# DESIGN AND USE OF LOW WATER STREAM CROSSINGS IN KANSAS

by

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# INTRODUCTION

## Problem Statement and Purpose

A low water stream crossing (hereafter referred to as LWSC), is a structure designed to allow the fording of a watercourse during periods of low flow. The structure is submerged during periods of high flow.

This study presented was conducted to determine the extent to which LWSCs are used in Kansas, the attitudes of county engineers and road supervisors toward LWSCs and their experience with them, the outlook for future use of these structures in Kansas, and some of the problems encountered in their design, construction, and maintenance. Another purpose was to adapt existing design information about these structures to local conditions.

## Scope

This thesis will deal only with conditions in Kansas. Aspects in site selection, hydrology, hydraulics, roadway geometry, crossing material and construction, signing, and maintenance were considered. The information presented herein was derived primarily from three sources: county maps from the state of Kansas[5]; phone[13] and personal[12] interviews with county engineers and road supervisors; and reports, one of which is entitled "Design Manual for Low Water Stream Crossings"[9] published at Iowa State University, and "Design and Construction of Low Water Stream Crossings"[8] published by Sheladia and Associates, Inc., in Maryland for the Federal Highway Administration. Information from these reports and from other sources listed in Appendix I were modified for conditions in Kansas.

## Definitions

The definitions of the different types of LWSCs are given below. These are taken largely from Ref. 9.

Fords are those structures that are designed to allow the day to day streamflow to pass over the top of the structure. Fords are generally founded on the beds of rivers or streams, and consist for the most part of a slab of reinforced concrete on grade. A typical ford is shown in Fig. 1.

Vented Fords are simply dips with vents or pipes placed below the road surface to allow the passage of day to day flow. They are used in place of simple fords if the depth of water flowing over an unvented ford would exceed four to six inches. A typical vented ford is shown in Fig. 2.

Low-water Bridges differ from "normal" bridges in that they are constructed lower with respect to the water surface and are designed with the idea that they will occasionally be under water for some portion of the year. Like the other types of crossings, their approaches are also made by lowering the grade of the roadway. They provide for the passage of day to day flow through openings designed to handle a larger flow than simple drain pipes. A simple low-water bridge is shown in Fig. 3.

Other definitions include the meanings of "shall", "should", and "may" for the placement of warning and regula-

Figure 1

Ford

Figure 2

Vented Ford

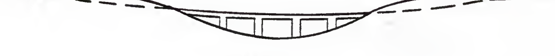


Figure 3

Low Water Bridge

tory signs on the approaches to the structure. "Shall" is a mandatory condition. "Should" is an advisory condition, but if these recommendations are ignored, documentation should be provided to reduce liability. "May" is an optional condition.

# EXISTING CONDITIONS, ATTITUDES, AND EXPERIENCES IN KANSAS

## Introduction

This section of the thesis is concerned with the existing conditions in the state of Kansas with regard to LWSCs. Included in this discussion is a report on the number and distribution of the structures which exist in the state, as well as some comments on attitudes toward and experience concerning them.

## Conditions

Based on the best information available, the number of LWSCs in use in the state is 1763. This figure was determined by consulting county maps published between 1978 and 1983[5]. All symbols for fords found on these maps were noted and counted to give the results in Table 1 and Fig. 4. Using this data, Fig. 5 was prepared to show the distribution of the crossings across the state. This figure leads to some general assumptions. First is that, with some exceptions, relatively few LWSC's are used in western Kansas. Second, more crossings are used in southeast Kansas than in other areas. Third, very few are used in the more densely populated counties such as Sedgewick, Wyandotte, and Shawnee.

## Phone Survey

To determine the attitudes toward LWSCs and experience with them, 20 counties were contacted by telephone (see Fig. 6). These counties were chosen because of their proxi-

| County | No. | County | No. | County | No. |
|---|---|---|---|---|---|
| Allen | 51 | Greeley | 2 | Osborne | 3 |
| Anderson | 62 | Greenwood | 131 | Ottawa | 7 |
| Atchison | 6 | Hamilton | 0 | Pawnee | 34 |
| Barber | 23 | Harper | 24 | Phillips | 0 |
| Barton | 62 | Harvey | 0 | Pottawatomie | 17 |
| Bourbon | 50 | Haskell | 0 | Pratt | 41 |
| Brown | 0 | Hodgeman | 13 | Rawlins | 6 |
| Butler | 51 | Jackson | 1 | Reno | 18 |
| Chase | 9 | Jefferson | 12 | Republic | 1 |
| Chautauqua | 30 | Jewell | 0 | Rice | 17 |
| Cherokee | 11 | Johnson | 12 | Riley | 8 |
| Cheyenne | 1 | Kearny | 1 | Rooks | 10 |
| Clark | 20 | Kingman | 17 | Rush | 13 |
| Clay | 6 | Kiowa | 7 | Russell | 25 |
| Cloud | 7 | Labette | 51 | Saline | 11 |
| Coffey | 40 | Lane | 10 | Scott | 3 |
| Comanche | 16 | Leavenworth | 5 | Sedgwick | 1 |
| Cowley | 67 | Lincoln | 4 | Seward | 0 |
| Crawford | 16 | Linn | 44 | Shawnee | 5 |
| Decatur | 13 | Logan | 11 | Sheridan | 40 |
| Dickinson | 26 | Lyon | 43 | Sherman | 0 |
| Doniphan | 0 | Marion | 41 | Smith | 1 |
| Douglas | 7 | Marshall | 6 | Stafford | 0 |
| Edwards | 5 | McPherson | 5 | Stanton | 0 |
| Elk | 32 | Meade | 9 | Stevens | 0 |
| Ellis | 41 | Miami | 21 | Sumner | 28 |
| Ellsworth | 3 | Mitchell | 6 | Thomas | 22 |
| Finney | 0 | Montgomery | 33 | Trego | 19 |
| Ford | 18 | Morris | 32 | Wabaunsee | 17 |
| Franklin | 20 | Morton | 3 | Wallace | 10 |
| Geary | 11 | Nemaha | 3 | Washington | 4 |
| Gove | 30 | Neosho | 36 | Wichita | 11 |
| Graham | 9 | Ness | 8 | Wilson | 19 |
| Grant | 1 | Norton | 0 | Woodson | 21 |
| Gray | 0 | Osage | 16 | Wyandotte | 0 |

Table 1

Number of Low Water Stream Crossings
by County

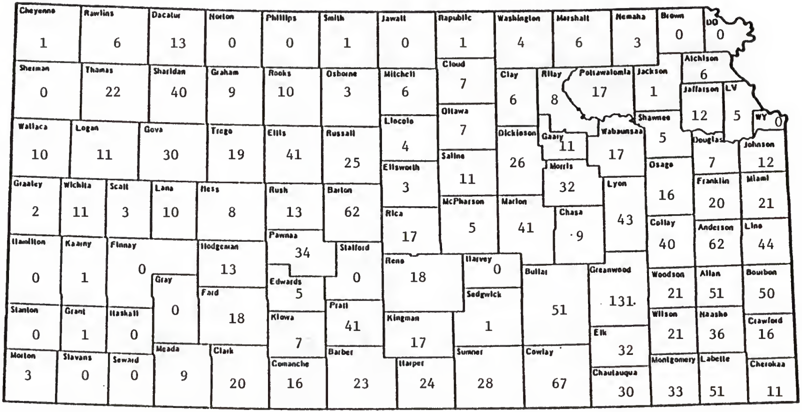
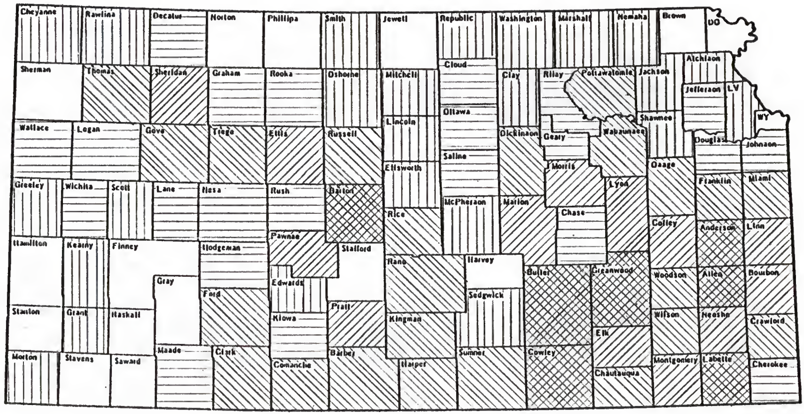



Figure 4

Number of Low Water Stream
Crossings in Kansas
by County




Key:

0 – (blank)

1-6 – (vertical lines)

7-15 – (horizontal lines)

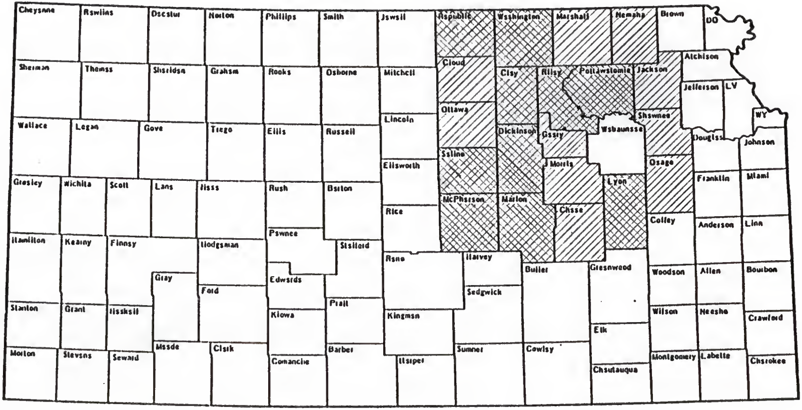
16-30 – (diagonal lines, \)

31-50 – (diagonal lines, /)

51+ – (crosshatch)

Figure 5

Distribution of Low Water Stream Crossings in Kansas by County




Key:

Phoned -

Phoned and Personally Interviewed -

Figure 6

Counties Chosen for Phone and Personal Interviews mity to Manhattan. Note that Wabaunsee county was not contacted due to some difficulty encountered in attempts to match schedules with that county's road supervisor. A standard questionnaire was filled out during these interviews (see Appendix III for a copy of the form).

Before each phone interview, several pieces of data were entered on the form. Included were the name of the county engineer or road supervisor, the number of crossings in the county according to the maps, and the roadway system (township or county unit).

In general, most of the county engineers or supervisors agreed with the estimate of LWSC's in their county. A few said that the figure was far too high. One explanation of this may be that in counties using the township system, LWSCs may exist that the county engineer or road supervisor is not aware of. Another possibility is that the definitions of a LWSC may differ on the state and county levels.

Many of the county engineers or road supervisors contacted were never personally involved with either the design or construction of a LWSC, even though some LWSCs existed in their county. This was mainly because the crossings were constructed in the county before the official was hired. Of those that had some experience with LWSCs, none had had dealings with more than 5. This leads to the conclusion that many of the crossings in Kansas were constructed some time ago.

Several engineers or supervisors knew of other possible sources of information for the project. The consulting engineering firm of Schwab Eaton PA, and B and G Associates, both located in Manhattan, were mentioned.

Most of the people interviewed remarked on their experiences with maintenance of LWSC's. Some of the most common problems were washout, too frequent overtopping, siltation, erosion around the ends, and plugging of the drainage pipes. Some of those interviewed later commented that these problems made LWSC's uneconomical. Others believe that even though LWSCs have higher maintenance cost than bridges, the added costs still do not exceed the expense of a bridge.

Most of those interviewed believed that more LWSC's would be used in the future by their county. However, many stated that they personally did not like this type of structure due to the greater liability risk. It was generally believed that the cost of a LWSC was substantially lower than that of a bridge, but one interviewee remarked that to construct a LWSC "right", the cost would not be much less than that of a bridge.

## County Interviews

Of the 20 counties contacted during the phone survey, 10 were selected for personal interviews (see Fig. 6). This selection was based on the number of LWSC's in the county, the experience of the engineer or road supervisor with them, and the interest of the interviewee in LWSC's in general. The latter was deduced mainly from the phone interview by listening for tone of voice as well as direct statements about the structures.

A copy of the form taken to the interviews is presented in Appendix III. Some of the data on the form was filled in from the phone interview. This included the number of crossings in the county, type and amount of involvement with LWSC's, and the name of the county engineer or road supervisor. The rest of the process involved merely filling in the blanks and noting comments during the interview.

Most of the comments on design led to the conclusion that LWSCs are installed on low volume rural roads, and usually for economic reasons. No formal analysis was usually carried out, with the designer depending on his experience and engineering judgement. No design life was determined as such, but one respondent stated that one of his crossings had been in place for 75 years without undue maintenance problems. Several of the interviewees said that at one time or another they had installed a temporary LWSC, and the main difference between these and permanent LWSCs involved the design of the surfacing material and venting. Time spent on design varied from 3 or 4 hours to 3 or more days.

Most of the counties construct and install their own LWSC's. Construction time ranged from 3 1/2 days to as much as a month. Most of the people questioned stated that summer was the best time for construction of LWSC's. This is because the streams are usually at their lowest flows at this time and the soil is generally easier to work with. The most numerous problems encountered in construction were supervision, weather, and logistics.

The most common maintenance problem with LWSC's was plugging of the venting pipes. One respondent who has had experience with LWSC's in western Kansas noted that there is a difference between sizing pipes for that area of the state compared to eastern Kansas. He said that larger pipes must be used in the western part of the state because the LWSC's in that area are usually plugged with tumbleweeds, whereas in the eastern areas, the problem is with logs and limbs. Other common problems included washing out at the ends, siltation, erosion, and loss of pavement. No one seemed to experience any unusual problems with ice. Maintenance time varied from county to county, but was rarely put at more than two to three days per year. Most of the counties interviewed did not keep separate records of expenses on LWSC's, but most of the generalizations described the cost as a minimal amount.

Many of the people interviewed said that they signed LWSC's as recommended in the Handbook on Traffic Control for Low Volume Rural Roads[6] (hereafter referred to as the LVR Handbook).

Only one of the people interviewed said that he had any problems with accidents on LWSC's. One stated that this is because the speeds and volumes on the roads are low. According to the responses given, LWSC's meet with mixed feelings from the driving public. Some are happy to have any type of crossing, while others wanted a bridge instead of the LWSC. Lodged complaints are noted, and responded to when time and manpower permits.

# DESIGN GUIDELINES FOR LOW WATER STREAM CROSSINGS

## Site Selection

There are many considerations to take into account when deciding to construct a LWSC. These include the hydrology of the area, the traffic patterns, the road type, and the site geometry. In general, LWSC's should be installed on low volume rural roads on a stream that drains a relatively small watershed. In Kansas, it is usually not feasible to place such a structure on a major waterway. This is done occasionally in arid regions such as Arizona and New Mexico, where the flows even on the major watercourses are intermittent.

The hydrology is generally the first problem considered. The structure must not be in an area where it will be under water for a large percentage of the time. One criterion that is suggested in the Sheladia report[8] is that the crossing be flooded no more that four times a year. This is the basis for the hydrologic design presented in this thesis.

The road on which the crossing is to be located is another item for consideration. The LVR Handbook[6] notes that LWSC's are inconsistencies in the roadway that violate driver expectancy. It is recommended that these structures not be installed on paved roads, and if they are, they should be well signed. On extremely low volume roads, the speeds and expectancies of the driver are different, and the crossings need not necessarily be signed. However, sound engineering judgement should be used.

The site geometry may also be an influencing factor in the decision to use a LWSC or a bridge. If the stream banks are extremely steep and relatively close together, a bridge may in fact be more feasible to construct. Excessive earthwork on the ends of a crossing may lead to siltation problems later on in the life of the crossing.

Design life may also play a part in the decision. There are times when only a temporary solution to a crossing problem is desired. This may occur, for example, during the construction or maintenance of a bridge. One county interviewed stated that 47 bridges had to be repaired or replaced due to structural problems. In some places, LWSCs were installed to keep the roads open.

. Hydrology and Hydraulics

As was previously mentioned in the Introduction of this thesis, the basic assumption made when it has been decided to construct a LWSC is that part of the time it will be submerged and therefore impassable. The problem encountered is in the determinition of the average amount of time per year that the LWSC is submerged, or how often this occurs. The Iowa State report[9] deals mainly with the former. Unfortunately, there is insufficient data to do a similar study in Kansas. Hence this report will deal only with the frequency of overtopping.

In the report by Sheladia and Associates[8], an overtopping frequency of four times per year was given as the maximum acceptable. However, another frequency could be chosen using other criteria. Using this four times per year frequency, a method was developed to determine the runoffs and hence the inflow hydrograph peaks for a LWSC. The refer ence for this method is Technical Release No. 55, Soil Conservation Service (SCS)[11], hereafter referred to as TR-55. This report deals with urban hydrology for small watersheds. It is very rare that LWSCs are constructed in urban areas, but the approach in this report was determined to be applicable to non-urban areas as well.

The following procedure was adopted from Kansas SCS design procedures for small ponds. It is necessary to determine the following:

1. The drainage area above the crossing in acres (A)
2. The total length of the longest drainage way from the drainage area boundary to the outlet in feet (L)
3. The composite SCS curve number (see Table 2)
4. The average land slope of the drainage area (NOT the drainage way slope)
5. The four times per year runoff value from Fig. 7 (The development of Fig. 7 is explained later.)

Soil surveys and topographic maps are recommended as reference materials when determining the above data.

Using the above and TR-55[11], the following procedure is recommended:

1. From Fig. 8, determine the equivalent drainage

TABLE 2
SCS Runoff Curve Numbers

| Land-use and Conservation Practice | Hydrologic Condition | Hydrologic Soil Group | | |
|---|---|---|---|---|
| | | B | C | D |
| Row crops | | | | |
| Straight rows | Poor | 81 | 88 | 91 |
| Straight rows | Good | 78 | 85 | 89 |
| Contoured | Poor | 81 | 88 | 91 |
| Contoured | Good | 78 | 85 | 89 |
| Contoured and terraced | Poor | 74 | 80 | 82 |
| Contoured and terraced | Good | 71 | 78 | 81 |
| Small grains | | | | |
| Straight rows | Poor | 76 | 84 | 88 |
| Straight rows | Good | 75 | 83 | 87 |
| Contoured | Poor | 74 | 82 | 85 |
| Contoured | Good | 73 | 81 | 84 |
| Contoured and terraced | Poor | 72 | 79 | 82 |
| Contoured and terraced | Good | 70 | 78 | 81 |
| Close-seeded legumes | | | | |
| Straight rows | Poor | 77 | 85 | 89 |
| Straight rows | Good | 72 | 81 | 85 |
| Contoured | Poor | 75 | 83 | 85 |
| Contoured | Good | 69 | 78 | 83 |
| Contoured and terraced | Poor | 73 | 80 | 83 |
| Contoured and terraced | Good | 67 | 76 | 80 |
| Pasture or range | | | | |
| | Poor | 79 | 86 | 89 |
| | Fair | 69 | 79 | 84 |
| | Good | 61 | 74 | 80 |
| Woods | | | | |
| | Poor | 66 | 77 | 83 |
| | Fair | 60 | 73 | 79 |
| | Good | 55 | 70 | 77 |

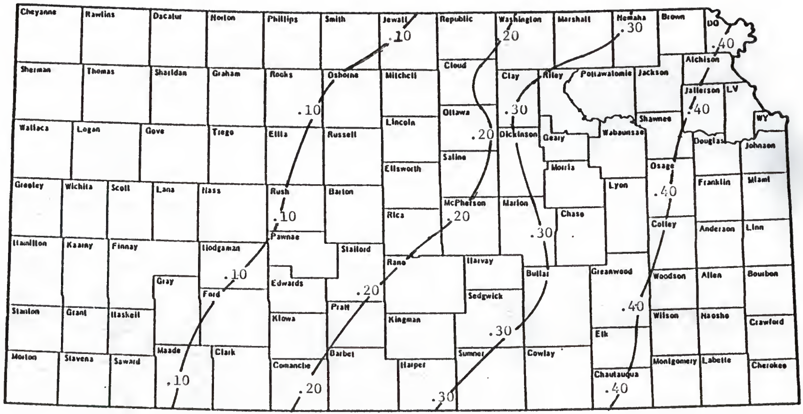



Figure 7

Isohyetal Lines of the
Four Times Per Year Runoff
(in Inches)

area (Ae) from the drainage way length (L).

2. Using the SCS curve number, the equivalent drainage area (Ae), and Figs. 9, 10, and 11, find the unit peak discharge (q) from the proper set of curves using the average watershed slope.
3. From table 3, select a slope adjustment factor (Sa).
4. Compute the peak discharge per unit runoff,

   $$C = q * Sa * (A/Ae) \quad \text{(cfs/inch)}$$

5. Using the runoff from the 4 times per year frequency curve, find the flow, $Q=RC$

The determination of the required underflow capacity is illustrated in the following example.

Given: A hypothetical crossing in the vicinity of Independence, Kansas.

Drainage Area = A = 250 ac

Drainage Way Length = L = 4200 ft

Composite Curve Number = 72

Average Ground Slope = 3.8%

From Fig. 8: Ae = 155 ac

From Fig. 10 (moderate slope): q = 72 cfs/in (using equivalent area)

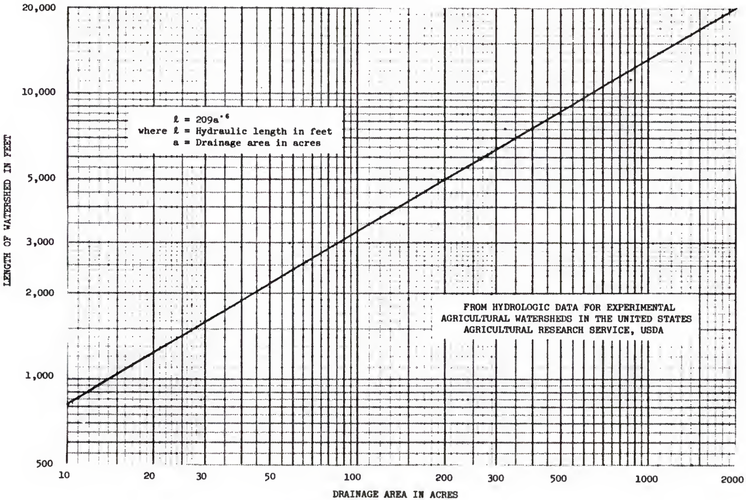



Figure 8

Hydraulic Length and Drainage Area Relationship

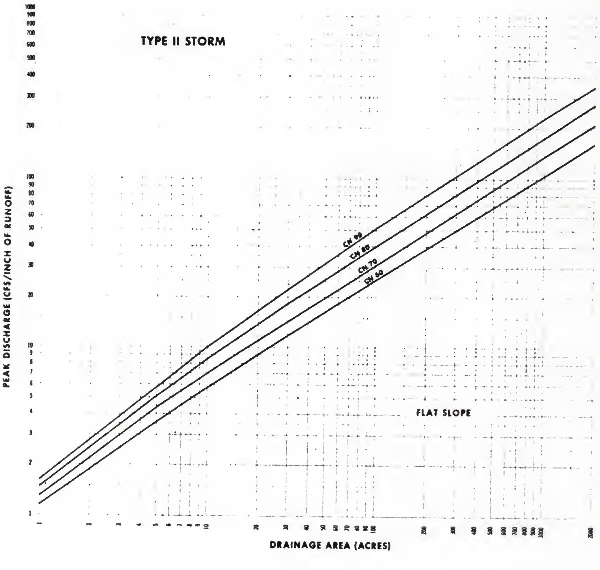



Figure 9

Peak Rates of Discharge for Small Watersheds
(24-hour, Type-II Storm Distribution)

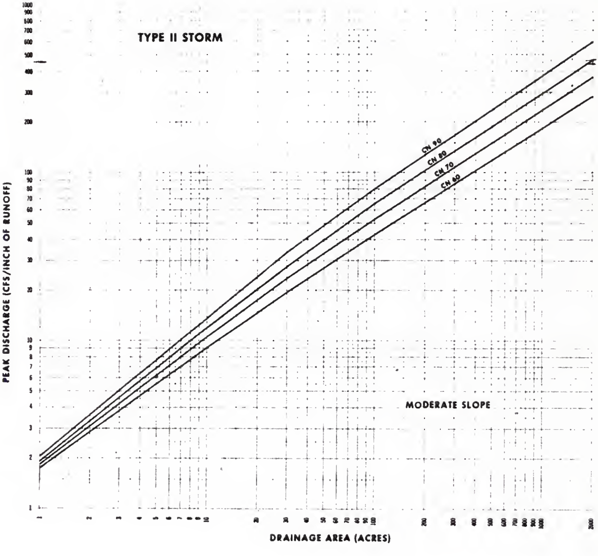



Figure 10

Peak Rates of Discharge for Small Watersheds
(24-hour, Type-II Storm Distribution)

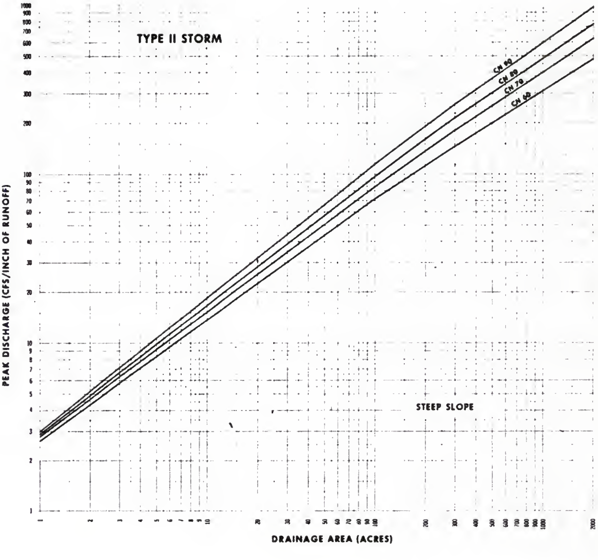



Figure 11

Peak Rates of Discharge for Small Watersheds
(24-hour, Type-II Storm Distribution)

| Slope (per-cent) | 10 acres | 20 acres | 50 acres | 100 acres | 200 acres | 500 acres | 1,000 acres | 2,000 acres |
|---|---|---|---|---|---|---|---|---|
| **FLAT SLOPES** | | | | | | | | |
| 0.1 | 0.49 | 0.47 | 0.44 | 0.43 | 0.42 | 0.41 | 0.41 | 0.40 |
| 0.2 | .61 | .59 | .56 | .55 | .54 | .53 | .53 | .52 |
| 0.3 | .69 | .67 | .65 | .64 | .63 | .62 | .62 | .61 |
| 0.4 | .76 | .74 | .72 | .71 | .70 | .69 | .69 | .69 |
| 0.5 | .82 | .80 | .78 | .77 | .77 | .76 | .76 | .76 |
| 0.7 | .90 | .89 | .88 | .87 | .87 | .87 | .87 | .87 |
| 1.0 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 1.5 | 1.13 | 1.14 | 1.14 | 1.15 | 1.16 | 1.17 | 1.17 | 1.17 |
| 2.0 | 1.21 | 1.24 | 1.26 | 1.28 | 1.29 | 1.30 | 1.31 | 1.31 |
| **MODERATE SLOPES** | | | | | | | | |
| 3 | .93 | .92 | .91 | .90 | .90 | .90 | .89 | .89 |
| 4 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 5 | 1.04 | 1.05 | 1.07 | 1.08 | 1.08 | 1.08 | 1.09 | 1.09 |
| 6 | 1.07 | 1.10 | 1.12 | 1.14 | 1.15 | 1.16 | 1.17 | 1.17 |
| 7 | 1.09 | 1.13 | 1.18 | 1.21 | 1.22 | 1.23 | 1.23 | 1.24 |
| **STEEP SLOPES** | | | | | | | | |
| 8 | .92 | .88 | .84 | .81 | .80 | .78 | .78 | .77 |
| 9 | .94 | .90 | .86 | .84 | .83 | .82 | .81 | .81 |
| 10 | .96 | .92 | .88 | .87 | .86 | .85 | .84 | .84 |
| 11 | .96 | .94 | .91 | .90 | .89 | .88 | .87 | .87 |
| 12 | .97 | .95 | .93 | .92 | .91 | .90 | .90 | .90 |
| 13 | .97 | .97 | .95 | .94 | .94 | .93 | .93 | .92 |
| 14 | .98 | .98 | .97 | .96 | .96 | .96 | .95 | .95 |
| 15 | .99 | .99 | .99 | .98 | .98 | .98 | .98 | .98 |
| 16 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 20 | 1.03 | 1.04 | 1.05 | 1.06 | 1.07 | 1.08 | 1.09 | 1.10 |
| 25 | 1.06 | 1.08 | 1.12 | 1.14 | 1.15 | 1.16 | 1.17 | 1.19 |
| 30 | 1.09 | 1.11 | 1.14 | 1.17 | 1.20 | 1.22 | 1.23 | 1.24 |
| 40 | 1.12 | 1.16 | 1.20 | 1.24 | 1.29 | 1.31 | 1.33 | 1.35 |
| 50 | 1.17 | 1.21 | 1.25 | 1.29 | 1.34 | 1.37 | 1.40 | 1.43 |

Table 3

Slope Adjustment Factors
by Drainage Areas

From Table 2: $Sa = 0.98$ (interpolate, using actual drainage area)

$$C = (q * Ae * Sa) / A$$

$$= (72 * 250 * .98) / 155$$

$$= 114 \text{ cfs/in}$$

From Figs. 7 and 12, for Independence with a CN of 72,

$$R = 0.34''$$

$$Q = R * C$$

$$= .34 * 114$$

$$= 39 \text{ cfs} \quad \text{(The required underflow capacity)}$$

Using this result, the hydraulic design may be easily completed by using a standard set of pipe flow charts similar to those presented in Hydraulic Engineering Circular 5[4].

The procedure presented is relatively simple. However, it may be simplified or made more sophisticated. One possibly valid simplification is to eliminate the slope adjustment factor. Since this factor is in general approximately one and because it is based on a difficult to make estimate of average watershed slope, it may be desirable to simply determine if the slope is flat, moderate, or steep and make no other adjustments.

There are possible modifications to "C" that make the estimate more sophisticated. Tables E-2, E-3, and E-4 in TR-55[11] provide modifications to account for swampy areas and ponding within the watershed. Another modification may be made when there are small ponds in the drainage area controlled by the crossing. For the design storm, the areas

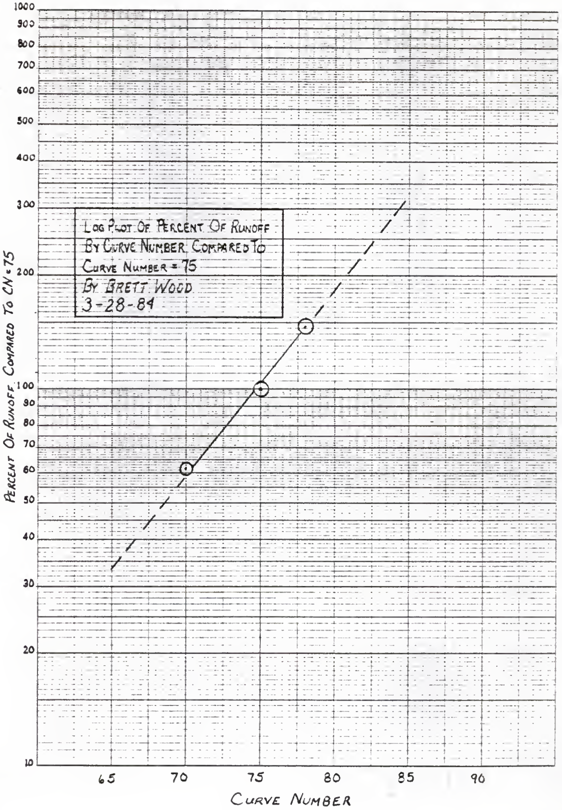



Figure 12

Curve Number Adjustment Factors

controlled by these ponds may be removed from consideration. The assumption is that for these events the ponds will either completely control the runoff or slow the contribution of their drainage areas to the crossing such that thay add no significant amount to the peak discharge.

Because of the sensitivity of high frequency runoff events to soil moisture conditions, and the scarcity of data for high frequency rainfall events (the Weather Service Technical Paper 40[2] reports nothing more frequent than the one year return period event), it was necessary to develop an alternate procedure for the high frequency design. The procedure described below is based on results from a large number of runs of the KSU Potential Yield Model[7] which in turn uses the SCS curve number as the basis for watershed modeling.

Data was examined for long periods of record (59 to 81 years). From this data, the runoff that was exceeded four times a year was plotted on the map for the cities of Independence, Ellsworth, Norton, Manhattan, Garden City, Burr Oak, Horton, Concordia, and Clay Center in Kansas. Isohyetal lines of runoff were interpolated between them.

For example, Independence has records from 1900-1979 (80 years). Therefore, the runoff that was exceeded four times per year or with a frequency of 320 for the record was determined for the plot where the SCS curve number equalled 75. An interpolation of the data gave a value of .44 inches of runoff. This was done for the other cities of record in eastern Kansas and a curve number versus the percent of the value of runoff for the curve number equal to 75 was derived (see Fig. 12). Western Kansas was not included because in that region of the state the anticedent moisture is very rarely 2 and this made the use of those cities invalid. However, use of this chart will result in oversizing of the pipes. Using this, many rural curve numbers may be used to find the runoff.

Road Geometry

LWSC's are designed to allow for occasional overtopping by streamflow. To allow for this, the road must have a sag vertical curve at this point, commonly referred to as a dip. It is desirable to keep this dip at a minimum. The reasons for this are twofold. First, adequate sight distance must be maintained. Second, this dip is an inconsistency in the roadway geometry that violates the driver's expectency.

There are two general types of geometry to consider at a LWSC. One is a relatively flat approach, where minimal cut must be made to accomodate the crossing. The other is a narrow stream with higher banks that requires deeper cuts to allow for adequate sight distance. The Design Manual for Low Water Stream Crossings[9] treats this subject in some detail.

The Design Manual[9] discusses adequate sight distance problems and how one goes about solving them. A discussion of the formula for stopping sight distance is presented, and using this formula, the following table was prepared:

| Velocity (mph) | Perception and Reaction Distance (ft) | Braking Distance (ft) | Stopping Distance (ft) |
|---|---|---|---|
| 5 | 18.4 | 8.3 | 27 |
| 10 | 36.8 | 33.3 | 70 |
| 15 | 55.1 | 75.0 | 130 |
| 20 | 73.5 | 133.3 | 210 |
| 25 | 91.8 | 208.3 | 300 |
| 30 | 110.3 | 300.0 | 410 |

Crest vertical curve calculations may be made from the following formulas presented in AASHO[1].

When the stopping sight distance is greater than the curve length:

$$L = (Ad^2)/\{100[(2h_1)^{0.5} + (2h_2)^{0.5}]^2\}$$

When the stopping sight distance is greater than the curve length:

$$L = 2d - \{200[(h_1)^{0.5} + (h_2)^{0.5}]^2\}/A$$

where:

$L$ = length of crest vertical curve in feet

$A$ = algebraic difference in grades in percent

$h_1$ = height of drivers eye in feet

$h_2$ = height of object in feet

The eye height should be set at 3.50 feet and the height of the object at .50 feet. Using these heights, the equations reduce to:

for $d < L$

$$L = (Ad^2)/1329$$

for $d > L$

$$L = 2d - (1329)/N$$

Sag vertical curves are designed so that the sight distance for a standard headlight beam is adequate for safe stopping sight distance. The formulas for the length of the curve are:

for $d < L$

$$L = (Ad^2)/(400 + 3.5d)$$

for $d > L$

$$L = 2d - (400 + 3.5d)/A$$

where:

L = length of sag vertical curve in feet

d = headlight beam distance in feet

A = algebraic difference in grades in percent

Once the lengths of the vertical curves are established, the cross section of the crossing must be designed. The cross section must accomodate the vehicles that use the road as well as allowing occasional high flows to pass over the structure. Although the volume of traffic on the typical road where a LWSC would be installed is small enough to assume one way travel on the structure, it should be designed to allow the meeting of two passenger vehicles. Another factor in setting the cross section width is that these structures will often be used by farm vehicles with transport widths varying from 16 to 28 feet. With this in mind, a minimum top width of 16 feet is necessary, with 20 feet or greater desirable. The Design Manual for Low Water Stream Crossings[9] developed at Iowa State recommends the cross section given in Fig. 13.

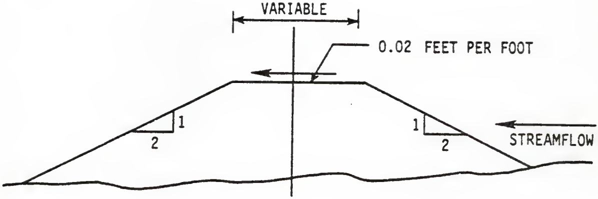



Figure 13

Typical LWSC Cross Section

## Crossing Materials and Construction

Once the crossing size has been determined, the specifications can be prepared for the crossing materials to be used and for construction. The report on the Design and Construction of Low Water Stream Crossings by Sheladia Associates[8] gives a detailed design of the erosion protection that is necessary for a LWSC if the water velocity is known. In general, the report recommends dumped or hand-placed riprap as erosion prevention for LWSCs. This type of riprap is the least expensive type of erosion protection. Other types available are wire-enclosed riprap or gabions, grouted riprap, concrete riprap in bags, and concrete slab riprap. The report states "The selection of type and size of coverage, above all, must be commensurate with the funds available and the degree of protection desired."

The design of each crossing varies with the location. In western Kansas, a simple slab on grade may be adequate. In other areas, the type of soil foundation present may make a difference as to whether or not cutoff walls must be installed to prevent erosion and undermining of the structure. Pipe size and amount and type of cover necessary vary with the design. For this reason, detailed design guidelines will not be presented in this thesis.

## Signing

LWSCs are structures that are not frequently encountered by the average driver, and therefore may be considered inconsistencies. The LVR Handbook[6] recommends that the approaches to LWSCs "should" be signed on Type A roads, and "may" be signed on Types B and C roads (See Ref. 6 for further details and descriptions of these types of roads). If the decision is made to sign these structures, the Handbook recommends that the signs "Flood Area Ahead", "Impassable During High Water", and "Do Not Enter When Flooded" be installed in that order on the approaches. Note that the first two signs are warning signs, and the third is a regulatory sign. The regulatory sign is used to make it illegal to enter a flooded LWSC and thus, hopefully, to lessen the liability associated with LWSCs. If the road is Type C, only the "Flood Area Ahead" sign is recommended, while the use of the others is optional.

The Handbook[6] notes that the "Kansas Statute Annotated (K.S.A.) 68-119, requires a depth gage to indicate the water depth over fords on township roads." This gage "consists of a white background with black numbers. The zero-foot mark shall be at the same elevation as the low point in the crossing." If installed, this gage "shall" be placed on the upstream side of the crossing.

## Maintenance

The usual maintenance problems encountered on a LWSC are washout of the ends and surface, undercutting, plugging of the vents, and siltation. One solution to the washout of the ends is given in Ref. 3. The Tonto, Prescott, and Kaibab Forest service agencies use Jersey barriers as fordwalls. Undercutting may be handled by the use of sheet piles. Depending upon the location and type of debris that plugs the vents, a change in vent size may solve the problem. Siltation, however, must be removed whenever it occurs.

The maintenance may usually be performed by small crews, but should be carried out as soon as possible after a problem is discovered. The problems may be discovered in several ways. Many county engineers and road supervisors rely on their maintainer operators for this information, while others make it a habit to inspect these structures personally on a regular basis. The signs on the approaches to the crossing must also be maintained. Farm machinery tends to knock down object markers. A continuous sign inventory would be of assistance in this area. See Ref. 6 for guidelines on sign inventories.

## SUMMARY

A LWSC is a structure designed to allow for the fording of a watercourse during periods of low flow. The structure is submerged during high flows. There are three types of these structures: the ford, the vented ford, and the low-water bridge.

These structures are used extensively in some parts of Kansas, and sparingly in others. From phone and personal interviews with county personnel in northeast Kansas, it may be concluded that these structures are economical when compared with the cost of a standard bridge, and that their use will increase in the future.

The main considerations to be taken into account in the design and construction of a LWSC are the amount and type of traffic using the road, the hydrology of the area, the hydraulics, the roadway geometry, the crossing materials, and signing. Maintenance of these structures often is necessary because of siltation, undermining, erosion of the ends, and plugging of the vents.

## RECOMMENDATIONS FOR FURTHER RESEARCH

Upon reviewing this thesis, the author recommends the further research listed below.

1. The hydrology section of this thesis could be modified by developing a more sophisticated model for the runoff than simply the event that occurs on the average 4 times per year. A study could be done to get results similar to those obtained in the Iowa report , in which the crossing is designed to be submerged some percentage of the time rather than a given number of times.

2. A better isohyetal map similar to Fig. 7 could be made if more runs of the POTYLD program were made with more and varying stations than those selected.

3. The phone and personal interview study could be improved by including either more of the counties that have a greater number of LWSCs or perhaps by a statewide study.

4. A more in-depth study of the hydraulics could be conducted to determine how the outflow could be controlled to reduce downstream erosion.

5. A more detailed study of the structural aspects of of LWSCs is probably in order.

## APPENDIX I - LIST OF REFERENCES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## APPENDIX II - NOTATION

A = drainage area above the crossing in acres.

L = total length of the longest drainage way from the drainage area boundary to the outlet in feet (also called the length of watershed).

CN = SCS curve number

Ae = equivalent drainage area in acres.

q = unit peak discharge in cfs per inch of runoff.

Sa = slope adjustment factor.

R = runoff in inches.

C = coefficient of unit peak discharge in cfs per inch of runoff.

Q = inflow to the structure in cfs.

L = length of crest vertical curve in feet.

A = algebraic difference in grades in percent.

$h_1$ = height of the driver's eye in feet

$h_2$ = height of object in feet.

d = stopping sight distance in feet.

## APPENDIX III - PHONE AND PERSONAL INTERVIEW QUESTIONNAIRES

PHONE INTERVIEW RECORD
FOR COUNTY
WITH , PE
06/ /1983

1. Hello. My name is Brett Wood, and I'm a graduate student at K-State. I'm working with Dr. Bob Smith on a departmental research project dealing with low water stream crossings. Do you have a few minutes to discuss this with me?
(If no, see when I can call back depending on intuitive feel for what the response was)

2. This project will lead to a manual for criteria on installation of LWSC's. My latest information tells me that you are on the {county unit/township} system. Also, according to my latest map of your county, you have LWSC's. Is this approxiamately correct? {If no, find out what has changed, and make sure if they aren't on C.U. they still take into account township LWSC's.}

3. Were you personally involved in the design of any of these structures? If not, were they (a) before your time (b) done by consulting firm (c) other.

4. Were you personally involved in the construction of any of them ? If no, were they (a) before your time (b) done by a consulting firm (c) other

5. Have you ever had any first-hand experience with any of these structures?

6. Do you know of anyone who has had experience with LWSC's? (Consultants, previous county engineers, etc.)

7. On the LWSC's that are in your county, have you experienced any maintenance problems?

8. What is your opinion about the use of LWSC's in the future?

9. If it is alright with you, I'd like to call you back at a later date to possibly set up an appointment for a personal more in depth interview that is mutually agreeable with both of our schedules.

COMMENTS

PERSONAL INTERVIEW - DRAFT 2

County-
Name of Engineer -
Area of work with LWSC's (design/construction)

1. As I informed you during our telephone conversation, Mr./Ms. , I am doing research on low water stream crossings with Dr. Bob Smith at Kansas State University. (Show the map of the county with LWSC's indicated) According to our phone conversation, you have LWSC's in your county. I have them located on this map. Are they in the correct places? (If not, note on the map any changes or corrections.)

2. According to our phone conversation, you have had personal involvement in the (design/construction/both) aspect with some LWSC's. (If with LWSC's in this county) - Could you point out which ones of the crossings these were? (Note on the map with a d/c/b)

3. AREA OF SPECIALIZATION-

a. DESIGN

Taking this (any of the LWSC's he/she designed) as an example, why did you decide to build a LWSC instead of a bridge?

Did you take any of the following into consideration when you finally decided to build a LWSC?

Traffic Analysis-

Hydrologic Parameters-

Soils-

How was the design life determined?

Was there any time that you decided to install a temporary LWSC instead of a permanent one, and if so, what design changes did you consider?

How were the costs determined, and what exactly did you take into consideration when you were determining them?

How much time did you spend on design.

b. CONSTRUCTION

Who has done the construction of LWSC's in your county? (Firm name, address, who in the firm knows most about it)

(If county does there own construction, who is in charge, and can I talk to him/her?)

How long does the construction of a LWSC take?
What exactly does constructing a LWSC entail?

Is there a particular season or time of the year that is conducive to their construction and why?

Were there any crossings that were a particular pain to build and why? (Note them on the map)

MAINTENANCE

What is the usual maintenance procedure for a LWSC?

How often do you check on them? (After a heavy rain, every few weeks, etc.)

Do you experience any particular problems with ice in the winter?

How long does it take to repair a LWSC after overtopping?

Do you consider having to close the road when the structure is overtopped as part of the maintenance?

Are there any of your county's crossings that are really a pain in the sense that you must send someone to close the road or to install signing of some sort when the crossing is overtopped? (Point out on the map)

Are there any of your LWSC's that are more or less maintenance free (point out on map)?

How much does the county spend a year for maintenance on the average?

SIGNING

How does your county sign LWSC's?

Do you sign different types of roads differently?

Do you have any good ideas on how to tell motorists that the water is too high to allow safe crossing other than that given in the MUTCD?

ACCIDENTS AND COMPLAINTS

Do you have any LWSC that has had a bad accident record?

If so, were these accidents collisions, run off roads, or did they involve water pushing cars off of the road?

Do you have a crossing that got a lot of criticism when it was constructed?

Do any of your crossings get complaints, and if so, what are they?

What action do you take when a complaint is lodged?

CLOSE

May I go out and inspect a few of these crossings for pictures, etc.?

Thank you for your time.
(Optional) You have been a great help in my research.

I may contact you in the future for further information.

DESIGN AND USE OF LOW WATER STREAM CROSSINGS IN KANSAS

by

BRETT L. WOOD

B.S., Kansas State University, 1982

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AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Civil Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1984

ABSTRACT

A low water stream crossing (also referred to as a LWSC) is a structure designed to allow the fording of a watercourse during periods of low flow. During times of high flow, the structure is submerged. The structure is installed with the acceptance of the fact that this will occur several times per year. One standard is that this should not happen more than 4 times per year on the average.

There are three types of LWSCs. The first is the ford, which is basically a slab on grade that is designed to be submerged to some extent year round. The second is the vented ford. It is similar to a ford with the exception that it is designed to pass the daily flow under the structure through a series of pipes. The third is a low water bridge. It differs from a "normal" bridge in that it's approach grades are lowered and that it is designed to be overtopped occasionally.

LWSCs are used extensively in some counties in Kansas, and not at all in others. Phone and personal interviews with county engineers and road supervisors were conducted to determine current conditions, attitudes, and experiences with LWSCs. From these interviews it may be concluded that these structures are economical when compared with the cost of a standard bridge, and that their use will increase in the future.

The main considerations to be taken into account in the design and construction of a LWSC are the amount and type of

traffic using the road, the hydrology of the area, the hydraulics, the roadway geometry, the crossing materials, and the signing. Once in place, maintenance of these structures is often necessary due to siltation, undermining of the structure, erosion of the approaches, and plugging of the vents.