Memo

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From	**Brett A. Howey, P.E.** **Ken Fergason, P.G.**	cc	
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Date	**January 30, 2008**		

Subject **Earth Fissure Investigation and Preliminary Fissure Mitigation Technical Memorandum**
Siphon Draw Drainage Improvement Project
Maricopa County, Arizona

1.0 INTRODUCTION

This technical memorandum is submitted pursuant to completion of a geologic hazard review and appraisal by AMEC Earth & Environmental, Inc. (AMEC) of the Siphon Draw Drainage Improvement Project site. Presented is a summary of the completed earth fissure investigation, a discussion of the investigation results, preliminary revised earth fissure risk zones, and alternatives for engineered earth fissure defense solutions, including preliminary design details and profiles. This analysis was performed for use by Stanley Consultants, Inc. (Stanley), and the Flood Control District of Maricopa County (District) and its project partners, for the development and evaluation of design alternatives for the Siphon Draw Drainage Improvement Project, Contract No. FCD 2007C012.

Earth fissure defense solution concepts discussed herein have been developed as a starting point for the Failure Modes and Effects Analysis (FMEA) workshop, scheduled for February 2008. Outcomes developed during the FMEA workshop will assist the project team in identifying risk tolerances and associated mitigation. Results of the FMEA will be documented by AMEC and incorporated into final design recommendations for this project.

2.0 PROJECT DESCRIPTION

The current, contracted portion of the Siphon Draw Drainage Improvement Project includes pre-design, value engineering, final design, and the preparation of construction plans, special provisions and an engineer's estimate. The project is a partnership between the District and the City of Mesa (City) for the design of flood control improvements north of Elliot Road along the Meridian Road alignment in western Pinal County and eastern Maricopa County. The project begins at Meridian Road approximately one mile north of the Elliot Road alignment and ends at the intersection of 104th Street and Elliot Road. The primary goal of the project is to intercept flood waters at Meridian Road to protect properties west of Meridian Road. The project will include a flood control channel, basin(s), and a storm drain along Elliot Road. A design criterion for the project has been established as the 100-year flood event. Stanley is the lead project consultant with AMEC providing geotechnical and geologic hazard consultancy services.

3.0 INVESTIGATIVE APPROACH

The investigative approach for the earth fissure investigation was comprised of six primary elements: 1) review of existing data, including reports, Synthetic Aperture Radar Interferometry (InSAR), and high resolution aerial imagery, 2) ground reconnaissance, 3) seismic refraction profiling, 4) excavation of test trenches, 5) updating the earth fissure risk zones, and 6) recommending mitigations.

The primary data source utilized was the Preliminary Earth Fissure Risk Zone Investigation Report and the data sources referenced therein. Additional InSAR has been evaluated and will be presented in the final report. Existing high resolution aerial photography was also reviewed as part of this task, including historical aerial photography from 1937, 1997, and 2007.

Seventy-five (75) seismic refraction profiles were first performed as part of the initial investigation (see Figures 1-5) for the purpose of identifying possible concealed earth fissures. These 75 seismic lines were located at the approximate location of the proposed Meridian Channel in a continuous, overlapping profile from Elliot Road north to the end of Reach 1. In order to further characterize the known earth fissures and their potential extension toward the proposed basin, an optional task consisting of ten (10) additional seismic lines was initiated. Ten of the seismic profiles will be fully interpreted and utilized in the geotechnical characterization of the proposed channel and basin. The geologic reconnaissance was performed in concert with the geophysical field work.

Based on the results of the seismic refraction profiling, an optional task to excavate 125 lineal feet of test trenches was initiated. Four (4) test trenches were excavated at the known earth fissure and at seismic anomalies identified by the seismic profiling. A change order was approved to excavate an additional five (5) test trenches (approximately 150 lineal feet) to address additional seismic anomalies identified, for a total of nine (9) test trenches.

4.0 DISCUSSION

The AMEC 2006 report indicates that the proposed basin and channel system lie within a moderate to high earth fissure risk zone and that the southwestern-most earth fissure (southwestern fissure) in the SRP fissure complex trends toward the proposed basin(s) location. A second earth fissure (eastern fissure) is located east of the southwestern fissure, trending north and south. Also identified were a number of lineaments that may be associated with earth fissuring.

Examination of historical aerial photography from 1937 showed that a majority of the identified lineaments were present at that time, which is presumed to be prior to the initiation of subsidence sufficient magnitude to cause earth fissuring. Other lineaments as determined by field inspection are local erosional features, generally appearing to be anthropogenic in origin. Therefore the identified lineaments were determined to not be associated with earth fissuring.

The initial seventy-five (75) seismic refraction surveys identified six (6) anomalies. A seismic anomaly is identified by a method of visually examining seismic traces for a sudden decrease in signal amplitude (attenuation) and/or increase in arrival time (time offset) of the seismic signal between adjacent geophones. Five of the six identified anomalies were characterized as weak anomalies and one was characterized as a strong anomaly. Strong seismic anomalies are generally considered to have a greater probability of resulting from the presence of a soil discontinuity than weak anomalies. The optional ten (10) seismic lines identified three (3) additional weak seismic anomalies, two along the projection of the southwestern fissure and one at the southernmost surficial indication of the eastern fissure. Several geologic conditions are recognized as potential sources of seismic anomalies. In addition to the presence of soil discontinuities and ground strain, these conditions include dipping stratigraphic beds, sub-vertical cementation variations, and abrupt compositional changes such as buried channel deposits.

A few days prior to performing the optional seismic lines, a rain event occurred where 2 to 3 inches of rain fell in the Apache Junction area. This event extended the surficial expression of the southwestern fissure approximately an additional 250 feet from the end of the previous surficial expression identified in the previous AMEC (2006) investigation (Figure 1). This extension occurred toward the southwest, which is approaching the location of the proposed basin(s). No change was observed in the eastern fissure.

Nine (9) test trenches were excavated by District operators and equipment as part of this investigation. Test Trench TT-1 was excavated a few feet beyond the end of the extended surficial expression of the southwestern fissure (Figure 1). Test Trenches TT-2 and TT-3 were excavated at seismic anomalies about 250 and 550 feet, respectively, beyond along the fissure's projection. Test Trenches TT-4 through TT-9 were excavated at seismic anomalies along the long seismic profile, with TT-4 excavated at the strong seismic anomaly. One weak seismic anomaly was not trenched. This anomaly is located at the southernmost surficial indication of the eastern fissure, and is removed from proposed project elements.

Test Trench TT-1 was excavated at the end of the surficial expression of the southwestern fissure with the intent of observing the character of the earth fissure in cemented soils. After excavation of the trench and prior to detailed logging, a rain event occurred that initiated lateral flow in the southwestern fissure, filling TT-1 with water. Water remained ponded within the excavated trench and did not drain through the earth fissure, indicating a lack of connectivity between the earth fissure and test trench. Over a period of five (5) hours, the water level in the trench fell about 0.27 feet (about 3¼ inches), indicating a relatively low infiltration rate. The water was pumped out of the trench by District personnel and the trench was re-excavated with a backhoe for safety. The amount of moisture in the trench as a result of flooding prevented detailed logging of soil discontinuities and observation of the fissure at depth.

No evidence of earth fissuring was identified in Test Trenches TT-2 through TT-9. Test Trenches TT-2, TT-3, and TT-6 through TT-9 were also excavated at times when rain events either flooded or partially flooded the trenches. Logging sufficient to identify trench stratigraphy and the presence or absence of earth fissures was accomplished, but logging detailed enough to identify subtle soil discontinuities and evidence of strain was prevented by the level of moisture in the soil. Test Trenches TT-4 and TT-5 were not inundated with water.

In summary, the southwestern fissure (see Figures 1 and 2) trends toward the proposed basin(s). Field observations show that this fissure extended an additional approximately 250 feet toward the proposed basin(s) after a rain event. Two seismic anomalies were identified along the trend of the fissure, though no fissuring was evident in Test Trenches TT-02 and TT-03 excavated at these locations. No other earth fissures were found in proximity to proposed infrastructure.

5.0 EARTH FISSURE RISK ZONES

The earth fissure risk zonation presented in the previous AMEC (2006) report was preliminarily updated based upon the findings of this investigation. As depicted on Figure 6, the following is offered as definitions of four earth fissure risk zones in order of decreasing hazard:

- **Zone 1 (Red)** - Earth fissures are present or have a high probability of being present at this time, and will likely continue to develop in the future, as evidenced by multiple investigative methods including published and un-published mapping, photo lineament analysis, InSAR data and patterns, subsidence history, and ground reconnaissance.

- **Zone 2 (Orange)** - Conditions for the development of earth fissures are present through multiple lines of evidence; however, earth fissures have not been positively identified. A high probability for the future development of fissures exists, and there is a distinct possibility that concealed earth fissures are present. Evidence supporting the possible presence of concealed fissures and the probability for future fissuring includes the proximity to, and trends of known earth fissures, InSAR data and patterns, subsidence history, and the distribution and orientation of photo-lineaments.

- **Zone 3 (Yellow)** - A moderate probability of future earth fissure formation is present, if future differential subsidence occurs, coupled with the current elevated state of horizontal, tensional strain. Evidence supporting this designation includes InSAR data and patterns, subsidence history, and photo-lineament analysis.

- **Zone 4 (Green)** - A low probability of future earth fissure formation exists in Zone 4. Evidence suggests that no significant tensional strain will develop from the occurrence of future subsidence following current patterns.

The observation of the extension of the southwestern earth fissure by about 250 feet following a rain event provides direct evidence that there is a high probability of continued extension of this fissure to the southwest. Therefore, a significant portion of the proposed basin(s) falls within Zones 1 and 2. Reach 1 of the Meridian Channel falls within Zone 3 and no elements of the project are in Zone 4.

6.0 POTENTIAL ENGINEERING DEFENSE SOLUTIONS FOR EARTH FISSURES

The Siphon Draw Drainage Improvement Project pre-design alternatives positioned in the earth fissure risk zones include the potential for an unlined or concrete lined conveyance channel and a detention basin. The discussion that follows includes details associated with the potential failure modes and the design of potential engineered earth fissure defense solutions. Implementation of the defense mechanisms may be recommended in areas where earth fissures are present or may impact the flood control facility in the future. The intent of the defense mechanism is to provide a means by which the District and its municipal partners may reduce the risk associated with catastrophic failure of the flood control project's components as a result of earth fissuring.

6.1 Potential Failure Modes

The two potential failure modes discussed below have been identified as requiring engineering defense solutions to reduce the potential for catastrophic failure of the flood control project as a result of active earth fissuring. These two failure modes discussed below are the most recognized. However, other project specific potential failure modes may be associated with this project. The formal FMEA will identify and analyze other potential failure modes associated with the Siphon Draw Drainage Improvement Project. Results and recommendations developed during the FMEA workshop will be incorporated into the final design recommendations.

(1) An advancing fissure intercepts the channel or basin which results in erosion and flows outside of the project boundaries.

(2) Flood waters within the basin or channel during design operation provide water to and underlying earth fissure which results in fissure erosion and flows outside the project boundaries.

6.2 Potential Defense Solutions

Since the driving mechanism for earth fissuring is groundwater depletion and associated land subsidence the ability for the project owners to control future regional groundwater use and levels is very difficult. Therefore, the potential for further subsidence and associated earth fissuring must be conservatively assumed. The result is the consideration to incorporate engineering defense mechanisms into the overall project design. The intent of the solutions is to maintain full operation of the flood control project during a single design storm event without catastrophic failure. Damage to the project may occur during the design storm event that would require maintenance and possible repair, but the integrity of the system would be relatively maintained.

The potential engineering design solutions presented herein were developed to defend against the two potential failure modes. Generally the defense mechanisms have been designed to intercept and control surface runoff to prevent fissure gully formation and loss of foundation support, and to intercept and control shallow subsurface flow within a fissure to prevent undermining or erosion of the channel and basin. Sheets 1 through 3 depict the defense solutions discussed below.

6.2.1 Avoidance

In high fissure risk zones, avoidance of the location may be considered a primary and more favorable alternative. To the extent feasible, the alternative avoids planning and siting of flood control infrastructure in these areas. This alternative is a more favorable alternative to reduce the risk associated with construction of flood control projects in a high fissure risk zone. Nevertheless, siting of flood control structures outside the high fissure risk zones may not be feasible. To that end, implementation of an engineered defense mechanism(s) and long-term post-project construction instrumentation and monitoring for the occurrence of future fissure formation, is an option.

For the Siphon Draw basin and the channel along the Meridian Road alignment, we have incorporated fissure defense mechanisms into the alternatives as an initial starting point for failure modes assessment and discussion. Defense mechanisms for the basin and channel are discussed in the following sections.

6.2.2 Flood Control Basin

The defense mechanism for the flood control basin includes four principal components. However, prior to construction of the defense mechanisms, the existing earth fissure gullies are over excavated to a cemented soil foundation and then backfilled with engineered structural fill. The first component includes a series of four permeable backfill cut-offs transverse to the existing and projected earth fissure alignment along the east side of the basin. The cut-offs provide a means to intercept the formation of an earth fissure gully as it advances towards the basin in a perpendicular or skewed orientation. A 4-foot wide trench excavated into underlying cemented soils (±16 to 18 feet deep) is positioned transverse to the earth fissure alignment. The trench is backfilled with a permeable backfill material wrapped on all sides, top and bottom, with a 16 oz. non-woven geotextile. A minimum of 3 feet of compacted earthfill is provided on top of the trench backfill.

The second component overlies the first defense mechanism and is a surface water diversion berm designed to intercept and control surface runoff to prevent fissure gully formation. The diversion berm extends from approximately the northern most project property boundary southwest to the edge of the basin. The berm is positioned to cover the existing surface expression of the documented earth fissures as well as the projected direction that the fissure would advance should it erode towards the basin. The diversion berm is an engineered structural fill with a minimum height of 4 feet above adjacent grade and extending laterally away from the fissure zone with minimum 8 to 1 (horizontal to vertical) side slopes. Atop the diversion berm, contoured landscape and overbuild fill could be placed to meet landscape aesthetic goals and to provide on-site waste of basin excavation spoils.

To defend against fissure gully formation and erosion within the basin reservoir area, the third component includes incorporation of a single layer of 16 oz. non-woven geotextile within the basin footprint. The single layer of geotextile potentially could cover the entire basin bottom and side slopes or a portion of the basin. Sheet 1 depicts a full basin footprint coverage. The geotextile is placed on a minimum of 12 inches of prepared subgrade and overlain with a minimum of 3 feet of engineered earthfill.

To intercept the formation of an earth fissure gully at the southwest corner of the basin the fourth component includes incorporation of a single layer 40-mil High Density Polyethylene (HDPE) liner beneath the basin slope in the projected area of possible fissure development. The HDPE liner extends from the basin edge to a minimum distance of 10 feet into the basin from the basin slope toe. The HDPE liner is imbedded in a 10-foot deep vertical trench cut-off positioned within the basin away from the slope toe. To avoid damage to the liner during periodic basin maintenance, the liner is covered by a minimum of 3 feet of engineered earthfill.

6.2.3 Flood Control Channel

The potential defense mechanism for a flood control channel includes two principal components. The first component is the channel type. Use of a reinforced concrete channel alternative may be the more preferred alternative type that provides an added defense against catastrophic failure during fissure formation. Reinforced concrete provides some means to "bridge" over an eroding fissure should one develop beneath the channel. Further consideration will need to be provided to establish an appropriate spanning potential of the structural section. Use of concrete also provides a permanent means to monitor stress development within the geologic section. Our experience indicates concrete lined channels in active fissure risk zones often show increased frequencies of cracking, indicative of ground stress relief.

The second component includes a permeable backfill cut-off that parallels the east side of the channel to intercept the formation of an earth fissure gully as it approaches the channel in a perpendicular or skewed orientation from the east side. A 4-foot wide trench excavated into underlying cemented soils (±16 to 18 feet deep) is positioned parallel and adjacent to the channel. The trench is backfilled with a permeable backfill material wrapped on all sides, top and bottom, with a 16 oz. non-woven geotextile. A minimum of 3 feet of compacted earthfill is provided on top of the trench backfill.

7.0 PRELIMINARY COST ESTIMATES

Preliminary cost estimates for the potential engineering defense solutions are provided in Appendix A. The preliminary cost estimates were developed by accounting for major construction activities and materials and should be used for planning purposes only. AMEC will participate with the consultant team in developing a more refined construction cost estimate for the final alternative.

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8.0 REFERENCES

AMEC Earth & Environmental, Inc. (AMEC), 2006, Preliminary Earth Fissure Risk Zone Investigation Report, Hawk Rock Study Area, Maricopa and Pinal Counties, Arizona Prepared for the Flood Control District of Maricopa County, Contract FCD 2006C005 Work Assignment 2, AMEC Job No. 6-117-001053, September 26.

Please do not hesitate to contact us if you have any questions concerning this report.

Respectfully submitted,

AMEC Earth & Environmental, Inc.

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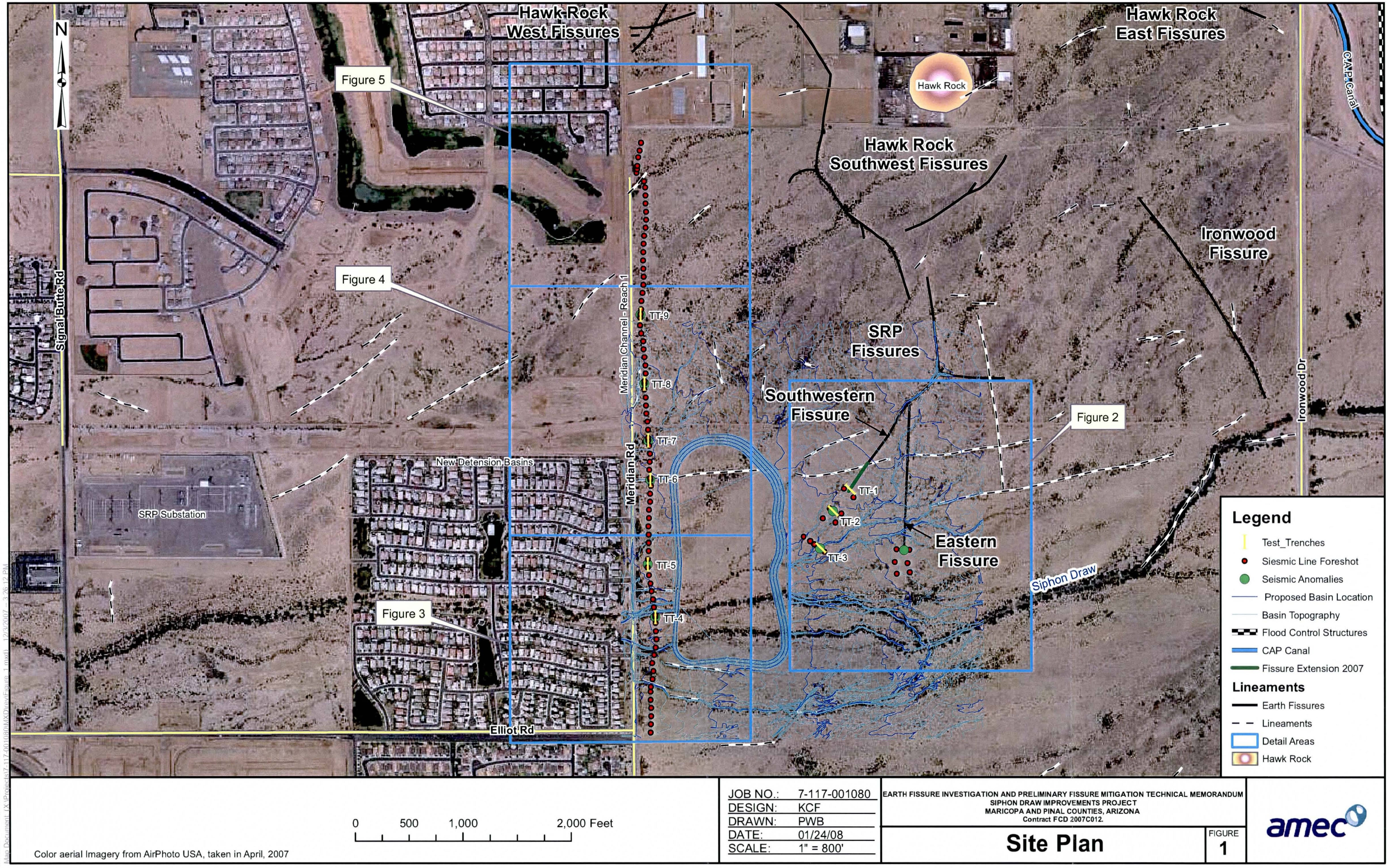
FIGURES



Color aerial Imagery from AirPhoto USA, taken in April, 2007

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EARTH FISSURE INVESTIGATION AND PRELIMINARY FISSURE MITIGATION TECHNICAL MEMORANDUM
SIPHON DRAW IMPROVEMENTS PROJECT
MARICOPA AND PINAL COUNTIES, ARIZONA
Contract FCD 2007C012

Site Plan

FIGURE 1

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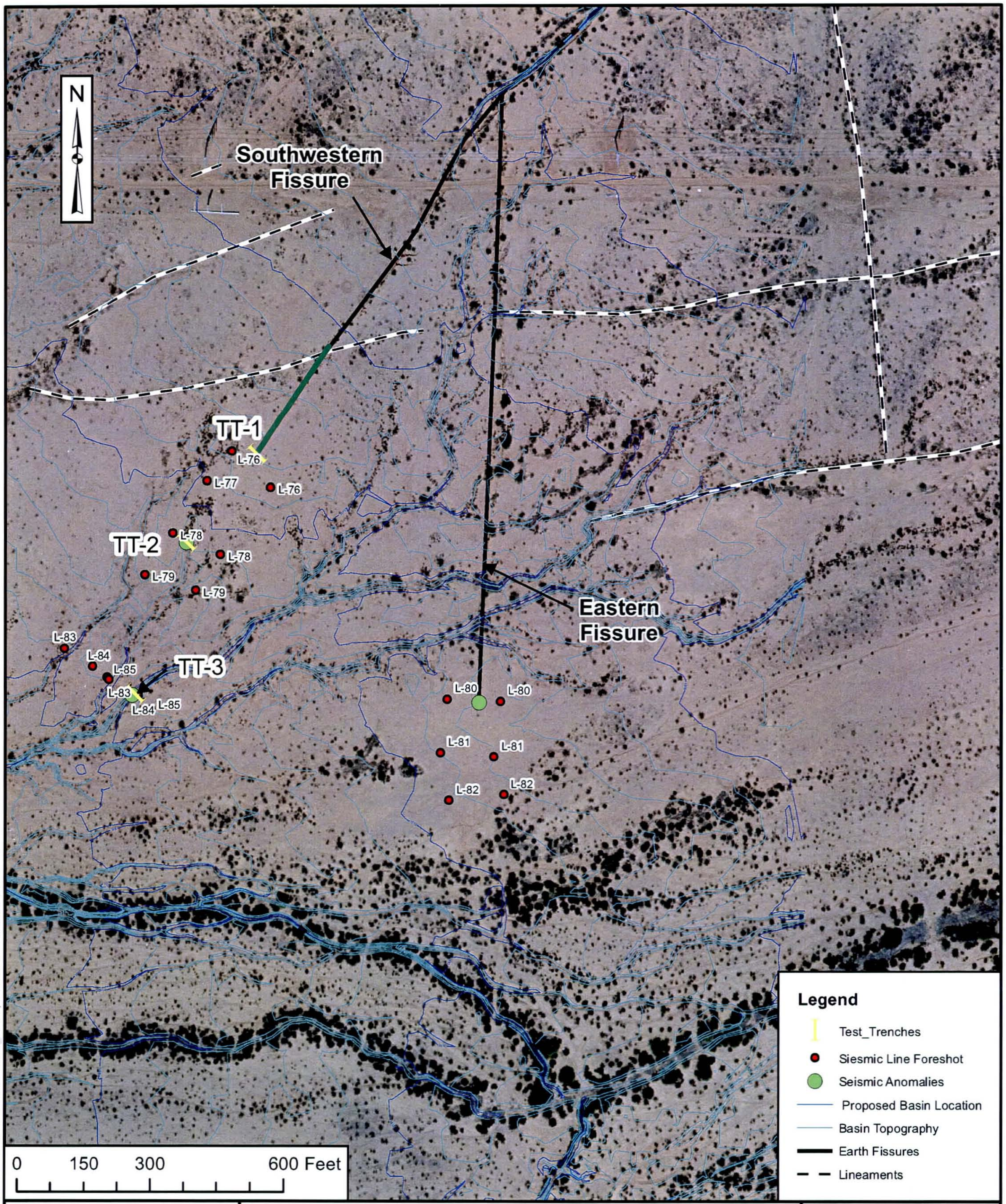

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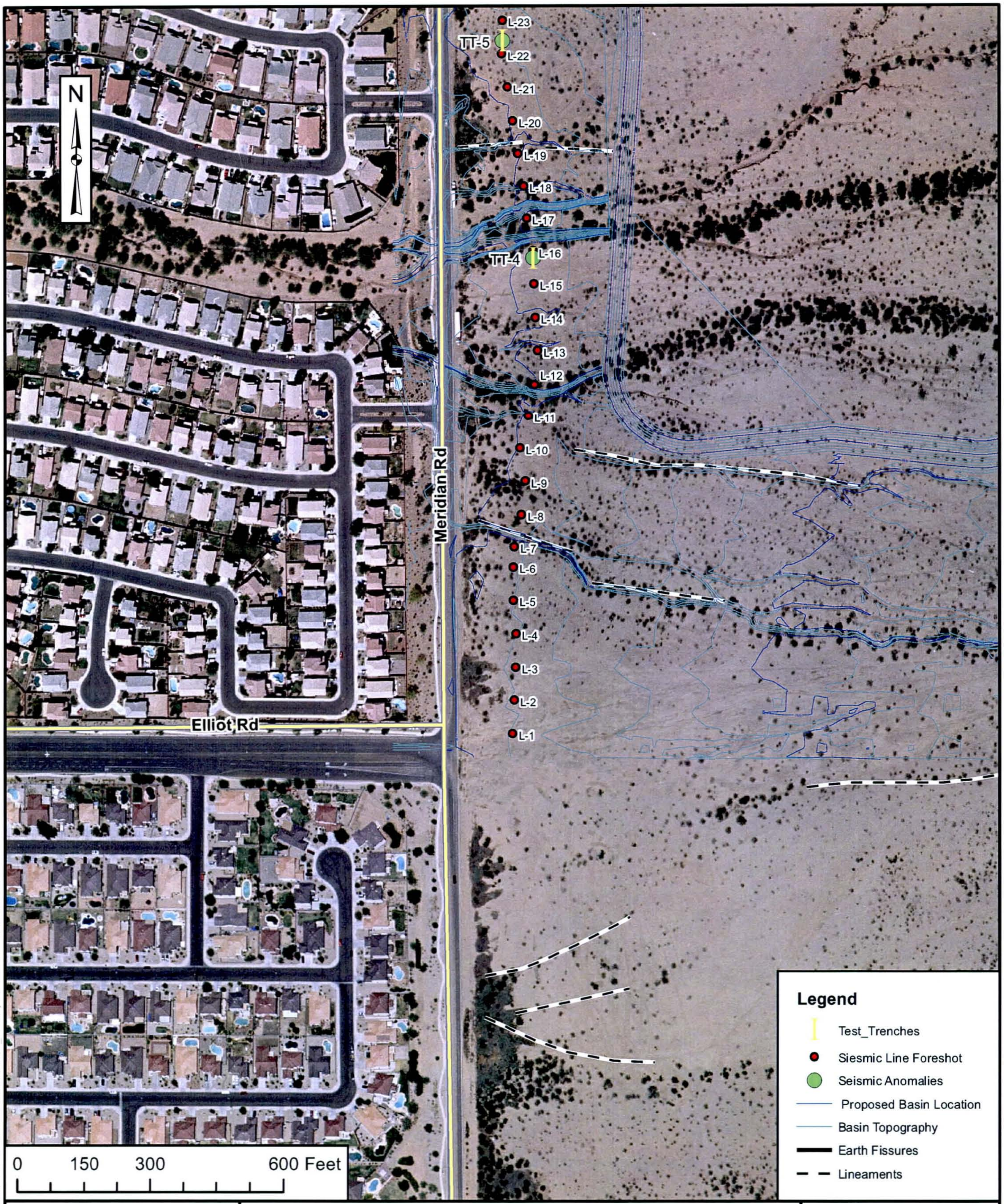

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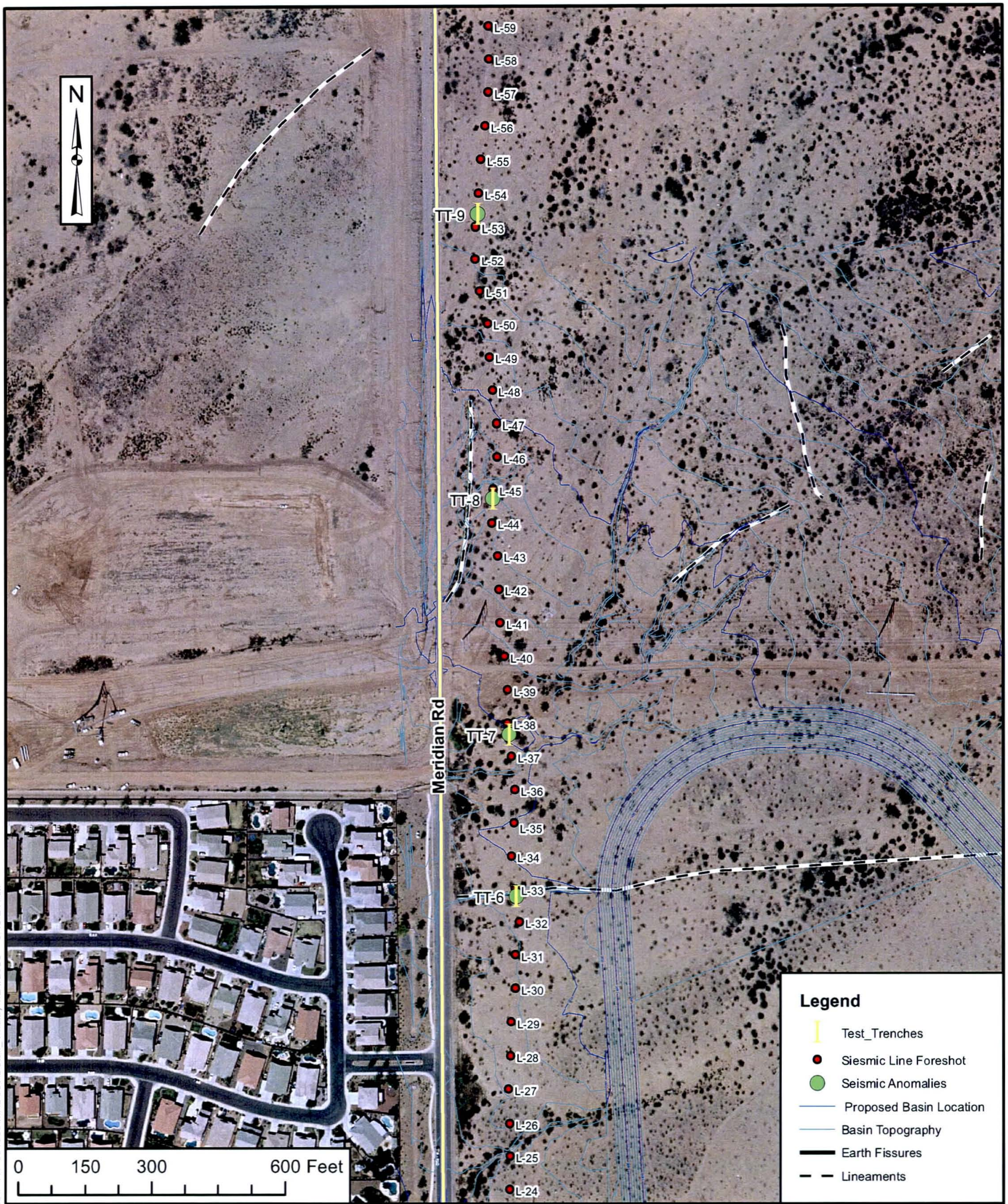

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FIGURE
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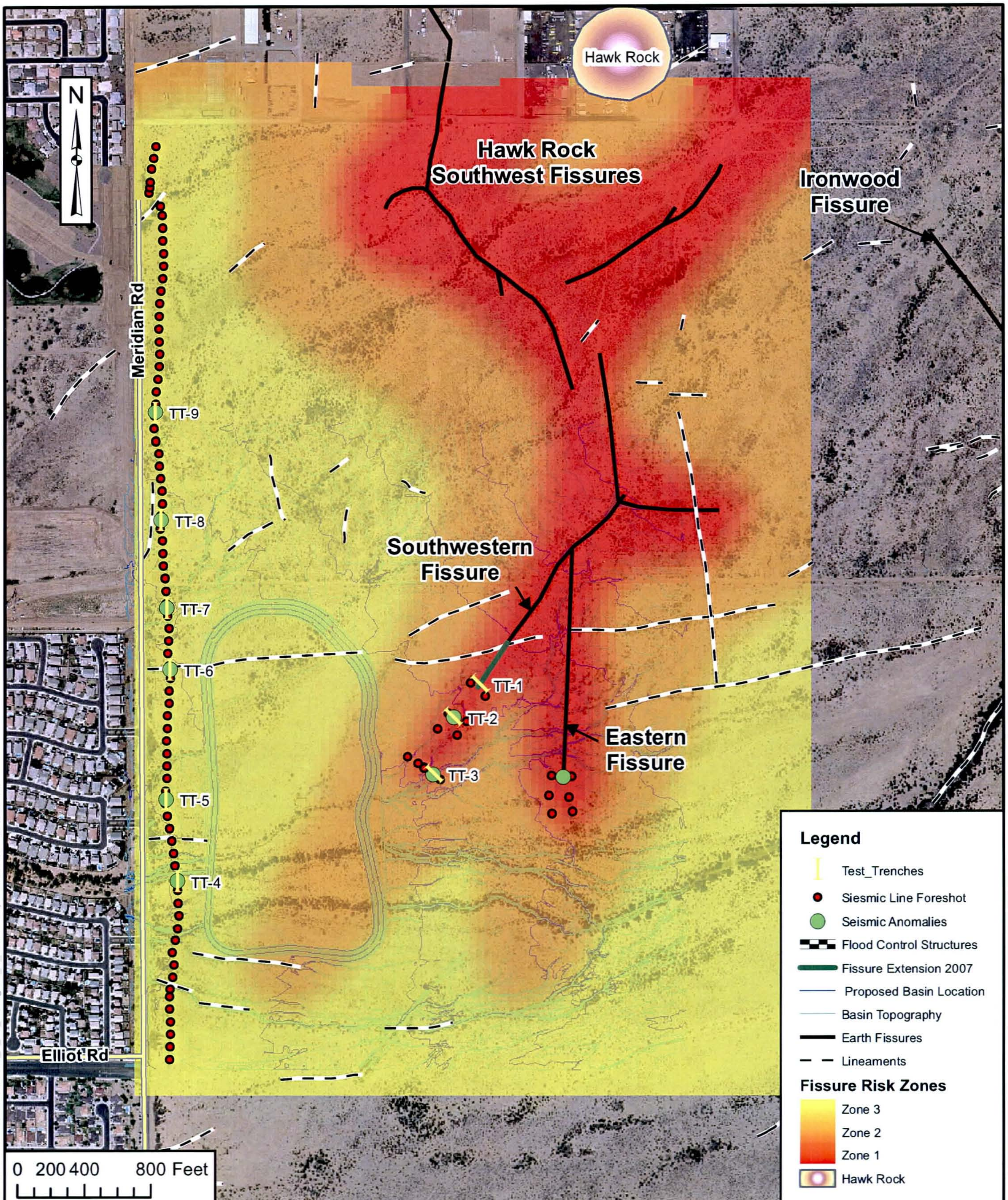

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Preliminary Earth Fissure Risk Zones

FIGURE
6

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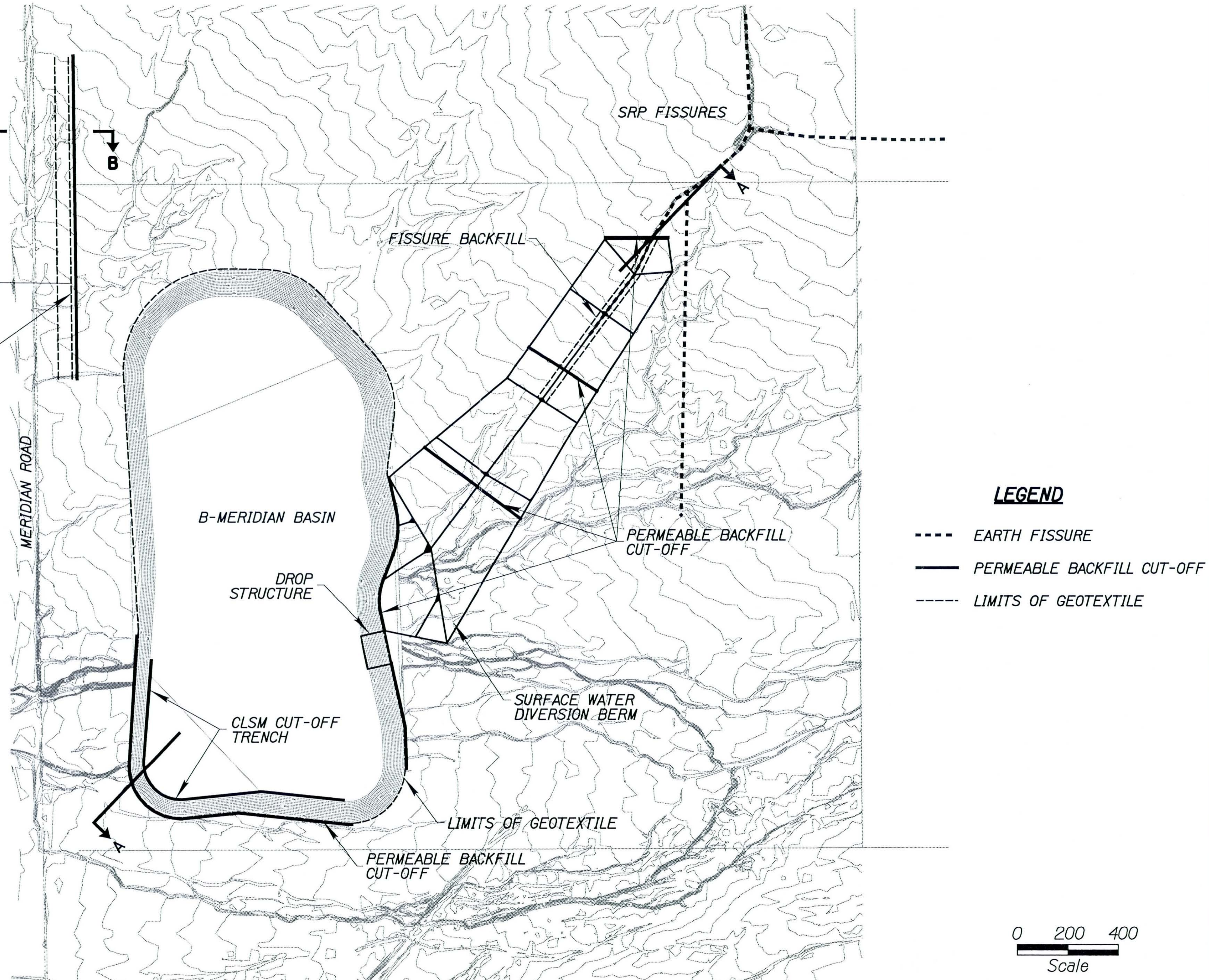

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SHEET NO. 1

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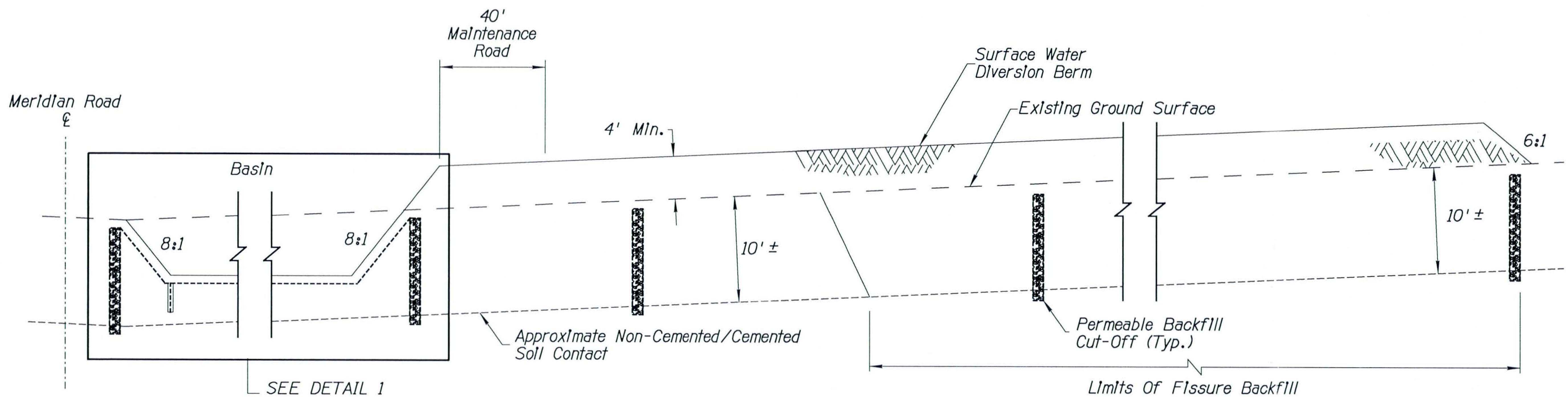

SECTION A-A

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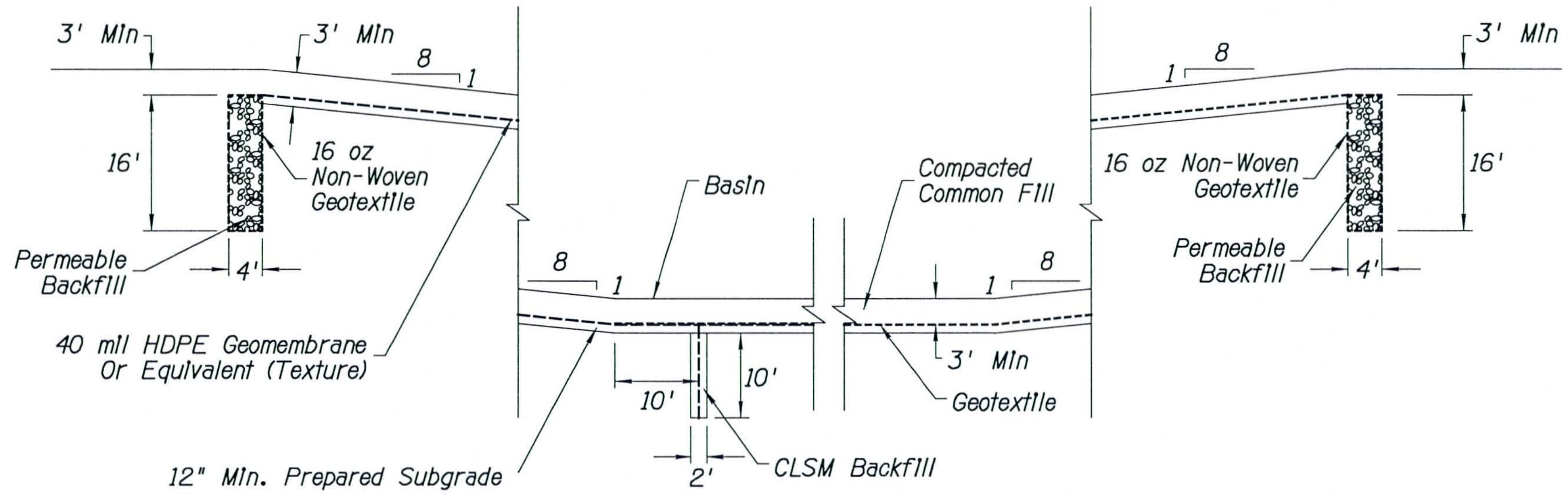

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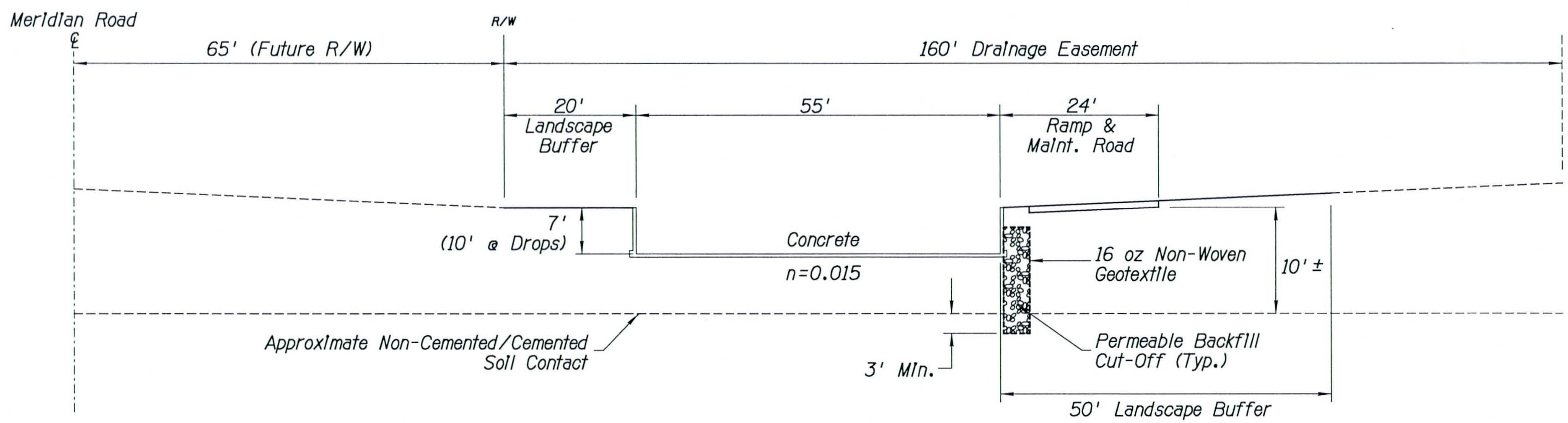

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APPENDIX A

Preliminary Cost Estimates for Earth Fissure Mitigation

Description	Unit	Quantity	Unit Price	Cost
Diversion Berm & Cut-offs				
Earth fissure excavation and structural backfill	CY	5,555	$8.00	$44,440
Permeable cut-off excavation	CY	3,955	$5.00	$19,775
Permeable cut-off geotextile	SY	7,911	$4.25	$33,622
Permeable cut-off granular fill	CY	3,955	$42.00	$166,110
Structural fill	CY	49,000	$8.00	$392,000
Subtotal				**$655,947**
Contingency (20%)				**$131,189**
Total				**$787,136**
Basin Mitigation				
Over-excavation	CY	325,080	$4.00	$1,300,320
Structural fill and subgrade fill	CY	325,080	$8.00	$2,600,640
Geotextile	SY	214,046	$3.75	$802,673
CLSM anchor trench excavation	CY	1,130	$5.00	$5,650
HDPE geomembrane	SY	14,740	$3.50	$51,590
CLSM	CY	1,130	$150.00	$169,500
Permeable cut-off excavation	CY	2,711	$5.00	$13,555
Permeable cut-off geotextile	SY	5,422	$4.25	$23,044
Permeable cut-off granular fill	CY	2,711	$42.00	$113,862
Subtotal				**$5,080,833**
Contingency (20%)				**$1,016,167**
Total				**$6,097,000**
Concrete Channel Mitigation				
Permeable cut-off excavation	CY	4,690	$5.00	$23,450
Permeable cut-off geotextile	SY	9,390	$4.25	$39,908
Permeable cut-off granular fill	CY	4,690	$42.00	$196,980
Subtotal				**$260,338**
Contingency (20%)				**$52,068**
Total				**$312,405**