# Mobile Mapping for Earthworks Monitoring

## A Case Study on the Convergence of Photogrammetry with Advanced Positioning Techniques for Maximum Productivity and Accuracy

## The Arabian Canal Experience

LIMITLESS

Dr. Nedal Al-Hanbali

9/15/2009

## Introduction

- This paper presents a case study on the efficiencies and practicality of using mobile mapping on a large-scale Earth moving project for Real Estate development
- Mobile Mapping: Collecting geo-spatial measurements from a moving platform using advanced photogrammetric and positioning technology

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# Overview

- The Project
- The Challenge
- The Solution: Mobile Mapping
- Quality Control Methodology
- Sample Data Products
- Accuracy Assessment
- Sample Final Deliverables
- Summary









# The Project



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# The Project: Arabian Canal, Dubai

75 km man-made canal complete with terraced landscaping

Mixed use real estate, developed by some of the worlds top firms


http://www.arabiancanal.com



# The Project: Arabian Canal, Dubai

Limitless responsible for managing the overall design and construction, as well as developing an area in excess of 10,000 hectares

# The Project: Arabian Canal, Dubai





# The Project: Arabian Canal, Dubai



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# The Project: Arabian Canal, Dubai







# The Challenge



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# The Challenge: Earthworks Monitoring

- Canal Completion within ***3 to 5 years***
  ***Requires 24 hours operation, 7 days a week!***
- Earthworks monitoring:
  Monitor and measure dig and deposit on 24 hour cycle for
  - Progress
  - Visualization (quality control, marketing)
  - Invoicing
- Data Requirements:
  Absolute accuracy 10 cm RMS (minimum)
  Depths up to 55 m
  Widths greater than 300 m, depending upon slope
- Collection Constraints:
  Only able to collect data between shift changes
  No guaranteed access to edge of canal
  Huge area to collect: 100 hectares within hours



# Data Collection Options

- Static survey (Total Station/GPS/3D Scanner)
  Pros:
  - Proven technology
  - High accuracy
  - Relatively low capital costs

  Cons:
  - Many crews and equipment to cover large area => high personnel costs, many data sets to merge, logistical nightmare for quality control
  - Access required to edge of canal, in canal among large earth moving equipment => dangerous
  - Manual equipment setup and collection => slow

# Data Collection Options

- Mobile Mapping (helicopter and/or vehicle based photogrammetry and LIDAR)
  - Pros:
    - No set up required => fast
    - Only 1 or 2 data sets to merge/quality control => high reliability
    - Single pilot or driver => low personnel costs
    - One set of equipment can cover large area => efficient
    - Remote acquisition => safe
  - Cons:
    - Relatively High capital costs
    - Unproven accuracy
    - Logistically complex and expensive (esp. airborne)



# Trade-off Study

- Analysis showed:
  - Significant risk static methods could not complete collection in required times
    - Could result in huge cost overruns if progress delayed and not detected in time
  - Improved efficiencies of mobile over large area should offset higher capital costs
  - Fairly low risk accuracy could not be met by mobile
- Conclusion:
  - Employ mobile mapping to eliminate schedule risk
  - Reduce accuracy risk by deploying airborne *and* land systems for redundancy

# The Solution



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## Choosing the Right Mobile Mapping Sensors

- Like in static surveying, many different options available to do a job
- Some are very expensive!
- Challenge is to understand the requirements well enough to choose those sensors that meet the requirements while at the same time minimizing capital cost:

  *The right tool for the job*

- How to do this? *Come to PhoWo to learn what is state of the art in the industry!*





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# Airborne Requirements

- Provide orthophoto Maps of construction area for planning and visualization:
  - Ground Sample Distance: 10 cm (max), Ortho accuracy 12 cm RMS.
- Provide point measurements for volume calculations of cut/fill areas:
  - Points spacing 25 cm to 1.5 m, accuracy 10-12 cm RMS (max)
  - Altitudes from 200 to 450 m







# Airborne System: Applanix DSS + LIDAR

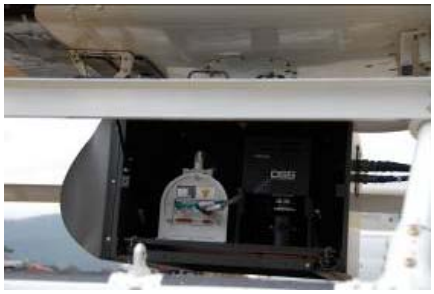
- Applanix DSS 439 camera system plus Q240i Laser scanner system mounted in Bell 206 heli pod
- Complete workflow software to generate orthomosaic maps, DEM, filtered point clouds ready for volume calculations
- Reasons:
  - DSS a turn-key, low-cost fully integrated mapping solution with GNSS, IMU, Flight Management system and ortho mapping software meeting GSD and accuracy requirements
  - DSS is certified mapping grade by USGS
  - Q240i meets point cloud density, range and accuracy requirements at relatively low cost
- Deliverables: Maximum One Week from flying

# Airborne System: Applanix DSS + LIDAR

Electronics

GNSS Antenna

Pod



Pod with Camera and Laser



# Terrestrial Requirements

- Provide point measurements for volume calculation of cut/fill areas
- Collection within one hour or less
- Ranges up to 300 m
- Point spacing 25 cm to 1.5 m, accuracy 10 cm RMS (max)
- Accuracy must be maintained even at bottom of dig with GPS satellites highly masked
- Georeferenced videolog of scanned area for visualization

# Terrestrial System: Trimble LANDMark

- Trimble LANDMark mobile mapping system configured with single video camera and Q240i laser scanner, highest accuracy RLG IMU (POS LV 610)
- Complete workflow sw for georeferencing video, and *same workflow* as airborne system for generating filtered point clouds
- Reasons:
  - Only needed single camera and scanner since always driving in and out of or around dig
  - Q240 meets point cloud density requirements and accuracy at low cost
  - Only highest accuracy IMU could maintain position accuracy during outages





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# Terrestrial System: Trimble LANDMark

Electronics

GNSS Antenna

Pod with Camera and Laser

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# Key Features

- Same laser scanner used in air and on ground
  - Built-in back up
  - Consistent error characteristics
- Same georeferencing workflow (Differential GNSS - Inertial processing)
- Same workflow used to generate/filter point clouds, generate DSM and do volume calculations
  - Check DSM accuracy against each other
  - Merge data sets









# Quality Control



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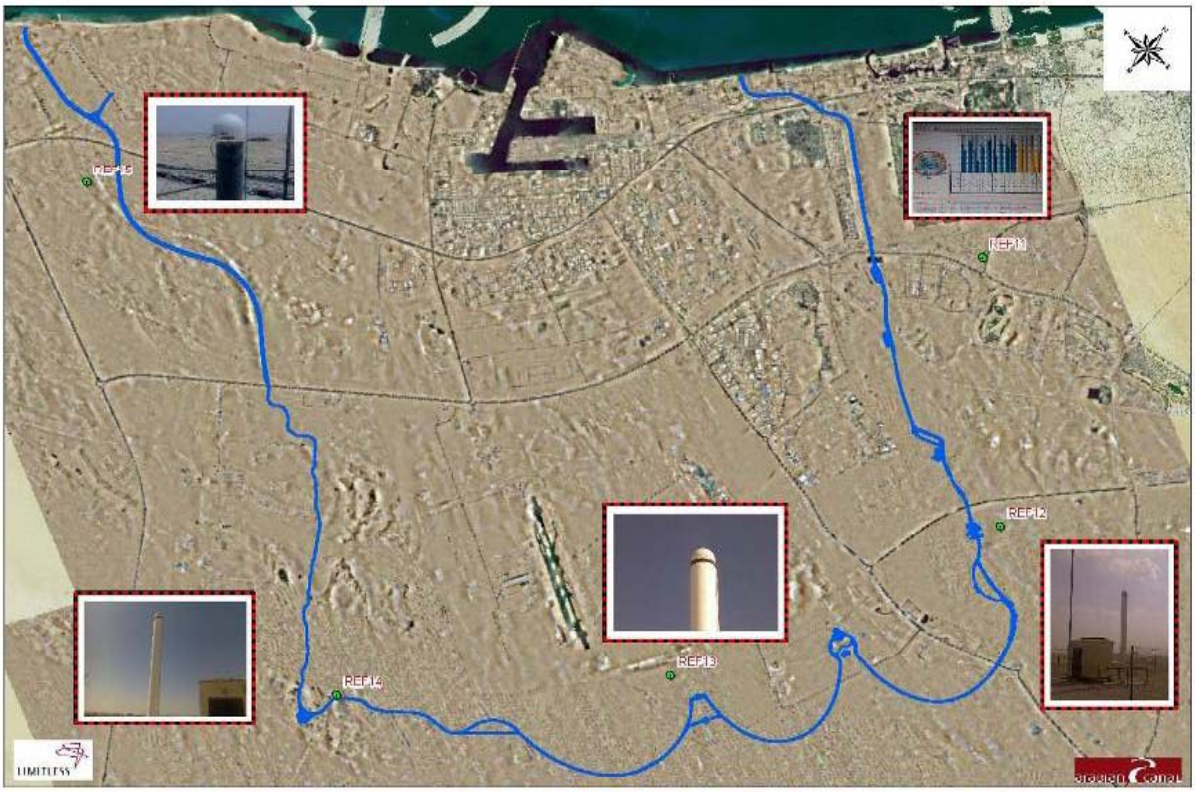
# Quality Control Methods

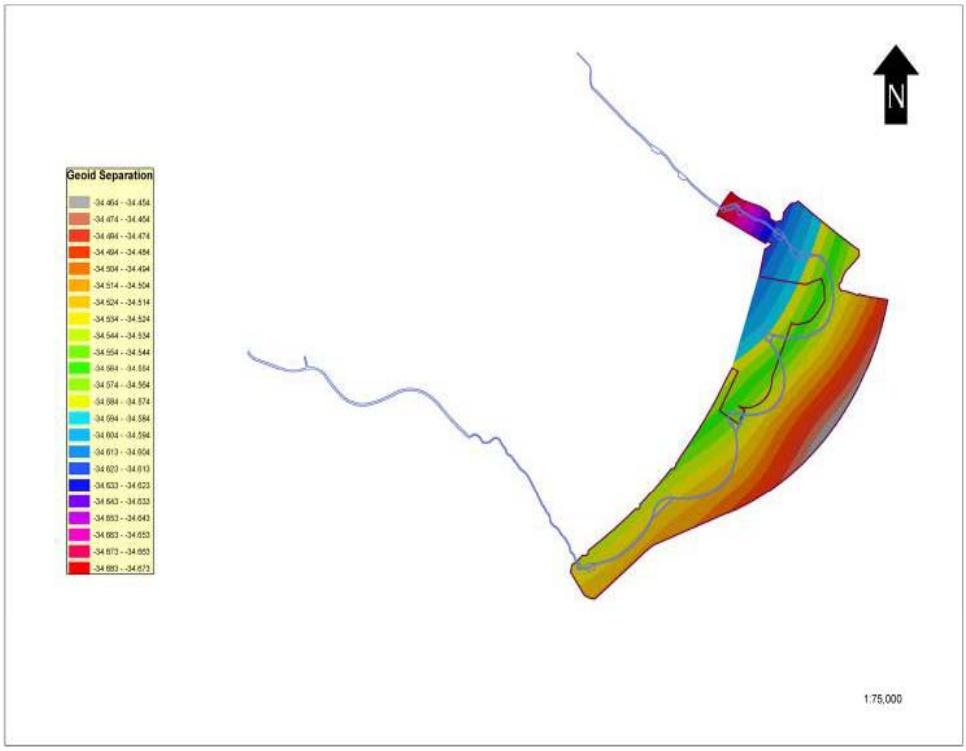
- Establish dedicated network of GNSS stations
- Establish control points in and around project areas:
  - Permanent
  - Temporary
- Establish local V datum and use throughout entire project
- Validate map and point cloud products against each other, control points and V datum, before generating final products



# GNSS Reference Station Layout



# Vertical Datum





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# Why GNSS is poor… (and QC so important!)

# Sample Data Products



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# Typical DSS Trajectory






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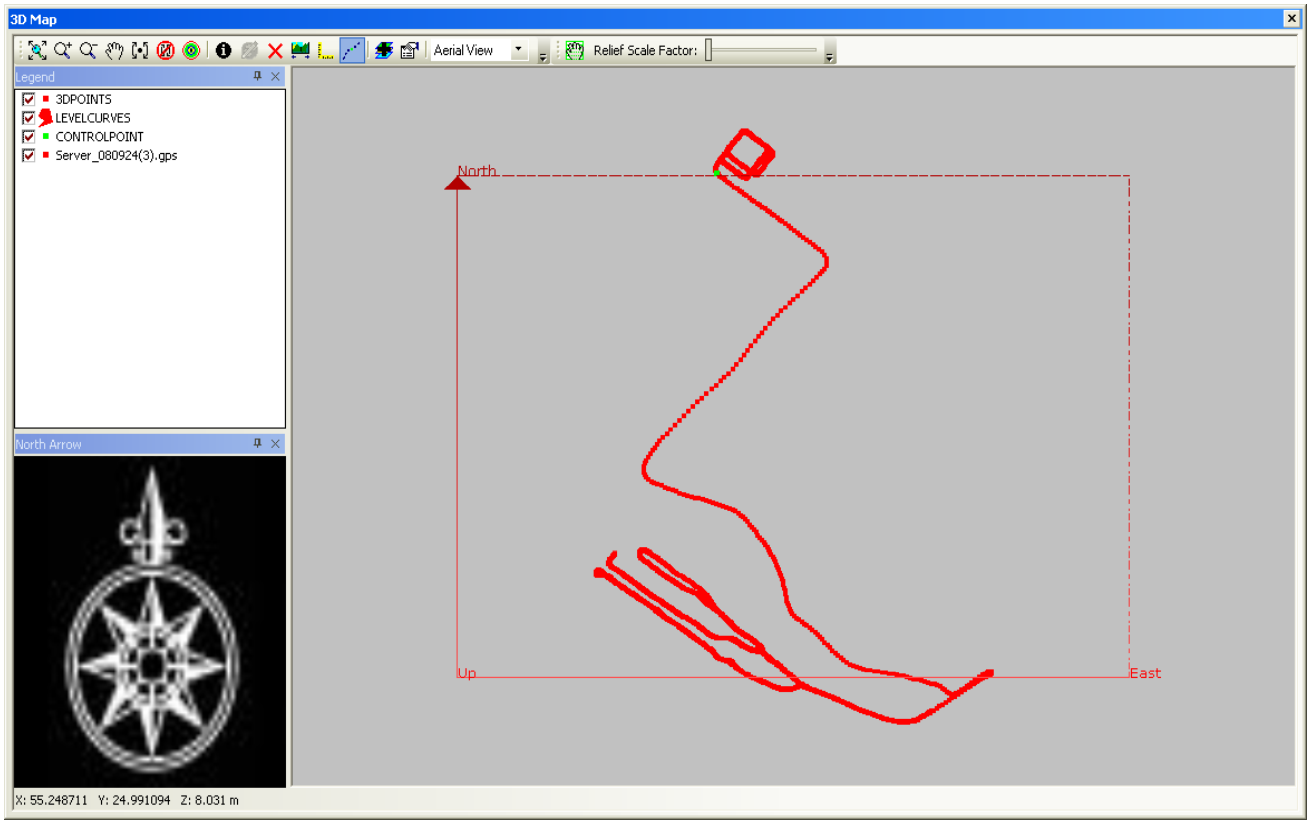
# Sample LANDMark Trajectory





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# Orthomosaic Map of Dig



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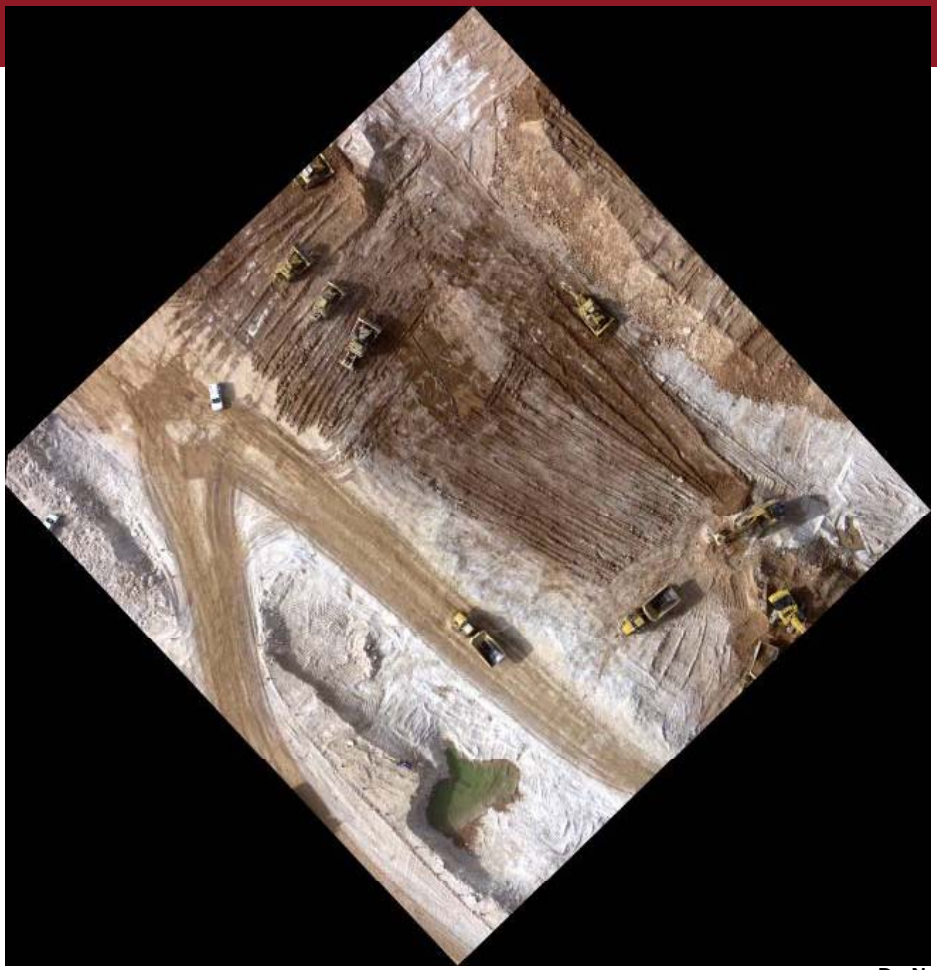
# Detail

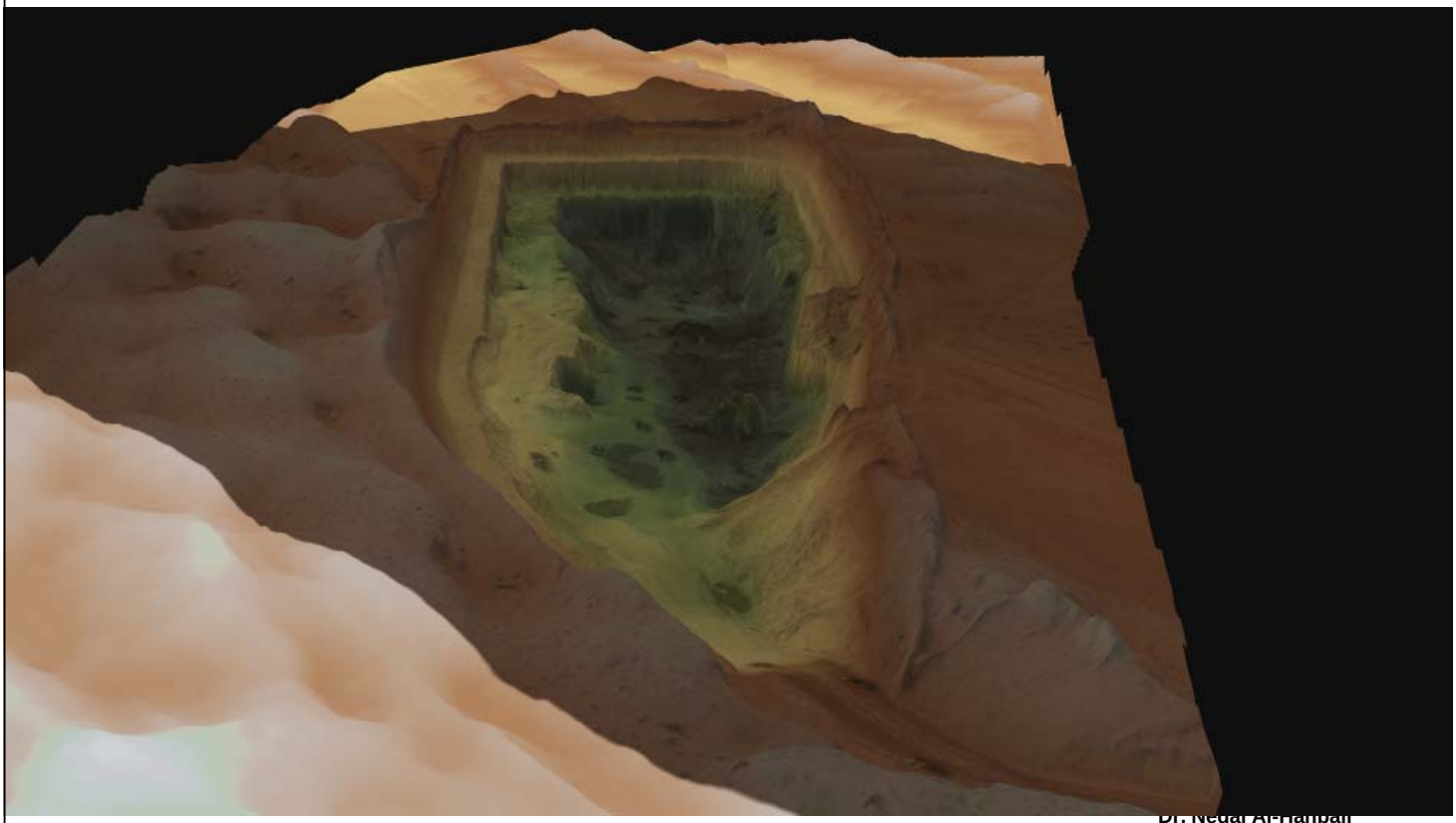




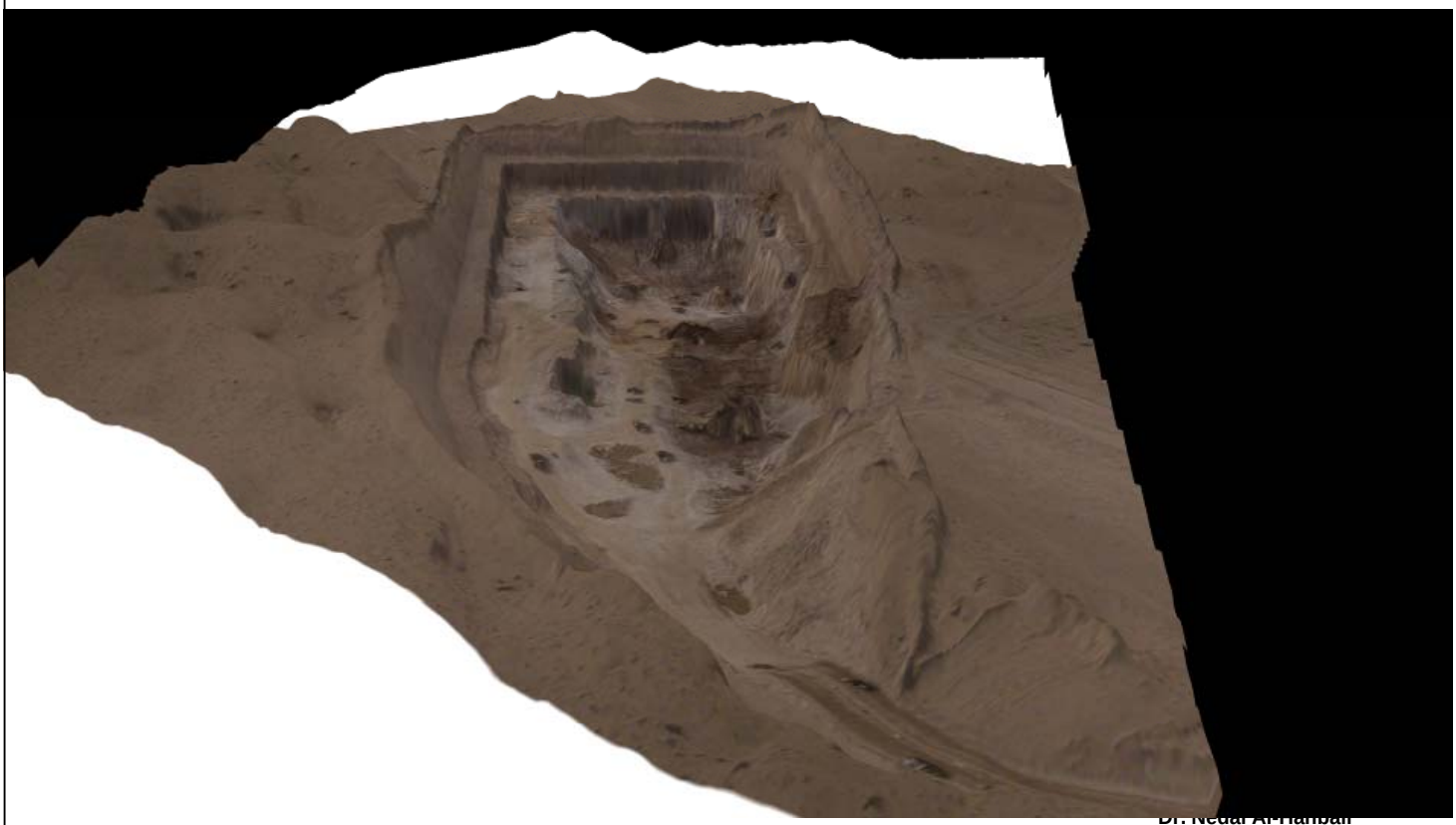




# Digital Surface Model (Airborne)



# Digital Surface Model (Airborne)





# Orthomosaic Map of Deposit

# Digital Surface Model (Airborne)



# View of Dig

# Local Hazards!

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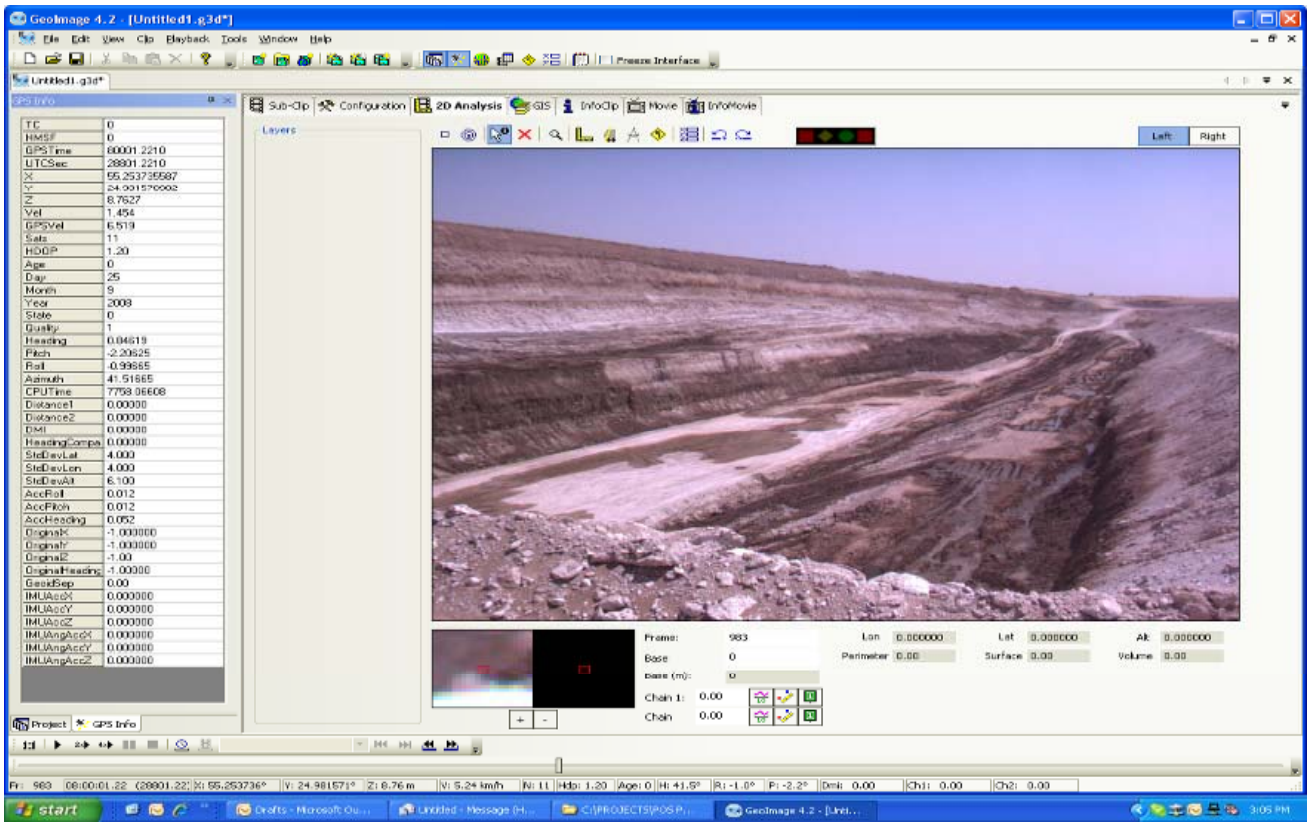
# View of Dig

Hanbali

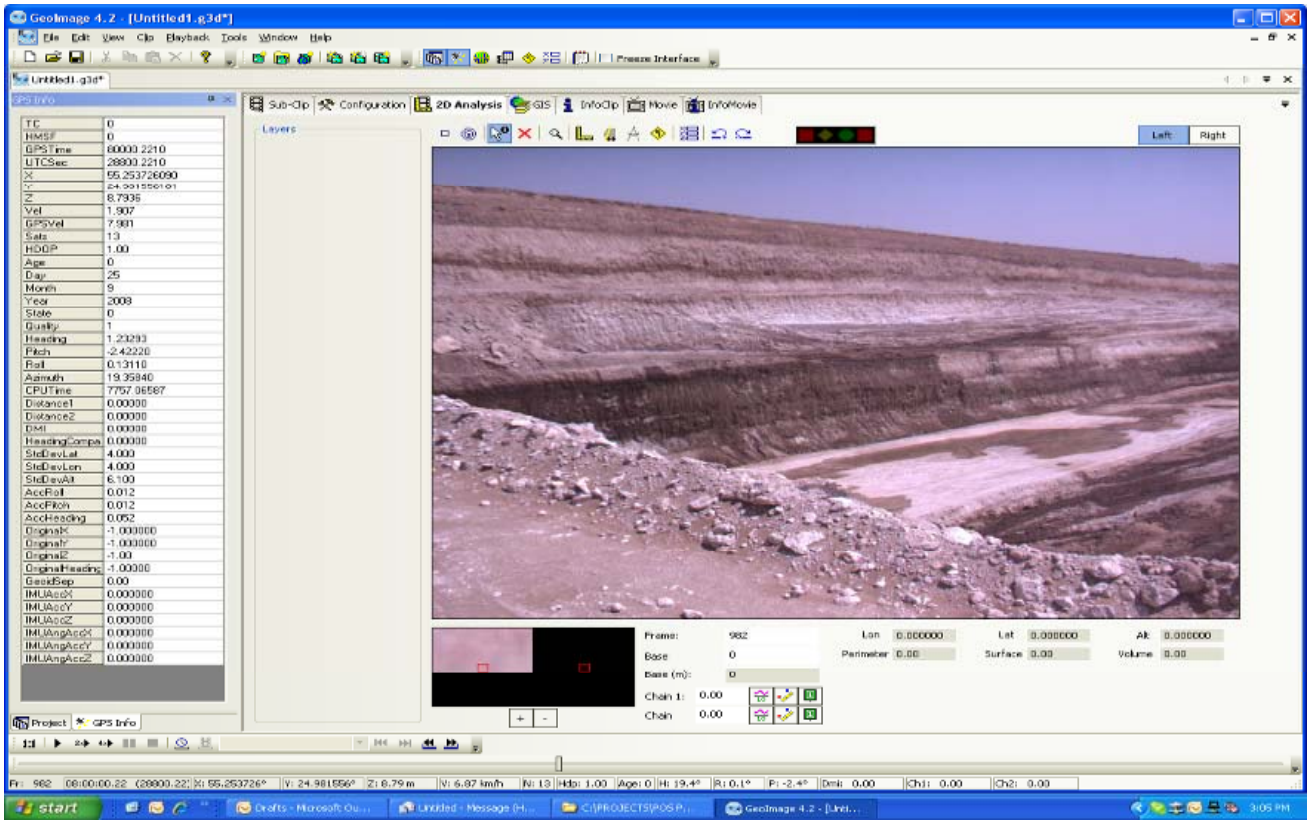
# View of Dig




# Georeferenced Video



# Georeferenced Video





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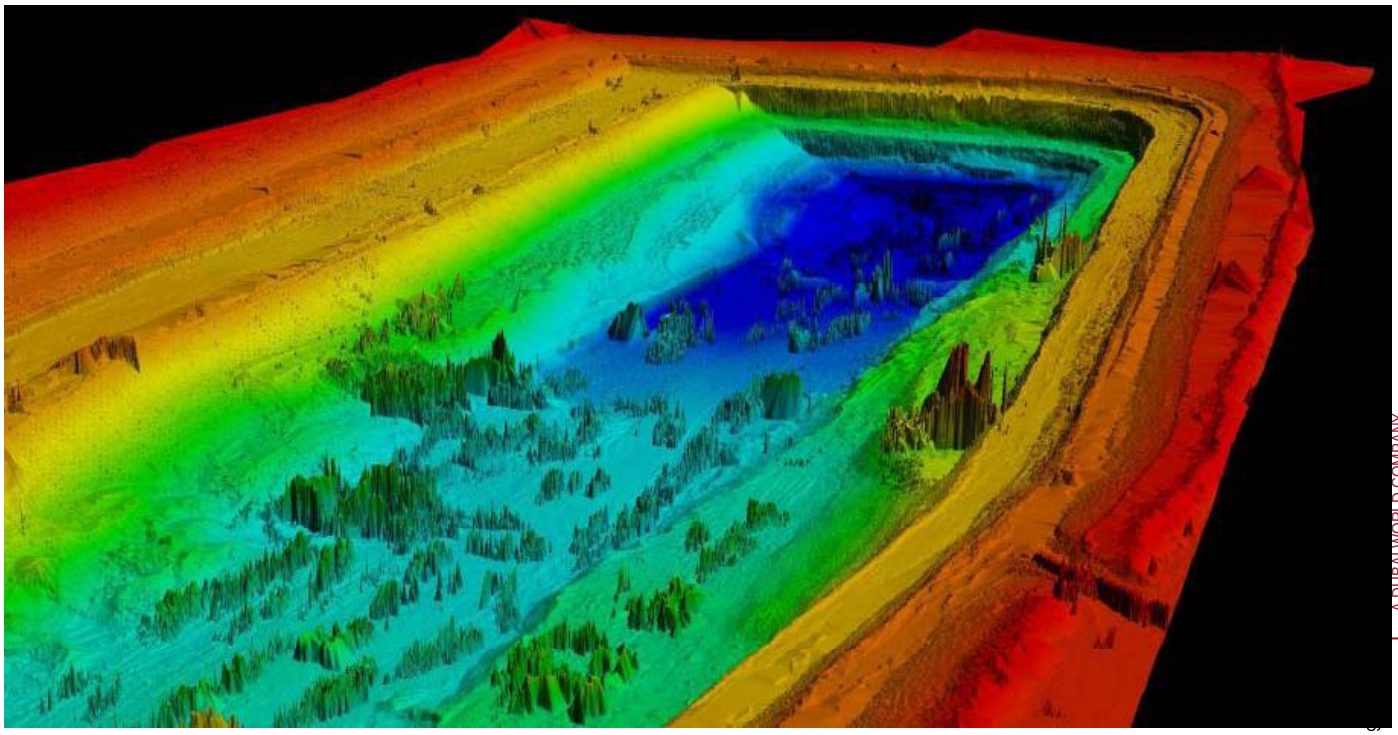
# Digital Surface Model (Terrestrial)





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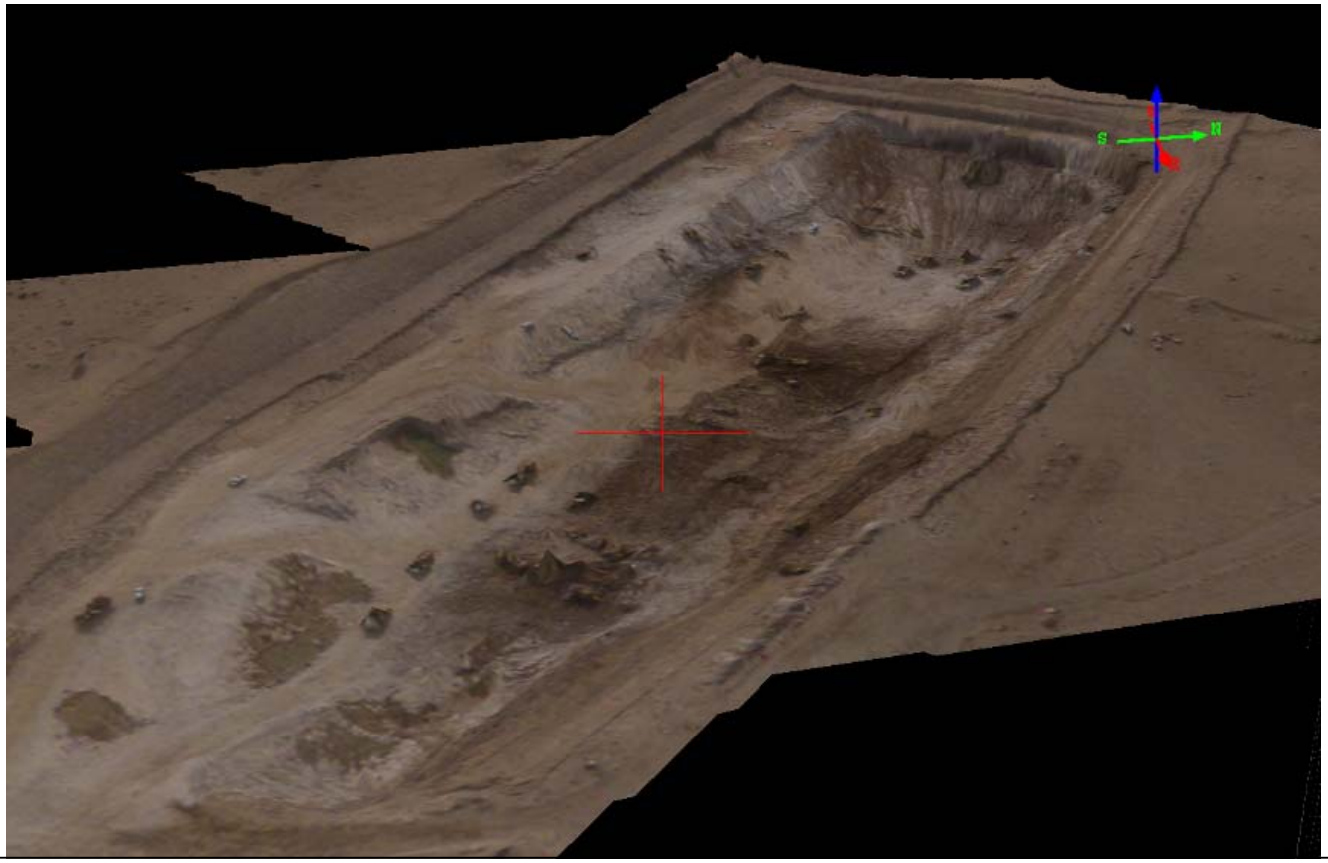
# Digital Surface Model (Terrestrial)










# Accuracy Assessment



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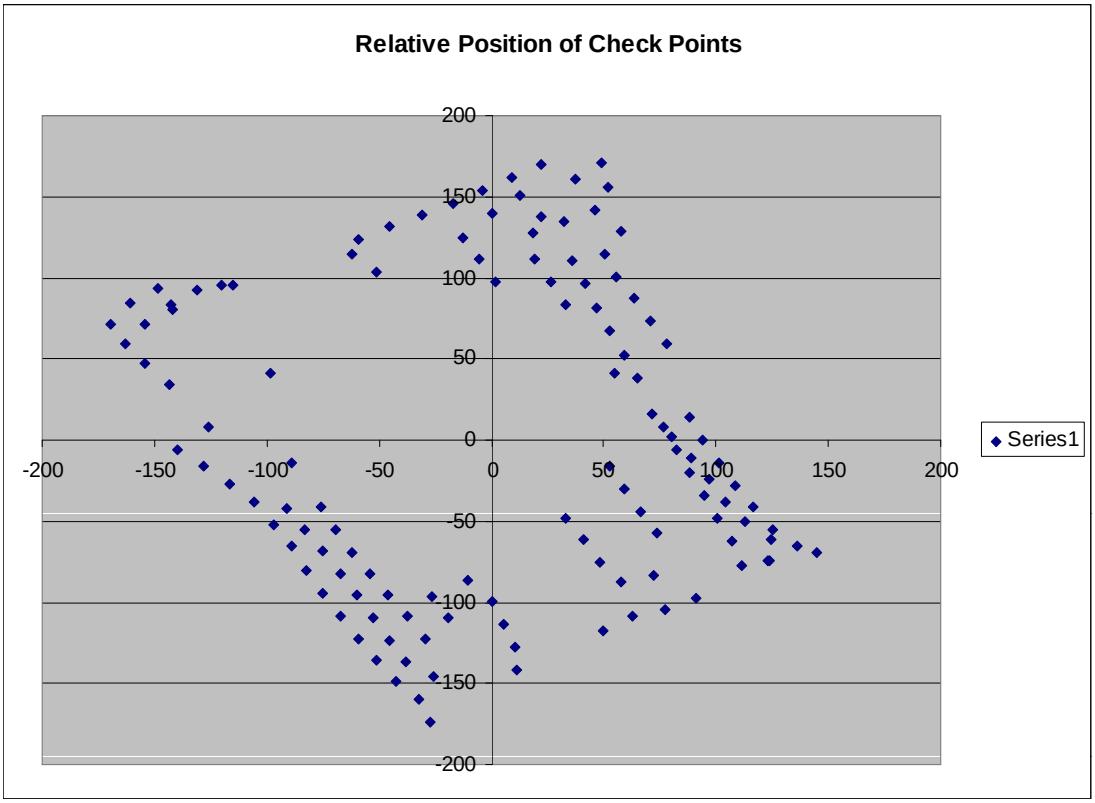
# Accuracy Assessments

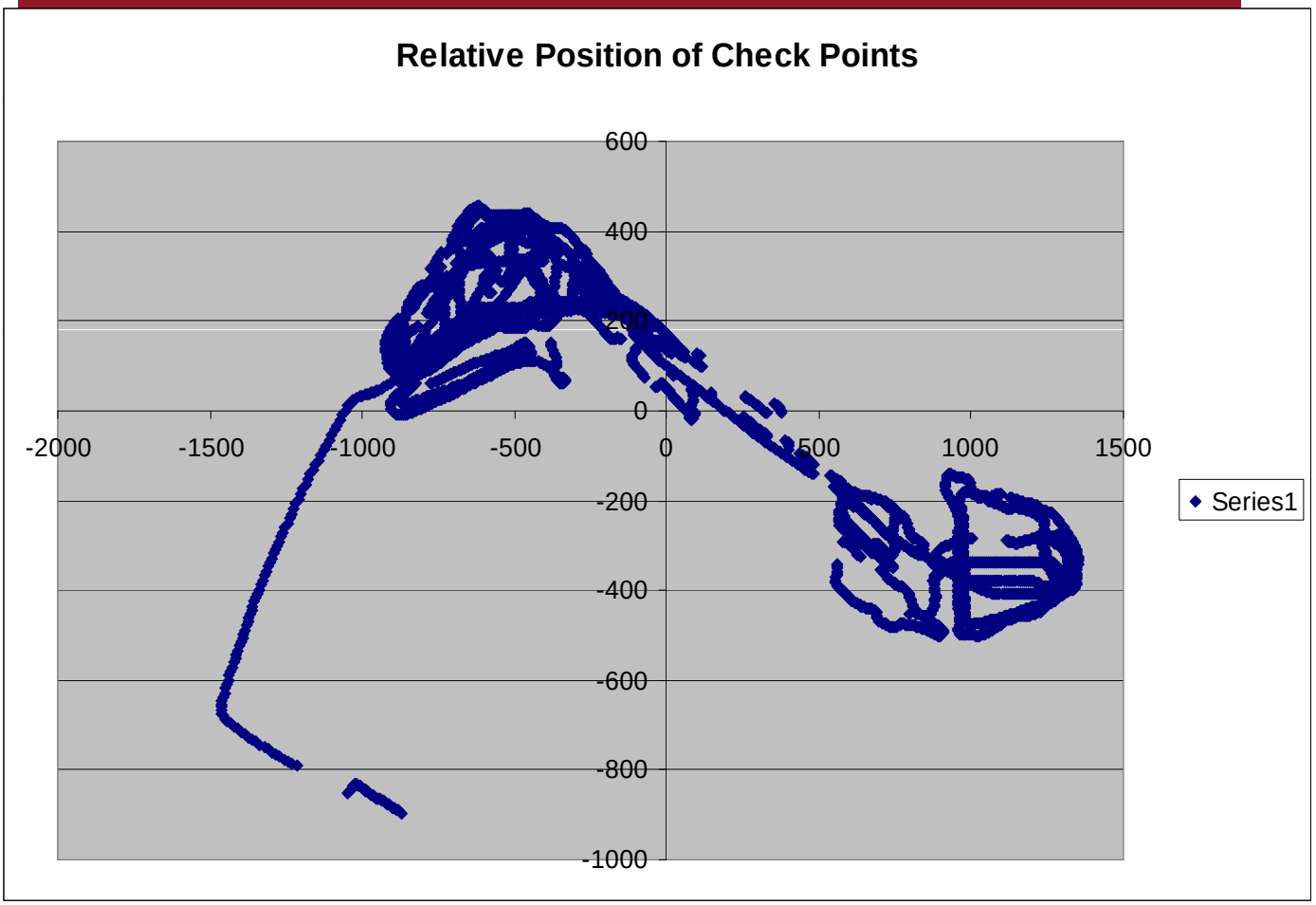
- Method 1: Traditional GCP analysis established using GPS (orthomaps and DSM)
- Method 2: Utilize car mounted RTK GNSS to get very dense point clouds of chosen areas and rings around the site (ie use RTK GNSS to create a reference surface model to compare to LANDMark and DSS LIDAR DSM)



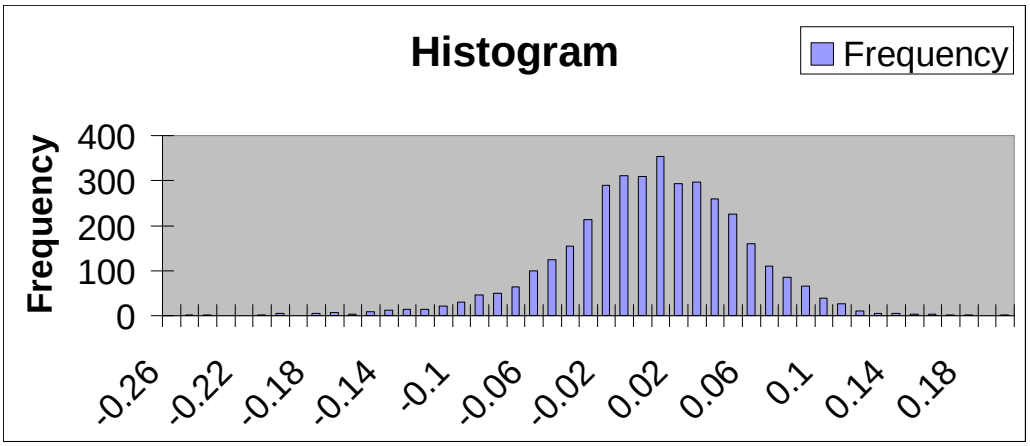
# Checkpoint Analysis



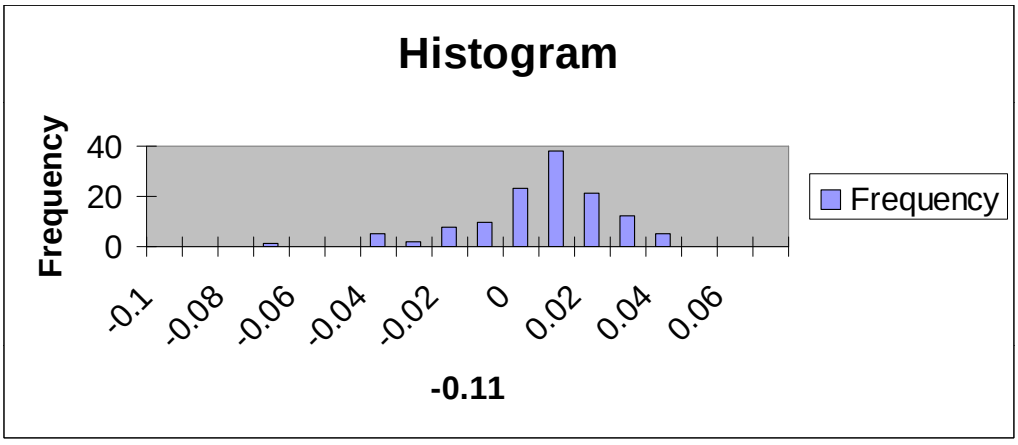
# Surface Analysis




# Typical Results, Vertical




| DSS System | | |
|---|---|---|
| Sigma 1 | Sigma 2 | Sigma 3 |
| 5 cm | 10 cm | 15 cm |
| area% | | |
| 0.7582 | 0.9588 | 0.9917 |




| Landmark System | | |
|---|---|---|
| Sigma 1 | Sigma 2 | Sigma 3 |
| 2 cm | 4 cm | 6 cm |
| area% | | |
| 0.80 | 0.99 | 1.00 |

# Vertical Accuracy Results

- Results from various tests for both LANDMark and DSS systems:
  - Average height offset: 6 to 8 cm
  - Standard deviation: 3 to 6 cm
  - RMS: 8 to 9 cm

- Notes:
  - systematic errors in GPS measurements are about 2-5 cm based on various aspects related to antenna base height due to terrain tilt (car tilting to one or to the other side); air-tires level.
  - In the area under heavy machinery work, errors vary from 5 to 15 cm due to Truck operation in the AOI changing ground heights.









# Final Deliverables



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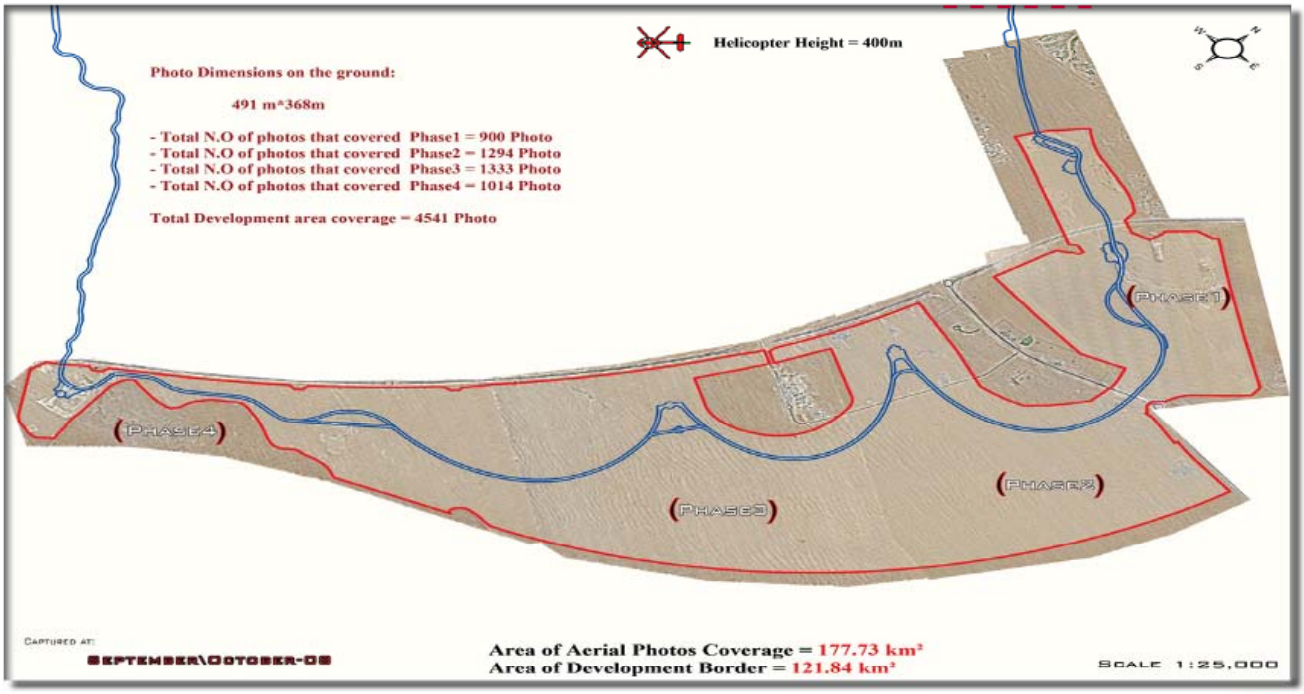
# Planning Map

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OrthoPhoto

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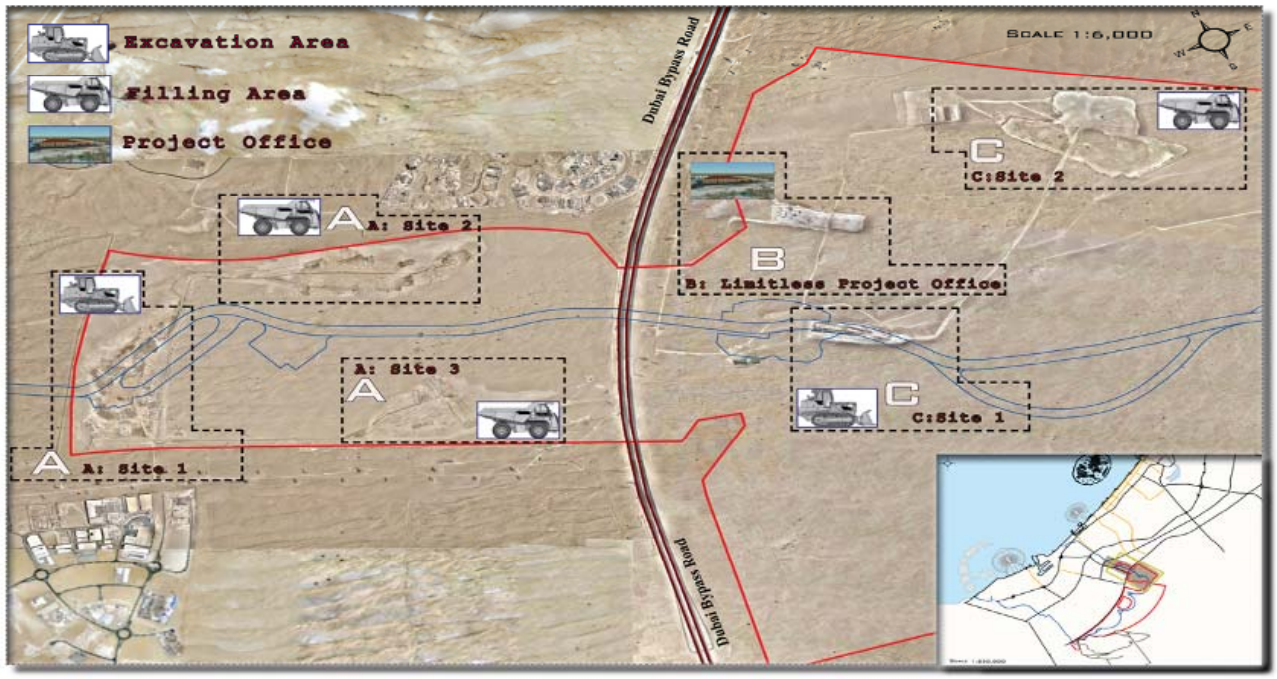
# Active Areas Map

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Excavation & Filling Sites

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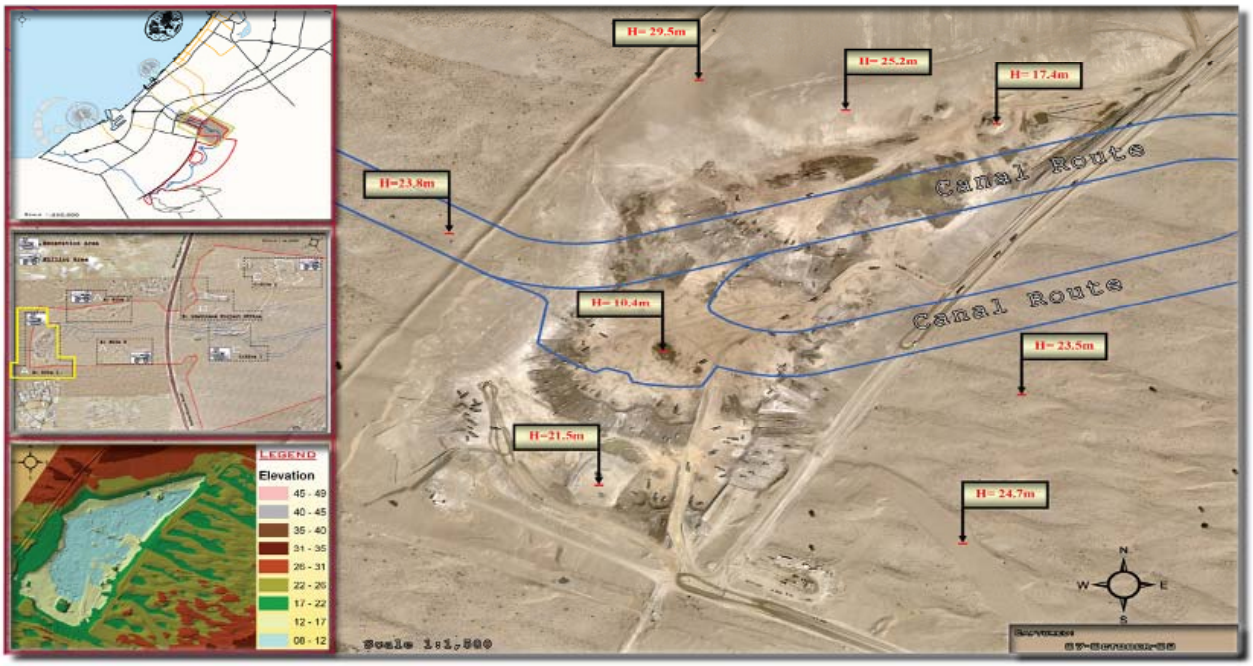
# 2D Progress Map

(A:Site 1): Deep Excavation

PHASE 1

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OrthoPhoto

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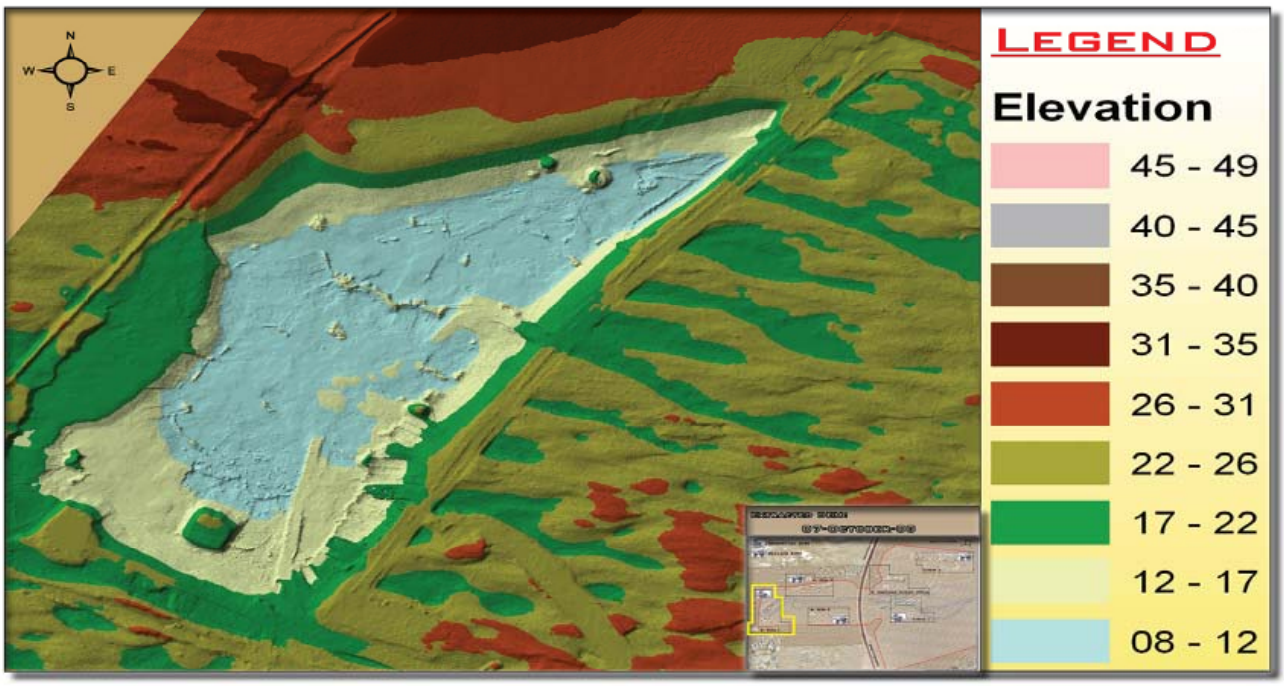
# 3D Progress Map

(A:Site 1): Deep Excavation

PHASE 1

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Depth Color Coded

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# 3D Progress Map

(A:Site 1): Deep Excavation

PHASE 1


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Perspective View

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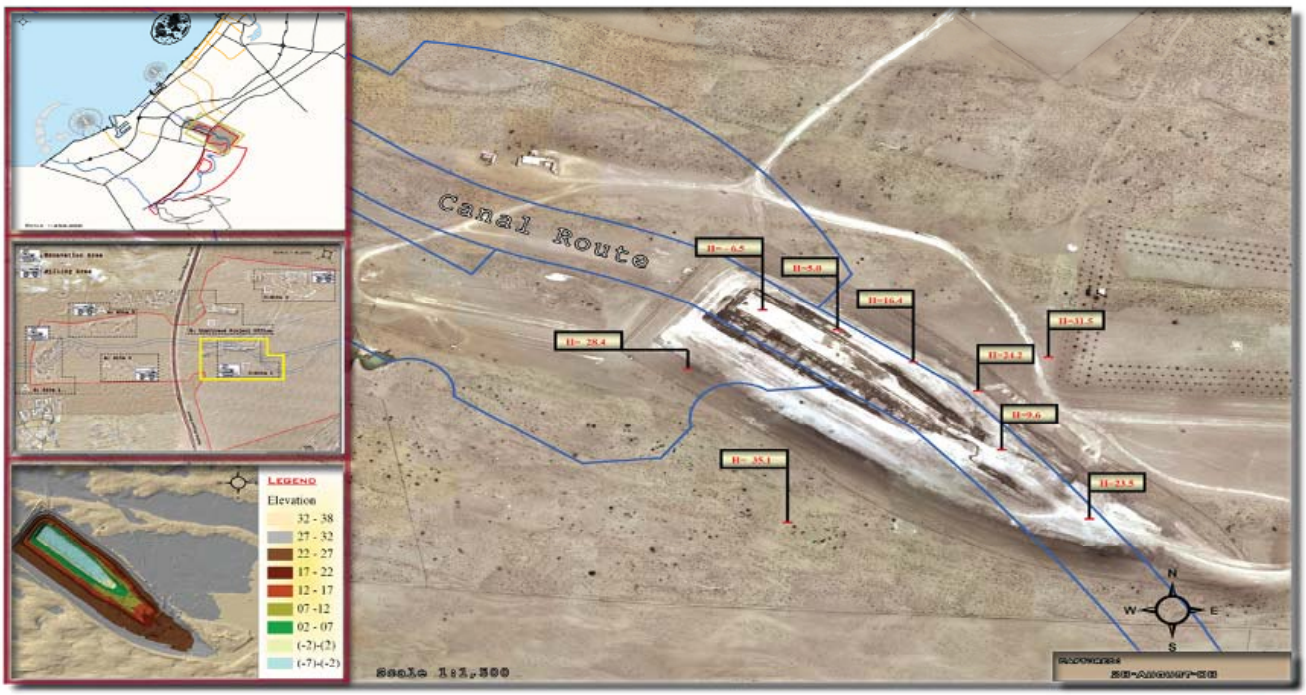
# 2D Progress Map

(C:Site 1): Deep Excavation

PHASE 1




20 | arabian canal

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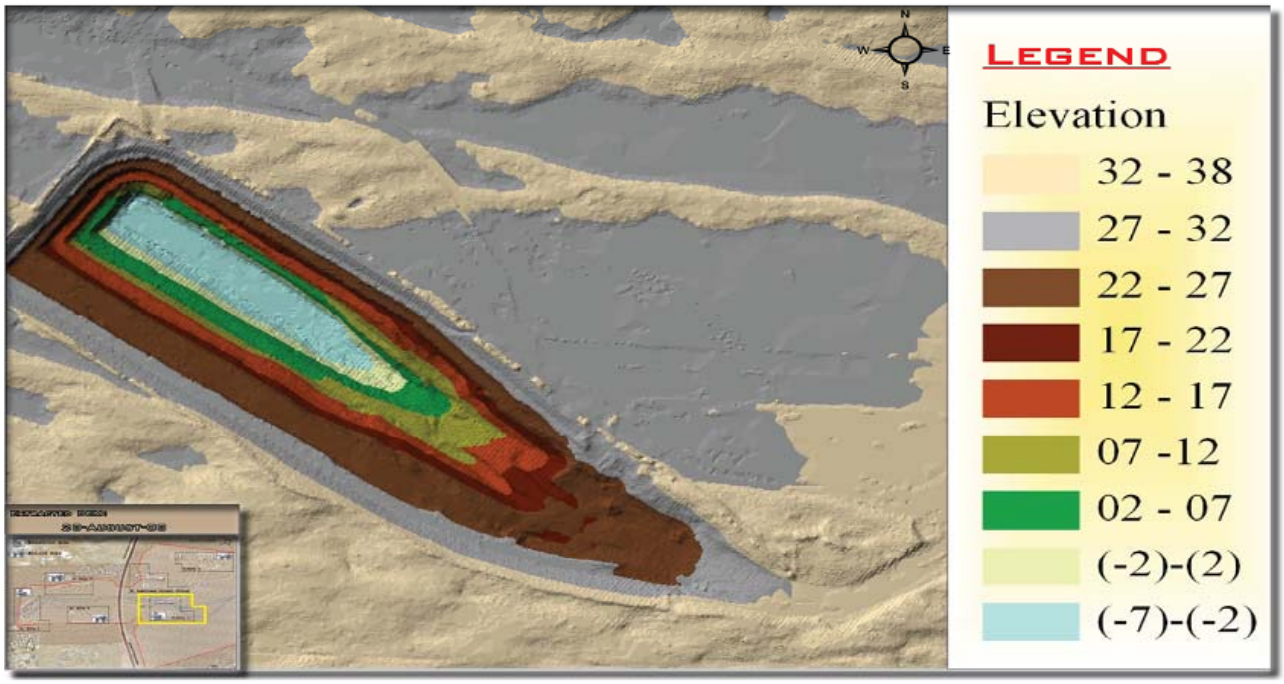
# 3D Progress Map

(C:Site 1): Deep Excavation

PHASE 1

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Depth Color Coded

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# 3D Progress Map

(C:Site 1): Deep Excavation

PHASE 1

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3D View

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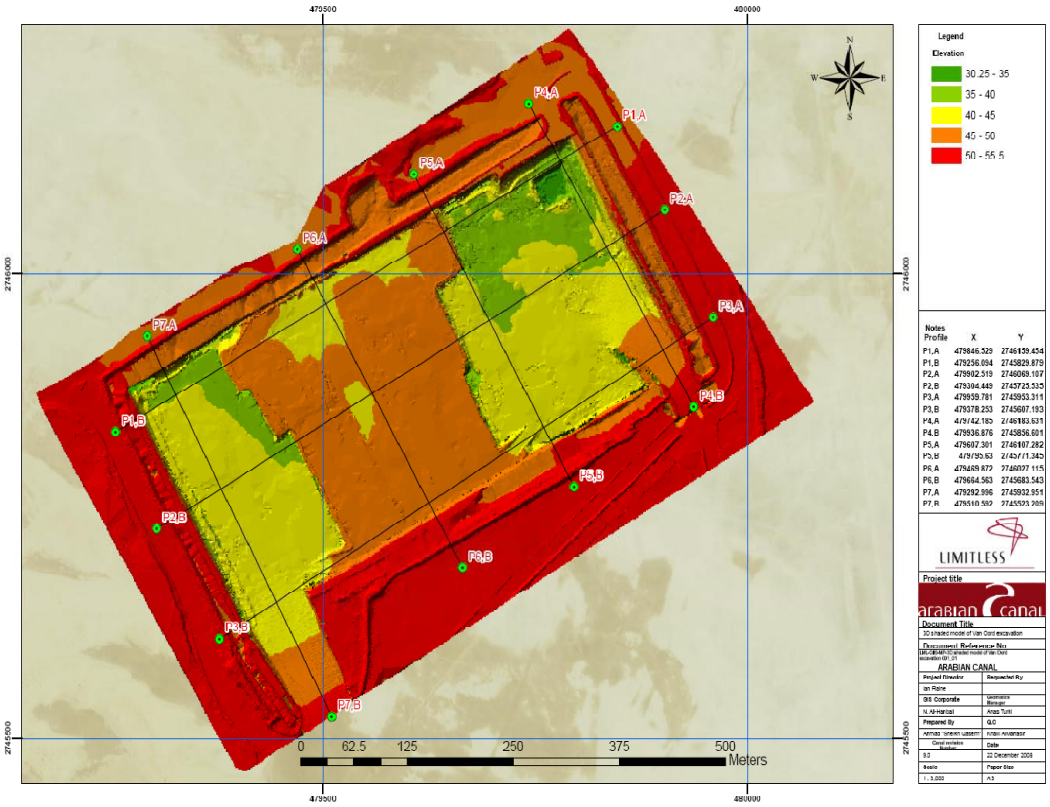
# 3D Volume Map, Dig





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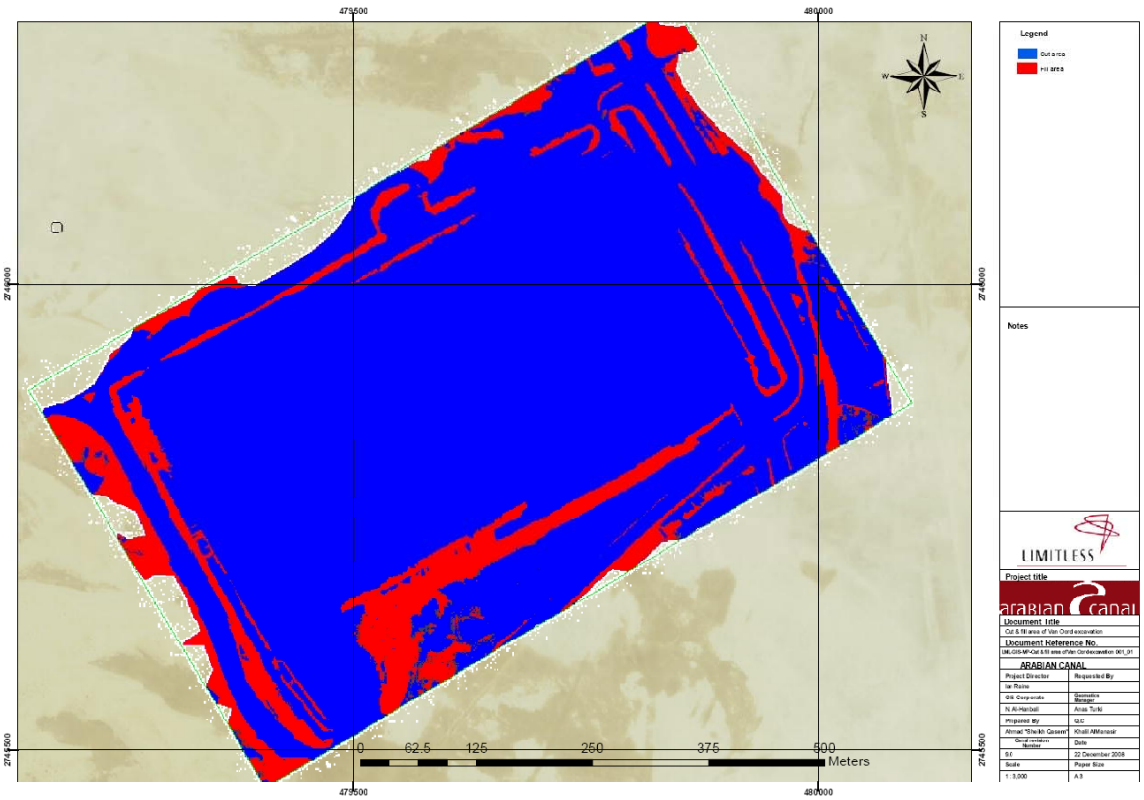
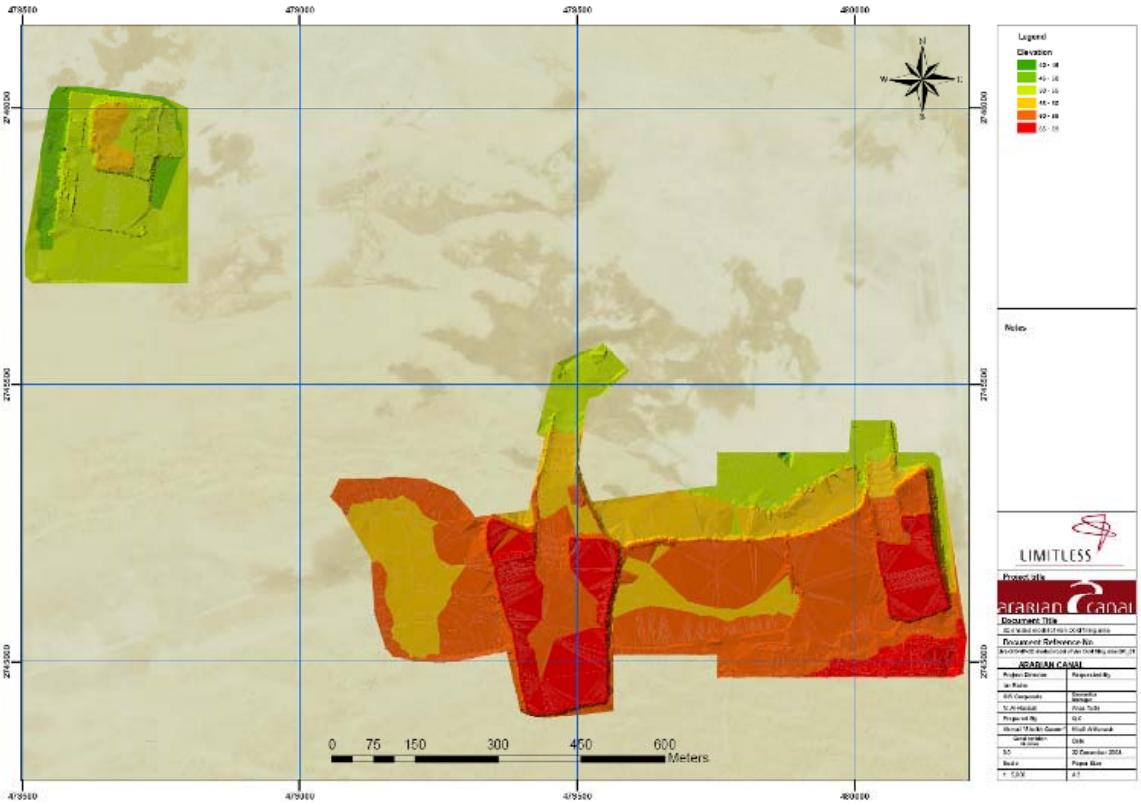
# Cut/Fill Area wrt Base Survey



# 3D Volume Map, Deposit

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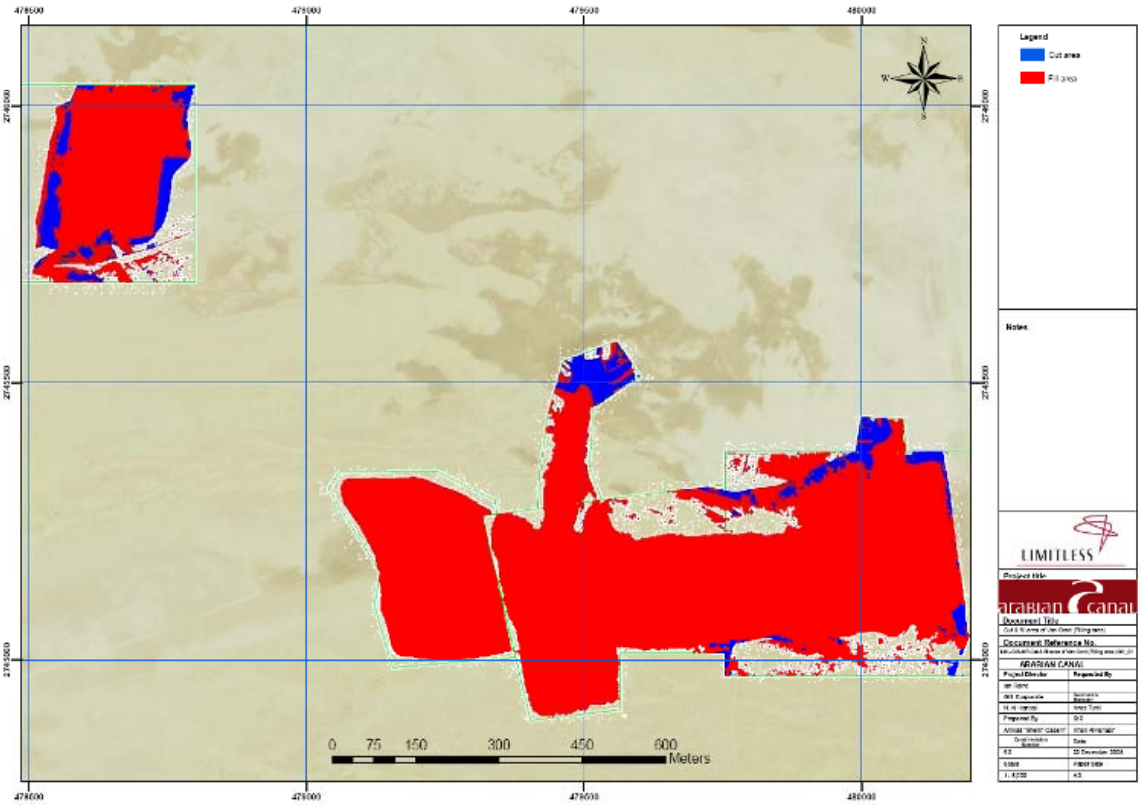
# Cut/Fill Areas wrt Base Survey



# Progress Snapshot

arabian canal

October 2008

January 2009

March 2009

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# Summary



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# Conclusion

Limitless Geomatics Information System Department has proven that an integrated airborne and land mobile mapping system is the preferred approach for earthwork monitoring for the Arabian Canal project:

- Traditional earthwork monitoring surveying techniques imposed a significant risk as far as data acquisition completion during the allocated time.
- Traditional techniques could have resulted in huge cost overruns if earthwork progress had been delayed and not detected on time.
- Higher mobile mapping system cost is well absorbed due to its efficiency over traditional techniques, especially in large areas
- Mobile Mapping systems provide high accuracy and short turn around compared to traditional techniques
- Mobile Mapping systems eliminate schedule risk
- Integrated Airborne/land mobile mapping systems reduce any accuracy risk due to their complementary nature.





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# Results to Date

- The airborne DSS system can collect 25 km^2 within four hours of flying, while the LANDMark system covers 100 hectares mapped in an hour
- Final 3D map products meeting accuracy requirements for volume calculation are routinely produced within 1 week:
  - Current bottlenecks are in the point cloud filtering and redundancy checking
  - Efforts are underway to automate both and reduce turn-around time to < 3 days
- **Proven ability to produce accurate measurements in a short time, reinforcing our distinctive, innovative approach to development.**





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