An Adaptive Management Approach for Groundwater Remediation in Deep Fractured Rock

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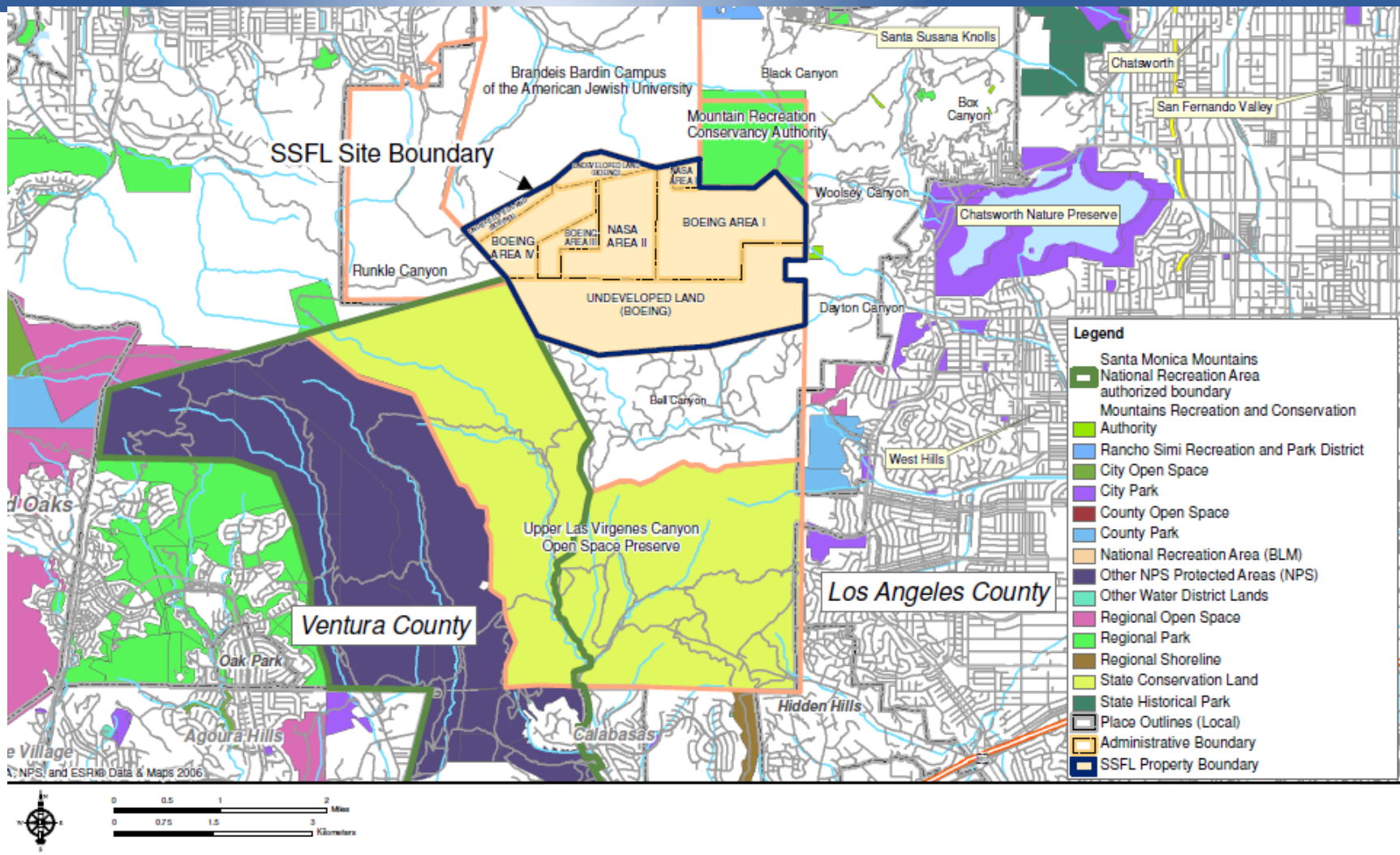
Agenda

- Background
- Challenges
- The need for Adaptive Management and its benefits for complex sites
- Near term activities that will inform future site decisions
- Adaptive Management implementation activities
- Closing

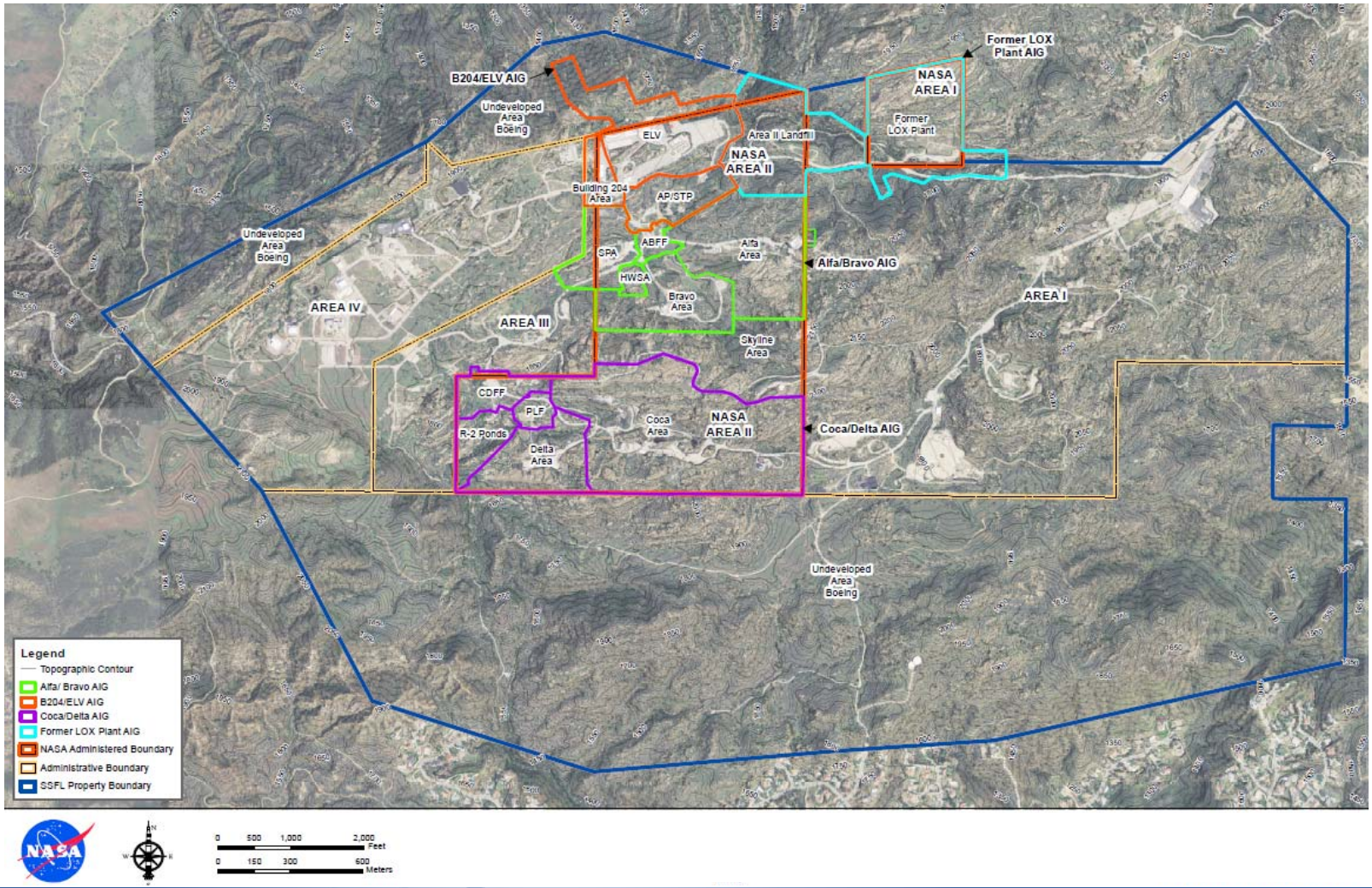
Background - NASA's Site History at SSFL

- Since 1948 – research, development, and testing of liquid-fueled rocket engines and associated components
- Use primarily petroleum-based compounds as "fuel" and liquid oxygen (LOX) as oxidizer
- TCE was the primary solvent used for cleaning rocket engine components; also used for other cleaning purposes
- NASA gradually discontinued testing starting in the 1980's and conducted final tests in 2006
- In 2007, NASA, Boeing, and DOE signed a Consent Order for Corrective Action with the California Department of Toxic Substance Control that governs investigation and remediation
- This presentation only addresses work at NASA's portion of SSFL

Regional Map

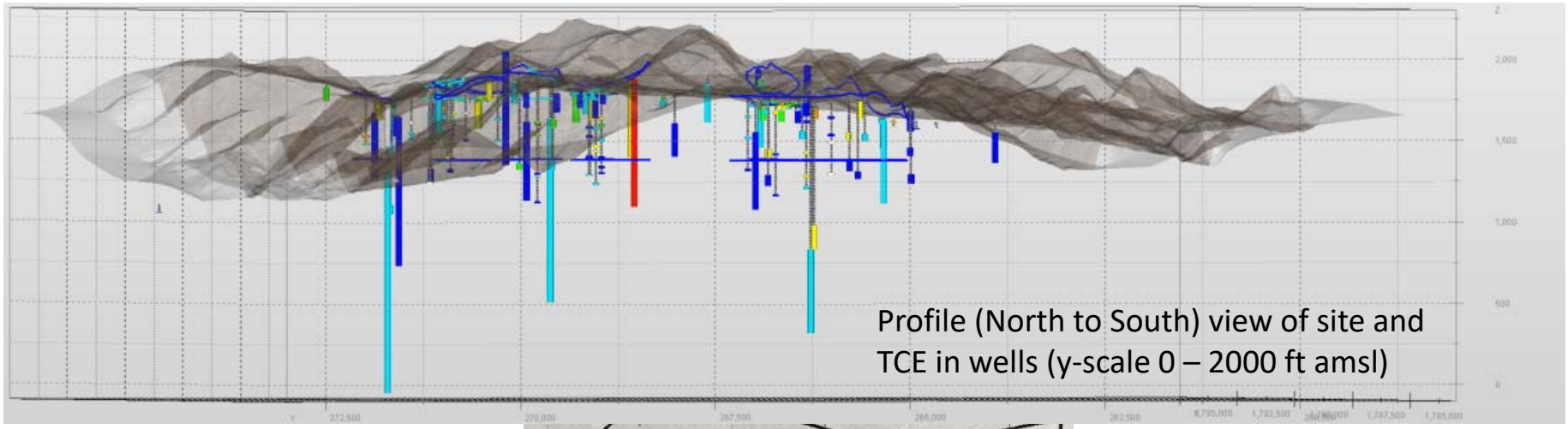


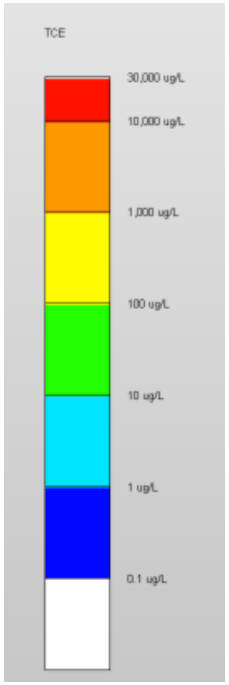
Site Overview



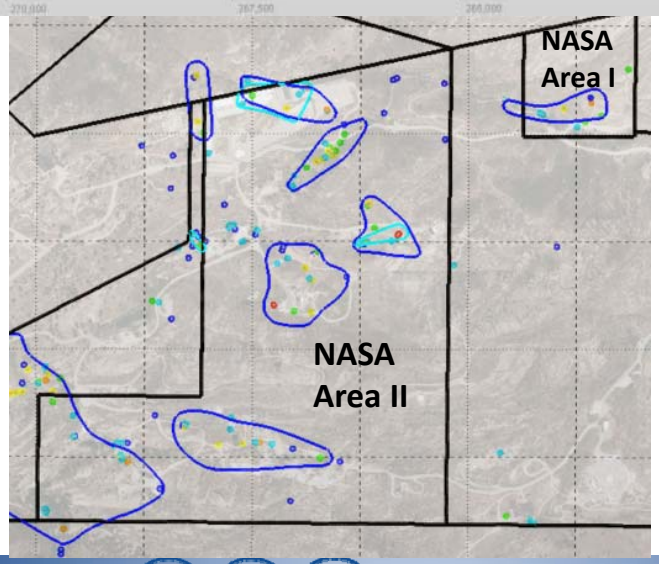
Challenging Topography

Rocket Engine Testing/Challenging Terrain for Investigation





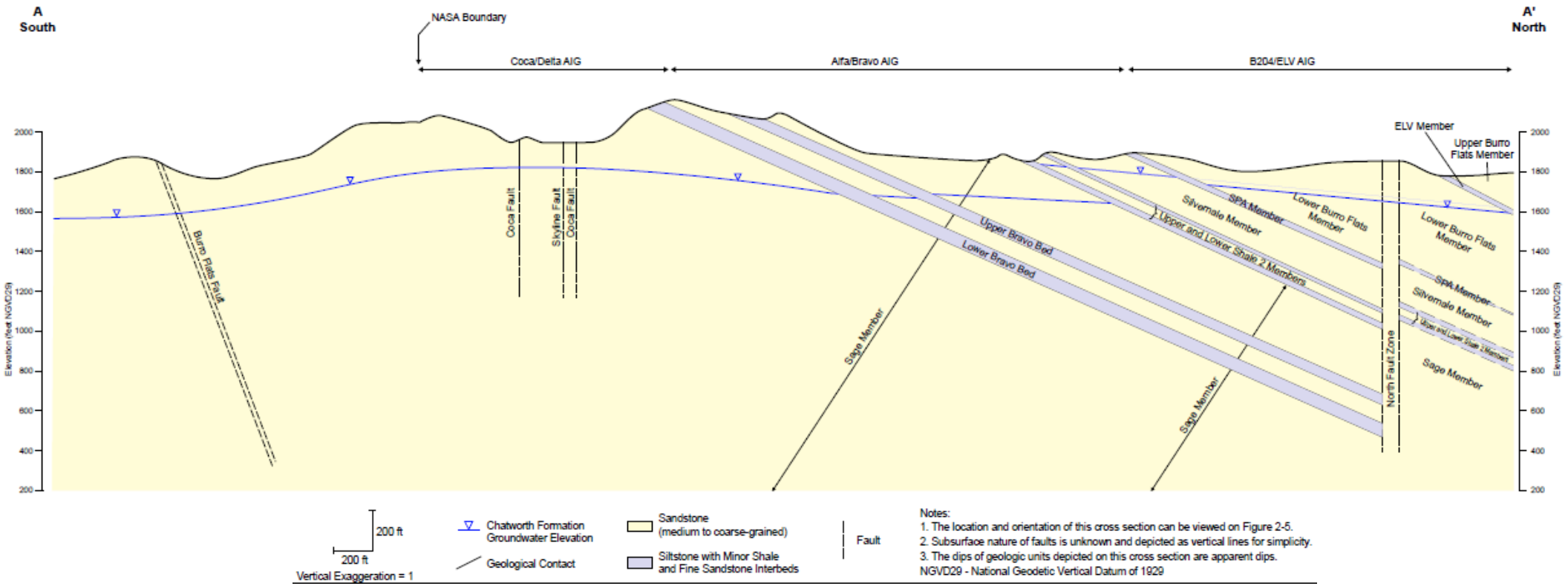
Numerous CVOC plumes
(TCE at 5 ppb)



Extent of TCE above 5 µg/L in:
Chatsworth Formation Groundwater
Near-surface Groundwater

0 1250 feet

Complex Geology with Fractured Sandstone



Why a typical “linear” regulatory process is not practical for this complex site

- Challenges in site characterization
  - Optimal locations are sometimes inaccessible to rigs
  - Contamination is very deep in some locations (over 800 feet)
  - Wells are expensive $250K to $750 (geophysics, packer testing, some converted to FLUTe wells) - perfect nature and extent characterization is not practicable
  - One recent slant well installed to demonstrate groundwater not migrating past fault ($800K data point [weight-of-evidence pointed to this conclusion already])
- 99% of mass is expected to be in the rock matrix
  - 60 years of diffusion into rock likely results in a longer time period for it to back-diffuse out of rock
  - Difficult to estimate time of remediation

Linear Process VS Adaptive Management

- Linear Process - Continue to characterize the site and wait until all data gaps have been addressed and filled, before commencing with cleanup
- Adaptive Management (…an approach worth considering)
  - Prioritize cleanup activities at known source areas (Phase 1 CMS),
  - Continue to address important data gaps (design investigations and monitoring programs)
  - Implement best technologies to assess how they perform (implement Phase 1 CMS alternatives, interim actions)
  - Use results of above three to inform Phase 2 CMS

Benefits of Adaptive Management to NASA

- Continues momentum toward meaningful cleanup and addresses data gaps on a parallel path
- Stands by their commitment to the community to implement meaningful cleanup actions as soon as possible
- Study field implementation of likely remediation technologies to better understand what they can, and cannot, accomplish
- Allows for a Phase 2 CMS to be built on site-specific information and known performance of technologies at site (rather than projected models)

Adaptive Management Activities NASA is Implementing

- Constructed groundwater extraction system, water being treated at treatment system operated by Boeing
- Implementation of enhanced insitu bioremediation (EISB) pilot study, with recirculation at one source area
- Implementation of long-term bedrock vapor extraction (BVE) treatment at 1 or 2 locations
- Implementation of robust monitored natural attenuation (MNA) program as a template to define parameters and metrics for long-term natural attenuation monitoring

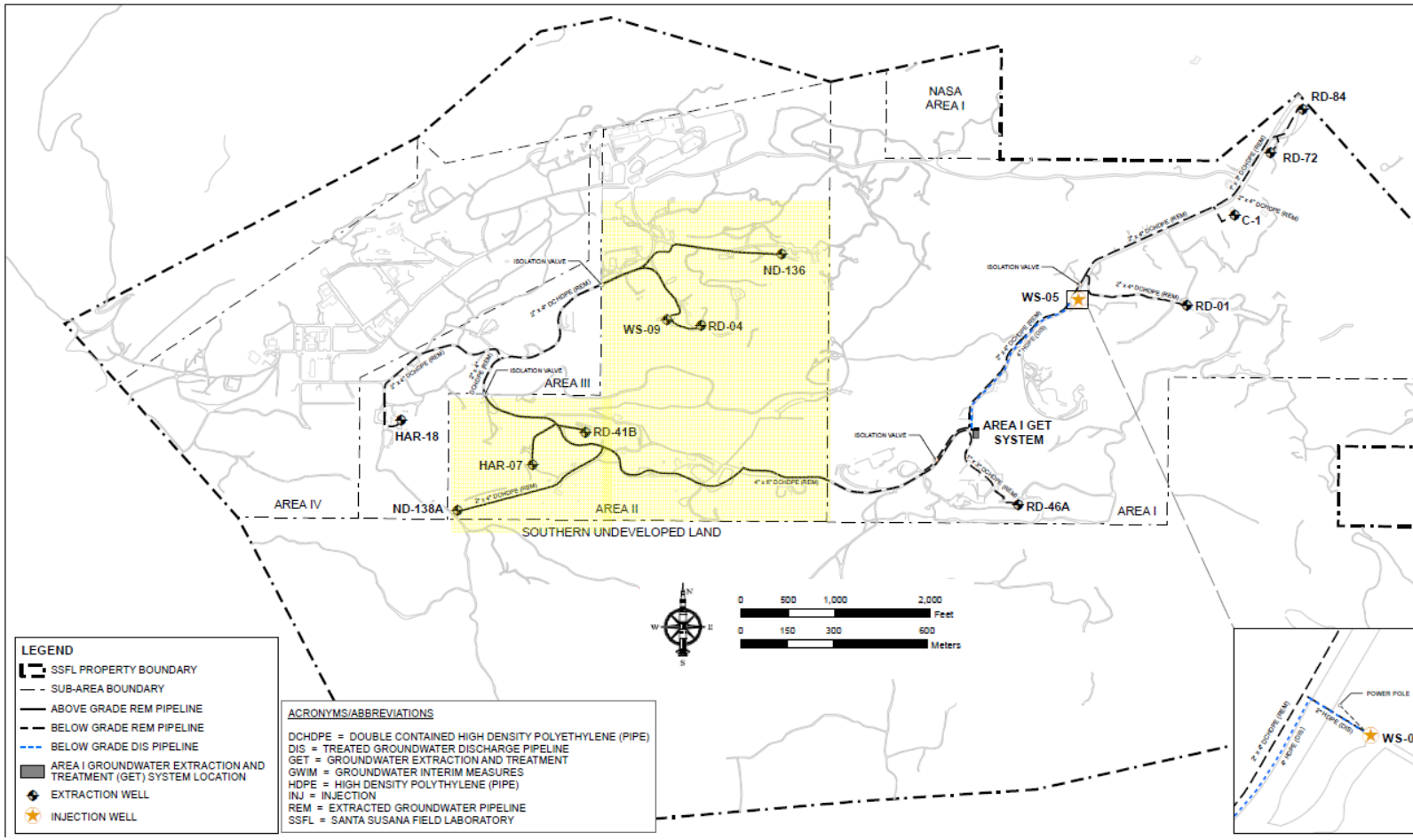
Answers to below questions will guide future work

Questions to be Answered	GETS	EISB Pilot	BVE	MNA
How much mass removal/reduction is probable?	x	x	x	x
How sustainable are mass reduction rates?	x	x	x	x
How sustainable are groundwater extraction rates?	x			
What is the optimal operating frequency (continuous, pulsed, intermittent)?	x	x	x	
What are estimated project life cycle costs?	x	x	x	x
Is technology cost-effective?	x	x	x	x
How do costs compare to other technologies (e.g., cost per unit mass treated)?	x	x	x	x
What does an exit strategy for technology look like (and how long will technology operate)?	x	x	x	x
What kind of capture is possible with technology	x	x	x	
What kind of distribution of reagents can we anticipate?		x		
How is groundwater moving between injection and extraction wells?		x		
Will we see an accumulation of daughter products?		x		
How relatable are findings to other potential areas at NASA SSFL?	x	x	x	x

Groundwater Extraction and Treatment System (GETS)

Early Estimates for Five NASA wells

- Initial pumping rates range from 1 – 10 gpm
- Mass recovery ranges from 0.001 to 106 grams VOC/1,000 gallons pumped



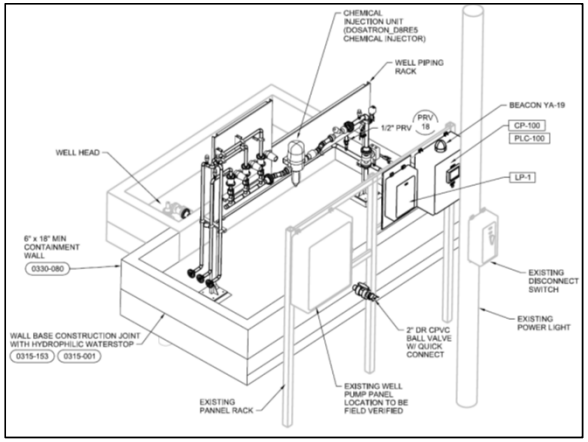
EISB with Recirculation Pilot System

Plan View of Pilot Study Area

Extraction, Injection, and Monitoring wells (7 total) to approx. 500 ft deep

Will employ tracer study to better understand flow rates and migration

Extraction Well Location



Process Flow Diagram

Bedrock Vapor Extraction (BVE)

- Two short-term pilot studies conducted at site, with VOC removal rates on order of 10-12 lbs per week.
- Evaluating implementation at another location where VOC recovery rates could be much greater
- Longer term evaluations will be conducted to assess performance

Monitored Natural Attenuation Lines of Evidence

- Data shows stable plumes at leading edges
- NASA will evaluate other lines of evidence to assess natural attenuation, beyond typical MNA parameters:
  - CENSUS quantitative polymerase chain reaction (qPCR) for 1,4-dioxane - DNA based method to quantify specific microorganisms and functional genes responsible for biodegradation of contaminants
  - QuantArray® for chlorinated VOCs –advanced qPCR method that rapidly detects and quantifies key microorganisms and functional genes responsible for biodegradation
  - Compound specific isotope analysis (CSIA) for TCE, cis-1,2-DCE, vinyl chloride, 1,1-DCA and 1,4-dioxane
  - 1,4-dioxane stable isotope probing (SIP)– this uses a Bio-Trap® amended with a carbon-13 “labeled” contaminant to conclusively determine whether biodegradation has occurred
- Results will be used to develop a framework for future MNA decisions

Adaptive Management…an approach worth considering

- Cleanup can start earlier at the most contaminated sites
- Some challenging regulatory questions may be answered by implementing additional work (investigation by remediation)
- NASA and regulators will have a much better understanding of what treatment can, and cannot, accomplish
- Future Phase 2 CMS and Statement of Basis will be underpinned by decision frameworks based on actual site-specific technology performance rather than theoretical models

Thank you to our awesome project team

- Peter Zorba, NASA SSFL Program Director
- Jacobs Team
  - Allen Elliot, SSFL Program Manager
  - Randy Dean, Site Operations Project Manager
  - Kathryn Brown, Groundwater Project Manager
  - Peter Lawson, Principal Hydrogeologist
  - Dave Patterson, GETS Project Manager
  - Jim Hartley, BVE Subject Matter Expert and Engineer of Record