Tables

Table 3.13 Lionkol: Main Pits Physical Properties

Basin Name	watershed area (ac.)	addn'l watershed area (ac.)	valley length (ft.)	drainage density (ft./ac.)	head elev (ft.)	base elev (ft.)	total relief (ft.)	head slope	base slope
South 1	1.78	0.00	186.65	105.15	6667.26	6624.45	42.81	-20%	-18%
South 2	2.67	0.00	309.53	116.05	6692.80	6643.98	48.81	-31%	-12%
Southeast	3.38	5.47	475.95	122.23	6700.00	6650.00	50.00	-13%	-9%
Southeast R1	3.33	1.00	343.88	103.28	6719.78	6675.33	44.46	-12%	-10%
Southwest	4.28	0.00	901.18	119.87	6671.38	6581.29	90.09	-9%	-7%
Southwest L1	5.91	0.00	319.98	54.10	6702.13	6668.06	34.07	-9%	-9%
Northeast 1	1.52	0.00	225.83	149.00	6731.76	6681.61	50.15	-20%	-17%
Northeast 2	1.70	0.00	242.18	142.59	6721.73	6661.86	59.87	-22%	-20%
Northeast 3	2.10	0.00	390.00	186.01	6710.90	6632.32	78.58	-29%	-11%
Northeast 4	5.39	0.00	728.10	228.77	6633.95	6573.14	60.81	-12%	-5%
Northeast 4 R1	0.42	0.00	233.66	552.35	6632.32	6599.59	32.73	-14%	-12%
North	13.25	0.00	1137.43	85.85	6689.63	6570.51	119.12	-12%	-5%
Northwest 1	1.72	0.00	334.53	194.50	6633.89	6582.27	51.63	-14%	-11%
TOTAL	**47.45**	**6.47**							

Table 3.14 Lionkol: Main Pits Runoff Parameters

Basin Name	*Bank-full Conditions**				*Flood-prone Conditions***			
	width range (ft.)	depth range (ft.)	Shields shear stress, (psf)	Qpk (cfs)	width range (ft.)	depth range (ft.)	Shields shear stress, (psf)	Qpk (cfs)
South 1	0.18 to 1.19	0.02 to 0.12	0.25 to 1.59	0.64	0.43 to 2.92	0.05 to 0.34	0.38 to 2.41	2.39
South 2	0.19 to 1.46	0.02 to 0.15	0.18 to 1.24	0.96	0.47 to 3.58	0.05 to 0.41	0.27 to 1.88	3.59
Southeast	0.11 to 2.31	0.01 to 0.23	0.07 to 1.46	2.41	0.28 to 5.68	0.03 to 0.65	0.11 to 2.22	9.03
Southeast R1	0.17 to 1.63	0.02 to 0.16	0.14 to 1.10	1.20	0.41 to 4.01	0.05 to 0.46	0.21 to 1.67	4.48
Southwest	1.45 to 3.16	0.14 to 0.32	0.92 to 1.85	4.49	3.55 to 7.76	0.41 to 0.89	1.39 to 2.82	16.84
Southwest L1	0.48 to 2.17	0.05 to 0.22	0.33 to 1.34	2.12	1.19 to 5.34	0.14 to 0.61	0.51 to 2.03	7.96
Northeast 1	0.01 to 1.10	0.00 to 0.11	0.02 to 1.32	0.54	0.03 to 2.70	0.00 to 0.31	0.03 to 2.00	2.04
Northeast 2	0.56 to 1.12	0.06 to 0.11	0.85 to 1.55	0.57	1.37 to 2.76	0.16 to 0.32	1.29 to 2.36	2.13
Northeast 3	0.33 to 1.29	0.03 to 0.13	0.85 to 1.55	0.55 to 0.95	0.80 to 3.18	0.09 to 0.36	0.83 to 1.44	2.82
Northeast 4	0.04 to 2.74	0.00 to 0.27	0.03 to 1.07	3.38	0.10 to 6.74	0.01 to 0.77	0.05 to 1.63	12.68
Northeast 4 R1	1.71 to 1.79	0.17 to 0.18	1.19 to 1.64	1.45	4.20 to 4.41	0.48 to 0.51	1.81 to 2.49	5.43
North	0.08 to 3.25	0.01 to 0.33	0.06 to 1.52	4.76	0.19 to 7.99	0.02 to 0.92	0.10 to 2.32	17.83
Northwest 1	0.38 to 1.17	0.04 to 0.12	0.37 to 0.95	0.62	0.92 to 2.88	0.11 to 0.33	0.56 to 1.45	2.32

Table 3.15 Lionkol: Lower Pit Physical Properties

Basin Name	watershed area (ac.)	addn'l watershed area (ac.)	valley length (ft.)	drainage density (ft./ac.)	head elev (ft.)	base elev (ft.)	total relief (ft.)	head slope	base slope
Main	1.82	6.90	694.12	344.42	6,590.00	6,542.11	47.89	-18%	-6%
R-1	1.64	2.30	448.02	273.85	6,597.97	6,550.27	47.70	-10%	-6%
R-2	1.65	0.90	317.60	375.60	6,583.51	6,542.29	41.22	-12%	-9%
TOTAL	**5.11**	**10.10**							

Table 3.16 Lionkol: Lower Pit Runoff Parameters

Basin Name	*Bank-full Conditions**				*Flood-prone Conditions***			
	width range (ft.)	depth range (ft.)	Shields shear stress, (psf)	Qpk (cfs)	width range (ft.)	depth range (ft.)	Shields shear stress, (psf)	Qpk (cfs)
Main	2.89 to 4.34	0.29 to 0.35	0.66 to 3.69	8.19	6.69 to 9.89	0.70 to 1.13	1.04 to 5.28	27.3
R-1	1.69 to 2.17	0.17 to 0.22	0.92 to 1.36	2.12	3.91 to 5.03	0.45 to 0.57	1.32 to 1.95	7.06
R-2	1.06 to 1.75	0.11 to 0.17	0.87 to 1.09	1.37	2.47 to 4.05	0.28 to 0.46	1.25 to 1.56	4.57

Table 3.17 Lionkol: Lower Spoils Physical Properties

Basin Name	watershed area (ac.)	addn'l watershed area (ac.)	valley length (ft.)	drainage density (ft./ac.)	head elev (ft.)	base elev (ft.)	total relief (ft.)	head slope	base slope
Main East	3.56	0.00	781.8	219.33	6601.51	6560	41.51	-7%	-6%
Main	7.5	0.00	1179.87	208.59	6623.72	6550	73.72	-8%	-6%
R-1	1.09	0.00	240.1	219.96	6615.98	6588.77	27.22	-12%	-6%
TOTAL	**12.15**	**0.00**							

Table 3.18 Lionkol: Lower Pit Runoff Parameters

Basin Name	*Bank-full Conditions**				*Flood-prone Conditions***			
	width range (ft.)	depth range (ft.)	Shields shear stress, (psf)	Qpk (cfs)	width range (ft.)	depth range (ft.)	Shields shear stress, (psf)	Qpk (cfs)
Main East	0.09 to 2.29	0.01 to 0.18	0.04 to 0.58	1.92	0.21 to 4.80	0.02 to 0.55	0.06 to 0.83	6.4
Main	0.36 to 3.81	0.04 to 0.27	0.11 to 1.08	6.54	0.75 to 8.83	0.08 to 1.01	0.18 to 1.54	21.8
R-1	0.56 to 1.14	0.06 to 0.11	0.41 to 0.52	0.59	1.30 to 2.65	0.15 to 0.30	0.59 to 0.74	1.96

Table 3.19 Lionkol: Lower Pit Impoundment Properties

DESIGN DISCHARGES, 100 YR, 24 HR STORM EVENT

	Surface Area	Peak Flow (cfs)	Discharge (cf)	Discharge (cy)	Discharge (ac-ft)
North Area	17.7	29.9	90088	3337	2.1

Note:

No routing was performed on drainages, so peak flow amount probably excessive and time early, without delays due to time of concentration

DESIGN STORAGE CAPACITY

Start elev.	End elev.	Volume (cf)	Volume (cy)	Volume (ac-
6542	6543	1	0	0.0
6543	6544	873	32	0.0
6544	6545	1745	65	0.0
6545	6546	3373	125	0.1
6546	6547	5001	185	0.1
6547	6548	8004	296	0.2
6548	6549	11006	408	0.3
6549	6550	14195	526	0.3
6550	6551	17384	644	0.4
	TOTAL	**61581**	**2281**	**1.4**

Additional discharge passes down drainage total attenuation time not estimated.

Table 3.20 Lionkol: Lower Pit USA-COE Steep Slope Riprap Design

Structure ID	Peak Flow IN (cfs)	Bottom Width (feet)*	Unit Discharge (sf/s)**	Grade (ft/ft)	D30 Rock (feet)	D50 Rock (feet)	D50 Rock (inch)	D50 SPEC'D (inch)
DROP 1	576	12	60.0	0.1429	3.20	3.00	36.0	36
DROP 2	29.9	12	3.1	0.1667	0.49	0.50	6.0	6
DROP 3	8.75	5	2.2	0.25	0.48	0.50	6.0	6
GC-1	7.33	10	0.9	0.2	0.24	0.35	4.2	6
GC-2	172.3	5	43.1	0.0289	1.06	1.00	12.0	15
GC-3	306.3	6.5	58.9	0.0261	1.23	1.30	15.6	15
GC-4	425.4	7	76.0	0.0251	1.43	1.50	18.0	15
GC-5	120.1	12	12.5	0.154	1.17	1.20	14.4	15

*Assume Bw of V-ditches is 2' due to construction practices

**Multiplied by C=1.25

Table 3.21 Lionkol: Lower Pit Rock Structure Summary

Drop Structure ID	Peak Flow IN (cfs)	Bottom Width (feet)*	Length (feet)	Grade (ft/ft)	Depth (feet)	Side Slope h:v	Apron Length (feet)	Riprap Class (inch)	Riprap Depth (inch)	Riprap Quantity (cy)*	Bedding Quantity (cy)*	Fabric Quantity (sf)*
DROP 1	576	12	63	0.1429	4	3	12	36	54	574	64	5830
DROP 2	29.9	12	60	0.1667	3	3	10	6	12	98	49	3864
DROP 3	8.75	5	18	0.25	3	3	7	6	12	28	15	1523

Grade Control ID	Peak Flow IN (cfs)	Bottom Width (feet)*	Length (feet)	Grade (ft/ft)	Depth (feet)	Side Slope h:v	Riprap Class (inch)	Riprap Depth (inch)	Riprap Quantity (cy)*	Bedding Quantity (cy)*	Fabric Quantity (sf)*
GC-1	7.33	10	15	0.2	3	3	6	12	17	9	1080
GC-2	172.3	5	10	0.0289	3	4	15	30	30	6	1100
GC-3	306.3	6.5	10	0.0261	3	4	15	30	31	6	1138
GC-4	425.4	7	10	0.0251	3	4	15	30	32	6	1150
GC-5	120.1	12	20	0.154	3	3	15	30	61	12	1575

*10% factor added

4.0 AML 17H-2B-III Lionkol Drainage Reclamation Project

The Lionkol Drainage Reclamation Project was completed in the fall of 2012 to regrade a reach of the Lionkol drainage which was incised between the historic railroad grade and the mine haul road. Over time, the channel became incised due to the straightened alignment and lack of floodplain, which were encroached upon by the rail grade and the road. The incised channel was close to the existing road, creating steep and dangerous banks along the shoulder of the road, and erosional cuts which crossed the road, making it impassable until repairs were completed. The goal of the project was to re-establish the channel and floodplain to a stable configuration resembling the pre-mine conditions. A zoned embankment, utilizing bentonite mixed backfill, was constructed at the downstream end of the regraded channel to contain flows and minimize runoff flowing through the BLM Wild Horse Holding Facility. Bentonite was a necessary additive to add cohesion and impermeability to the native silty-sand materials. In addition, the impoundment contributed to efforts by the City of Rock Springs to reduce their flood plain designation.

The Natural Regrade™ software was used to provide a stable and aesthetically pleasing geomorphic channel. Restoring the channel to a stable configuration was achieved by excavating the steep banks and raising the channel bottom elevation. Excess material from the excavation was used to construct the embankment at the downstream end of the project, which balanced the earthworks. The embankment and associated impoundment were necessary to raise the channel elevation and reduce the channel slope. The embankment serves as a grade control structure at the downstream end of the channel reconstruction.

The project was constricted by the narrow valley and numerous cultural features. Removal of the coal railroad bed proved difficult, as the coal slack had to be disposed of onsite. Numerous historic concrete foundations that had to be avoided were scattered throughout the project. The new channel alignment was broken up into two basins to manipulate the design around cultural concrete foundations, which proved challenging. Some of the design work was completed in AutoCAD to connect the channels between the two basins. The channel widths and side slopes were maintained from the Natural Regrade™ sections.

In the previous phases, shear stresses were kept within the design limits by utilizing small basins and traditional structures, or by accepting high shears as representative of the native environment. For this project, regional regression equations were used to estimate the contributing area runoff (Miller, 2003). This resulted in more realistic flow estimates due to the natural routing of flows, and moved the shear stresses closer to the design criteria. Section 4.1 discusses Miller (2003) in more detail. The shear range for many of the channels exceeds the Natural Regrade™ software's recommended stability criteria for shear stress. Experience on multiple Natural Regrade™ projects completed for AML suggest that while the Shields shear stresses indicate the size of particles that can be brought into motion by a shear of a particular magnitude, it provides no information on the distance that particle may be transported. It also gives no indication on the quantity of particles of a similar size that may be transported. These are both factors which would affect the amount of erosion a channel may experience. Excessive quantities of materials transported large distances would be perceived as channel failure due to erosion, but a moderate, even progress of sediment through the system would be perceived as healthy channel development. As a result, if the reclaimed channel reaches are designed such that they match the native channel grades, cross sections, and stability parameters, the sediment transport through the site would match the approximate quantities in motion above and below the project area, neither creating erosion or allowing deposition, and appearing stable through time as uniform quantities of sediment are conveyed through the native and reclaimed channel reaches.

Shear stresses on the Main channel were allowed to exceed the design criteria of 1.0 for the bankfull and 1.5 for the flood prone condition because the channel grades were designed flatter than the native grades. In addition, the impoundment constructed at the end of the project would not only serve as a grade control structure, but also as a failsafe to catch any eroded sediment should excessive erosion occur. However, the channel has performed well during recent storm flows. See Section 4.2.4 for more on the performance evaluation.

CMP culverts were installed along the Lionkol road with rip-rap erosion control structures at the outlets, and the Lionkol road was resurfaced through the site. Following the construction phase, agronomic activities were completed on the disturbed areas. This included the application of fertilizer, gypsum and granular humic acid, hauling and spreading of manure, discing in of the manure and other soil amendments, drill seeding, and mulching and crimping grass hay.

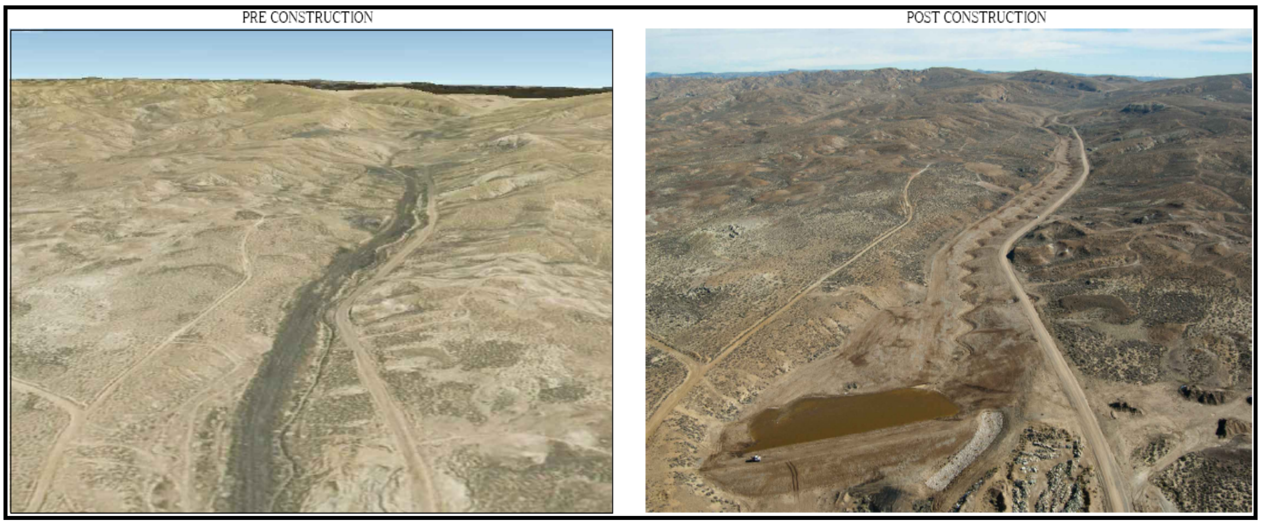


Figure 20: Lionkol Drainage Before and After Construction

4.1 Lionkol Drainage: Hydrologic Features Summary

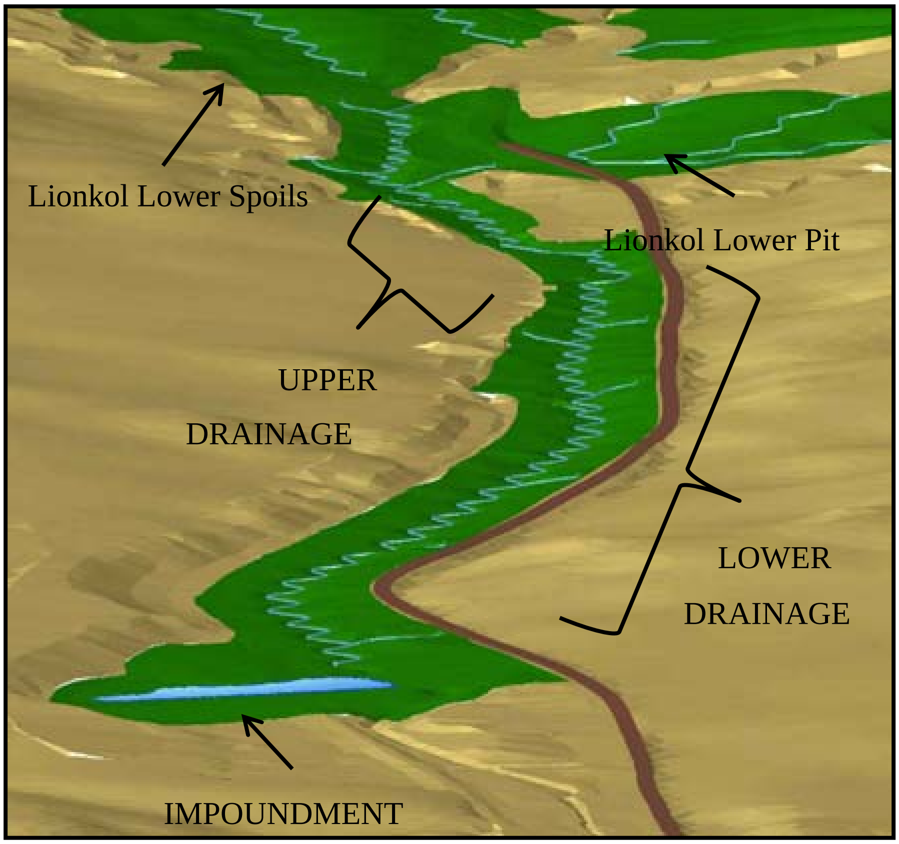


Figure 21: Lionkol Drainage Design 3-Dimensional Rendering

4.1.1 Lionkol Drainage: Geomorphic Channels

Two NR basins were used to model the Lionkol Drainage: Lionkol Upper and Lionkol Lower, as shown in Figure A-4.1 in Appendix A4.2. The channel is continuous through this reach, but required two basins to manipulate the channel design around cultural features. Some of the design work was completed in AutoCAD to connect the channels between the two basins. The valley length through the regraded section is approximately 1.2 miles long with an elevation drop of 120 feet. The basin physical properties are shown in Table 4.1 and 4.2. The NR design section ends at the Lionkol Stock Reservoir. The purpose of the reservoir was to assist the City of Rock Springs in limiting flood flows in the downtown area. Twelve side tributaries are connected to the two basins. Five culverts were installed through the main access road to bring side tributary flows into the main channel and reduce washing of the road. The design runoff parameters are shown in Table 4.3 and 4.4. Shear stresses were slightly elevated in some of the side tributaries due to the steep slopes required to drop into the main channel. All but one of the left side "A" channels were conveyed by a culvert with a rock structure. Higher shears were also present in the main channel under the flood-prone condition due to the large contributing area upstream. Due to the volume of data, detailed data for Shields shear values by station are not included in this report but are available upon request.

4.1.2 Lionkol Stock Reservoir

The Lionkol Stock Reservoir was designed at the downstream end of the Lionkol Drainage project to contain storm flows and reduce sediment transport in the downstream channel. Impounding the storm flows assisted the City of Rock Springs in their city planning for flood mapping in the downtown area. The reservoir also limited flows through the BLM's Wild Horse Holding Facility, located just downstream. The Lionkol Stock Reservoir is permitted with the State Engineer's Office (Appendix D4.2) with a capacity of 16 acre-feet. The 100-year runoff for the Lionkol drainage at this location is 15.4 acre-feet (Miller 2003, Craig and Rankl 1978).

4.1.3 Lionkol Drainage: Riprap Structures

Riprap structures were included at the outlets of 5 newly installed 24-inch CMP culverts and one existing 24-inch CMP culvert. Six-inch rock riprap was used for the rock structures based on the flow capacity of a 24-inch CMP culvert. A rock drop structure was designed using 12-inch (Class 12) riprap for the Lionkol Stock Reservoir spillway. Though the reservoir has the capacity to contain in excess of the 100-year storm event, future capacity could be diminished through silt and sedimentation. The riprap was obtained from the Pete Lien quarry near Rawlins, WY. The dimensions and quantities of the rock structures are shown in Table 4.5 and Table 4.6 of Appendix B4.2.

4.1.4 Lionkol Drainage: Performance Evaluation

A field inspection of the Lionkol Drainage channels was completed in late July and early August 2013. Revegetation had been completed the previous year, and no re-vegetative growth was observed. Drought conditions have persisted in the region for the past 3 years, and this has played a large role in the lack of vegetation growth. Even without vegetation, the majority of the channels in the project area were functioning properly with little or no erosion occurring.

The main channels in both the upper and lower portions of the drainage performed well even during the unseasonably large rainfall experienced in September and October 2013. Their performance was very similar to the performance of other geomorphic channels including the Reliance No.11 channels (see Section 2.2.6 for channel performance summary). Only sparse vegetation has been observed to have taken hold in either drainage, a majority being cheat grass and other weed species. However, the area only had a single growing season to revegetate at the time of the observation.

Figure 22: Freshly Constructed Lionkol Channel Following High Runoff Flows

The tributary channels performed worse overall than the main drainages, with five requiring extension of rock structures and/or channel reinforcement. These tributaries included L1 and R3, feeding into the Upper Main Drainage as well as L1, L2, and L4 tributaries draining into the Lower Main Drainage (see as-built drawing in Figure A-4.1 within Appendix A4.2). The tributary channels were steep, and were initially protected with partial rock structures as it was clear that high shears would be experienced on these short steep channels. However, the armored sections were not long enough, and in most cases the channels exiting the riprap structures at the mouth of the tributary had become incised greater than 18 inches and the rock structures were becoming filled with sediment. In order to address these issues, the channels were widened and reinforced with the rock structures extended to protect the channel bottom.

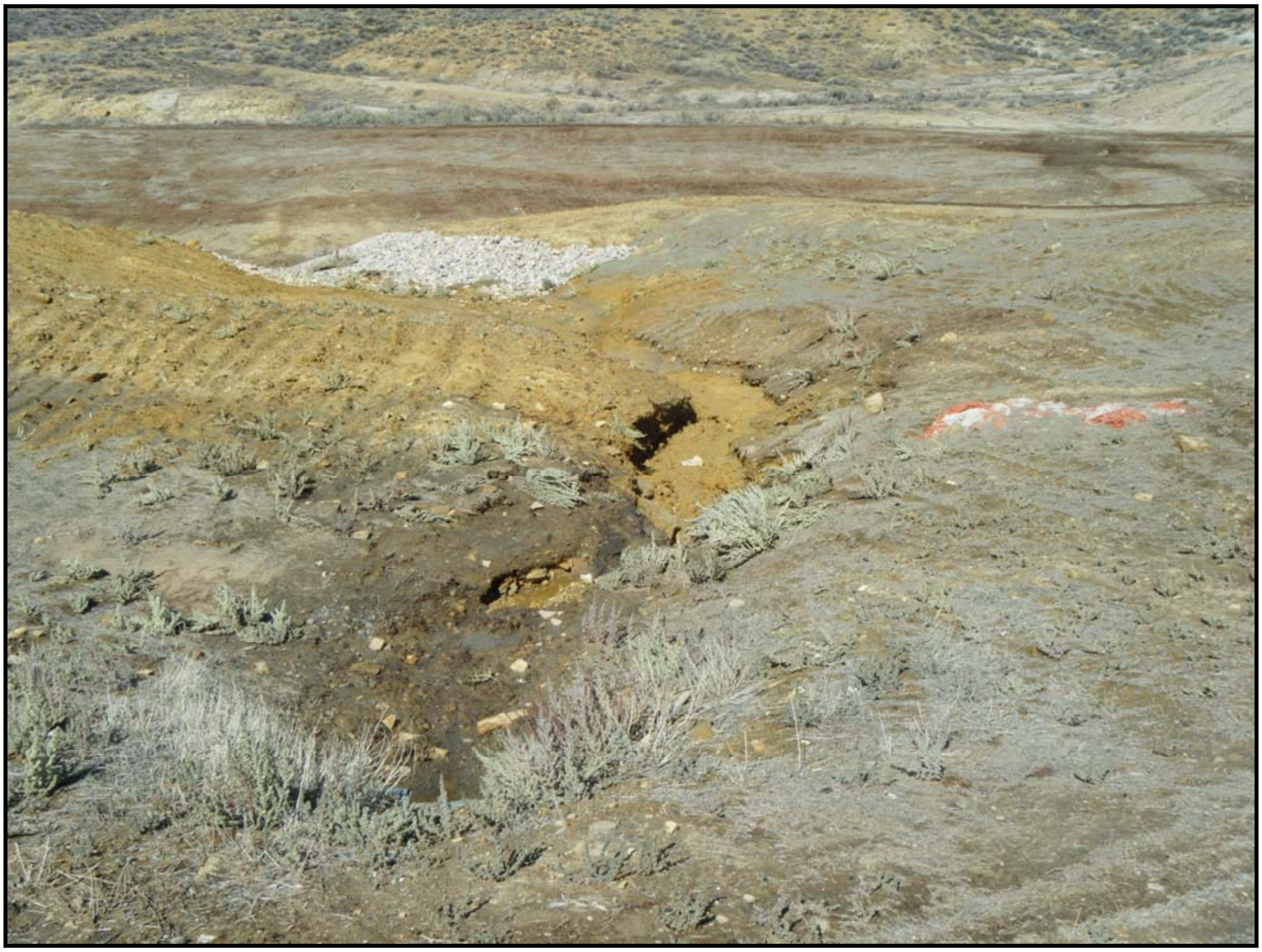


Figure 23: Lionkol Upper Main Drainage: Tributary L1 Failure Upstream of Rock Structure.

Shortly after the last large flow event in the fall of 2013, high water marks were identified and marked for survey, just upstream of the Lionkol Stock Reservoir. A channel survey was completed to estimate the peak discharge and evaluate the frequency of the event.

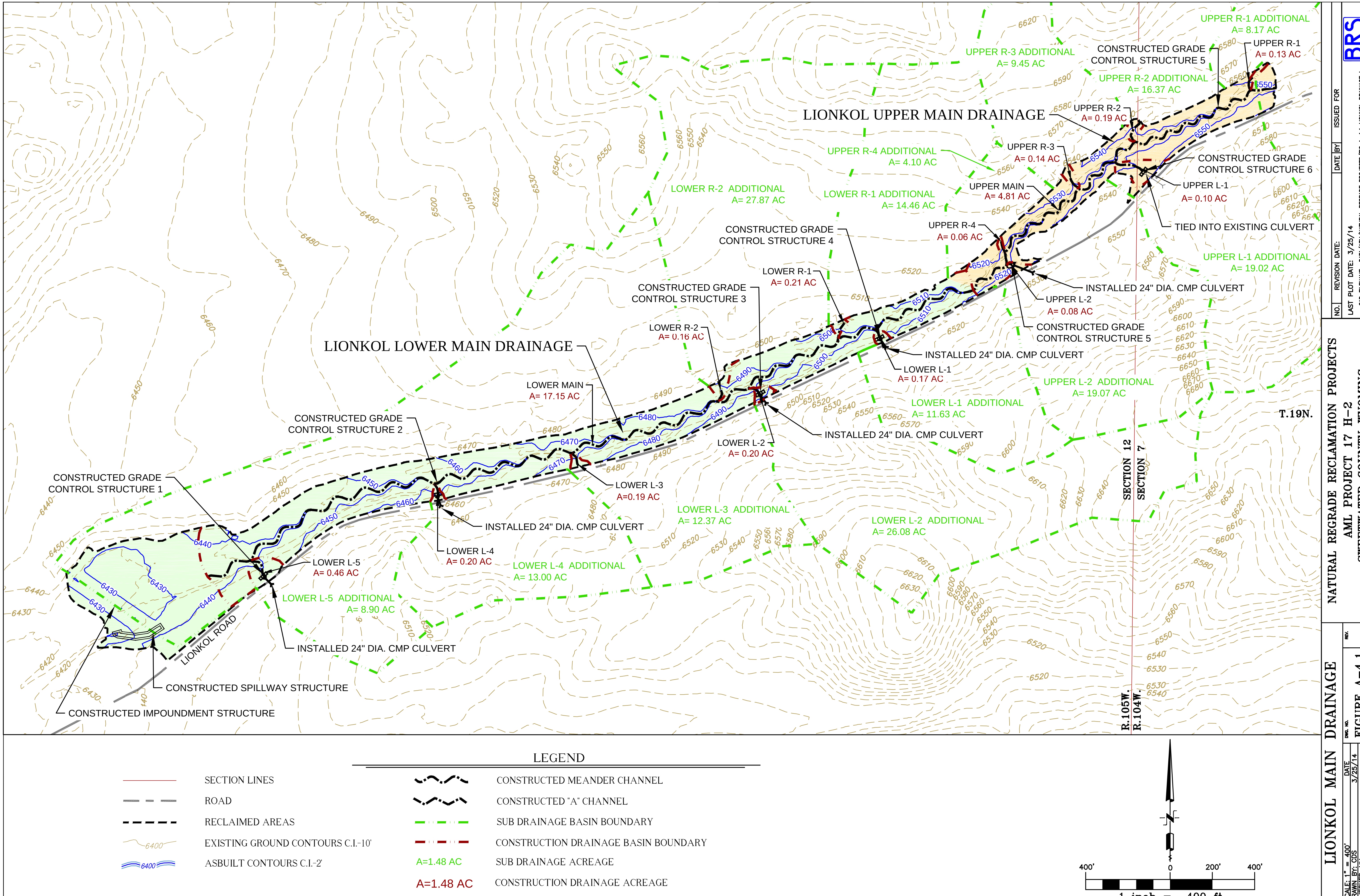
The data were analyzed in AutoCAD to determine station and offsets of the four surveyed cross sections. Data were entered in the U.S. Army Corp. of Engineers Hydraulic Engineering Center River Analysis System (HEC-RAS) software to estimate the flow discharge. Roughness factors were estimated from soil type, vegetation cover, and channel transitions observed in the field. The surface water profiles calculated in HEC-RAS were checked against the observed high-water marks. Though not a perfect match, the surface water profiles matched the general trend of the observed high-water marks. A rating curve was plotted in HEC-RAS for cross-section 4 and the flow at the high-water mark was estimated to be 63 cubic feet per second (cfs).

Return interval runoff was evaluated using the regional regression equation developed by the U.S. Geological Survey (Miller, 2003). Table 4.7 shows the runoff estimates for the channel at the survey location. From Miller (2003), the storm event of 63 cfs is fairly close to a 10-year storm. In general, the main channel performed very well considering the fact that it was newly constructed and virtually void of any vegetation. Data analysis from HEC-RAS is available in Appendix D4.2.

Table 4.7 Lionkol Channel Runoff Return Interval

Drainage area (ac)		Qp	cfs	ac-ft
915	(ac)	Q2	15	1.4
1.43	(mi^2)	Q5	42	3.5
		Q10	71	5.5
		Q25	121	8.8
		Q50	169	11.8
		Q100	227	15.4

Miller (2003) Region 6



LIONKOL UPPER MAIN DRAINAGE
LIONKOL LOWER MAIN DRAINAGE
UPPER R-1 ADDITIONAL A= 8.17 AC
UPPER R-1 A= 0.13 AC
UPPER R-3 ADDITIONAL A= 9.45 AC
CONSTRUCTED GRADE CONTROL STRUCTURE 5
UPPER R-2 ADDITIONAL A= 16.37 AC
UPPER R-2 A= 0.19 AC
UPPER R-3 A= 0.14 AC
UPPER R-4 ADDITIONAL A= 4.10 AC
CONSTRUCTED GRADE CONTROL STRUCTURE 6
UPPER L-1 A= 0.10 AC
LOWER R-2 ADDITIONAL A= 27.87 AC
LOWER R-1 ADDITIONAL A= 14.46 AC
UPPER MAIN A= 4.81 AC
TIED INTO EXISTING CULVERT
UPPER R-4 A= 0.06 AC
CONSTRUCTED GRADE CONTROL STRUCTURE 4
UPPER L-1 ADDITIONAL A= 19.02 AC
LOWER R-1 A= 0.21 AC
INSTALLED 24" DIA. CMP CULVERT
CONSTRUCTED GRADE CONTROL STRUCTURE 3
UPPER L-2 A= 0.08 AC
LOWER R-2 A= 0.16 AC
CONSTRUCTED GRADE CONTROL STRUCTURE 5
INSTALLED 24" DIA. CMP CULVERT
LOWER L-1 A= 0.17 AC
UPPER L-2 ADDITIONAL A= 19.07 AC
LOWER MAIN A= 17.15 AC
LOWER L-1 ADDITIONAL A= 11.63 AC
T.19N.
CONSTRUCTED GRADE CONTROL STRUCTURE 2
INSTALLED 24" DIA. CMP CULVERT
LOWER L-2 A= 0.20 AC
CONSTRUCTED GRADE CONTROL STRUCTURE 1
LOWER L-3 A=0.19 AC
SECTION 12
SECTION 7
LOWER L-3 ADDITIONAL A= 12.37 AC
LOWER L-2 ADDITIONAL A= 26.08 AC
INSTALLED 24" DIA. CMP CULVERT
LOWER L-4 A= 0.20 AC
LOWER L-5 A= 0.46 AC
LOWER L-4 ADDITIONAL A= 13.00 AC
LOWER L-5 ADDITIONAL A= 8.90 AC
LIONKOL ROAD
INSTALLED 24" DIA. CMP CULVERT
CONSTRUCTED SPILLWAY STRUCTURE
CONSTRUCTED IMPOUNDMENT STRUCTURE
R.105W.
R.104W.
LEGEND
SECTION LINES
ROAD
RECLAIMED AREAS
EXISTING GROUND CONTOURS C.I.-10'
ASBUILT CONTOURS C.I.-2'
CONSTRUCTED MEANDER CHANNEL
CONSTRUCTED "A" CHANNEL
SUB DRAINAGE BASIN BOUNDARY
CONSTRUCTION DRAINAGE BASIN BOUNDARY
A=1.48 AC SUB DRAINAGE ACREAGE
A=1.48 AC CONSTRUCTION DRAINAGE ACREAGE
400' 0 200' 400'
1 inch = 400 ft
BRS ENGINEERING
NO. REVISION DATE: DATE BY ISSUED FOR
LAST PLOT DATE: 3/25/14
CAD FILENAME: DATA/17H/NATURAL REGRADE PROJECTS/FIG A-4.1 LIONKOL DRAINAGE.dwg
NATURAL REGRADE RECLAMATION PROJECTS
AML PROJECT 17 H-2
SWEETWATER COUNTY WYOMING
LIONKOL MAIN DRAINAGE
DWG. NO. FIGURE A-4.1
SCALE: 1" = 400'
DRAWN BY: CDS
CHECKED: HH
APPROVED: HH
DATE 3/25/14

Tables

Table 4.1 Lionkol Channel: Lower Drainage Physical Properties

Basin Name	watershed area (ac.)	addn'l watershed area (ac.)	valley length (ft.)	drainage density (ft./ac.)	head elev (ft.)	base elev (ft.)	total relief (ft.)	head slope	base slope
L-1	0.17	11.63	82.93	493.55	6,507.06	6,498.07	9.00	-14%	-7%
L-2	0.20	26.08	78.08	381.57	6,490.00	6,482.64	7.36	-12%	-11%
L-3	0.19	12.37	87.86	474.52	6,475.67	6,463.14	12.52	-14%	-13%
L-4	0.20	13.00	94.95	468.63	6,460.13	6,450.22	9.91	-13%	-5%
L-5	0.46	8.90	142.32	311.74	6,443.98	6,434.37	9.61	-8%	-2%
Main	17.15	0.00	3984.47	277.02	6,510.00	6,430.00	80.00	-2%	-1%
R-1	0.21	14.46	122.96	579.60	6,504.10	6,493.77	10.33	-9%	-3%
R-2	0.16	27.87	52.08	319.99	6,482.00	6,479.59	2.41	-6%	-2%
R-3	0.22	10.91	105.51	480.26	6,477.68	6,463.83	13.85	-12%	-2%
TOTAL	**18.96**	**125.22**							

Table 4.2 Lionkol Channel: Upper Drainage Physical Properties

Basin Name	watershed area (ac.)	addn'l watershed area (ac.)	valley length (ft.)	drainage density (ft./ac.)	head elev (ft.)	base elev (ft.)	total relief (ft.)	head slope	base slope
L-1	0.10	19.02	81.72	847.79	6,535.65	6,528.27	7.39	-12%	-2%
L-2	0.08	19.07	82.35	1029.24	6,523.23	6,512.27	10.95	-16%	-15%
Main	4.81	0.00	1892.99	508.46	6,548.00	6,510.00	38.00	-2%	-2%
R-1	0.13	8.17	109.10	859.96	6,559.86	6,544.25	15.61	-18%	-8%
R-2	0.19	16.37	122.81	649.34	6,544.53	6,531.27	13.26	-11%	-9%
R-3	0.14	9.45	92.18	661.67	6,532.00	6,524.29	7.71	-13%	-2%
R-4	0.06	4.10	65.69	1185.23	6,523.71	6,515.48	8.23	-20%	4%
TOTAL	**5.51**	**76.18**							

Table 4.3 Lionkol Channel: Lower Drainage Runoff Parameters

Basin Name	*Bank-full Conditions**				*Flood-prone Conditions***			
	width range (ft.)	depth range (ft.)	Shields shear stress, (psf)	Qpk (cfs)	width range (ft.)	depth range (ft.)	Shields shear stress, (psf)	Qpk (cfs)
L-1	1.50 to 1.71	0.15 to 0.14	0.36 to 1.78	1.06	8.15 to 8.19	0.95 to 0.98	1.32 to 5.98	18.79
L-2	2.17 to 2.45	0.22 to 0.20	1.01 to 1.55	2.17	9.37 to 9.43	1.07 to 1.12	2.97 to 4.37	24.83
L-3	1.58 to 1.79	0.16 to 0.14	0.74 to 1.58	1.17	8.33 to 8.37	0.96 to 1.00	2.65 to 5.18	19.61
L-4	1.72 to 1.95	0.17 to 0.16	0.60 to 1.55	1.37	7.78 to 7.83	0.89 to 0.93	1.87 to 4.36	17.13
L-5	1.43 to 1.71	0.14 to 0.14	0.22 to 0.78	1.06	7.77 to 7.89	0.90 to 0.94	0.80 to 2.64	17.42
Main	8.02 to 10.72	0.57 to 0.77	0.52 to 0.77	37.05	30.98 to 40.27	3.44 to 4.46	1.67 to 2.52	450.41
R-1	1.64 to 1.88	0.16 to 0.15	0.33 to 1.00	1.27	8.63 to 8.69	1.00 to 1.04	1.16 to 3.26	21.14
R-2	2.01 to 2.26	0.20 to 0.18	0.22 to 0.75	1.86	10.21 to 10.25	1.18 to 1.23	0.78 to 2.52	29.38
R-3	1.49 to 1.72	0.15 to 0.14	0.25 to 1.19	1.08	8.05 to 8.12	0.93 to 0.97	0.89 to 4.00	18.45

Table 4.4 Lionkol Channel: Upper Drainage Runoff Parameters

Basin Name	Bank-full Conditions*				Flood-prone Conditions**			
	width range (ft.)	depth range (ft.)	Shields shear stress, (psf)	Qpk (cfs)	width range (ft.)	depth range (ft.)	Shields shear stress, (psf)	Qpk (cfs)
L-1	1.77 to 1.99	0.18 to 0.16	0.30 to 1.36	1.43	9.25 to 9.29	1.07 to 1.11	1.08 to 4.38	24.14
L-2	1.83 to 2.06	0.18 to 0.16	1.01 to 1.88	1.53	9.36 to 9.40	1.08 to 1.13	3.54 to 5.95	24.71
Main	6.21 to 8.00	0.44 to 0.57	0.47 to 0.68	20.60	22.87 to 30.96	2.53 to 3.44	1.47 to 2.13	266.39
R-1	1.35 to 1.53	0.13 to 0.12	0.34 to 1.73	0.84	7.45 to 7.48	0.86 to 0.90	1.30 to 5.93	15.68
R-2	1.70 to 1.94	0.17 to 0.16	0.52 to 1.25	1.37	8.99 to 9.06	1.04 to 1.09	1.88 to 4.09	22.97
R-3	1.42 to 1.62	0.14 to 0.13	0.19 to 1.27	0.95	7.77 to 7.81	0.90 to 0.94	0.71 to 4.30	17.10
R-4	1.16 to 1.31	0.12 to 0.10	0.77 to 1.55	0.62	6.24 to 6.26	0.72 to 0.75	2.85 to 5.14	10.98

Table 4.5 Lionkol Channel: Upper and Lower Drainage USA-COE Steep Slope Riprap Design

Structure ID	Peak Flow IN (cfs)	Bottom Width (feet)*	Unit Discharge (sf/s)**	Grade (ft/ft)	D30 Rock (feet)	D50 Rock (feet)	D50 Rock (inch)	D50 SPEC'D (inch)
DROP 1	56	12	5.8	0.25	0.92	0.94	11.3	12
DROP 2	31	12	3.2	0.16	0.49	0.54	6.5	12
OS-1	20	12	2.1	0.04	0.17	0.30	3.6	4
OS-2	11.5	12	1.2	0.04	0.12	0.30	3.6	4
OS-3	81.1	12	8.4	0.01	0.20	0.30	3.6	4
OS-4	115.4	12	12.0	0.01	0.25	0.30	3.6	4

*Assume

**Multiplied

Table 4.6 Lionkol Channel: Upper and Lower Drainage Basin Rock Structure Summary

Drop Structure ID	Peak Flow IN (cfs)	Bottom Width (feet)*	Length (feet)	Grade (ft/ft)	Depth (feet)	Side Slope h:v	Apron Length (feet)	Riprap Class (inch)	Riprap Depth (inch)	Riprap Quantity (cy)*	Bedding Quantity (cy)*
DROP 1	56	12	40	0.25	4	12	12	24	235	59	4602
DROP 2	30	12	100	0.16	2	12	12	24	455	114	8142

Grade Control ID	Peak Flow IN (cfs)	Bottom Width (feet)*	Length (feet)	Grade (ft/ft)	Depth (feet)	Side Slope h:v	Riprap Class (inch)	Riprap Depth (inch)	Riprap Quantity (cy)*	Bedding Quantity (cy)*	Fabric Quantity (sf)*
OS-1	20	12	12	0.04	2	8	6	12	22	11	1368
OS-2	11.5	12	12	0.04	2	8	6	12	22	11	1368
OS-3	81.1	12	12	0.01	2	8	6	12	22	11	1368
OS-4	115.4	12	12	0.01	2	8	6	12	22	11	1368

*10% factor added

5.0 AML 17H-2B-IV Lionkol West Drainage Reclamation Project

The Lionkol West Drainage Reclamation Project is located around the BLM Wild Horse Holding Facility, just north of Rock Springs, Wyoming. Similar to the Phase 3 project, the drainage was straightened by channelizing the flow to make room for the old mine haul road and railroad grades. The BLM Wild Horse Holding Facility also restricted the channel near the viewing area by realigning the channel around the facility and eliminating meanders in the channel. When a channel is straightened, the gradient becomes steepened, resulting in incision and increased erosion. Once the channel incises, flows no longer have access to the floodplain and concentrate in the incised channel, creating more erosion during each storm event. The reclamation goal for this project was to stabilize the channel and re-establish the floodplain. Unlike Phase 3, raising the channel bottom was not possible due to three existing culvert crossings within the project limits, where paved road and access roads crossed the drainage. The reclaimed channel gradient was required had to match these fixed locations and provide a stable channel. To accomplish this, the project was split into 3 design segments to address each reach of channel constrained by the culverts: The East Reach, the Central Reach, and the West Reach. Due to the incised and constrained nature of the channel, achieving earthworks balance was not possible, and the project resulted in excess material, unlike the 2B-III project which achieved earthworks balance through a combination of cut on the channel banks and fill in the eroded flow line.

Another design challenge was the management of runoff from the BLM Wild Horse Holding Facility, due to the site's designation as a Confined Animal Feeding Operation (CAFO) by the Wyoming Department of Environmental Quality (WDEQ). As such, a retention system was necessary to collect nutrient dense flows through the facility. The Lionkol drainage is a tributary to Kilpecker Creek, which is listed as an impaired stream due to elevated levels of fecal coliform. BRS, through a separate contract with the BLM, provided design and permitting services to integrate the projects from a design standpoint. The Lionkol drainage ran through the middle of the corrals, and the constrained valley made it difficult to site a retention pond. Two smaller retention ponds were proposed and integrated into the overall design to assist the BLM in the management of their storm water runoff.

BLM approached AML regarding the bidding and construction of the BLM ponds and other facilities related to the Wild Horse Holding Facility. AML agreed, and project bidding and construction were combined. The BLM work items were separated in the contract, and the BLM funded the work on their retention system through the AML contract. Combining the projects reduced costs to both the BLM and AML through economy of scale. In addition, the excess material from the AML project was used to construct one of the retention structures and also to provide a stockpile of material for use in the BLM facility, aiding in the earthworks balance for both projects.

On the west end of the project, the stormwater flows from the BLM office building parking lot were incising and eroding material into the Lionkol drainage. The design incorporated a rip rap lined "A" channel to convey the flows into the main Lionkol drainage and prevent further erosion. Near the downstream end of the project, a pipeline right-of-way and cultural area restricted the project limits. The Natural Regrade™ channel design had to be manipulated in the area to avoid interference with the pipeline and cultural area. Orange safety fence was used to restrict these areas and prevent accidental disturbance, as shown in the Post Construction photo below.

The large contributing drainage areas provided a challenge to designing a stable channel during Phase IV. Regional regression equations were used to estimate the contributing area runoff (Miller, 2003) as utilized in Phase III as well. This resulted in more realistic flow estimates due to the natural routing of flows, and lowered the shear stresses closer to the design criteria. Section 4.1 discusses Miller (2003) in more detail. Shear stresses on the Main channel were allowed to exceed the design criteria of 1.5 for the flood prone condition because the channel grades were designed flatter than the native grades. The channel has performed well during recent significant runoff flow events. See Section 5.2.4 the site performance evaluation.

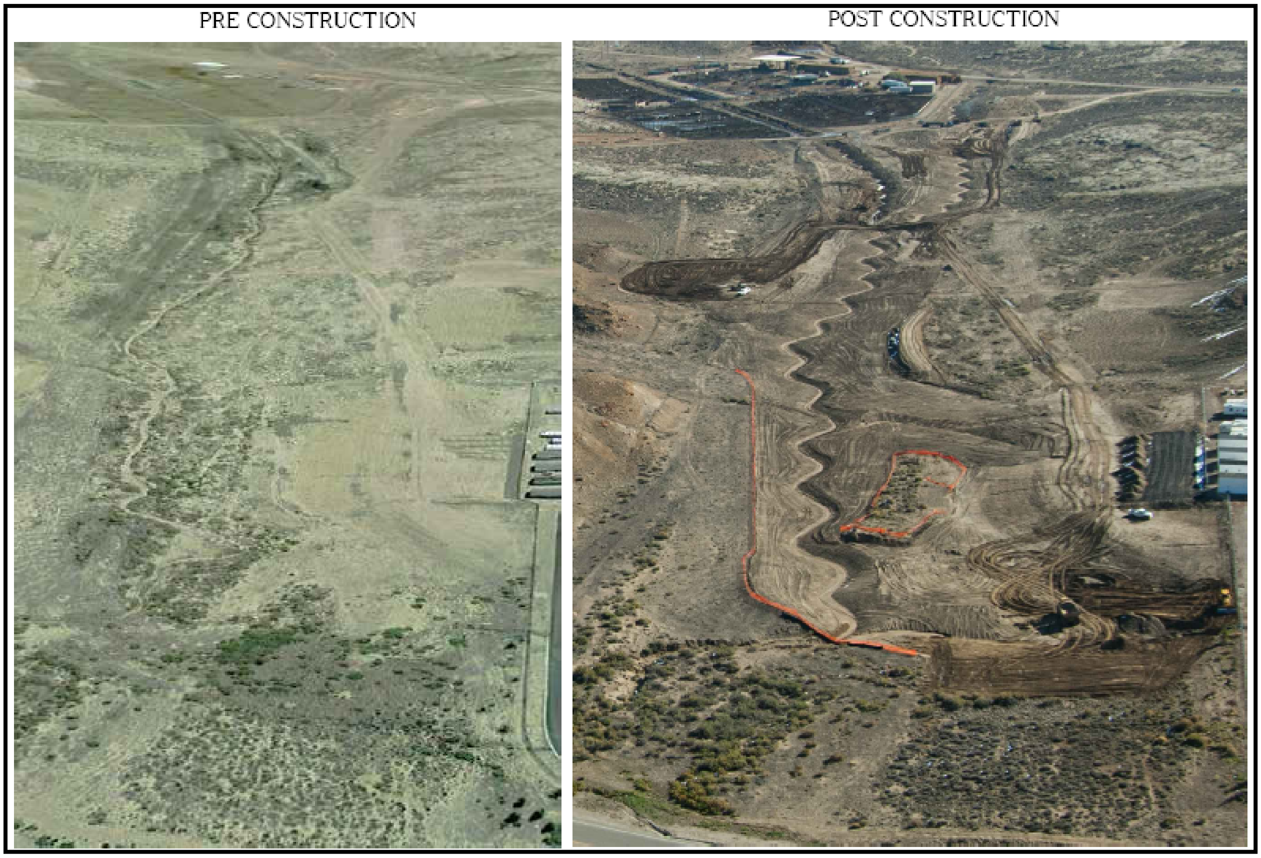


Figure 24: Before and After Photos of the Lionkol Phase 4 Project.

5.1 Lionkol West: Hydrologic Features Summary

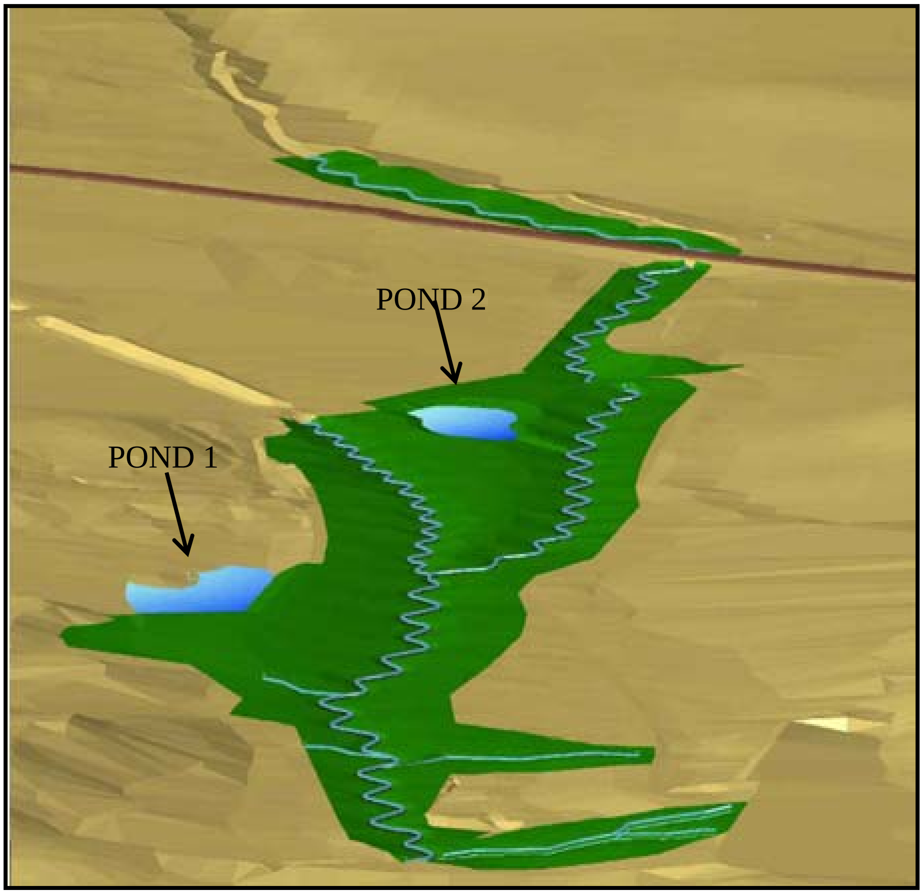


Figure 25: Lionkol West Drainage Design 3-Dimensional Rendering

5.1.1 Lionkol West: Geomorphic Channels

Three NR basins were used to model the Lionkol West Drainage: Lionkol West, Lionkol Central, and Lionkol East, as shown in Figure A-5.1, Figure A-5.2, Figure A-5.3, and Figure A-5.4 in Appendix A5.3. The basins are separated by culvert crossings. The valley length through the regraded section is approximately 0.9 miles long with an elevation drop of approximately 60 feet. The basin physical properties are shown in Table 5.1. The design runoff parameters are shown in Table 5.2. Shear stresses were mostly within the design criteria. Under the flood-prone condition, the West Main and East Main channels slightly exceed the shear stress criteria due to the large contributing areas. The flood-prone flows in the Central Main reach are lower than the connecting upstream East Main reach due to expected pooling at the box culvert under the Lionkol Road. Flow in excess of 100 cubic feet per second may overtop Lionkol Road. Due to the volume of data, detailed data for Shields shear values by station are not included in this report but are available upon request.

5.1.2 Lionkol West: BLM Ponds

Two ponds were constructed to contain 25-year, 24-hour storm flows from the BLM Wild Horse Facility. A WYPDES permit is required by the WDEQ due to the Wild Horse Facility's designation as a CAFO. The Wild Horse Stock Reservoir (aka Pond 1) was constructed to collect storm flows through the facility on the north side of the Lionkol drainage. This site required a permit from the State Engineer's Office (SEO), which is included in Appendix C5.3. Pond 2 was constructed to contain storm flows through the facility on the south side of the drainage. Pond 2 is a pit-style pond with no embankment, and did not require a permit from the SEO.

5.1.3 Lionkol West: Riprap Structures

Riprap structures were included at the inlet and outlet of Pond 2, through the spillway of the Wild Horse Stock Reservoir, and along the entire "A" channel from the BLM parking lot. Class 6 riprap was used for the rock structures based on the design flow capacity through the Wild Horse Facility, and on the culvert size from the BLM parking lot. The riprap was obtained from the South Pass quarry near South Pass, WY. The dimensions and quantities of the rock structures are shown in Table 5.3.

5.1.4 Lionkol West: Performance Evaluation

The Lionkol West project was recently completed at the time of this report. Therefore, data on the finished performance of the channels was not collected on this site. However, during construction, the site experienced three separate heavy storm flows, with a return interval of between a 10-year and 25-year storm as discussed below. The flow during these events was up to three feet deep in the main channel and cut into the banks in one location up to two feet deep.

Figure 26: Lionkol West Drainage Upper Main During Construction, Channel Failure

Erosion damage from the storm required the contractor to refinish sections of the channel. The storms provided a real world test of the various channels while an engineer was onsite to observe. Because the multiple storm events were of similar magnitudes (0.23 to 0.5 inches per 24 hours), it was possible to see how the repairs performed and make changes to the repair strategy where necessary.

A few areas highlighted by the storm flows needed significant repairs during construction. One such area was the channel exiting the box culvert underneath the roadway between the upper easternmost portion and the central portion of the main channel (see Appendix A5.3 for as-built figures). This section of the channel developed a 1-foot-deep scour hole downstream of the box culvert. In the upper area of the main channel near the box culvert, a telephone pole required a reworking of the original channel design. The channel incised nearly a foot in this area. Near the head of the channel in the upper section, a 2-foot headcut developed that required repair.

Smaller repairs in the channels consisted primarily of using the dozer to collapse cut banks and widen the channel bottom. The large headcut in the upper portion of the main channel was repaired by replacing the eroded material, to maintain a stable grade. Below the box culvert, a concrete apron was poured to dissipate the energy from the flow, and a rock structure was installed at the end of the apron to prevent damage to the channel.

An "A" channel was damaged through its entire length near the BLM parking lot. This channel originated from a culvert under the BLM parking lot in the lower (western) portion of the site (see as-built drawing in Figure A-5.2 in Appendix A5.3). The channel material in this area is sandy, and it was not able to maintain the designed shape even under normal flows due to lack of cohesion of the materials. Widening the channel would have been an insufficient solution in the poor material, so the channel was lined with rock to disperse the energy of the water and protect the channel.

Shortly after the last storm event in September 2013, high water marks were identified and marked for survey, just upstream of the box culvert over Lionkol Road. A channel survey was completed to estimate the peak discharge and evaluate the frequency of the event.

Figure 27: Lionkol West Channel Following Heavy Fall Precipitation

The data were analyzed in AutoCAD to determine station and offsets of the four surveyed cross sections. Data were entered in the U.S. Army Corp. of Engineers Hydraulic Engineering Center

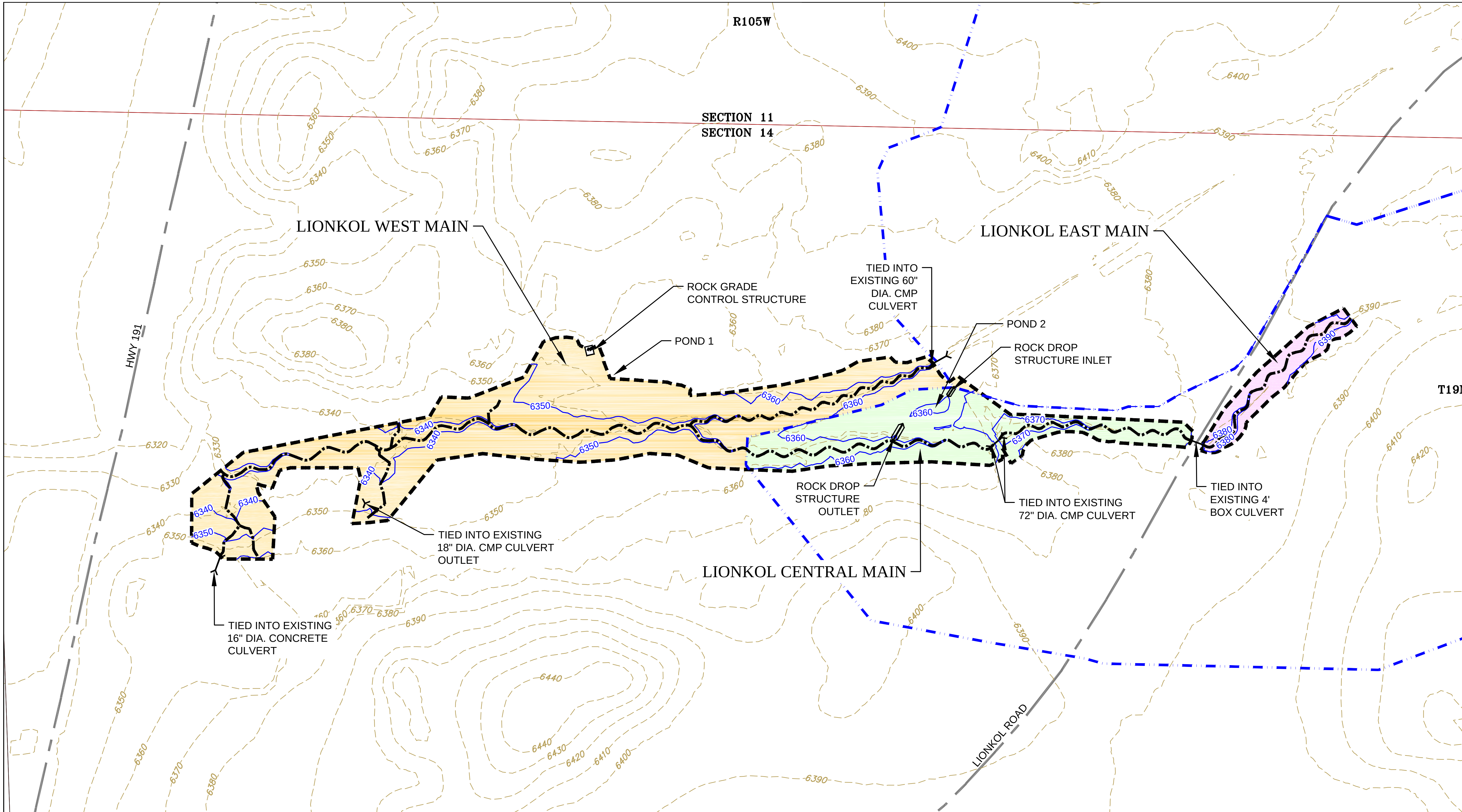
River Analysis System (HEC-RAS) software to estimate the flow discharge. Roughness factors were estimated from soil type, vegetation cover, and channel transitions observed in the field. The surface water profiles calculated in HEC-RAS were checked against the observed high-water marks to see if they matched. Though not a perfect match, the surface water profiles matched the general trend of the observed high-water marks. A rating curve was plotted in HEC-RAS for cross-section 4 and the flow at the high-water mark was estimated to be 94 cubic feet per second (cfs).

Return interval runoff was evaluated using the regional regression equation developed by the U.S. Geological Survey (Miller, 2003). Table 5.4 shows the return-interval runoff estimates for the channel at the survey location. From Miller (2003), the storm event of 94 cfs is between the 10-year and 25-year storm. In general, the meander channels performed very well considering the fact that they were newly constructed and virtually void of any vegetation. The HEC-RAS data output is presented in Appendix D5.3.

Table 5.4 Lionkol West Channel Runoff Return Interval

Drainage area (ac)	Qp	cfs	ac-ft
835 (ac)	Q2	14	1.3
1.30 (mi^2)	Q5	40	3.3
	Q10	67	5.3
	Q25	115	8.5
	Q50	162	11.4
	Q100	217	14.8

Miller (2003) Region 6



LEGEND

SECTION LINES	CONSTRUCTED MEANDER CHANNEL
ROAD	CONSTRUCTED "A" CHANNEL
RECLAMED AREAS	DRAINAGE BASIN BOUNDARY
EXISTING GROUND CONTOURS C.I.-10'	A= 1.48 DRAINAGE BASIN AREA
ASBUILT CONTOURS C.I.-10'	

300' 0 150' 300'

1 inch = 300 ft

NATURAL REGRADE PROJECTS
AML PROJECT 17 H-2
SWEETWATER COUNTY WYOMING

LIONKOL WEST OVERALL MAP

FIGURE A-5.1

BRS ENGINEERING

REVISION DATE:
LAST PLOT DATE: 5/31/13
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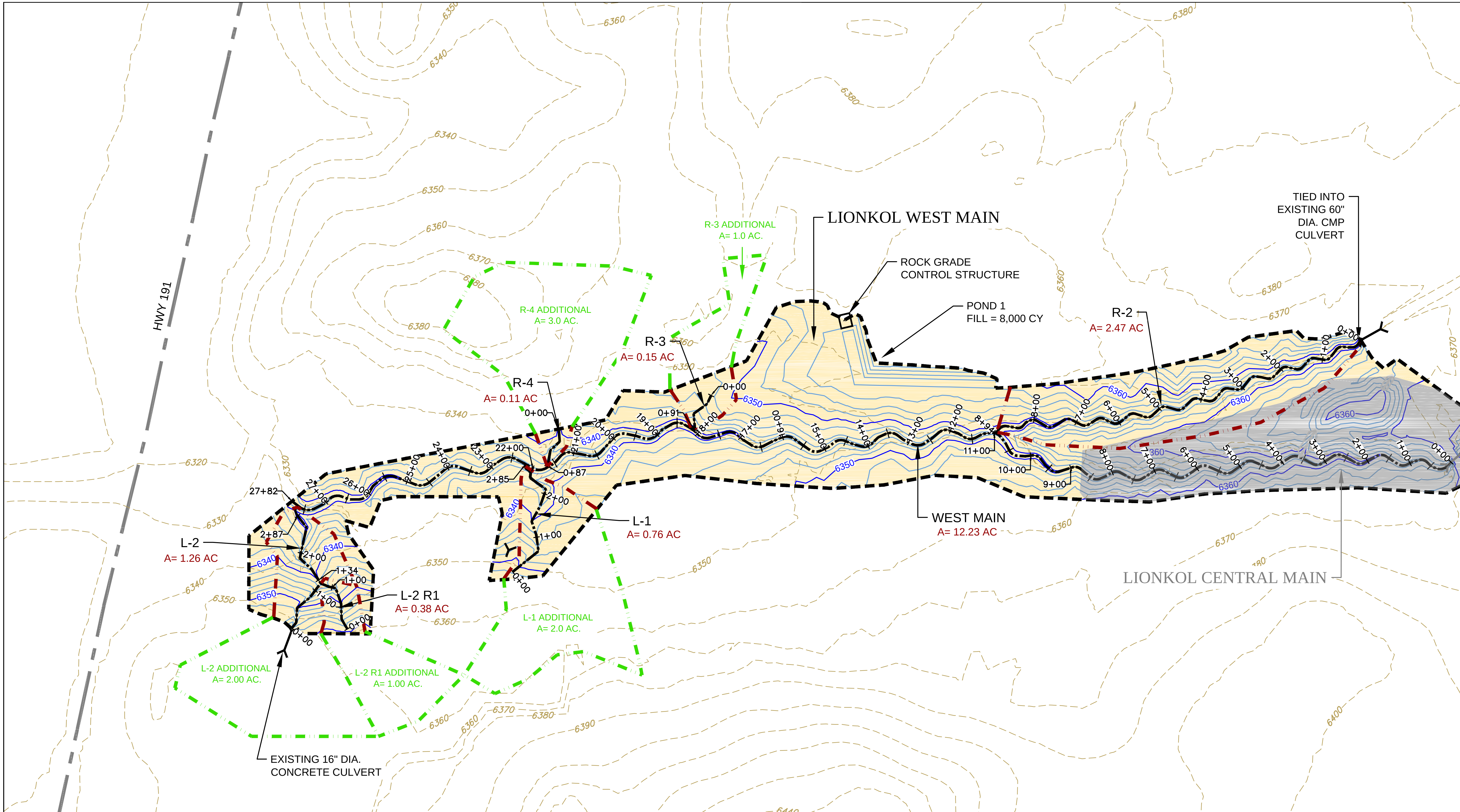

LEGEND

SECTION LINES	CONSTRUCTED MEANDER CHANNEL	0+00 0+100	CHANNEL STATIONING
ROAD	CONSTRUCTED "A" CHANNEL	A=1.48 AC	DRAINAGE BASIN AREA
RECLAIMED AREAS	DRAINAGE BASIN BOUNDARY	A=1.48 AC	CONTRIBUTING SUB-BASIN AREA
EXISTING GROUND CONTOURS C.I.-10'	SUB-BASIN BOUNDARY	A=1.48 AC	CONSTRUCTED SUB-BASIN AREA
ASBUILT CONTOURS C.I.-2'	CONSTRUCTED SUB-BASIN BOUNDARY		

200' 0 100' 200'
1 inch = 200 ft

BRS ENGINEERING

NO. | REVISION DATE: | DATE | BY | ISSUED FOR

LAST PLOT DATE: 3/25/14
CAD FILENAME: DATA/17H/NATURAL REGRADE PROJECTS/FIG A-5.2 Lionkol West.dwg

LIONKOL AREA GEOMORPHIC RECLAMATION
AML PROJECT 17 H-2, 2B-II, 2B-III, & 2B-IV
SWEETWATER COUNTY WYOMING

LIONKOL WEST

DWG. NO. FIGURE A-5.2

REV.

SCALE: 1" = 200'
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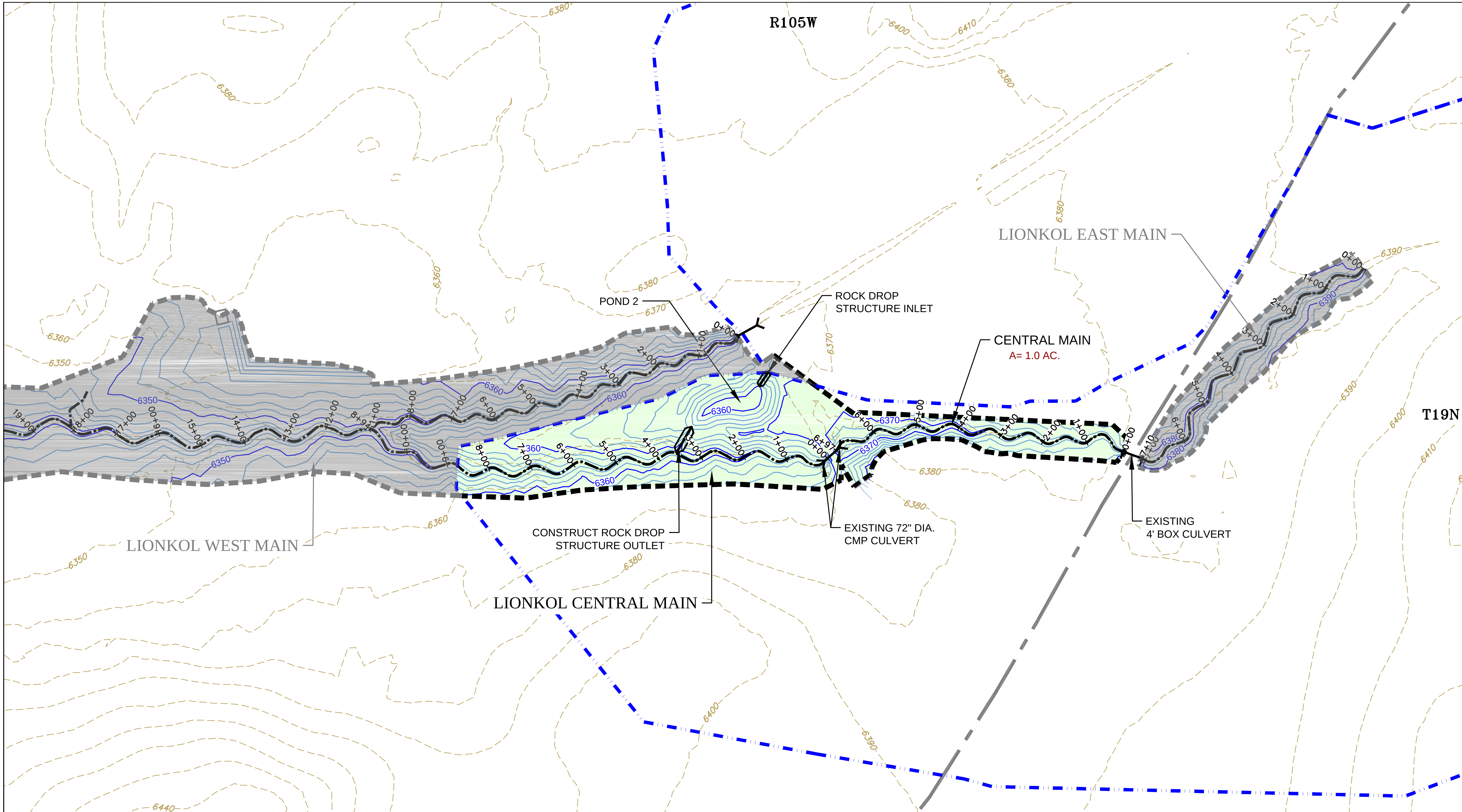
DATE 3/25/14



LEGEND

	SECTION LINES		CONSTRUCTED MEANDER CHANNEL	0+00 0+100	CHANNEL STATIONING
	ROAD		CONSTRUCTED "A" CHANNEL		
	RECLAIMED AREAS		DRAINAGE BASIN BOUNDARY	A=1.48 AC	DRAINAGE BASIN AREA
6400	EXISTING GROUND CONTOURS C.I.-10'		SUB-BASIN BOUNDARY	A=1.48 AC	CONTRIBUTING SUB-BASIN AREA
6400	ASBUILT CONTOURS C.I.-2'		CONSTRUCTED SUB-BASIN BOUNDARY	A=1.48 AC	CONSTRUCTED SUB-BASIN AREA

200' 0 100' 200'

1 inch = 200 ft

BRS ENGINEERING

NO. | REVISION DATE: | DATE | BY | ISSUED FOR

LAST PLOT DATE: 3/25/14

CAD FILENAME: NATURAL REGRADE PROJECTS/LIONKOL WEST/FIG A-5.3 LIONKOL CENTRAL.dwg

LIONKOL AREA GEOMORPHIC RECLAMATION
AML PROJECT 17 H-2, 2B-II, 2B-III, & 2B-IV
SWEETWATER COUNTY WYOMING

LIONKOL CENTRAL

DWG. NO. FIGURE A-5.3 | REV.

DATE 3/25/14

SCALE: 1" = 200'
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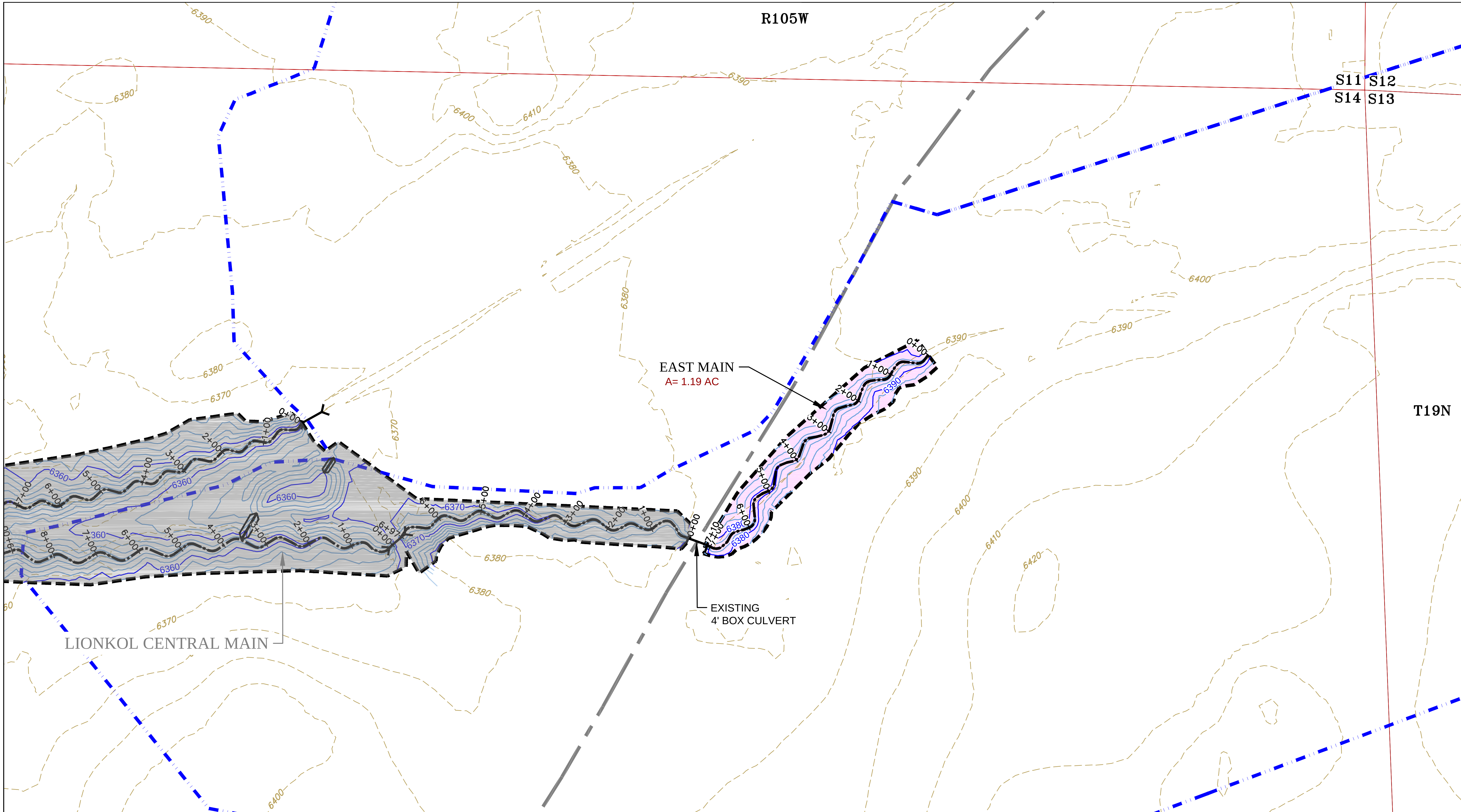
APPROVED: HH



LEGEND

SECTION LINES		CONSTRUCTED MEANDER CHANNEL		0+00 0+100	CHANNEL STATIONING
ROAD		CONSTRUCTED "A" CHANNEL		A=1.48 AC	DRAINAGE BASIN AREA
RECLAIMED AREAS		DRAINAGE BASIN BOUNDARY		A=1.48 AC	CONTRIBUTING SUB-BASIN AREA
EXISTING GROUND CONTOURS C.I.-10' (6400)		SUB-BASIN BOUNDARY		A=1.48 AC	CONSTRUCTED SUB-BASIN AREA
ASBUILT CONTOURS C.I.-2' (6400)		CONSTRUCTED SUB-BASIN BOUNDARY			

200' 0 100' 200'

1 inch = 200 ft

BRS ENGINEERING

NO. | REVISION DATE: | DATE | BY | ISSUED FOR

LAST PLOT DATE: 3/25/14

CAD FILENAME: NATURAL REGRADE PROJECTS/LIONKOL WEST/FIG A-5.4 LIONKOL EAST.dwg

LIONKOL AREA GEOMORPHIC RECLAMATION
AML PROJECT 17 H-2, 2B-II, 2B-III, & 2B-IV
SWEETWATER COUNTY WYOMING

LIONKOL EAST

DWG. NO. FIGURE A-5.4 REV.

SCALE: 1" = 200'
DRAWN BY: CDS
CHECKED: HH
APPROVED: HH
DATE 3/25/14

Tables

Table 5.1 Lionkol: West Drainage Physical Properties

Basin Name	watershed area (ac.)	addn'l watershed area (ac.)	valley length (ft.)	drainage density (ft./ac.)	head elev (ft.)	base elev (ft.)	total relief (ft.)	head slope	base slope
West Main	12.23	0.00	2524.80	349.11	6,363.35	6,326.77	36.58	-2%	-1%
Central Main	1.00	0.00	635.45	636.98	6,375.56	6,363.85	11.71	-2%	-2%
East Main	1.19	0.00	646.34	542.85	6,388.08	6,375.77	12.31	-2%	-2%
L-1	0.76	2.00	254.45	336.63	6,352.14	6,333.60	18.53	-12%	-1%
L-2	1.26	2.00	279.41	332.75	6,355.80	6,326.87	28.93	-14%	-1%
L-2 R1	0.38	1.00	141.50	374.91	6,359.19	6,341.42	17.77	-18%	-11%
R-1	0.12	2.00	83.92	706.84	6,364.55	6,356.91	7.64	-10%	-4%
R-2	2.47	0.00	821.38	332.38	6,359.27	6,347.57	11.70	-2%	-1%
R-3	0.15	1.00	77.67	515.15	6,347.43	6,338.75	8.68	-11%	-3%
R-4	0.11	3.00	88.22	807.20	6,339.56	6,334.30	5.26	-8%	-2%
TOTAL	**19.67**	**11.00**							

Table 5.2 Lionkol: West Design Runoff Parameters

Basin Name	Bank-full Conditions*				Flood-prone Conditions**			
	width range (ft.)	depth range (ft.)	Shields shear stress, (psf)	Qpk (cfs)	width range (ft.)	depth range (ft.)	Shields shear stress, (psf)	Qpk (cfs)
West Main	6.84 to 9.76	0.49 to 0.70	0.40 to 0.67	32.36	20.87 to 29.55	2.24 to 3.17	1.01 to 1.75	244.84
Central Main	6.24 to 6.32	0.50 to 0.51	0.51 to 0.59	14.39	18.99 to 19.07	2.09 to 2.10	1.17 to 1.37	100.92
East Main	6.60 to 6.70	0.47 to 0.48	0.45 to 0.67	14.47	24.02 to 24.10	2.65 to 2.65	1.38 to 2.07	161.09
L-1	1.32 to 1.73	0.13 to 0.14	0.12 to 1.01	1.08	2.57 to 3.05	0.26 to 0.33	0.15 to 1.21	2.53
L-2	1.33 to 2.15	0.13 to 0.17	0.16 to 1.28	1.68	2.58 to 3.79	0.26 to 0.42	0.22 to 1.53	3.91
L-2 R1	0.96 to 1.10	0.10 to 0.11	0.77 to 1.19	0.54	1.87 to 2.13	0.21 to 0.24	0.92 to 1.43	1.26
R-1	1.33 to 1.52	0.13 to 0.12	0.42 to 1.07	0.83	2.59 to 2.68	0.26 to 0.30	0.56 to 1.28	1.94
R-2	5.00 to 5.27	0.36 to 0.38	0.28 to 0.35	8.97	19.26 to 19.47	2.14 to 2.15	0.93 to 1.14	105.27
R-3	0.95 to 1.11	0.09 to 0.09	0.22 to 0.82	0.45	1.84 to 1.97	0.19 to 0.22	0.29 to 1.04	1.06
R-4	1.62 to 1.84	0.16 to 0.15	0.22 to 0.88	1.22	3.15 to 3.25	0.32 to 0.36	0.29 to 1.06	2.85

Table 5.3 Lionkol West Design: Rock Structure Summary

Drop Structure ID	Bottom Width (feet)*	Length (feet)	Grade (ft/ft)	Depth (feet)	Drop (feet)	Apron Length (feet)	Side Slope h:v	Riprap Class (inch)	Riprap Depth (inch)	Riprap Quantity (cy)*	Bedding Quantity (cy)*	Fabric Quantity (sf)*
Pond 2 Outlet	2	56	0.1	3	8	(2) 4	3	6	12	48	25	3400
Pond 2 Inlet	2	34	0.2	2	7	(2) 4	3	6	12	22	12	2100

Grade Control ID	Bottom Width (feet)*	Length (feet)	Grade (ft/ft)	Depth (feet)	Side Slope h:v	Riprap Class (inch)	Riprap Depth (inch)	Riprap Quantity (cy)*	Bedding Quantity (cy)*	Fabric Quantity (sf)*
Pond 1	20	24	0.005	1	4	6	12	27	14	2300

*10% factor added

6.0 Summary and Conclusions

The Lionkol Project fully implemented new methods in geomorphic mine land reclamation to achieve a sustainable reclaimed landscape which blends with native topography and provides for long-term stability against erosion. The project was funded primarily through the Office of Surface Mining with additional funding provided by BLM. The project addressed hazards and environmental degradation related to historic surface and underground coal mining while preserving the historic aesthetic. Additionally, both the City of Rocks Springs and the BLM benefitted from this project.

Overall, the project reclaimed 320 acres of intensely disturbed mine lands including four open pit complexes, associated mine spoils, and numerous underground mine portals, shafts, and subsidence features. In addition, over 5 miles of degraded mainstream drainages were restored. The Lionkol Project was supportive of efforts by the City of Rock Springs to attenuate peak runoff events critical to reducing floodplain designations, and was integrated with BLM efforts at its Wild Horse Holding Facility to control surface runoff and be compliant with WYPDES regulations.

The four reclamation projects completed using the Natural Regrade™(NR) design concept were reviewed in the Lionkol drainage to assess channel stability and overall project success. The time since completion of the projects ranges from a couple of months (2B-IV Lionkol West) to five years (2B Reliance No. 11) and provides an adequate sampling of sites to evaluate project success. The timeline also provides for evaluation of the design concepts of NR and review of the input parameters.

The geomorphic reclamation methods at each successive site evolved to reflect lessons learned from the previous phases. Whereas the first phases relied heavily on a mix of traditional and geomorphic reclamation techniques, the subsequent phases came to incorporate more NR designed structures as well as more realistic native channel and surface water runoff characteristics. Although no extreme failure of any channel was observed, the overall behavior of the geomorphic channels is judged to have been superior to the traditionally designed channels, both in function and aesthetics.

In total, 14 out of 85 channels experienced damage requiring repairs. Of these, three were failures of the entire channel. The remaining areas required repairs to limited reaches within the channel. Significantly, all of the failures were related to over-steepened “A” channels in uplands areas with contributing basin areas. The majority of these failures were located on the Lionkol Main Pit, Reliance North Pit, and Lionkol Drainage. For the Lionkol Main Pit and Reliance North Pit failures, the failed channels are located on ridges with steep natural gradients. For the Lionkol Drainage, all of the failures were related to over-steepened channels downstream of culverts under Lionkol Road. These failures cannot be attributed Natural Regrade, but to the modification of gradient required by the road and culverts, and inadequate engineering controls in the initial design, which were subsequently repaired. None of the main meander channels, including ones with large contributing basin areas, experienced failure. Future design emphasis will be placed on managing contributing flows in steep uplands basins.

Variability in the performance of the channels within the Lionkol Project speaks to the variable components impacting the runoff of any singular basin. Any of the components of failure (e.g. steep slopes, high shear stresses, large drainage area, high runoff) taken singularly is not likely to result in failure. However, combinations of these factors have been observed to cause unacceptable amounts of erosion. As such, understanding of the magnitude of each component's role in failure assists in the improvement of future NR designs and will benefit from future investigation.

In conclusion, the performance of the NR features in comparison to the traditionally designed elements in the Lionkol project areas supports the continued use of geomorphically designed elements in future reclamation projects. The authors recommend that such reclamation projects include NR design methods which integrate changes in paradigm effecting design parameters, site characterization, monitoring, control and retention structures, and adjustments to NR design output. Following is a discussion of each.

Design Parameters

Selection of design events should be based on the local setting and purpose of the reclamation projects. If there is potential for downstream flood damage, greater levels of control and/or more conservative design events may be considered. The Lionkol Project is located in an unpopulated area, however the BLM Wild Horse Holding Facility, a state highway, and the city of Rock Springs are located downstream of the site. Design parameters for the Lionkol Project included:

- Bank-full conditions; 2-year, 1-hour precipitation event.
- Flood-prone conditions; 50-year, 6-hour precipitation event.
- Storm water retention and/or grade control structures and impoundments; 100-year, 24-hour precipitation event for stability and back-to-back events for storage.
- Regression models were used to determine contributing runoff during later phases (Miller, 2003).

Site Characterization

Accurate surveys of existing channel profiles and cross sections are needed within the design reach and surrounding native channels including:

- Drainage density,
- "A" or tributary channel reach lengths,
- Bankfull and Flood-prone channel dimensions (e.g. width, depth, meander length),
- Vegetation types and locations,
- Erosional and depositional modes (e.g. rilling, piloting, armoring, braiding, point barring), including sediment load and grain size distribution
- Sinuosity of native channels,
- Channel gradients,
- Channel capacities, and
- Sufficient topographic mapping to define all contributing drainage areas and local drainage divides.

Adjustments to Natural Regrade™ Design Output

Natural Regrade™(NR) software optimizes geomorphic stability, but does not always produce constructible earthwork designs. The algorithm functions best in conditions with limited vertical relief. Open pit highwalls and large mine waste stockpiles often have extreme vertical relief over relatively short distances, which present a challenge to NR design. This requires multiple design iterations wherein the NR output is adjusted in ACAD. Typical requirements for steep terrain projects include:

- Prior to application of the NR software, define limits and main design features of the project including the location and alignment of major drainages and basins;
- After developing a preliminary or conceptual design surface, apply NR to that surface;
- NR will generate slope and aspect conditions which are not constructible and need to be adjusted including:
  - Slopes 3:1 (H:V) or steeper should be reduced to 3:1 or less while maintaining ridge break lines and channel flow lines if possible.
  - Sharp breaks (up to 90^{o}) need to be smoothed to reflect typical turn radii of heavy equipment while maintaining ridge breaks and channel flow lines, if possible.
  - Channel parameters such as "A" channel length and meander channel sinuosity and cross sectional area should be adjusted for construction constraints of heavy equipment.
- NR does not optimize earthwork volumes. The design engineer needs to be conscious of this fact and seek to develop cost-effective designs.

Control and Retention Structures

NR does not incorporate retention and/or surface drainage control structures. Such structures are often necessary for steep terrain and for downstream protection. When structures are necessary to achieve channel stability and/or limit peak downstream flow, the NR designs need to be broken into separate basins with design input reflecting the controlled conditions.

Monitoring

Ongoing monitoring of NR projects is recommended. NR is a relatively new application that could benefit from construction and performance feedback. Monitoring should include routine inspections of the main and tributary channels for erosion and sediment transport, inspection of drainage control structures, and vegetative cover and diversity.