Assessment of Culverts Designed to Meet Stream Simulation Requirements

Brad Hansen and John Nieber
Dept. of Bioproducts &Biosystems Engineering
University of Minnesota

Sara Johnson and Jeff Marr
St. Anthony Falls Laboratory
University of Minnesota

Technical Advisory Panel

- Petra DeWall Project Manager Minnesota Department of Transportation (Technical Liason)
- Alan Forsberg, Blue Earth County Engineer
- Al Goodman, Lake County Engineer
- Jon Bergstrand, Minnesota Department of Transportation
- Brian Walters, Hancock Concrete
- Nelson Cruz, Minnesota Department of Transportation (Administrative Liason)
- Nicole Danielson-Bartelt, Minnesota Department of Transportation
- Bruce Holdhusen, Minnesota Department of Transportation
- Peter Leete, Department of Natural Resources
- Rick West, Otter tail County Engineer
- Matt Hemmila, St. Louis County Engineer
- Shae Kosmalski, Cook County Engineer

Disclaimer

The human brain starts working the moment you are born and never stops until you stand up to speak in public.

-George Jessel

Objectives

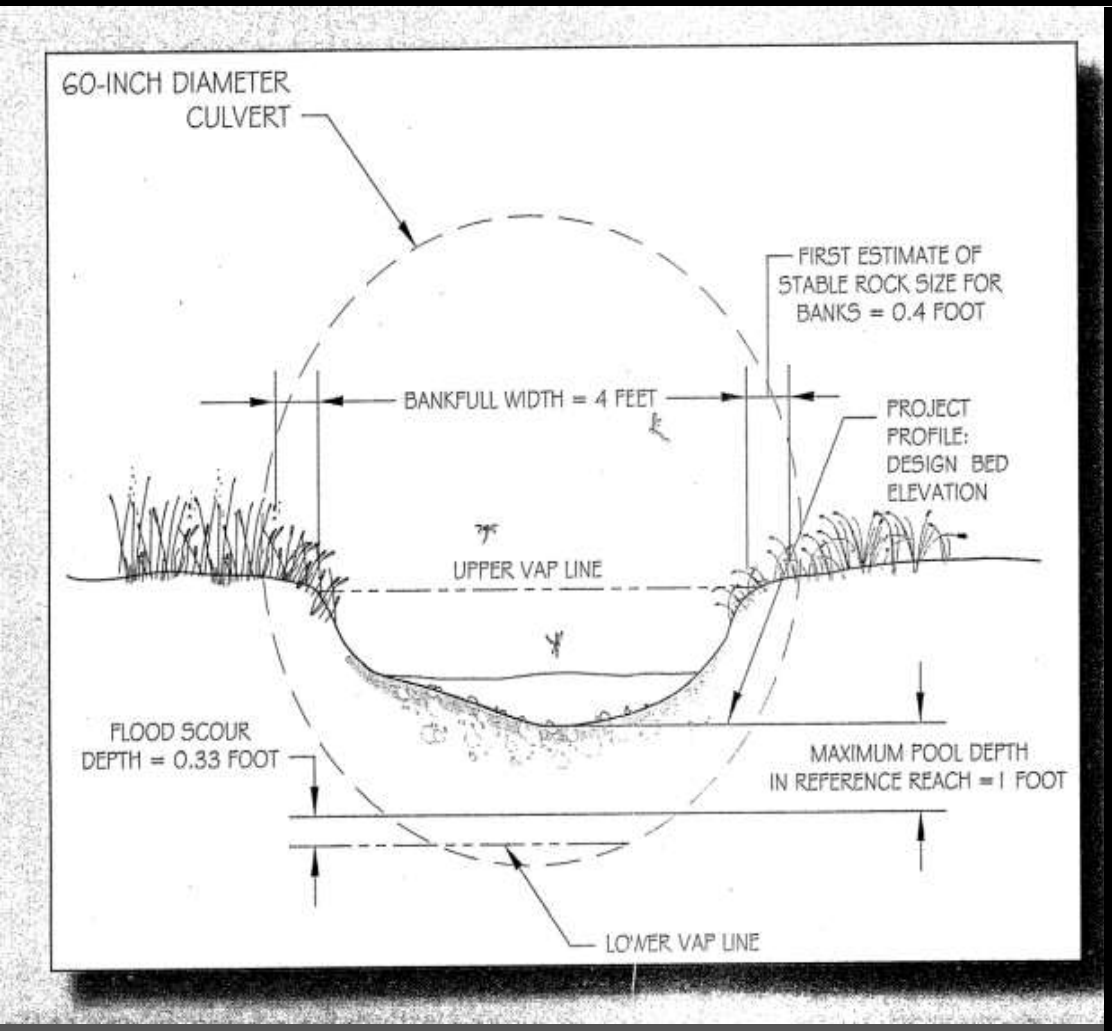
1. Assess the function of culverts designed using stream simulation elements

2. Understand the hydraulics of recessed culverts and the possible impacts they have on adjoining stream characteristics

Stream simulation design elements

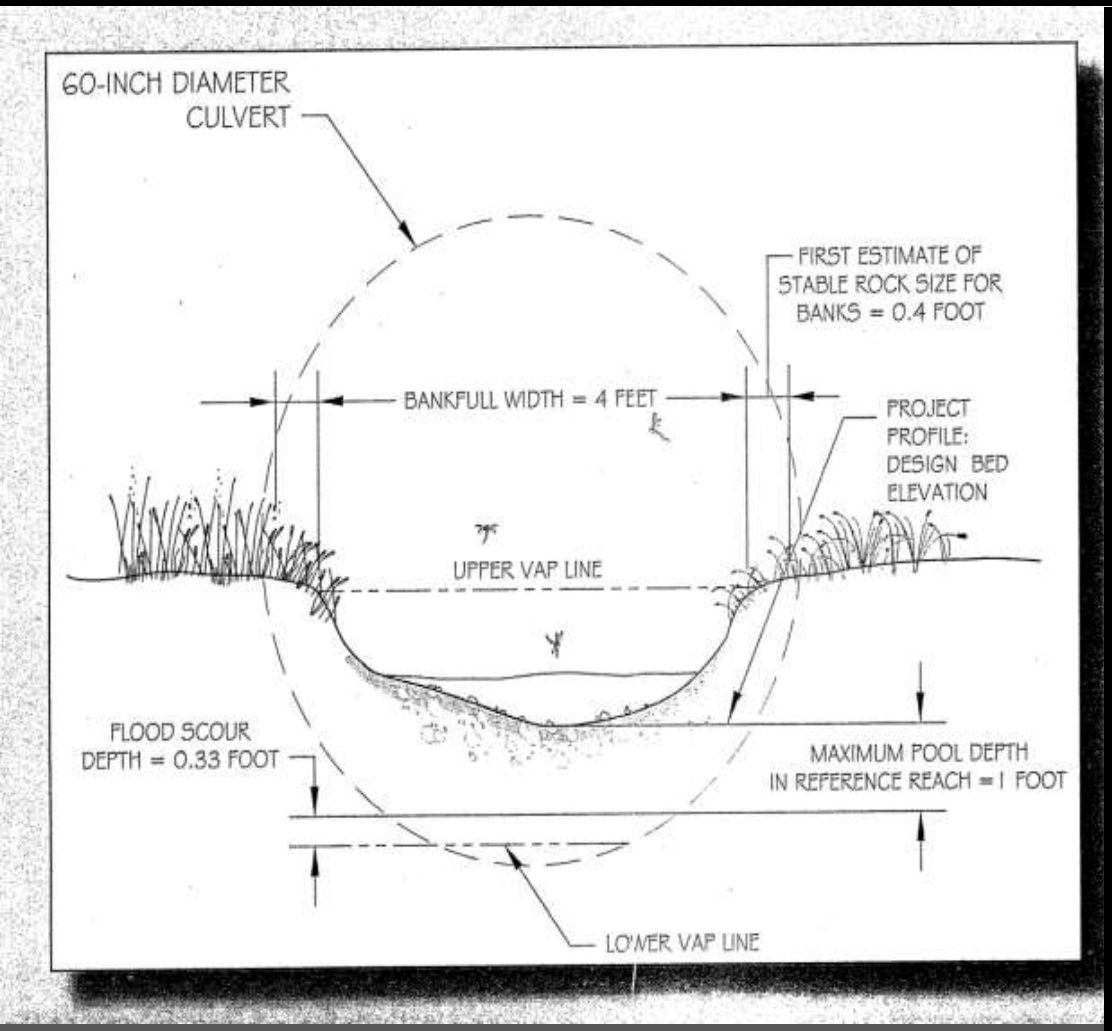
1. Recess culvert bottom below natural stream flow line
2. Matching culvert width to bankfull stream width
3. Setting culvert slope equal to stream slope
4. Off set multiple barrels
5. Account for head cut potential

Recessed culvert



- Reduce velocity
- Pathway for aquatic organisms
- Compensate for fluctuations in streambed

Match culvert to bankfull width

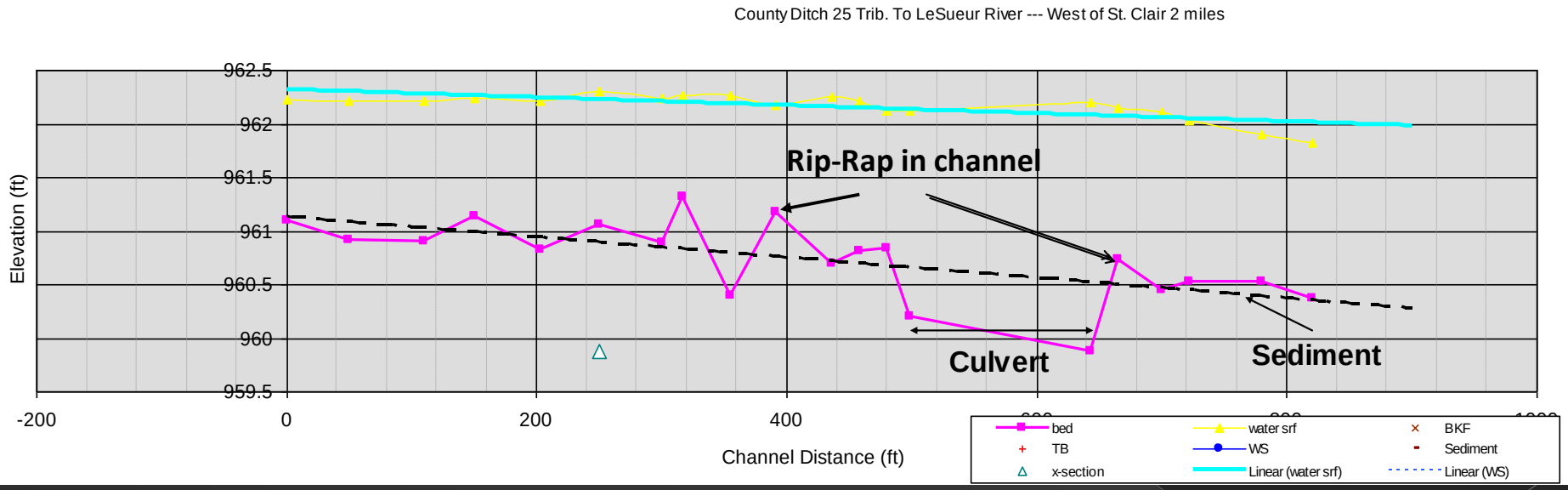


- Match stream channel velocity
- Prevent scour from high velocity
- Maintain minimum flow depth

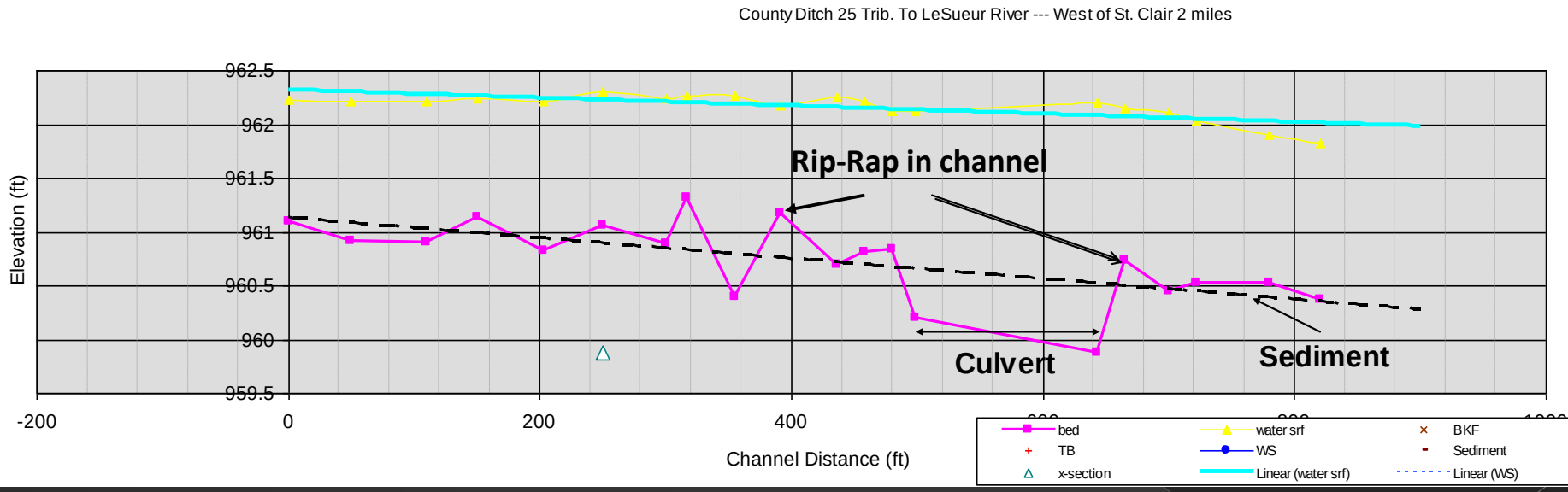
Off set culvert

- Additional flow capacity
- Reduce low flow potential
- Reduce sediment accumulation in off set barrel

Match culvert slope to channel slope



Head cut potential



Site characteristics

Site Characteristics					
Region	County	Stream	Design	Year installed	drainage area (sq. mi)
NE	St. Louis	Stanley Creek	Recessed (rocks)	2008	2.1
NE	Lake	East Br. Beaver River D/S	Recessed (rocks)	2007	28
NE	Lake	East Br. Beaver River U/S	Recessed (rocks)	2007	24
NE	Lake	West Br. Knife River	Recessed (rocks)	2001	4.4
NE	Cook	Kimball Creek	Recessed (rocks)	2009	11.1
NC	Itasca	Splithand Creek	Recessed	2004?	7.8
NC	Itasca	Unnamed at Rearing Pond Rd.	Recessed	2006	6.84
NC	Cass	Shingobee Creek	Recessed	2001	15
NC	Mille Lacs	Bogus Brook	Recessed	2007	24.2
NC	Benton	Stoney Brook	Weir	2000	
SC	Nobles	Trib. to Little Rock	Not recessed	1996	13.5
SC	LeSueur	LeSueur Creek	Not recessed	1999	38.5
SC	Blue Earth	Trib. to LeSueur (ditch)	Bank full bench (ditch)	2000	2.7
SC	Nobles	Trib. To Champepadan	Bank full bench	2002	1.2
SE	Fillmore	Donaldson Creek	Recessed	2007	9.2
SE	Goodhue	Clear Creek	Recessed	2003	2.1
SE	Fillmore	Duschee Creek	Recessed	2004	17.4
SE	Omsted	Bear Creek	Recessed	2000	21.6
SE	Wabasha	Gorman Creek	Recessed	1994	15

Culvert types

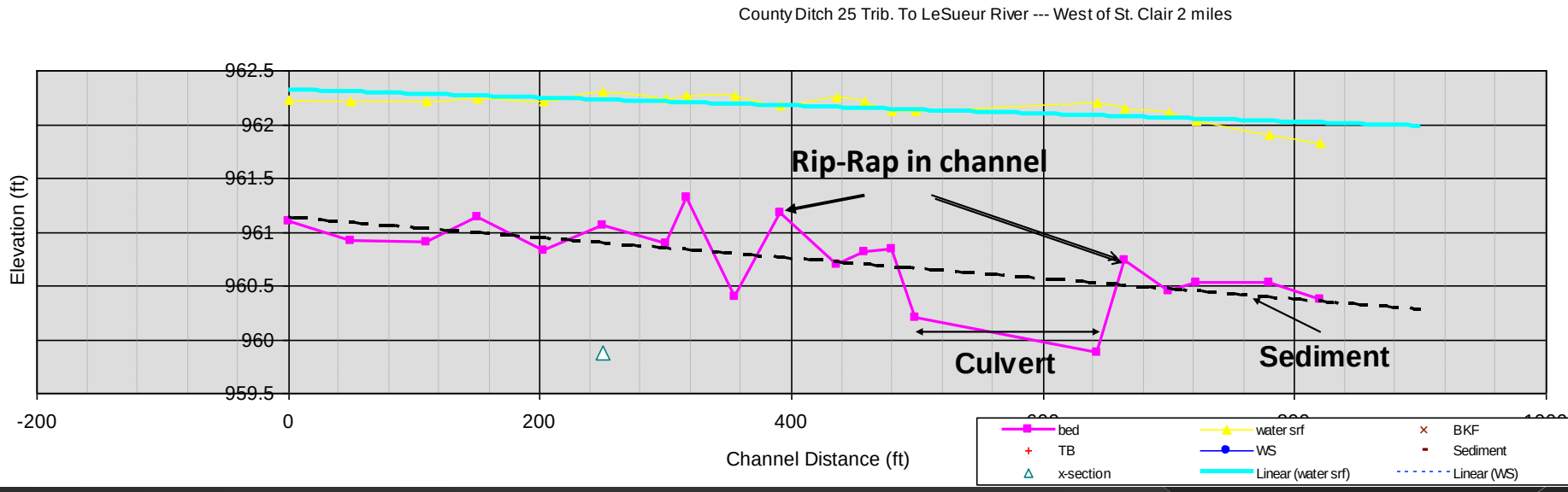
13 - Recessed culverts
2 - Weirs
2 - Bankfull Bench Culverts
2 - Not Recessed/Standard Culvert

What did we measure?

- Longitudinal profile
- Cross-section (upstream)(classification)
- Channel substrate (channel and culvert)
- Velocity (channel and culvert)
- Sediment depth
- Pfankuch Stability Index (U/S and D/S)
- Rosgen stream classification
- Culvert dimension

Objective:
Understand the hydraulics of recessed culverts and the possible impacts they have on adjoining stream characteristics

Head cut potential



Rock weir protecting against headcut

Rip-rap upstream of pool

Headcut potential

Head cut moving upstream

Objective:
Assess the function of culverts designed using stream simulation elements

Assessment criteria

- The presence or absence of sediment in the recessed culvert barrel was used as the criteria to determine if the culvert was functioning as intended
- Using that evaluation metric, 6 of the 13 recessed culvert sites did not have sediment accumulated in the barrel.

Why is there no sediment in 6 recessed culverts?

1. A recent large flood event washed out sediment
2. The culvert has not been in place long enough for a range of flows to transport sediment into the culvert
3. Inadequate transport of sediment due to immobile bed materials
4. The culvert slope or width not matching channel dimensions, creating high velocities that prohibit sediment accumulation
5. Excessive sediment accumulated in side barrels, reducing flow capacity and increasing velocity in the main barrel

Sediment analysis

				Materials				
Region	Stream	D84	Location	Boulder	Cobble	Gravel	Sand	Silt/Clay
NE	Stanley Creek	104	Channel	4	31	38	27	0
			Culvert	Filled with rip rap				
NE	East Br. Beaver River D/S	39	Channel		3	81	15	1
			Culvert	No sediment in culvert				
NE	East Br. Beaver River U/S	209	Channel	12	54	33	2	
			Culvert	No sediment in culvert				
NE	West Br. Knife River	48	Channel		10	74	15	1
			Culvert	No sediment in culvert				
NE	Kimball Creek	135	Channel		40	52	8	0
			Culvert		11	89	0	0
NC	Splithand Creek	1	Channel			3	96	1
			Culvert			0	100	0
NC	Rearing Pond	0.6	Channel				100	
			Culvert				100	
NC	Shingobee Creek	24	Channel		5	48	38	5
			Culvert	No sediment in culvert				
NC	Bogus Brook	47	Channel		12	67	19	2
			Culvert	sediment near ends of culvert 10% of area				
NC	Stoney Brook	47	Channel		12	67	19	2
			Culvert	sediment near ends of culvert 10% of area				
SC	Trib to Little Rock	0.4	Channel			11	80	9
			Culvert			0	76	24
SC	LeSueur Creek (in m)	43	Channel		12	62	22	4
			Culvert		0	67	24	10
SC	trib to LeSueur (ditch)	0.5	Channel					
			Culvert			3	89	7
SC	Trib. To Champepadan	3	Channel			32	58	10
			Culvert			5	85	10
SE	Donaldson	0.2	Channel				81	19
			Culvert				16	84
SE	Clear Creek	79	Channel		29	43	17	11
			Culvert	Could not sample				
SE	Duschee	156	Channel		46	54	0	1
			Culvert	No sediment in culvert				
SE	Bear Creek	37	Channel				100	
			Culvert				100	
SE	Gorman Creek	0.8	Channel			8	91	1
			Culvert			32	67	1

Sediment conclusions

- Range of substrates from silt to boulders with sand and gravel predominating most channels
- Stream substrate were coarser than substrate in culvert at 18 of the 19 sites

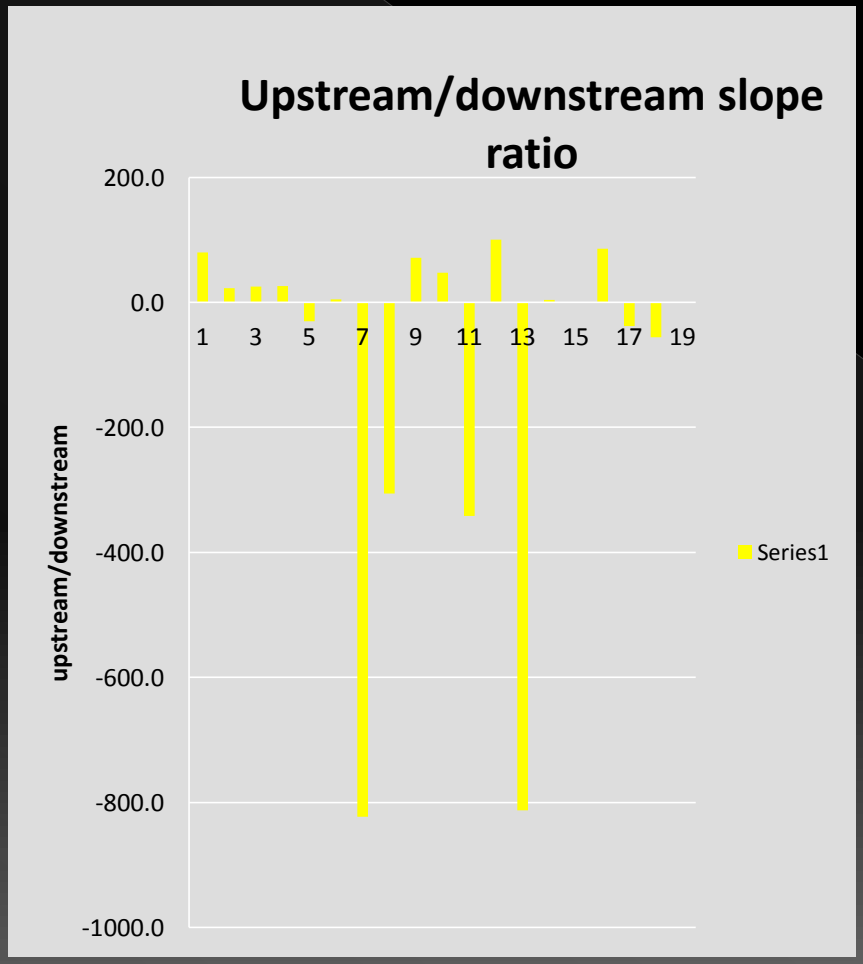
Sediment breakdown culverts with no sediment

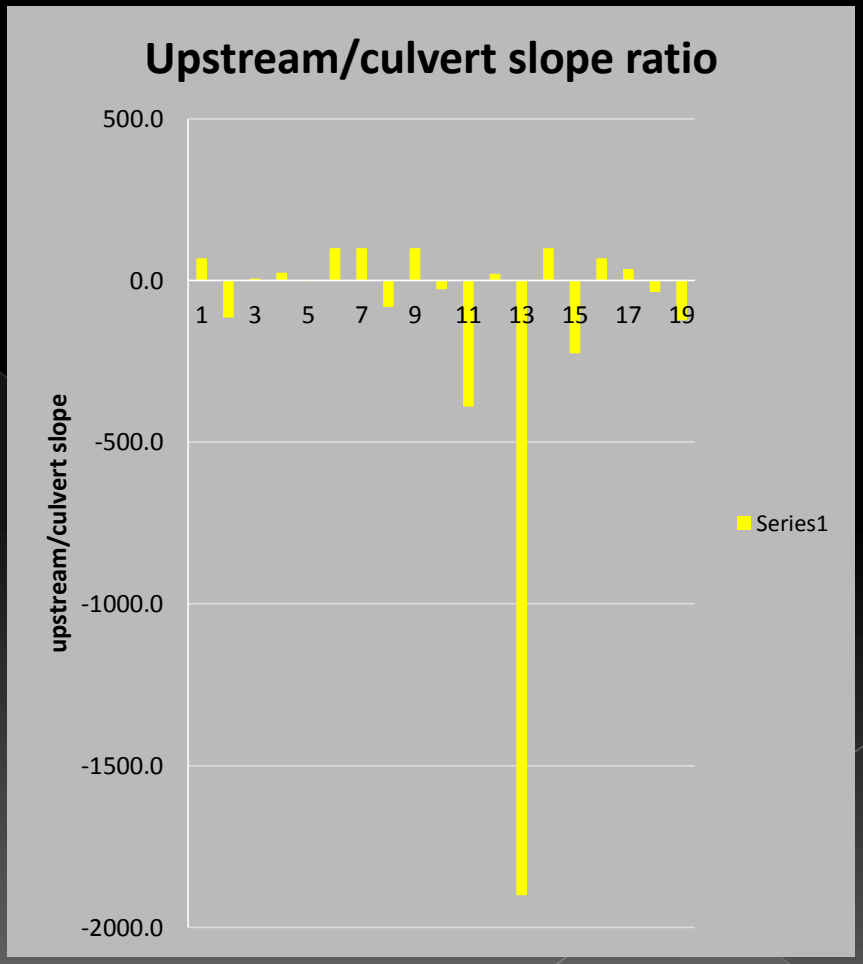
Region	River	D84	Boulder	Cobble	Gravel	Sand	Silt/Clay
NE	East Br. Beaver River D/S	39		3	81	15	1
NE	East Br. Beaver River U/S	209	12	54	33	2	
NC	Shingobee Creek	24		5	48	38	5
NC	Bogus Brook	47		12	67	19	2
NE	West Br. Knife River	48		10	74	15	1
SE	Duschee	146	0	30	43	13	11

Slope or culvert width

The culvert **slope** or **width** not matching channel dimensions, creating high velocities that prohibit sediment accumulation

Slope


Upstream/downstream slope ratio
200.0
0.0
-200.0
-400.0
-600.0
-800.0
-1000.0
1
3
5
7
9
11
13
15
17
19
upstream/downstream
Series1


Upstream/culvert slope ratio
500.0
0.0
-500.0
-1000.0
-1500.0
-2000.0
1
3
5
7
9
11
13
15
17
19
upstream/culvert slope
Series1

Total culvert width / bankfull width

NC	Shingobee Creek	1	12 x 8	12	12	24.8	0.483871
SC	LeSueur Creek	2	12 x 10	24	12	48.8	0.4918033
NE	East Br. Beaver River D/S	2	12 x 12, 12 x 10	24	12	46.7	0.5139186
NE	East Br. Beaver River U/S	2	10 x 8, 10 x 10	20	10	38	0.5263158
NE	West Br. Knife River	1	12 x 8	12	12	22.6	0.5309735
NC	Bogus Brook	2	2 @ arch 157"X97'	24	13	29.9	0.8026756
SC	Trib to LeSueur (ditch)	1	14 x 10	14	14	17.4	0.8045977
NC	Splithand Creek	3	arches ~10' x 5'	18	8.5	18.9	0.952381
NE	Kimball Creek	2	10 x 10, 10 x 9	20	10	17.7	1.1299435
NC	Rearing Pond	2	8 x 6, 8 x 5	16	8	13.2	1.2121212
SE	Duschee	3	12 x 5, 12 x 6, 12 x	36	12	26.4	1.3636364
NC	Stoney Brook	2	2 @ 10' x 8' weir	20	10	14.2	1.4084507
SE	Bear Creek	4	4 @12' x 5'	48	12	30	1.6
SE	Clear Creek	2	10 x 10, 10 x 8	20	10	9.4	2.1276596
NE	Stanley Creek	2	10 x 4, 10 x 6	20	10	9.2	2.173913
SE	Gorman Creek	2	12 x 8, 12 x 9	24	12	10.7	2.2429907
SC	Trib to Little Rock	2	10 x 6	20	10	8.7	2.2988506
SE	Donaldson	3	12 x 8, 12 x 9, 12 x	36	12	11.8	3.0508475
SC	Trib. To Champepadan	3	2@ 14 x 5, 14 x 6	42	14	10.4	4.0384615

Effect of sediment accumulation in side barrels

Sediment accumulation in side barrel

River	Recessed culvert/BFW	Total culvert width/BFW
Rearing pond	0.61	1.21
Kimball	0.56	1.29
Duschee	0.45	1.36
Stoney	0.7	1.4
Gorman	1.12	2.24

Stream type/channel width

Region	Stream	Bankfull width	Stream type u/s
SC	Trib to Little Rock	8.7	E5
NE	Stanley Creek	9.2	E3/4
SE	Clear Creek	9.4	E4
SC	Trib. To Champepadan	10.4	E5
SE	Gorman Creek	10.7	G5
SE	Donaldson	11.8	E5
NC	Rearing Pond	13.2	E5
NC	Stoney Brook	14.2	E4
SC	ib to LeSueur (ditch)benc	17.4	G5
NE	Kimball Creek	17.7	C3/4
NC	Splithand Creek	18.9	E5
NE	West Br. Knife River	22.6	C4
NC	Shingobee Creek	24.8	C4
SE	Duschee	26.4	C3/4
NC	Bogus Brook	29.9	C4
SE	Bear Creek	30	C5
NE	East Br. Beaver River U/S	38	B3
NE	East Br. Beaver River D/S	46.7	C4
SC	LeSueur Creek (in m)	48.8	C4

Influence of stream stability

		Above		Below	
Region	Stream	Pfankuch Stability Index	Rating	Pfankuch Stability Index	Rating
NC	Shingobee Creek	70	Good	74	Good
NC	Bogus Brook	55	Good	116	Poor
NC	Stoney Brook	93	Fair	133	Poor`
NC	Splithand Creek	87	Fair	87	Fair
NC	Rearing Pond	71	Good	no channel	
NE	East Br. Beaver River U/S	49	Good	49	Good
NE	Kimball Creek	59	Good	59	Good
NE	East Br. Beaver River D/S	80.5	Good	75	Good
NE	West Br. Knife River	54	Good	54	Good
NE	Stanley Creek	64	Good	72	Good
SC	LeSueur Creek (in m)	119	Poor	123	Poor
SC	Trib to Little Rock	103	Poor	97	Poor
SC	Trib. To Champepadan	115	Poor	112	Poor
SC	trib to LeSueur (ditch)bench	108	Fair	105	Fair
SE	Duschee	69	Good	62	Good
SE	Bear Creek	104	Fair	113	Poor
SE	Clear Creek	66	Good	102	Poor
SE	Donaldson	95	Fair	117	Poor
SE	Gorman Creek	106	Good	119	Poor

Donaldson Creek

Conclusions

- At all but one of the surveyed sites headcut potential was addressed with some sort of grade control

- Five of six recessed culverts with no sediment had total culvert widths less than 80 percent of the channel width suggesting inadequate culvert width was the main reason for no sediment in culvert barrel

Conclusions

- A number of sites had significant sediment accumulation in side barrels. At the time of survey it was determined to be the cause for no sediment in culvert at only one site.
- Wider “C” type channels correlated with 5 of the 6 sites with no sediment in the recessed barrel

I am done any questions?

Data collection/Design

- Need better data
- Properly size the culvert width to better maintain or recruit sediment in culvert
- Calculate the necessary recessed depth
- Better location and elevation for multiple barrel designs

Locations


Kimball Cr.
Rearing Pond
E. Branch Beaver R. (2 sites)
Spilthand R.
Stanley Creek
W. Br. Knife
Shingobee Cr.
Minnesota
Bogus Br.
Stony Brook
LeSueur Cr.
Clear Cr.
Gorman Cr.
LeSueur ditch
Bear Cr.
Trib Champepadan
Trib. to Little Rock
Duschee Cr.
Donaldson Cr.
Wisconsin
Image USDA Farm Service Agency
© 2011 Google
Google

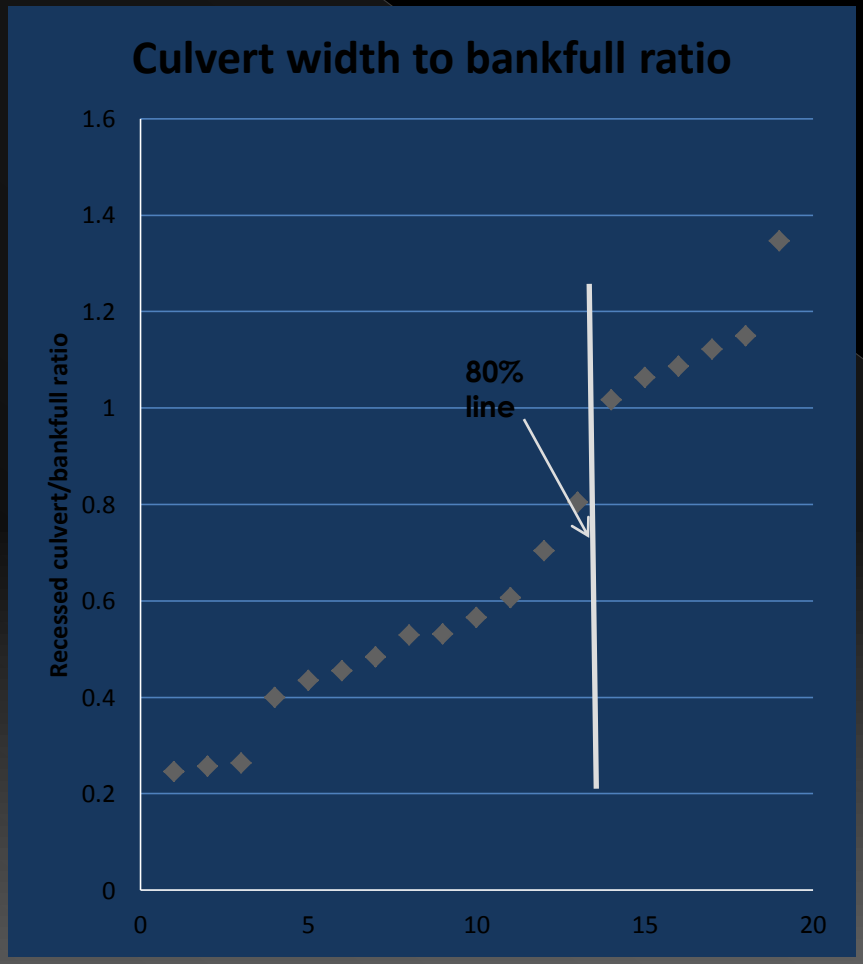

E5-Channel

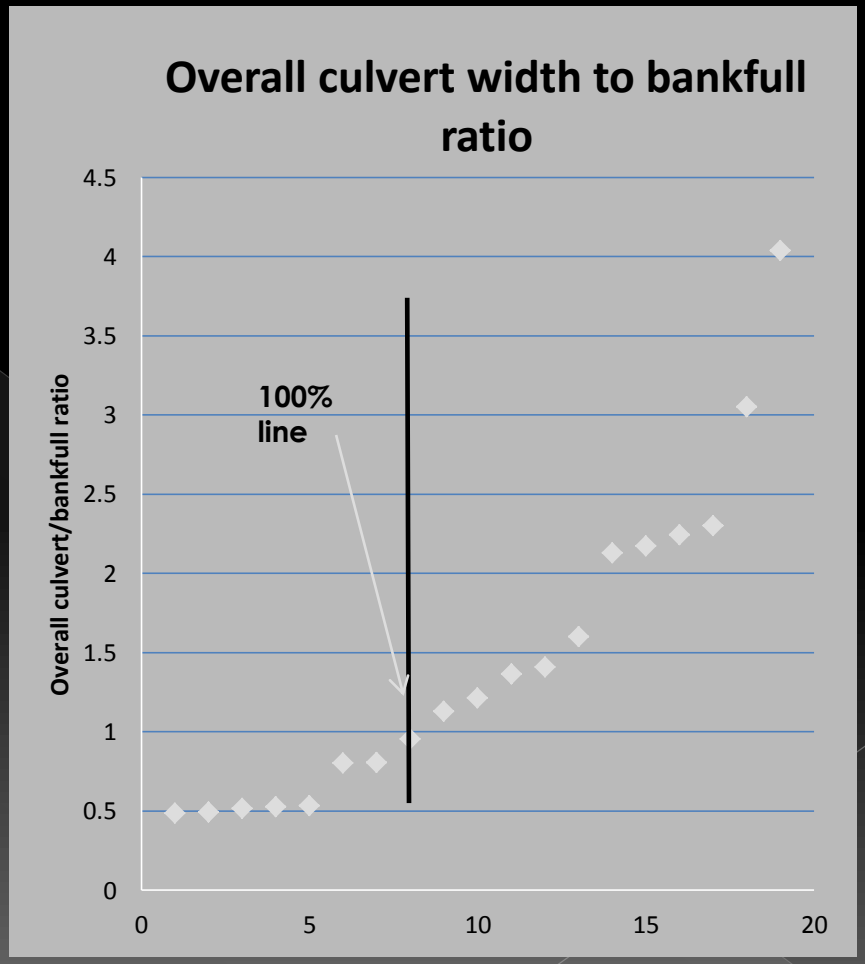

G5-Channel


B3- Channel


C4-Channel

Culvert width / bankfull channel width comparison





Stream stability statistics

- Stream types
  - Eight channels E3 – E5
  - Eight channels C3 – C5
  - Two channels G5 (one natural stream, one ditch)
  - One channel B3
- Pfankuch upstream rating
  - 11 “Good”
  - 5 “Fair”
  - 3 “Poor”

Site selection

- Good accessibility for surveying
- Recessed below the flow line elevation
- Perennial stream (flowing year round)
- Age of the culvert
- Range of channel substrates from sand to cobble
- Culvert configuration and size
- Stream size
- Drainage area

Recess culvert and match channel slope and bankfull width

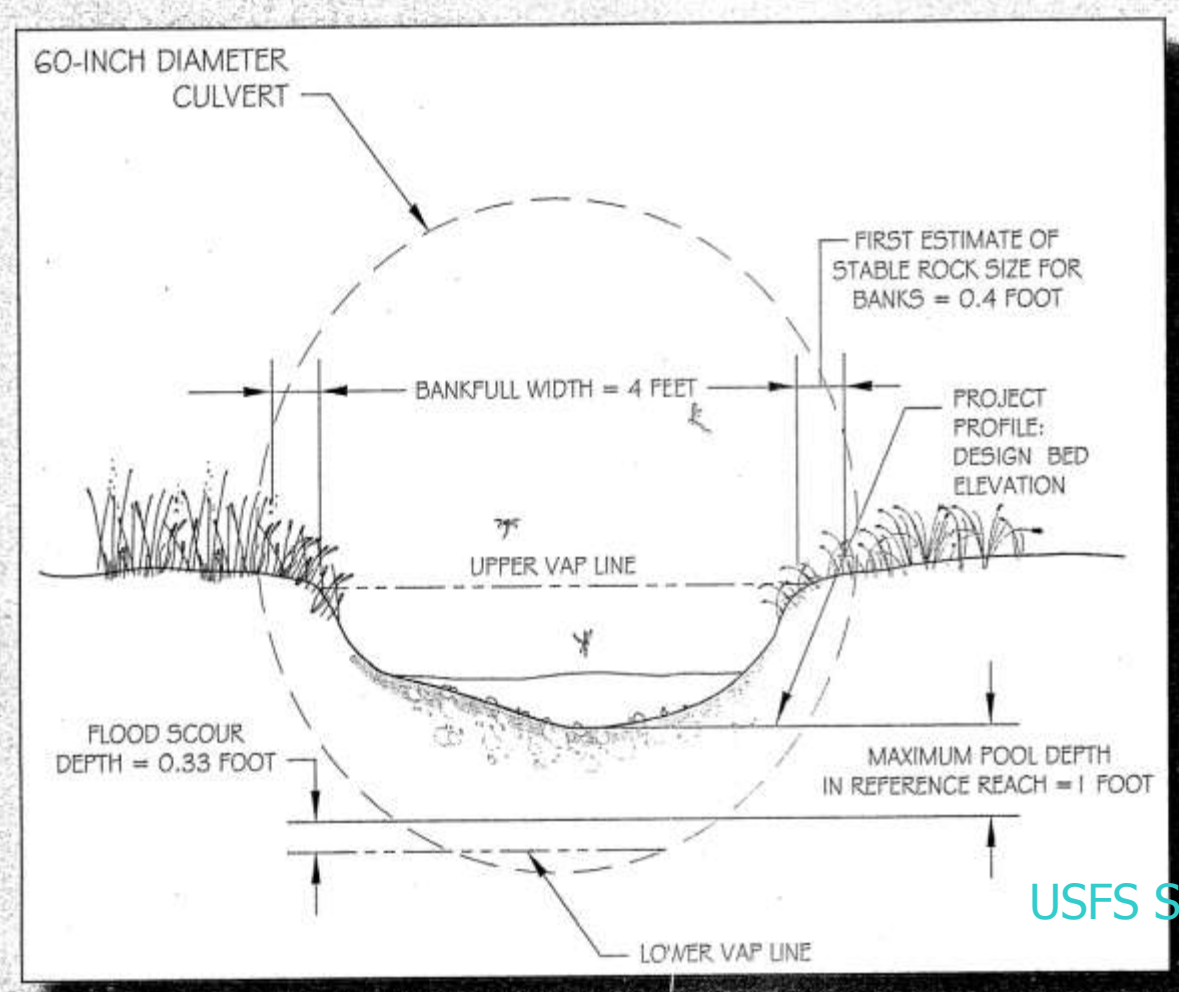


Figure 6.29—Hypothetical example of using reference reach channel size and bed material (described in text) to size a small culvert. VAP lines shown in the figure were determined from a longitudinal profile analysis. This drawing does not show the designed simulated channel bed; rather, it shows how the culvert would fit around the reference reach.

USFS Stream Simulation Design Manual

Slope

- Six sites have culvert slopes that were greater than the upstream slopes
- In this data set there is no correlation between higher culvert slope and a lack of accumulated sediments in the recessed culvert
- The difference in slope between upstream and downstream was associated with land use changes in 5 of 6 sites

Sediment accumulation in side barrels

Region	Stream	Elevation of sediment in recessed barrel (ft) A	Elevation of sediment in side barrel (ft B	Elevation difference column B-A C	Channel bankfull depth (ft) D	Columns C-D E	Overall culvert width	Recessed culvert width	Bankfull channel width
NE	Stanley Creek	101	102.5	1.5	1.3	0.2	20	10	9.2
NE	East Br. Beaver River D/S	100	102.5	2.5	2	0.5	24	12	46.7
NE	East Br. Beaver River U/S	100	102.5	2.5	2.1	0.4	20	10	38
NE	West Br. Knife River	100	100	0			12	12	22.6
NE	Kimball Creek	100	102	2	1.5	0.5	20	10	17.7
NC	Splithand Creek	101.5	101.75	0.25	2.1	-1.85	18	8.5	18.9
NC	Rearing Pond	100.15	102.55	2.4	1.7	0.7	16	8	13.2
NC	Shingobee Creek	100	100	0			12	12	24.8
NC	Bogus Brook	100	100.5	0.5	1.9	-1.4	24	13	20
NC	Stoney Brook	100	104.65	4.65	2.3	2.35	20	10	14.2
SC	Trib to Little Rock	100.15	101.15	1	1.6	-0.6	20	10	8.7
SC	LeSueur Creek	100	102.5	2.5	2.6	-0.1	24	12	48.8
SC	Trib to LeSueur (ditch)	101	101	0			14	14	17.4
SC	Trib. To Champepadan	100.5	101	0.5	1.5	-1	42	14	10.4
SE	Donaldson	101.9	101.9	0	2.9	-2.9	36	12	11.8
SE	Clear Creek	101.25	103.55	2.3	2.7	-0.4	20	10	9.4
SE	Duschee	100	101.7	1.7	2.3	-0.6	36	12	26.4
SE	Bear Creek	102	103	1	2.4	-1.4	48	12	30
SE	Gorman Creek	100.4	103.9	3.5	1.4	2.1	24	12	10.7

Recessed culvert width / bankfull channel width comparison

Region	Stream	# of barrels	culvert size	Overall culvert width	Recessed culvert width	Bankfull channel width	Ratio Recessed culvert W/BFW
SC	LeSueur Creek	2	12 x 10	24	12	48.8	0.2459016
NE	East Br. Beaver River D/S	2	12 x 12, 12 x 10	24	12	46.7	0.2569593
NE	East Br. Beaver River U/S	2	10 x 8, 10 x 10	20	10	38	0.2631579
SE	Bear Creek	4	4 @12' x 5'	48	12	30	0.40
NC	Bogus Brook	2	2 @ arch 157"X97'	24	13	29.9	0.4347826
NC	Splithand Creek	3	arches ~10' x 5'	18	8.5	18.9	0.45
SE	Duschee	3	2 x 5, 12 x 6, 12 x	36	12	26.4	0.4545455
NC	Shingobee Creek	1	12 x 8	12	12	24.8	0.483871
NE	West Br. Knife River	1	12 x 8	12	12	22.6	0.5309735
NE	Kimball Creek	2	10 x 10, 10 x 9	20	10	17.7	0.56
NC	Rearing Pond	2	8 x 6, 8 x 5	16	8	13.2	0.61
NC	Stoney Brook	2	2 @ 10' x 8' weir	20	10	14.2	0.70
SC	Trib to LeSueur (ditch)	1	14 x 10	14	14	17.4	0.80
SE	Donaldson	3	2 x 8, 12 x 9, 12 x	36	12	11.8	1.02
SE	Clear Creek	2	10 x 10, 10 x 8	20	10	9.4	1.06
NE	Stanley Creek	2	10 x 4, 10 x 6	20	10	9.2	1.09
SE	Gorman Creek	2	12 x 8, 12 x 9	24	12	10.7	1.12
SC	Trib to Little Rock	2	10 x 6	20	10	8.7	1.15
SC	Trib. To Champepadan	3	2@ 14 x 5, 14 x 6	42	14	10.4	1.35

Side barrel sediment accumulation conclusions

- If sediment and vegetation accumulate to a depth greater than the bankfull depth of the channel it could create excess velocity through the main culvert barrel

Matching culvert widths to bankfull channel width conclusions

- The 6 recessed culverts with no sediment had culvert widths less than 50 percent of the channel width
- 5 of the recessed culverts with no sediment had total culvert widths less than 80 percent of the channel width
- Inadequate culvert width inhibiting sediment accumulation in recessed barrel