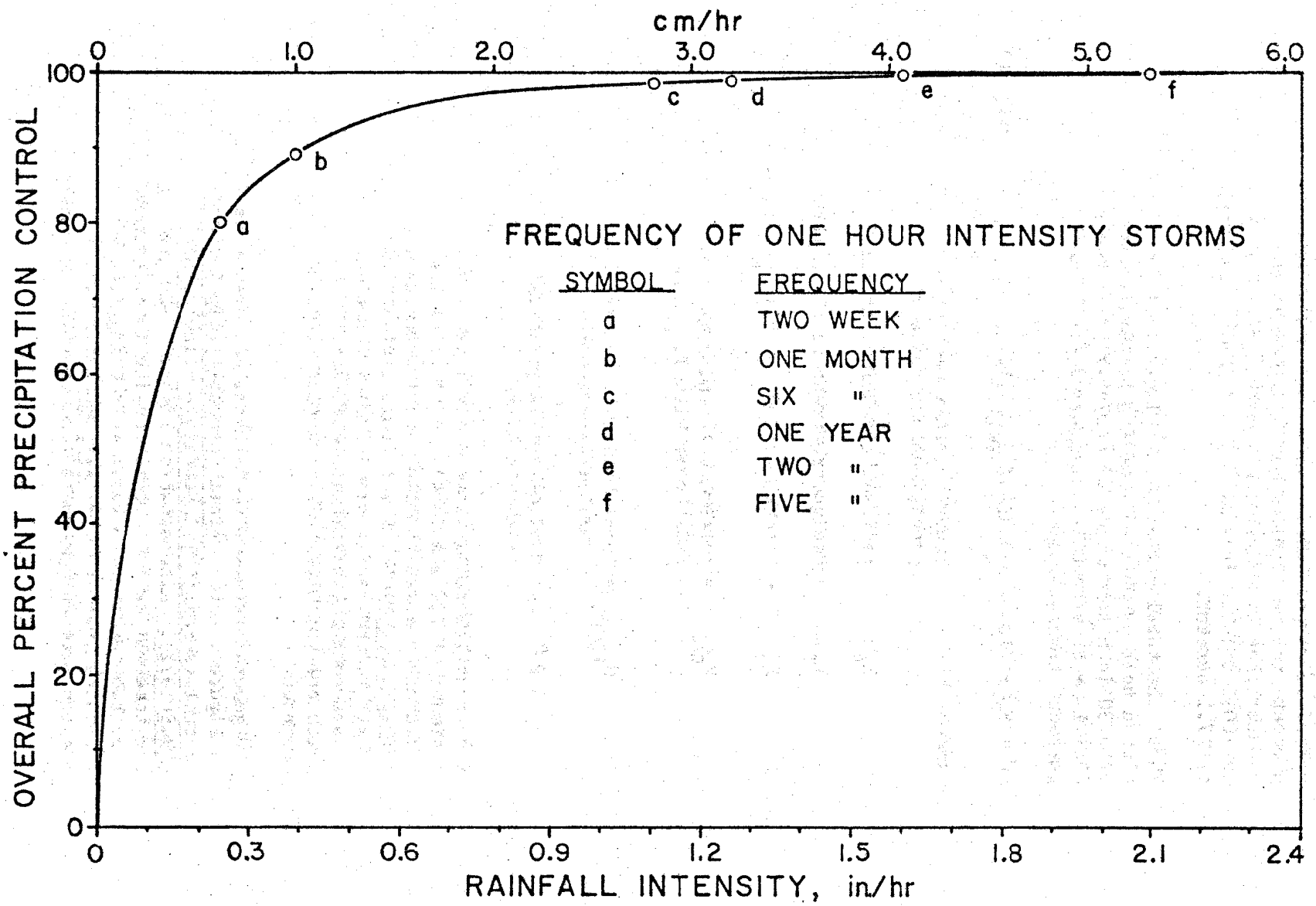

Figure VI-20. Overall Percent Precipitation Control vs Rainfall Intensity - Atlanta, GA (1948-1972)

Frequencies larger than a month or two approach total capture of the volume. These results indicate that for the NCWQ study, virtually all of the volume would be processed with a control unit operating at an intensity associated with the two year - one hour storm. However, one could control nearly as much precipitation by using a much smaller size control unit. Alternatively, the marginal gain from using these much larger units is quite small. For comparative results, the same three figures were generated using 25 years of hourly data for San Francisco. The results are presented in Figure VI-21, Percent of Total Precipitation Volume vs Rainfall Intensity - San Francisco, CA (1948-1972), Figure VI-22, Percent of Total Precipitation Hours vs Rainfall Intensity - San Francisco, CA (1948-1972), and Figure VI-23, Overall Percent Precipitation Control vs Rainfall Intensity - San Francisco, CA (1948-1972).

Only the future will tell which, if any, of the above cost estimating procedures will provide the most accurate estimate of national control costs. Within the severe data gathering limitations imposed by a national estimate, this study has attempted to make the results as site specific as possible. Improved estimates for a specified city can be obtained using local data. In particular topographic information and knowledge of the number of outfalls permits inclusion of pumping costs and analysis of the optimal combination of control units and interceptor sewers. The interested reader can use a more compact summary of this assessment procedure presented in a report by Heaney, Huber, and Nix to obtain a preliminary estimate for his city or cities.[27]

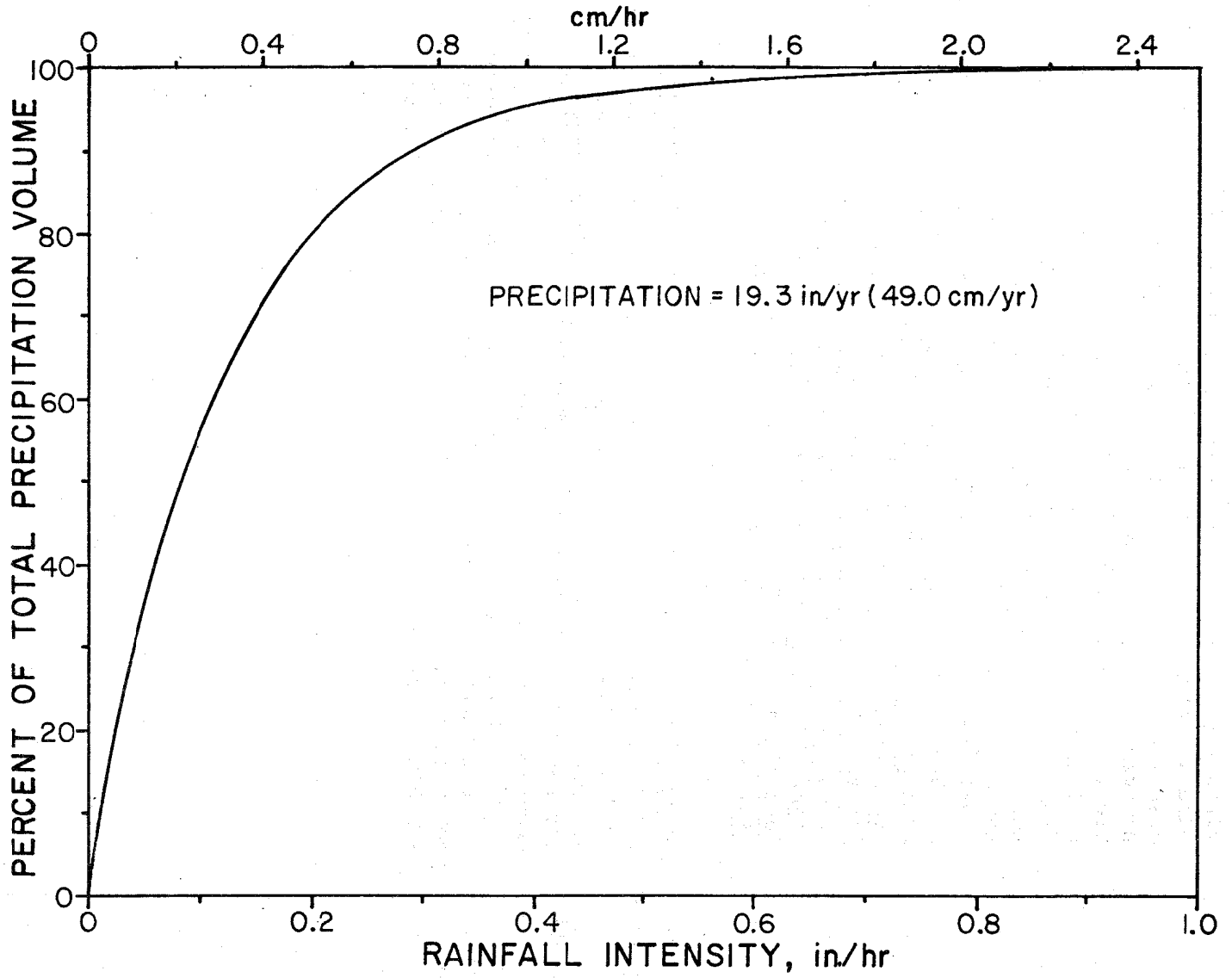

Figure VI-21. Percent of Total Precipitation Volume vs Rainfall Intensity - San Francisco, CA (1948-1972)

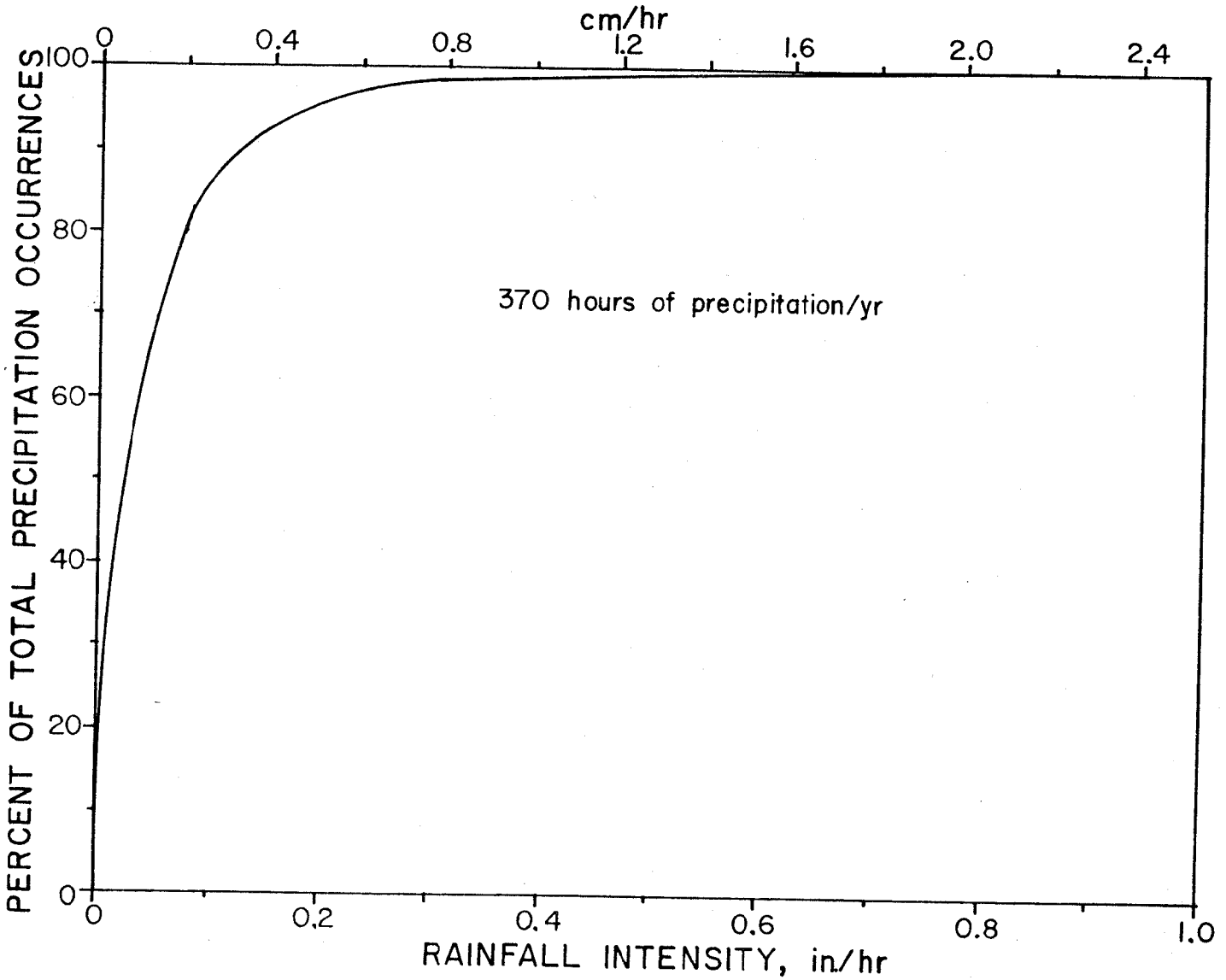

Figure VI-22. Percent of Total Precipitation Hours vs Rainfall Intensity - San Francisco, CA (1948-1972)

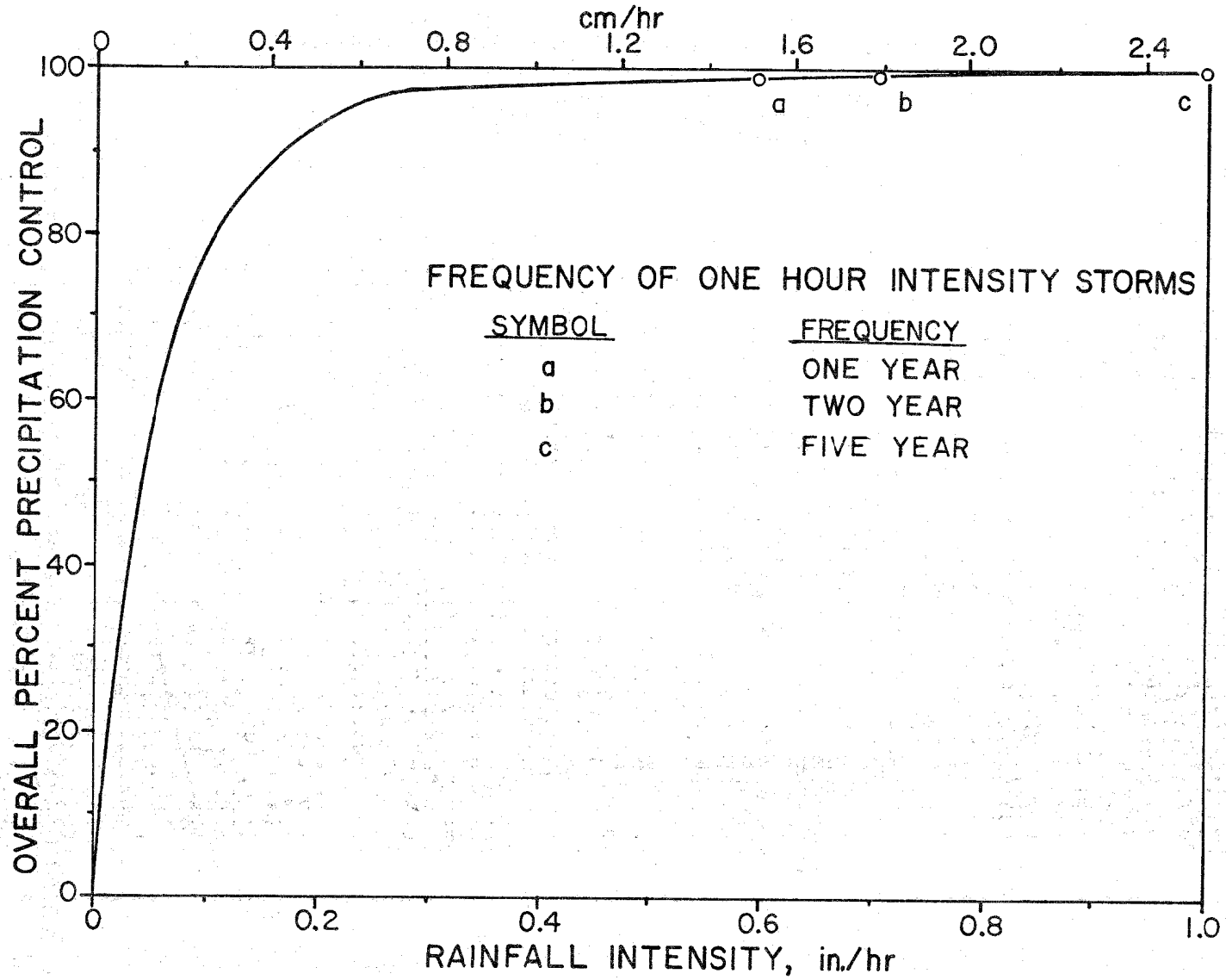

Figure VI-23. Overall Percent Precipitation Control vs Rainfall Intensity - San Francisco, CA (1948-1972)

ABBREVIATIONS AND SYMBOLS

a	Coefficient, inches per hour
A	Catchment or sewerage area, acres
A_1	Combined sewered area, acres
A_2	Storm sewered area, acres
A_3	Unsewered area, acres
A_{tot}	Total developed area, acres
AR	Annual runoff, inches per year
b	Coefficient, inches per hour
BOD	Biochemical oxygen demand
BOD_5	Five-day biochemical oxygen demand
β	Coefficient, percent^{-1}
c	Coefficient, percent R^{-1}
c_E	Unit treatment cost for excess capacity, annual dollars per acre-inch/hour
c_{tert}	Unit incremental cost of tertiary treatment, annual dollars per pound
c_S	Unit cost of storage, annual dollars per acre-inch
c_T	Unit cost of treatment, annual dollars per acre-inch/hour
C	Unamortized capital cost, dollars, also annual unit costs, dollars per acre
C_{tert}	Total annual incremental cost of tertiary treatment plant, dollars
CR	Gross runoff coefficient
CR′	Net runoff coefficient = developed runoff coefficient minus undeveloped runoff coefficient
d	Coefficient, inch^{-1}

D	Actual sewage flow, mgd
E'	Excess capacity at sewage treatment plant, mgd
E	Excess capacity at sewage treatment plant per total area, inches per hour
ENR	Engineering News Record Cost Index
η	Treatment plant efficiency
f	Coefficient, percent R^{-1}
$f(R_1;S,T)$	Production function relating percent pollutant control (R_1) to storage (S) and treatment (T)
F_B	Percent of annual precipitation volume for which $I_R \leq I_T$
F_C	Percent of total annual precipitation hours for which $I_R \leq I_T$
g	Coefficient
γ_i	Fraction of non-separable cost assigned to purpose i
h	Coefficient
i	24-hour rainfall for design frequency, inches
I	Percent imperviousness
I_R	Rainfall intensity, inches per hour
I_T	Design treatment rate, inches per hour
k	Coefficient
K	Coefficient
l	Coefficient
L	Pipe length
m	Urban land use
mg	Million gallons
mgd	Million gallons per day
M	Annual pollutant loading, pounds per acre-year

$\overline{M}$	Average annual pollutant loading, pounds per acre-year
MC	Marginal cost of pollutant removal, annual dollars per pound
MRS_{ST}	Marginal rate of substitution of storage for treatment
NSC	Non-separable cost, annual dollars per acre
N_{TOTAL}	Total number of precipitation hours per year
OE	Number of overflow events per year
p	Coefficient
P	Annual precipitation, inches per year
PD	Gross population density, persons per acre
PD_d	Population density in developed portion of urban area, persons per acre
PT	Annual overall percent of precipitation control (treated)
ϕ_i	Annual cost assigned to purpose i, dollars per year
q	Coefficient
R	Percent runoff control = percent of annual runoff volume passing through treatment unit
R_1	Percent pollutant control (removal)
$\overline{R}_1$	Maximum percent pollutant control (removal)
R_1^*	Optimal percent pollutant control prior to using tertiary treatment
ρ	Fraction of total wet-weather pollution load controlled (removed)
s	Coefficient
S	Storage volume, inches
S*	Optimal storage volume for wet-weather pollution control, inches
S_2^*	Maximum of S* or V, inches
SC_i	Separable cost assigned to purpose i, annual dollars per acre
SS	Suspended solids

T	Treatment rate, inches per hour
T^*	Optimal treatment rate for wet-weather pollution control, inches per hour
T_1	Treatment rate at which isoquant is parallel to the ordinate, inches per hour
T_2	Treatment rate at which isoquant intersects the abscissa, inches per hour
TAC	Total annual costs, dollars per year
v	Coefficient
V	Volume of storage required for wet-weather quantity control, inches
w	Pollutant removal, pounds per acre-year
w_i	Pollutant removal from type of sewered area i, pounds per acre-year
w_i^*	Optimal pollutant removal from type of sewered area i, pounds per acre-year
w^*	Optimal annual pounds per acre of wet-weather pollutants to control (remove) prior to using tertiary treatment, pounds per acre-year
WP	Total annual wet-weather pollution load from developed urbanized area, pounds per year
y	Coefficient
z	Coefficient
Z	Total annual cost, dollars per acre
Z^*	Optimal total annual cost, dollars per acre
Z_p	Annual cost for primary control unit, dollars per acre
Z_s	Annual cost for secondary control unit, dollars per acre
Z_1'	Annual cost of dry-weather quality control, dollars
Z_1	Annual cost of dry-weather quality control, dollars per acre
Z_2	Annual cost of wet-weather quality control, dollars per acre
Z_3	Annual cost of wet-weather quantity control, dollars per acre

Z_{12}	Annual cost of dry-weather quality and wet-weather quality control, dollars per acre
Z_{13}	Annual cost of dry-weather quality control and wet-weather quantity control, dollars per acre
Z_{23}	Annual cost of wet-weather quantity and quality control, dollars per acre
Z_{123}	Annual cost of dry-weather quality, wet-weather quality, and wet-weather quantity control, dollars per acre

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