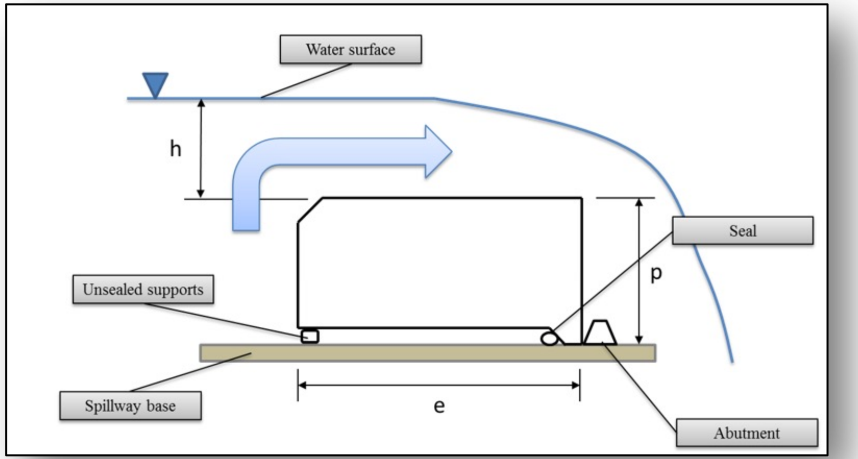
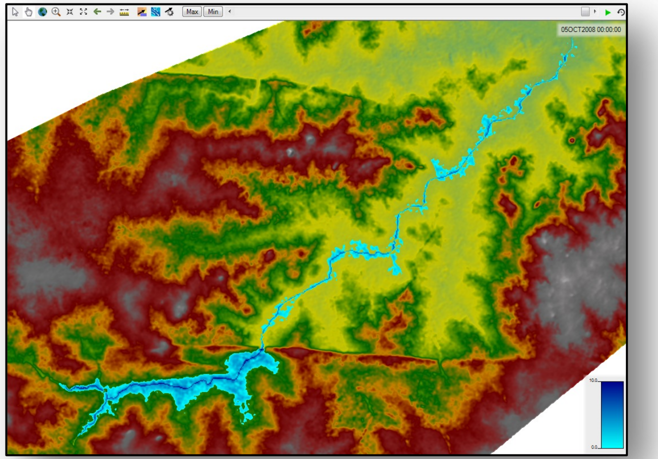
Hydrological and hydraulic modelling of concrete fuse plug operation for small dams

Presented by Maxim Fortin, P. Eng., M.Sc.





Presenter

- Maxim Fortin, Water Resources Engineer & Project Manager based in Canada specialized in WASH for development, flood management and modelling

- Research project completed as part of WEDC M.Sc. in Water and Waste Engineering Program (2016) and in collaboration with Cowater International-implemented ECED-Sahel Project (funded in Burkina Faso by Global Affairs Canada, IAMGOLD and One Drop Foundation)

Research Project Aim and Objectives

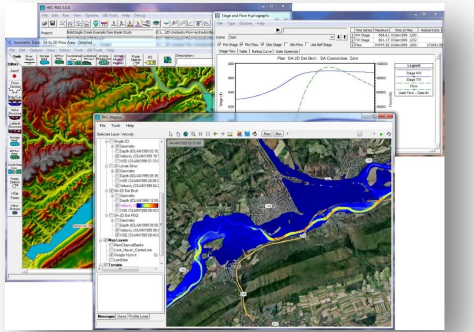
Assess the use of concrete fuse plugs to increase storage capacity and spillway discharge for Yacouta Dam (Burkina Faso)

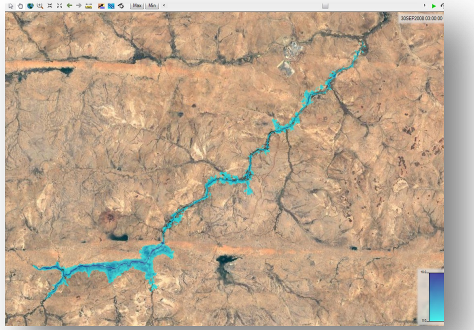
→

Identify a low-cost hydrological and hydraulic modeling methodology for flood mapping

→

Develop methodology to model river floods caused by the operation of concrete fuse plugs on small dams

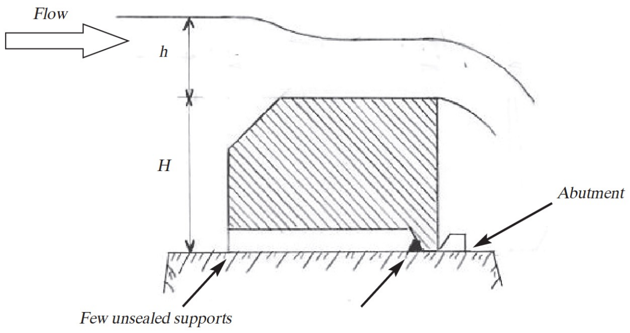




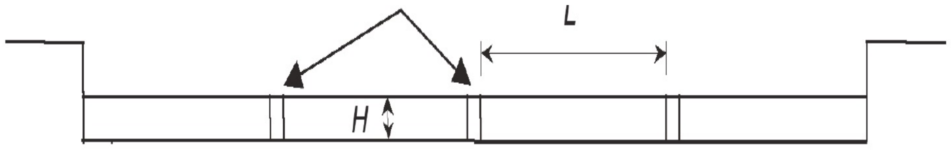
Project Aim and Objectives

- What are concrete fuse plugs?
  - Concept first introduced in 2010 by the Committee on Costs Savings in Dam Construction of the International Commission on Large Dams (ICOLD, 2010)
  - Simple, massive concrete blocks placed side-by-side on a spillway crest of sill
  - Blocks are sized to be free standing until water in the reservoir reaches a certain level, where they start tilting and are pushed out of the spillway
  - Can be designed to increase dam safety OR increase available storage
  - Three installations documented in Vietnam and Burkina Faso (Nombré, 2016)
  - More advanced versions also developed (i.e. Hydroplus Fuse Gate)

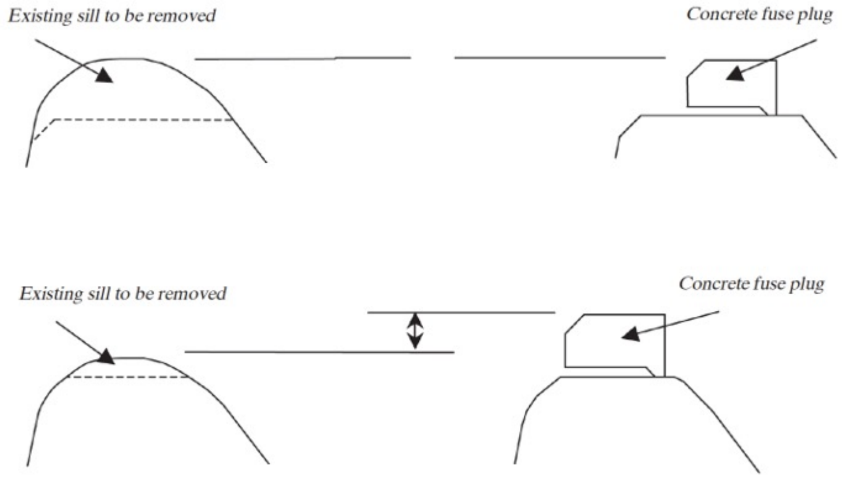
Cross section view:



Front view:



Cross section of configuration depending on objective (increase safety or storage):



Source: ICOLD, 2010

Research Plan

Literature Review
- Spillway enhancement options
- Hydraulic modeling for dam and flooding analysis
- Yacouta Dam

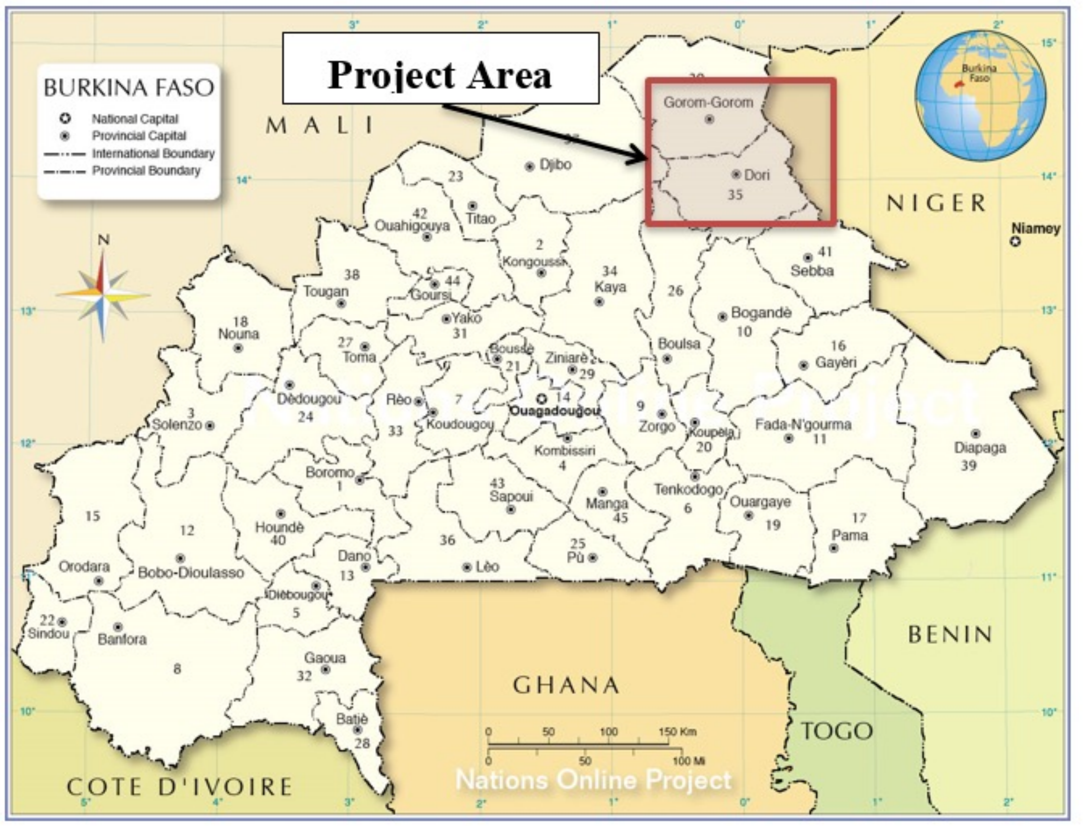
Concrete Fuse Plug Design
- Preliminary design

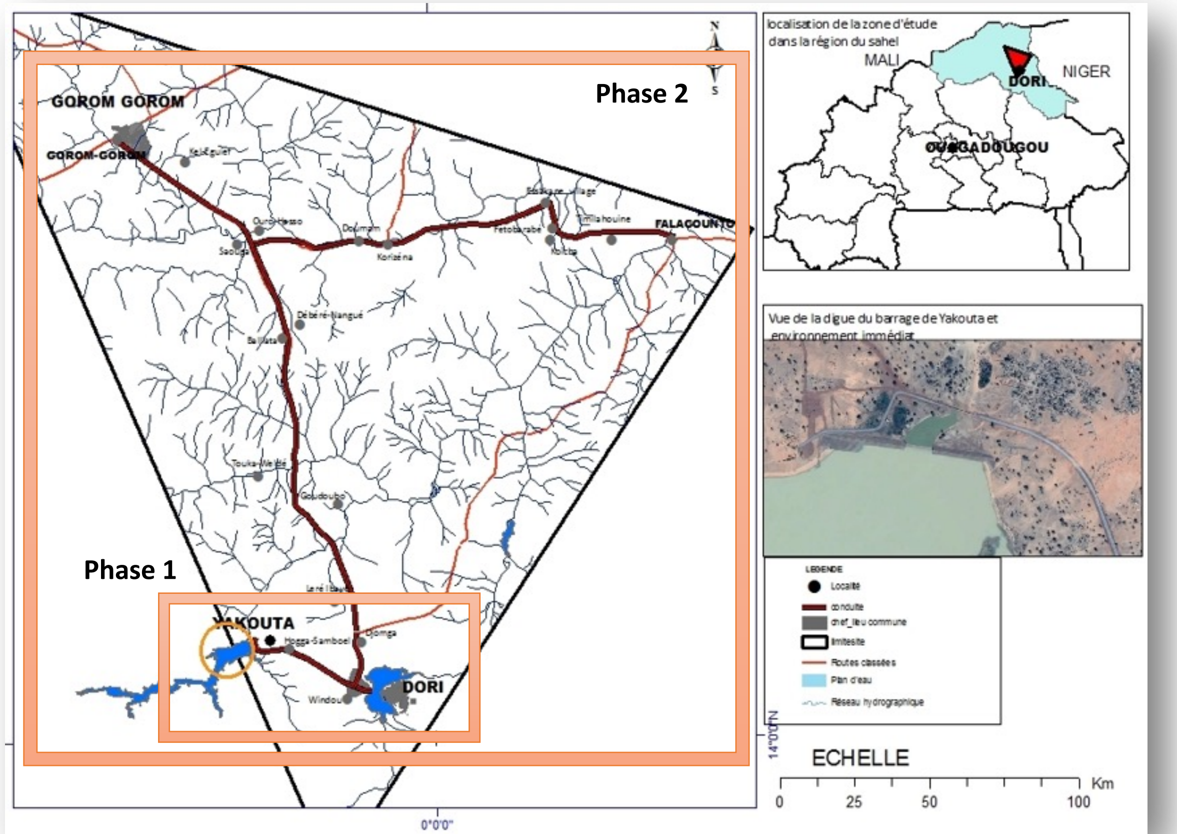
Hydraulic Modeling
- Prepare data inputs (geospatial and hydrology)
- Develop hydraulic model
- Validate model
- Document the approach

Data Analysis
- Run model according to different scenarios
- Evaluate flooding extent
- Analyse results and prepare recommendations

Case Study: Yacouta Dam, Burkina Faso

- Key component of ECED-Sahel: a large-scale regional drinking water supply project in the Sahel region of Burkina Faso:
  - Phase 1: supply drinking water to city of Dori and 20 neighboring villages (40,000 people)
  - Phase 2: expand water supply production to towns of Gorom-Gorom and Falagountou and neighboring villages (100,000+ people)
- Dam completed in 2005, earth embankment, 765 m long and 9.5 m high with an estimated storage capacity of 26 M m^3 on the Goudebo River (ONBAH, 1999)
- Hydrological study shows that there is a risk of water deficit every 8 years, below the set of criteria of 10 years, if phase 2 is implemented (IFEC, 2016)
- Recommendation to increase available storage by either decreasing elevation of water intake or **increasing invert elevation of spillway** (+50 cm = + 8.56 M m^3)





Source: Nations Online, 2016 (left) and Cowater, 2016 (right)

Source: Cowater, 2016

Case Study: Yacouta Dam, Burkina Faso

- Research considerations in the context of the ECED-Sahel project:
  - Could concrete fuse plugs be used to increase available storage for the Yacouta Dam and increase water security for an eventual phase 2 of the project?
  - Would the operation of the concrete fuse plugs during a flood event create a flood wave that would significantly increase flood risks for the main town of Falagountou (10,000 people), located about 50 km downstream of the dam?
  - Can free software tools and datasets be used to assess this flood risk (order-of-magnitude) and could the methodology replicated in a developing country context?

Case Study: Yacouta Dam

- Concrete fuse plug design

Simplified formula for preliminary sizing (Hydrocoop, 2013):

$$E = h + 0.4*P$$

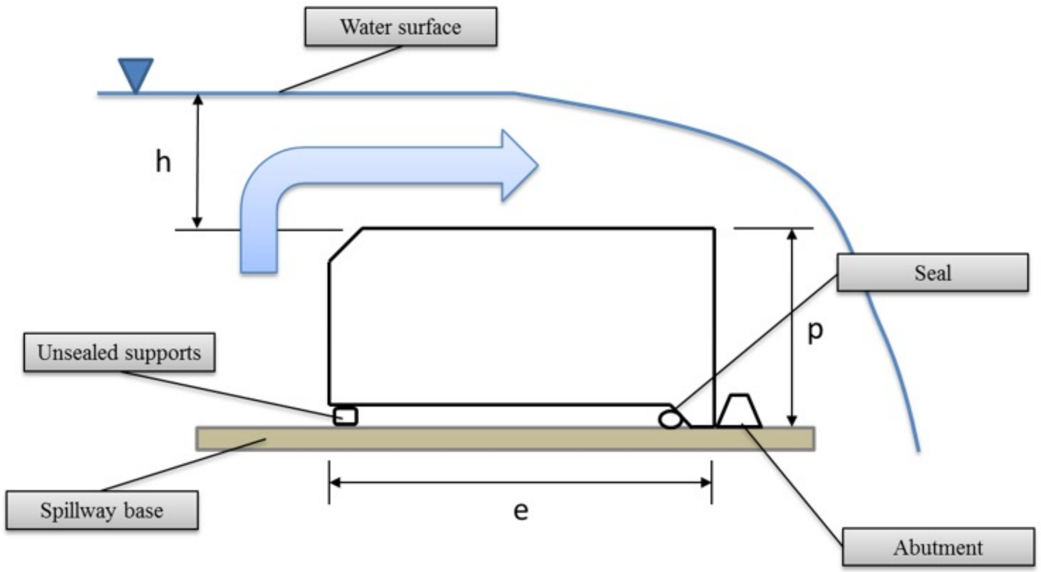
Where:

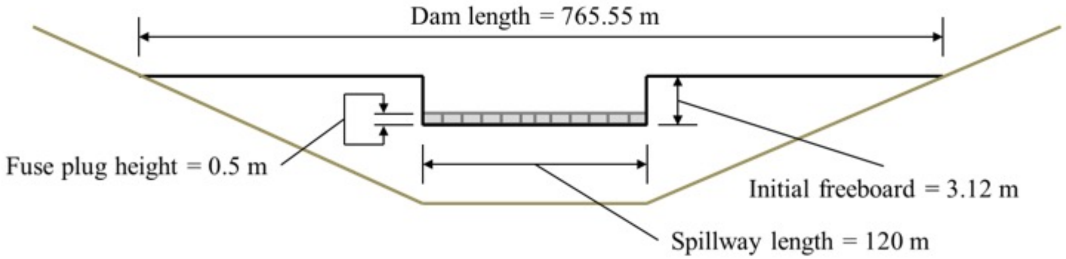
E = Upstream to downstream base width of plug (m)

h = Upstream water depth over plug for tilting (m)

P = Height of fuse plug (m)

Schematics of results for Yacouta Dam (cross-section and front view):



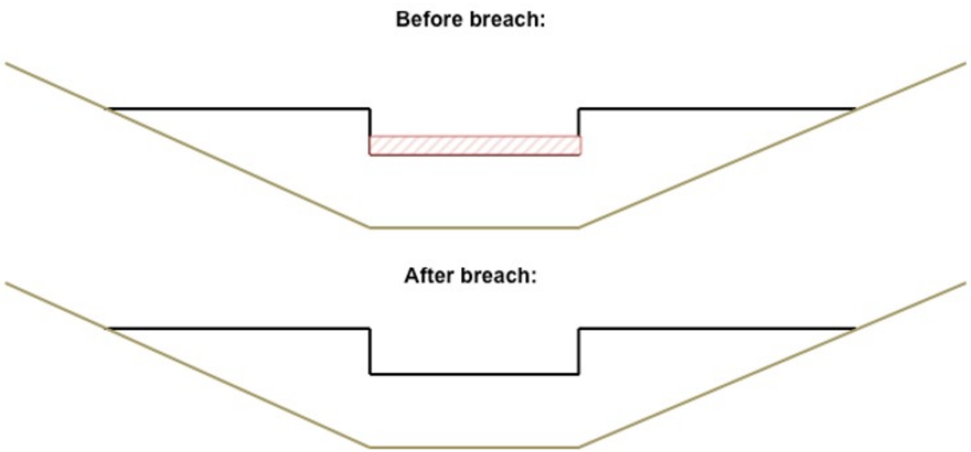


Case Study: Yacouta Dam

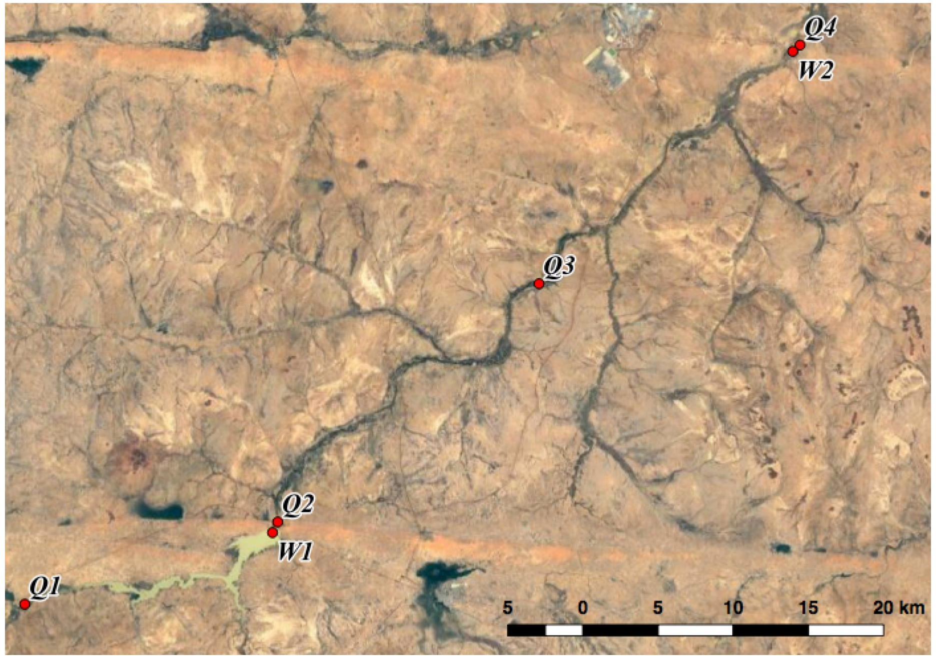
- Hydrological and hydraulic modeling:
  - 100-year inflow design flood (IDF) from dam design study used to simulate fuse plug behavior / trigger water level (350 m^3/s)
  - ASTER GDEMV2 used for Digital Terrain Model – DTM with an average vertical error of 8.8 m (NASA, 2011)
  - DTM modified with simplified watercourse geometry / bathymetry
  - 2D hydraulic modeling approach using free software HEC-RAS for modeling and open-source QGIS for geospatial data preparation
  - Operation of concrete fuse plug simulated based on overtopping style dam breach feature
  - Simulation results obtained for 3 scenarios:
    - Scenario 1 – Baseline (concrete fuse plug is in place but not operated)
    - Scenario 2 – Concrete fuse plug operated over 1 minute
    - Scenario 3 – Concrete fuse plug operated over 12 hours

Case Study: Yacouta Dam

Schematic of dam breach shape definition:

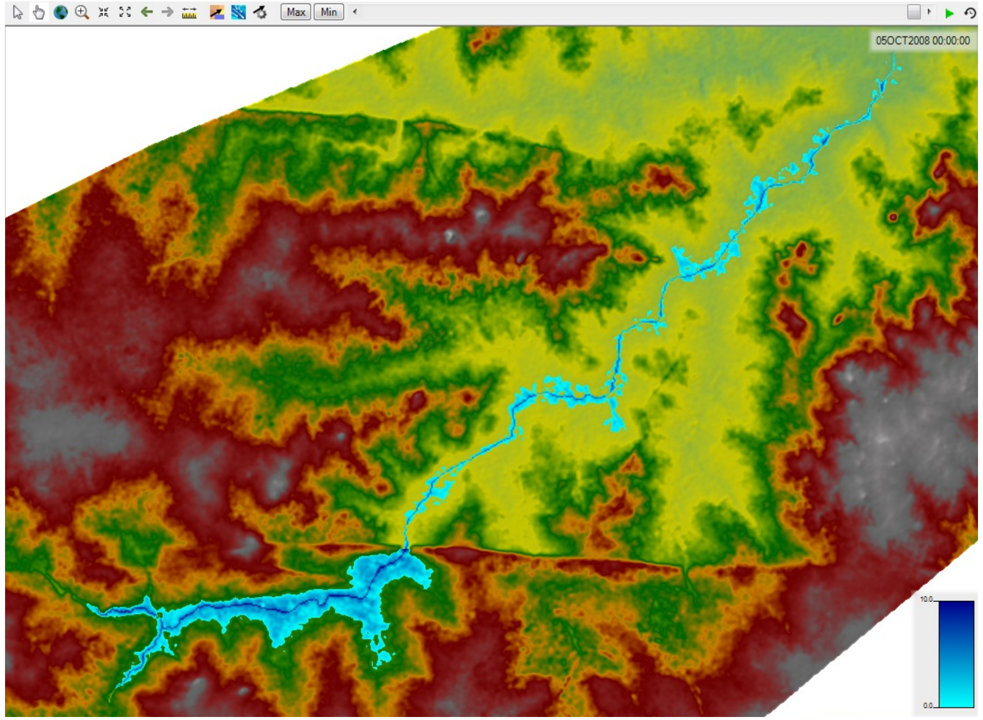


Comparison points over project area (flow and water levels):

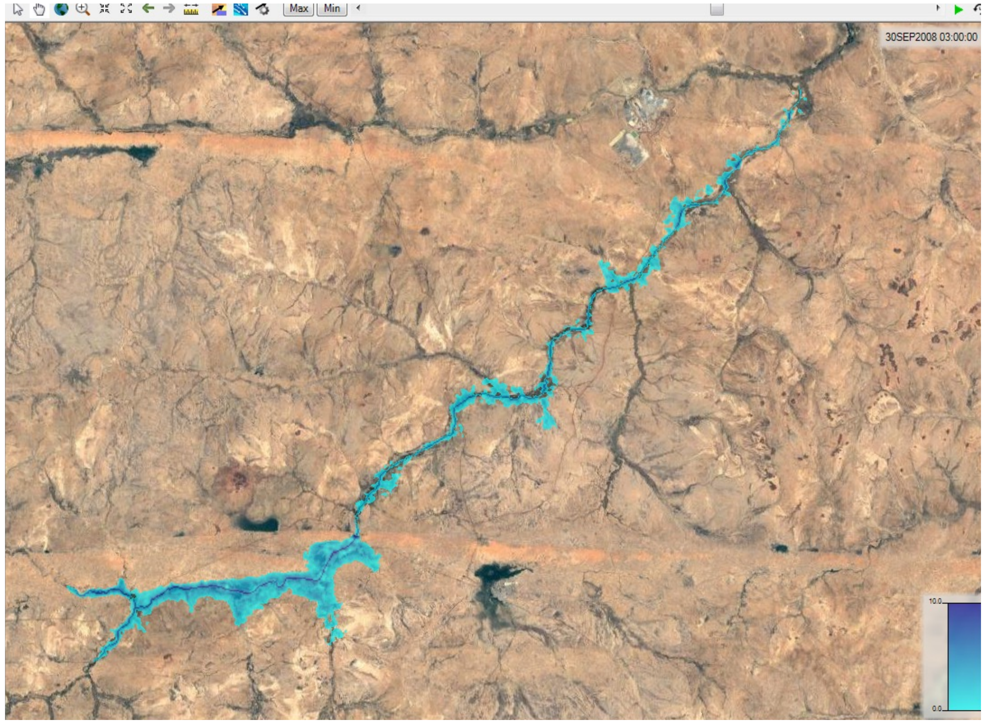


Case Study: Yacouta Dam

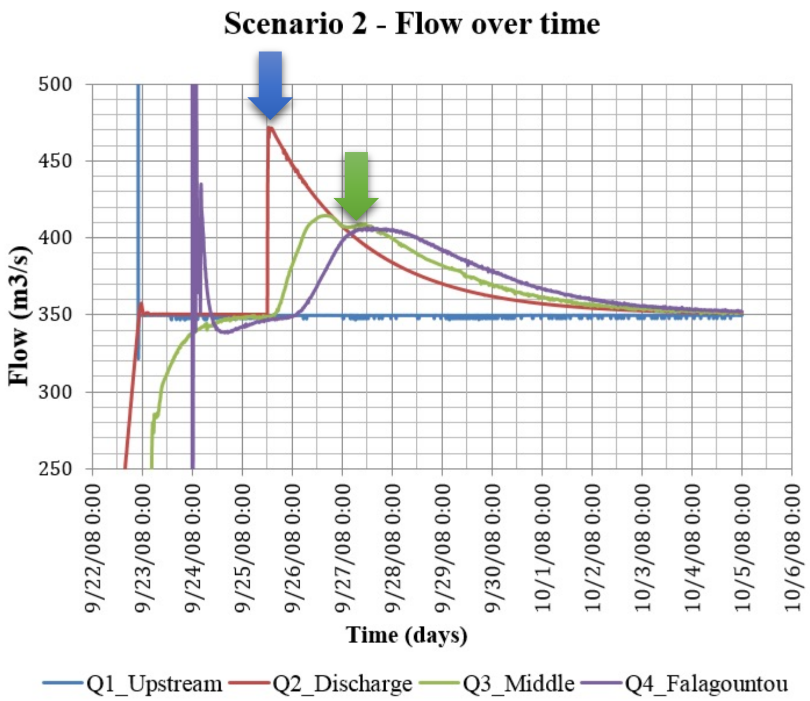
Simulation results with water depth on DTM:

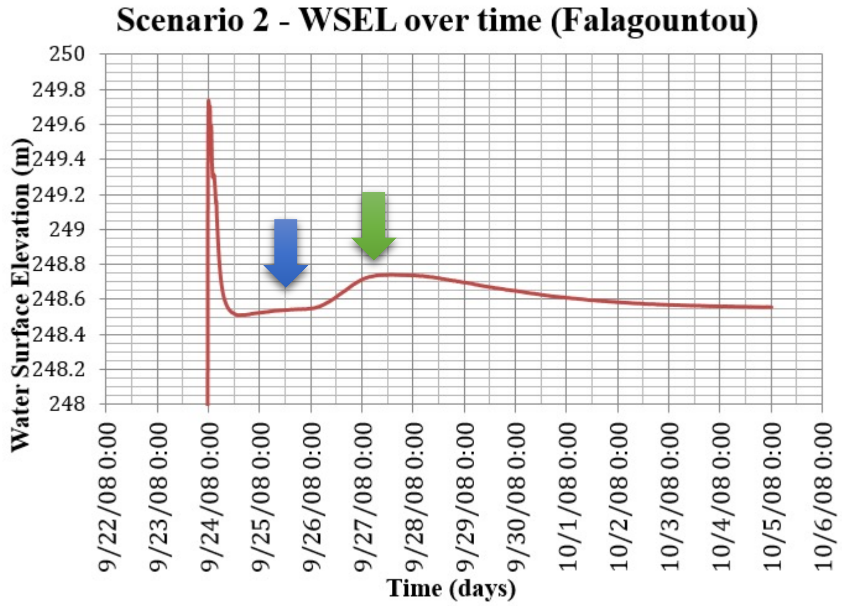


Simulation results with water depth on satellite imagery:



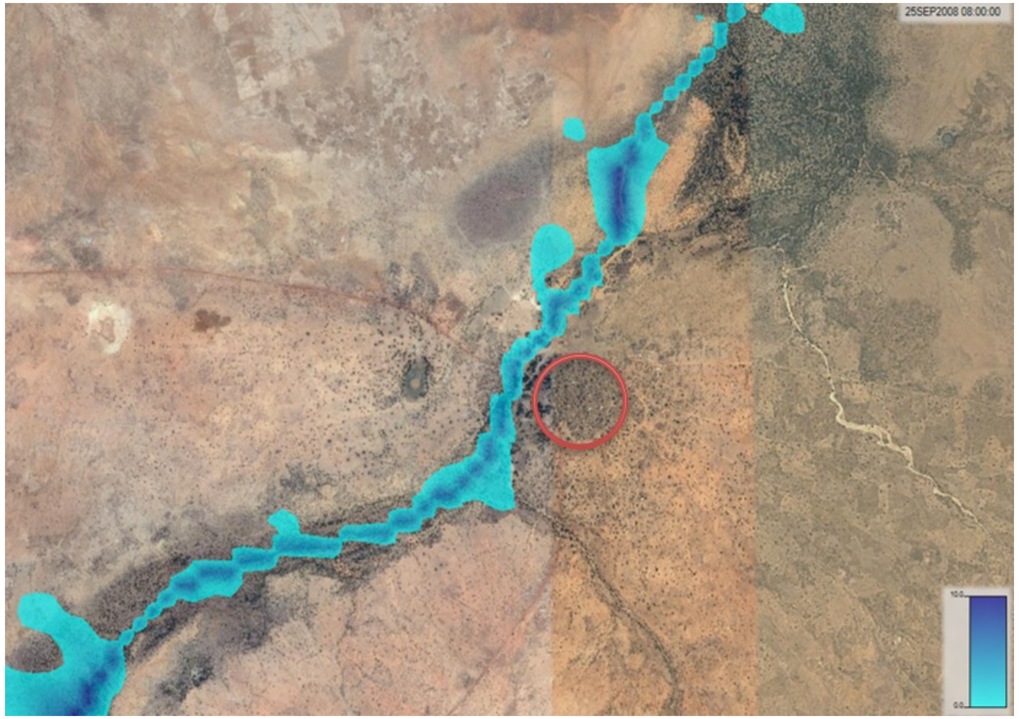
Case Study: Yacouta Dam



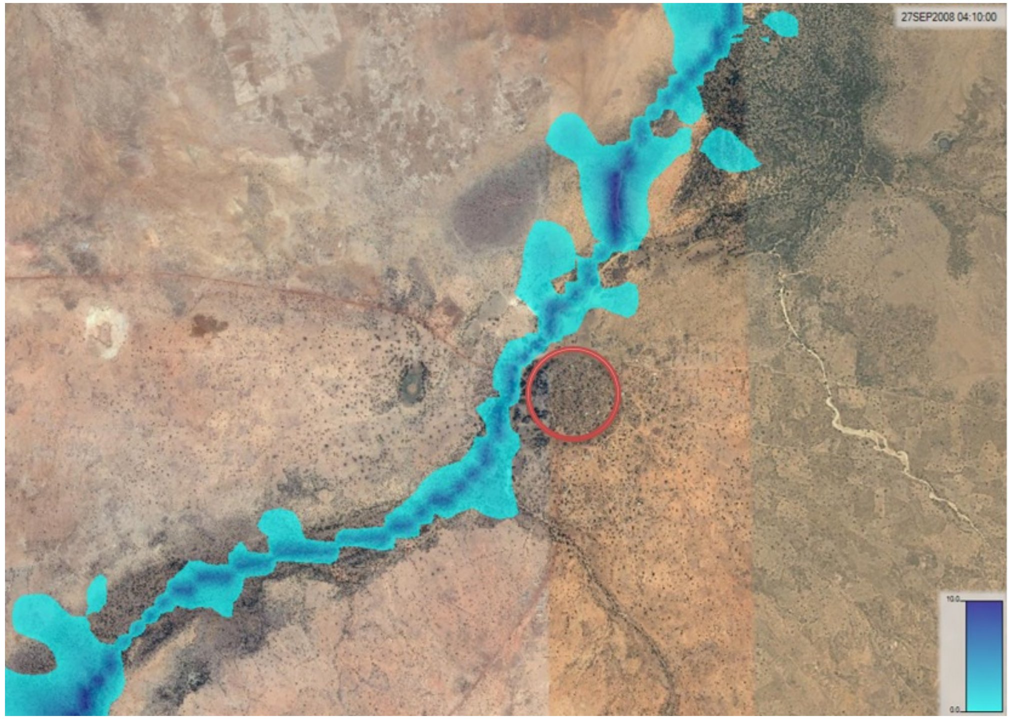


Case Study: Yacouta Dam

Falagountou before concrete fuse plug operation:



Falagountou with flood wave caused by concrete fuse plug:



Conclusion

- Concrete fuse plug was designed to increase water storage capacity of Yacouta Dam, with limited flooding impacts on main towns located downstream
- Hydraulic modeling methodology using non-commercial software and dataset was developed and can be used to simulate the operation of concrete fuse plugs for a rough order-of-magnitude (ROM)
- Limitations and associated recommendations:
  - Climate change considerations in hydrological analysis: regional trends for changes in rainfall event intensity and variability
  - Low accuracy of DTM used: bathymetric surveys required for detailed 1D/2D modeling, along with drone LiDAR survey
  - Simplified model without road crossings (1) and secondary tributaries: field surveys for hydraulic structures and additional modeling for tributaries
  - Lack of model calibration: hydrometric campaign at measurement points along the watercourse and complete hydrological and hydraulic calibration

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Questions?