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Addendum to the

Design Manual for Low Water Stream Crossings

June 1984

Iowa DOT Project HR-247
ERI Project 1599
ISU-ERI-Ames-85001

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report

College of Engineering
Iowa State University

Addendum to the

Design Manual for Low Water Stream Crossings

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DEPARTMENT OF CIVIL ENGINEERING
ENGINEERING RESEARCH INSTITUTE
IOWA STATE UNIVERSITY, AMES

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1. SUMMARY REPORT OF RESEARCH ON THE HYDRAULIC MODELING OF LOW WATER STREAM CROSSINGS

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May 1984

1.1. Development of Equations

The goal of this study was to develop an equation for the total head of water upstream of a low water stream crossing (LWSC) during a flood of a given magnitude. Ideally, this subject should be studied in a field situation using actual LWSCs. But because of the large number of LWSCs and the difficulties of testing LWSCs during flood flow conditions, a hydraulic modeling study was determined to be the best approach.

First, an equation was developed for a small scale model. Through principles of similitude and modeling theory, this equation could then be applied to a full size LWSC. Various geometric dimensions, such as the length and the width of an LWSC, the height of the roadway above the streambed, the width of the stream channel, and the total upstream head, were all varied to determine their effects on the stream flow. These parameters are shown in Fig. 1.1 and defined as follows.

Q = total stream flow, cfs

V = average upstream velocity, ft/s

H = total upstream head, ft

h = upstream depth head, ft

h_v = upstream velocity head, ft

L = length of LWSC, normal to flow, ft

T = width of upstream water surface, ft

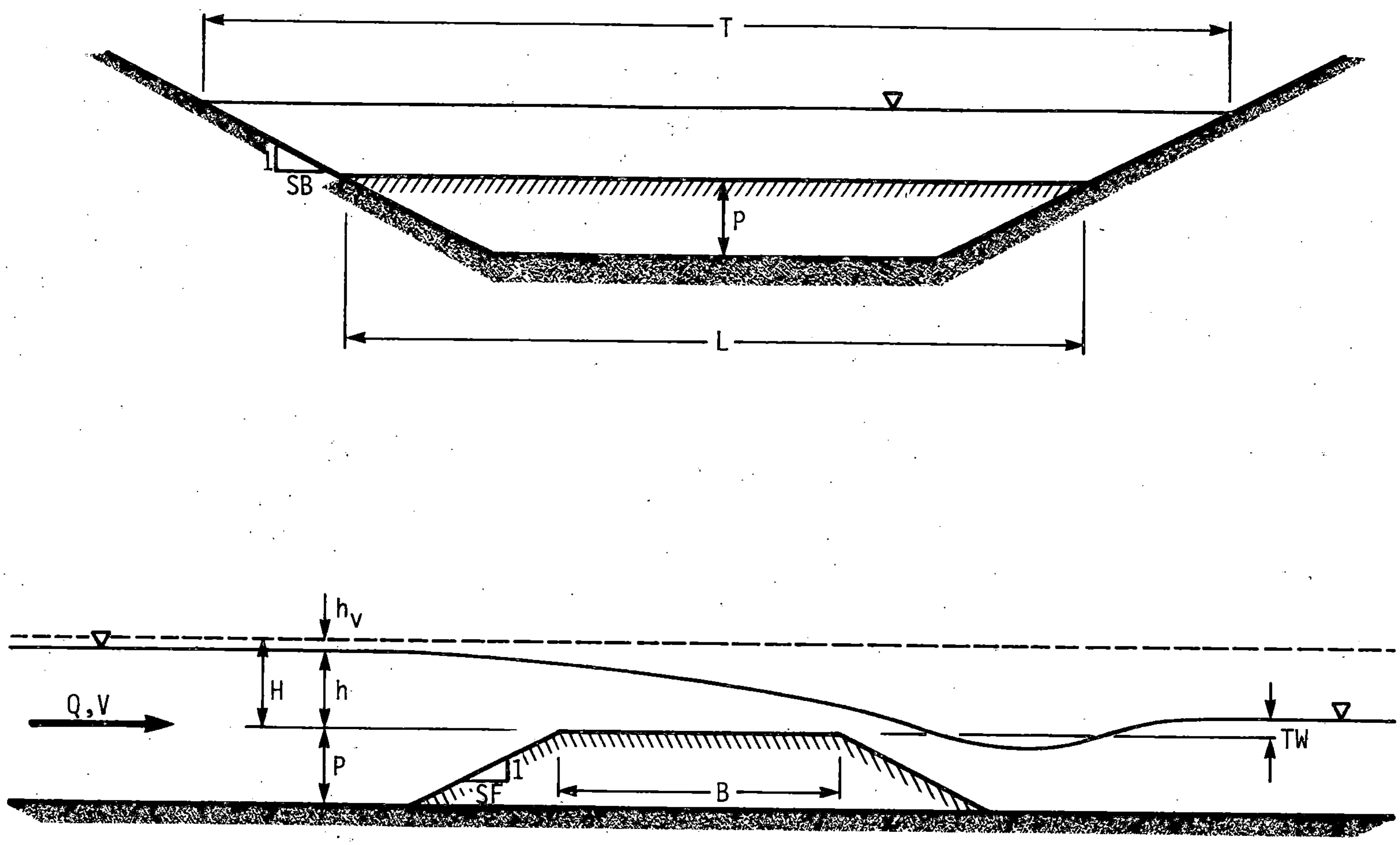


Figure 1.1. Cross section and profile views of a low water stream crossing.

B = width of LWSC, parallel to flow, ft

P = height of LWSC surface above streambed, ft

TW = tailwater depth relative to LWSC surface, ft

SB = slope of stream channel banks, ft/ft

SF = slope of LWSC foreslope, ft/ft

All experimental work was done in the Water Resources Laboratory located in Town Engineering Building at Iowa State University. The water recirculation system in the laboratory was used for the testing of the models in a 12 feet long concrete block flume.

The roughness of the entire model set-up was properly scaled to simulate an actual LWSC setting. The model of the stream channel was constructed from a wooden frame and a roughened concrete surface, while the model LWSCs were made from wood with a sanded, varnished surface to simulate a gravel LWSC surface.

To verify the equations that resulted from laboratory work, three duplicate sets of data were made from 201 experimental runs. In each of these runs, Q, V, H, L, B, and P were measured and varied to find the relationship between all the variables.

All the data were analyzed using the Statistical Analysis System (SAS) on the AS/6 computer at the Iowa State University Computation Center. By using the SAS linear regression procedure, relationships were found between the variables. The "best-fit" equation was found through the method of least squares.

One variable that had poor correlation and thus did not seem to significantly affect the flow, Q, was the height of the LWSC above streambed, P. Also, the width of the road crossing, B, seemed to have only a minor effect on the flow. The final analysis resulted in the following equation:

$$Q = 4.83\ L^{0.823} H^{1.67} \tag{1.1}$$

This can be rearranged as follows.

$$H = 0.389\ Q^{0.599} L^{-0.493} \tag{1.2}$$

Equation (1.2) can be used when the flood flow of a recurrence interval of, say, 10 years, and the length, L, of the crossing are known. This determines the total upstream head, H, not the depth upstream or the depth of water on the LWSC surface. The determination of the latter was not the subject of this study. The data were not sufficient to determine the depth at the middle of the roadway, but did indicate that this depth may be between 0.60 and 0.65 of the total upstream head, H. This contrasts with Hulsing (1967) who reported that the depth over the roadway is five-sixth of H.

In an effort to verify the results of experimentation, Eq. (1.1) was compared to the standard broad-crested weir equation

$$Q = CLH^{1.50} \tag{1.3}$$

where C is a coefficient dependent primarily on the total head, H, and the surface roughness.

An LWSC is normally situated in a trapezoidal-shaped channel (Fig. 1.1) and, since Eq.(1.3) is for a rectangular-shaped channel, a computer program was written to divide the trapezoidal cross section into X number of sections and then treat each section as a rectangular channel of width L/X. The C value for each small section was determined from Hulsing's work. The flows for each section could be found by using Eq. (1.3), and then they were summed together to determine the total flow, Q, over the LWSC.

The composite C could then be solved for by using Eq. (1.3) again, since the total Q, L, and H were known. This resulted in highly varying values of C for a constant length, L, and varying head, H. C would not vary as much if the channel was of rectangular rather than of trapezoidal shape, because in a rectangular channel the constant length, L, and the water surface width, T, are always equivalent, irregardless of the depth of water; but in a trapezoidal channel, as H increases, T becomes significantly larger than L.

Therefore, when L was replaced with an average of L and T, values of C were more constant. Using (L + T)/2 in place of L in Eq. (1.4) could possibly be viewed as transforming that trapezoidal channel into a rectangular cross section of length (L + T)/2.

This resulted in the following equation:

$$Q = 2.77 \frac{L + T}{2} H^{1.50} \tag{1.4}$$

This is for a trapezoidal channel but does not include losses that will occur from the eddy action on the approach grades to the LWSC.

Since these approach grades are at a milder slope, they will cut into the stream bank, thus causing some turbulence in the water that is flowing over the LWSC.

Since Eq. (1.1) does include losses due to this turbulence, an equivalent for it was found in similar form to Eq. (1.4).

$$Q = 2.65 \frac{L + T}{2} H^{1.50} \tag{1.5}$$

$$Q = 4.83 L^{0.823} H^{1.67} \tag{1.1}$$

Equations (1.1) and (1.5) were developed for a stream channel with approximately 2:1 bank slopes (SB in Fig. 1.1) and 2:1 foreslopes (SF). They can be applied to most values of L and H and any values of B and P.

Equations (1.1) and (1.5) give very similar results so can be used interchangeably for most LWSC situations. The exception to this is when L is small (25 feet or less) and H is large (5 feet or more). In this case, Eq. (1.1) should be used.

1.2. Use of Developed Equations

Since Eq. (1.2) deals only with the flows over the top of a vented LWSC and not with the flows passing through the pipes, an example problem is given below to determine the portion of a flood passing over a LWSC by using the Hydraulic Charts for the Selection of Highway Culverts (HEC No. 5). Using this information the upstream head, H, can then be calculated from Eq. (1.2).

Using HEC No. 5 in this example problem is different than using it to design the LWSC. In the latter case, the flows over the ford and through the pipes are both known. In the former case, the total flood flow is known, but the proportions over the LWSC and through the pipes are not. Therefore, a trial-and-error method using HEC No. 5 must be employed to determine these proportions. Then, through Eq. (1.2), the total upstream head can be determined.

An already-designed LWSC from Rossmiller et al. (1983) is used in this example.

The variables used are defined as follows:

Q_{10} = flood flow of ten year recurrence inverval, cfs

= $Q_{top} + Q_{pipe}$

Q_{top} = the portion of Q_{10} that passes over the top of the LWSC, cfs

Q_{pipe} = the portion of Q_{10} that passes through the pipes, cfs

$Q_{HEC\ 5}$ = the pipe flow determined from HEC No. 5; it should equal Q_{pipe} in the final analysis, cfs

The general procedure begins with the assumption that Q_{top} is 90% of Q_{10}. Then calculate H from Eq. (1.2) using Q_{top}. Add H and P to find HW. Using HW and D, go to the proper HEC No. 5 charts for inlet and outlet control and compare this $Q_{HEC\ 5}$ with Q_{pipe}.

If $Q_{HEC\ 5} > Q_{pipe}$, decrease Q_{top}.

If $Q_{HEC\ 5} < Q_{pipe}$, increase Q_{top}.

Since $Q_{HEC\ 5}$ will not change significantly with changes in HW, try $Q_{top} = Q_{10} - Q_{HEC\ 5}$. ($Q_{pipe}$ now equals $Q_{10} - Q_{top}$).

Repeat the process until $Q_{HEC\ 5} = Q_{pipe}$.

1.2.1. Example Problem

$$Q_{10} = 3900 \text{ cfs}$$

$$P = 3.5 \text{ ft}$$

$$L = 91 \text{ ft}$$

The ford has nine 15" corrugated metal pipes with mitered ends.

Try

$$Q_{top} = 0.9Q_{10} = 0.90(3900) = 3510 \text{ cfs}$$

$$H = 0.3890Q_{top}^{0.599}\ L^{-0.493} \qquad \text{(Eq. (1.2))}$$

$$= 0.389(3510)^{0.599}(91)^{-0.493}$$

$$= 5.6 \text{ ft}$$

$$HW = H + P = 5.6 + 3.5$$

$$= 9.1 \text{ ft}$$

$$Q_{pipe} = Q_{10} - Q_{top} = 3900 - 3510$$

$$= 390 \text{ cfs total} = 390/9 \text{ pipes}$$

$$= 43 \text{ cfs/pipe}$$

Check inlet control, using Chart 5 in HEC 5.

$$HW/D = 9.1/1.25 = 7.3$$

$$Q_{HEC\ 5} = 12 \text{ cfs} < 43 \text{ cfs}$$

Therefore, increase proportion of Q_{10} that flows over the top, i.e. increase Q_{top}.

$$Q_{top} = Q_{10} - Q_{HEC\ 5} = 3900 - (12 \times 9) = 3792 \text{ cfs}$$

$$H = 5.9 \text{ ft} \quad \text{(from Eq. (1.2))}$$

$$HW = 5.9 + 3.5 = 9.4 \text{ ft}$$

Check inlet control again.

$$HW/D = 7.5$$

$$Q_{HEC\ 5} = 12 \text{ cfs/pipe} \quad \text{OK}$$

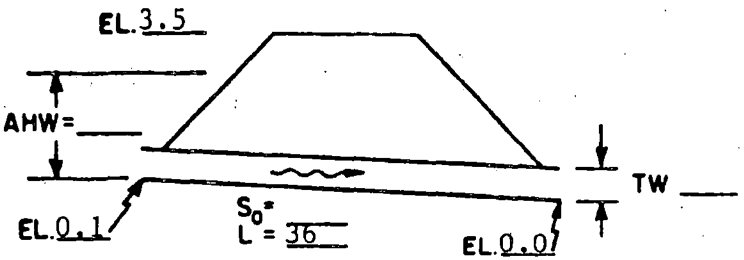
Now check outlet control (Fig. 1.2).

$$K_e = 0.7$$

HYDROLOGIC AND CHANNEL INFORMATION
Q_1 = ______ TW_1 = ______
Q_2 = ______ TW_2 = ______
(Q_1 = DESIGN DISCHARGE, SAY Q_{25})
(Q_2 = CHECK DISCHARGE, SAY Q_{50} OR Q_{100})

SKETCH

STATION : ______



MEAN STREAM VELOCITY = ______
MAX. STREAM VELOCITY = ______

CULVERT DESCRIPTION (ENTRANCE TYPE)	Q	SIZE	HEADWATER COMPUTATION: INLET CONT.		OUTLET CONTROL $HW = H + h_o - LS_o$								CONTROLLING HW	OUTLET VELOCITY	COST	COMMENTS
			$\frac{HW}{D}$	HW	K_e	H	d_c	$\frac{d_c+D}{2}$	TW	h_o	LS_o	HW				
CMP mitered	13	15			0.7	8.2	1.25	1.25	8.5	8.5	0.1	16.6	16.6			decrease Q
" "	4.5	15			0.7	1.0	1.25	1.25	8.5	8.5	0.1	9.4	9.4			

SUMMARY & RECOMMENDATIONS:

Figure 1.2. Headwater depths for a pipe operating under outlet control.

From a stage-discharge curve for Q_{10}, the tailwater depth

$h_o = 8.5$ ft

HW = 16.6 ft (Chart 11) outlet controls

Now Q_{pipe} must be decreased so that the outlet control HW is equal to the HW that results from Eq. (1.2).

$Q_{pipe} = 4.5$ cfs/pipe

H = 1.0 ft (Chart 11)

HW = 9.4 ft

So

$Q_{pipe} = 4.5$ cfs/pipe $\times$ 9 pipes = 40 cfs

$Q_{top} = 3900 - 40 = 3860$ cfs

Check H again using this new Q_{top}

H = 5.9 ft (Equation 1.2) OK

So, in summary,

$Q_{10} = 3900$ cfs

$Q_{top} = 3860$ cfs

$Q_{pipe} = 4.5$ cfs/pipe = 40 cfs total

H = 5.9 ft

H is the total upstream head as defined in Fig. 1.1. Note that the tailwater, TW, also defined in Fig. 1.1, is 5.0 feet. This results in a TW/H ratio of 0.85 which, according to Hulsing, slightly decreases Q over the LWSC.

Practically, the effect that this high tailwater will have is to back up the water upstream, increasing H.

1.3. References

Herr, L. A., and H. G. Bossy, "Hydraulic Charts for the Selection of Highway Culverts," Hydraulic Engineering Circular No. 5, Washington, D.C., U.S. Department of Transportation, 1965.

Hulsing, H., "Measurement of Peak Discharge at Dams by Indirect Methods," Techniques of Water Resources Investigations of the United States Geological Survey, Chapter A5, Washington, D.C., U.S. Geological Survey. 1967.

Rossmiller, R. L., R. A. Lohnes, S. L. Ring, J. M. Phillips, and B. C. Barrett, "Design Manual for Low Water Stream Crossings," ISU-ERI-Ames 84029, Department of Civil Engineering, Engineering Research Institute, Iowa State University, Ames, Iowa, 1983.

2. REPORT ON LOW WATER STREAM CROSSING INVENTORY

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May 1984

2.1. Introduction

Subsequent to the publication of the "Design Manual for Low Water Stream Crossings" (Rossmiller et al. 1983), an inventory of low water stream crossings (LWSCs) was developed.

The object of the inventory was to compile and correlate various data on materials, drainage areas, and usage of LWSCs.

A questionnaire was sent to every county in Iowa (see Fig. 2.1). Out of 99 counties, 93 replied, and of those 93, 42 counties had a combined total of 220 LWSCs. Figure 2.2 shows the distribution of vented (including low water bridges) and unvented LWSCs in Iowa. There are 98 LWSCs which are either vented or low water bridges, 53 unvented, and 69 LWSCs where it was impossible to determine whether they were vented or unvented from the answers received.

The quality and quantity of the responses received from the questionnaire limited this inventory. The Appendix only contains a list of responses to selected questions from the questionnaire since the insufficient response to the other questions did not warrant inclusion in the list.

2.2. Results

Referring to the Appendix, the following highlights of the inventory are revealed.

The county with the most LWSCs is Benton County with a total of 45, most of these being low water bridges (LWBs). The average number of LWSCs per county is 5.

Return to: Dr. Ronald Rossmiller
351 Town Engineering Building
Iowa State University
Ames, IA 50011

RETURN BY JULY 25, 1983

County ______________

INVENTORY OF LOW WATER STREAM CROSSINGS IN IOWA

County ____________________ Location: ____________________

Road no. ________ or location in section ________ Road direction at crossing ______________

What structure did crossing replace? ____________________ FHWA no., if available ________

Stream name ______________________________ D.A. ______________ square miles.

Year constructed __________ Traffic count __________ Design flood __________ year.

Surfacing material road __________ Crossing __________ Crossing foreslope __________

Crossing core material(s) ______________________________ Attach sketch

Are there cutoff walls? ________ If yes, describe or attach sketch ____________________

____

Vented ford: No. of pipes __________ ; Size __________ in.; Material ______________

Not vented, describe: ____

Total cost: $ _____ Contract ____ Force account ____ Attach bid items and quantities, if available

Stream slope at site ____ ft/ft

Height of low point in road above streambed __________ ft. Above pipe invert __________ ft.

Nature of stream channel material: ____

Average number of days water is over roadway per year ______________________________

Channel and valley cross section: Draw sketch on back, label breaks in slopes with elevation and distance from left end, list Manning's n values.

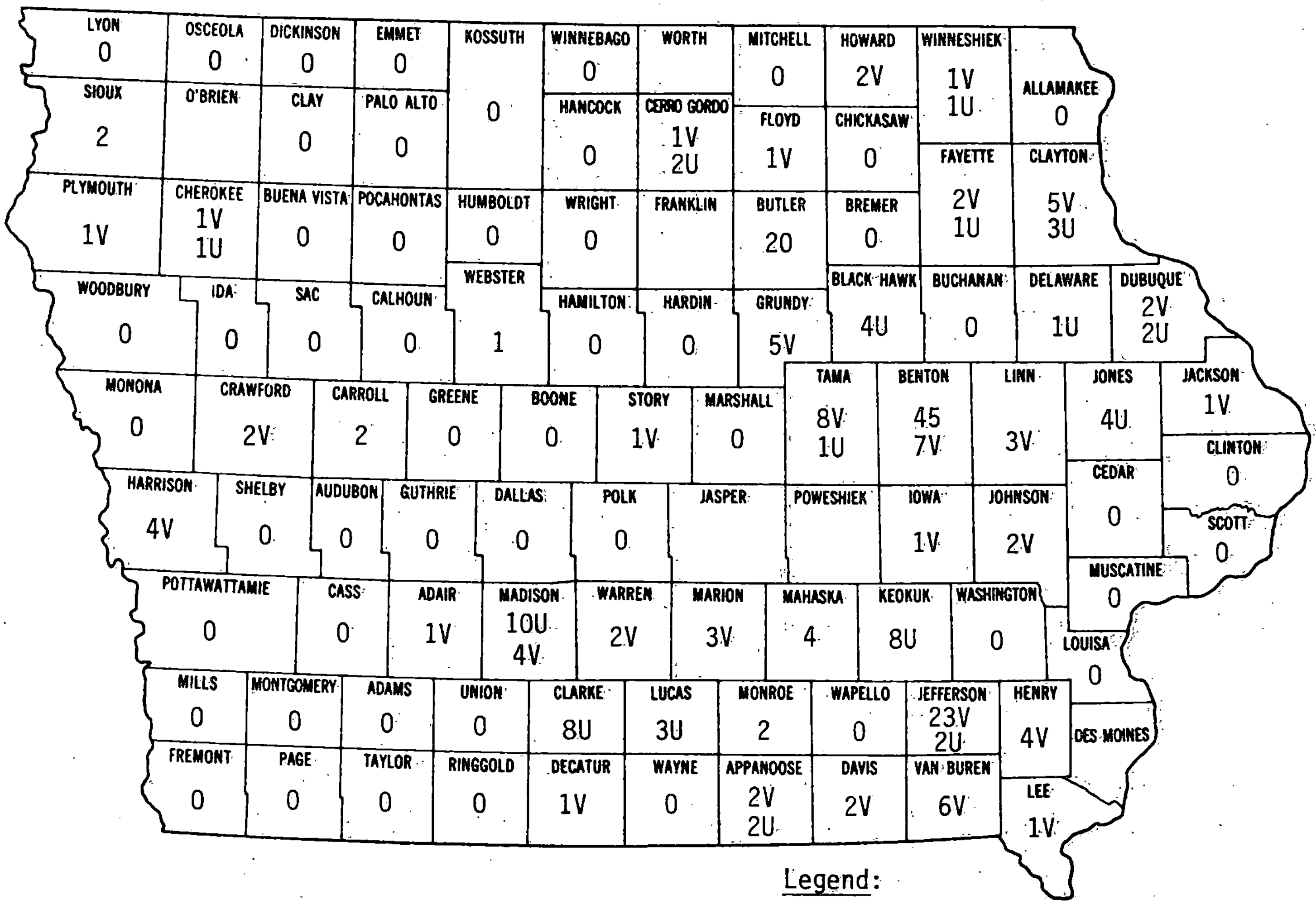
Roadway vertical alignment: Attach plans or draw sketch on back; list grades, curve data and stations.

Roadway horizontal alignment: Attach plans or draw sketch on back; list curve data and stations.

PERFORMANCE DATA

Use separate sheet of paper write a short history of maintenance and costs, if known, and a short history of performance during floods and repairs needed, if known.

Figure 2.1. Inventory Questionnaire



Legend:

? - Type Unknown
V - Vented (Including Low Water Bridges)
U - Unvented
- No Reply

Figure 2.2. Distribution of LWSCs in Iowa, June 1984.

The drainage area above a LWSC ranges from 0.01 square miles (Dubuque County) to 400 square miles (Jefferson County) with an average of 39 square miles.

Howard County has an average daily traffic (ADT) of 300 over one of its LWSCs while the minimum ADT is zero and the average ADT is 22.

Although an unvented ford is generally inundated for 365 days a year, on two vented LWSCs in Henry County the minimum of days wet is two. The average number of days wet is 102.

The maximum height above streambed is 12.5 feet on a LWB in Davis County. The minimum height is, of course, zero feet and the average is 2.7 feet.

The most popular material used in LWSCs is concrete, with 52% of all LWSCs using it. Second is riprap at 32% followed by dirt and stone at 9% and 7%, respectively. Often a combination of materials are used, such as concrete for the roadway and riprap protection on the upstream and downstream slopes.

The number and size of pipes used in LWSCs varies considerably. However, corrugated metal pipe is by far the most popular material used. Plastic and concrete pipe as well as reinforced concrete boxes and super-span CMP culverts are also used.

2.3. Comparison of Materials Used and Those Recommended

This comparison takes two forms: 1) a general comparison in which the materials used are compared to those suggested by the manual without including a factor of safety and 2) a detailed analysis of three LWSCs.

Table 2.1 lists drainage area, material used, and the minimum material that the manual suggests would withstand the 10 year flood, based on drainage area. In 53% of the cases, the material used was concrete and the design was conservative. Dirt or crushed stone was used in 16% of the cases and was considered to be unconservative as the manual suggested that at least a 6" riprap protection be used. The materials used agreed with those suggested by the manual in 32% of the cases where riprap was used, although size of riprap used was not given.

Three LWSCs were selected on the basis that data was available on drainage area, bed slope, and cross section. Two LWSCs are in Marion County and have drainage areas of 32.6 and 232 square miles. The third LWSC is in Adair County and has a drainage area of 35 square miles.

Cross-sectional area of flow, wetted perimeter, and hydraulic radiis corresponding to different depths were obtained for each LWSC and substituted into Manning's equation (Eq. (2.1)) to obtain velocities corresponding to different flow depths.

$$V = \frac{1.49R^{2/3}\ S^{1/2}}{n} \tag{2.1}$$

where

V = Velocity in fps

R = Hydraulic Radius = $\frac{A}{P}$ in ft

$= \frac{\text{Area of Flow}}{\text{Wetted Perimeter}}$

S = Bed slope in ft/ft

Table 2.1. Comparison of materials used and suggested by manual.

DA Sq Mi	Material Used	Region	Suggested Material 10 Year Flood	Material Used Conservative?
35.00	Riprap	I	6" Riprap	
0.23	"	"	"	
0.25	"	"	"	
0.31	"	"	"	
0.13	"	"	"	
35.60	Concrete	"	"	Y
28.40	"	"	"	Y
26.40	"	"	"	Y
51.00	"	"	"	Y
124.30	"	"	"	Y
59.20	"	"	"	Y
33.10	"	"	"	Y
34.20	"	"	"	Y
26.00	Dirt	II	15" Riprap	N
19.00	Concrete	I	6" Riprap	Y
12.00	Riprap	"	"	
7.00	"	"	"	
9.00	"	"	"	
3.00	"	"	"	
12.00	"	"	"	
9.00	"	"	"	
25.00	"	"	"	

Table 2.1. (Continued).

DA Sq Mi	Material Used	Region	Suggested Material 10 Year Flood	Material Used Conservative?
4.00	Rock	I	6" Riprap	
80.00	Concrete	"	"	Y
7.00	"	"	"	Y
0.01	"	"	"	Y
14.00	"	"	"	Y
1.50	"	"	"	Y
21.90	"	"	"	Y
4.98	"	"	"	Y
4.22	"	"	"	Y
2.70	Rock	"	"	
2.70	"	"	"	
2.30	"	"	"	
1.40	"	"	"	
18.20	"	"	"	
0.04	Concrete	"	"	Y
0.17	"	"	"	Y
0.44	"	"	"	Y
1.78	"	"	"	Y
82.00	"	"	"	Y
91.00	"	"	"	Y
30.60	"	"	"	Y
15.00	"	"	"	Y

Table 2.1. (Continued).

DA Sq Mi	Material Used	Region	Suggested Material 10 Year Flood	Material Used Conservative?
14.84	Concrete	I	6" Riprap	Y
8.28	"	"	"	Y
81.25	"	"	"	Y
8.28	"	"	"	Y
16.36	"	"	"	Y
9.59	"	"	"	Y
12.71	"	"	"	Y
324.00	"	"	"	Y
11.91	"	"	"	Y
23.00	"	"	"	Y
10.24	"	"	"	Y
400.00	Rock	"	"	Y
0.23	Dirt	"	"	N
2.30	"	"	"	N
7.74	"	"	"	N
1.16	"	"	"	N
1.76	"	"	"	N
2.74	"	"	"	N
0.73	"	"	"	N
8.21	"	"	"	N
64.00	Rock	"	"	
2.24	Dirt	"	"	N

Table 2.1. (Continued).

DA Sq Mi	Material Used	Region	Suggested Material 10 Year Flood	Material Used Conservative?
4.84	Dirt	I	6" Riprap	N
4.84	"	"	"	N
36.00	Stone	"	"	N
8.80	Concrete	"	"	Y
6.50	C'Stone	"	"	N
24.40	"	"	"	N
21.10	"	"	"	N
0.29	Riprap	"	"	
2.52	"	"	"	
2.49	"	"	"	
15.00	C'Stone	"	"	N
2.00	"	"	"	N
2.00	Rock	"	"	
11.00	"	"	"	
2.00	"	"	"	
0.16	Riprap	"	"	
32.60	Concrete	"	"	Y
232.00	"	"	"	Y
163.55	"	"	"	Y
3.35	"	"	"	Y
23.40	"	"	"	Y
18.00	"	"	"	Y

Table 2.1. (Continued).

DA Sq Mi	Material Used	Region	Suggested Material 10 Year Flood	Material Used Conservative?
7.40	Concrete	I	6" Riprap	Y
0.65	"	"	"	Y
2.20	"	"	"	Y
31.90	"	"	"	Y
1.75	"	"	"	Y
27.00	"	"	"	Y
24.20	"	"	"	Y
1.50	"	"	"	Y
6.00	"	"	"	Y
123.40	"	"	"	Y
17.60	"	"	"	Y

Total responses = 99

Legend

Y	Yes	52/99 =	52%
N	No	16/99 =	16%
Blank	Agree	32/99 =	32%
			100%

DA . . . . Drainage Area

C'Stone . . . . Crushed Stone

n = Manning's Roughness Coefficient (Assumed = 0.035)

Then discharge in cfs was calculated from

$$Q = VA \tag{2.2}$$

and tractive force from

$$\tau = 62.4RS \tag{2.3}$$

where 62.4 = unit weight of water in lb/ft^2.

Next, material recommendations were made based on design manual criteria and calculated τ and V. These material recommendations were compared to the materials actually used and those recommended by the manual using τ and V based on drainage area alone, in Table 2.2.

Table 2.2 shows that there is reasonable agreement between those values of tractive force and velocity calculated and those predicted by the manual. The material recommendations, without including a factor of safety, are the same in all cases while the materials used for erosion protection follow the recommendations.

2.4. Conclusions

The conclusions of this report are as follows:

- A large number of LWSCs exist in Iowa, with the larger part being either vented or LWBs.
- There are wide ranges in ADT, drainage areas, size of LWSC and number of days wet.

Table 2.2. Comparison of materials for detailed analysis.

County	Region	Drainage Area Sq Mi	Manual τ lb/ft^2	Manual V fps	Detailed Analysis τ lb/ft^2	Detailed Analysis V fps	Material Used	Material Suggested By Manual	Material Suggested By Analysis
Marion	I	32.6	0.9	6.3	0.52	5.0	Concrete + Riprap	6" Riprap	6" Riprap
Marion	I	232.0	0.8	8.0	1.46	9.86	Concrete + Riprap	6" Riprap	6" Riprap
Adair	I	35.0	0.9	6.0	0.8	5.5	Riprap	6" Riprap	6" Riprap

- The current design of LWSCs tends to be conservative. However, the design manual is a good tool for the prediction of erosive forces and economical design of LWSCs.

2.5. Appendix

County	Number of X-ings (1)	Drain Area Sq. Mi. (2)	Average Daily Traffic (3)	Surface Material (4)	Crossing Material (5)	Pipes #/"/M (6)	Height of Low Point(Ft) (7)	Bed Material (8)	Number of Days Wet/Year (9)
Adair	1	35.00	4	Rock	Riprap	2/30/M	7.40	M	270
Appanoose	4	0.23	5	Dirt	"	1/24/M	4.90		5
		0.25	5	"	"	1/24/M	4.50		5
		0.31	5	"	"		0.00		10
		0.13	5	"	"		0.00		10
Benton	45	35.60	10	Rock	Concrete		4.00		4
		28.40	10	Dirt	"		2.00		4
		26.40	10	Rock	"		8.00		4
		51.00	30	Dirt	"		4.50		4
		124.30	25	"	"				4
		59.20	10	Rock	"		3.00		4
		33.10	20	"	"		2.00		4
Black Hawk	4	303.00	270	Rock	Rock				
		369.00	85	"	"				
		14.00	40	"	"				
			100	"	"				
Butler	20								
Carroll	2								
Cerro Gordo	3	26.00	10	Dirt	Dirt	2/48/M	5.00	S	10
				Concrete	Concrete		0.00		
				"	"		0.00		
Cherokee	2	19.00		Dirt	Concrete	5/15/M	5.00		10
			38	Gravel	"		0.00	SG	365
Clarke	8	12.00	2	Dirt	Riprap		0.00		365
		7.00	4	"	"		0.00		365
		9.00	2	"	"		0.00		365
		3.00	1	"	"		0.00		365
			4	"	"		0.00		365
		12.00	0	"	"		0.00		365
		9.00	15	"	"		0.00		365
		25.00	1	"	"		0.00		365
Clayton	8		10	Gravel	Concrete	RCB	6.00		15
		15.80	20	"	"	5X5RCB	6.00		15
			60	"	"	RCB	5.00		15
		25.50	6	"	Rock	5/36/M	4.00	L'stone	30
		852?	5	Dirt	"			"	365
			5	Gravel	Wood deck		4.00	"	10
			2	Dirt	Rock			"	365
Crawford	2	2.86	10	"	Dirt	1/48/M	7.00		12
Davis	2	4.00	10	Rock	Rock	1/ /M	12.50	CS	
		80.00	35	Dirt	Concrete	7/18/M	0.00	SM	5
Decatur	1		8	"	"	2/12/M	2.00	S & Loam	12
Delaware	1	7.00	80	Rock	"				365
Dubuque	4	0.01	40	Gravel	"	1/18/M	4.00	G	6
		14.00		Asphalt	"		1.70	"	
		1.50	10	Gravel	"	1/36/M	4.00	"	10
			10	"	"				
Fayette	3	21.90		C'L'stone	"	RCB 60*6	4.20	"	10
		4.98		"	"	RCB72*28	4.80	"	5
		7.00	35	Rock	Rock			G	2
Floyd	1	4.22	27	C'Stone	Concrete	4/36/M	4.50	"	

(Continued).

County	Number of X-ings (1)	Drain Area Sq. Mi. (2)	Average Daily Traffic (3)	Surface Material (4)	Crossing Material (5)	Pipes #/"/M (6)	Height of Low Point(Ft) (7)	Bed Material (8)	Number of Days Wet/Year (9)
Grundy	5	2.70	20	Dirt	Rock	2/36/M			6
		2.70	5	"	"				6
		2.30	30	"	"	2/36/M			6
		1.40	5	"	"	2/36/M			6
		18.20	15	"	"	4/48/M			6
Harrison	4	50.00	36	Rock	Concrete	2/30/M	8.00		10
		10.00	12	Dirt	"	1/18/M	5.00		10
		10.00	16	"	"	1/18/M	5.00		10
		5.00	8	"	"	1/18/M	6.00		10
Henry	4	0.04	28	Dirt	Concrete	1/24/M	3.50		3
		0.17	16	Gravel	"	1/24/M	3.00		2
		0.44	4	Dirt	"	1/15/M	2.00		2
		1.78		Gravel	"	1/15/M	2.00		5
Howard	2	82.00	300	Rock	Concrete	5/48/M	7.50	GS	7
		91.00	30	"	"	15/36/M		"	7
Iowa	1	9.00	5	Rock	Concrete	2/48/M	1.50	S	5
Jackson	1	30.60	5	Dirt	Concrete	8/15/M	2.30	GS	18
Jefferson	25	15.00	5	Dirt	Concrete	2/12/P	2.25		
		14.84	5	"	"	2/12/P	2.25	SM	
		8.28	10	"	"	2/12/P	2.25	"	
		81.25	0	"	"	4/12/P	2.25	"	
		8.28	3	"	"	2/12/P	2.25	"	
		16.36	5	"	"	2/18/P	2.75	Shale H	
		9.59	15	"	"	2/12/P	2.25	SM	
		12.71	5	"	"	2/12/P	2.25	"	
		324.00	25	Gravel	"	2/18/P	2.75	"	
		11.91	10	Dirt	"	2/12/P	2.25	"	
		23.00	20	"	"	2/12/P	2.25	"	
		10.24	5	"	"	2/30/C		"	
		400.00	15	"	Rock		0.00	"	
		0.23	5	"	Dirt	2/24,30/M		"	
		2.30	10	"	"	2/36/M		"	
		7.74	25	"	"	2/30/M		"	
		1.16	20	"	"	1/30/M		"	
		1.76	35	"	"	1/24/M		"	
		2.74	15	"	"	1/60/M		"	
		0.73	10	"	"	1/30/M		"	
		8.21	10	"	"	1/30/M		"	
		64.00	25	"	Rock		0.00	"	
		2.24	15	"	Dirt	1/48/M		"	
		4.84	0	"	"	2/30/M		"	
		4.84	0	"	"	1/24/M		"	
Johnson	2	36.00	185	Stone	Stone	4/84/M	9.00	S	
		6.40	227	Asphalt		1/ /M	4.00	"	
Jones	4			Dirt					
				"					
				"					
Keokuk	8	0.89	15	Dirt	Concrete				10
			5	"	"				10
			5	"	Riprap				10
			10	"	"				7
		25.00	5	"	"				12
		0.78	5	"	"				12
		5.67	5	"	"				12
			5	"	"				7
Lee	1	5.80	5	Rock	Concrete	2/24/M	2.00	GS	

(Continued).

County	Number of X-ings (1)	Drain Area Sq. Mi. (2)	Average Daily Traffic (3)	Surface Material (4)	Crossing Material (5)	Pipes #/"/M (6)	Height of Low Point(Ft) (7)	Bed Material (8)	Number of Days Wet/Year (9)
Linn	3	6.50	50	C'Stone	C'Stone	2/50,54/M			
		24.40	20	"	"	6/42/M			
		21.10	10	"	"	4/24,30/M			
Lucas	3	0.29	20	Rock	Riprap		0.00	C & M	200
		2.52	10	Dirt	"		0.00	S & C	200
		2.49	10	"	"		0.00	C	200
Madison	14		4	"	C'Stone	2/36/M	0.00		
		2.00	10						
			0	"		1/ /	0.00		365
				Rock	Rock		0.00		365
		15.00	12	Dirt	C'Stone		0.00	L'stone	365
		2.00		"	"				
		4.00	7	"					365
		2.00	2	Rock	Rock	1/36/M			365
				"	Concrete		0.00	L'stone	
				Dirt	LSt		0.00	"	
		11.00	7	"	Rock		0.00		365
		2.00	10	"	"		0.00		365
		0.16	4	"	Riprap		4.50		365
Mahaska	4								
Marion	3	32.60	10	Dirt	Concrete	3/42/M	4.50		6
		232.00	26	Rock	"	1/48X72/C	4.00		10
		21.66	20	Dirt	"	9/12/M	2.00		15
Monroe	2								
Plymouth	1		20	Gravel	"	3/36/M	4.00	SM	4
Sioux	2								
Story	1	3.44	1		Concrete	3/12/M			25
Tama	9	0.22	20	Dirt		1/54/M			
		163.55	40	"	Concrete	5/48/M	4.00		18
		3.35	10	"	"	2/36/M	3.75		
		23.40	25	"	"	2/24/M			
		18.00	25	"	"	1/30/M			
		7.40	16	"	"		0.00		
			17	"		1/24/M			
		0.65		"	Concrete	1/18/M			
		2.20		"	"	1/30/M	2.75		
Van Buren	6	31.90	5	"	"	2/12/P	2.50		10
		1.75	20	"	"	3/12/P	3.00		12
		27.00	15	"	"	5/12/P	2.50	S & C	15
		24.20	25	C'Stone	"	3/12/P	3.50	S & Rock	20
		1.50	5	Dirt	"	2/12/P	2.20	M	8
		6.00	20	"	"	2/12/P	2.20	S	10
Warren	2	123.40	18	"	"	19/12/P	4.60		37
		40.00			Rock	2/48/M			12
Webster	1								

(Continued).

County	Number of X-ings (1)	Drain Area Sq. Mi. (2)	Average Daily Traffic (3)	Surface Material (4)	Crossing Material (5)	Pipes #/"/M (6)	Height of Low Point(Ft) (7)	Bed Material (8)	Number of Days Wet/Year (9)
Winneshiek	2	17.60	10	Gravel Dirt	Concrete Rock	RCB36X120	4.00	Rock	365

Legend:

Column #4 and #5: Surface Material, Crossing Material

- C'L'stone . . . . Crushed Limestone
- C'Stone . . . . Crushed Stone
- L'stone . . . . Limestone

Column #6: Pipes

- #/"/M . . . . Number/Size(inches)/Material
- C . . . . Concrete
- M . . . . Corrugated Metal Pipe
- P . . . . PVC Plastic
- RCB . . . . Reinforced Concrete Box

Column #8: Bed Material

- C . . . . Clay
- CM . . . . Silty Clay
- CS . . . . Sandy Clay
- G . . . . Gravel
- GS . . . . Sandy Gravel
- L'stone . . . . Limestone
- M . . . . Silt
- S . . . . Sand
- Shale H . . . . Hard Shale
- SM . . . . Silty Sand