APPENDIX 5-3

Lower Robinson Creek
Culvert and Diversion Analysis

By: Dr. James E. Nelson - Assistant Professor, Civil and Environmental Engineering - Brigham Young University

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STATE OF UTAH

Culvert Analysis for Drainages near Lower Robinson Creek

This report summarizes the design and analysis of two culverts proposed to be located on the crossings on Lower Robinson Creek (RCreek) and a small tributary (RCTrib) near Alton Utah.

Figure 1 shows the watersheds above the proposed culvert crossings on the map. The larger drainage **RCreek** has an area of **3.55 sq. mi**. and the smaller drainage **RCTrib** has a drainage area of **0.09 sq. mi**. The average elevation of the watersheds is about 7830 ft. The watersheds were delineated and basin data calculated from the digital elevation model (DEM) of the Alton quadrangle.

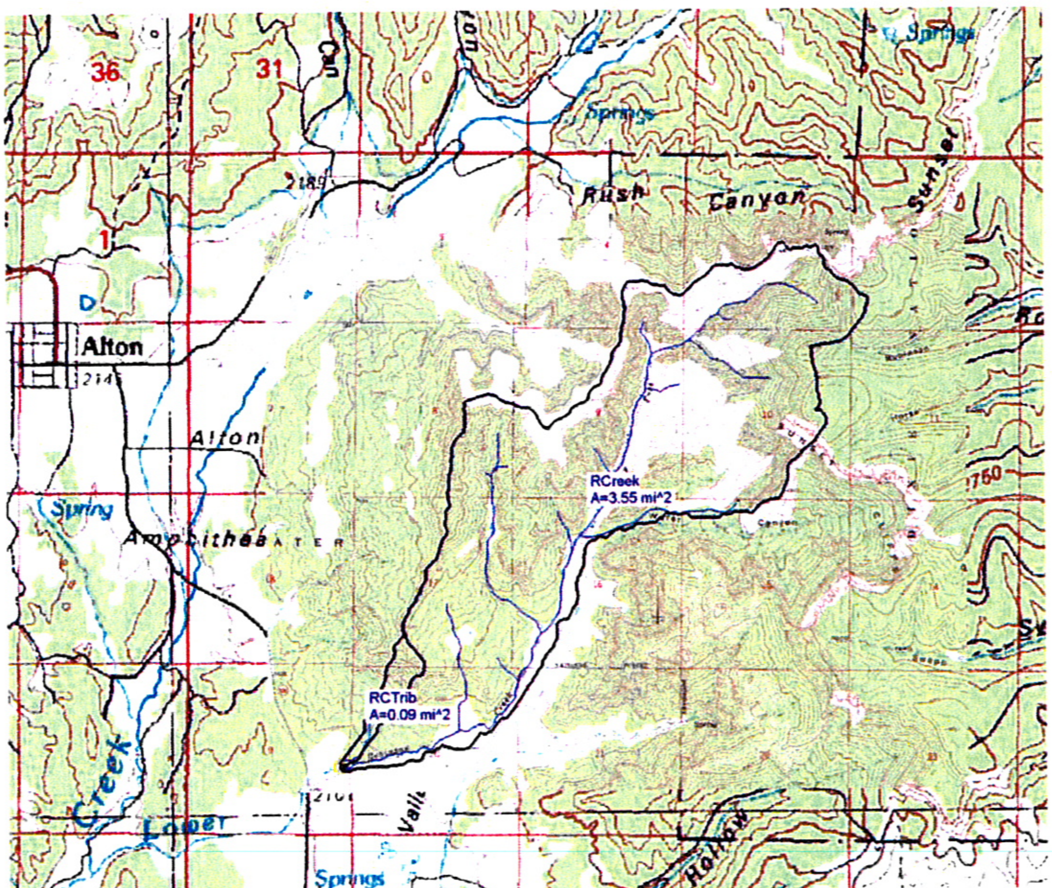

Figure 1 – Delineated Basins for Lower Robinson Creek and a Small Tributary.

The culverts need to be designed such that they can pass a peak flow resulting from the 100-year six hour storm. In order to compute this peak flow the HEC-1 program was used with the 100-year six hour precipitation from NOAA. Losses (initial abstractions and infiltration) are determined using the SCS Curve Number (CN), and excess rainfall transformed to a peak flow and runoff hydrograph using the SCS unit hydrograph method. Land use and hydrologic soil types are required to compute a composite CN. Soil type data were downloaded from the NRCS (formerly SCS) soils data mart. Land use was downloaded from the USGS seamless data website and overlaid with the delineated basins as shown in Figure 2.

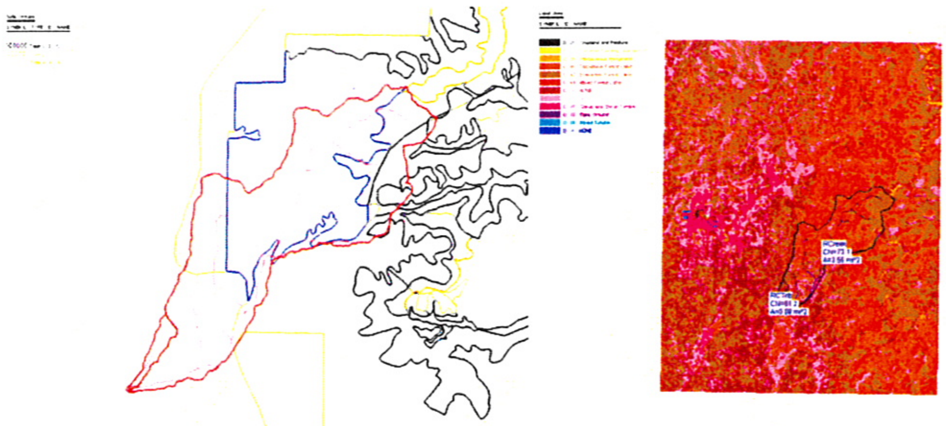

Figure 2 – Digital Land Use and Soils Data Overlaid with Robinson Creek Watersheds.

A CN was computed by averaging the individual CN's determined from the unique land use and soil combinations in conjunction with the table of values prepared for use by the Utah Department of Transportation (UDOT) as shown in Table 1.

Table 1 – CN values for typical USGS land use classifications

ID	Description	CNA	CNB	CNC	CND
-1	"Average Forested Values"	40	60	70	78
11	"Residential"	60	74	82	87
12	"Commercial Services"	89	92	94	95
13	"Industrial"	81	88	91	93
14	"Transportation and Communication"	76	85	89	91
16	"Mixed urban or built up land"	77	85	90	93
17	"Other urban or built up land"	71	82	88	90
21	"Cropland and Pasture"	49	68	78	84
22	"Orchards, Groves, Vineyards, Nurseries"	47	67	77	83
23	"Confined Feeding Operations"	55	63	66	68
24	"Other Agricultural Land"	62	74	82	86
31	"Herbaceous Rangeland"	45	66	77	82
32	"Shrub and Brush Rangeland"	44	64	77	82
33	"Mixed Rangeland"	46	66	77	83
41	"Decideous Forest Land"	31	58	68	75
42	"Evergreen Forest Land"	35	59	73	79
43	"Mixed Forest Land"	39	61	74	80
52	"Lakes"	0	0	0	0
53	"Reservoirs"	0	0	0	0
61	"Forested Wetlands"	44	58	68	75
62	"Nonforested Wetlands"	32	55	68	75
74	"Bare Exposed Rock"	98	98	98	98
75	"Strip Mines"	71	80	85	88
76	"Transitional Areas"	69	78	84	88
81	"Shrub and Shrub Tundra"	60	74	83	87
82	"Herbaceous Tundra"	66	76	83	87
83	"Bare Ground"	74	83	87	90
85	"Mixed Tundra"	50	65	74	80

The RCreek watershed has a compute average CN of 73, whereas the computed average CN for RCTrib is 61, though in order to be conservative a value of 73 was also used for the small watershed. The higher value was used because the watershed is so small that it did not fit well within the resolution and resulted in almost zero runoff. The watershed is similar in land use and soil to the larger RCreek and therefore the same CN value was used.

Digital rainfall data from NOAA for Utah was downloaded from NOAA and overlaid with the basin in order to determine watershed average values for the 100-year six hour storm. Figure 3 shows the rainfall data and basin (small black area in the south-eastern portion of the state).

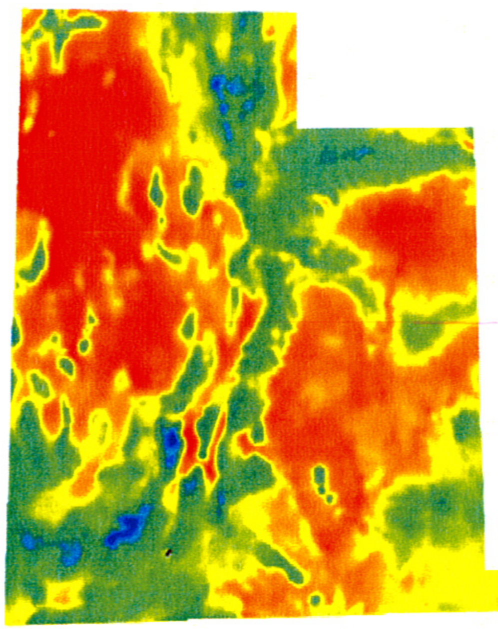

Figure 3 – NOAA Rainfall Data for the 100-Year Six Hour Storm.

Using the NOAA data a rainfall depth of 2.35 inches for RCreek was computed and a depth of 2.27 for RCTrib. These values were spread out over a six hour period using a standard SCS temporal distribution typical for design of hydraulic structures.

The information computed from the digital data and the Watershed Modeling System (WMS) was used to develop the parameters for an HEC-1 model as summarized in Table 2.

Table 2 – Parameter Summaries for HEC-1 Model

Basin	Area (sq. miles)	Precip (inches)	CN	Lag Time (hrs)
RCreek	3.55	2.35	73	.95
RCTrib	.09	2.27	73	.42

HEC-1 is a computer program developed by the US Army Corps of Engineers to develop rainfall runoff peak flows and hydrographs. The data summarized in Table 2 was formatted by WMS into an input file as shown in Table 3.

Table 3 – HEC-1 Input File

```
IDHEC-1 Analysis using WMS
ID
ID
*DIAGRAM
IT     7 01JAN94         0       200
IO     0
KKRCreek
KO     0         0     0.0         0        22
BA3.5506
PB 2.348
IN     7 01JAN94         0
* SCS-StdEmergencySpillway
PC   0.0   0.008  0.0162  0.0246  0.0333  0.0425  0.0524   0.063  0.0743  0.0863
PC 0.099  0.1124  0.1265   0.142  0.1595    0.18   0.205   0.255   0.345   0.437
PC  0.53   0.603   0.633    0.66   0.684   0.705   0.724   0.742   0.759   0.775
PC  0.79  0.8043   0.818  0.8312  0.8439  0.8561  0.8678   0.879  0.8898  0.9002
PC0.9103  0.9201  0.9297  0.9391  0.9483  0.9573  0.9661  0.9747  0.9832  0.9916
PC   1.0
LS   0.0   73.08     0.0
UD0.9461
KK    4R   CNAME      4C
KO     0         0     0.0         0        22
RN    4R
KKRCTrib
KO     0         0     0.0         0        22
BA0.0935
PB 2.274
IN     7 01JAN94         0
* SCS-StdEmergencySpillway
PC   0.0   0.008  0.0162  0.0246  0.0333  0.0425  0.0524   0.063  0.0743  0.0863
PC 0.099  0.1124  0.1265   0.142  0.1595    0.18   0.205   0.255   0.345   0.437
PC  0.53   0.603   0.633    0.66   0.684   0.705   0.724   0.742   0.759   0.775
PC  0.79  0.8043   0.818  0.8312  0.8439  0.8561  0.8678   0.879  0.8898  0.9002
PC0.9103  0.9201  0.9297  0.9391  0.9483  0.9573  0.9661  0.9747  0.9832  0.9916
PC   1.0
LS   0.0    73.0     0.0
UD0.4207
KK    3R   CNAME      3C
KO     0         0     0.0         0        22
RN    3R
ZZ
```

The results of the HEC-1 model determined the peak flow for RCreek to be 336 cfs (see Figure 4) and for RCTrib the peak flow was computed to be 11 cfs (see Figure 5). Values from the USGS regional regression NFF equations for the same basins were 408 cfs and 117 cfs respectively. It should be noted though that the NFF equations are for a 100-year event, but no durations (i.e. six hour) are specified. The larger basin compared quite well (336 to 408) even considering the differences. However the HEC-1 computed value of 11 cfs would seem low compared to the NFF computed value of 117 cfs. On the other hand the NFF equations were not developed for computing runoff from such small basins and therefore the computed value of 117 (besides not being developed from a six hour storm) is suspect and greater confidence can be given to the HEC-1 computed peak flow.

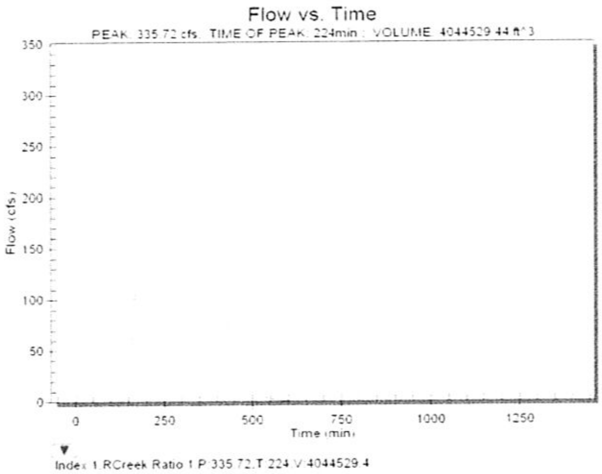

Figure 4 – Computed Runoff Hydrograph for RCreek

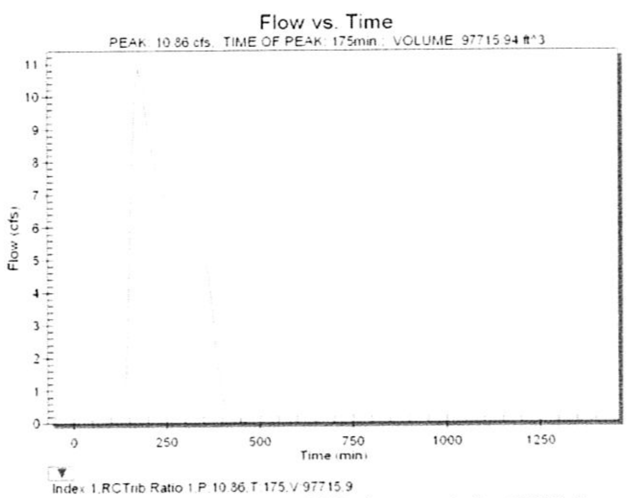

Figure 5 – Computed Runoff Hydrograph for RCTrib

Culvert Analysis

The FHWA HY-8 program for culvert analysis was used with the peak flows of 336 cfs and 11 cfs computed using the HEC-1 analysis described above. Because of the large watershed above RCreek the culvert was analyzed for two different conditions: 1) a smaller sized barrel that is sufficiently large so that overtopping of the roadway (assumed 18 feet above the culvert invert from the provided profile information), but that does surcharge the culvert for the 100-year six hour event, and 2) a larger barrel that carries the design flow with surcharging the culvert.

Culvert Data Summary – 5.5 foot Circular for RCreek

Barrel Shape: Circular

Barrel Diameter: 5.50 ft

Barrel Material: Corrugated Steel

Table 5 - Summary of Culvert Flows at Crossing: RCreek for 5.5 foot culvert

Headwater Elevation (ft)	Total Discharge (cfs)	Circular Discharge (cfs)	Roadway Discharge (cfs)	Iterations
100.00	0.00	0.00	0.00	1
102.77	40.00	40.00	0.00	1
104.07	80.00	80.00	0.00	1
105.17	120.00	120.00	0.00	1
106.24	160.00	160.00	0.00	1
107.54	200.00	200.00	0.00	1
109.52	240.00	240.00	0.00	1
111.76	280.00	280.00	0.00	1
114.22	320.00	320.00	0.00	1
115.35	336.00	336.00	0.00	1
118.23	400.00	370.29	29.56	7

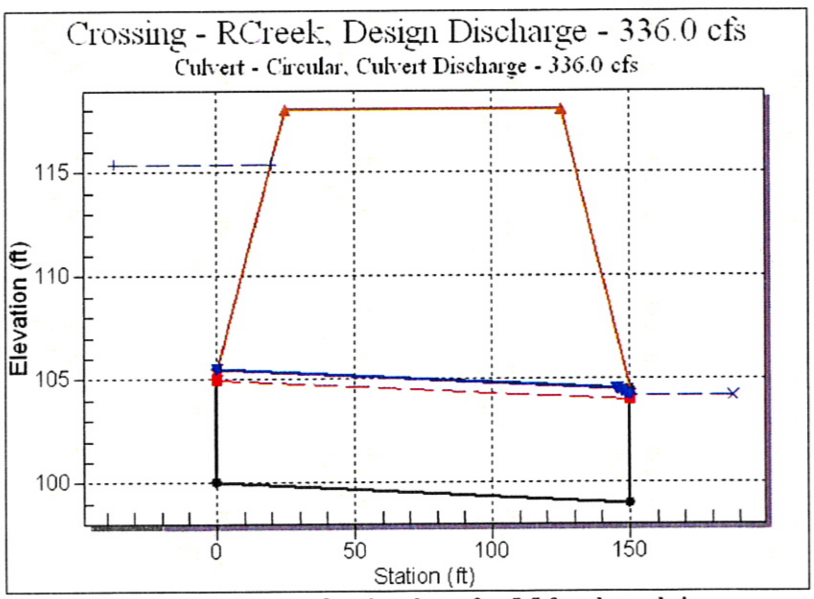

Figure 6 – Profile through RCreek culvert for 5.5 foot barrel size.

Culvert Data Summary – 8.0 foot Circular for RCreek Crossing

Barrel Shape: Circular

Barrel Diameter: 8.00 ft

Barrel Material: Corrugated Steel

Table 5 - Summary of Culvert Flows at Crossing: RCreek for 8.0 foot culvert

Headwater Elevation (ft)	Total Discharge (cfs)	Circular Discharge (cfs)	Roadway Discharge (cfs)	Iterations
100.00	0.00	0.00	0.00	1
102.46	40.00	40.00	0.00	1
103.57	80.00	80.00	0.00	1
104.43	120.00	120.00	0.00	1
105.19	160.00	160.00	0.00	1
105.88	200.00	200.00	0.00	1
106.52	240.00	240.00	0.00	1
107.13	280.00	280.00	0.00	1
107.73	320.00	320.00	0.00	1
107.96	336.00	336.00	0.00	1
108.91	400.00	400.00	0.00	3

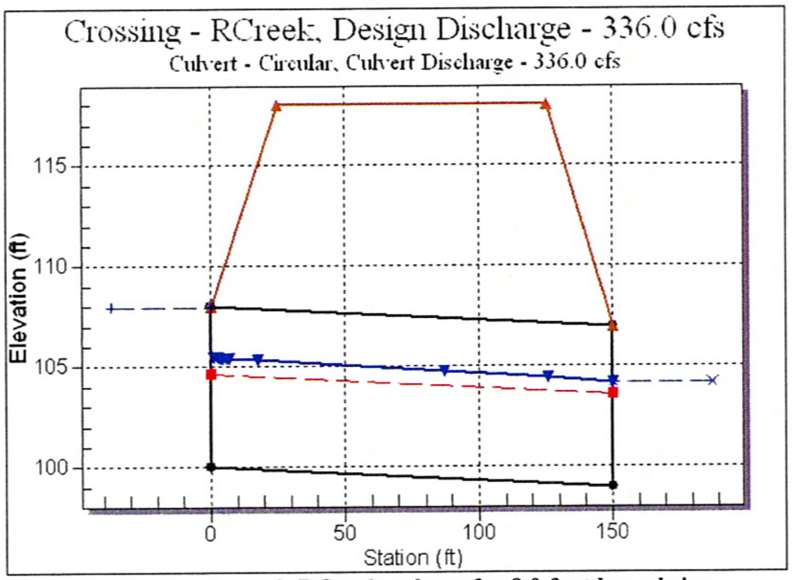

Figure 7 – Profile through RCreek culvert for 8.0 foot barrel size

Culvert Data Summary – 2.5 foot Circular for RCTrib

Barrel Shape: Circular

Barrel Diameter: 2.50 ft

Barrel Material: Corrugated Steel

Table 6 - Summary of Culvert Flows at Crossing: RCTrib for 2.5 foot culvert

Headwater Elevation (ft)	Total Discharge (cfs)	Circular Discharge (cfs)	Roadway Discharge (cfs)	Iterations
100.00	0.00	0.00	0.00	1
100.82	2.50	2.50	0.00	1
101.19	5.00	5.00	0.00	1
101.49	7.50	7.50	0.00	1
101.75	10.00	10.00	0.00	1
101.85	11.00	11.00	0.00	1
102.23	15.00	15.00	0.00	1
102.48	17.50	17.50	0.00	1
102.74	20.00	20.00	0.00	1
103.11	22.50	22.50	0.00	1
103.70	25.00	25.00	0.00	1

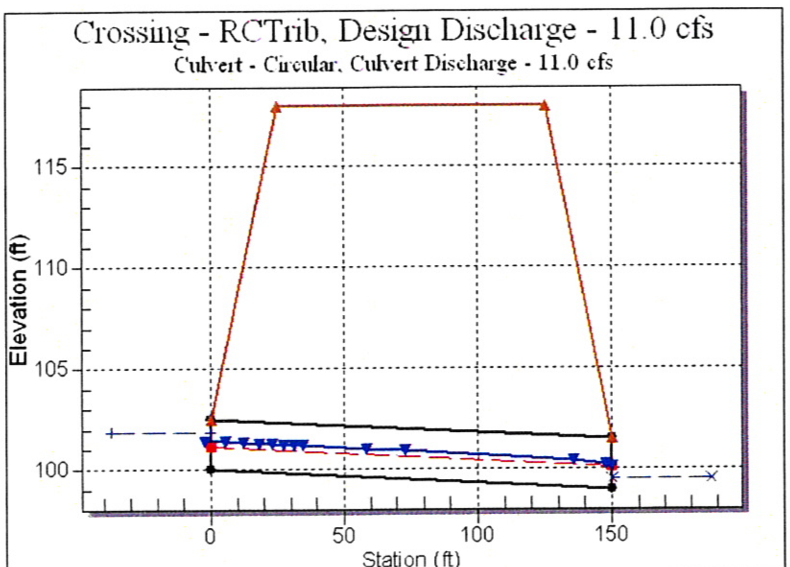

Figure 8 – Profile through RCTrib culvert for2.5 foot barrel size

Diversion Ditch Analysis for Drainages near Lower Robinson Creek

In a previous study we sized culverts for a 100-year six hour storm. A diversion ditch was also analyzed for a 100-year event, but without lining the ditch in concrete it would be impossible to protect it from the highly erosive super critical flows which occur during larger events primarily because of the relatively steep slopes (.01 to .028). In fact it has been reported that as is the channel appears to be constantly changing due to erosion as a result of larger storms. Even if you were to protect this section with concrete lining of the diversion canal problems above and below are likely to continue and cause additional problems for the stability of the diversion ditch. This report reviews the hydrologic calculations used to determine the 10-year peak flow followed by an analysis of the same ditch designed for the 100-year flow with protection against erosion for the 10-year event. The hydrologic analysis is almost identical to the previous report for culvert design with the exception that the 10-year precipitation is used instead of the 100-year precipitation.

Figure 1 shows the watersheds above the proposed culvert crossings on the map. The larger drainage **RCreek** has an area of **3.55 sq. mi**. and the smaller drainage **RCTrib** has a drainage area of **0.09 sq. mi**. The average elevation of the watersheds is about 7830 ft. The watersheds were delineated and basin data calculated from the digital elevation model (DEM) of the Alton quadrangle.

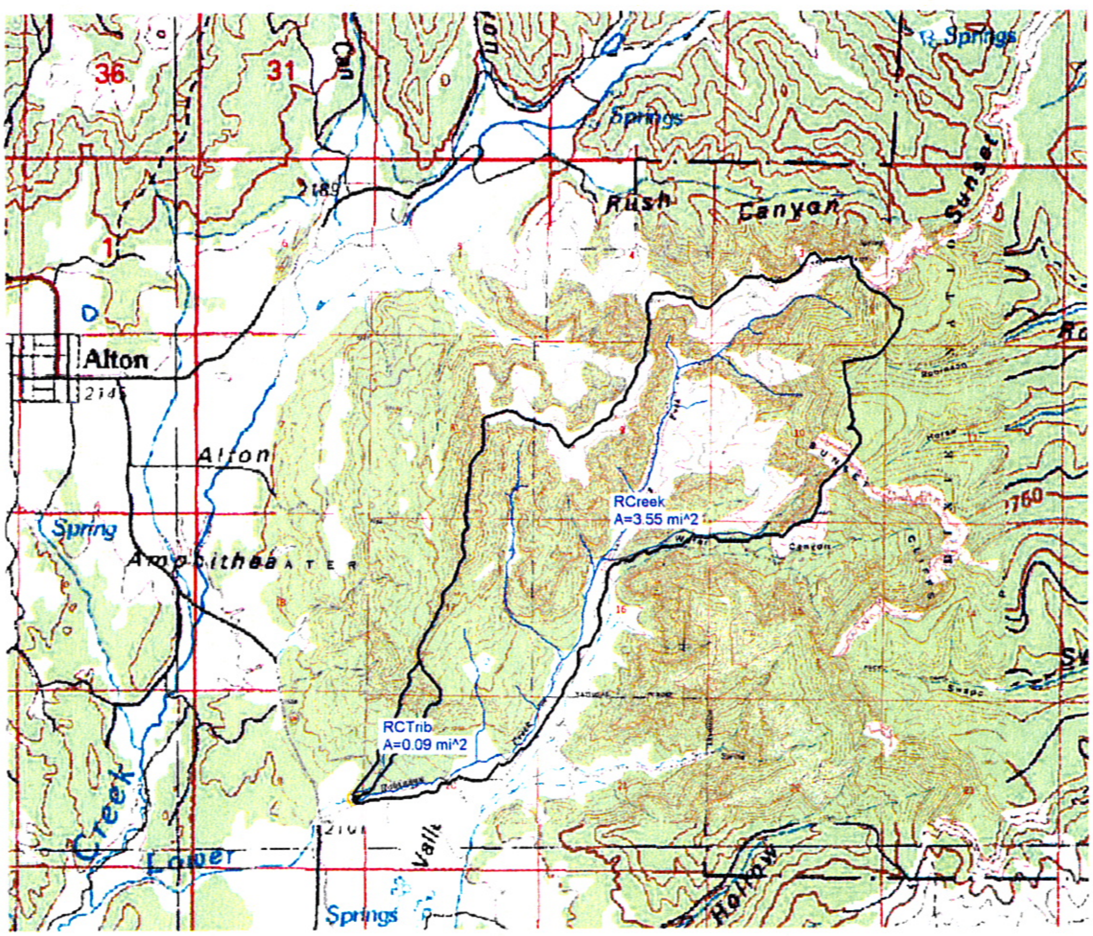

Figure 1 – Delineated Basins for Lower Robinson Creek and a Small Tributary.

The ditch needs to be designed such that it can convey a peak flow resulting from the 10-year six hour storm. In order to compute this peak flow the HEC-1 program was used with the 10-year six hour precipitation from NOAA. Losses (initial abstractions and infiltration) are determined using the SCS Curve Number (CN), and excess rainfall transformed to a peak flow and runoff hydrograph using the SCS unit hydrograph method. Land use and hydrologic soil types are required to compute a composite CN. Soil type data were downloaded from the NRCS (formerly SCS) soils data mart. Land use was downloaded from the USGS seamless data website and overlaid with the delineated basins as shown in Figure 2.

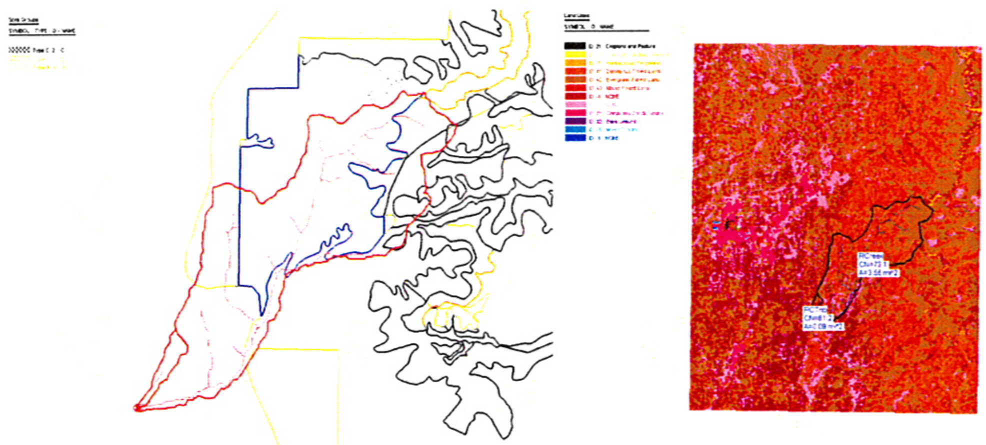

Figure 2 – Digital Land Use and Soils Data Overlaid with Robinson Creek Watersheds.

A CN was computed by averaging the individual CN's determined from the unique land use and soil combinations in conjunction with the table of values prepared for use by the Utah Department of Transportation (UDOT) as shown in Table 1.

Table 1 – CN values for typical USGS land use classifications

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ID    Description                   CNA CNB CNC CND
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11, "Residential", 60, 74, 82, 87
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13, "Industrial", 81, 88, 91, 93
14, "Transportation and Communication", 76, 85, 89, 91
16, "Mixed urban or built up land", 77, 85, 90, 93
17, "Other urban or built up land", 71, 82, 88, 90
21, "Cropland and Pasture", 49, 68, 78, 84
22, "Orchards, Groves, Vineyards, Nurseries", 47, 67, 77, 83
23, "Confined Feeding Operations", 55, 63, 66, 68
24, "Other Agricultural Land", 62, 74, 82, 86
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32, "Shrub and Brush Rangeland", 44, 64, 77, 82
33, "Mixed Rangeland", 46, 66, 77, 83
41, "Decideous Forest Land", 31, 58, 68, 75
42, "Evergreen Forest Land", 35, 59, 73, 79
43, "Mixed Forest Land", 39, 61, 74, 80
52, "Lakes", 0, 0, 0, 0
53, "Reservoirs", 0, 0, 0, 0
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61, "Forested Wetlands", 44, 58, 68, 75
62, "Nonforested Wetlands", 32, 55, 68, 75
74, "Bare Exposed Rock", 98, 98, 98, 98
75, "Strip Mines", 71, 80, 85, 88
76, "Transitional Areas", 69, 78, 84, 88
81, "Shrub and Shrub Tundra", 60, 74, 83, 87
82, "Herbaceous Tundra", 66, 76, 83, 87
83, "Bare Ground", 74, 83, 87, 90
85, "Mixed Tundra", 50, 65, 74, 80
```

The RCreek watershed has a compute average CN of 73, whereas the computed average CN for RCTrib is 61, though in order to be conservative a value of 73 was also used for the small watershed. The higher value was used because the watershed is so small that it did not fit well within the resolution and resulted in almost zero runoff. The watershed is similar in land use and soil to the larger RCreek and therefore the same CN value was used.

Utah 37.42162 N 112.4207 W 7746 feet
from "Precipitation-Frequency Atlas of the United States" NOAA Atlas 14, Volume 1, Version 4
G.M. Bonnin, D. Martin, B. Lin, T. Parzybok, M.Yekta, and D. Riley
NOAA, National Weather Service, Silver Spring, Maryland, 2006

Precipitation Frequency Estimates (inches)

ARI* (years)	5 min	10 min	15 min	30 min	60 min	120 min	3 hr	6 hr	12 hr	24 hr	48 hr	4 day	7 day	10 day	20 day	30 day	45 day	60 day
1	0.15	0.24	0.29	0.39	0.49	0.56	0.65	0.82	1.14	1.40	1.66	1.99	2.39	2.73	3.61	4.41	5.24	6.23
2	0.20	0.30	0.37	0.50	0.62	0.71	0.81	1.01	1.42	1.74	2.08	2.49	3.00	3.44	4.52	5.53	6.60	7.86
5	0.28	0.42	0.52	0.70	0.86	0.94	1.05	1.27	1.74	2.18	2.61	3.14	3.82	4.41	5.65	6.89	8.32	9.95
10	0.34	0.52	0.65	0.87	1.08	1.16	1.27	1.49	2.02	2.54	3.05	3.68	4.48	5.19	6.56	7.95	9.68	11.58
25	0.46	0.69	0.86	1.16	1.43	1.50	1.60	1.81	2.41	3.04	3.66	4.43	5.40	6.29	7.79	9.36	11.52	13.80
50	0.56	0.85	1.05	1.41	1.75	1.82	1.89	2.08	2.72	3.43	4.14	5.04	6.13	7.16	8.74	10.44	12.96	15.53
100	0.68	1.03	1.28	1.72	2.13	2.21	2.28	2.39	3.04	3.84	4.66	5.68	6.90	8.09	9.72	11.52	14.44	17.31
200	0.82	1.25	1.55	2.08	2.58	2.67	2.75	2.84	3.40	4.26	5.20	6.36	7.70	9.06	10.71	12.61	15.96	19.15
500	1.05	1.60	1.98	2.67	3.30	3.42	3.50	3.59	3.93	4.85	5.94	7.30	8.81	10.43	12.07	14.05	18.05	21.65
1000	1.27	1.93	2.39	3.22	3.98	4.12	4.19	4.28	4.65	5.31	6.54	8.06	9.69	11.52	13.12	15.15	19.68	23.61

Table 2 – NOAA Rainfall Data for the Robinson Creek location.

The rainfall depth for the Robinson Creek location for a 10-year six hour storm is 1.49 inches. This rainfall depth is spread out in HEC-1 over a six hour period using a standard SCS temporal distribution typical for design of hydraulic structures.

The information computed from the digital data and the Watershed Modeling System (WMS) was used to develop the parameters for an HEC-1 model as summarized in Table 2.

Table 3 – Parameter Summaries for HEC-1 Model

Basin	Area	Precip	CN	Lag Time

	(sq. miles)	(inches)		(hrs)
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KKRCreek
KO      0        0     0.0        0       22
BA3.5506
PB 2.348
IN      7 01JAN94        0
* SCS-StdEmergencySpillway
PC    0.0    0.008  0.0162  0.0246  0.0333  0.0425  0.0524   0.063  0.0743  0.0863
PC 0.099   0.1124  0.1265   0.142  0.1595    0.18   0.205   0.255   0.345   0.437
PC   0.53    0.603   0.633    0.66   0.684   0.705   0.724   0.742   0.759   0.775
PC   0.79   0.8043   0.818  0.8312  0.8439  0.8561  0.8678   0.879  0.8898  0.9002
PC0.9103   0.9201  0.9297  0.9391  0.9483  0.9573  0.9661  0.9747  0.9832  0.9916
PC    1.0
LS    0.0    73.08     0.0
UD0.9461
KK     4R    CNAME      4C
KO      0        0     0.0        0       22
RN     4R
KKRCTrib
KO      0        0     0.0        0       22
BA0.0935
PB 2.274
IN      7 01JAN94        0
* SCS-StdEmergencySpillway
PC    0.0    0.008  0.0162  0.0246  0.0333  0.0425  0.0524   0.063  0.0743  0.0863
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PC    1.0
LS    0.0     73.0     0.0
UD0.4207
KK     3R    CNAME      3C
KO      0        0     0.0        0       22
RN     3R
ZZ
```

The results of the HEC-1 model determined the peak flow for RCreek to be 81.22 cfs (see Figure 4) and for RCTrib the peak flow was computed to be 2.25 cfs (see Figure 5). A value of 83.5 cfs will be used for the stabilization of the diversion ditch.

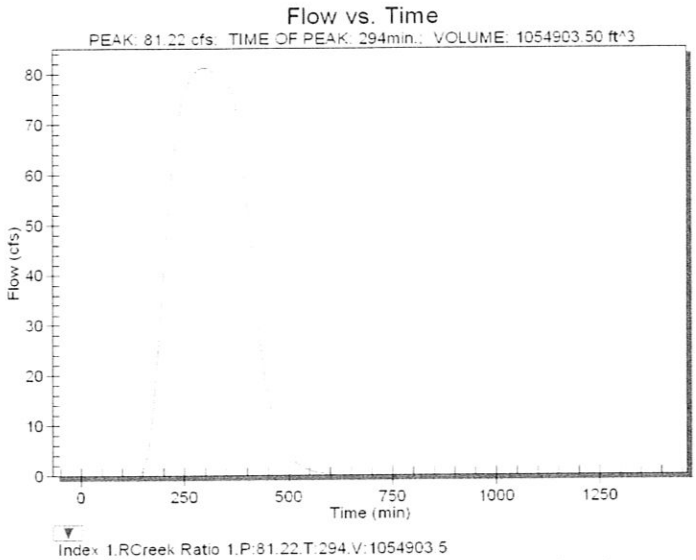

Figure 4 – Computed Runoff Hydrograph for RCreek

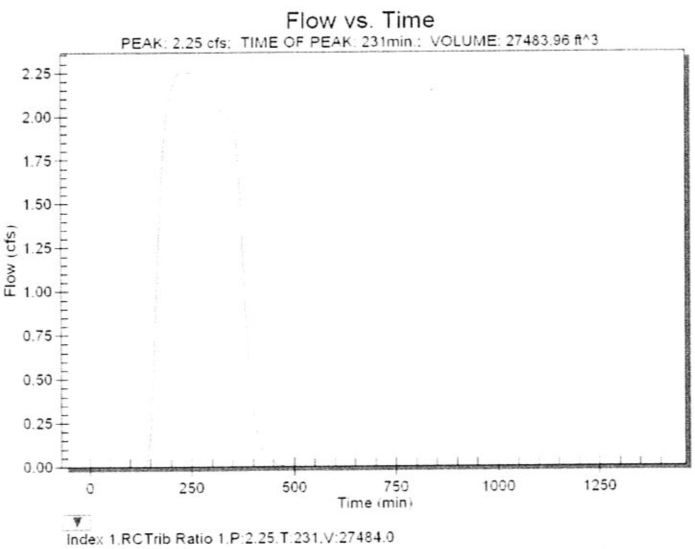

Figure 5 – Computed Runoff Hydrograph for RCTrib

Diversion Ditch Design

In performing the analysis against erosion for the diversion ditch I find the following to be the pertinent issues that need to be considered:

1. I'm assuming the size will remain the same (larger than needed for the 10-year flow) but that we will look at protection against the 10 year flow.
2. Are the in situ soils capable of withstanding the shear stresses induced by the flows corresponding to the 10-year flow.
3. What level of riprap, if any is needed in the channel to protect against bed shear stresses.
4. What level of riprap protection is required at the bends of the diversion ditch, including the point of diversion, the 90° turn in the middle of the diversion ditch and the point where the diversion ditch returns flows to the natural channel.

In reviewing the channel design I am primarily following the guidelines of the Federal Highways Administration (FHWA) Hydrologic Engineering Circular No. 15 (HEC 15) entitled, "Design of Roadside Channels with Flexible Linings." I will paste the relevant tables where cited, but you can view the entire document at: http://www.fhwa.dot.gov/engineering/hydraulics/library_arc.cfm?pub_number=15&id=32.

Hydraulic Properties and Calculations:

Based on the drawings provided and included with this report I determined the following properties:
Bottom width: 2 feet
Side Slopes: 3:1
Slope station 0+00 to station 11+00 10 feet in 350 or .0286
Slope station 11+00 to station 21+50 10 feet in 1000 or .01
Manning's rougness of .025 as determined for bare soil from Table 2.1 of HEC 15

Table 2.1. Typical Roughness Coefficients for Selected Linings

Lining Category	Lining Type	Manning's n[1]		
		Maximum	Typical	Minimum
Rigid	Concrete	0.015	0.013	0.011
	Grouted Riprap	0.040	0.030	0.028
	Stone Masonry	0.042	0.032	0.030
	Soil Cement	0.025	0.022	0.020
	Asphalt	0.018	0.016	0.016
Unlined	Bare Soil[2]	0.025	0.020	0.016
	Rock Cut (smooth, uniform)	0.045	0.035	0.025
RECP	Open-weave textile	0.028	0.025	0.022
	Erosion control blankets	0.045	0.035	0.028
	Turf reinforcement mat	0.036	0.030	0.024

[1]Based on data from Kouwen, et al. (1980), Cox, et al. (1970), McWhorter, et al. (1968) and Thibodeaux (1968).
[2]Minimum value accounts for grain roughness. Typical and maximum values incorporate varying degrees of form roughness.

Using these parameters and the design flow of 83.5 cfs the following channel hydraulic properties were computed for Stations 0+00 to 11+00

Flow 83.500 cfs
Depth 1.471 ft
Area of Flow 9.438 sq ft
Wetted Perimeter 11.306 ft
Average Velocity 8.847 fps
Top Width (T) 10.829 ft
Froude Number 1.670
Critical Depth 1.868 ft
Critical Velocity 5.880 fps
Critical Slope 0.00938
Critical Top Width 13.206 ft
Calculated Shear Stress 2.571 lb/ft^2
Permissible Shear Stress 4.000 lb/ft^2 (12-inch boulders)
Stability Factor 1.556

For stations 11+00 to 21+50
Flow 83.500 cfs
Depth 1.842 ft
Area of Flow 13.863 sq ft
Wetted Perimeter 13.650 ft
Average Velocity 6.023 fps
Top Width (T) 13.052 ft
Froude Number 1.030
Critical Depth 1.867 ft
Critical Velocity 5.882 fps
Critical Slope 0.00939
Critical Top Width 13.204 ft
Calculated Shear Stress 1.149 lb/ft^2
Permissible Shear Stress 4.000 lb/ft^2 (12-inch boulders)
Stability Factor 3.480

Channel Sizing

The computed depths of 1.471 and 1.842 in the two segments indicate that the overall size of the channel is larger enough to convey the design flow.

Stability of In Situ Soils and Riprap Protection

The steep slopes along with the high flows creates a condition of super critical flow in both segments (average velocity is greater than critical velocity). However in the second segment where the slope is approximately .01 the velocity is only slightly greater than critical. The calculated shear stresses are still above stable limits for bare soils as identified in Table 2-3 of HEC 15. At the 10-year design flows the channel should be stable with a heavy riprap D_{50}=1.0 ft in order to protect the steeper sloped section and a D_{50}=.5 ft for the more shallow sloped segment (see Table 2-3 below).

Table 2.3. Typical Permissible Shear Stresses for Bare Soil and Stone Linings

Lining Category	Lining Type	Permissible Shear Stress N/m^2	Permissible Shear Stress lb/ft^2
Bare Soil[1] Cohesive (PI = 10)	Clayey sands	1.8-4.5	0.037-0.095
	Inorganic silts	1.1-4.0	0.027-0.11
	Silty sands	1.1-3.4	0.024-0.072
Bare Soil[1] Cohesive (PI ≥ 20)	Clayey sands	4.5	0.094
	Inorganic silts	4.0	0.083
	Silty sands	3.5	0.072
	Inorganic clays	6.6	0.14
Bare Soil[2] Non-cohesive (PI < 10)	Finer than coarse sand D_{75}<1.3 mm (0.05 in)	1.0	0.02
	Fine gravel D_{75}=7.5 mm (0.3 in)	5.6	0.12
	Gravel D_{75}=15 mm (0.6 in)	11	0.24
Gravel Mulch[3]	Coarse gravel D_{50} = 25 mm (1 in)	19	0.4
	Very coarse gravel D_{50} = 50 mm (2 in)	38	0.8
Rock Riprap[3]	D_{50} = 0.15 m (0.5 ft)	113	2.4
	D_{50} = 0.30 m (1.0 ft)	227	4.8

[1]Based on Equation 4.6 assuming a soil void ratio of 0.5 (USDA, 1987).
[2]Based on Equation 4.5 derived from USDA (1987)
[3]Based on Equation 6.7 with Shield's parameter equal to 0.047

Protecting Bends in the Channel

The three right angle turns in the diversion channel create additional locations of concern. According to the HEC 15 manual the shear stress on the sides of a channel is a function of the calculated bottom shear stress times a coefficient determined from the radius of curvature to top width. I estimated the radius of curvature of the middle bend to be approximately 150 feet. R_c/T for both segments is approximately equal to 7. From equation 3.7 in HEC 15 the coefficient for the bend (K_b) would be 1.3.

$$K_b = 2.00 \qquad R_C/T \leq 2$$

$$K_b = 2.38 - 0.206\left(\frac{R_c}{T}\right) + 0.0073\left(\frac{R_c}{T}\right)^2 \qquad 2 < R_C/T < 10 \qquad (3.7)$$

$$K_b = 1.05 \qquad 10 \leq R_C/T$$

where,

R_c = radius of curvature of the bend to the channel centerline, m (ft)

T = channel top (water surface) width, m (ft)

With the computed shear stress of 2.57 lb/ft^2 in the section containing this bend the resulting shear stress on the sides of the channel would be on the order of 3.34 lb/ft^2. 12-inch boulder riprap would still be sufficient to protect the bend.

The beginning and ending points of the diversion channel make almost right angle turns with very small radii of curvature increasing the K_b factor to 2.0 and associated shear stresses would be slightly higher than 5 lb/ft^2 at the point of diversion where the slope is steeper and 2.3 lb/ft^2 along the shallower slope where the diversion channel returns to the natural stream alignment. The 12-inch boulders would not be sufficient at the point of diversion where the slope is steeper. The 6-inch boulders would be sufficient in the lower shallower slope segment where the diversion ditch returns flow to the natural channel, but 12-inch boulders should be adequate.