ADVANCEMENTS IN GEOMORPHIC MINE RECLAMATION DESIGN APPROACH

WYOMING ABANDONED MINE LAND PROJECT 17H-2B
LIONKOL COAL MINING DISTRICT
SWEETWATER COUNTY, WYOMING

Geomorphic Reclamation on the Lionkol Project

SUBMITTED TO:

American Society of Mining and Reclamation

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SUBMITTED BY:

Harold J. Hutson, P.E., P.G.

Robert W. Thoman, P.E.

BRS, Inc.

1130 Major Avenue

Riverton, WY 82501

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Project Summary

Following the successful pioneering application of Natural Regrade™ geomorphic reclamation design technology to surface mine reclamation efforts at its AML Project 16N, D-9 and K Pit Reclamation Project in 2007, the Wyoming AML Division and consulting engineering firm, BRS Inc. of Riverton, Wyoming, applied this surface reclamation approach to the Lionkol Project located in Sweetwater County north of Rock Springs, Wyoming. A general location map follows. Refer to Figure A-1.1, Appendix A1, for a more detailed location map.

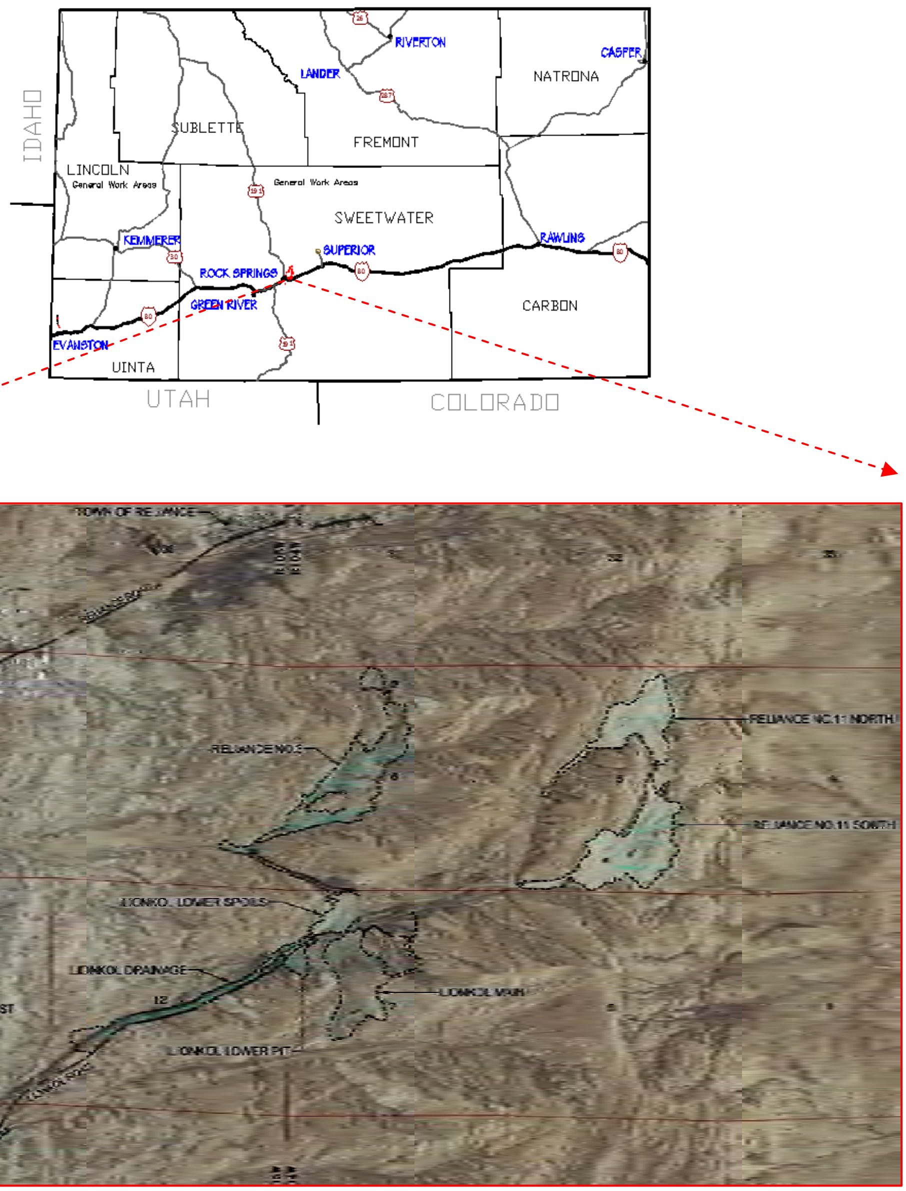


Figure 1: Lionkol Project Location Map

The Lionkol Project is located within a historic coal mining district in Sweetwater County, Wyoming which had been intensely impacted by underground mining beginning in the early 1900's through the 1940's. This was then followed by open pit mining into the early 1970's.

The reclamation of the Lionkol area was completed in four phases over a six year period, with the final phase completed in the fall of 2013. Overall, the project reclaimed 320 acres of mine lands including four open pit mine complexes, associated mine spoils, and numerous underground mine portals, shafts, and subsidence features. In addition, over 5 miles of degraded mainstream drainages were restored to approximate pre-mine conditions. The Lionkol Project was supportive of efforts by the City of Rock Springs to attenuate peak runoff events which contrbuted to flood plain designations restricting building in the down town area. In addition, the project and was integrated with Bureau of Land Management (BLM) efforts at its Wild Horse Holding Facility to control surface runoff for compliance with the Wyoming Pollutant Discharge Elimination System (WYPDES) program regulations.

Project reclamation designs addressing direct mining related disturbances and mine related impacts to surface drainages were completed using a combination of conventional earthwork design using Autocad™ (ACAD) and geomorphic designs utilizing Natural Regrade™ software (NR). NR software assists the design engineer in the development of geomorphically stable, diverse landscapes mimicking natural soft sediment landforms. This reclamation design approach simulates native topography to develop a sustainable landform that requires minimal maintenance. The main features of the design include; slopes that transition from convex to concave profiles, concave drainage profiles, multiple small drainage basins that break up the surface topography, and meandering channels that assist in reducing the drainage gradient. To implement these reclamation designs on the ground, it was necessary to employ GPS machine control for final grading. The following figures depict pre and post construction views of the Reliance No. 3 mine portion of the project.

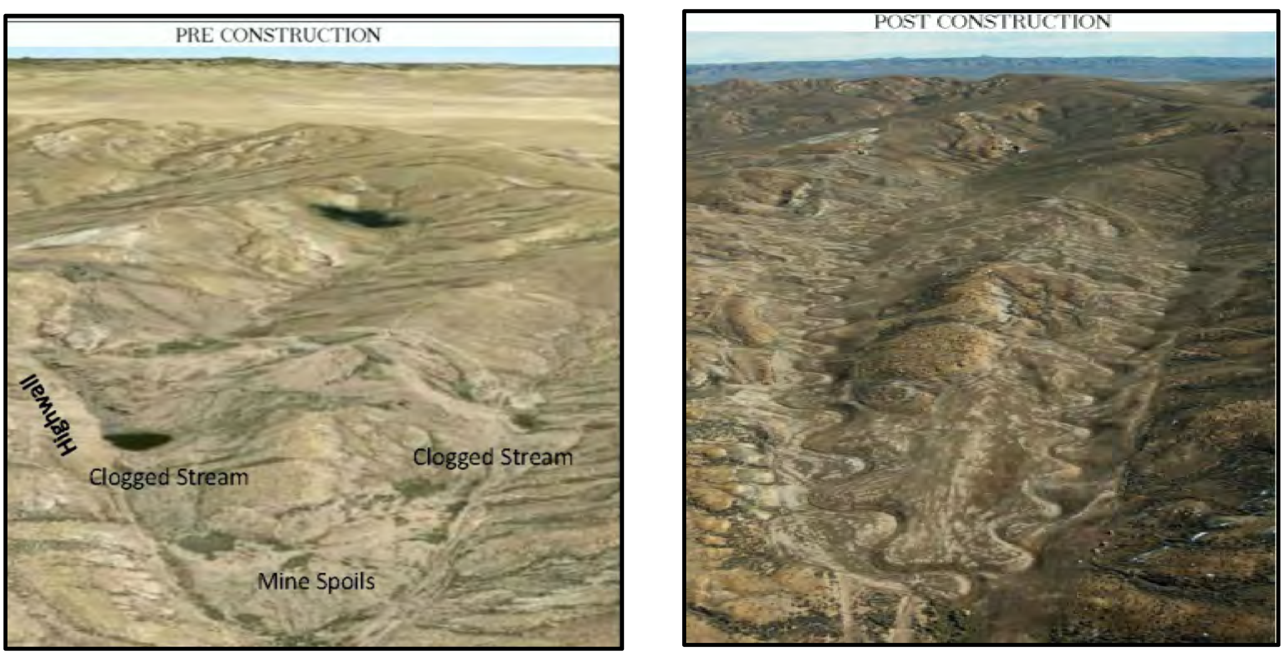


Figure 2: Reliance No. 3 Before and After Construction

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 ameliorated hazards and environmental degradation related to historic surface and underground coal mining while still preserving the historic aesthetic and cultural resources. In addition, the City of Rock Springs benefitted by improved flood control and the BLM benefitted with respect to runoff containment at their Wild Horse Facility.

Since the Lionkol Project was completed in four phases, the geomorphic reclamation methods at each site evolved to reflect lessons learned from the previous phases. The first phase relied heavily on a mix of traditional and geomorphic reclamation techniques. The subsequent phases came to incorporate more NR designed structures and fewer traditional reclamation techniques, as well as improving methods for estimation of native channel and surface water runoff characteristics.

The following document is intended to be a discussion of the Lionkol project with respect to:

- Design methodology,
- Cataloguing of hydrologic and physical basin and channel properties,
- Evaluation of performance of each project phase including successes and failures, and
- Providing a basis for future site monitoring.

It is the authors' intention to provide reference and insight relative to future geomorphic mine reclamation design projects within the state of Wyoming and elsewhere.

1.0 Introduction

The Lionkol drainage is located in a historic coal mining district in Sweetwater County, Wyoming, approximately one mile northeast of Rock Springs along the Lionkol road. Four different phases, spanning six years, were completed in the Lionkol drainage as part of the Wyoming Department of Environmental Quality (WDEQ) Abandoned Mine Lands (AML) reclamation project. The first phase of the project was initiated in the fall of 2008, and the final phase of the project was completed in the fall of 2013. Overall, the project reclaimed 320 acres of intensely disturbed mine lands including four open pit complexes and 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 supported efforts by the City of Rock Springs to reduce flood plain designations which impacted portions of the down town district by attenuation of peak flows from the Lionkol drainage reporting to Killpecker Creek. In addition, the project was integrated with BLM efforts at the Wild Horse Holding Facility designed to control surface water runoff and achieve compliance with WYPDES regulations.

Reclamation of surface mining features in the Lionkol drainage was completed using a combination of conventional methods and Carlson NR software. This software creates geomorphically stable, diverse, and more naturally appearing landforms that promote diverse vegetative growth. This approach seeks to replace traditional reclamation which commonly consists of continuous constant-grade slopes with cross-slope ditching and maintenance intensive grade control structures. The NR design approach seeks to mimic the native topography while providing a sustainable landform that requires little, if any, continued maintenance but rather functions similar to a native system. The main features created by the software include slopes that transition from convex to concave profiles, concave drainage profiles, multiple small drainage basins that break up the surface topography, and meandering channels that reduce gradients for improved stability. When combined, these design features create a variable terrain which is aesthetically pleasing and appears natural. To evaluate the success of the Lionkol project, a summary of the design parameters focusing mostly on the NR hydrologic design parameters is provided along with comparative field inspection data.

The Lionkol projects consisted of four major phases, with some of the phases containing multiple areas. A key map of the project area and the phase areas is shown below. Detailed maps and as-built drawings of each area may be found in the appendices attached to the end each project section.

The individual project phases include:

- AML 17H-2B: Reliance No. 11 North and South Pits
- AML 17H-2B-II Reliance No. 3 and Lionkol Pits
- AML 17H-2B-III Lionkol Drainage
- AML 17H-2B-IV Lionkol West

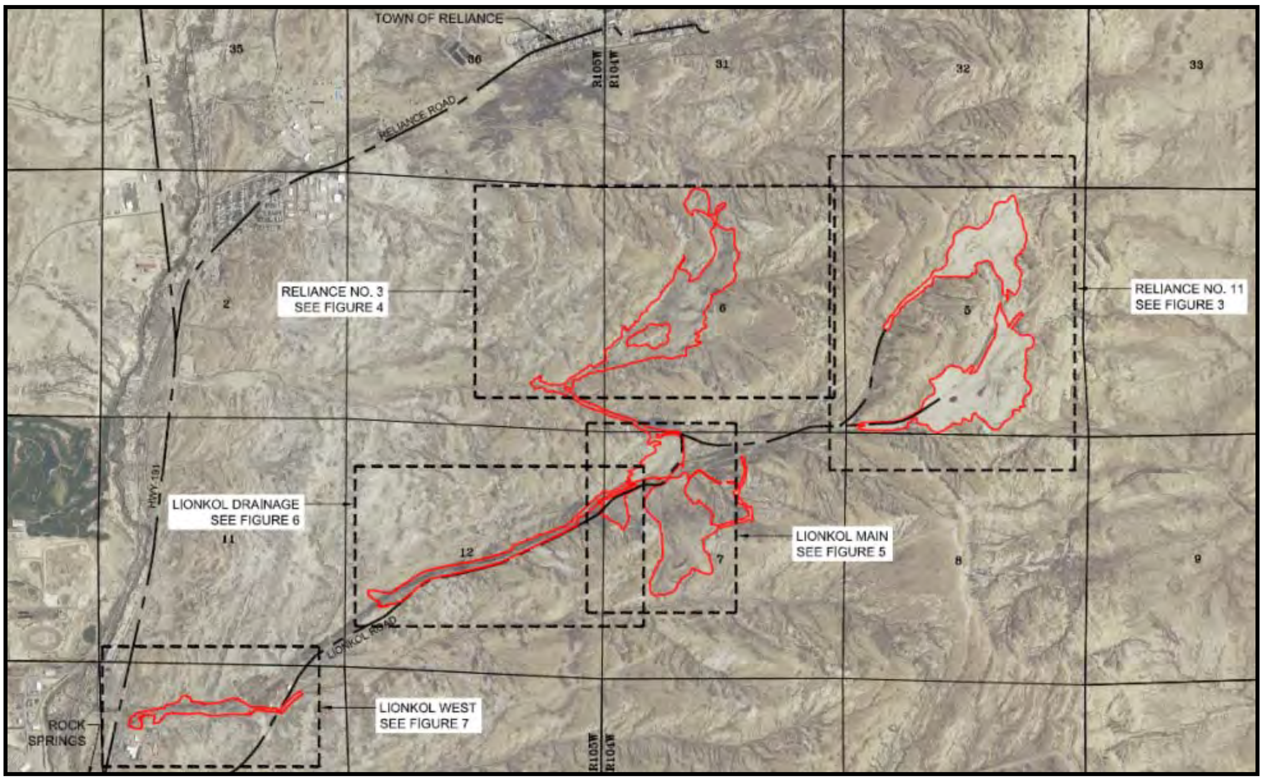


Figure 3: Lionkol Area Key Map: Detailed Map in Appendix A1, Figure A-1.2.

Nomenclature

Bankfull: Channel flow condition (including flow rate, depth, etc.) resulting from a storm with a 50% probability of occurring within any given year (i.e. once every 2 years in frequency or 0.40 inches in 1 hour for this project area)

Flood-prone: Channel flow condition (including flow rate, depth, etc.) resulting from a storm with a 2% probability of occurring within any given year (i.e. once every 50 years in frequency or 1.50 inches in 6 hours for this project area)

Riprap: Well graded mixture of loose rock used as an engineering material. Classified by 50% passing size (D50) in inches and with the largest stone sizes no greater than the 1.5 times the D50 size (Example: Class 6 riprap is nominally 6 inches in diameter with 50% of the material being less than or equal to 6 inches and the largest rock in the mixture being no greater than 9 inches)

Geomorphic Channel: A channel designed to fit the characteristics of native channels (dimensions, sinuosity, reach length, etc.) and accommodate run-off while performing like a native channel.

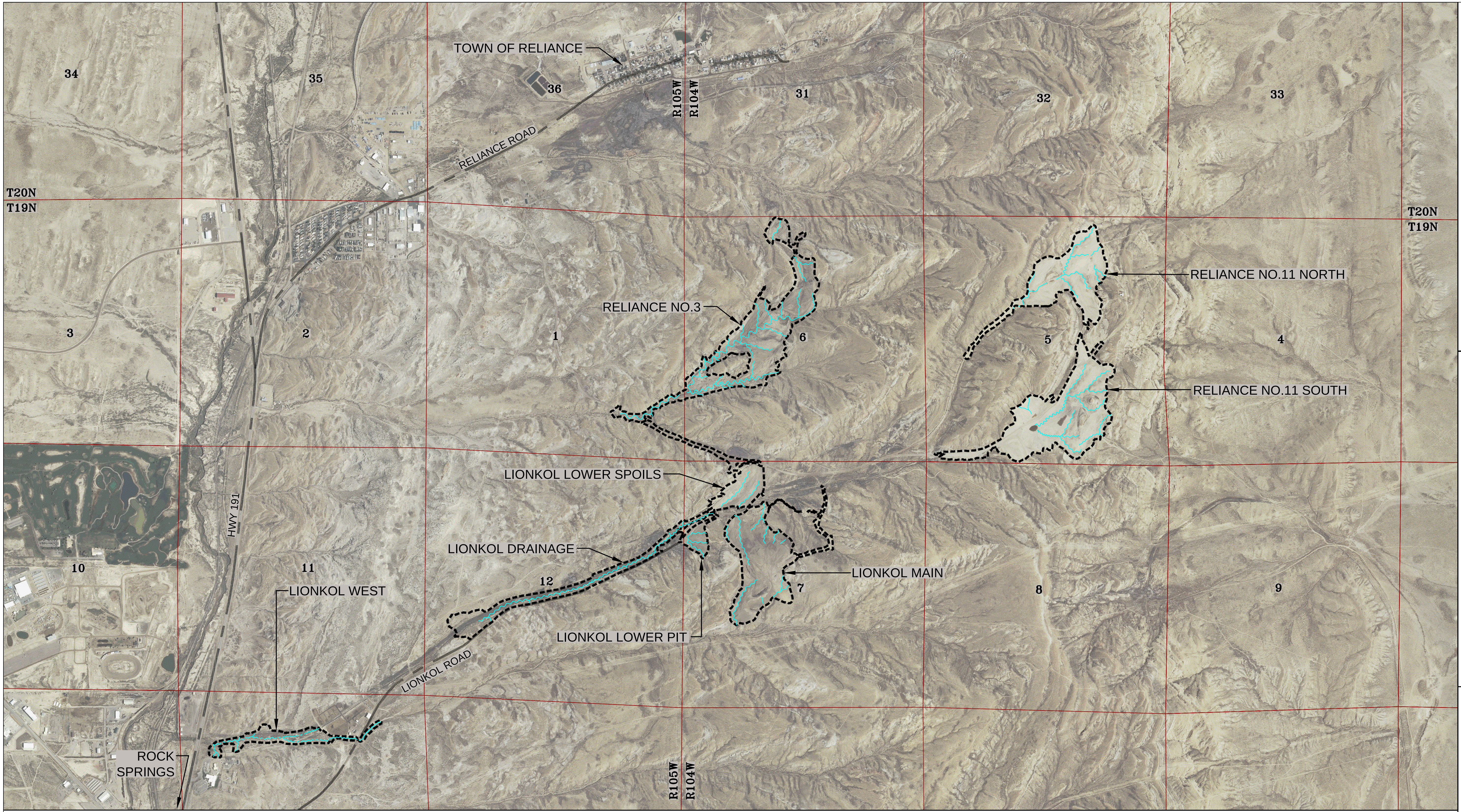
“A” Channel: A channel designation within the Natural Regrade™ software described as having a slope greater than 4%, and having an angular bend alignment, as compared to a rounded meandering configuration. Typically, “A” channels are found in uplands areas and are tributary to Meander Channels.

Meander Channel: A Natural Regrade™ channel designation for second order channels with slopes less than 4% and with an “S-curve” alignment.

Shields Shear Stress: A method of evaluating erosion based on incipient particle motion. The Natural Regrade™ software uses this to identify the tractive shear force that flowing water applies to the channel as a measure of stability.

Table 1.1 General Terms and Abbreviations

	Term	Abbreviation
Shear Stress	Pounds per Square Feet	psf
Volumetric Flow Rate	Cubic Feet per Second	cfs
Water Volume	Acre Feet	ac-ft
Basin Area	Acre	ac
Software Package	Carlson Natural Regrade™	NR
Software Package	AutoCAD™	ACAD
US Dept. of Interior Land Mgr.	Bureau of Land Management	BLM
Wyo. Dept. Environmental Quality, Water Quality Div.	Wyoming Pollutant Discharge Elimination System	WYPDES



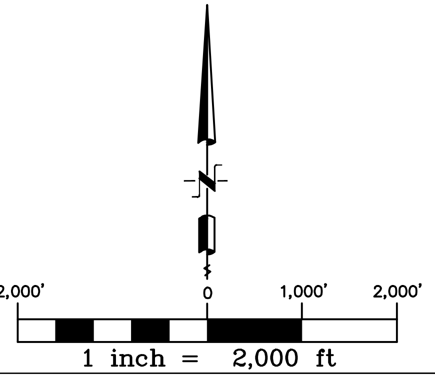
LEGEND

SECTION LINES

ROAD

CONSTRUCTED CHANNELS

RECLAMED AREAS



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

LIONKOL PROJECT LOCATION MAP

SCALE: 1" = 2,000'
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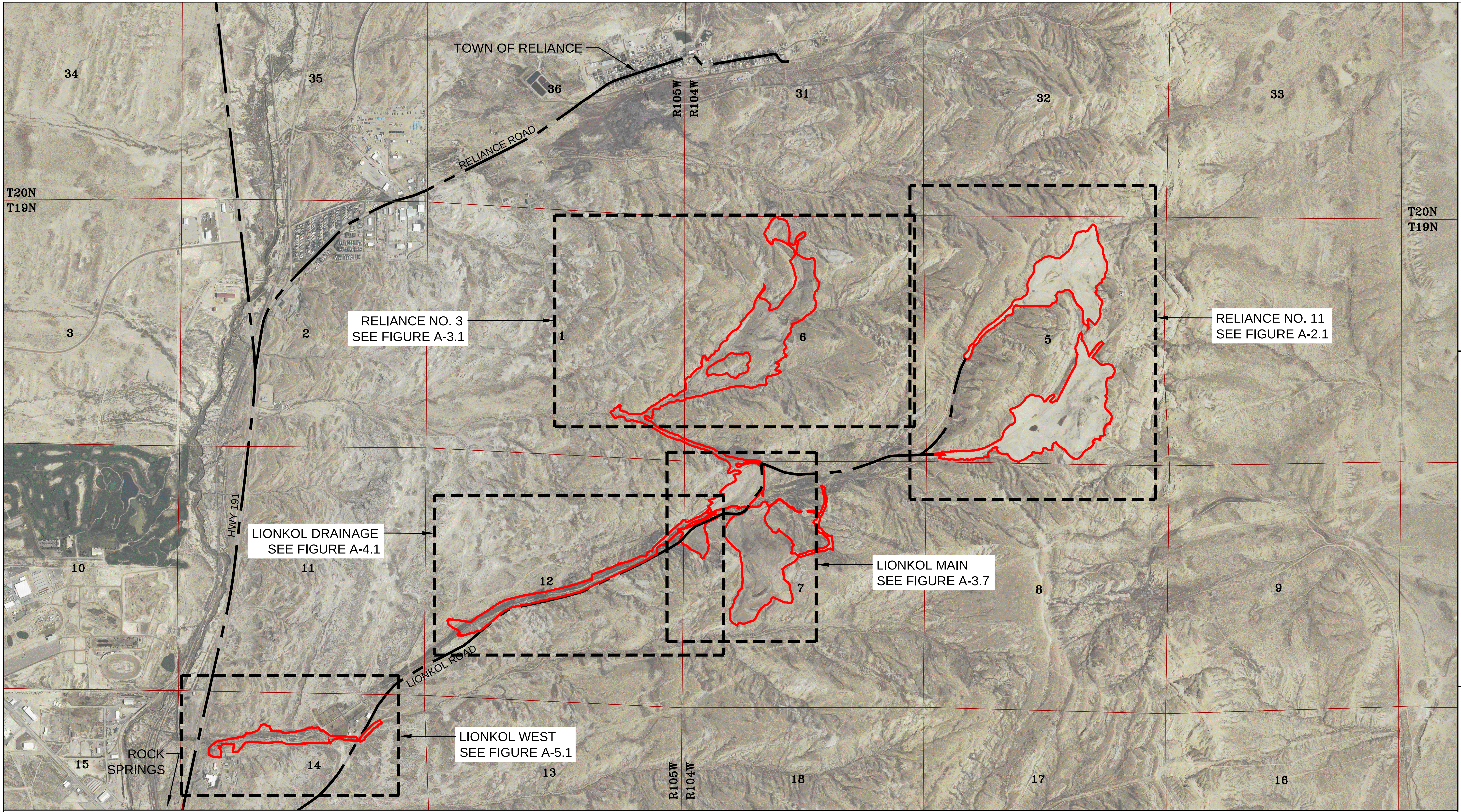

LEGEND

SECTION LINES

ROAD

RECLAMED AREAS

DETAIL SHEET REFERENCE

N

2,000' 0 1,000' 2,000'

1 inch = 2,000 ft

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

LIONKOL PROJECT PHASES DETAIL KEY MAP

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2.0 AML 17H-2B Reliance No. 11 Pits

AML Project 17H-2B, Reliance No. 11 North and South Pits Reclamation Project, reclaimed two separate open pit coal mine areas using a combination of NR and traditional reclamation techniques. This was the second design project completed by BRS utilizing the NR software. The first application of the NR software for mine reclamation in Wyoming was AML Project 16N, Phase 3, the Central Spoils in the West Gas Hills where BRS was also the Project Engineer. In the case of AML 16N, project the application of NR was implemented as a change to an existing construction contract. AML Project 17H-2B was the first Wyoming AML project designed and bid incorporating the NR approach from the beginning of the project.

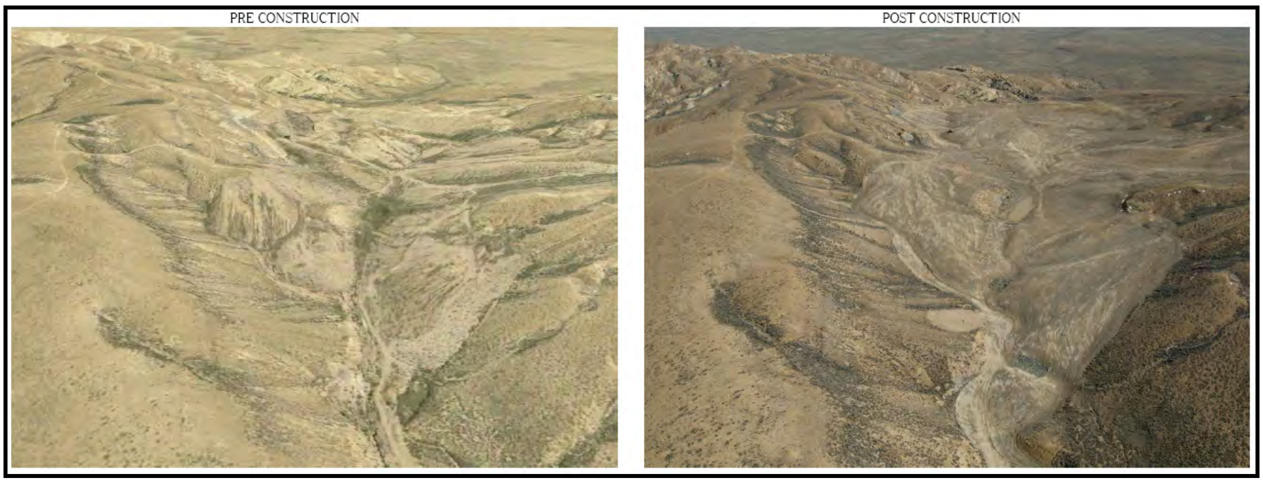


Figure 4: Reliance No. 11 North Before and After Construction

Figure 5: Reliance No. 11 South Before and After Construction

For the AML 16N project, the overall basin sizes were small, and the designs were completed utilizing NR software without extensive manipulation. Carlson software's recommended Shields shear stress channel stability criteria of less than 1.0 psf for the bankfull flow condition and less than 1.5 psf for the flood-prone flow conditions were readily achievable due to the low flow rates from the small basins. For the 17H-2B project design on the Reliance No. 11 North and South

Pit areas, the basins were larger than those encountered on the AML 16N project, and the overall basin gradients and total vertical relief were higher. As a result, the Shields shear stresses could not be kept below Carlson's recommended limits working within the NR software alone. In order to reduce the shear stresses to values within the recommended ranges, the design decision was made to incorporate traditional storm water runoff structures and concepts with the NR channels to decrease flow quantities and rates. Traditional storm water runoff controls utilized in the design included: runoff attenuation impoundments, a traditional flat bottom channel, and riprap erosion control structures as described below. The traditional design features were combined with NR channel and ridge 3D line work in ACAD Land Desktop to create the final design product. Five separate NR projects were completed for the basins shown on Figure A-2.1, Figure A-2.2, and Figure A-2.3, available in Appendix A2.2, Appendix A3.2 and Appendix A3.3 respectively. By incorporating the traditional storm water controls, the design channel Shield shear stresses were completed at or near Carlson's recommended stability criteria. The NR channel hydrologic and physical properties will be discussed in Section 2.2.1.

Figure 6: Reliance No. 11 North Following Revegetation

Four surface water attenuation impoundments were constructed for this project: two at the North Pit and two at the South Pit. In addition to providing flow attenuation within the Reliance No. 11 project area, the impoundments also decreased off-site discharge. This was important since the pre-reclamation site conditions included pits which completely retained all site runoff at both the North and South Pit sites, and it would have been potentially damaging to downstream channel sections to re-introduce these flows into a hydrologic system that they had not been contributing to since the early 1970's. Additionally, at this time, the Lionkol Drainage had not been reclaimed and was experiencing extreme downward erosion. Increasing the contributing acreage within the drainage basin, and the resultant increase in surface water flow during runoff events, would have increased the potential for downstream damage. Thus, retaining flood waters on-site was recommended to minimize off-site degradation. During subsequent phases, the City of Rock Springs expressed an interest in decreasing flows through the downtown area so that they could revise an existing flood plain determination which increased the cost of insurance for Rock Springs businesses. Although this issue was not a factor in determining to retain water on site at the time of the 2B project, it was later found to benefit the City of Rock Springs in their efforts.

Two riprap erosion control drop structures were installed on the North Pit outlet channel to compensate for the excessive vertical differential between spoils in the disturbed mine site and the native outlet channel. For this channel portion, a traditional 12-foot flat bottom channel was constructed with a meandering alignment for a smooth transition into the drop structures. In addition, a riprap grade control structure was installed at the outlet of each of the impoundments to protect the impoundment from failure in the event that a high flow event overtopped the outlet. No revegetation was completed during this phase. The regraded areas were completed with the 17H-2B-II during the fall of 2009. A detailed description of each of the hydrologic design elements follows by area.

2.1 Reliance No. 11 North: Hydrologic Features Summary

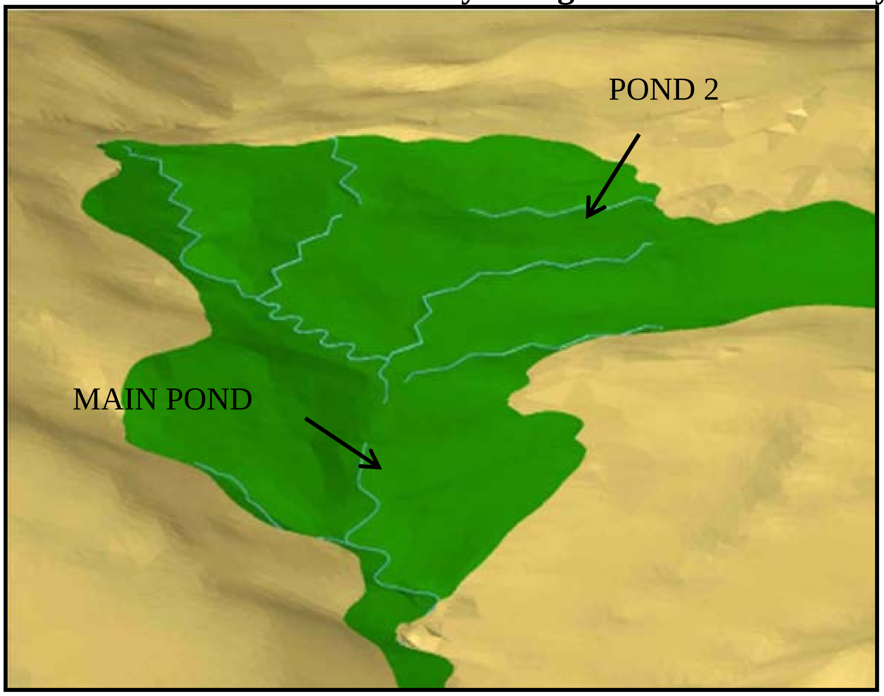


Figure 7: Reliance No. 11 North Design 3-Dimensional Rendering

2.2.1 Reliance No. 11 North: Geomorphic Channels

Five separate NR basins were modeled for the Reliance No. 11 North design as shown on Figure A-2.1. The physical properties of each basin are shown in Tables 2.1 through 2.5 in Appendix B2.2. The total basin area for the North project was 27.5 acres. Total relief in the basin was high, with an average channel relief of 40 feet. This was a contributing factor to the initial high shear stresses modeled for the project area, and resulted in the implementation of additional design controls. The design runoff parameters are shown in Tables 2.6 through 2.10. The design Shields shear stresses for both the bank-full condition, representing the 2-year, 1-hour precipitation event which defines the bottom of the channel for typical annual flows, and the flood-prone condition, which represents the 50-year, 6-hour precipitation event that would be expected to be on the verge of overtopping the channel banks. Through the implementation of flow controls, including the surface water attenuation impoundments, the majority of the channel shear ranges fell below the Carlson software's recommended stability criteria for shear stresses. Those that exceed the values for the maximum shears only do so for very short segments. 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.

2.2.2 Reliance No. 11 North: Surface Water Impoundments

Two surface water impoundments were constructed on the Reliance No. 11 North site as shown on Figure A-2.2 in Appendix A2.2. Both impoundments provide runoff attenuation to downstream reaches, with Pond 1 essentially at zero discharge and the Main Pond providing peak flow attenuation with approximately a 30 minute delay of peak channel discharge.

None of the impoundments constructed on the Reliance No. 11 project required permitting with the Wyoming State Engineer's Office (SEO) based upon guidance from the SEO in a letter dated June 4, 2008. The impoundments were small and existed in closed basins near the head of the drainage, and would have little impact on historical or future water use in the basin.

2.2.3 Reliance No. 11 North: Pond 1

Pond 1 as shown on the as-built drawing in Figure A-2.2 was initially not intended to be constructed in the first design iteration, and instead it was to be drained by the Main Channel. However, due to the basin acreages and high Shields shear stresses, it was decided to construct an impoundment which also had the impact of minimizing earthwork quantities. The design discharges for the impoundments utilized ACAD Land Desktop's hydrology module employing the TR-55 method for estimating discharges. A 100-year, 24-hour storm event was employed for estimation of peak flows and discharge quantities as shown in Table 2.11.

Pond 1 had a pre-reclamation capacity of 0.6 acre-feet. After construction, an additional 0.7 acre-feet of storage was created. Based upon the design discharges, Pond 1 has the capacity to store the volume of two 100-year, 24-hour storm events. This impoundment is unlikely to discharge flows to the North Main Pond, except under unusual and extreme conditions. As a result, this area was not included in the runoff calculations for downstream features.

2.2.4 Reliance No. 11 North: Main Pond

The Main Pond, as shown on Figure A-2.2, utilized an existing low area within the North Pit disturbance. The existing, shallow, grassy depression had negligible capacity. As such, an impoundment structure including a riprap outlet was constructed to increase the storage capacity to 3.1 acre-feet as shown in Table 2.12.

For the Main Pond, a total discharge of 5.7 acre-feet was estimated for the 100-year, 24-hour event; exceeding the 3.1 acre-feet capacity of the pond. Based upon the time of concentration, the downstream channel section would experience its peak flow 30 minutes before the Main Pond would overflow as shown in Table 2.13.

2.2.5 Reliance No. 11 North: Riprap Structures

The United States Army Corps of Engineers (USACE) Steep Slope Riprap Design Method was used to size the riprap for the outlet and drop structures. This method is conservative and over-sizes the rock with multiple safety factors built into the formulas. Design peak discharges were based upon the TR-55 method for estimating discharges utilizing ACAD Land Desktop's hydrology module. A 100-year, 24-hour storm event was employed for estimation of peak flows for the riprap structures.

A riprap outlet structure was constructed at the outlet of both North Pond 1 and North Main Pond as shown in Figure A-2.2. The design discharge area is shown in Table 2.14. Also included in this tabulation are the outlet structures for the impoundments at the Reliance No. 11 South site. All the outlet structures were constructed with Class 4 riprap. The dimensions and quantities of the outlet structures are also shown in Table 2.15 and Table 2.16 in Appendix A2.2.

The vertical differential between the North Main Pond outlet and the downstream natural channel grade was significant, since the North Pond had an elevated base level due to large quantities of mine spoils placed in the flow-line. The cost to fully remove this material and replace it in the pit area would have been excessive. In order to address the large vertical differential, two conventional drop structures were constructed of Class 12 riprap as shown in Table 2.15. Dimensions and quantities of this structure are shown in Table 2.16. Drop Structure 1 reduced the vertical relief in the channel by 10 feet and Drop Structure 2 by another 16 feet.

2.2.6 Reliance No. 11 North: Performance Evaluation

A field inspection of the channels on the Reliance No. 11 North and South Pits was completed in late July and early August 2013. The site was re-vegetated in the fall of 2009, providing four full growing seasons for regrowth to occur. Site re-vegetation was variable, ranging from no vegetation present to small islands of sparse range grass and forbs. The site exists in an arid area, with little to no coversoil material available, and pH and salinity issues in the spoils, all contributing to a difficult area for re-establishment of revegetation. As a result, little attenuation of runoff is occurring due to vegetation. Notwithstanding the relatively poor vegetative cover, the majority of the channels on-site were functioning properly.

The following observations were made of the geomorphic channels:

- All of the geomorphic channels were found to have stable uplands.
- Meandering channels exhibited repetitive phases of cutting and deposition 50 feet long by 6 inches in depth, consistent with natural channel behavior in the area.
- Pilot channels 8 to 10 inches deep were created by focused flows, typically related to adjustment of the channel bed to inconsistencies in the channel grading and/or downstream of confluences with higher combined volumes of flow.
- Moderate armoring and stabilization of the pilot channels with 4-8 inch diameter rock was occurring where spoil materials allowed.
- Vegetation was successfully established in the majority of the armored channels.
- Minimal amounts of coal or other undesirable materials were being exposed and redistributed.

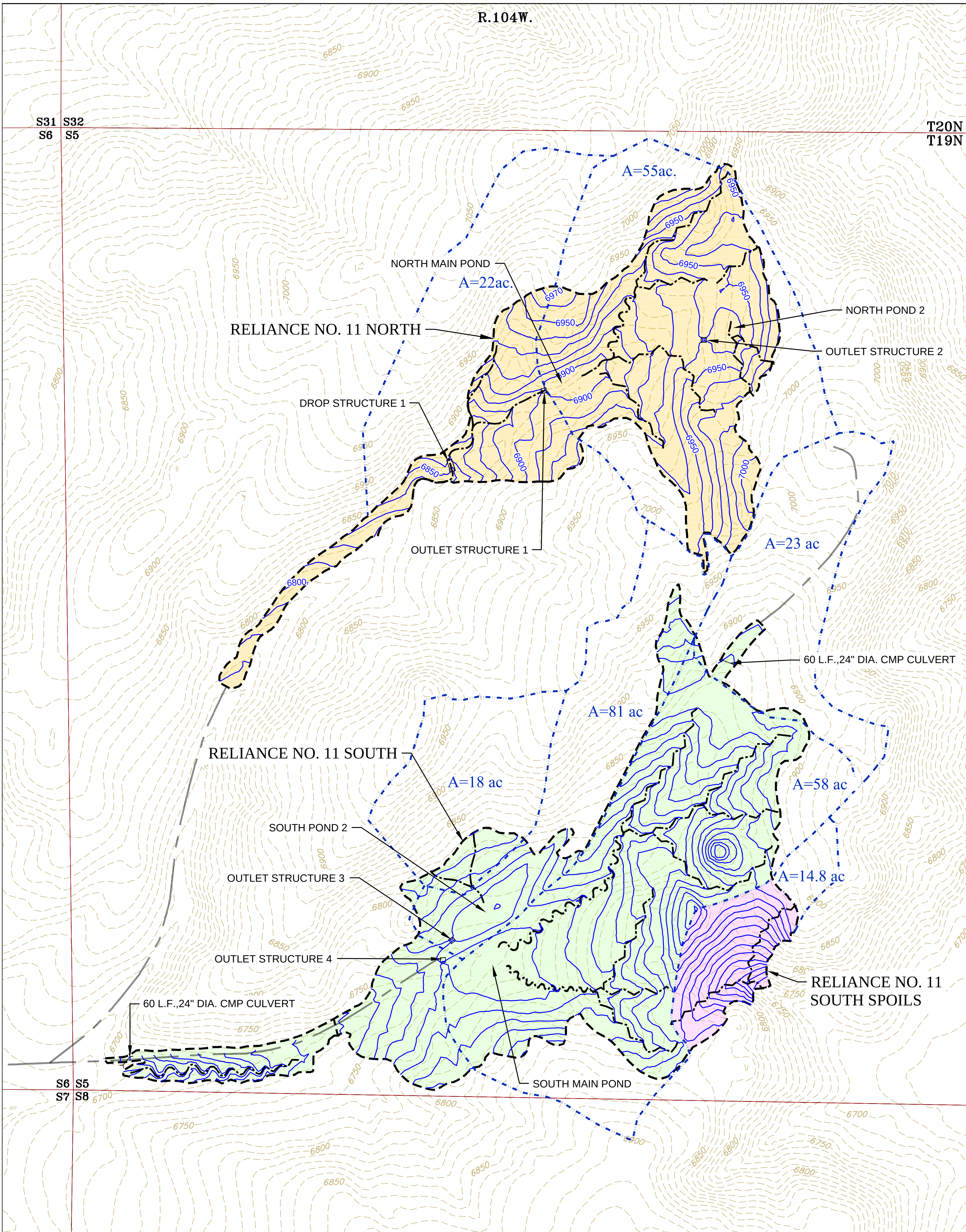
The performance of the geomorphic channels in Reliance No.11 North is consistent with natural channel behavior, which is the goal of the project.

Figure 8: Reliance No. 11 North R1-3: Looking upstream at Properly Performing Channel

A single failure, requiring repair, occurred within the traditional channels located west of the North Main Pond, Traditional Channel Main and Traditional Channel L1 (see as-built drawing in Figure A-2.2 in Appendix A2.2). The Main channel was constructed along the boundary of the reclaimed area following the alignment and grades of a pre-existing drainage beside a spoils pile. Steep channel gradient (>10%) and the 22 acre contributing drainage basin caused failure of the channel, resulting in a 50 feet long by 2 to 2.5 feet deep pilot channel forming upstream of the confluence between the Traditional Channel Main and the Traditional Channel L1, exposing coal and shale. Erosion diminished and ended in an area of deposition 30 feet downstream of the confluence.

Figure 9: Traditional Channel Main: Failure in August 2013, Looking Downstream

Repairs were made to the traditional channels on October 24th, 2013. Wheel rolling the pilot channel with a scraper was performed to restore a widened channel flow-line and provide compaction. In the event that the channel continues to erode following these repairs, future redesign of the drainage as an “A-channel” rather than a traditional channel is the recommended solution. In general, the geomorphic channels designed using NR provided superior performance compared to the traditional channels in Reliance No. 11 North Basins.



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(line)	SECTION LINES	(line)	CONSTRUCTED MEANDER CHANNEL
(line)	ROAD	(line)	CONSTRUCTED "A" CHANNEL
(line)	RECLAMED AREAS	(line)	DRAINAGE BASIN BOUNDARY
6400	EXISTING GROUND CONTOURS C.I.-10'	A= 1.48	DRAINAGE BASIN AREA
6400	ASBUILT CONTOURS C.I.-10'		

500' 0 250' 500'
1 inch = 500 ft

RELIANCE NO. 11 OVERALL MAP

SCALE: 1" = 500' DATE 3/21/14
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APPROVED: HH

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

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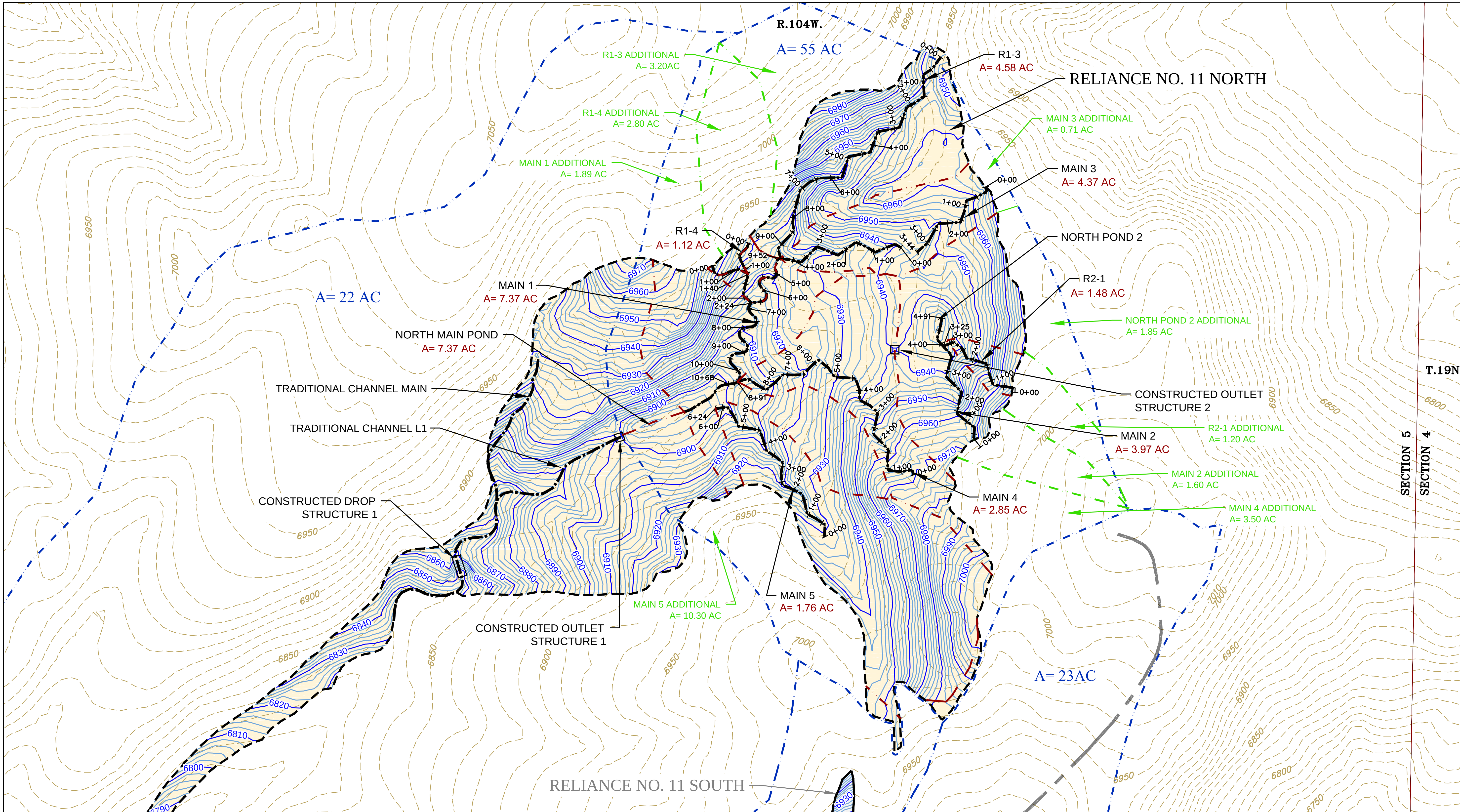

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	SECTION LINES		CONSTRUCTED MEANDER CHANNEL	0+00 0+100	
	ROAD		CONSTRUCTED "A" CHANNEL		CHANNEL STATIONING
	RECLAIMED AREAS		DRAINAGE BASIN BOUNDARY	A=1.48 AC	DRAINAGE BASIN AREA
6400	EXISTING GROUND CONTOURS C.I.-10'		SUB-BASIN BOUNDARY	A=1.48 AC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

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300' 0 150' 300'

1 inch = 300 ft

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

RELIANCE NO. 11 NORTH

DWG. NO. FIGURE A-2.2

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APPROVED: HH
DATE 3/25/14

Tables

Table 2.1 Reliance No. 11 North: Main 1 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	7.37	0.00	411.00	55.00	6,920.24	6,900.00	20.24	-4%	-3%
R1-3	4.58	0.00	831.94	181.69	6,964.64	6,919.45	45.19	-11%	-3%
R1-4	1.12	0.00	233.60	198.76	6,930.93	6,911.54	19.39	-12%	-3%
TOTAL	**13.07**	**0.00**							

Table 2.2 Reliance No. 11 North: Main 2 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 2	3.97	1.60	495.68	196.56	6,966.50	6,925.00	41.50	-18%	-3%
R2-1	1.48	1.20	285.16	192.20	6,983.72	6,934.54	49.19	-20%	-7%
TOTAL	**5.45**	**2.80**							

Table 2.3 Reliance No. 11 North: Main 3 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 3	4.37	0.71	782.52	179.22	6,960.00	6,921.59	38.41	-9%	-6%
TOTAL	**4.37**	**0.71**							

Table 2.4 Reliance No. 11 North: Main 4 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 4	2.85	3.50	776.78	272.37	6,970.15	6,901.0	69.15	-8%	-6%
TOTAL	**2.85**	**3.50**							

Table 2.5 Reliance No. 11 North: Main 5 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 5	1.76	10.30	554.83	314.84	6,932.0	6,897.0	35.00	-6%	-8%
TOTAL	**1.76**	**10.30**							

Table 2.6 Reliance No. 11 North: Main 1 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)
Main 1	6.13 to 6.93	0.38 to 0.43	0.69 to 0.76	12.30	11.59 to	1.07 to 1.21	1.16 to 1.78	41.01

Table 2.7 Reliance No. 11 North: Main 2 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)
Main 2	1.23 to 2.80	0.12 to 0.22	0.40 to 1.29	2.87	2.84 to 5.88	0.30 to 0.65	0.64 to 1.86	9.56
R2-1	1.07 to 1.59	0.11 to 0.16	0.71 to 1.43	1.14	2.47 to 3.68	0.28 to 0.42	1.01 to 2.05	3.79

Table 2.8 Reliance No. 11 North: Main 3 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)
Main 3	0.04 to 2.53	0.00 to 0.20	0.01 to 0.64	2.35	0.10 to 5.30	0.01 to 0.60	0.02 to 0.92	7.84
R1-3	0.36 to 2.59	0.04 to 0.21	0.14 to 0.45	2.47	0.81 to 5.43	0.08 to 0.56	0.21 to 0.65	8.22

Table 2.9 Reliance No. 11 North: Main 4 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)
Main 4	0.17 to 2.92	0.02 to 0.23	0.10 to 1.26	3.15	0.39 to 6.13	0.04 to 0.70	0.14 to 1.81	10.50
R1-4	0.34 to 1.27	0.04 to 0.10	0.16 to 0.38	0.61	0.71 to 2.67	0.07 to 0.29	0.25 to 0.54	2.02

Table 2.10 Reliance No. 11 North: Main 5 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)
Main 5	0.38 to	0.04 to	0.10 to 1.15	5.98	0.84 to 8.44	0.09 to 0.96	0.15 to 1.65	19.95
			Stability Criteria	**<1.0**			**Stability Criteria**	**<1.5**

Table 2.11 Reliance No. 11 North: Pond Design Discharges

	Surface Area	Peak Flow (cfs)	Discharge (cf)	Discharge (cy)	Discharge (ac-ft)
North Area	56.0	85.6	248697	9211	5.7

Notes:

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

Table 2.12 Reliance No. 11 North: Main Pond Design Storage Capacity

Start elev	End elev	Volume (cf)	Volume (cy)	Volume (ac-ft)
6891	6892	532	20	0.0
6892	6893	2358	87	0.1
6893	6894	5201	193	0.1
6894	6895	8043	298	0.2
6895	6896	12926	479	0.3
6896	6897	17809	660	0.4
6897	6898	23506	871	0.5
6898	6899	29203	1082	0.7
6899	6900	35881	1329	0.8
	TOTAL	**134926**	**4997**	**3.1**

Additional discharge passes down drainage with total attenuation time = 30 minutes

Table 2.13 Reliance No. 11 North: Main Pond Routing Summary

Pond	Peak	Peak	Volume	Storage	Peak flow	Volume
MAIN	85.6	732	5.7	3.1	13.7	2.6

Routed Peak Time (min)	Receiving Feature	Receiving Peak Time (min)	Total Attenuation (min)
756	CHANNEL	726	30

Table 2.14 Reliance No. 11 North: 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 Bw of V-ditches is 2' due to construction practices

**Multiplied by C=1.25

Table 2.15 Reliance No. 11 North: Drop Structures Summary

Drop Structure ID	Peak Flow IN (cfs)	Bottom Width (feet)*	Length (feet)	Grade (ft/ft)	Depth (feet)	Apron Length (feet)	Riprap Class (inch)	Riprap Depth (inch)	Riprap Quantity (cy)*
DROP 1	56	12	40	0.25	4	12	12	24	235
DROP 2	30	12	100	0.16	2	12	12	24	455

Table 2.16 Reliance No. 11: Outlet Structures Summary

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

*10% factor added

2.2 Reliance No. 11 South: Hydrologic Features Summary

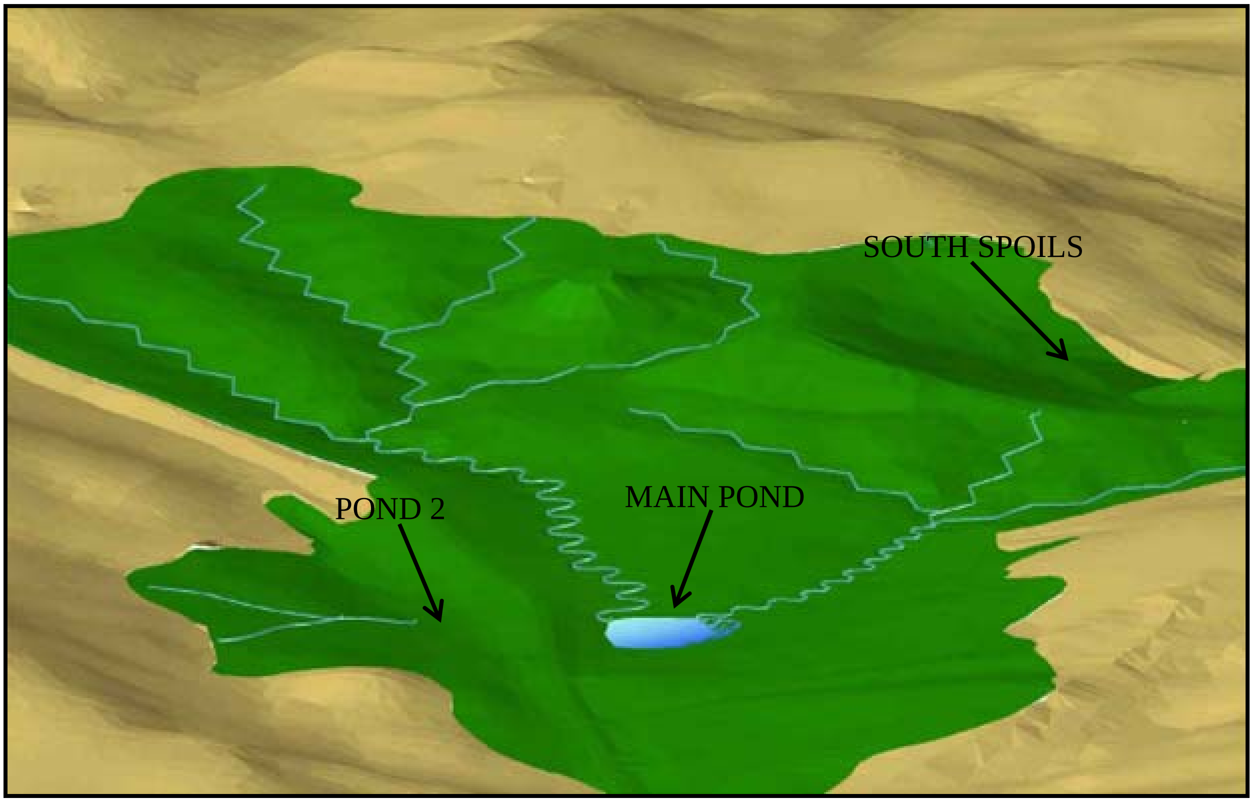


Figure 10: Reliance No. 11 South Design 3-Dimensional Rendering

2.3.1 Reliance No. 11 South: Geomorphic Channels

Two separate NR basins were modeled for the Reliance No. 11 South design as shown on Figure A-2.3 in Appendix A2.3. The first basin, which drains to the South Main Pond, was constructed as two separate basins each draining into the pond, although the modeling was completed with the L2 channel and its tributaries connecting to the Main channel. The South Spoils was modeled separately because the channels flow off-site independently of the main channel (see Figure A-2.4 in Appendix A2.3). The South Spoils is discussed below in Section 2.3.6. The physical properties of the South Main basin are shown in Tables 2.17 in Appendix B2.3. The total basin area for the South project was 80.4 acres. Total relief in the south basin was high, with an average channel relief of 66 feet. This was a contributing factor to the initial high shear stresses modeled for the project area. As a result, retention of off-site drainage areas were contained in Pond 2, a pre-existing feature created by spoils placement which blocked the drainage into the head of the main channel. The design runoff parameters are shown in Table 2.18, providing the design Shields shear stresses for both the bank-full and the flood-prone condition. Through the majority of the channel, shear ranges fall below the Carlson software's recommended stability criteria for shear. Notably, the channels that exceed the recommended values for the maximum shears are the Main Channel and L-1, a principal tributary. These drainages are characterized by the highest acreages and corresponding peak discharges. 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.

2.3.2 Reliance No. 11 South: Surface Water Impoundments

Two surface water impoundments were constructed on the Reliance No. 11 South site as shown on Figure A-2.3 in Appendix A2.3, and one existing off site impoundment was retained to diminish the amount of runoff impacting the main channel. These impoundments provide runoff attenuation to downstream reaches, with each of the three impoundments having a capacity roughly double that of a 100-year, 24-hour storm event, essentially allowing no off-site discharge.

The impoundments constructed on the Reliance No. 11 project did not require a permit with the State Engineer's Office (SEO) based upon guidance from the SEO in a letter dated June 4, 2008. The impoundments are located in closed basins near the head of the drainage and as such would have little impact on historical or future water use in the basin.

2.3.3 Reliance No. 11 South: Existing Off Site Impoundment

The existing off-site impoundment as shown on the as-built drawing Figure A-2.3 was initially intended to be drained by the main channel into the south main pond. However, due to the high Shields shear stresses calculated for the main channel as shown in Table 2.18, it was decided to keep the impoundment in order to minimize impacts to the main channel stability. The design discharges for the impoundments utilized ACAD Land Desktop's hydrology module employing the TR-55 method for estimating discharges. A 100-year, 24-hour storm event was used to estimate the peak flows and discharge quantities as shown in Table 2.19.

The existing off-site impoundment had a pre-reclamation capacity of 6.3 acre-feet. Meanwhile the discharges resulting from a 100-year, 24-hour storm event were calculated to be 2.7 acre-feet. As such, the impoundment has over twice the capacity of the 100-year storm event and was not included in the runoff calculations for downstream features.

2.3.4 Reliance No. 11 South: Main Pond

The South Main Pond as shown on the as-built drawing in Figure A-2.3 is located in the vicinity of the Reliance No. 11 South Pit. As discussed previously, it would have been potentially damaging to downstream channel sections to backfill the pit and re-introduce runoff from the Reliance No. 11 Pits to the degraded Lionkol Drainage downstream of the site. In addition, not providing flow-through minimized the backfill requirements, reducing the overall project quantities and costs. The South Main Pond was located so that no additional runoff would occur downstream above that which has been historically discharged since the mine pits were constructed in the early 1970's. The design discharges for the impoundments utilized ACAD Land Desktop's hydrology module employing the TR-55 method for estimating discharges. A 100-year, 24-hour storm event was used to estimate the peak flows and discharge quantities as shown in Table 2.20.

The South Main Pond has a capacity of 12.8 acre feet. Based upon the design discharges, this impoundment has the capacity to store more than twice the volume of the 100-year, 24-hour storm event, which indicates that only under the most unusual circumstances will this impoundment ever discharge flows off site. As a result, this area was not included in the runoff calculations for the Phase III & IV Lionkol Drainage projects downstream. A riprap outlet structure was constructed at the pond outlet to protect the outlet in the unlikely event that the impoundment does overflow. See Tables 2.15 and 2.16 for information on the riprap structures.

2.3.5 Reliance No. 11 South: Pond 2

The Main Pond and Pond 2 areas were originally a single pond and were part of the main pit centered roughly where the Main Pond is now located (see Figure A-2.3). The American Tower Corporation had an old access road for one of their cellular towers through the pit, and it was difficult to access during times when water was present in the pit. As a result, the road was built up on a fill as shown on the as-built drawing Figure A-2.3, and drainage was diverted to two separate ponds, Main Pond and Pond 2. As discussed with the South Main Pond previously, it would be potentially damaging to downstream channel sections to backfill the pit and re-introduce runoff from area to the degraded Lionkol Drainage downstream of the site. As a result, impoundments were constructed where the original pit was located so that no additional runoff would occur downstream above the amounts which had been discharged since the mine pits were constructed. The design discharges for the impoundments utilized ACAD Land Desktop's hydrology module employing the TR-55 method for estimating discharges. A 100-year, 24-hour storm event was employed for estimation of peak flows and discharge quantities as shown in Table 2.21.

The South Pond 2 has a final capacity of 8.6 acre feet. Based upon the design discharges, this impoundment has the capacity to store the volume of two 100 year 24 hour storm events, which indicates that only under the most unusual circumstances will this impoundment ever discharge flows off site. As a result, this area was not included in the runoff calculations for the Phase III&IV Lionkol Drainage projects downstream. A riprap outlet structure was constructed on the pond outlet to protect the outlet in the unlikely event that the impoundment does overflow. See Tables 2.14 and 2.15 above for information on the riprap outlet structures.

2.3.6 Reliance No. 11 South: South Spoils Geomorphic Channels

The South Spoils was an area where a large quantity of mine waste was dozed over the edge of a steep natural escarpment. This created an over-steepened fill slope that covered a steep native drainage primarily developed on exposed bedrock. The earthworks design proposed to excavate this area to approximate pre-mine topographic contours. In practice, only portions of the design were constructed to grade as native bedrock began to be exposed prior to meeting the design grades. As a result, the constructed surface reflects the design surface with adjustments for exposed bedrock. In addition, off road use has all but obliterated any sign of the design channels. However, due to the resistant nature of the bedrock materials exposed by the excavation, little erosion is occurring on the site and it is anticipated that the natural forces of wind and water will sculpt the area to a natural surface with time. As the design surface was not accurately constructed but rather approximated due to bedrock contours, the NR design criteria in the following paragraph is presented for information only. As such, in this area the design provides only a loose framework for long term evaluation of the existing surface.

The physical properties of the South Spoils basin are shown in Table 2.22 in Appendix A2.2. The total basin area for the South Spoils area is 12.4 acres. Total relief in the south basin is very high and steep, with an average channel relief of 108 feet and grades in excess of 8%. The design runoff parameters are shown in Table 2.23. Maximum Shields shear stresses well in excess of the stability criteria are shown on the runoff parameters tabulation. However, it was anticipated that this area would be excavated to a native bedrock surface, and as such would be stable with steeper gradients than are permissible on loose, unconsolidated spoils and backfill materials. As a result, no excessive erosion has been observed in this area.

Figure 11: Reliance No. 11 South Site Incorporation of Native Formations into Reclaimed Surface

2.3.7 Reliance No. 11 South: Performance Evaluation

A field inspection of the channels on the Reliance No. 11 North and South Pits was completed in late July and early August 2013. The site was re-vegetated in the fall of 2009, providing four full growing seasons for re-vegetation to occur. Similar to the northern portion of the Reliance No. 11 reclamation area, the southern channels were observed to be generally stable in the uplands with islands of weak to moderately sparse range grass and forbs vegetation (see Section 2.2.6 for geomorphic channel performance summary).

Geomorphic channels within the South Spoils area were found to have been damaged by vehicles, as they had been used as roadways following completion of reclamation. However, the channels were still performing well. Natural bedding of bedrock was observed to be anchoring the channel flow-lines and no unnatural level of erosion was observed to be occurring at the time of inventory, despite the post-reclamation damage to the channels by off-road vehicles.

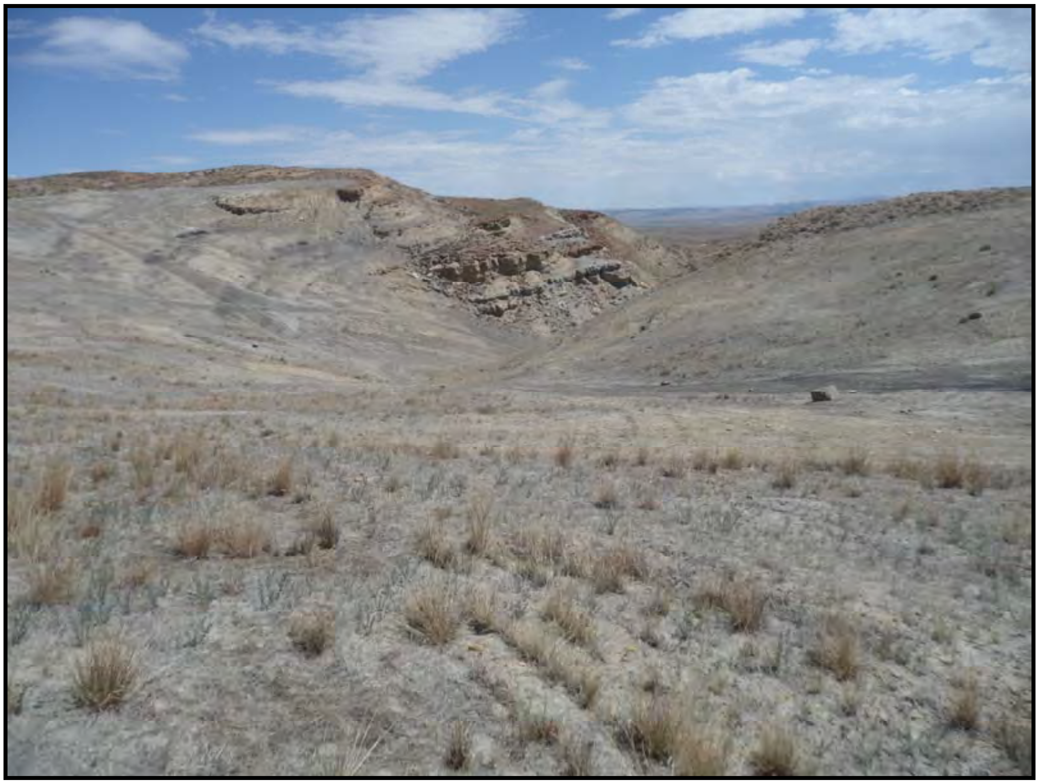
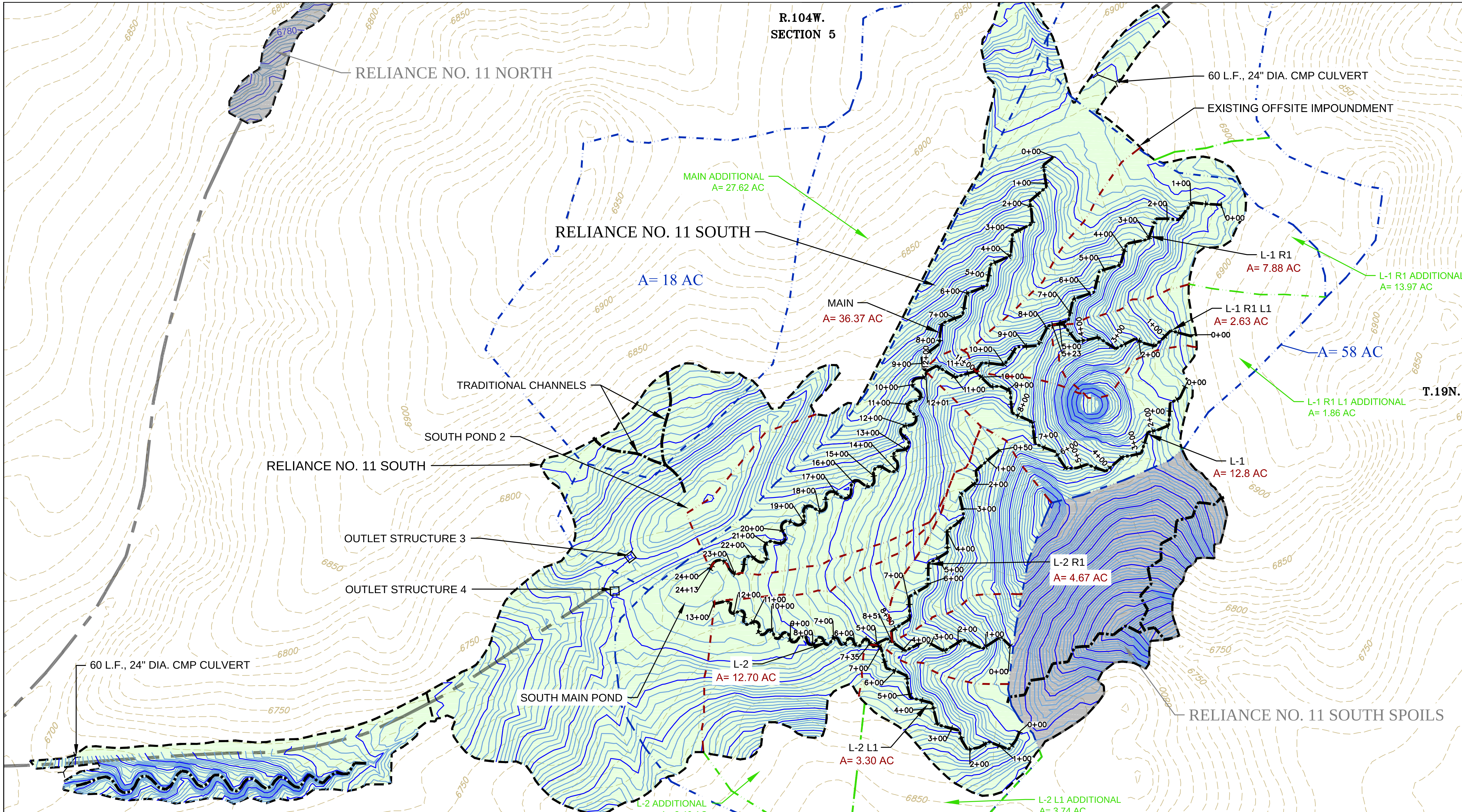


Figure 12: Reliance No. 11 South: South Spoils. Looking Downstream into Main-L1

The most active channel pilot formation in the area occurred within a 20 foot channel segment within the South Main geomorphic channel, immediately upstream of the Main-L1R1 confluence (see Figures A-2.3 and A-2.4 in Appendix A2.3 for as-built drawings). Following multiple unseasonably heavy rain events during October 2013, the site was revisited and the original 18 inch deep pilot channel had repaired itself. However, a sub-ridge failure upstream of the same confluence on L1R1 drainage had developed and was cutting 10 to 18 inches deep along a 150 foot long segment of the channel. A repair of the L1R1 channel segment was performed on October 29th, 2013 by widening the flow-line and reinforcing the channel banks using a dozer. This repair is expected to decrease the linear flow rate within the channel and reduce erosion to an acceptable level. No other repairs were deemed necessary on the site.

The traditionally designed channels and slope draining into South Pond 2 did not perform as well as the slopes containing geomorphic design elements. The traditional channels were moderately vegetated with brush and weakly incised with pilot channels less than 6 inches deep. However, weak to moderate rilling was observed across the surface of the slope indicating some runoff flowing outside of the designed channels. Low material quality, high gradient (> 10%) and low channel density over this traditional reclamation basin are the primary factors for the water flow outside of the designed channels. Rilling was overprinted by vegetation and had no fresh sediment movement. As such, the re-vegetation is sufficient to retain the stability of the slope and a more natural drainage pattern is developing naturally. No repairs were determined to be necessary.



LEGEND

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

300' 0 150' 300'
1 inch = 300 ft

BRS ENGINEERING

NO. | REVISION | DATE | BY | ISSUED FOR

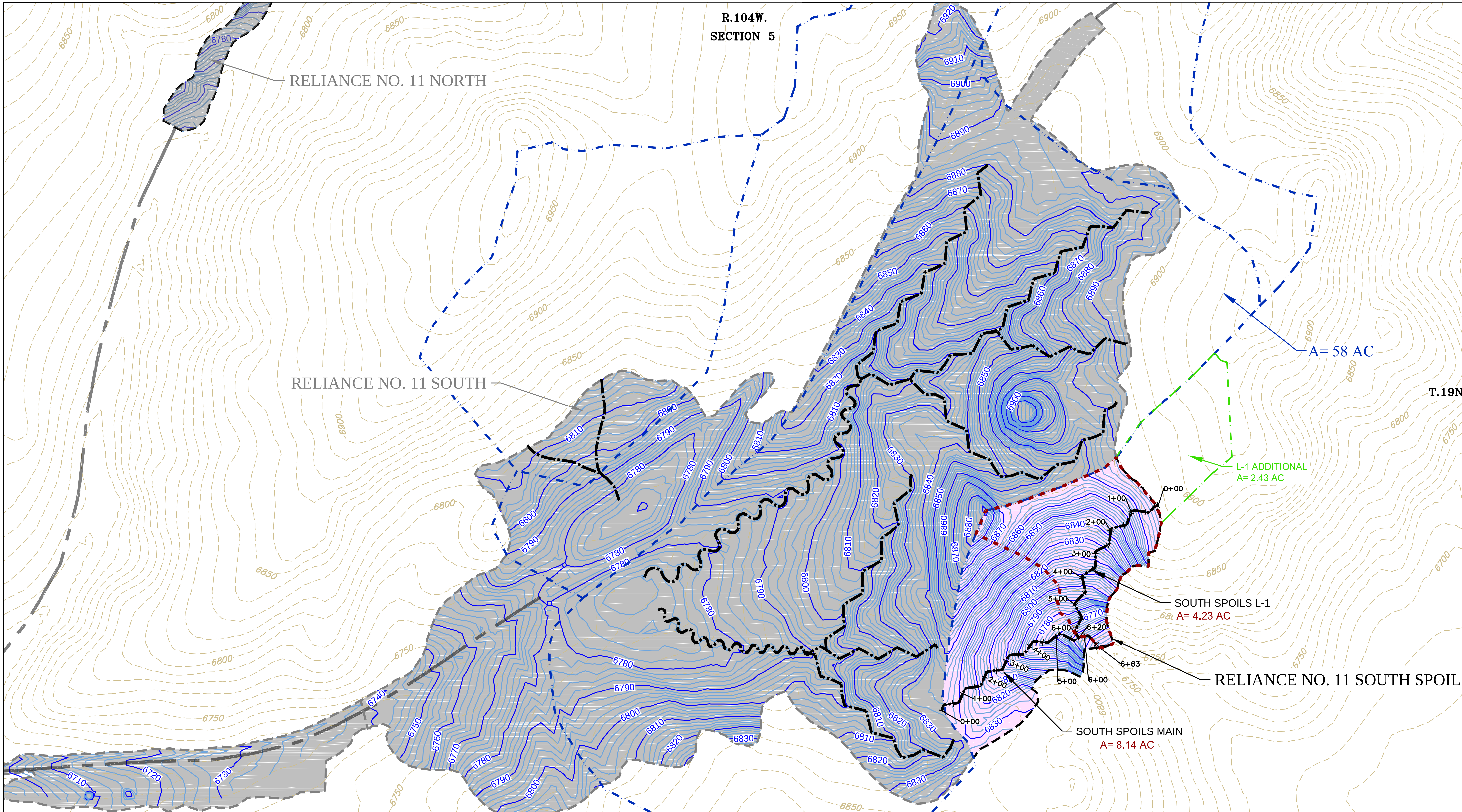
LAST PLOT DATE: 3/21/14
CAD FILENAME: DATA/17H/NATURAL REGRADE PROJECTS/FIG A-2.3 Reliance 11 South.dwg

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

RELIANCE NO. 11 SOUTH

SCALE: 1" = 300'
DRAWN BY: CDS
CHECKED: HH
APPROVED: HH
DATE 3/21/14

DWG. NO. FIGURE A-2.3
REV.



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	
6400 EXISTING GROUND CONTOURS C.I.-10'		SUB-BASIN BOUNDARY	A=1.48 AC	CONSTRUCTED SUB-BASIN AREA	
6400 ASBUILT CONTOURS C.I.-2'		CONSTRUCTED SUB-BASIN BOUNDARY			

300' 0 150' 300'

1 inch = 300 ft

NO.	REVISION DATE:	DATE	BY	ISSUED FOR

LAST PLOT DATE: 3/25/14

CAD FILENAME: NATURAL REGRADE PROJECTS/FIG A-2.4 Reliance 11 South Spoils.dwg

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

RELIANCE NO. 11 SOUTH SPOILS

REV.

DWG. NO. FIGURE A-2.4

SCALE: 1" = 300'
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