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PROFESSIONAL ASSOCIATION

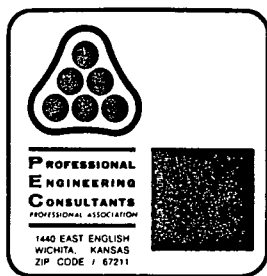
DESIGN COMPUTATIONS
ECHO HILLS PHASE 2
STORM WATER SEWER
FOR
CITY OF WICHITA, KANSAS

SEPTEMBER 2, 1986

SUBMITTED BY:
PROFESSIONAL ENGINEERING CONSULTANTS, P.A.
WICHITA, KANSAS 67211

OWNER: INLAND INVESTMENT CO., INC.
10300 W. CENTRAL
WICHITA, KANSAS 67212

MEMO



TO: File PROJECT NO. 32-86349-1-1120
PROJECT: Echo Hills Phase II SWS
ATTN: _____ DATE: _____

COPIES TO:

M.E. Lindebak, P.E.,
Attn: C.L. Gipson, P.E.

FROM: Michael W. Berry, P.E.
REFERENCE: Storm Sewer Design Computations

PLEASE ADVISE IMMEDIATELY OF ANY MISCONCEPTIONS OR OMISSIONS YOU BELIEVE TO BE CONTAINED HEREIN.

Attached hereto are the computations for the referenced project.

The publication "Interim Drainage and Storm Sewer Policy for Design Criteria and Documentation, City of Wichita," as revised 4/15/86, was used as the reference for the hydrologic and hydraulic computations. This publications is hereinafter referred to as the "Design Manual."

Manual #1, as referenced herein, refers to "Design of Urban Highway Drainage - The State of the Art," by Reitz & Jens, Inc., April, 1980. Manual #2 refers to "Drainage of Highway Pavements, Hydraulic Engineering Circular #12," by Tye Engineering, Inc., March, 1984.

HYDROLOGY METHODS

The rational method was used for hydrologic analysis. Runoff coefficients were based on the table provided in Attachment D, of the Design Manual. The average lot in this development is 1/6 Ac; thus, the average of the 1/8 and 1/4-Ac values was used for C.

The time of concentration for overland flow was determined by either the velocities given in Attachment E, of the Design Manual, or by the Kinematic Wave Theory, as presented in Section 4.1.3, of Manual #2. Time of travel in street gutters was determined by the method used in Section 4.1.3, of Manual #2. The minimum time of concentration for design purposes was taken to be fifteen minutes.

The two-year design storm was used to size inlets. In all cases, a check was made that the 100-year runoff was confined to the right-of-way.

HYDRAULIC DESIGN

For each inlet, street flooding and inlet capacity was checked for the minor storm. Conveyance in the street was based on the modified Manning Eq:

$$Q = 0.56 (S_x)^{5/3} (T)^{8/3} \sqrt{S} / n \quad (\text{Eq. 4, Manual \#2})$$

It was assumed that t_c , for street flow, was equal to t_c , for pipe flow. This is a conservative assumption, as pipe velocities generally exceed gutter velocities.

For local streets, curb-deep flow is tolerable for the minor storm. For collectors, a single eight-foot center lane should remain unflooded for the minor storm.

Inlet capacities were determined by the methods presented in Manual #2, using chart 12. All inlets are sump inlets.

In this analysis, City of Wichita Type 1A Inlets, 3/8 in/ft street cross-slope, and 6-5/8" Std. curb and gutter were assumed to be utilized.

As noted in the memo dated 8/19/86, the available outfall pipe has limited capacity. Pipe hydraulics were computed for the 1-year recurrence interval under current design criteria. Greater storms will cascade through a series of crests and sumps to the Thirteenth Street right-of-way. All crests are designed to be lower than the top of curb elevation at the nearest upstream sump.

Hydraulic computations for the pipe system was performed using PEC's Storm Program. This program uses Manning's Equation to calculate friction losses in pipes flowing full. Minor losses are accounted for using conservation of momentum principles. It is desirable to keep the hydraulic grade line approximately one-foot below the top of curb elevations.

MAJOR STORM OVERFLOW

For each subarea, a check was made for conveyance capacity of the major storm. To simplify analysis, the following assumptions were made:

1. The time of concentration is identical for both the major and minor storm.
2. The pipe system capacity during the major storm is assumed to be the same as during the minor storm. This is a conservative assumption, because increased ponding during the major storm event will increase the available head on the inlet/pipe system, thus increasing the capacity.

Page 3

3. The street conveyance was analyzed using only the street width. Depths above the curb up to the walk grade were used, but the conveyance of the parking was neglected. In general, the parking area conveyance is quite small, due to the relatively higher n factor. Again, Eq. 4, of Manual #2, was used.

OFF-SITE BASIN

The area immediately west of this project is scheduled to be replatted. Detailed analysis of subareas was not possible due to the change in street alignments. The basin was analyzed as an entire unit, assuming the street alignment shown on the enclosed drainage map. Single family density with 1/6 acre lots was assumed.

DESIGN AIDS

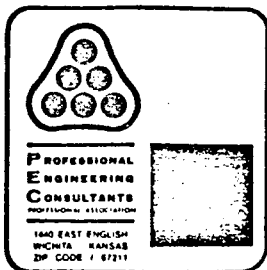
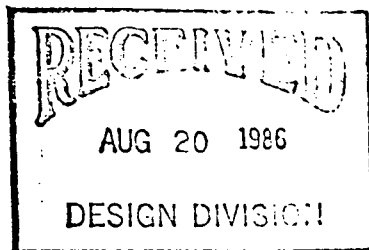
All charts, graphs, tables, and nomographics used in the design are reprinted herein.

DRAINAGE MAP

A 1"=100' scale drainage map is included.

MWB/mkm

MEMO



TO: File

PROJECT NO. 32-86349-1

PROJECT: Echo Hills Phase II
Storm Sewer

DATE: 8/19/86

COPIES TO:

Michael E. Lindebak, P.E.,

Attn: Carl Gipson, P.E.

ATTN:

FROM: Michael W. Berry, P.E. *MMB*

REFERENCE: Design Concept Discussion

PLEASE ADVISE IMMEDIATELY OF ANY MISCONCEPTIONS OR OMISSIONS YOU BELIEVE TO BE CONTAINED HEREIN.

A meeting to discuss design concepts for the above-referenced project was held at the offices of the City Engineer on 8/16/86. In attendance were the following:

| | | | |
|---------------|--------|---------------|-----------|
| Vicky Huang) | | Gary Schock) | |
|) | C.O.W. |) | PEC, P.A. |
| Carl Gipson) | | Mike Berry) | |

The storm sewer systems built as part of Briarwood Estates and of the Thirteenth Street Improvements are smaller than those shown on the approved Drainage Plan at the time of platting. Research determined that the 30" diameter outfall provided at 13th and Parkridge was based on revised hydrologic computations. These revised computations used the FAA formula for overland flow to determine the time of concentration for the uppermost basin, and was discussed and approved by City Staff prior to April 1981.

The City of Wichita issued the "Interim Drainage and Storm Sewer Policy for Design Criteria and Documentation," on 4/15/86. The hydrologic design methodology presented therein indicates that the existing 30" diameter outfall pipe is inadequate for conveyance of the two-year design storm.

After a lengthy discussion, it was agreed that the following approach should be taken:

1. The existing 30" diameter outfall should be extended to the west end of the current project, and will extend in the future to the intersection of Judith & Nantucket.
2. Street grades will be designed to provide positive drainage across crests into Thirteenth Street right-of-way without curb overtopping.

3. Inlet capacity should be sufficiently large to utilize the full capacity of the outfall.

The justifications and ramifications of this approach are as follows:

1. The outfall provided will be utilized to its maximum capacity.
2. By current design criterion, the two-year design storm cannot be conveyed in the underground system. The recurrence interval for the storm sewer system would fall between the one- and two-year storms.
3. The two-year storm will not overtop the street curbs due to street grade design.
4. A short stretch of Thirteenth Street will be subjected to somewhat greater and/or more frequent flooding than permitted by the current criterion.
5. The storm sewer system serving Thirteenth Street was designed to accommodate overflows from Echo Hills in excess of the capacity of the Echo Hills system. For recurrence intervals between two and 100 years, no significant changes will be made from that shown on the approved Drainage Plan.

MWB/mkm

On-Site Hydrology



Date B-20-86 MB Page 1 of 8

Project ECHO HILLS PH II SWS 32-86349-1

Item HYDROLOGY

I. GENERAL

STORM SEWER NODE NO.'S ARE SAME AS DRAINAGE PLAN,
EXCEPT AREAS 890 & 900 ARE COMBINED
HYDROLOGY METHOD BY COW INTERIM DRAINAGE MANUAL

BASIN SLOPE (YARDS) 1% (1.0%)

II. COEFFICIENT OF RUNOFF

1/6 Acre Lots: Avg 1/4 and 1/8 Ac VALUES

Prorate by %-age of B & C Soil Group

Reference: Cow Manual Attachment D

| AREA | B SOIL GROUP | | | | C SOIL GROUP | | | | Composite 2 Yr | C 100 Yr |
|------|--------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|-------------------|----------------|
| | % B | 1/4 AC | 1/8 AC | 1/6 AC | % C | 1/4 AC | 1/8 AC | 1/6 AC | | |
| 840 | 80 | 0.44/ 10.61 | 0.52/ 10.67 | 0.48/ 10.64 | 20 | 0.48/ 10.68 | 0.55/ 10.73 | 0.52/ 10.71 | 0.49 | 0.65 |
| 850 | — | } | } | } | 100 | } | } | } | 0.52 | 0.71 |
| 860 | 70 | | | | 0.49 | | | | 0.66 | |
| 870 | — | | | | 0.52 | | | | 0.71 | |
| 880 | 5 | | | | 0.52 | | | | 0.71 | |
| 900 | 30 | | | | 0.44/ 10.61 | | | | 0.52/ 10.67 | 0.48/ 10.64 |



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1440 EAST ENGLISH
WICHITA, KANSAS
ZIP CODE / 67211

Date 8/20/86 MAB Page 2 of 8

Project ECHO HILLS PH II SWS 82-86349-1

Item HYDROLOGY

III. TIMES OF CONCENTRATION

OVERLAND FLOW: YARD = 150' FOR ALL BASINS EXC. 870

FROM COW MANUAL ATTACHMENT E

$$\frac{150'}{0.28 \text{ ft/sec}} \times \frac{1 \text{ min}}{60 \text{ sec}} = 8.93 \text{ min.}$$

Using CHART C, HEC 12, Find V_g = ^{average} velocity in gutter & T_g = time in gutter & ΣT

BASIN 840

$$L = 400', S = 1\%, S_x = 1/32, T_1/T_2 = 0, T_a = 0.65(14) = 9.1'$$

$$V_g = 3.0 \text{ ft/s} \quad T_g = \frac{400}{3.0} \left(\frac{1}{60} \right) = 2.2 \text{ min} \quad \Sigma T = 8.9 + 2.2 = 11.1 \text{ min}$$

USE $T_c = 15$ minutes

BASIN 850

$$L = 220', S = 0.32\%, T_a = 0.65(17) = 11.1'$$

$$V_g = 1.95 \text{ ft/s} \quad T_g = \frac{220}{1.95} \left(\frac{1}{60} \right) = 1.9 \text{ min} \quad \Sigma T = 10.8 \text{ min}$$

USE $T_c = 15$ minutes

BASIN 860 (Same as 840)

$$L = 400', S = 1\%, T_a = 9.1' \quad V_g = 3 \text{ ft/s} \quad T_g = 2.2 \text{ min} \quad \Sigma T = 11.1 \text{ min}$$

USE $T_c = 15$ minutes

BASIN 870

Overland flow (Park)

$$L = 300', S = 1\%, n = 0.450 - \text{Solve by Kinematic Wave}$$

Assume $i = 2 \text{ in/hr}$
4.8

Find $t_c = 48 \text{ min}$
Find $t_c = 375$

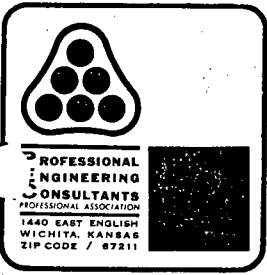
Actual $i = 2 \text{ in/hr}$ OK 2-YR
 $i = 4.83 \text{ in/hr}$ OK 100-YR

Gutter flow

$$L = 250' \quad S = 0.80\% \quad T_a = 11.1'$$

$$V_g = 3.1 \text{ ft/s} \quad T_g = \left(\frac{250}{3.1} \right) \left(\frac{1}{60} \right) = 1.35 \text{ min}$$

$\Sigma T = 49 \text{ min}$



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Project ECHO HILLS PH II SWS 32-86349-1

Item HYDROLOGY

III CONT

BASIN 880

$L = 850'$, $S = 0.32\%$, $T_a = 11.1'$

$V_g = 1.95 \text{ ft/s}$ $T_g = 7.2 \text{ min}$ $\Sigma T = 8.9 + 7.2 = 16.1 \text{ min}$

$T_c = 16.1 \text{ min}$

~~BASIN 890~~

~~$L = 1150'$, $S = 0.32\%$, $T_a = 11.1'$~~

~~$V_g = 1.95 \text{ ft/s}$ $T_g = 9.8 \text{ min}$ $\Sigma T = 9.8 + 8.9 = 18.7 \text{ min}$~~

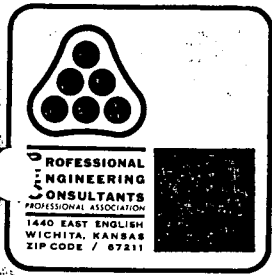
~~$T_c = 18.7 \text{ min}$~~

BASIN 900

$L = 1400'$, $S = 0.32\%$ $T_a = 11.1'$

$V_g = 1.95 \text{ ft/s}$ $T_g = 1400 / (1.95)(60) = 11.9$ $\Sigma T = 11.9 + 8.9 = 20.8 \text{ min}$

$USE T_c = 21 \text{ min}$



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 Project ECHO HILLS PH II 32-86349-1
 Item HYDROLOGY

IV DESIGN FLOWRATES

| BASIN | AREA, AC | TWO-YEAR DESIGN | | | 100-YEAR DESIGN | | |
|-------|----------|-----------------|-------------|-----------|-----------------|-------------|-----------|
| | | T_c , min | i , in/hr | Q , cfs | T_c , min | i , in/hr | Q , cfs |
| 840 | 1.7 | 15 | 3.83 | 3.2 | 15 | 7.37 | 8.1 |
| 850 | 0.9 | 15 | 3.83 | 1.8 | 15 | 7.37 | 4.7 |
| 860 | 1.7 | 15 | 3.83 | 3.2 | 15 | 7.37 | 8.1 |
| 870 | 1.8 | 49 | 4.97 | 1.8 | 38 | 4.79 | 6.1 |
| 880 | 2.7 | 16 | 3.72 | 5.2 | 16 | 7.18 | 13.8 |
| 890 | | | 5.4 | 7.5 | | 6.6 | 11.7 |
| 900 | 5.9 | 21 | 3.25 | 9.8 | 21 | 6.39 | 26.0 |

V INLET CAPACITY

ALL INLETS ARE IN SUMP. USE CHART 12, HEC 12, ASSUMING
 COW TYPE IA INLETS FOR INLET INTAKE. USE CHART 3, HEC 12
 FOR FLOW DEPTH IN GUTTER.

SEE SH NO 5 FOR COMPUTATION. SUMMARY IS MADE ON SH NO 6
 IN ACCORDANCE WITH EXHIBIT 3 OF THE DESIGN MANUAL.

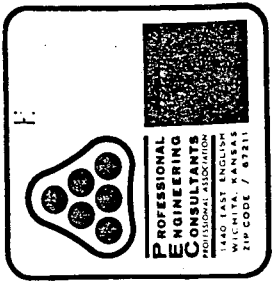
VI MAJOR STORAGE CHECK

ASSUME TRAVEL TIME IN GUTTER = TRAVEL TIME IN PIPE.

THIS WILL YIELD STREET FLOWRATES ON THE CONSERVATIVE SIDE,
 SINCE GUTTER VELOCITIES FALL IN THE 2 TO 3 FT/SEC RANGE AND

PIPE VELOCITIES WILL GENERALLY EXCEED 5 FT/SEC

SEE SH NO 6 FOR TABULATION



Date 0/20/86 Page 5 of 5 Comp by MWB

Project ECHO HILLS PHASE III SWWS 32-86349-1

Item INLET CAPACITY 2-YR

$z/n = 2.000$

| NODE No. | HYDROLOGY | | APPROACHING FLOW | | | | INLET | | | ON-GRADE COMP. | | | SUMP COMP. | | | | |
|----------|--------------------|------------------------------------|--------------------|----------------------|-------|------|-------|-----|-------|----------------|------|-------------------|------------|-------|--------------------|--------------------|-----|
| | Q ₀ cfs | Q ₀ +Q _b cfs | S ₀ o/o | S _x in/ft | d ft | T ft | TYPE | L | Lt ft | L/Lt | E ft | d _i ft | d ft | T ft | Q ₁ cfs | Q _b cfs | |
| 900 | E | 1.0 | 0.32 | 3/8 | 0.21' | 6.8 | 1A | 5' | | | | | | | | | |
| 850 | W | 8.8 | 0.32 | 3/8 | 0.47' | 15.0 | 1A | 10' | | | | 0.45' | 0.28' | 9.0 | 9.8 | -0- | -0- |
| 820 | | 1.8 | 0.45 | 3/8 | 0.25' | 8.0 | 1A | 5' | | | | 0.2' | 0.05' | 11.0' | 1.8 | -0- | -0- |
| 870 | | 5.2 | 0.32 | 3/8 | 0.41' | 13 | 1A | 5' | | | | 0.41' | 0.24' | 7.7' | 5.2 | -0- | -0- |
| 870 | | 1.8 | 0.45 | 3/8 | 0.25' | 8.5 | 1A | 5' | | | | 0.2' | 0.03' | 11.0' | 1.8 | -0- | -0- |
| 860 | N | 1.0 | 0.8 | 3/8 | 0.18 | 5.6 | A | | | | | | | | | | |
| 860 | E | 2.2 | 1.0 | 3/8 | 0.23 | 7.2 | 1A | 5' | | | | 0.29' | 0.12' | 3.8' | 3.2 | -0- | -0- |
| 840 | | 3.2 | 1.0 | 3/8 | 0.26 | 8.3 | 1A | 5' | | | | 0.29' | 0.12' | 5.8' | 3.2 | -0- | -0- |



| NODE | Tc MIN | Q1 cfs | Q100 cfs | Q100-Q1 cfs | Σ Q cfs | So % | Bk-Bk Street Width | MAX DISCHARGE (cfs) @ d = | | | REMARKS |
|------|--------|--------|----------|-------------|---------|-------|--------------------|---------------------------|--------|--------|--|
| | | | | | | | | T.C. | T.C. | T.C. | |
| 900 | 21 | 7.4 | 26 | 18.6 | 28.5 | 0.25% | 35' | +0.3' | +0.41' | +0.52' | OK @ MIN WK. GR. |
| 880 | 16 | 3.9 | 13.6 | 9.9 | 28.5 | 0.25% | 35' | +0.3' | +0.41' | +0.52' | RESULTANT HYDRAULIC GRADIENT CREST-TOP CREST |
| 840 | 15 | 2.4 | 8.1 | 5.7 | 28.5 | 0.25% | 35' | +0.3' | +0.41' | +0.52' | INT. NANTUCKET & CHAMBERS |
| 850 | 15 | 1.4 | 4.7 | 3.3 | 28.5 | 0.25% | 35' | +0.3' | +0.41' | +0.52' | INT. PARKRIDGE & NANTUCKET |
| 860 | 15 | 2.4 | 8.1 | 5.7 | 28.5 | 0.25% | 35' | +0.3' | +0.41' | +0.52' | INT. PARKRIDGE & NANTUCKET |
| 870 | 49 | 1.4 | 6.1 | 4.7 | 19.4 | | | | | | INT. PARKRIDGE & NANTUCKET |
| | | | | | 47.9 | | | | | | 47.9 → MUST ELONG ACCESS CREST @ N.I.L. 13TH / NIDA 13TH |

MAJOR STORM CHECK

± Add peak on peak

Date 8/20/06 MB

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Comp by MWS

Project Echo Hills # 32-86349-1-1120 CK by

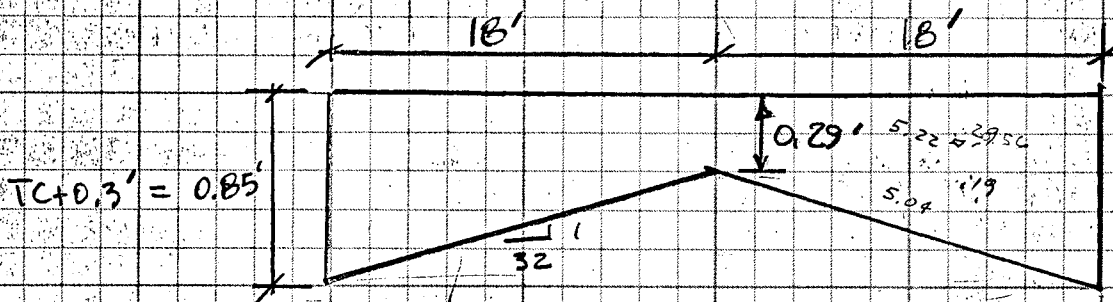
Item



Date B-20-86 Page 7 of 8
 Project ECHO HILLS PH II SWS
 Item HYDROLOGY

CHECK WEIR FLOW CONDITION OVER CREST @ N.L. 13TH ON PARKRIDGE.

ASSUME FLOW DEPTH @ WK GR = T.C + 0.3', IGNORE CONVEYANCE IN STREET PARKING.



$$Q = CLH^{1.5}$$

USE $C = 3.0$
 $L = 36'$

What is effective H? By Centroid of Area = 0.54'

$$Q = 3(36)(0.54)^{1.5} = 43 \text{ cfs}$$

TRY T.C + 0.35' Eff. H = 0.57' 6.25' x 0.17
9.45' x 0.52

$$Q = 3(36)(0.57)^{1.5} = 47 \text{ cfs} \approx 47.9$$

WILL BE CONFINED TO R/W FOR WK GR = T.C + 0.35' OR GREATER.

SUMP INLET DESIGN DATA TABULATION

SH. NO. OF

PROJECT: ECHO HILLS PHASE 2 SNS
 PROJECT NO. 468-76-245-8 -000-000-001
 DESIGN STORM FREQUENCY (YEARS) 2
 GUTTER DEPRESSION AT INLETS (IN): 2
 WIDTH OF GUTTER DEPRESSION AT INLETS (FT): 2

PROFESSIONAL ENGINEERING CONSULTANTS, P.A.
 COMPUTED BY: M. BERRY DATE: 9-21-86

| INLET LOCATION | TOP OF INLET ELEVATION | INLET AREA (ACRES) | TIME OF CONCENTRATION (MIN) | RUNOFF COEFF. C | RAINFALL INTENSITY (IN/HR) | D.A. RUNOFF (CFS) | FLOW OVER INLET (CFS) | INLET CAPACITY (CFS) | INLET LENGTH (FT) | INLET LENGTH PROVIDED (FT) | COMPUTED PONDING ELEV. (FT) | COMPUTED PAVEMENT SPREAD (FT) | ALLOWABLE PONDING ELEV. (FT) | PAV'T. SPREAD (FT) | PAV'T. WIDTH (FT) | CROSS SLOPE (FT/FT) | STREET CLASSIFICATION | REMARKS |
|----------------|------------------------|--------------------|-----------------------------|-----------------|----------------------------|-------------------|-----------------------|----------------------|-------------------|----------------------------|-----------------------------|-------------------------------|------------------------------|--------------------|-------------------|---------------------|-----------------------|---------|
| 900 | 156.50 | 5.90 | 21.00 | 0.51 | 3.25 | 9.78 | 0.00 | 9.78 | 10.00 | 10.00 | 156.23 | 9.00 | 156.48 | 17.00 | 35.00 | 0.0313 | LOCAL COLLECTOR | |
| 850 | 155.58 | 0.90 | 15.00 | 0.52 | 3.83 | 1.79 | 0.00 | 1.79 | 5.00 | 5.00 | 155.06 | 1.00 | 155.48 | 14.00 | 37.00 | 0.0313 | LOCAL COLLECTOR | |
| 880 | 156.50 | 2.70 | 16.00 | 0.52 | 3.72 | 5.22 | 0.00 | 5.22 | 5.00 | 5.00 | 156.19 | 7.70 | 156.48 | 17.00 | 35.00 | 0.0313 | LOCAL COLLECTOR | |
| 870 | 156.10 | 1.80 | 49.00 | 0.52 | 1.97 | 1.84 | 0.00 | 1.84 | 5.00 | 5.00 | 155.58 | 1.00 | 156.08 | 17.00 | 35.00 | 0.0313 | LOCAL COLLECTOR | |
| 860 | 156.48 | 1.70 | 15.00 | 0.49 | 3.83 | 3.19 | 0.00 | 3.19 | 5.00 | 5.00 | 156.05 | 3.80 | 156.37 | 14.00 | 37.00 | 0.0313 | COLLECTOR | |
| 840 | 155.59 | 1.70 | 15.00 | 0.49 | 3.83 | 3.19 | 0.00 | 3.19 | 5.00 | 5.00 | 155.16 | 3.80 | 155.48 | 14.00 | 37.00 | 0.0313 | COLLECTOR | |

Hydraulics



Date 8/20/84 MAB Page 1 of 4
Project ECHO HILLS PH II SWS 32-86349-1-1120
Item HYDRAULICS

I. DESIGN PARAMETERS

OUTFALL LIMITED TO 30" RCP, SINCE THE EXISTING SYSTEM WAS DESIGNED BASED HYDROLOGIC COMPUTATION METHODS DIFFERENT THAN THE CURRENT STANDARD, THE PIPE IS UNDERSIZED FOR CURRENT DESIGN METHODOLOGY.

THE EXISTING 30" DIAMETER LINE WILL BE RETAINED TO THE WEST LIMIT OF THE CURRENT PROJECT. EVALUATION OF THE 1-YEAR DESIGN STORM UNDER CURRENT CRITERIA INDICATES ADEQUATE HYDRAULIC CAPACITY. STORMS OF GREATER MAGNITUDE WILL CASCADE THRU A SERIES OF SUMPS & CRESTS INTO THIRTEENTH ST. RIGHT-OF-WAY. STREET GRADES HAVE BEEN SET TO PROVIDE POSITIVE OVERFLOW ROUTES PRIOR TO REACHING TOP OF CURB ELEVATIONS.

HYDRAULIC ANALYSIS WAS MADE USING THE PEC "STORM" PROGRAM, OUTPUT FROM WHICH IS ATTACHED. THE RESULTS ARE SUMMARIZED ON SH NO 4 AS SHOWN IN TABLE 5-7 OF MANUAL #1.

Date: 08-21-1986
Time: 09:30:45

Input File: 1yr012.stm

ECHO HILLS PHASE 2 S.W.S
30" DIA OUTFALL LINE --- 1-YEAR --- n=0.012
MWB 8/20/86

Storm Frequency = 1-Year

* * * H Y D R O L O G Y * * *

| ***** | | | | | | | | | | | | | ***** | | | | | | | |
|----------------|-----|-----------|-----------|-------------|-------------|--------------|------------|----------|-----------|---------|-------------|-------|---------------------|-------------|----------|-------------|--------------|--|--|--|
| Tributary Area | | | | | | | | | | | | | Hydrology Summation | | | | Conduit Data | | | |
| ***** | | | | | | | | | | | | | ***** | | | | ***** | | | |
| Node to Node | C | Area (Ac) | Slope (%) | Length (Ft) | TC(0) (Min) | I(0) (In/Hr) | Q(0) (CFS) | TC (Min) | I (In/Hr) | Q (CFS) | Sum Q (CFS) | Size | Velocity (Ft/Sec) | Length (Ft) | TT (Min) | TT+TC (Min) | | | | |
| ***** | | | | | | | | | | | | | ***** | | | | ***** | | | |
| 910 | 880 | 0.47 | 22.00 | 0.00 | 0.0 | 20.00 | 2.72 | 25.50 | 20.00 | 2.72 | 25.50 | 25.50 | 30" | 5.19 | 375.00 | 1.20 | 21.20 | | | |
| 900 | 850 | 0.51 | 5.90 | 0.00 | 0.0 | 21.00 | 2.67 | 7.40 | 21.00 | 2.67 | 7.40 | 7.40 | 18" | 4.19 | 41.00 | 0.16 | 21.16 | | | |
| 880 | 870 | 0.52 | 2.70 | 0.00 | 0.0 | 16.00 | 2.96 | 3.90 | 21.20 | 2.66 | 3.49 | 36.39 | 30" | 7.41 | 341.00 | 0.77 | 21.97 | | | |
| 860 | 870 | 0.49 | 1.70 | 0.00 | 0.0 | 15.00 | 3.04 | 2.40 | 15.00 | 3.04 | 2.40 | 2.40 | 15" | 1.96 | 83.00 | 0.71 | 15.71 | | | |
| 870 | 850 | 0.52 | 1.80 | 0.00 | 0.0 | 38.00 | 2.01 | 1.40 | 21.97 | 2.62 | 0.81 | 39.30 | 30" | 8.01 | 80.00 | 0.17 | 22.14 | | | |
| 840 | 850 | 0.49 | 1.70 | 0.00 | 0.0 | 15.00 | 3.04 | 2.40 | 15.00 | 3.04 | 2.40 | 2.40 | 15" | 1.96 | 44.00 | 0.37 | 15.37 | | | |
| 850 | 839 | 0.52 | 0.90 | 0.00 | 0.0 | 15.00 | 3.04 | 1.40 | 22.14 | 2.61 | 1.20 | 42.59 | 30" | 8.68 | 158.00 | 0.30 | 22.44 | | | |

Date: 08-21-1986
Time: 09:30:45

Input File: 1yr012.stm

ECHO HILLS PHASE 2 S.W.S
30" DIA OUTFALL LINE --- 1-YEAR --- n=0.012
MWB 8/20/86

Storm Frequency = 1-Year

* * * HYDRAULICS * * *

| Node | Hyd-Slope (Ft/Ft) | Friction (Ft) | Bend (Ft) | Transition (Ft) | Manhole (Ft) | Deflection (Ft) | Junction (Ft) | Total (Ft) | Hyd-01 Elevation | Desired Elevation | Diff. (Ft) |
|------|----------------------|------------------|--------------|--------------------|-----------------|--------------------|------------------|---------------|---------------------|----------------------|---------------|
| 910 | 0.00329 | 1.2350 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 1.2350 | 157.0266 | 160.0000 | 2.97 |
| 900 | 0.00423 | 0.1734 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.1734 | 155.9650 | 156.5000 | 0.53 |
| 880 | 0.00671 | 2.2869 | 0.0000 | 0.0434 | 0.0000 | 0.0000 | 0.8952 | 3.2254 | 155.7916 | 156.5000 | 0.71 |
| 860 | 0.00118 | 0.0976 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0976 | 152.6633 | 156.4300 | 3.82 |
| 870 | 0.00782 | 0.6259 | 0.0000 | 0.0142 | 0.0000 | 0.3156 | 0.3239 | 1.2796 | 152.5662 | 156.1000 | 3.53 |
| 840 | 0.00118 | 0.0518 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0518 | 151.3334 | 155.5900 | 4.25 |
| 850 | 0.00919 | 1.4514 | 0.0000 | 0.0173 | 0.0000 | 0.0356 | 0.3822 | 1.8866 | 151.2866 | 155.5800 | 4.29 |
| 839 | 0.00000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 149.4000 | 155.1900 | 5.79 |

Off-Site Hydrology



Date 8/14/86 MB Page 1 of 2
 Project ECHO HILLS PH II S.D. 32-86349-1
 Item OFF SITE BASIN TO WEST

JUDITH / PINE GROVE BASIN

I. DESIGN PARAMETERS

DRAINAGE PATTERN IS UNDETERMINED AT THIS TIME. WILL USE OLD STREET PATTERN TO DETERMINE FLOW LENGTH.
 BASIN SLOPE (YARDS) 1%. GUTTER GRADE \approx 0.32%.
 SINGLE FAMILY 1/4 AC LOTS.
 80% C SOIL 20% B SOIL

$$C_z = 0.8(0.48) + 0.2(0.44) = 0.47$$

$$C_{100} = 0.8(0.68) + 0.2(0.61) = 0.67$$

OVERLAND FLOW

$$L = 150' \quad S = 1\% \quad n = 0.450$$

USING CHART 1, HEC-12, SOLVE FOR t_c BY KINEMATIC WAVE

Assume $i = 5$
 $i = 3$
 $i = 2.5$
 $i = 2.6$

Find $t_c = 23$
 $t_c = 29$
 $t_c = 31$
 $t_c = 32$

Actual $i = 3.1$
 $i = 2.7$
 $i = 2.6$
 $i = 2.6$ OK
 OK

Check $i > 2 = 2.6 \times 150 < 500$ KINEMATIC WAVE NOT USABLE

\therefore USE VELOCITY METHOD

$$V = 0.28 \text{ ft/sec} \quad t = \frac{150 \text{ ft}}{0.28 \text{ ft/sec}} \times \frac{1 \text{ min}}{60 \text{ sec}} = 8.9 \text{ min}$$

GUTTER FLOW

$$L = 1900' \quad n = 0.015$$

$$Y = 0.32\% \quad S_x = 1/32$$

$$\sum T_o + T_g = T_c = 20.3 \text{ min}$$

USE 20 min

Assume curb deep $T = 17'$

From Chart 2, HEC-12 $V = 2.8 \text{ ft/sec}$

$$T = 1900 \text{ ft} / 2.8 \text{ ft/sec} \times (1 \text{ min} / 60 \text{ sec}) = 11.4 \text{ min}$$



Date B/14/86 MWB Page 2 of 2
Project ECHO HILLS Pt II S.W.S. 32-86349-1
Item _____

$$T_c @ \text{basin outlet} = 20 \text{ min} \quad i_2 = 3.33 \text{ in/hr} \quad i_{100} = 6.53 \text{ in/hr}$$

$$Q_2 = 0.47 \times 3.33 \frac{\text{in}}{\text{hr}} \times 22 \text{ Ac} = 34 \text{ cfs}$$

$$Q_{100} = 0.67 \times 6.53 \frac{\text{in}}{\text{hr}} \times 22 \text{ Ac} = 96 \text{ cfs}$$

Current COW Design Procedure computes 34 cfs for this basin (2-year). Drainage Plan computed 40 cfs. SWS 191 computed 19 cfs.

CHECK HYDRAULIC GRADIENT IN AN ASSUMED 30" ϕ RCP.

$$T.C. @ \text{JUDITH \& NANTUCKET} = 160' \pm$$

$$H.G.L. @ \quad \quad \quad = 159'$$

$$HGL @ \#890 \text{ ON DRAINAGE PLAN} = 157'$$

$$L = 270'$$

$$S = \frac{1.6}{270} = 0.006 \text{ ft/ft}$$

$Q = K\sqrt{S} = 410 \sqrt{0.006} = 32 \text{ cfs} \approx \text{OK}$, BUT WHAT ABOUT ADDITIONAL FLOW DOWNSTREAM? APPEARS PIPE UNDERSIZED BY CURRENT CRITERIA.

Design Aids

April 15, 1986

ATTACHMENT A
DRAINAGE CRITERIA MANUAL

CITY OF WICHITA, KANSAS

RAINFALL INTENSITY TABLE FOR SEDGWICK COUNTY, KANSAS

The following tabulation contains rainfall intensity in inches per hour as derived from ESSA Weather Bureau Technical Paper 40 Modified to NWS Hydro-35, 1977 During First Hour

| DURATION IN MINUTES | RETURN PERIODS OF | | | | | | |
|------------------------|-------------------|------|------|-------|-------|-------|--------|
| | 1-YR | 2-YR | 5-YR | 10-YR | 25-YR | 50-YR | 100-YR |
| 5 | 4.18 | 5.57 | 6.53 | 7.41 | 8.52 | 9.48 | 10.32 |
| 6 | 3.99 | 5.32 | 6.25 | 7.09 | 8.16 | 9.09 | 9.89 |
| 7 | 3.81 | 5.09 | 5.99 | 6.81 | 7.84 | 8.74 | 9.50 |
| 8 | 3.66 | 4.89 | 5.75 | 6.55 | 7.55 | 8.42 | 9.15 |
| 9 | 3.52 | 4.70 | 5.54 | 6.31 | 7.28 | 8.13 | 8.83 |
| 10 | 3.39 | 4.52 | 5.34 | 6.09 | 7.04 | 7.86 | 8.54 |
| 11 | 3.27 | 4.36 | 5.16 | 5.89 | 6.81 | 7.61 | 8.27 |
| 12 | 3.18 | 4.21 | 4.99 | 5.71 | 6.60 | 7.38 | 8.02 |
| 13 | 3.05 | 4.08 | 4.84 | 5.53 | 6.41 | 7.17 | 7.79 |
| 14 | 2.96 | 3.95 | 4.69 | 5.37 | 6.23 | 6.97 | 7.57 |
| 15 | 2.87 | 3.83 | 4.56 | 5.22 | 6.06 | 6.78 | 7.37 |
| 16 | 2.78 | 3.72 | 4.43 | 5.08 | 5.90 | 6.60 | 7.18 |
| 17 | 2.71 | 3.61 | 4.31 | 4.95 | 5.75 | 6.44 | 7.00 |
| 18 | 2.63 | 3.51 | 4.20 | 4.83 | 5.61 | 6.29 | 6.84 |
| 19 | 2.56 | 3.42 | 4.10 | 4.71 | 5.47 | 6.14 | 6.68 |
| 20 | 2.50 | 3.33 | 4.00 | 4.60 | 5.35 | 6.00 | 6.53 |
| 21 | 2.44 | 3.25 | 3.90 | 4.50 | 5.23 | 5.87 | 6.39 |
| 22 | 2.38 | 3.17 | 3.81 | 4.40 | 5.12 | 5.75 | 6.26 |
| 23 | 2.32 | 3.10 | 3.73 | 4.31 | 5.01 | 5.63 | 6.13 |
| 24 | 2.27 | 3.03 | 3.65 | 4.22 | 4.91 | 5.52 | 6.01 |
| 25 | 2.22 | 2.96 | 3.57 | 4.13 | 4.81 | 5.41 | 5.90 |
| 26 | 2.20 | 2.90 | 3.50 | 4.05 | 4.72 | 5.31 | 5.79 |
| 27 | 2.16 | 2.84 | 3.43 | 3.98 | 4.63 | 5.21 | 5.69 |
| 28 | 2.14 | 2.78 | 3.37 | 3.90 | 4.55 | 5.12 | 5.59 |
| 29 | 2.11 | 2.72 | 3.30 | 3.83 | 4.47 | 5.03 | 5.49 |
| 30 | 2.08 | 2.67 | 3.24 | 3.76 | 4.39 | 4.94 | 5.40 |
| 31 | 2.05 | 2.62 | 3.19 | 3.70 | 4.32 | 4.86 | 5.32 |
| 32 | 2.02 | 2.57 | 3.10 | 3.63 | 4.25 | 4.79 | 5.22 |
| 33 | 1.99 | 2.52 | 3.05 | 3.57 | 4.18 | 4.71 | 5.14 |
| 34 | 1.96 | 2.48 | 3.01 | 3.51 | 4.11 | 4.63 | 5.07 |
| 35 | 1.93 | 2.44 | 2.98 | 3.46 | 4.05 | 4.56 | 5.00 |
| 36 | 1.91 | 2.39 | 2.93 | 3.41 | 3.99 | 4.50 | 4.93 |
| 37 | 1.89 | 2.35 | 2.88 | 3.36 | 3.93 | 4.43 | 4.86 |
| 38 | 1.87 | 2.32 | 2.84 | 3.31 | 3.87 | 4.37 | 4.79 |
| 39 | 1.85 | 2.28 | 2.80 | 3.26 | 3.82 | 4.31 | 4.73 |
| 40 | 1.83 | 2.24 | 2.76 | 3.22 | 3.76 | 4.25 | 4.66 |
| 41 | 1.81 | 2.21 | 2.72 | 3.17 | 3.71 | 4.19 | 4.60 |
| 42 | 1.79 | 2.18 | 2.68 | 3.13 | 3.66 | 4.13 | 4.54 |
| 43 | 1.77 | 2.14 | 2.64 | 3.09 | 3.61 | 4.08 | 4.49 |
| 44 | 1.75 | 2.11 | 2.61 | 3.05 | 3.57 | 4.03 | 4.43 |
| 45 | 1.73 | 2.08 | 2.57 | 3.01 | 3.52 | 3.98 | 4.38 |

ATTACHMENT A CONTINUED
Page 2

| DURATION IN MINUTES | RETURN PERIODS OF | | | | | | | |
|------------------------|-------------------|------|------|-------|-------|-------|--------|--|
| | 1-YR | 2-YR | 5-YR | 10-YR | 25-YR | 50-YR | 100-YR | |
| 46 | 1.70 | 2.05 | 2.54 | 2.97 | 3.48 | 3.93 | 4.33 | |
| 47 | 1.67 | 2.02 | 2.50 | 2.93 | 3.44 | 3.88 | 4.28 | |
| 48 | 1.66 | 2.00 | 2.47 | 2.90 | 3.39 | 3.84 | 4.23 | |
| 49 | 1.64 | 1.97 | 2.44 | 2.86 | 3.35 | 3.79 | 4.18 | |
| 50 | 1.61 | 1.95 | 2.41 | 2.83 | 3.32 | 3.75 | 4.13 | |
| 51 | 1.59 | 1.92 | 2.38 | 2.79 | 3.28 | 3.71 | 4.09 | |
| 52 | 1.56 | 1.89 | 2.35 | 2.76 | 3.24 | 3.67 | 4.05 | |
| 53 | 1.54 | 1.86 | 2.33 | 2.73 | 3.20 | 3.63 | 4.00 | |
| 54 | 1.52 | 1.84 | 2.30 | 2.70 | 3.17 | 3.59 | 3.96 | |
| 55 | 1.50 | 1.81 | 2.27 | 2.67 | 3.14 | 3.55 | 3.92 | |
| 56 | 1.47 | 1.79 | 2.25 | 2.64 | 3.10 | 3.51 | 3.88 | |
| 57 | 1.45 | 1.76 | 2.22 | 2.61 | 3.07 | 3.48 | 3.84 | |
| 58 | 1.43 | 1.74 | 2.20 | 2.59 | 3.04 | 3.44 | 3.81 | |
| 59 | 1.42 | 1.72 | 2.18 | 2.56 | 3.01 | 3.41 | 3.77 | |
| 60 | 1.40 | 1.69 | 2.15 | 2.53 | 2.98 | 3.37 | 3.73 | |
| 61 | 1.38 | 1.67 | 2.13 | 2.51 | 2.95 | 3.34 | 3.70 | |
| 62 | 1.36 | 1.65 | 2.11 | 2.48 | 2.92 | 3.31 | 3.67 | |
| 63 | 1.34 | 1.63 | 2.09 | 2.46 | 2.89 | 3.28 | 3.63 | |
| 64 | 1.33 | 1.61 | 2.07 | 2.44 | 2.86 | 3.25 | 3.60 | |
| 65 | 1.31 | 1.59 | 2.05 | 2.41 | 2.84 | 3.22 | 3.57 | |
| 66 | 1.30 | 1.57 | 2.03 | 2.39 | 2.81 | 3.19 | 3.54 | |
| 67 | 1.28 | 1.56 | 2.01 | 2.37 | 2.79 | 3.16 | 3.51 | |
| 68 | 1.26 | 1.54 | 1.99 | 2.35 | 2.76 | 3.13 | 3.48 | |
| 69 | 1.25 | 1.52 | 1.97 | 2.33 | 2.74 | 3.10 | 3.45 | |
| 70 | 1.24 | 1.50 | 1.95 | 2.31 | 2.71 | 3.08 | 3.42 | |
| 71 | 1.22 | 1.49 | 1.93 | 2.28 | 2.69 | 3.05 | 3.39 | |
| 72 | 1.21 | 1.47 | 1.92 | 2.26 | 2.67 | 3.02 | 3.36 | |
| 73 | 1.20 | 1.46 | 1.90 | 2.25 | 2.64 | 3.00 | 3.34 | |
| 74 | 1.18 | 1.44 | 1.88 | 2.23 | 2.63 | 2.98 | 3.31 | |
| 75 | 1.17 | 1.43 | 1.86 | 2.21 | 2.61 | 2.95 | 3.29 | |
| 76 | 1.16 | 1.41 | 1.85 | 2.19 | 2.58 | 2.93 | 3.26 | |
| 77 | 1.15 | 1.40 | 1.83 | 2.17 | 2.55 | 2.90 | 3.24 | |
| 78 | 1.13 | 1.38 | 1.82 | 2.15 | 2.53 | 2.88 | 3.22 | |
| 79 | 1.12 | 1.37 | 1.80 | 2.14 | 2.50 | 2.86 | 3.19 | |
| 80 | 1.11 | 1.36 | 1.79 | 2.12 | 2.48 | 2.84 | 3.16 | |
| 81 | 1.10 | 1.34 | 1.77 | 2.10 | 2.46 | 2.82 | 3.13 | |
| 82 | 1.09 | 1.33 | 1.76 | 2.08 | 2.43 | 2.79 | 3.10 | |
| 83 | 1.08 | 1.32 | 1.74 | 2.06 | 2.41 | 2.76 | 3.07 | |
| 84 | 1.07 | 1.31 | 1.73 | 2.04 | 2.39 | 2.74 | 3.04 | |
| 85 | 1.06 | 1.30 | 1.72 | 2.02 | 2.37 | 2.71 | 3.01 | |
| 86 | 1.05 | 1.28 | 1.70 | 2.00 | 2.34 | 2.69 | 2.99 | |
| 87 | 1.04 | 1.27 | 1.69 | 1.99 | 2.32 | 2.66 | 2.96 | |
| 88 | 1.03 | 1.26 | 1.68 | 1.97 | 2.30 | 2.64 | 2.93 | |
| 89 | 1.02 | 1.25 | 1.68 | 1.95 | 2.28 | 2.62 | 2.91 | |
| 90 | 1.01 | 1.24 | 1.66 | 1.93 | 2.26 | 2.59 | 2.88 | |

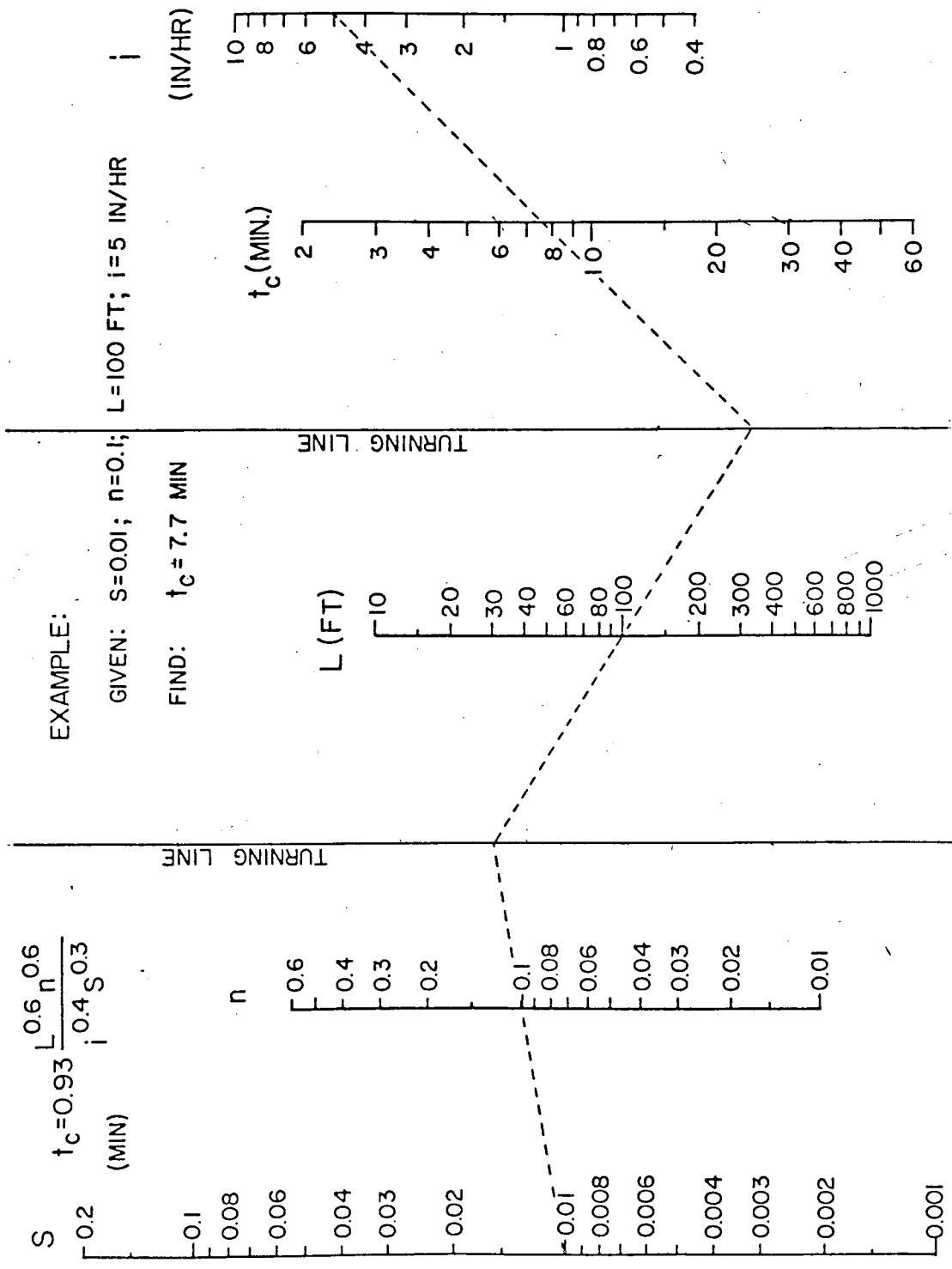


CHART 1. Kinematic wave formulation for determining time of concentration.

FROM: HEC-12, DRAINAGE OF HIGHWAY PAVEMENTS, FHWA, MAR. 1964.

Table 3. Spread at average velocity in a reach of triangular gutter.

| T_1/T_2 | 0 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 |
|-----------|------|------|------|------|------|------|------|------|------|
| T_a/T_2 | 0.65 | 0.66 | 0.68 | 0.70 | 0.74 | 0.77 | 0.82 | 0.86 | 0.90 |

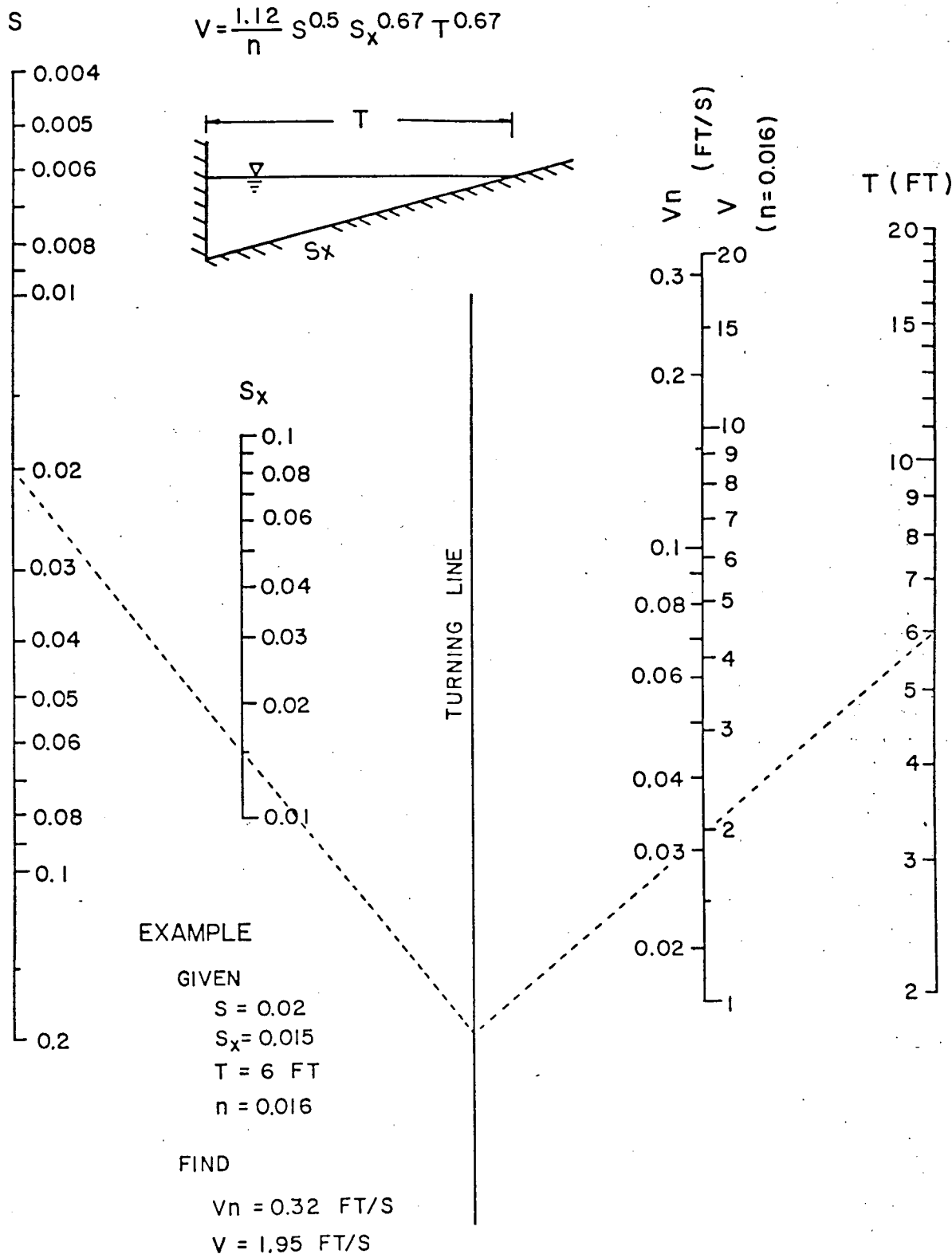


CHART 2. Velocity in triangular gutter sections.

$$Q = \frac{0.56}{n} S_x^{1.67} S^{0.5} T^{2.67}$$

EXAMPLE: GIVEN:
 $n=0.016$; $S_x=0.03$
 $S=0.04$; $T=6$ FT

FIND:
 $Q = 2.4$ FT³/S
 $Qn = 0.038$ FT³/S

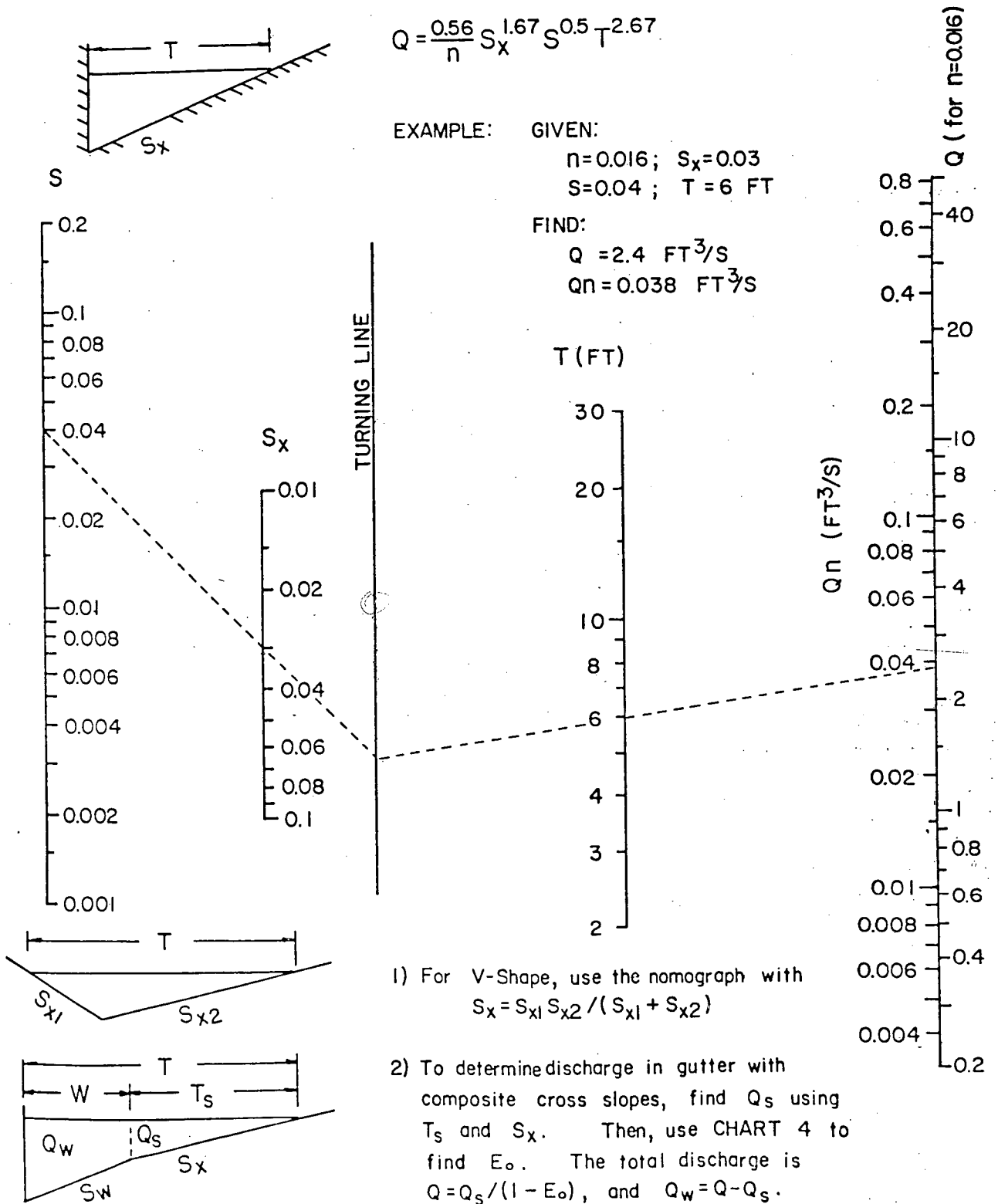
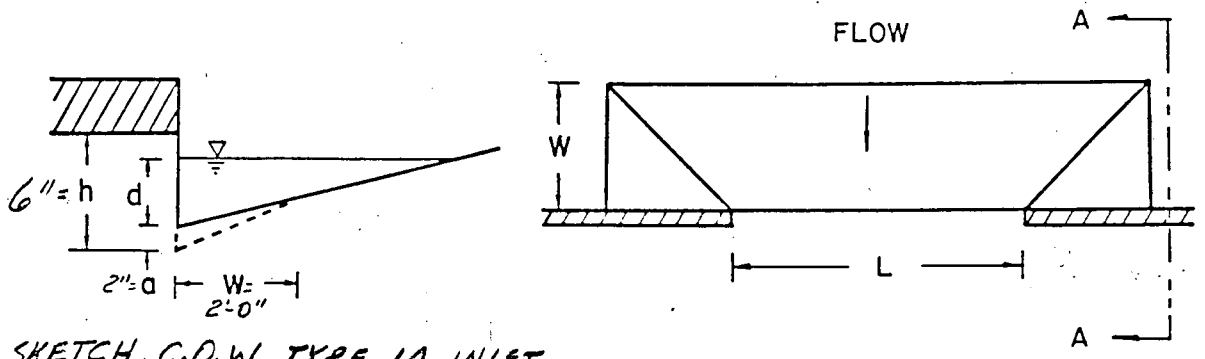


CHART 3. Flow in triangular gutter sections.

From: HEC-12 DRAINAGE OF HIGHWAY FURNISHES, F.H.W.A., Mar. 1964



DEF. SKETCH, C.D.W. TYPE 1A INLET

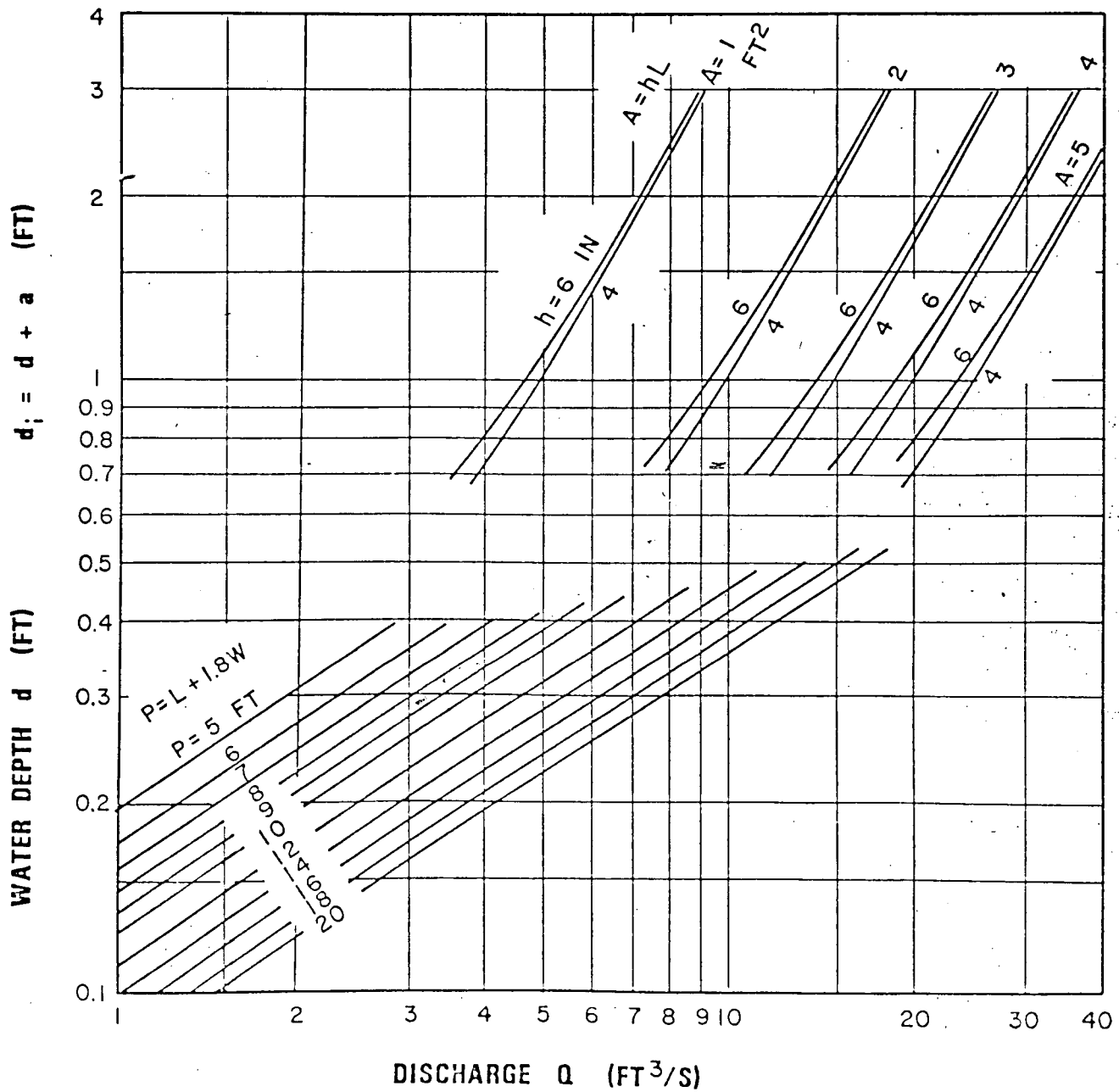


CHART 12. Depressed curb-opening inlet capacity in sump locations.

FROM: HEC-12, DRAINAGE OF HIGHWAY PAVEMENTS, F.H.W.A., MAR., 1984

TABLE 7.—Recommended Manning's Roughness Coefficients for Overland Flow

| Cover or treatment (1) | Residue rate (ton/acre) (2) | Value recommended (3) | Range (4) |
|--------------------------------------|-----------------------------------|-----------------------------|--------------|
| Concrete or asphalt ^a | | 0.011 | 0.01–0.013 |
| Bare sand ^a | | 0.01 | 0.010–0.016 |
| Graveled surface ^a | | 0.02 | 0.012–0.03 |
| Bare clay-loam (eroded) ^a | | 0.02 | 0.012–0.033 |
| Fallow—no residue | | 0.05 | 0.006–0.16 |
| Chisel plow | <1/4 | 0.07 | 0.006–0.17 |
| | <1/4–1 | 0.18 | 0.07–0.34 |
| | 1–3 | 0.30 | 0.19–0.47 |
| | >3 | 0.40 | 0.34–0.46 |
| Disk/harrow | <1/4 | 0.08 | 0.008–0.41 |
| | 1/4–1 | 0.16 | 0.10–0.25 |
| | 1–3 | 0.25 | 0.14–0.53 |
| | >3 | 0.30 | — |
| No till | <1/4 | 0.04 | 0.03–0.07 |
| | 1/4–1 | 0.07 | 0.01–0.13 |
| | 1–3 | 0.30 | 0.16–0.47 |
| Moldboard plow (Fall) | | 0.06 | 0.02–0.10 |
| Coulter | | 0.10 | 0.05–0.13 |
| Range (natural) | | 0.13 | 0.01–0.32 |
| Range (clipped) | | 0.10 | 0.02–0.24 |
| Grass (bluegrass sod) | | 0.45 | 0.39–0.63 |
| Short grass prairie ^a | | 0.15 | 0.10–0.20 |
| Dense grass ^b | | 0.24 | 0.17–0.30 |
| Bermuda grass ^b | | 0.41 | 0.30–0.48 |

^aFrom Woolhiser, Ref. 26. *

^bWeeping lovegrass, bluegrass, buffalo grass, blue gramma grass, native grass mix (OK), alfalfa, lespedeza (from Palmer, Ref. 18).

for conditions greatly different from the field experiments. These data should be valid for so-called sheet flow or shallow-depth overland flow that match the conditions in the experimental plots. Channelized flow was present in many of the experimental runs, especially where tillage marks were present or when rilling had occurred. Channelization was not so obvious when the residue rates were greater than 1/4 ton per acre (5.6 metric ton/ha) (G. R. Foster, personal communication).

The depth of calculated flow should not become too large. On long flow planes, the routing models may calculate depths that may be unrealistically large. The users must be aware of this and limit the flow plane lengths. It appears that excessive depths would not be encountered if the slope lengths are on the order of 150–300 ft (50–100 m).

These roughness values include the effect of rain drop impact, which tends to increase the effective roughness. The rainfall intensities used in these erosion plots are fairly high, ranging from 2–4 in./hr (50–100 mm/h). The effective roughness will probably be less than these values if no rainfall is considered to be falling.

From "Roughness Coefficients for Routing Surface Runoff," by Edwin T. Engman, Journal of Irrigation and Drainage Engineering, vol 112, no. 1, Feb, 1986, pp39-53.

FROM: CONCRETE PIPE DESIGN MANUAL
 AMERICAN CONCRETE PIPE
 ASSOC., JUNE 1960

BLE 3

FULL FLOW COEFFICIENT VALUES
 CIRCULAR CONCRETE PIPE

$Q = KR^5$
 $K = \frac{Q}{R^5}$

| D Pipe Diameter (inches) | A Area (Square Feet) | R Hydraulic Radius (Feet) | Value of $C_1 = \frac{1.486}{n} \times A \times R^{2.5} = K$ | | |
|-----------------------------------|-------------------------------|------------------------------------|--|---------|---------|
| | | | n=0.010 | n=0.011 | n=0.012 |
| 8 | 0.349 | 0.167 | 15.8 | 14.3 | 13.1 |
| 10 | 0.545 | 0.208 | 28.4 | 25.8 | 23.6 |
| 12 | 0.785 | 0.250 | 46.4 | 42.1 | 38.6 |
| 15 | 1.227 | 0.312 | 84.1 | 76.5 | 70.1 |
| 18 | 1.767 | 0.375 | 137 | 124 | 114 |
| 21 | 2.405 | 0.437 | 206 | 187 | 172 |
| 24 | 3.142 | 0.500 | 294 | 267 | 245 |
| 27 | 3.976 | 0.562 | 402 | 366 | 335 |
| 30 | 4.909 | 0.625 | 533 | 485 | 444 |
| 33 | 5.940 | 0.688 | 686 | 624 | 574 |
| 36 | 7.069 | 0.750 | 867 | 788 | 722 |
| 42 | 9.621 | 0.875 | 1308 | 1189 | 1090 |
| 48 | 12.566 | 1.000 | 1867 | 1698 | 1556 |
| 54 | 15.904 | 1.125 | 2557 | 2325 | 2131 |
| 60 | 19.635 | 1.250 | 3385 | 3077 | 2821 |
| 66 | 23.758 | 1.375 | 4364 | 3967 | 3636 |
| 72 | 28.274 | 1.500 | 5504 | 5004 | 4587 |
| 78 | 33.183 | 1.625 | 6815 | 6195 | 5679 |
| 84 | 38.485 | 1.750 | 8304 | 7549 | 6920 |
| 90 | 44.170 | 1.875 | 9985 | 9078 | 8321 |
| 96 | 50.266 | 2.000 | 11850 | 10780 | 9878 |
| 102 | 56.745 | 2.125 | 13940 | 12670 | 11620 |
| 108 | 63.617 | 2.250 | 16230 | 14760 | 13530 |
| 114 | 70.882 | 2.375 | 18750 | 17040 | 15620 |
| 120 | 78.540 | 2.500 | 21500 | 19540 | 17920 |
| 126 | 86.590 | 2.625 | 24480 | 22260 | 20400 |
| 132 | 95.033 | 2.750 | 27720 | 25200 | 23100 |
| 138 | 103.870 | 2.875 | 31210 | 28370 | 26010 |
| 144 | 113.100 | 3.000 | 34960 | 31780 | 29130 |

TABLE 4

FULL FLOW COEFFICIENT VALUES
 ELLIPTICAL CONCRETE PIPE

| Pipe Size R x S (HE) S x R (VE) (Inches) | Approximate Equivalent Circular Diameter (Inches) | A Area (Square Feet) | R Hydraulic Radius (Feet) | Value of $C_1 = \frac{1.486}{n} \times A \times R^{2.5} = K$ | | |
|---|---|-------------------------------|------------------------------------|--|---------|---------|
| | | | | n=0.010 | n=0.011 | n=0.012 |
| 14 x 23 | 18 | 1.8 | 0.367 | 138 | 125 | 116 |
| 19 x 30 | 24 | 3.3 | 0.490 | 274 | 232 | 202 |
| 22 x 34 | 27 | 4.1 | 0.546 | 405 | 368 | 339 |
| 24 x 38 | 30 | 5.1 | 0.613 | 547 | 497 | 456 |
| 27 x 42 | 33 | 6.3 | 0.686 | 728 | 662 | 607 |
| 29 x 45 | 36 | 7.4 | 0.736 | 891 | 810 | 746 |
| 32 x 49 | 39 | 8.8 | 0.812 | 1140 | 1036 | 948 |
| 34 x 53 | 42 | 10.2 | 0.875 | 1386 | 1260 | 1156 |
| 38 x 60 | 48 | 12.9 | 0.969 | 1878 | 1707 | 1565 |
| 43 x 68 | 54 | 16.5 | 1.106 | 2635 | 2395 | 2196 |
| 48 x 76 | 60 | 20.5 | 1.229 | 3491 | 3174 | 2910 |
| 53 x 83 | 66 | 24.8 | 1.352 | 4503 | 4094 | 3753 |
| 58 x 91 | 72 | 29.5 | 1.475 | 5680 | 5164 | 4734 |
| 63 x 98 | 78 | 34.6 | 1.598 | 7027 | 6388 | 5856 |
| 68 x 106 | 84 | 40.1 | 1.721 | 8560 | 7790 | 7140 |
| 72 x 113 | 90 | 46.1 | 1.845 | 10300 | 9365 | 8584 |
| 77 x 121 | 96 | 52.4 | 1.967 | 12220 | 11110 | 10190 |
| 82 x 128 | 102 | 59.2 | 2.091 | 14380 | 13070 | 11980 |
| 87 x 136 | 108 | 66.4 | 2.215 | 16770 | 15240 | 13970 |
| 92 x 143 | 114 | 74.0 | 2.340 | 19380 | 17620 | 16150 |
| 97 x 151 | 120 | 82.0 | 2.461 | 22190 | 20180 | 18490 |
| 106 x 166 | 132 | 99.2 | 2.707 | 28630 | 26020 | 23860 |
| 116 x 180 | 144 | 118.6 | 2.968 | 36400 | 33100 | 30340 |

TABLE 5

FULL FLOW COEFFICIENT VALUES
 CONCRETE ARCH PIPE

| Pipe Size R x S (Inches) | Approximate Equivalent Circular Diameter (Inches) | A Area (Square Feet) | R Hydraulic Radius (Feet) | Value of $C_1 = \frac{1.486}{n} \times A \times R^{2.5} = K$ | | |
|--------------------------------|---|-------------------------------|------------------------------------|--|---------|---------|
| | | | | n=0.010 | n=0.011 | n=0.012 |
| 11 x 18 | 15 | 1.1 | 0.25 | 65 | 59 | 54 |
| 13 1/2 x 22 | 18 | 1.6 | 0.30 | 110 | 100 | 91 |
| 15 1/2 x 26 | 21 | 2.2 | 0.36 | 165 | 150 | 137 |
| 18 x 28 1/2 | 24 | 2.8 | 0.45 | 243 | 221 | 203 |
| 22 1/2 x 36 1/4 | 30 | 4.4 | 0.55 | 441 | 401 | 368 |
| 26 3/8 x 43 3/4 | 36 | 6.4 | 0.68 | 736 | 669 | 613 |
| 31 1/2 x 51 1/2 | 42 | 8.8 | 0.80 | 1125 | 1023 | 938 |
| 36 x 58 1/2 | 48 | 11.4 | 0.90 | 1579 | 1435 | 1315 |
| 40 x 65 | 54 | 14.3 | 1.01 | 2140 | 1945 | 1783 |
| 45 x 73 | 60 | 17.7 | 1.13 | 2851 | 2592 | 2376 |
| 54 x 88 | 72 | 25.6 | 1.35 | 4641 | 4219 | 3867 |
| 62 x 102 | 84 | 34.6 | 1.57 | 6941 | 6310 | 5784 |
| 72 x 115 | 90 | 44.5 | 1.77 | 9668 | 8789 | 8056 |
| 77 1/2 x 122 | 96 | 51.7 | 1.92 | 11850 | 10770 | 9872 |
| 87 1/8 x 138 | 108 | 66.0 | 2.17 | 16430 | 14940 | 13690 |
| 96 1/4 x 154 | 120 | 81.8 | 2.42 | 21975 | 19977 | 18312 |
| 105 1/2 x 168 3/4 | 132 | 99.1 | 2.65 | 28292 | 25720 | 23577 |