DRAFT MEMORANDUM

TO: File 863CCQ01

FROM: Greg Roush

DATE: September 6, 1989

RE: Surface Water Hydrology

This memorandum outlines the development of the procedure used in the Cherry Creek Master plan to determine runoff quantity and phosphorous loads for sub-basins above Cherry Creek Reservoir.

I. DRURP Study

Rainfall-Runoff relationships were developed during the 3-year Denver Regional Urban Runoff Program (DRURP) study [1].

A. The DRURP study area consisted of nine (9) urban basins between the USGS South Platte River gaging stations at Littleton and 50th Avenue. (Exhibit No. 1).

B. The study involved monitoring runoff and various water quality constituents for a 2-year period.

C. A rainfall, percent effective imperviousness (PEI), runoff relationship was developed and is attached as Exhibit No. 2.

D. The rainfall, PEI, and phosphorous load relationship is shown in Exhibit No. 3.

E. Limitations on the use of Exhibits 2 and 3 are listed in Exhibit No. 4.

II. Application to the Cherry Creek Basin

Data and models derived as a part of the DRURP study were used in the Cherry Creek and Chatfield Clean Lakes Study to predict total phosphorous loading and runoff by land use type (i.e. Exhibits 2 and 3) [2]. Adjustments to the models were made to calibrate it to the upper Cherry Creek basin.

A. A storm size distribution and frequency analysis was conducted to provide needed rainfall information. The study assumed 1969 through 1982 daily precipitation records at Cherry Creek Dam were representative of the entire reservoir tributary area. Exhibit No. 5 shows the results of the analysis.

B. Annual runoff for each sub-basin is estimated as follows:

1. For each storm-size in Exhibit No. 5, the amount of runoff is determined for various land uses.

2. The frequency of each storm-size is then multiplied times the runoff amount in step 1 for each land use type.

3. The runoff for each storm-size for a particular land use is summed to get an annual unit runoff amount.

4. The number acres in each land use is multiplied times the annual unit runoff.

5. The annual runoff for each type of land use in a sub-basin is then summed to get the annual runoff from a sub-basin.

An example from the DRURP study is given as Exhibit No. 6.

C. Scaling factors were applied to the DRURP data and models for calibration to the Clean Lake study Basins (Cherry Creek and Chatfield). The scaling factors assess how much of the load and runoff will be conveyed out of the sub-basin to the reservoir indirectly accounting for factors such as basin slope, channel efficiency, soil type, etc.

D. Scaling factors were calculated by sub-basin individually for runoff and phosphorous loading by comparing predicted to measured 1982 loads. (Exhibit No. 7).

E. The average scaling factors by sub-basin were correlated against sub-basin PEI, to allow prediction of scaling factors for other basins, and future conditions. The resulting equations are shown on Exhibit No. 8.

F. Exhibit No. 9 shows the current (1982) predicted total phosphorous load and annual runoff volume. Exhibit No. 10 shows the projected loadings and annual runoff to the year 2010.

III. Questions and Concerns

1. The original study from which the models were developed were based on small urban basins, and the models were not to be used on large undeveloped basins (greater than 1,000 acres).

2. Rainfall duration and intensity are not considered, only total depth for any time period separated by 12 hours of no precipitation.

3. Daily rainfall records were analyzed. UDFCD is currently investigating hourly records for storm-size distribution and frequency.

4. Ben Urbonas at UDFCD stated that storms in Urban areas have to total more than .08 to .15 inches in rainfall depth for runoff to occur. Use of the two lower classifications (.02-.09 and .1 to .19 of precipitation, Exhibit No. 5) may overestimate loads and runoff.

5. The accuracy of runoff prediction decreases for basins having less than 10 percent PEI. According to a report by CDM the projected Cherry Creek Basin full build-out PEI is only 6.1 percent.

6. Calibration of the models to the Cherry Creek Basin required scaling factors that changed predicted results by orders of magnitude (see Exhibit No. 7) in either direction depending on the sub-basin.

7. The scaling factors were correlated to PEI for the Cherry Creek basin with satisfactory results. However, the Chatfield data could not be successfully correlated to PEI. Was the Cherry Creek relationship a function of limited data?

8. It was assumed that the Cherry Creek Dam precipitation gage was representative of the reservoirs tributary area. Annual precipitation at Cherry Creek Dam averaged 18.95 inches for the period 1969-1982. Cherry Creek Dam lies within the preferred South Suburban thunder storm track as identified in Figure 21 of Ref [1].

   Average annual precipitation of the Parker 6E weather station is 13.4 inches for the period 1941-70. Hourly records are also available at this station.

9. There are 246,000 acres or 384 square miles in the basin. The annual runoff volume predicted for current conditions is 685 AF (1982) and 870 to 1,860 AF for 1985 (Exhibits 9 and 10).

   Historic gaged flows of Cherry Creek near Melvin (336 mi^2), located at Arapahoe Road, average 8,500 AF per year for the period 1941-1969, and 1985. Cherry Creek near Franktown (169 mi^2) records show an average of 6,800 AF for the period 1941-1986.

10. In the DRURP study it is stated that extreme caution is to be used for storms greater than 1.5 inches total depth to determine runoff amount. Would regular peak discharge methods be applicable?

11. Can the data collected in 1986, 1987, and 1988 be useful in updating scaling factors, and other relationships? (currently, reviewing these documents.)

References:

[1] DRCOG, Sept. 1983, Urban Runoff Quality in the Denver Region, p. 156.

[2] DRCOG, June 1983, Clear Lakes Study Technical Memorandum No. 6, p. 72.

[3] DRCOG, April 1984, Cherry Creek Reservoir Clean Lakes Study, p. 165.

[4] DRCOG, Sept. 1985, Cherry Creek Basin Water Quality Management Master Plan Technical Report, p. 57.

[5] DRCOG, Sept. 1985, Cherry Creek Basin Water Quality Management Master Plan, p. 48.

[6] Richard P. Arber Assoc., Nov. 1986, Draft Cherry Creek Basin Authority Annual Report 1986, p. 46.

[7] In-Situ, Inc., Nov. 1987, Cherry Creek Basin Authority 1987 Annual Report, p. 41.

[8] In-Situ, Inc., Dec. 1988, Cherry Creek Basin Authority 1988 Annual Report Summary, p. 31.

Exhibit No. 1

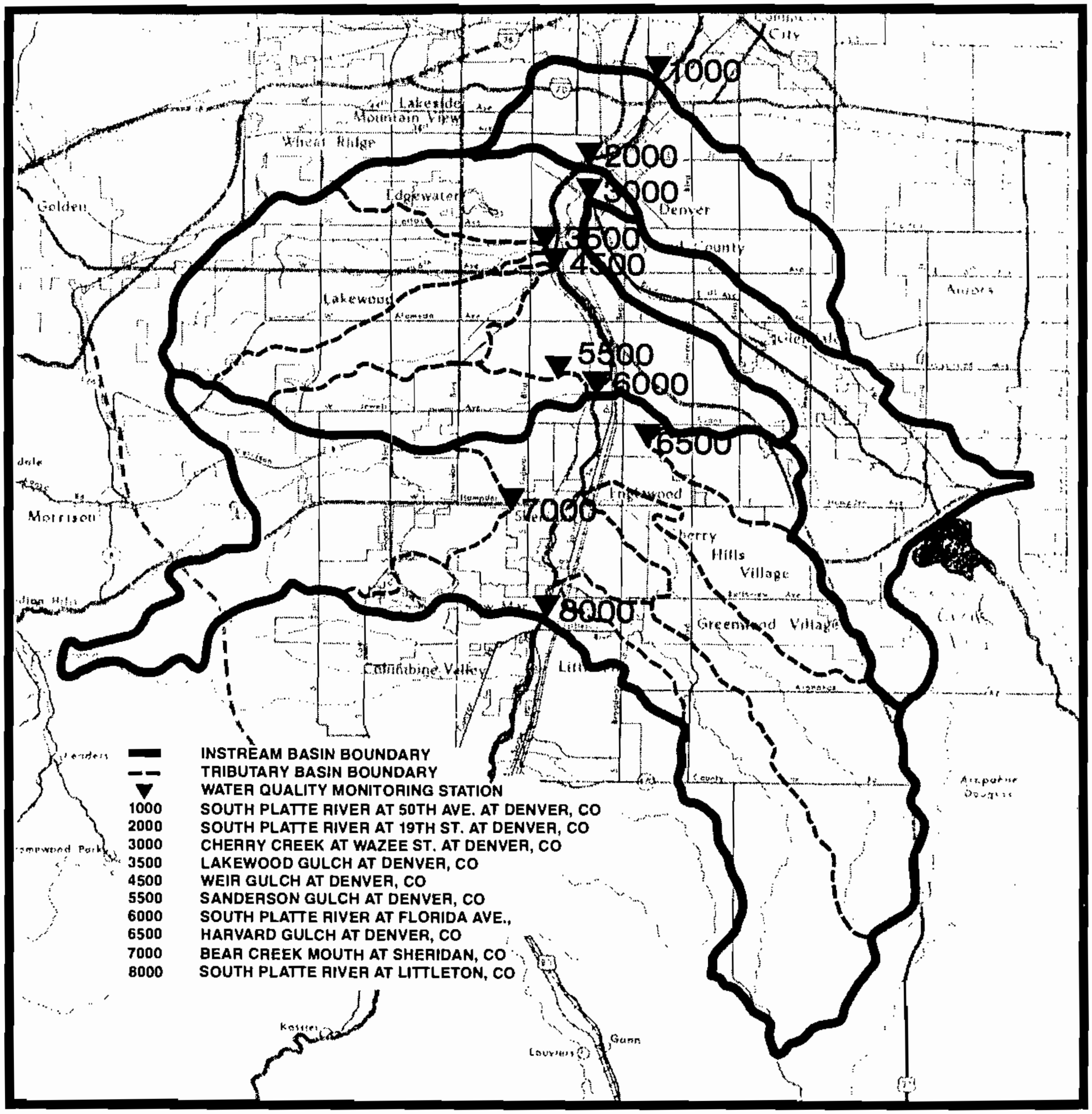

FIGURE 1. MAP OF STUDY AREA SHOWING INSTREAM AND TRIBUTARY BASINS.

Exhibit No 2

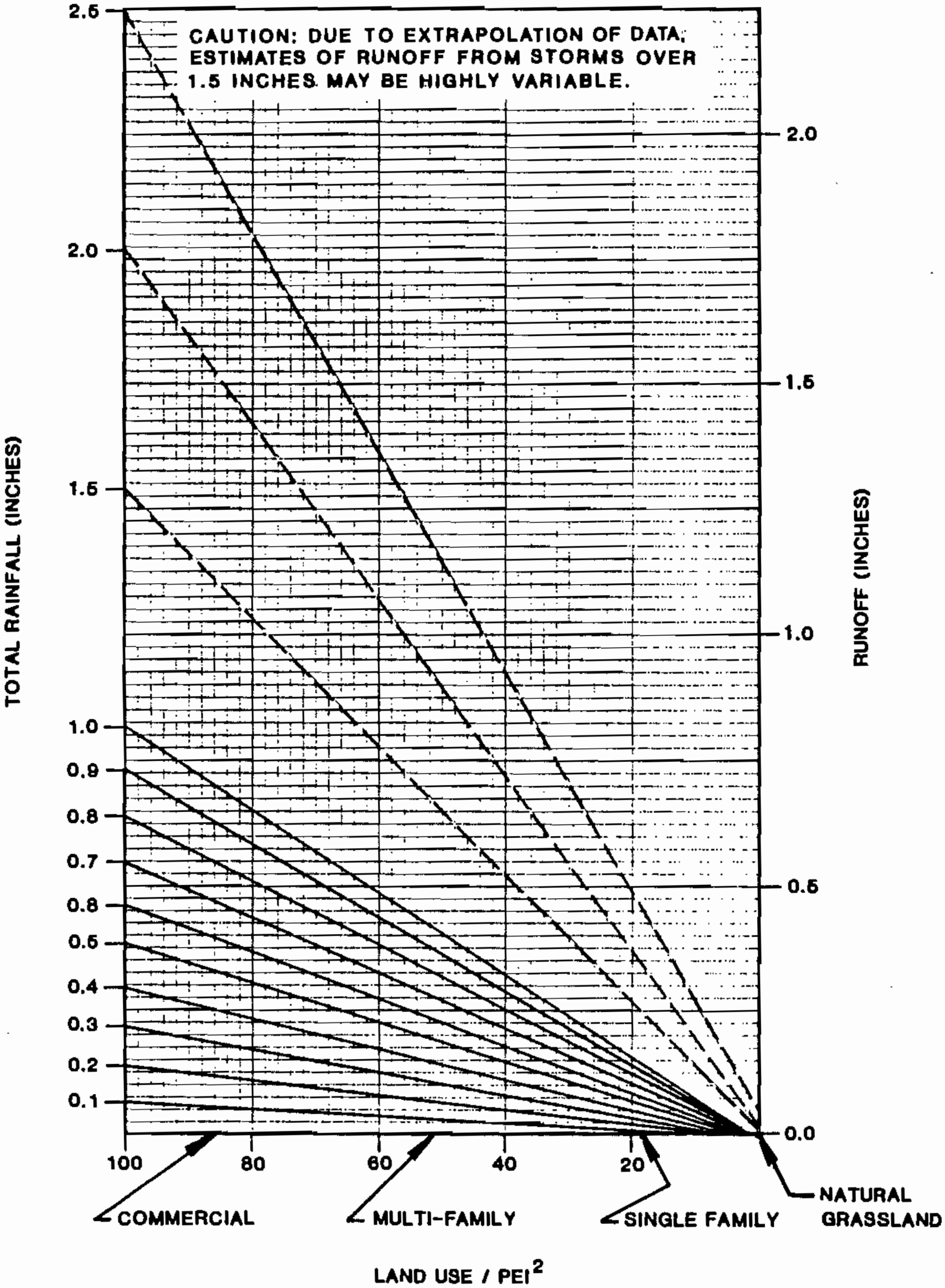

FIGURE 11. NOMOGRAPH FOR ESTIMATING RAINSTORM RUNOFF.[1]

[1] SEE TEXT FOR DISCUSSION OF USES, LIMITATIONS.

[2] LAND USES CORRESPOND TO REGIONAL AVERAGES FROM ALLEY AND VEENHUIS, 1979.

Exhibit No 3

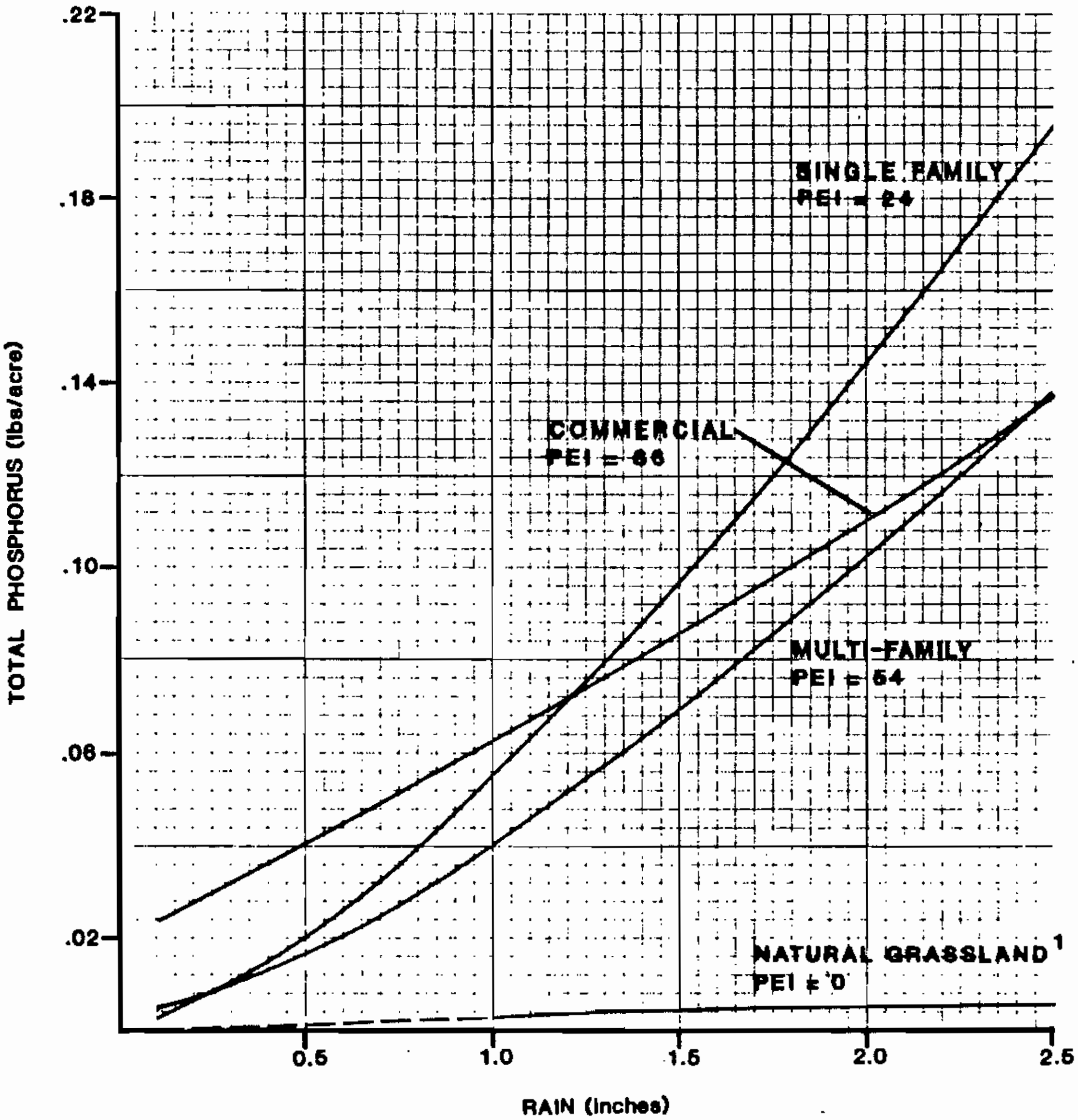

FIGURE 14. GRAPH RELATING UNIT-AREA LOADING OF TOTAL PHOSPHORUS (lbs/acre) TO RAINFALL (inches). (EQUATIONS FOR CURVES ARE CONTAINED IN TABLE.)

[1] FORMATION OF RUNOFF AND LOAD BELOW 1.0 INCHES RAINFALL IS HIGHLY VARIABLE.

Exhibit No. 4

The greatest load of lead per rainfall-inch would be expected from a commercial land use basin; the smallest load would be expected from a natural grassland. Loading of lead data from each land use were plotted as a function of rainfall.

Pollutant loading was found to be directly related to rainfall and PEI for all other constituents. In some cases, the greatest loading was found at moderate basin PEI (single family land use).

Figures for estimating storm loads of pollutants were developed based upon the relationships depicted in Figure 12 for the five constituents in Figures 4 and 5: total nitrogen, total phosphorus, total suspended solids, total lead, and zinc. These constituents were selected as, at least during wet months, major contributions of them to the South Platte River were found to be from urban runoff (Chapter IV). Graphs were constructed that estimate unit-area loading in lbs/ac based upon rainfall and land use by solving linear regression equations expressing loading in lbs/ac as a function of runoff (Table 23) with regression equations expressing runoff as a function of rainfall (Table 24). Data from the pairs of single family (Northglenn and Asbury Park Retention) and multi-family (Southglenn and Cherry Knolls) basins were combined, since it was determined that loadings were similar for the same land use (Figure 5). The resulting equations are presented in Table 25 and graphed in Figures 13 to 17 for a range of rainstorms between 0.1 to 2.5 inches. This range was chosen as it includes the majority of rainstorms in the DRURP study area. Figures for the remaining constituents monitored appear in a technical memorandum available through DRCOG.

Estimation of Urban Runoff Volume and Pollutants

Figures 13 through 17 can be used in a variety of ways for the preliminary assessment of effects of already-existing or proposed land uses on rainstorm-runoff quality. They permit a quick, relative comparison of pollutant loads between land uses. Also, Figure 11 can be used to estimate rainstorm-runoff volumes from various land uses or areas of known PEI.

Due to the limited number of storms sampled, small number of basins monitored, and large variability found in pollutant loading, application of these figures and data outside of the DRURP study area is not encouraged. It was originally thought that results of this study could be applied to other regions of similar climate and geographical characteristics. The above mentioned factors precluded this. Also, these figures were derived from data from small, developed basins. They should not be used to estimate runoff and loads from large undeveloped basins (greater than 1000 acres).

The following restrictions apply to the predictive figures in this section.

Figure 11. Nomograph for Estimation of Rainstorm Runoff:

1. Rainfall duration and intensity are not considered in this figure. Rainfall in figure refers to total storm amount over any time period, and rainfall data cannot be aggregated to estimate a runoff amount. Runoff has to be estimated for each rainfall level. That is, the the runoff from a one-inch rainstorm is not equal to twice the runoff from two half-inch storms;

2. This figure is most reliable for one inch or less of rainfall and caution is urged in using this figure to estimate runoff for storms greater than 1.5 inches;

3. The accuracy of runoff prediction decreases for basins having less than 10 percent PEI. Runoff from such sites is highly variable and dependent upon soil moisture and conditions which were not included in this analysis;

4. Specific runoff amounts may vary throughout PEI and the land uses due to factors not considered in the analysis such as: basin slope, residual soil moisture, soil type, rainfall intensity and duration, and presence of frozen soil surface. Estimates of runoff represent average runoff amounts to be expected from small basins in the DRURP study area;

5. Designated land uses correspond to average PEIs found in a study of various land uses within the Denver region.[6] If possible, known site PEI should be used; and,

6. This figure is not intended to replace standard engineering methods for runoff prediction. Its use should be limited to planning level analysis for water quality purposes.

Figures 13 thru 17. Graphs for Estimation of Rainstorm loads from Various Land Uses:

1. Rainfall data can not be aggregated over time. Loads must be estimated for each rainstorm size. For example, the load from a one-inch rainstorm is not equal to twice the load from a half-inch storm;

2. These figures are most accurate for rainstorms of one inch or less, but can only be used with a minimum of 0.1 inches of rain;

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[16] William M. Alley and Jack E. Veenhuis, "Determination of Basin Characteristics for an Urban Distributed Routing Rainfall-Runoff Model," Presented to Storm Water Management Model Users Group, Montreal, Canada, May 24-25, 1979.

3. Caution is urged in using these figures to predict loads from natural grasslands from rainstorms of one-inch or less. Runoff may only be produced from small storms in such areas when either saturated or frozen soil conditions exist;

4. The curve labelled "single family" in these figures was derived from data from high density developments (3-6 dwelling units/acre). This curve should not be used to estimate loads from low-density single family developments; and,

5. Actual rainstorm loads may vary depending upon residual soil moisture, antecedent dry days, storm characteristics, and other factors not accounted for in this analysis.

The following information can be gathered from Figure 11 and Figures 13 through 17:

- an estimate of individual rainstorm runoff volume and load;
- an estimate of individual rainstorm event mean concentration;
- an estimate of annual rainstorm runoff volume and load; and,
- an estimate of annual average rainstorm event mean concentration.

The use of Figure 11 is demonstrated in Figure 18. In this example, it is desired to estimate runoff in inches produced from an inch of rain on a single family development. To use the nomograph, use the following steps:

1. Locate 1.0 inch precipitation on left vertical axis labelled "Total Rainfall";

2. Proceed down and to the right along line associated with 1.0 inch total rainfall, stop above point on horizontal axis below (labelled "Land Use/PEI") designated single family;

3. Draw a horizontal line from this intersection straight across to right vertical axis labelled "runoff";

4. Read runoff amount (approximately 0.14 inches runoff).

The use of Figures 13 through 17 is illustrated in Figure 19. Loads are estimated using the same procedure for each of these graphs. To estimate a load from a given rainfall, draw a vertical line up from desired level of rainfall to appropriate line of designated land use. Draw a line horizontally from the intersection to the left hand axis labelled "Total Lead". Read unit-area load (lbs/ac) off of this axis. In the example illustrated in Figure 19, a one-inch rainstorm will produce 0.027 lbs/ac of total lead from commercial land use.

Exhibit No 5

Table 1

Distribution of Annual Precipitation by Storm Size

Cherry Creek Dam Gage[1]

Amount of Precipitation (inches)	Number of Storms Expected per Year
0.02-0.09	20.93
o.10-0.19	11.86
0.20-0.29	5.93
0.30-0.39	4.21
0.40-0.49	3.21
0.50-0.59	2.07
0.60-0.69	1.79
0.70-0.79	1.00
0.80-0.89	1.29
0.90-0.99	0.71
1.00-1.45	2.07
1.50-1.99	1.43
2.00-2.49	0.50
> 2.49	0.36

1 - Based upon record from 1969-1982. Events separated by at least 12 hours of no precipitation considered to be different storms.

Exhibit No. 6

a. estimated runoff from 0.20 inch rainstorm = 0.12 inches; runoff.

b. estimated runoff from 1.0 inch rainstorm = 0.73 inches runoff.

4. Convert runoff in inches to cubic feet using conversion formula in Table 26:

a. cubic feet runoff from 0.20 inch rainstorm =
0.12 inches x 75 acres x 3630 = 32,670 cu.ft.;

b. cubic feet runoff from 1.0 inch rainstorm =
0.73 inches x 75 acres x 3630 = 198,743 cu. ft.

5. Calculate estimated EMC for total lead from two rainstorms using formula in Table 26:

a. 0.20 inch rain EMC =

$$\frac{0.68 \text{ lbs}}{32{,}670 \text{ cu.ft.}} \div (6.245 \times 10^{-5}) = 0.33 \text{ mg/L};$$

b. 1.0 inch rain EMC =

$$\frac{2.03 \text{ lbs}}{198{,}743 \text{ cu.ft.}} \div (6.245 \times 10^{-5}) = 0.16 \text{ mg/L}.$$

6. Calculate estimated average EMC for total lead from two rainstorms using formula in Table 26:

$$\text{AEMC} = \frac{2.71 \text{ lbs}}{231{,}413 \text{ cu.ft.}} \div (6.245 \times 10^{-5}) = 0.19 \text{ mg/L}.$$

Conclusions:

The estimated event mean concentration of total lead was greater for the 0.20 inch rain despite the greater total load produced from the larger storm. For this to have occurred, the percentage increase in runoff volume had to have been greater than the increase in pounds total lead from the 0.2 to 1.0 inch rainstorm. The average estimated EMC of total lead represents the sum of loads divided by storm volumes for the two storms.

Example 4. Estimation of annual suspended solids load and comparison with estimated annual wastewater effluent load from same area.

A planning agency wishes to compare the annual suspended solids loading to receiving waters from urban runoff with secondary wastewater effluent from a 200 acre, one-quarter acre lot, single family development. The following additional information is provided:

- persons per households = 2.61,[17]
- per capita wastewater flow = 65 gallons/day,[18]
- secondary suspended solids effluent load = 30 mg/L.

Solution:

1. Calculate estimated annual suspended solids load from urban runoff from the development. This will require information on average expected yearly rainfall such as is presented in Table 27. This table gives the average number of storms of various sizes anticipated per year in the DRURP study area.

   Estimated annual load (L_T) equals the sum of the individual storm loads (I_i) for each precipitation level (X_i) times the average number of storms of that level expected per year (N_i):

   $$L_T = \sum_{i=1}^{n} I_i N_i.$$

   In this example, precipitation is aggregated into 13 levels (Table 27). Letting Y_1 denote the pollutant load per acre from all the < 0.10 inch events per year, Y_2 the annual load from 0.10-0.19 inches precipitation, up to Y_{13} as the annual load from 2.5 inches, the annual load per acre can be expressed as:

   L_T (lbs/acre) = $Y_1 + Y_2 + Y_3 + \ldots + Y_{13}$, where

   $Y_i = I_i \; N_i$ for any precipitation level X_i.

   The total estimated annual load for the development will then be equal to the annual load per acre multiplied by the total acreage.

   Using data from Table 27 and the line labelled "single family" in Figure 15, calculation of annual total suspended solids from urban runoff load appears in Table 28.

[17] Denver Regional Council of Governments, "Household and Household Size Forecasts for the Denver Region", DRCOG, July, 1982.
[18] Denver Regional Council of Governments, "Technical Report on Clean Water Plan", DRCOG, August, 1981.

Table 27

AVERAGE EXPECTED YEARLY RAINFALL AT STAPLETON INTERNATIONAL AIRPORT[1]

Rainfall (Inches) (X_i)		Average Number Storms Expected per year (N_i)
1)	<0.10[2]	20.5
2)	0.10-0.19	6.83
3)	0.20-0.29	3.58
4)	0.30-0.39	1.58
5)	0.40-0.49	0.92
6)	0.50-0.59	1.0
7)	0.60-0.69	0.17
8)	0.70-0.79	0.50
9)	0.80-0.89	0.58
10)	0.90-0.99	0.33
11)	1.00-1.49	1.08
12)	1.50-1.99	0.42
13)	2.00-2.49	0.08

Source: Adams County Planning Department

[1]Based upon data from years 1968 - 1979.
[2]Only storms producing greater than 0.02 inches rainfall were recorded.

Table 28

CALCULATION OF ANNUAL TOTAL SUSPENDED SOLIDS LOAD FROM URBAN RUNOFF

Precipitation in inches (X_i)	Load in lbs/ac(I_i)	Number storms per year (N_i)	Total suspended solids per year in lbs/ac(Y_i)
0.10	1	20.5	Y = 21
0.20	7	6.83	Y = 48
0.30	15	3.58	Y = 54
0.40	23	1.58	Y = 36
0.50	32	0.92	Y = 29
0.60	42	1.00	Y = 42
0.70	53	0.17	Y = 9
0.80	64	0.50	Y = 32
0.90	75	0.58	Y = 44
1.0	88	0.33	Y = 29
1.5	155	1.08	Y = 167
2.0	231	0.42	Y = 97
2.5	314	0.08	Y = 25
			Y_T = 633 lbs/acre/year

The estimated annual load per acre (L_T) is 633 lbs/acre/year.

Multiplying this by 200 acres (development size) gives an estimate of 126,600 lbs/year suspended solids from runoff.

2. Calculate estimated annual suspended solids load from a natural grassland of the same size as the development. This is necessary for a valid comparison of loading from wastewater effluent with urban runoff.

   Annual suspended solids load from the natural grassland is calculated using the same proceedure outlined in the previous step and the line labelled "natural grassland" in Figure 15. Calculations are omitted in order to conserve space and avoid redundancy.

   The estimated annual load per acre (L_T) is 10 lbs/acre/year.

   Multiplying this by 200 acres (development size) gives an estimate of 2000 lbs/year suspended solids.

3. Estimate annual total suspended solids loading from the development from secondary treated wastewater effluent:

   a. calculate persons in development:

   $$200 \text{ acres} \times \frac{4 \text{ houses}}{\text{acre}} \times \frac{2.61 \text{ persons}}{\text{house}} = \underline{2088 \text{ persons;}}$$

   b. calculate daily wastewater flow in liters:

   $$2088 \text{ persons} \times \frac{65 \text{ gals/person}}{\text{day}} \times \frac{3.785 \text{ liters}}{\text{gal.}} = \underline{513{,}700 \text{ liters/day;}}$$

   c. calculate daily suspended solids load:

   $$\frac{513{,}700 \text{ liters}}{\text{day}} \times \frac{0.03 \text{ gram}}{\text{liter}} \times \frac{1 \text{ pound}}{453.6 \text{ grams}} = \underline{34 \text{ lbs/day;}}$$

   d. calculate annual suspended solids load:

   $$\frac{34 \text{ lbs}}{\text{day}} \times \frac{365 \text{ days}}{\text{year}} = \underline{12{,}410 \text{ lbs/year.}}$$

4. Compare estimated annual total suspended solids loading from urban runoff with that from secondary wastewater effluent from the development:

   - annual load from urban runoff = 126,600 lbs/year;
   - annual load from effluent = 12,410 lbs/year;

- annual load from runoff from natural grassland = 2000 lbs/ year.

Conclusions:

The total estimated annual load of suspended solids from both municipal wastewater and urban runoff from the development is 139,010 pounds. Loading from urban runoff accounted 91 percent of the estimated total load. However, a more objective estimate of suspended solids loading can be made by subtracting the estimated load for the natural grassland of the same size as the development, from the development (urban runoff) load. In this manner, only the load attributable to development can be compared to the wastewater effluent load. If this is done, then the total estimated load of suspended solids becomes 137,010 pounds, but roughly 91 percent of this load is still from urban runoff. Suspended solids loading from the natural grassland is insignificant in this analysis. The majority of the estimated load is from urban runoff.

Summary and Conclusions

Methods and procedures for estimating rainstorm runoff quantity and quality in the DRURP study area for any time period, using a minimum of information and calculations were presented in this section. The figures and methods provided are based upon results and data from the urban runoff monitoring effort (Chapter III).

A graph was presented to estimate rainstorm-runoff quantity based upon land use or PEI. This figure was constructed based on the conclusions that runoff was well related curvilinearly to rainfall within a basin, and that the percent of rainfall occurring as runoff was well related linearly between basins.

Graphs that estimate pollutant loading were constructed based upon the findings that loading varied mainly as a function of runoff quantity, which was found to be dependent upon site PEI, and that loading rates tended to be similar for the same land use. Four practical examples were presented that, hopefully, demonstrated the applicability and usefulness of these graphs for estimating urban runoff quantities, constituent loads, and constituent concentrations.

A more detailed analysis of rainfall-runoff relationships, pollutant loading and model development that includes figures for the remaining constituents monitored (Table 6) is available in a separate technical report from DRCOG.

Exhibit No. 7

Table 4

Comparison of Measured vs. Predicted Storm Loads and Volumes
Cherry Creek Sub-basins*

Sub-basin	Storm Date	TP Load (lbs) Measured	TP Load (lbs) Predicted	Measured / Predicted	Runoff Vol. (Ft) Measured	Runoff Vol. (Ft) Predicted	Measured / Predicted
Cherry Creek	5/13-14/82	10.4	1,458	0.007	276,400	17,987,570	0.02
Cherry Creek	6/4/82	0.35	31.2	0.011	9,000	68,151	0.13
Cherry Creek	6/24-25/82	18.0	183.7	0.100	56,000	1,083,500	0.05
Cherry Creek	8/3-4/82	97.0	838.8	0.116	191,000	4,312,190	0.04
Piney Creek	8/17/82	5.6	3.2	1.74	15,500	70,990	0.2[illegible]
Piney Creek	8/20/82	0.24	16.8	0.014	3,500	204,390	0.0[illegible]
Lone Tree Creek	5/12-15/82	10.9	17.6	0.62	319,000	339,960	0.94
Lone Tree Creek	5/26/82	0.58	2.2	0.27	22,800	5,210	4.3
Cottonwood Creek	5/25-27/82	10.5	25.5	0.41	469,000	456,610	1.03
Cottonwood Creek	6/2-4/82	7.0	32.9	0.21	209,000	1,005,950	0.21
Cottonwood Creek	6/18-19/82	4.0	30.2	0.13	457,000	526,080	0.87
Cottonwood Creek	6/25/82	2.4	5.8	0.41	189,000	92,801	2.04
Cottonwood Creek	6/28-29/82	1.8	4.0	0.45	-	-	-
Cottonwood Creek	7/28-29/82	18.9	60.0	0.32	-	-	-
Cottonwood Creek	5/12-15/82	-	-	-	1,910,000	2,314,570	0.89
Shop Creek	5/12-14/82	322.0	33.1	9.7	1,120,000	550,790	2.0
Shop Creek	6/24/82	8.7	1.08	8.1	49,800	21,270	2.3
Shop Creek	7/28/82	520.0	36.5	14.2	1,083,000	639,690	1.7

* Only 1 storm monitored at Happy Canyon.

Exhibit No. 8

A. TP Loading:

Data from Shop Creek and Piney Creek were omitted in this analysis. Linear regression analysis between $\overline{S}_f$ and sub-basin PEI yielded the following equation:

$$S_f = 0.116 \text{ PEI} + 0.0039 \qquad r = 0.98 \quad .$$

This equation was used to predict scaling factors for TP loading based on basin PEI for all sub-basins except Shop Creek. The $\overline{S}_f$ for Shop Creek was held constant at 10.7 and used for development scenarios in the future.

B. Runoff Volumes:

Data from all sub-basins except Lone Tree Creek were used in this analysis. Lone Tree had an unexplainably high $\overline{S}_f$ for its PEI. Linear regression analysis between $\overline{S}_f$ and sub-basin PEI yielded the following equation:

$$S_f = 0.185 \text{ PEI} - 0.057 \qquad r = 0.98 \quad .$$

This equation was used to predict a S_f for runoff for all sub-basins.

Both of these regression equations could predict 1982 mean scaling factors sufficiently well, and appeared to predict reasonable scaling factors by sub-basin in the future based upon sub-basin PEI.

Chatfield Reservoir

Scaling factors were derived by dividing measured storm loads and runoff by predicted loads and runoff as was done in the Cherry Creek Reservoir Basin. Mean scaling factors ($\overline{S}_f$) were also calculated for each sub-basin. Measured and predicted loads and runoff and scaling factors are shown in Table 6 for Chatfield.

Table 9

Exhibit No. 9

CHERRY CREEK RESERVOIR:
1982 PREDICTED TOTAL PHOSPHORUS LOAD (ANNUAL POUNDS)
AND ANNUAL RUNOFF VOLUME (ACRE-FEET)

	1982 Load	1982 Runoff Volume
Unmonitored Area	378	174
Cherry Creek (includes Happy Canyon)	596	74
Lone Tree Creek	36	6
Cottonwood Creek	343	181
Piney Creek	223	91
Shop Creek	2,429	159
TOTAL	4,010	685

Table 10

CHATFIELD RESERVOIR:
1982 PREDICTED TOTAL PHOSPHORUS LOAD (ANNUAL POUNDS)
AND ANNUAL RUNOFF VOLUME (ACRE-FEET)

	1982 Load	1982 Runoff Volume
Massey Draw	125	113
Deer Creek	791	179
Plum Creek	5,711	979
Unmonitored Area (west of Reservoir)	275	42
Unmonitored Area (Plum Creek below Louviers)	549	202
TOTAL	7,450	1,520

Exhibit No 10

Table 36
Cherry Creek Reservoir
Stormflow Loading Projections

	1985		1990		2000		2010	
	DRCOG	Developer	DRCOG	Developer	DRCOG	Developer	DRCOG	Developer
TOTAL PHOSPHORUS LOADING (Pounds/Year)								
Unmonitored Area	417	580	462	742	615	1,164	792	1,671
Cherry Creek	1,209	1,778	1,807	3,165	3,184	6,109	4,950	8,563
Happy Canyon Creek	143	347	318	1,057	831	2,030	1,406	2,588
Lone Tree Creek	169	502	436	1,491	1,786	5,514	3,957	12,465
Cottonwood Creek	144	299	388	1,640	1,196	3,367	3,547	5,421
Piney Creek	245	341	338	529	509	776	644	1,098
Shop Creek	2,429	2,975	2,429	3,488	2,429	4,719	2,429	4,719
TOTAL	4,750	6,820	6,180	12,110	10,560	23,680	16,730	36,530
RUNOFF VOLUME (Acre-Feet/Year)								
Unmonitored Area	83	285	166	399	199	679	561	1,033
Cherry Creek	315	524	538	1,196	1,200	2,898	2,152	4,402
Happy Canyon Creek	53	172	151	631	461	1,255	812	1,612
Lone Tree Creek	90	331	282	1,082	1,306	4,242	3,007	9,792
Cottonwood Creek	61	156	205	1,091	747	2,327	1,704	3,855
Piney Creek	104	153	152	263	256	427	343	658
Shop Creek	164	240	164	329	164	563	164	563
TOTAL	870	1,860	1,660	5,000	4,330	12,400	8,740	21,920

SUMMARY OF SURFACE WATER HYDROLOGY INVESTIGATION

A. Reviewed references attached to Draft Memorandum which include, DRURP final report, Clean Lakes Study Report, Clean Lakes Technical Memorandum No. 6, Cherry Creek Water Quality Master Plan and Technical Report.

B. Contacted UDFCD, DRCOG, CWRPDA, and CWCB for any reports they had regarding rainfall/runoff relationships.

   - UDFCD has master plans for: Lonetree Creek
     Wind Mill Creek
     Dove Creek
     *Cottonwood in Progress
     Shop Creek
     Quincy Drain

   - UDFCD (Ben Urbonas) made a copy of a draft report entitled "Optimization of Stormwater Quality Capture Volume".

   - CWRPDA and CWCB did not have any reports they felt would help our investigation.

C. Investigated the methodology used to estimate annual runoff and phosphorous loading from sub-basins. Drafted a memorandum briefly outlining the methodology and stating our concerns and questions.

D. Currently, reviewing the Cherry Creek Basin Water Quality 1986-88 annual reports for data that could be used to check and update the methodology to predict runoff and phosphorous loads to Cherry Creek Reservoir.