Application of LIDAR Imagery in AML Reclamation: Case Example – Design of an AMD Passive Treatment System at the Rock Island No. 7 Airshaft, Oklahoma[1]

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Abstract: Mine pool discharges are currently a major concern for State and Federal environmental protection agencies. Application of passive acid mine drainage (AMD) treatment technologies are one possible solution for long-term remediation of this developing water quality problem. However, in many cases these discharges occur in low-lying floodplain areas that have a small topographic relief. This presents two problems for treatment facility design. First, there may be limited space for construction of the treatment cells. Second, due to the low topographic relief, there may be limited hydraulic head available to "power" the treatment system. Design of these sites requires detailed topographic mapping. Either aerial photographic- or LIDAR-based digital mapping may be employed for this design activity. This paper will use a case example to demonstrate the use of LIDAR imagery in the design of an AMD passive treatment system. The site, located near Hartshorne, Oklahoma, is discharging AMD which up wells from an abandoned airshaft of the Rock Island Coal Co. No. 7 Mine. Support for the LIDAR demonstration was provided by the Office of Surface Mining (OSM), Technical Innovation and Professional Services (TIPS) program.

Discussed in this paper will be the conversion of the raw LIDAR data to digital topographic data useful in GIS and CAD applications, the field verification of this digital data using real-time kinematics (RTK) GPS survey instrumentation, and a presentation of an example CAD-based design of a passive treatment system.

Additional Key Words: GIS, CAD, RTK, passive treatment, AMD

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Background

Problem: Acid mine drainage (AMD) discharging from several mine pools is impacting aquatic life in tributaries of Gaines Creek and in an arm of the Eufalla Reservoir in Pittsburg and Latimer Counties, Oklahoma. The AMD is associated with underground mining of the Hartshorne Coal Bed between about 1900 and the mid-1930's. Figure 1 shows the location of the problem area. The coal deposit mined is in the eastern half of

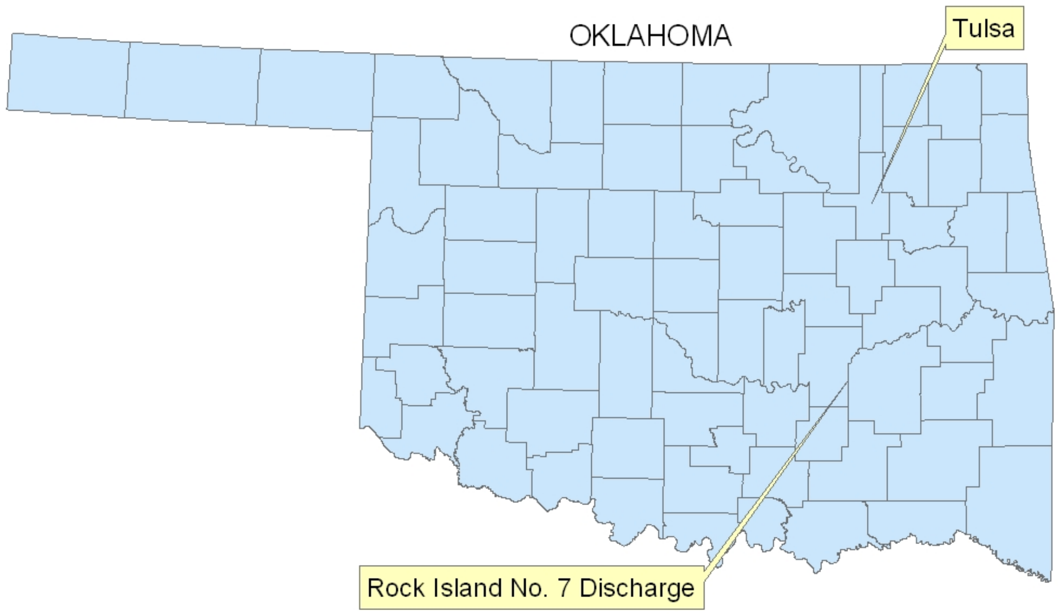
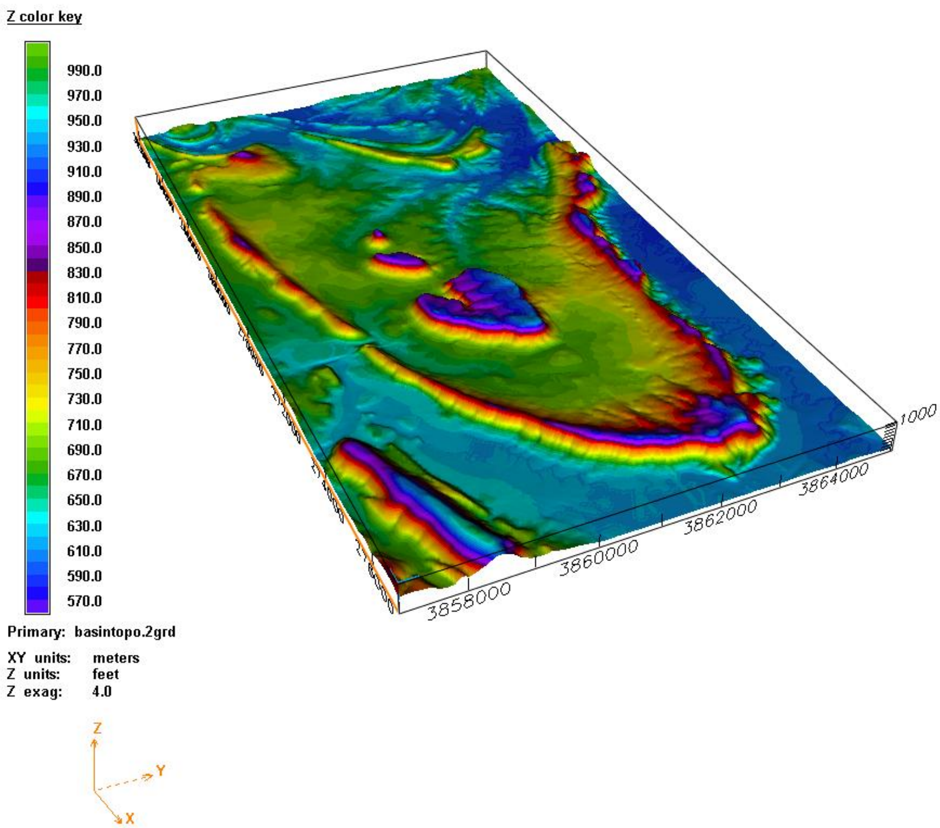


Figure 1. – Rock Island No. 7 Discharge is located immediately west of Hartshorne in East Central Oklahoma.

an elongated structural basin, the Hartshorne Coal Field. Modeling using Dynamic Graphics, Inc.'s (DGI) *earthVision* software was employed to evaluate the hydrogeologic setting of these discharges. DGI *earthVision* is one of OSM's TIPS program software suite. Figure 2 shows a 3-D topographic model of the project area based on a conventional digital elevation model (DEM). A contour plot of the base of the Hartshorne seam (Figure 3) and a geologic cross-section (Figure 4) illustrate the structural geology of the study area.

Solution: The current plan is to evaluate the use of passive treatment to remediate the Hartshorne basin discharges. The Oklahoma Conservation Commission (OCC), Oklahoma City, Oklahoma is heading up this effort with some assistance from the OSM Mid-Continental Regional Office (MCR) in Alton, Illinois. Wherever possible, passive AMD treatment systems (Behum and others, 2004; Hedin and others, 1994) will be constructed using OSM's Clean

Streams Initiative and other Federal funding mechanisms. This paper will describe how the use of LIDAR data will be applied to the development of treatment plans for AMD associated with discharges from underground coal mine pools by using a case example site, the remediation of an AMD discharge from the Rock Island No. 7 Airshaft.

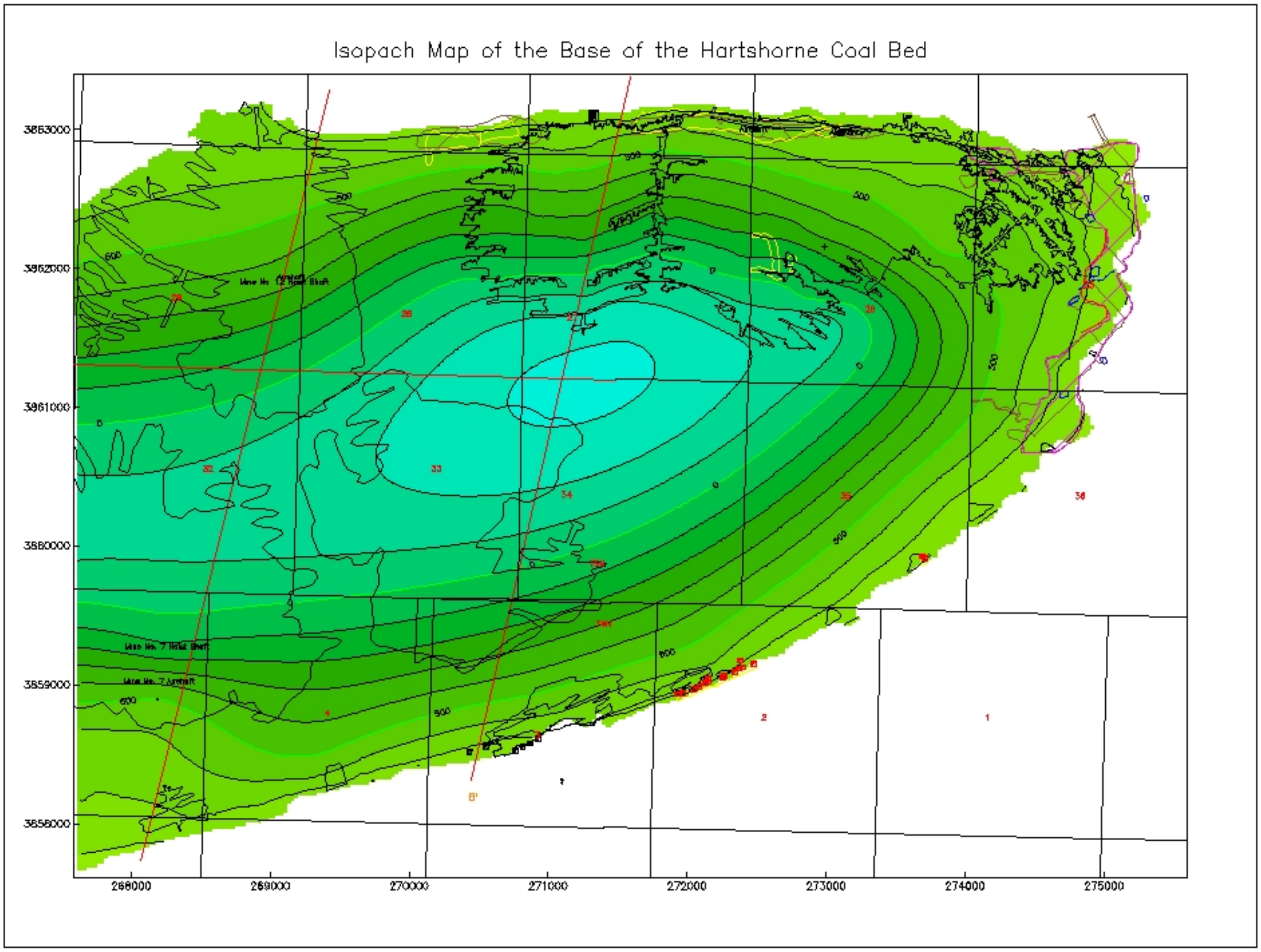


Model created by P. Behum using *earthVision*, Nov. 2004; vertical exaggeration = 4X; z = ft M.S.L.

Figure 2. – Perspective View of the Topographic Features of the Hartshorne Basin.

<u>Digital Terrain Mapping – Selecting LIDAR</u>: The traditional method for digital terrain model (DTM) development is thorough either the procurement of aerial photographic-based mapping or the use of conventional 7.5 minute DTM's (Figures 2 and 5). The dense cover of Eastern Red Cedar trees over much of the project site created conditions where traditional air photography would have to be accompanied by labor-intensive ground surveys to assure accuracy in the low-relief terrain. While 7.5 minute DTM's are readily available for the area, this digital topographic data is too coarse (10- to 20-foot contour interval) for use in treatment design. The Hartshorne area discharges occur near in the center of the basin which has a few erosional remnant hills, but otherwise has a low topographic relief (Figures 2 and 5). As a consequence there is limited

available hydraulic head for use to "power" the required cascade of repetitive, passive treatment cells.



Model created by P. Behum using *earthVision 7.5*, Nov. 2004, state plane coordinating system, Oklahoma south, NAD27.

Figure 3. – Isopach Map of the Base of the Hartshorne Coal bed. Note: the Outline of Abandoned Underground mines

z = feet M.S.L.

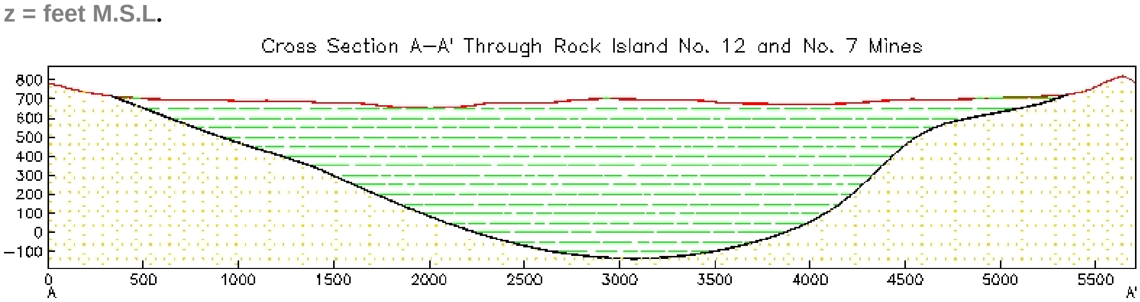
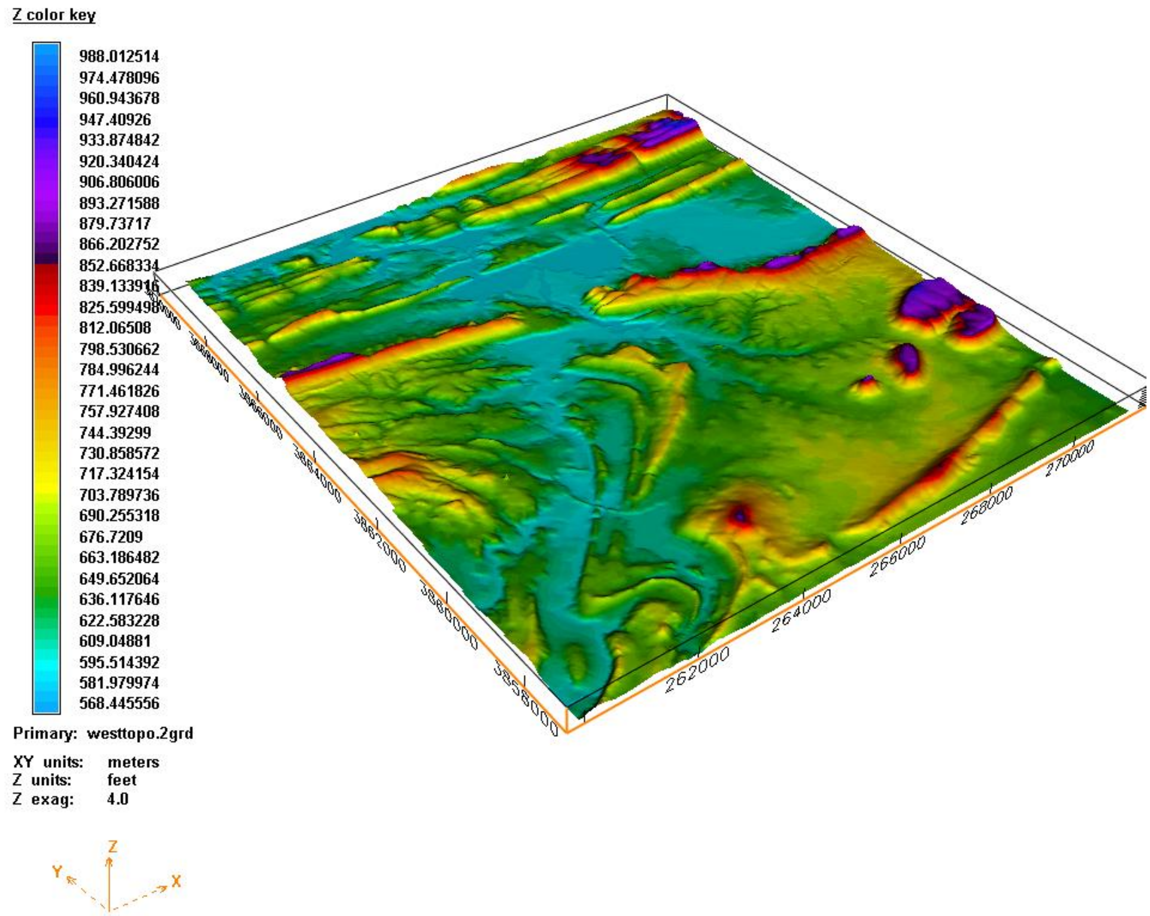


Figure 4. – Cross-Section A – A' of the Base of the Hartshorne Coal bed.



Model created by P. Behum using *earthVision 7.5*, Nov. 2004; vertical exaggeration = 4X; z = ft M.S.L.

Figure 5. – Topographic Model of the Site Area created from Conventional 7.5' DEM Data.

<u>LIDAR Technology</u>: Light detection and ranging (LIDAR) is a technology that emits pulses of laser light toward a target. The light is changed by the target and is received by the LIDAR instrument and analyzes the changes in reflected light. LIDAR topographic mapping uses this process to map the earth terrain with a high degree of accuracy and minimal ground control survey.

For topographic mapping applications, the LIDAR laser scanner is mounted photogrammetrically on the underside of an airplane. When combined with an Airborne GPS unit and an Inertial Measuring Unit, the LIDAR instrument calculates the terrain and land cover surfaces. For high accuracy mapping, the LIDAR system requires a surveyed ground reference location; established in the project area for correlation of both horizontal and vertical control. However, ground control points may be further apart than traditional photogrammetric mapping systems. In addition, LIDAR scanning can occur day or night, as long as clear sky conditions exist between the aircraft and the ground.

Modern LIDAR systems record up to 5 returns per pulse; providing the ability to map not only the actual ground elevation, but also surfaces above the earth such as tree canopy, understory, and even roof tops in urban areas. LIDAR systems may also be used to identify surface characteristics such as concrete, asphalt and snow cover in addition to elevation data. This is because they capture intensity reflectance data in addition to distance data. Reflectance values vary depending on the type of surface encountered and are termed "LIDAR intensity." Post-processing of this data produces an accurately geo-referenced raster file, which is orthometric and looks somewhat like a USGS orthophoto. These images are useful for many land management applications once correlated to a minimal number of ground control survey points.

Current vendors of LIDAR technology claim that it offers significant advantages over conventional airborne photogrammetry. Reported advantages include: the opportunity to collect terrain data in steep slopes, shadowed areas, and inaccessible areas such as mud flats. Other claims include the ability to conduct mapping during all seasons, regardless of leaf cover on trees, with a high degree of accuracy and the ability to map tree canopy height, and understory height at the same time as bare ground mapping. Applications are being established for forestry assessment of canopy attributes, and research continues for evaluation of crown diameter, canopy closure, and forest biometrics. LIDAR data cannot be acquired in foggy or rainy conditions as water vapor and droplets distort the signal.

Application of LIDAR to the Rock Island No. 7 Project

LIDAR data is being used to generate 1-foot contour interval topographic maps for the northern limb of the basin floor (Gowen Mine 40, Jeffrey's Field and GCI discharges; Flight Lines 1 and 2) and will provide data for treatment design for two discharges emanating from one large mine pool. A second pool exists along the southern limb where three additional discharges are located (McHugh Borehole, Paul Madden and the Rock Island Mine 7 discharges; see Figures 6 and 7). LIDAR data was used for the first passive treatment system in the Hartshorne basin which included treatment of several small, but highly acidic and metal-laden discharge from the Rock Island Mine 7 airshaft immediately east of the town of Hartshorne, Oklahoma (Figures 6, 7 and 8). This project, also known as the "Whitlock/Jones 145 CSI Project", was developed though the conceptual design phase as a joint project of the OCC and OSM. A contract has been negotiated between OCC and Burns and McDonnell Engineers and Associates, of Kansas City, Missouri for the final design of this remediation effort. This paper describes some of the results of conceptual design developed by OCC and OSM but does not reflect the final design developed by Burns and McDonnell.

<u>Whitlock/Jones 145 CSI Project Site Conditions</u>: The former Rock Island Coal Mining Co. Mine 7 is located immediately east of Hartshorne, OK (Figure 6) and was one of a series of mines

operated by the company during the early part of the 20th century (Figure 7). The No. 7 mine was abandoned in the 1930's and utilized three shaft entries and two parallel slope entries access the abandoned underground workings (Figure 7). An AMD discharge, ranging from the 19 to 76 L/min (5 to 20 GPM) of highly mineral-laden water discharges from a 55-m (180-ft) deep airshaft (Figure 8). Between 1999 and 2003 OCC and the OSM-MCR have collected water samples and measured the flow of the acidic discharge (Table 1 and Figure 8).

Table 1. Design Parameters: Untreated AMD Quality and Contaminant Load for the Rock Island Mine 7 Discharge, Oklahoma.*

Parameter	Range	Median	Units	Comments
pH	4.79 to 5.54	5.4	S.U.	25 measurements
Eh (est.)		100	mv	7 measurements
Conductivity		11,445	uS	24 measurements
DO		0.37	mg/L	23 measurements, mean = 0.45 mg/L
Dissolved Fe		770	mg/L	27 analyses, mean = 869 mg/L
Dissolved Al		0.25	mg/L	23 analyses, mean = 0.54 mg/L
Dissolved Mn		17.4	mg/L	27 analyses, mean = 20.8 mg/L
Dissolved Ni		0.025	mg/L	13 analyses, mean = 0.24 mg/L
Dissolved Zinc		0.089	mg/L	12 analyses, mean = 0.055 mg/L
T. Acidity		1,330	mg/L	14 analyses, calculated = 1,747 mg/L (8 tests)
T. Alkalinity		110	mg/L	23 analyses, mean = 114 mg/L
Calcium		318	mg/L	12 analyses, mean = 313 mg/L
Magnesium		230	mg/L	10 analyses, mean = 244 mg/L
Sulfate		7,202	mg/L	21 analyses, mean = 7,687 mg/L
Chloride		230	mg/L	13 analyses, mean = 240 mg/L
Sodium		1,786	mg/L	7 analyses, mean = 2,055 mg/L
Potassium		38.0	mg/L	6 analyses, mean = 36.2 mg/L
Flow @ Inlet		0.32	L/sec	5.0 GPM= median, mean = 5.15 GPM

*These tests are a combination of OCC and OSM, MCR field measurements, OCC/Oklahoma University lab, MCR field and in-house lab analysis and EPA-certified lab analysis.

Contaminant Load Calculations

Acid loading = 0.32 L/sec x 60 sec/min x 60 min/hr x 24 hr/d x 1,330 mg/L x 1 g/1000 mg = 35,942 g/d. Fe loading = 0.32 L/sec x 60 sec/min x 60 min/hr x 24 hr/day x 770 mg/L x 1 g/1000 mg = 21,290 g/d. Mn loading = 0.32 L/sec x 60 sec/min x 60 min/hr x 24 hr/day x 17.4 mg/L x 1 g/1000 mg = 481 g/d. SO_4 loading = 0.32 L/sec x 60 sec/min x 60 min/hr x 24 hr/day x 7,202 mg/L x 1 g/1000 mg = 199,120 g/d.

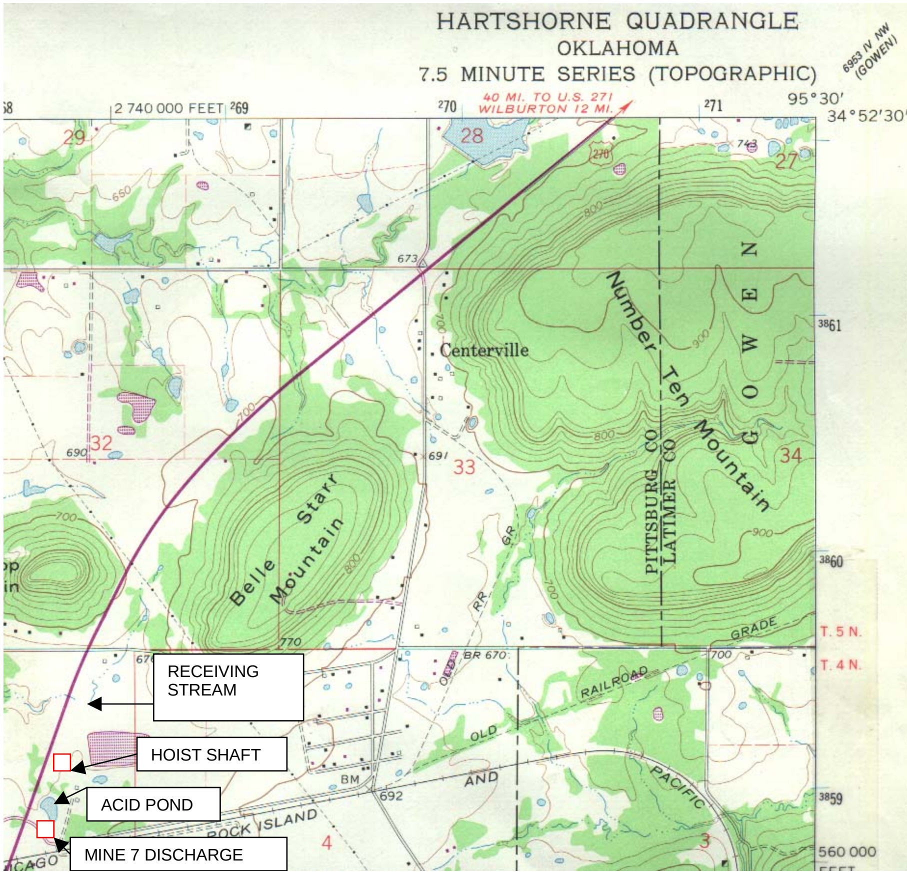


Figure 6. – Location of the Rock Island No 7 Mine Discharge.

Seeps around the periphery of a deteriorating concrete cap also discharge AMD except during periods of low precipitation (Figure 8). The pH of the discharge is moderately low, ranging from 4.79 to 5.54 S.U. (median 5.4 S.U.). However, this seep is a significant water quality problem, due to the high level of dissolved constituents, especially sulfate (1,200 to 13,260 mg/L, median = 7,202 mg/L; Table 2), dissolved iron (215 to 1,357 mg/L, median = 770 mg/L) and manganese (5.1 to 50 mg/L, median = 17.4 mg/L). The total acidity of the seep is between 810 and 2,300 mg/L (median = 1,330 mg/L, Table 2). Because of the low pH and high iron and sulfate levels, these water resources are unusable by both wildlife and livestock.

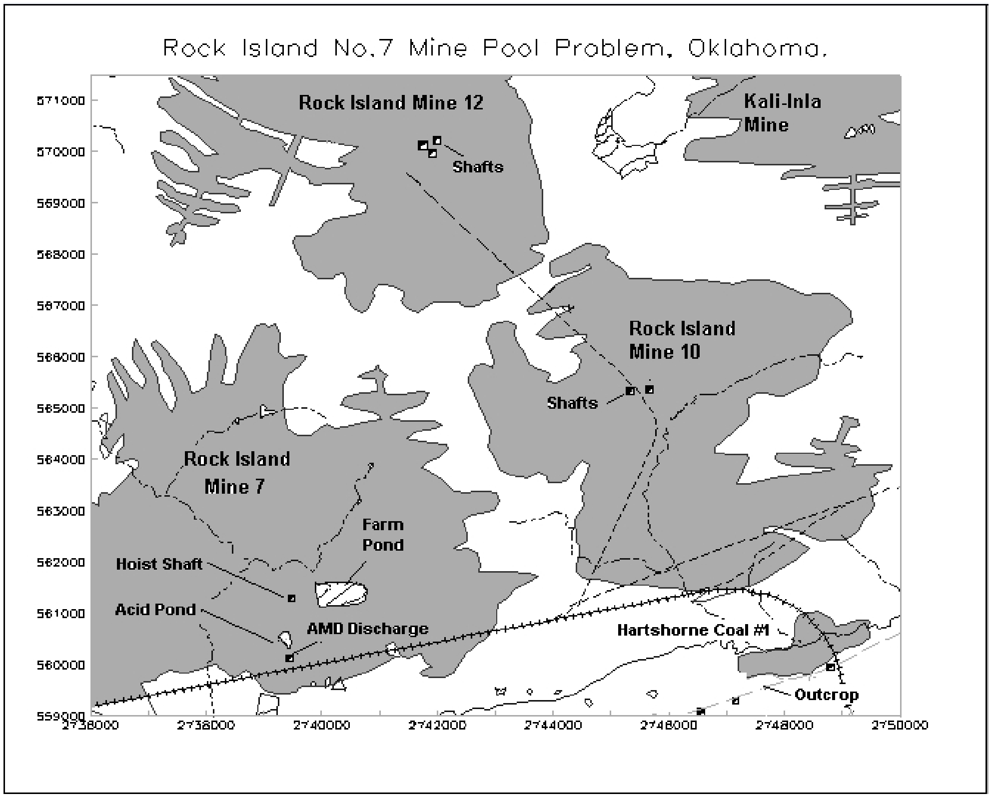


Figure 7. - Location of Underground Mines in the Southern Part of the Hartshorne Basin.

Figure 8. – Water Sampling and Real-time Kinematic GPS Survey Activities at the Rock Island No. 7 Airshaft, November, 2002.

Data Acquisition

OSM Western Regional Office procured the LIDAR and digital imagery data in 2001 using TIPS funding. The contractor selected was Spectrum Mapping, LLC (formerly Enerquest; www.enerquest.com). Spectrum operates an integrated hyperspectral sensor and digital color/multispectral camera configuration that collect digital data in a single mission. Spectrum was chosen in part due to the diversity of platforms that allowed collection of data in a small project area with limited flight line length. By integration of these two technologies, the production of accurate bare earth surfaces and the classification of laser returns are simplified.

Because proper classification of laser return data depends on the terrain and vegetation coverage, laser data cannot be "blindly" filtered. In Spectrum's experience, laser data certification and quality assurance require the imagery be reviewed to determine the effectiveness of data filtering in bare earth and/or canopy environs. The vendor notes that, for projects such as FEMA floodplain mapping (that require breaklines); imagery is the best solution for mapping purposes because LIDAR alone will not allow the creation of accurate breaklines.

Normally, at least three sets of LIDAR-intensity images are received: 1) the 1st signal return only provides data on locations other than the ground (i.e. vegetation, buildings), 2) the 2nd signal return provides data on the bare earth (in our case the desired data), and 3) the combined 1st and 2nd signal return data. A series of ortho tiles are captured and delivered in uncompressed GEOTIFF format.

Post-Processing

Post processing at the OSM Western Regional Office included:

1) Use of the LIDAR data to create a contour map with a 1-foot contour internal. in shapefile (*.shp) format;
2) Image files of raw LIDAR data;
3) Two Geotiff aerial photos with corresponding *.tfw files; and
4) An mpeg fly through (mine7.mpg).

MCR also converted some of this data for use in GIS software. First, a set of *ArcMap 8.1*-generated point data was imported into *SurvCADD XML* and then converted to a CAD drawing format. This topographic drawing file was then used by MCR to generate the conceptual passive treatment design presented in this paper. The OCC remediation design contractor was also supplied this drawing file for use in the final design. Second, *SurvCADD XML* was used to re-grid the digital topographic data (minimum tension grid method); then x-y-z data was exported to *earthVision 7.5* to create several 3-d perspective views presented in this paper.

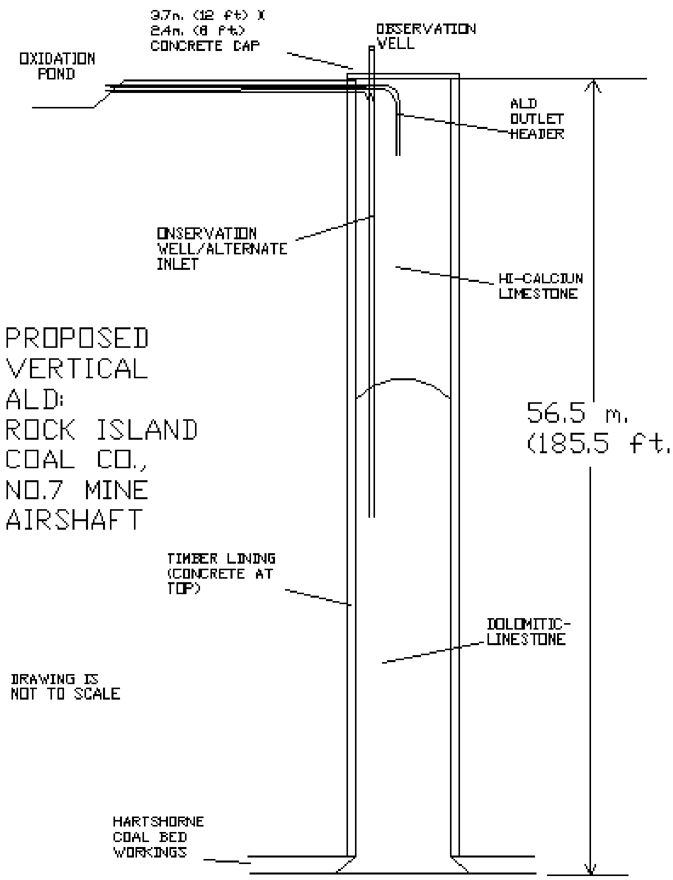
Georeferencing/Ground Truth Field Activity

Ground control was established for the project using a Trimble Real-Time Kinematic (RTK) Model *5700 RTK-GPS*, a combination GPS receiver/rover package. The RTK base station was set up in the vicinity of the discharge and allowed to collect continuous data for 30 minutes (Figure 9). The RTK Rover unit was then used to collect ground-control-points (GCP) at critical locations throughout the site and along an adjoining state highway right of way to establish a construction baseline. Locations included: culvert openings, pond spillways, the discharge point of the mine water.

Figure 9. –Real-time Kinematic GPS Survey Activities: Setting up a Base Station on top of the Waste Dump at the Rock Island No. 7 Airshaft, November, 2002.

Data Application – Development of a Passive Treatment Design

The concrete cap of the airshaft was deteriorated and represented a potential hazard to the local population. The OCC plans to repair/replace the cap and construct a shaft backfill that will act as a vertically-oriented anoxic limestone drain (ALD; Behum and others, 2004; Hedin and Watzlaf, 1994). This structure will serve the dual purposes of shaft backfill and AMD water treatment; eliminating a safety hazard and a portion of the environmental impact associated with the Rock Island Mine 7 airshaft. Figure 10 illustrates the suggested design for this structural shaft fill. The outlet of the vertical ALD may then be routed to a series of Vertical Flow Ponds (VFP's). Using the water quality data shown in Table 1, a conceptual design was prepared for a passive treatment system that would treat the AMD. Using spreadsheet-based design information two graphical products are prepared. First, a flowchart is created (Figure 11); then, using the LIDAR-based topographic data imported as x-y-z points into SurvCADD, a CAD drawing is prepared showing the location of each structure listed in the Flowchart. This drawing is shown in Figures 12 and 13.



Drawing is Not to Scale

Figure 10. Proposed Backfill Design by Using of a Vertical ALD.

The AMD treatment begins in the southern portion of the proposed facility (Figure 13). After alkaline addition in the vertical ALD, metals precipitate in an oxidation pond and aerobic wetland. Three vertical flow ponds (VFP #1, 2 and 3; Figures 11-13) add additional alkalinity with metal precipitation in oxidation ponds and aerobic wetlands. VFP #3 is a modified structure that splits a conventional vertical flow pond design into two cells. The first cell is a down-flow section where dissolved oxygen is removed, followed by an up-flow section where alkalinity is added. Dilution water from a small pond in the headwaters area (Figure 12) enters the system and flows through small limestone leach beds; adding 35-50 mg/L alkalinity (Black and others, 1999).

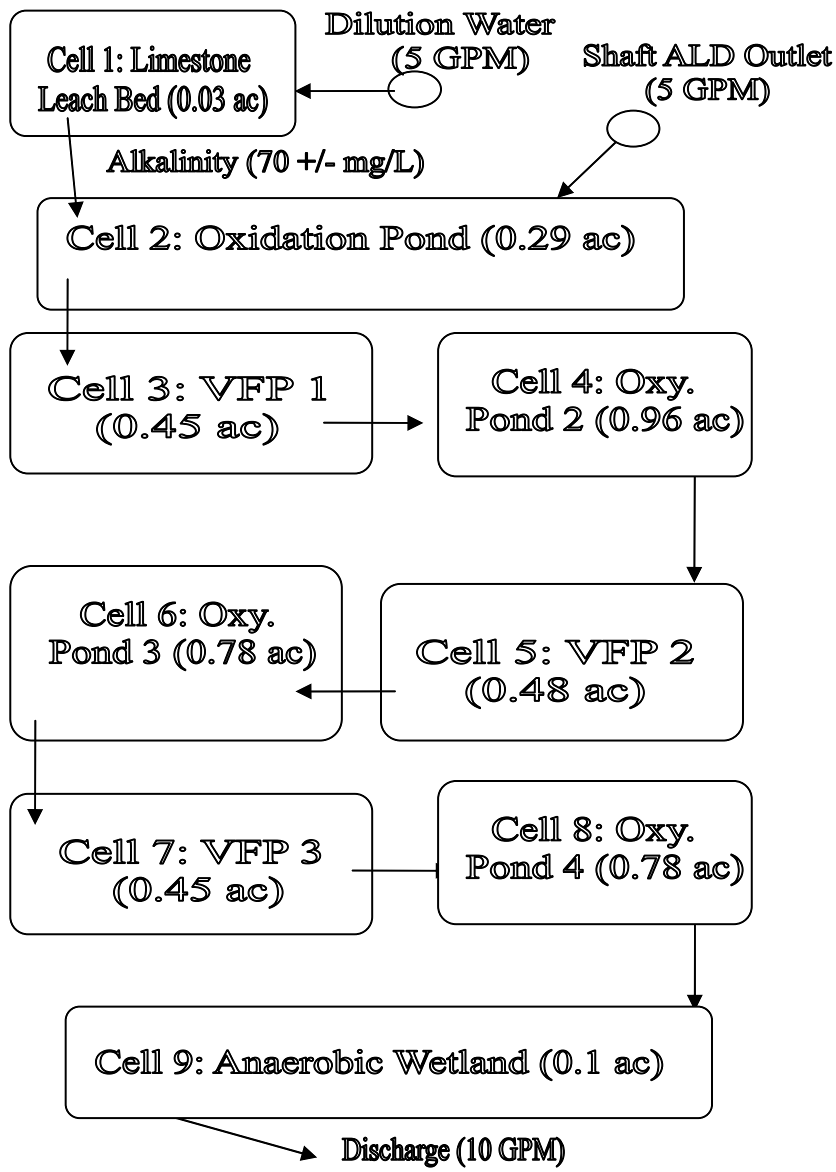
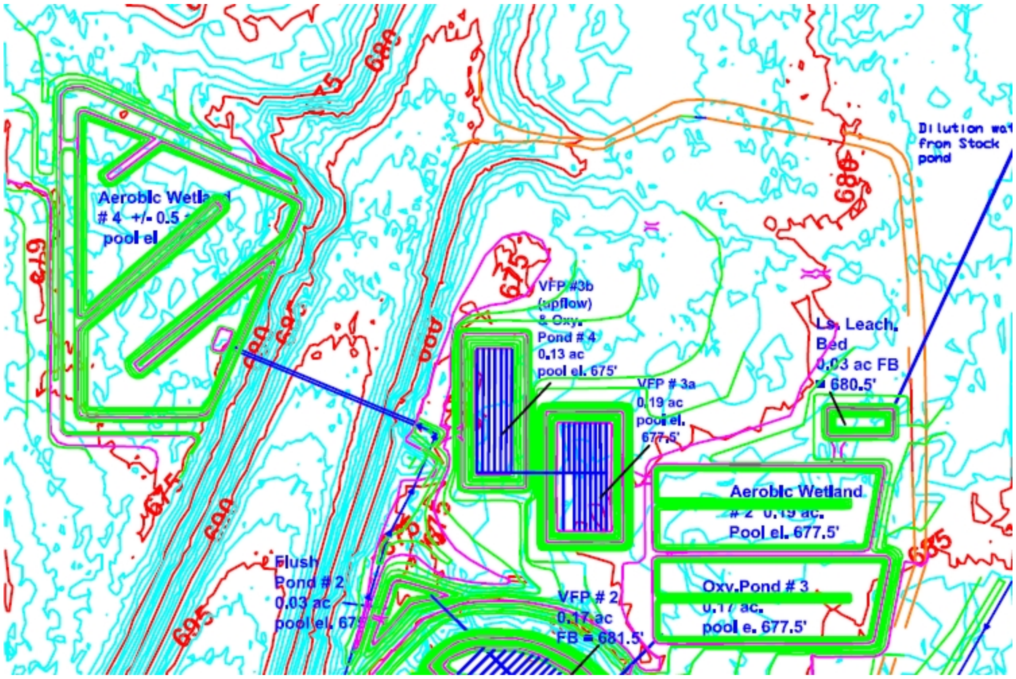
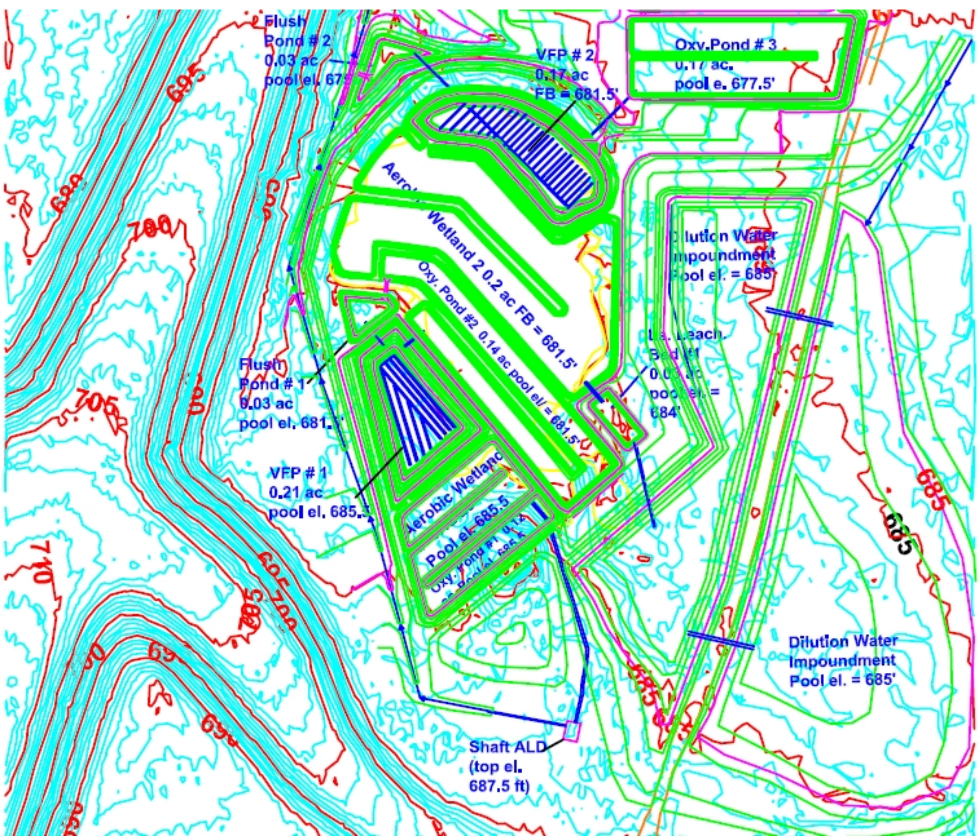


Figure 11. Possible Passive Treatment Flowchart for the Mine 7 Discharge



Drawing created by P. Behum using *SurvCADD XML*, Nov. 2004.

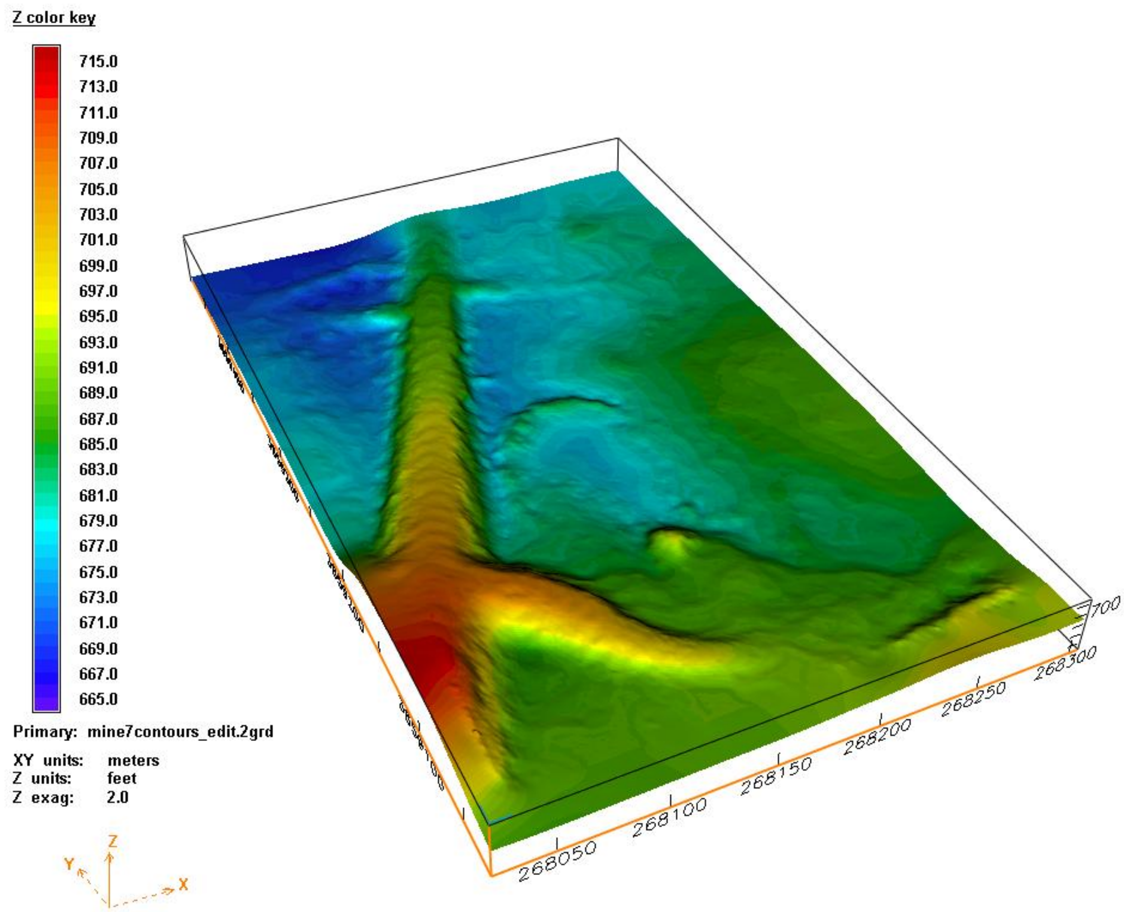
Figure 12. – Northern Half of the Proposed Passive Treatment System for the Rock Island Mine 7 Discharge Utilizing LIDAR-derived Topographic Data.



Drawing created by P. Behum using *SurvCADD XML*, Nov. 2004.

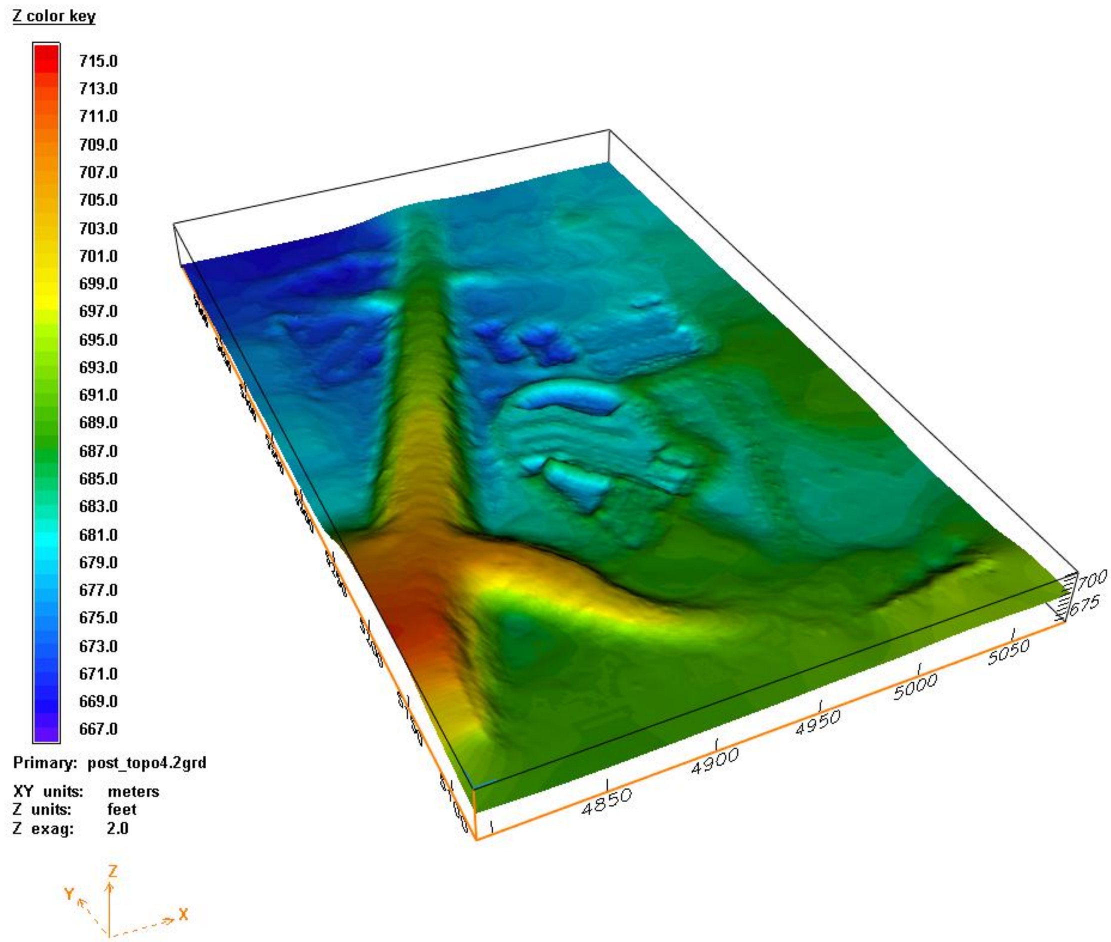
Figure 13-. – Southern Half of the Proposed Passive Treatment System for the Rock Island Mine 7 Discharge Utilizing LIDAR-derived Topographic Data.

Figures 14 and 15 illustrate the pre- and post-design topography of the treatment facility as proposed in the conceptual design. The dominant topographic feature is the elevated roadway of State Highway 270 on the left (west) side of the model. In the foreground is the off-ramp for Old Highway 270. A pre-existing stock pond is shown between these two roadways in Figure 13 (also see Acid Pond in Figure 6). This old pond is to be modified and re-used in the conceptual passive treatment design. The small hill in the pond headwaters is a waste rock dump created from the shaft excavation and mining effort.



Model created by P. Behum using *earthVision 7.5*, Nov. 2004; vertical exaggeration = 2X; z = ft. M.S.L.; State Plane Coordinate system, Oklahoma south, NAD83.

Figure 14. – Pre-Construction Topographic Model of the Site Area created from LIDAR Data.



Model created by P. Behum using *earthVision 7.5*, Nov. 2004; vertical exaggeration = 2X; z = ft. M.S.L.; local coordinate system; Note: CAD design drawn using SurvCADD XML.

Figure 15. – Topographic Model of the Site Area showing the AMD Passive Treatment Structures.

Conclusion

The use LIDAR data has been beneficial to the design of the Whitlock/Jones 145 CSI Project. Future AMD remediation projects will most likely use the additional flight line data procured in this effort. There will, however, be a need for some additional ground truth survey activity at each site. The selection of DTM acquisition technology should still be a site specific decision. For example, aerial photographic methods may be adequate for areas devoid of heavy brush and woodland vegetation but factors such as cost and delivery time must also be considered. The 3-D perspective views created in *earthVision* can also be used to provide private landowners and the general public with a visualization of impact of the proposed treatment facilities.

Acknowledgements

Mike Kastl and David Haggard of the OCC AML Program managed the Oklahoma project activity. Mike Sharp of the OCC AML Program assisted in the aquisition of digital topographic and geographic information system data. Geoff Canty, formerly of the OCC, provided water quality data for the Rock Island No. 7 discharge. Min Kim MCR and Dan Trout and Jeff Zingo, OSM, Tulsa Field Office, assisted in OSM's water quality data collection. Bill Ehler, OSM Appalachian Regional Office assisted in the borehole camera investigation.

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