PROGRESS | PROGRESSIVE REMEDIATION STRATEGIES

Geologic foundation. Process-based execution.

What is Remediation Geology and Why Should It Be a Part of Every PFAS Remedial Investigation?

Rick Cramer, PG
Mike Shultz, PhD
Colin Plank, CPG

May 2023

BURNS McDONNELL

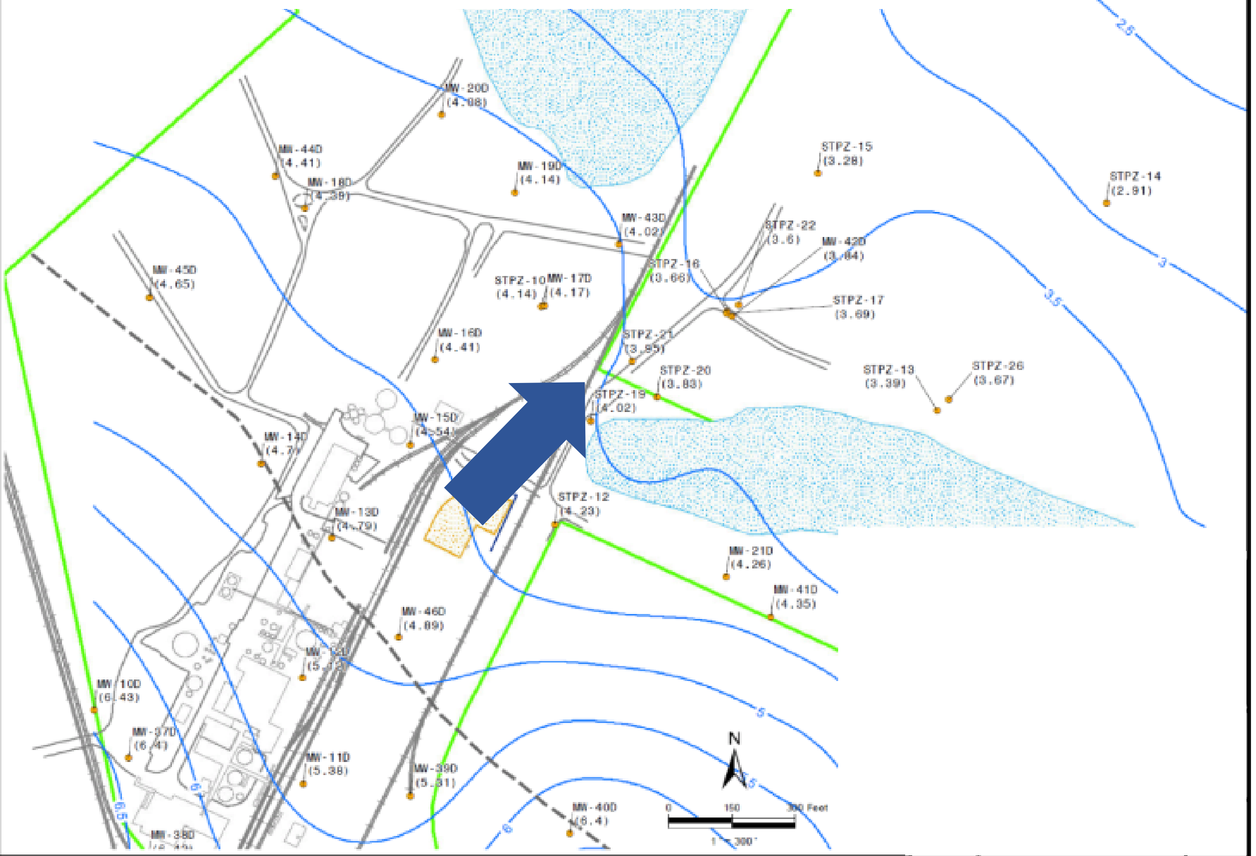
What is Remediation Geology?

BURNS & McDONNELL

"Plume Chasing" Approach

…assume homogeneous and isotropic conditions, oversimplified representation of the subsurface

Groundwater gradient = Groundwater flow

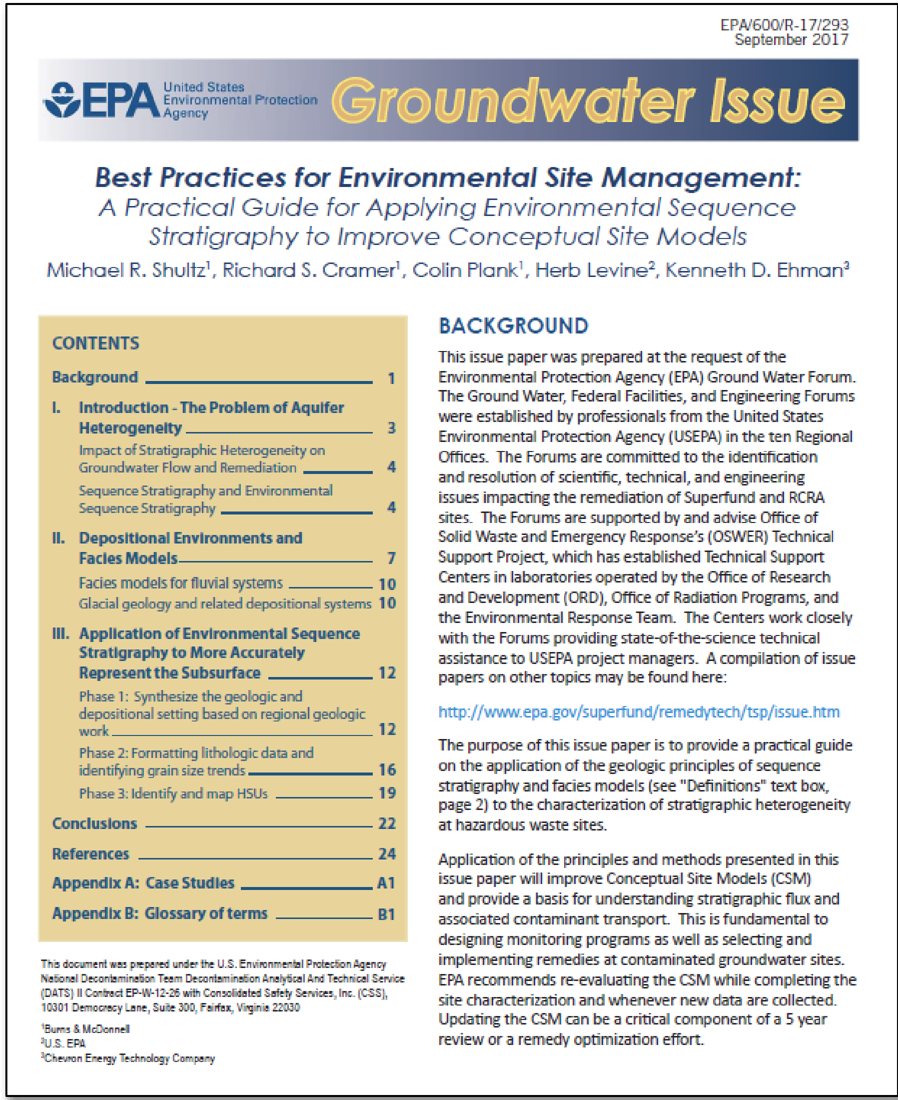


Contaminant plume

BURNS McDONNELL

ESS: US EPA Best Practice

- Step-by-step guidance document for CSM technical team (stratigrapher)
- Objective is to improve remedy performance
- 90% of mass flux contaminant transport at Superfund sites has been shown to move through only 10% of aquifer material…controlled by geology
- It is US EPA expectation that stratigraphic analysis utilizing the methods presented in the new EPA guidance be considered at each site
- Link to paper: https://nepis.epa.gov/Exe/ZyPDF.cgi/P100TN2C.PDF?Dockey=P100TN2C.PDF



EPA/600/R-17/293
September 2017

EPA United States Environmental Protection Agency **Groundwater Issue**

Best Practices for Environmental Site Management:
A Practical Guide for Applying Environmental Sequence Stratigraphy to Improve Conceptual Site Models

Michael R. Shultz[1], Richard S. Cramer[1], Colin Plank[1], Herb Levine[2], Kenneth D. Ehman[3]

CONTENTS

This document was prepared under the U.S. Environmental Protection Agency National Decontamination Team Decontamination Analytical And Technical Service (DATS) II Contract EP-W-12-26 with Consolidated Safety Services, Inc. (CSS), 10301 Democracy Lane, Suite 300, Fairfax, Virginia 22030

[1]Burns & McDonnell
[2]U.S. EPA
[3]Chevron Energy Technology Company

BACKGROUND

This issue paper was prepared at the request of the Environmental Protection Agency (EPA) Ground Water Forum. The Ground Water, Federal Facilities, and Engineering Forums were established by professionals from the United States Environmental Protection Agency (USEPA) in the ten Regional Offices. The Forums are committed to the identification and resolution of scientific, technical, and engineering issues impacting the remediation of Superfund and RCRA sites. The Forums are supported by and advise Office of Solid Waste and Emergency Response's (OSWER) Technical Support Project, which has established Technical Support Centers in laboratories operated by the Office of Research and Development (ORD), Office of Radiation Programs, and the Environmental Response Team. The Centers work closely with the Forums providing state-of-the-science technical assistance to USEPA project managers. A compilation of issue papers on other topics may be found here:

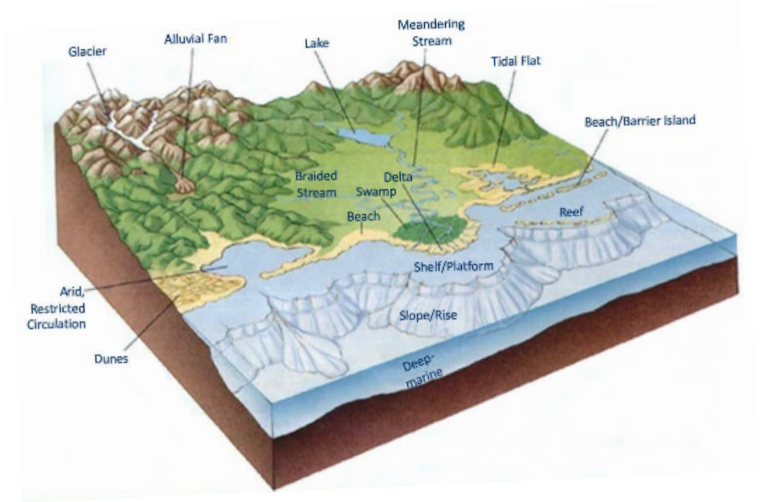
http://www.epa.gov/superfund/remedytech/tsp/issue.htm

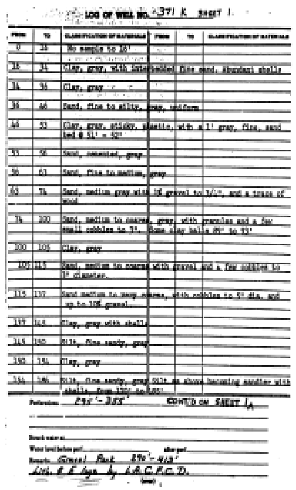
The purpose of this issue paper is to provide a practical guide on the application of the geologic principles of sequence stratigraphy and facies models (see "Definitions" text box, page 2) to the characterization of stratigraphic heterogeneity at hazardous waste sites.

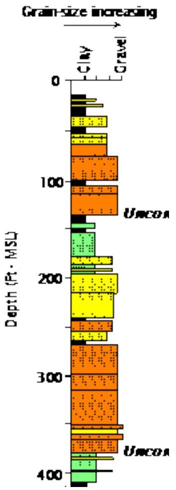
Application of the principles and methods presented in this issue paper will improve Conceptual Site Models (CSM) and provide a basis for understanding stratigraphic flux and associated contaminant transport. This is fundamental to designing monitoring programs as well as selecting and implementing remedies at contaminated groundwater sites. EPA recommends re-evaluating the CSM while completing the site characterization and whenever new data are collected. Updating the CSM can be a critical component of a 5 year review or a remedy optimization effort.

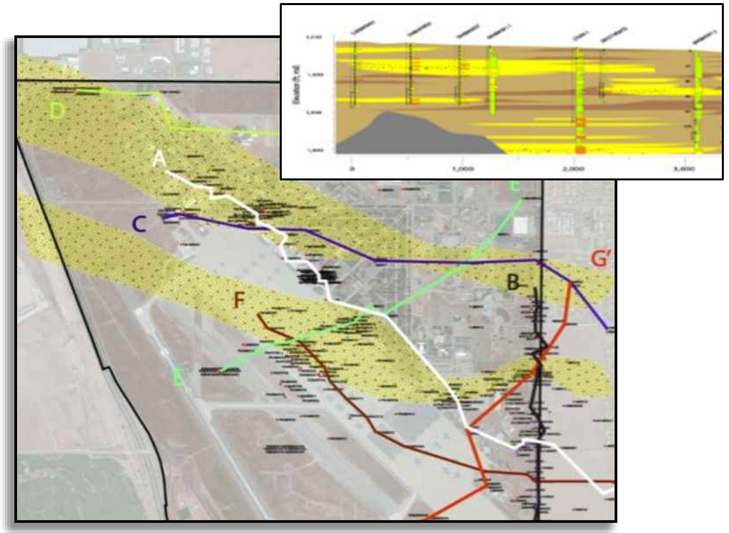
BURNS & McDONNELL

The Environmental Sequence Stratigraphy (ESS) Process









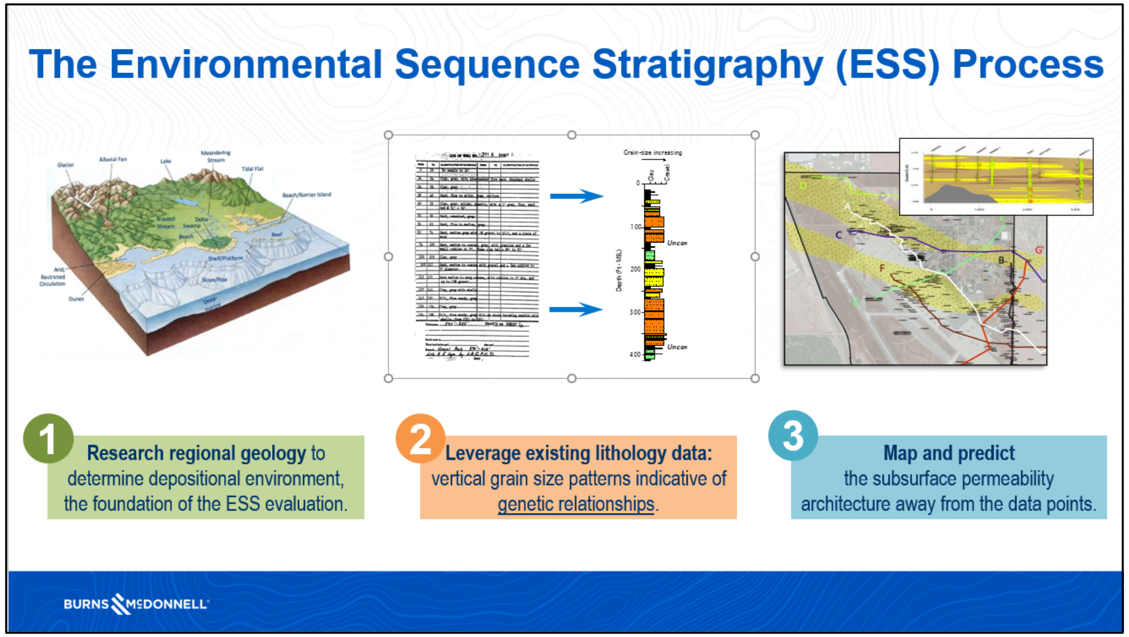
1 **Research regional geology** to determine depositional environment, the foundation of the ESS evaluation.

2 **Leverage existing lithology data:** vertical grain size patterns indicative of genetic relationships.

3 **Map and predict** the subsurface permeability architecture away from the data points.

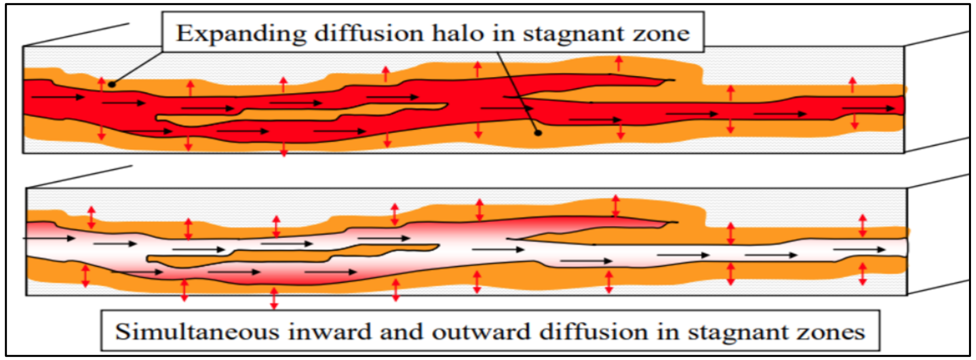
BURNS & McDONNELL

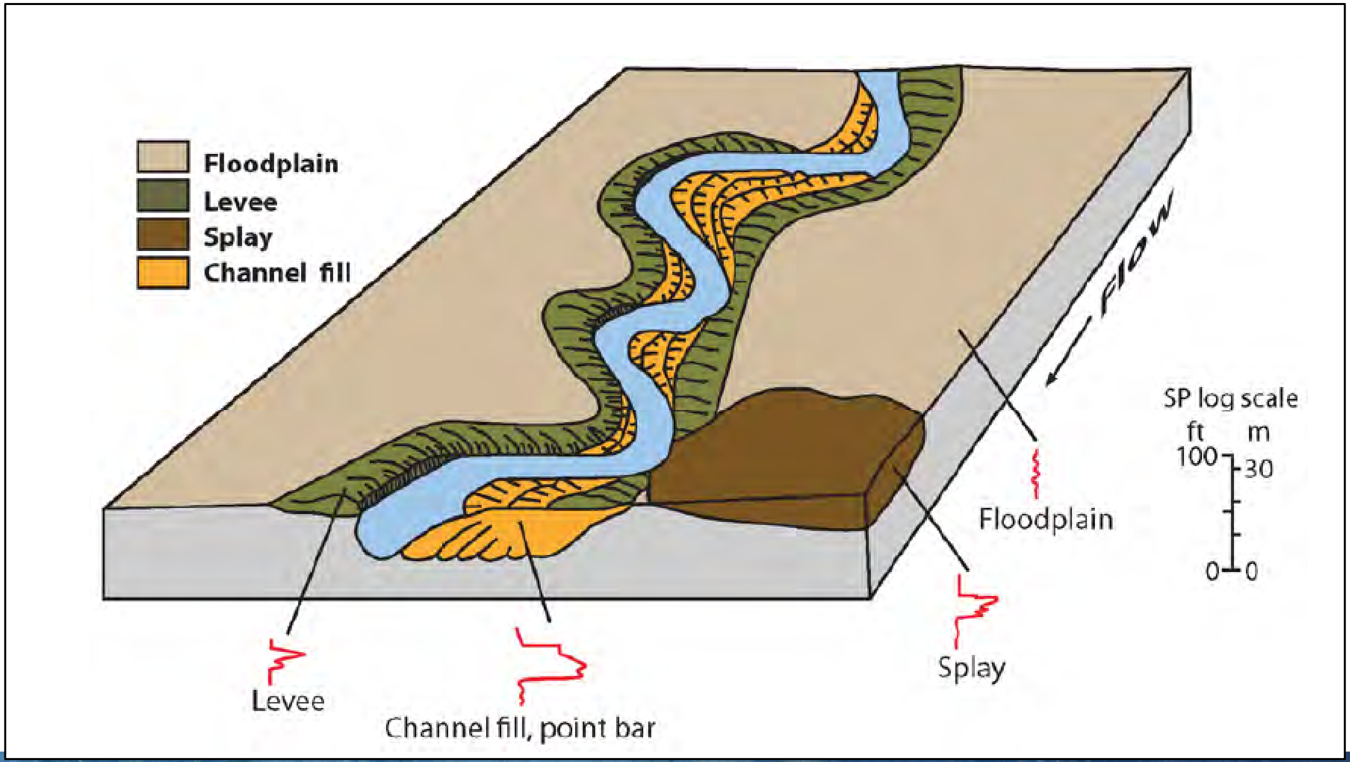
Depositional Environment / Hydrostratigraphic Units (HSUs)



Contaminant Transport HSU: High permeability coarse-grained (sand/gravel) channelized deposits.
Contaminant Storage HSU: Low permeability floodplain fines (silts/clays) sheetlike deposits.

Matrix diffusion





Expertise of the Practitioner

Geology

- Mineralogy
- Economic geology
- Geophysics
- Stratigraphy
- Marine geology
- Volcanology
- Geochemistry
- Structural geology
- Sedimentology
- Paleontology
- Seismology
- Hydrogeology
- Petroleum geology
- Tectonics
- Engineering geology
- Geomorphology
- Igneous petrology
- Metamorphic petrology

Expertise of the Practitioner

Geology

- Mineralogy
- Economic geology
- Geophysics
- **Stratigraphy**
- Marine geology
- Volcanology
- Geochemistry
- Structural geology
- Sedimentology
- Paleontology
- Seismology
- Hydrogeology
- Petroleum geology
- Tectonics
- Engineering geology
- Geomorphology
- Igneous petrology
- Metamorphic petrology

DoD Recognition of Remediation Geology

BURNS & McDONNELL

Accelerated Remedial Approaches Using Environmental Sequence Stratigraphy (ESS)

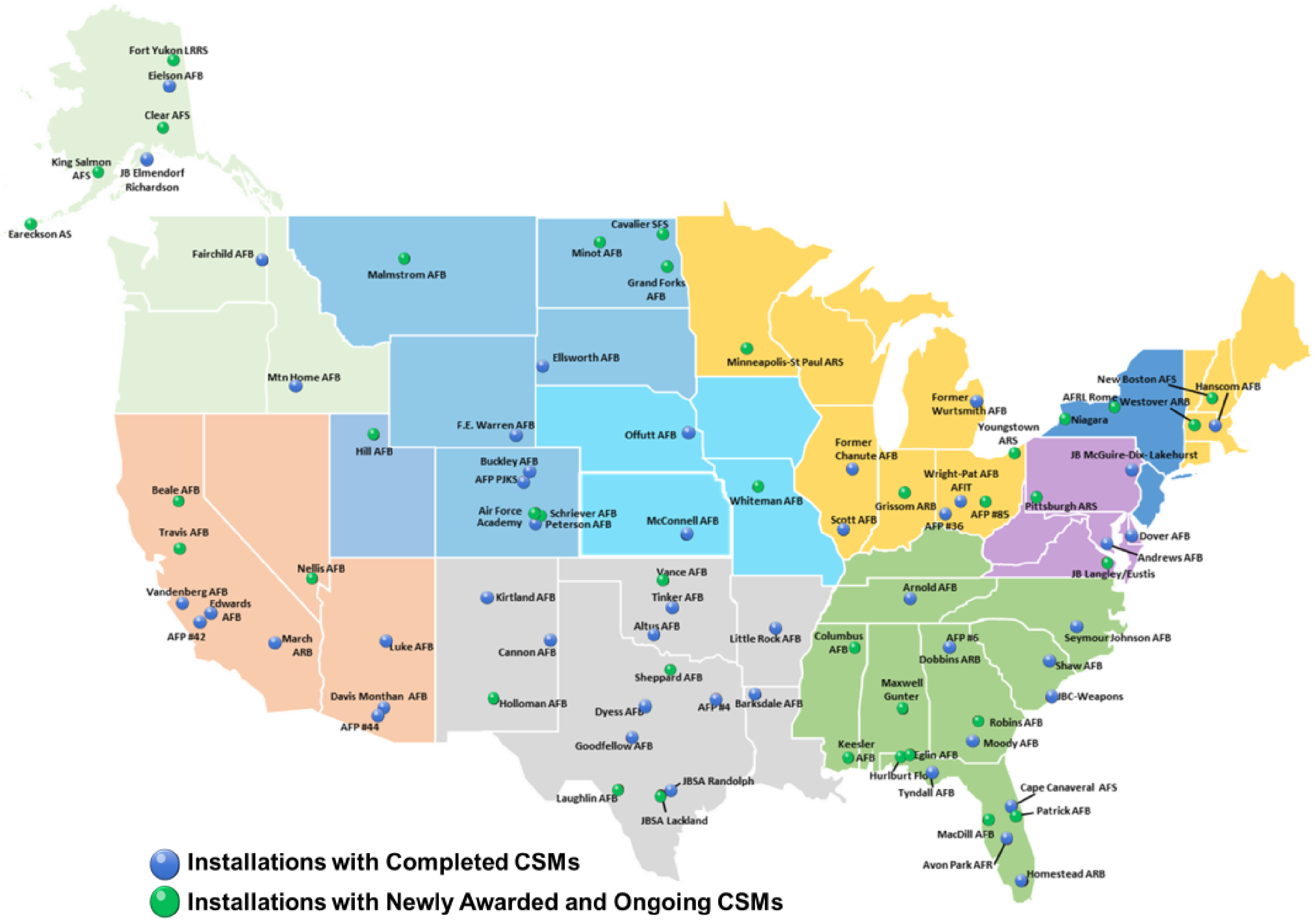
J. Mark Stapleton, Ph.D., P.E, BCEE, Noblis
John Gillespie, US Air Force Civil Engineer Center
Kent Glover, Ph.D., US Air Force Civil Engineer Center
Rick Cramer, PG, Burns & McDonnell
Colin Plank, CPG, Burns & McDonnell

26 May 2022

For the best of reasons

ESS Library

- **AFCEC conducted an enterprise-wide study** to capture performance and lessons learned information related to application of ESS principles to inform site remedial approaches.
- **58 ESS reports** at active Installations in the library
- Reports range from **regional/basewide to plume-scale to remediation-scale**; additional reports in development
- Over the next 4 years, AFCEC will be **conducting an additional 43 installation-level ESS CSMs**



noblis

Lessons Learned

- In general, the ESS methodology provides a **better understanding of the site geology and a more effective means of designing, installing, and optimizing a remedial system**.
- Minimizing site uncertainties **prevents overdesigning** of remedial systems.
- Increasing site knowledge and identification of key hydrostratigraphic units is **critical to achieving ever more stringent regulatory requirements**.
- Regardless of site status, implementation of the ESS approach in the remediation flow train can **result in significant cost avoidance and/or reduce Life Cycle Costs**.
- Analysis has shown that ESS can **accelerate the remedial process**, on average 2–4 years.
- Experienced and formally educated **Sequence Stratigraphers are essential**.
- Conceptual remedial designs to field **deployment was achieved in < 1 year**.

Navy Recognizes ESS…

ESS Practice was the subject of NAVFAC OER2 Technology Transfer Webinar

- NAVFAC Headquarters sponsored this technical transfer to inform all Navy Remediation Project Managers (RPMs) about the value of ESS as a remedy optimization tool.

NAVFAC
Naval Facilities Engineering Systems Command

Technology Transfer Update

Issue 200 June 7, 2021

NAVFAC Open Environmental Restoration Resources (OER2) Webinar: Environmental Sequence Stratigraphy (ESS) as a Remedy Optimization Tool

This OER2 webinar will discuss the ESS approach to complex sites and provide Navy case studies of the use of this approach for optimization. ESS is an example of the focus on geology to better define the heterogeneous subsurface that confounds many complex contaminated site remediation projects. This presentation will give an overview of the ESS approach and how it has evolved into a means for optimizing the pathway to response complete. The challenge is not only to define the subsurface geologic framework, but also to implement the geologic model to optimize remediation. Navy RPMs will share their case study examples of applying ESS to ER sites.

NAVFAC

Topic: ESS as a Remedy Optimization Tool
Presenters: Rick Cramer, Burns & McDonnell; JD Spalding, NAVFAC Southeast; and Dave Collins, NAVFAC Washington
Date: July 8, 2021
Time: 11 AM PT | 2 PM ET
Register at link below for the WebEx event:
https://battelle.webex.com/battelle/onstage/g.php?PRID=dda8c264fc0019f1fa3ec0d605127e19

2022 NAVFAC Environmental Sequence Stratigraphy Fact Sheet

FACT SHEET

Environmental Sequence Stratigraphy (ESS)

Introduction

Complex geological conditions pose challenges to designing successful remedial actions and achieving remedial goals within reasonable timeframes. With improved site investigation techniques, sites that have been challenging to address are often found to have more complex geology than originally defined. Environmental sequence stratigraphy (ESS) is an enhanced approach to characterize aquifer heterogeneity and predict contaminant fate and transport by understanding geologic depositional environments. ESS allows for more informed subsurface predictions of geological factors affecting site remediation. ESS is an established best practice for the development of conceptual site models (CSMs) as outlined by the United States Environmental Protection Agency (Shultz et al., 2017).

Technology Background

Groundwater flow and mass transport are controlled by the geometry and interconnectivity of high and low permeability layers within sedimentary aquifers. These layers are referred to as facies. Sequence stratigraphy is a correlation technique developed to predict heterogeneity and connectivity more accurately between boreholes based on lateral changes within the depositional environment. Figure 1 is a CSM showing the types of depositional environments in which ESS can be successfully implemented.

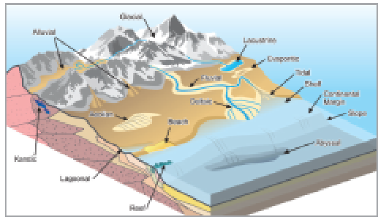


Figure 1. Depositional Environments Suitable for ESS Application (Courtesy of Battelle)

How Does It Work?

The ESS methodology as outlined by Schultz et al. (2017) can be conducted in three iterative steps using existing data to the extent possible. These steps include:

1) Evaluate the Depositional System: Regional geologic and geospatial data are compiled to build detailed knowledge of the geological history and identify which specific facies models are applicable.
2) Determine Grain Size Trends: Early in the ESS process, existing subsurface site data are reviewed to determine vertical grain size trends which are then compared and validated against previously identified facies models.
3) Correlate and Integrate into an Enhanced CSM: Validated vertical grain size trends are then used for subsurface correlation within a series of cross-sections to build a three-dimensional (3-D) geologic framework of the CSM. Hydrogeologic and chemistry data are also used to interpret hydrostratigraphic units in the context of the stratigraphy.

How Can It Help?

Following the ESS methodology above, zones of contaminant transport and storage can be refined in the CSM and inform additional data collection needs, remedial design, and remedial action. Overall, the ESS process can help to:

- ☐ Characterize aquifer heterogeneity;
- ☐ Identify preferential groundwater flow pathways;
- ☐ Improve prediction of contaminant fate and transport; and
- ☐ Optimize remedial design and cost efficiency.

Case Study 1: Joint Base Anacostia-Bolling | Case Study 2: Naval Base Kitsap-Keyport | Conclusions

Why PFAS RIs Require a Remediation Geology Approach

BURNS & McDONNELL

Why PFAS RI Requires Remediation Geology Approach

1. *Ubiquitous occurrence of PFAS,*
2. *Low retardation*
3. *Part per trillion detection/screening level*
4. *High solubility*
5. *Changing standards*
6. *Expanding lists of regulated PFAS compounds*

…not conducive to oversimplified "plume chasing" approach

.

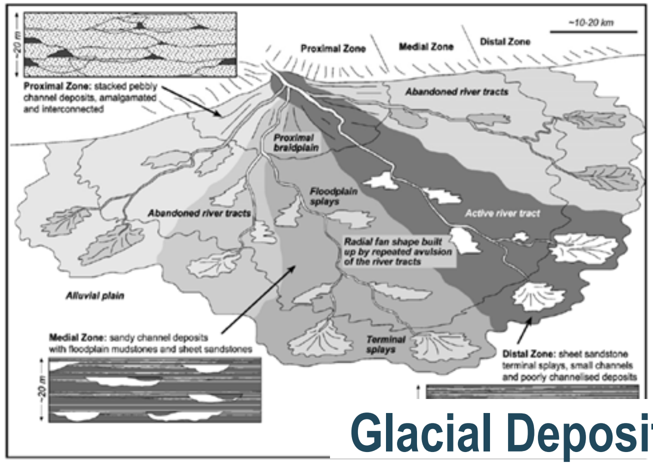
Example of Remediation Geology Approach

BURNS & McDONNELL

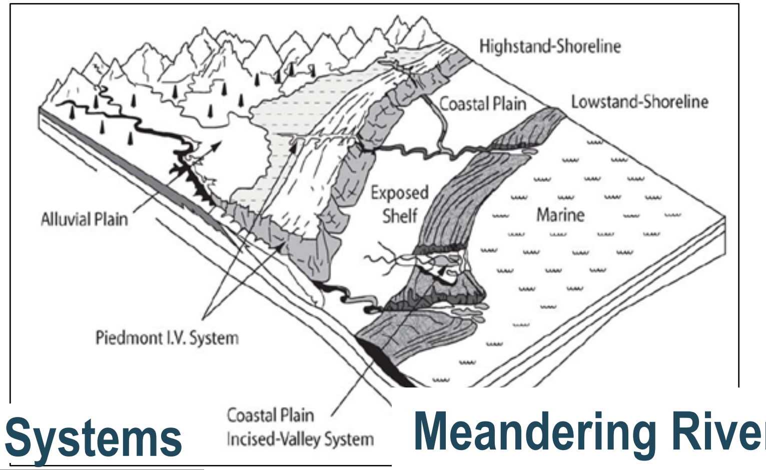
ESS is About Pattern Recognition

Examples of Facies Models

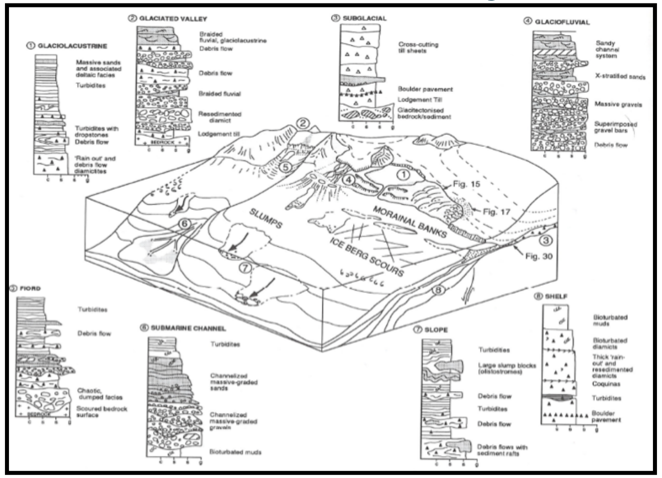
Alluvial Fan Facies Model



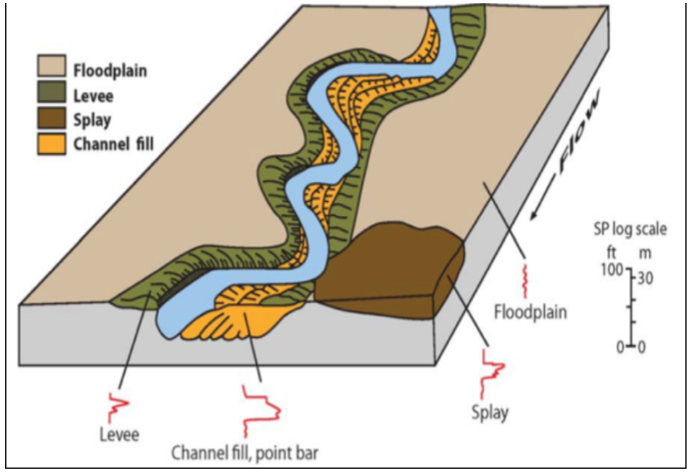
Coastal Depositional Systems



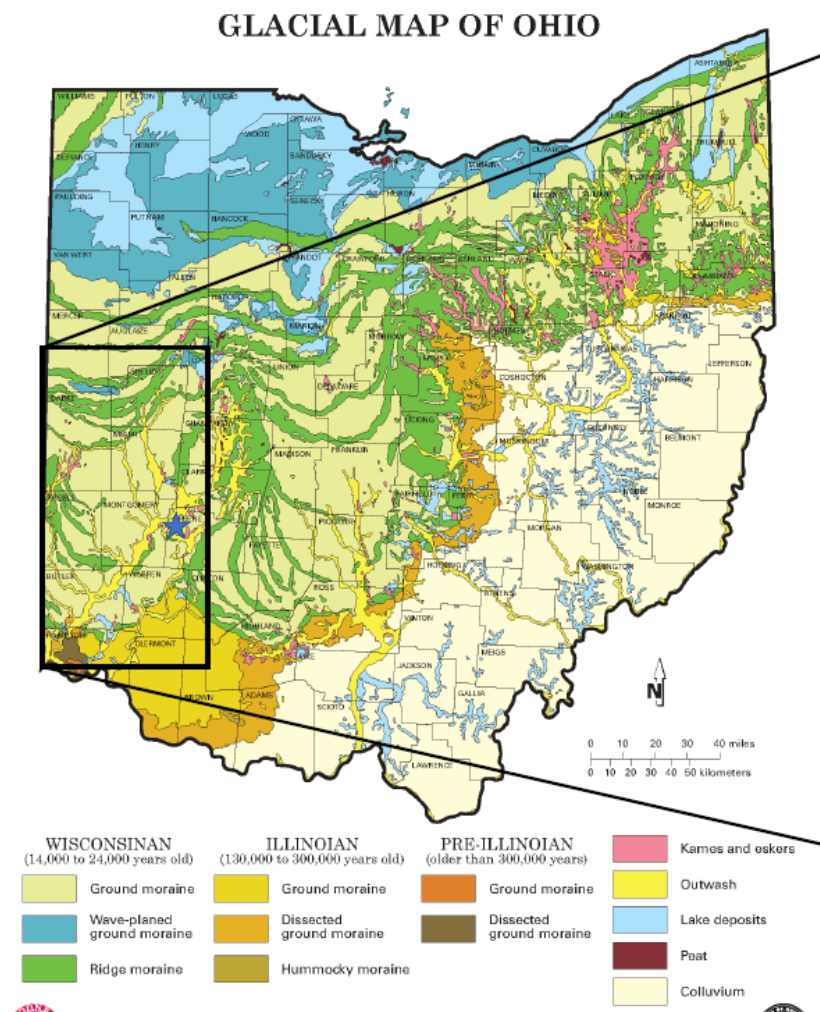
Glacial Depositional Systems



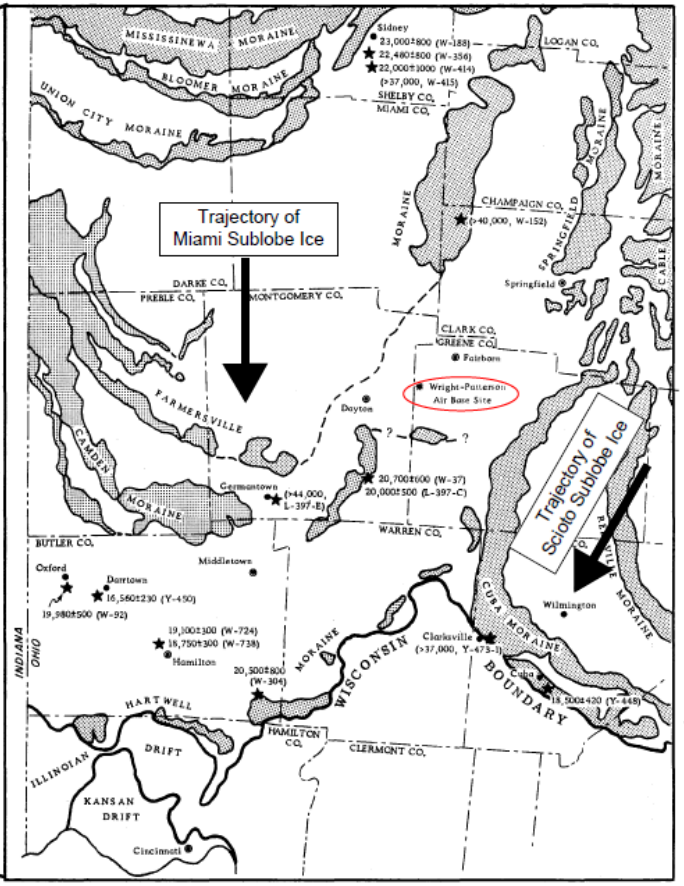
Meandering River Facies Model



Regional Geology

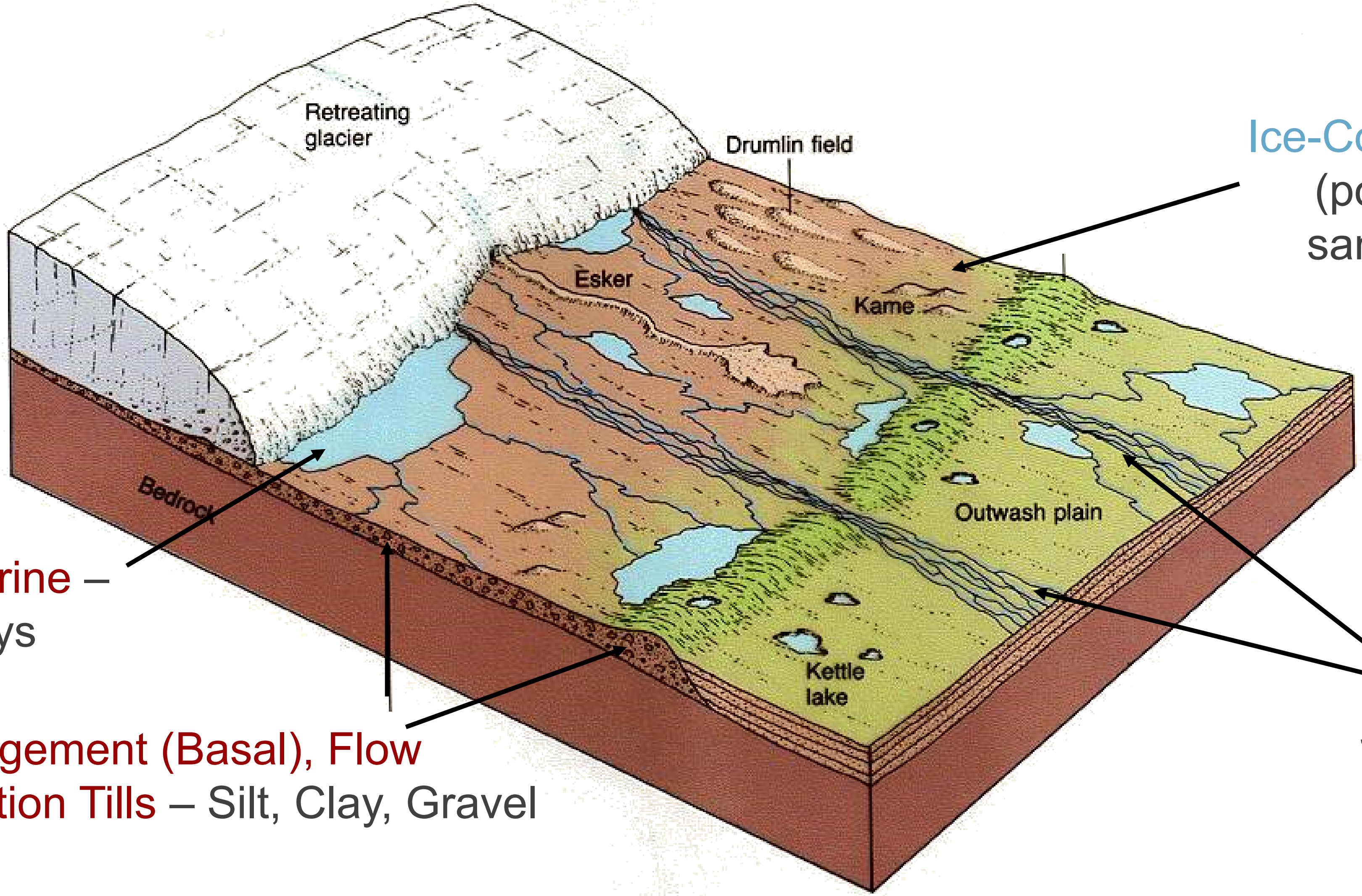


Ohio Division of Geological Survey, 2005. Glacial map of Ohio: Ohio Department of Natural Resources, Division of Geological Survey, page-size map with text, 2p., scale 1:2,000,000.



Forsyth, 1961

Glacial Facies Model: Aquifers vs. Aquitards



Aquifers

Ice-Contact Deposits – (poorly stratified sand and gravel)

Outwash – Stratified Sand and gravel

Aquitards

Proglacial Lacustrine – Silts and Clays

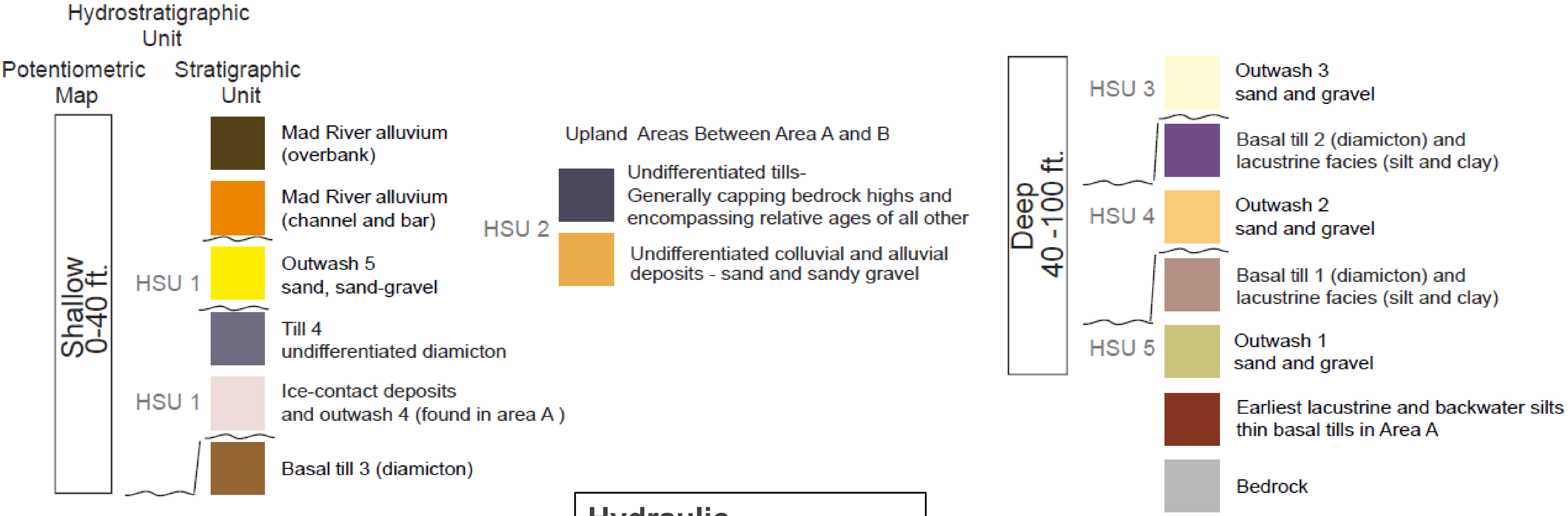
Lodgement (Basal), Flow and Ablation Tills – Silt, Clay, Gravel

Glacial Depositional Environments

Matanuska Glacier, AK

Gravel Pit in North Central Indiana, Indiana geological survey

Hydrostratigraphic Framework

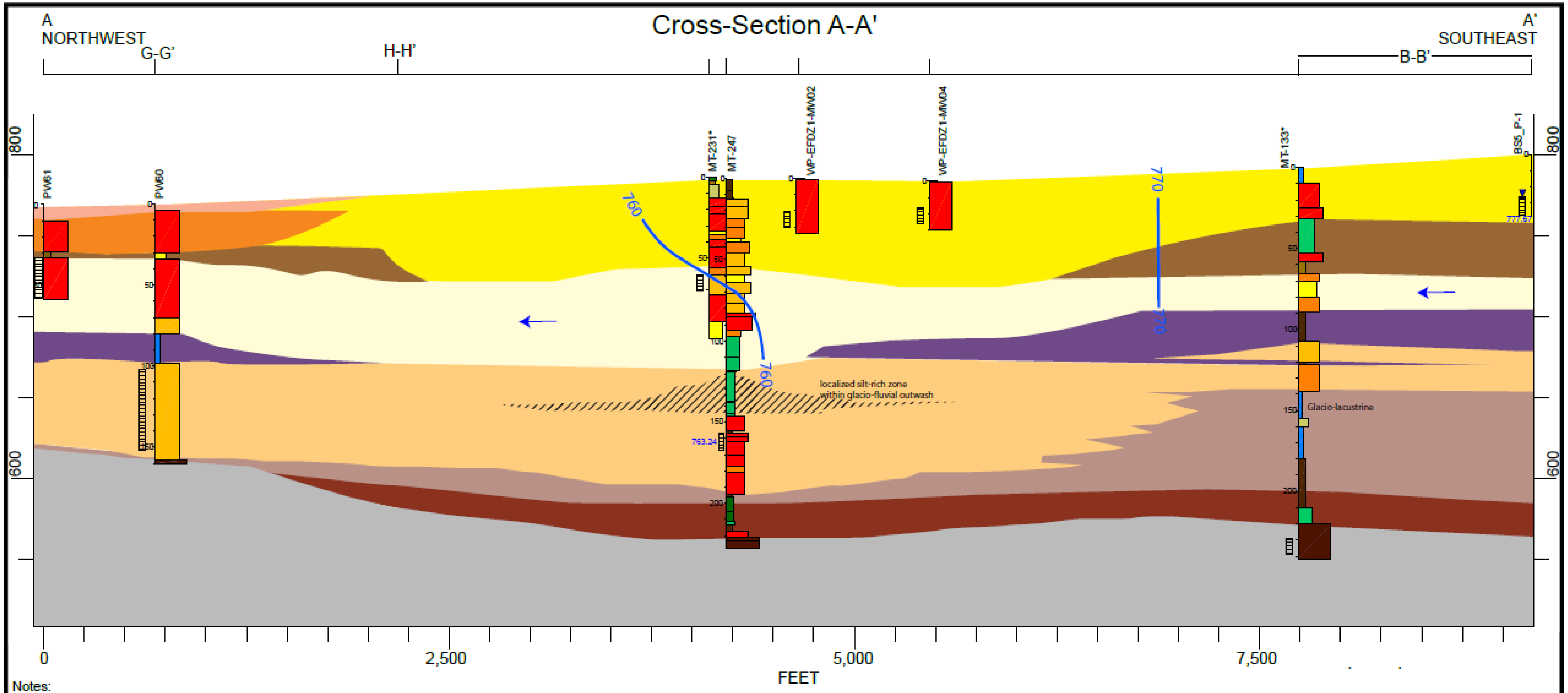


Hydraulic Conductivity K (cm/s)

Outwash: $10^{-0} – 10^{-2}$

Till: $10^{-5} – 10^{-6}$

Cross-Section A-A'



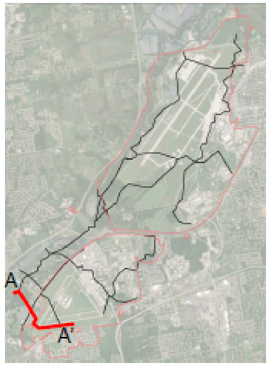
Notes:
1) Monitoring well screens with no groundwater elevation data noted were not measured during the synoptic round, not active, or abandoned.
2) * - indicates monitoring well was abandoned

Lithologic Legend

- Mad River Alluvium (overbank).
- Mad River Alluvium (channel & bar).
- Outwash Deposit 5: sand & gravel.
- Basal Till 4: undifferentiated diamicton.
- Ice contact deposits and Outwash Deposit 4 (found in Area A).
- Basal Till 3 (diamicton).
- Outwash Deposit 3: sand & gravel.
- Basal Till 2 (diamicton) and Lacustrine Facies (silt & clay).
- Outwash Deposit 2: sand & gravel.
- Basal Till 1 (diamicton) and Lacustrine Facies (silt & clay).
- Outwash Deposit 1: sand & gravel.
- Earliest lacustrine and backwater silts; thin basal tills in Area A.
- Bedrock.
- Disturbed ground/fill.

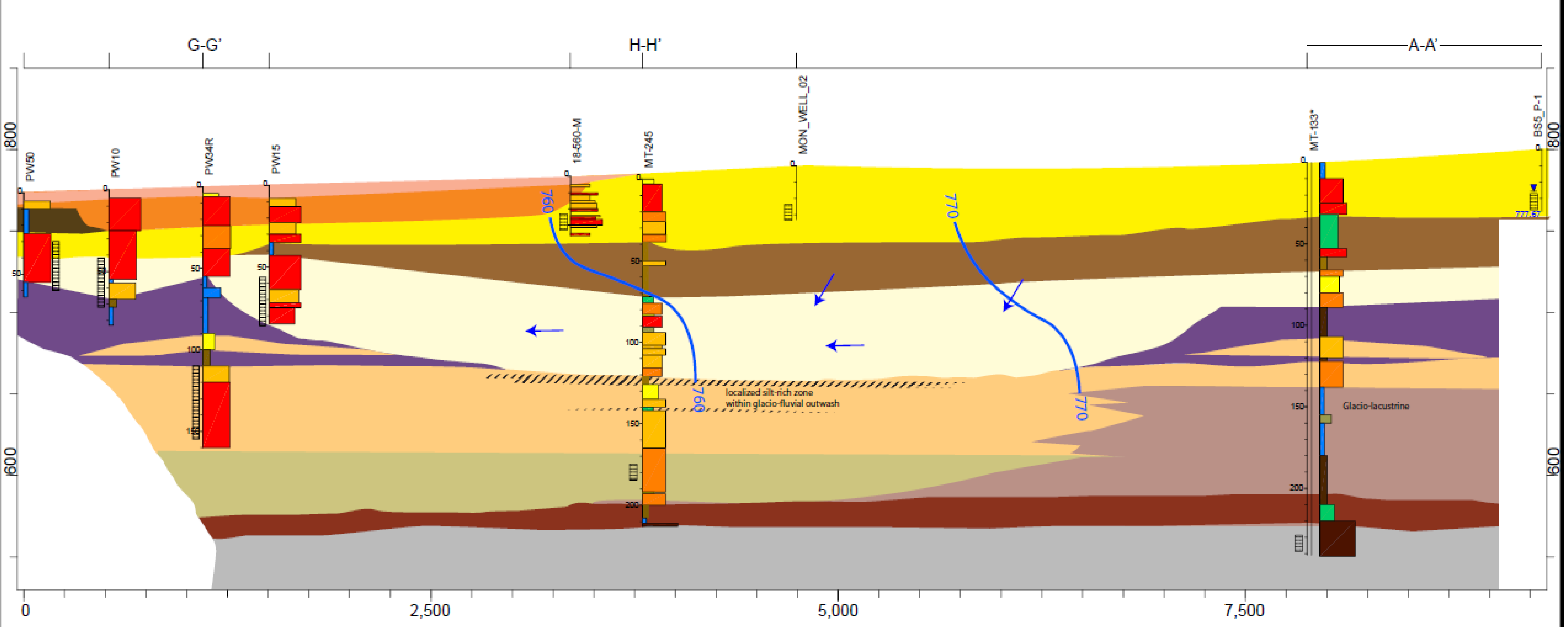
Upland Areas Between Areas A and B

- Undifferentiated tills: generally capping bedrock highs and encompassing relative ages of all other tills.
- Undifferentiated colluvial and alluvial deposits: sand & sandy gravel.



BURNS McDONNELL

Cross-Section B-B'



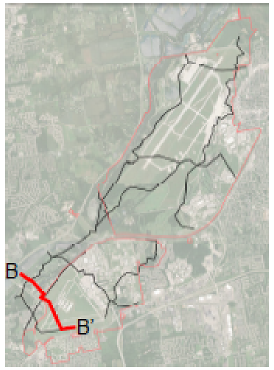
Notes:
1) Monitoring well screens with no groundwater elevation data noted were not measured during the synoptic round, not active, or abandoned.
2) * - indicates monitoring well was abandoned

Lithologic Legend

- Mad River Alluvium (overbank).
- Mad River Alluvium (channel & bar).
- Outwash Deposit 5: sand & gravel.
- Basal Till 4: undifferentiated diamicton.
- Ice contact deposits and Outwash Deposit 4 (found in Area A).
- Basal Till 3 (diamicton).
- Outwash Deposit 3: sand & gravel.
- Basal Till 2 (diamicton) and Lacustrine Facies (silt & clay).
- Outwash Deposit 2: sand & gravel.
- Basal Till 1 (diamicton) and Lacustrine Facies (silt & clay).
- Outwash Deposit 1: sand & gravel.
- Earliest lacustrine and backwater silts; thin basal tills in Area A.
- Bedrock.
- Disturbed ground/fill.

Upland Areas Between Areas A and B

- Undifferentiated tills: generally capping bedrock highs and encompassing relative ages of all other tills.
- Undifferentiated colluvial and alluvial deposits: sand & sandy gravel.

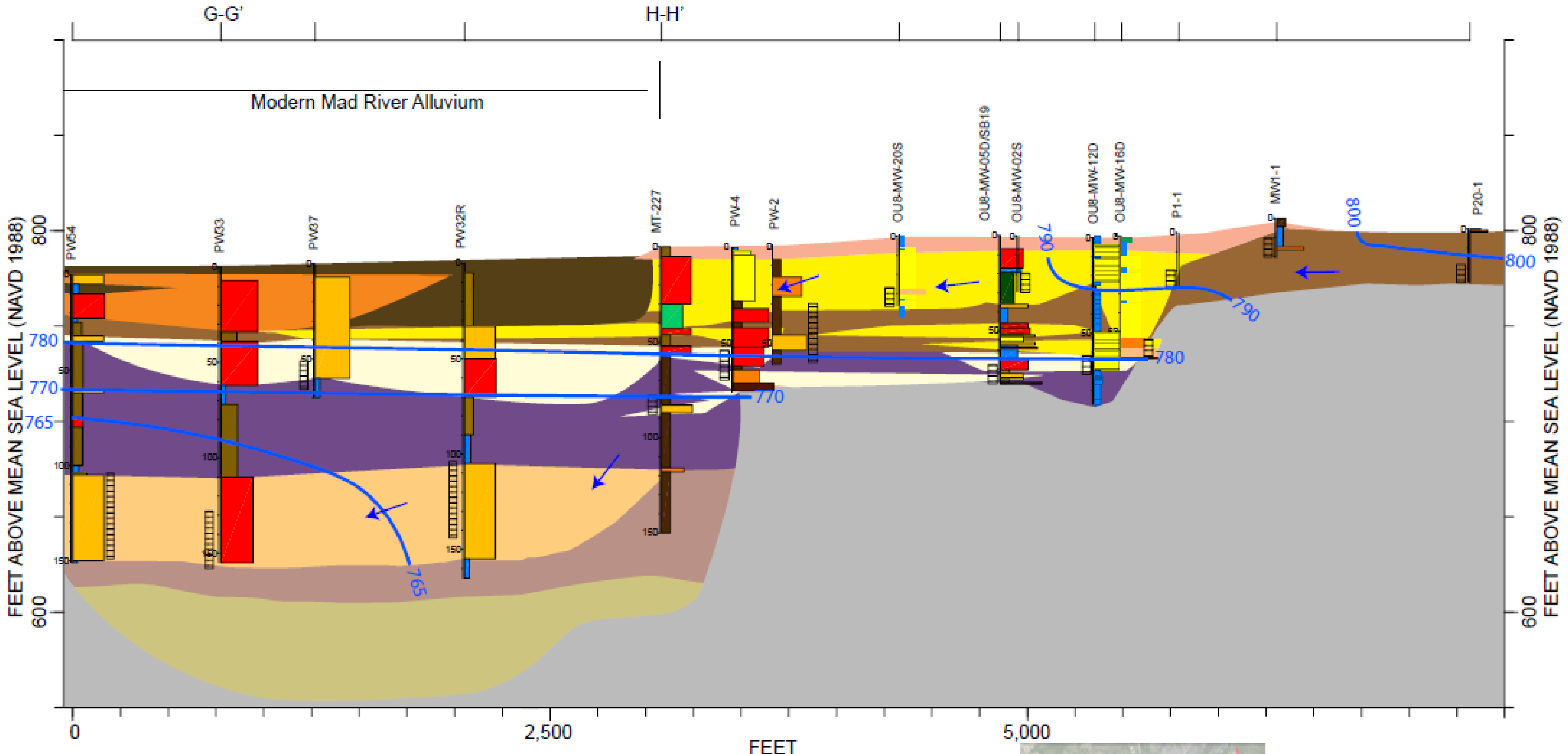


BURNS McDONNELL

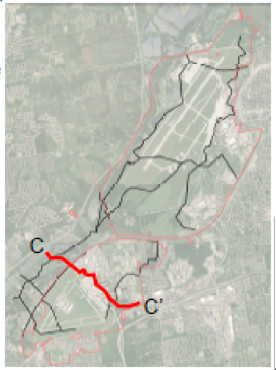
Cross-Section C-C'

C
NORTHWEST

CONTINUED ON
NEXT PAGE



Notes:
1) Monitoring well screens with no groundwater elevation data noted were not measured during the synoptic round, not active, or abandoned.
2) * - indicates monitoring well was abandoned



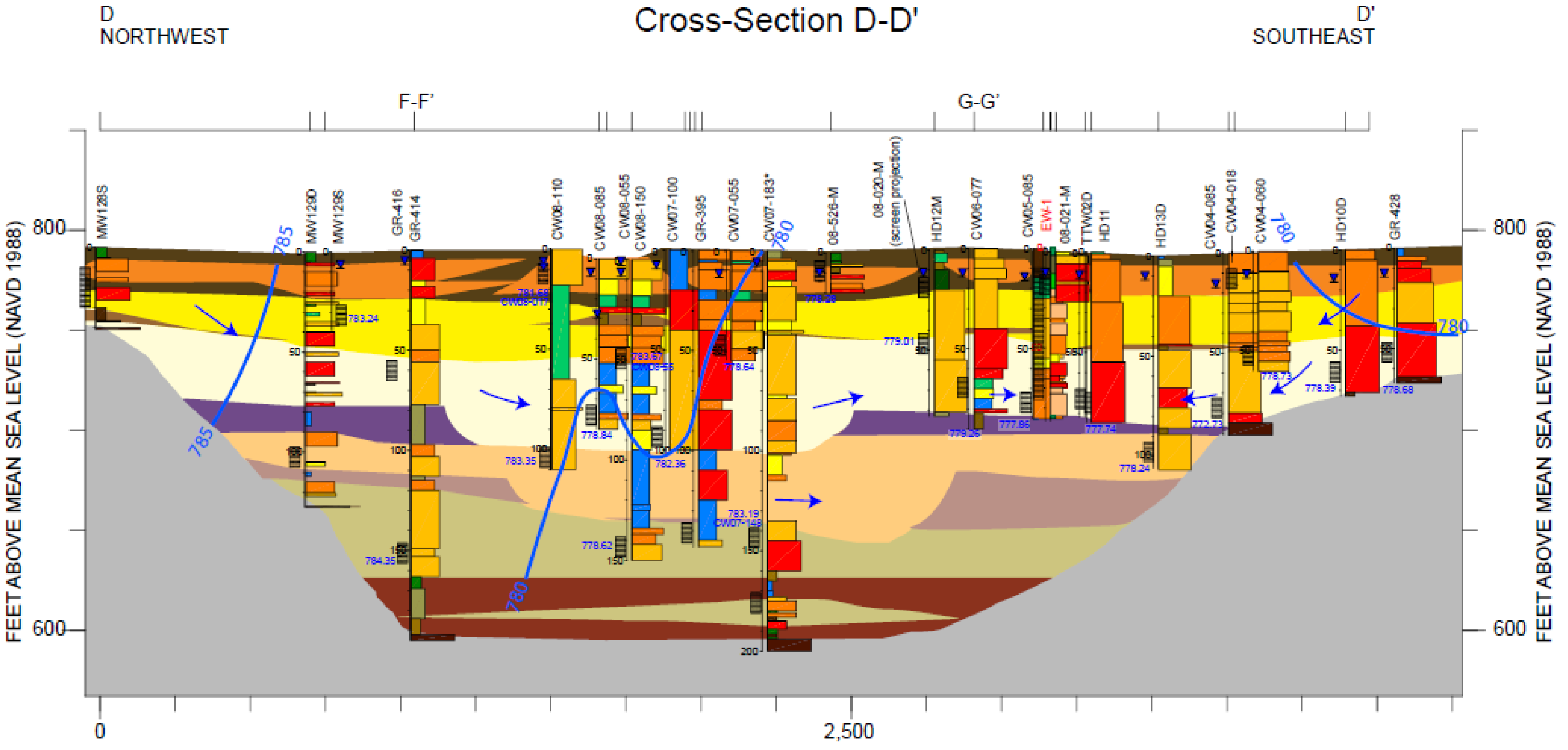
Lithologic Legend

- Mad River Alluvium (overbank).
- Mad River Alluvium (channel & bar).
- Outwash Deposit 5: sand & gravel.
- Basal Till 4: undifferentiated diamicton.
- Ice contact deposits and Outwash Deposit 4 (found in Area A).
- Basal Till 3 (diamicton).
- Outwash Deposit 3: sand & gravel.
- Basal Till 2 (diamicton) and Lacustrine Facies (silt & clay).
- Outwash Deposit 2: sand & gravel.
- Basal Till 1 (diamicton) and Lacustrine Facies (silt & clay).
- Outwash Deposit 1: sand & gravel.
- Earliest lacustrine and backwater silts; thin basal tills in Area A.
- Bedrock.
- Disturbed ground/fill.

Upland Areas Between Areas A and B

- Undifferentiated tills: generally capping bedrock highs and encompassing relative ages of all other tills.
- Undifferentiated colluvial and alluvial deposits: sand & sandy gravel.

Cross-Section D-D'



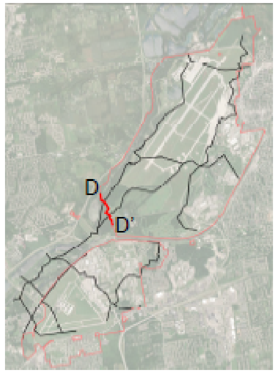
Notes:
1) Monitoring well screens with no groundwater elevation data noted were not measured during the synoptic round, not active, or abandoned.
2) * - indicates monitoring well was abandoned

Lithologic Legend

- Mad River Alluvium (overbank).
- Mad River Alluvium (channel & bar).
- Outwash Deposit 5: sand & gravel.
- Basal Till 4: undifferentiated diamicton.
- Ice contact deposits and Outwash Deposit 4 (found in Area A).
- Basal Till 3 (diamicton).
- Outwash Deposit 3: sand & gravel.
- Basal Till 2 (diamicton) and Lacustrine Facies (silt & clay).
- Outwash Deposit 2: sand & gravel.
- Basal Till 1 (diamicton) and Lacustrine Facies (silt & clay).
- Outwash Deposit 1: sand & gravel.
- Earliest lacustrine and backwater silts; thin basal tills in Area A.
- Bedrock.
- Disturbed ground/fill.

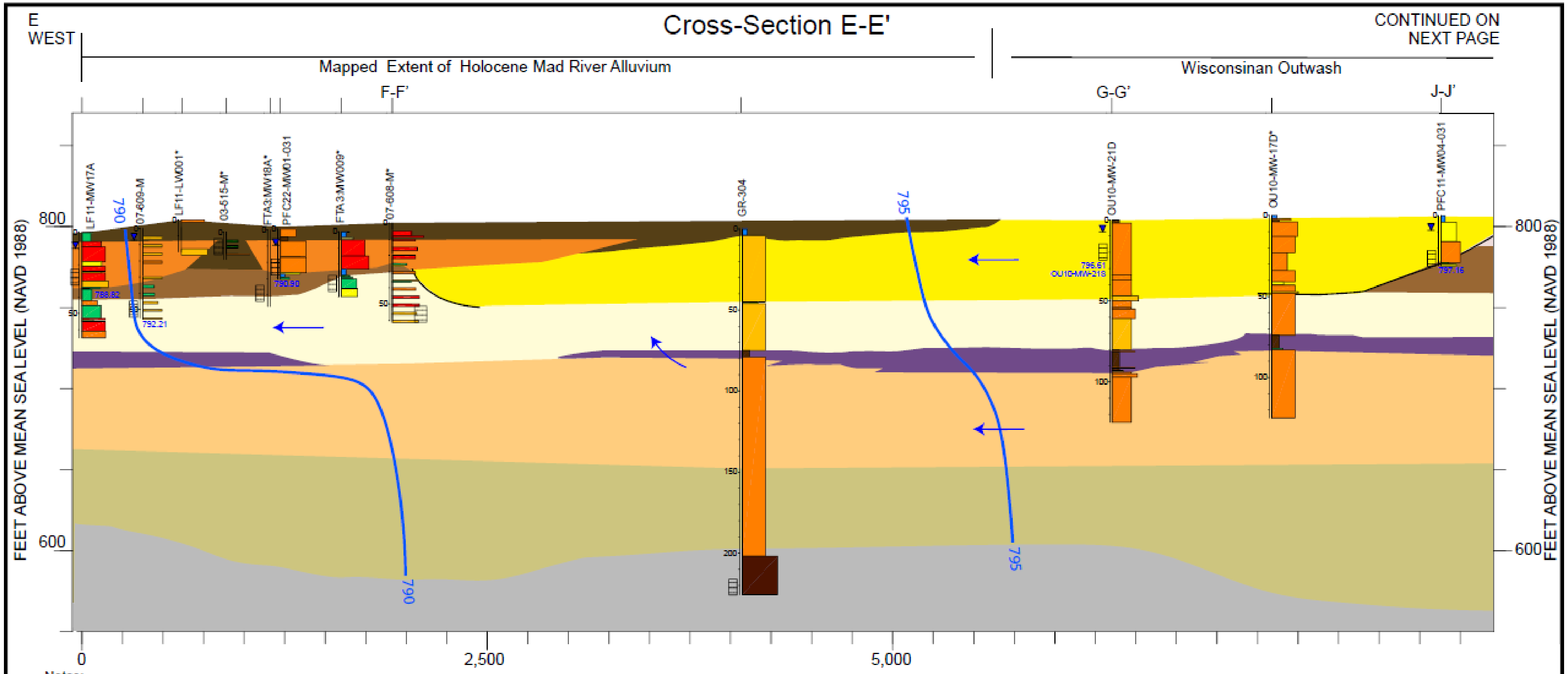
Upland Areas Between Areas A and B

- Undifferentiated tills: generally capping bedrock highs and encompassing relative ages of all other tills.
- Undifferentiated colluvial and alluvial deposits: sand & sandy gravel.



BURNS McDONNELL

Cross-Section E-E'



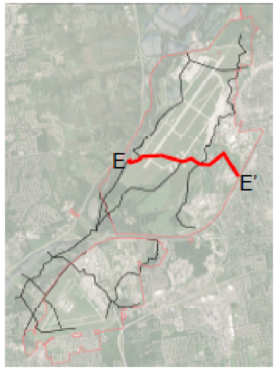
Notes:
1) Monitoring well screens with no groundwater elevation data noted were not measured during the synoptic round, not active, or abandoned.
2) * - indicates monitoring well was abandoned

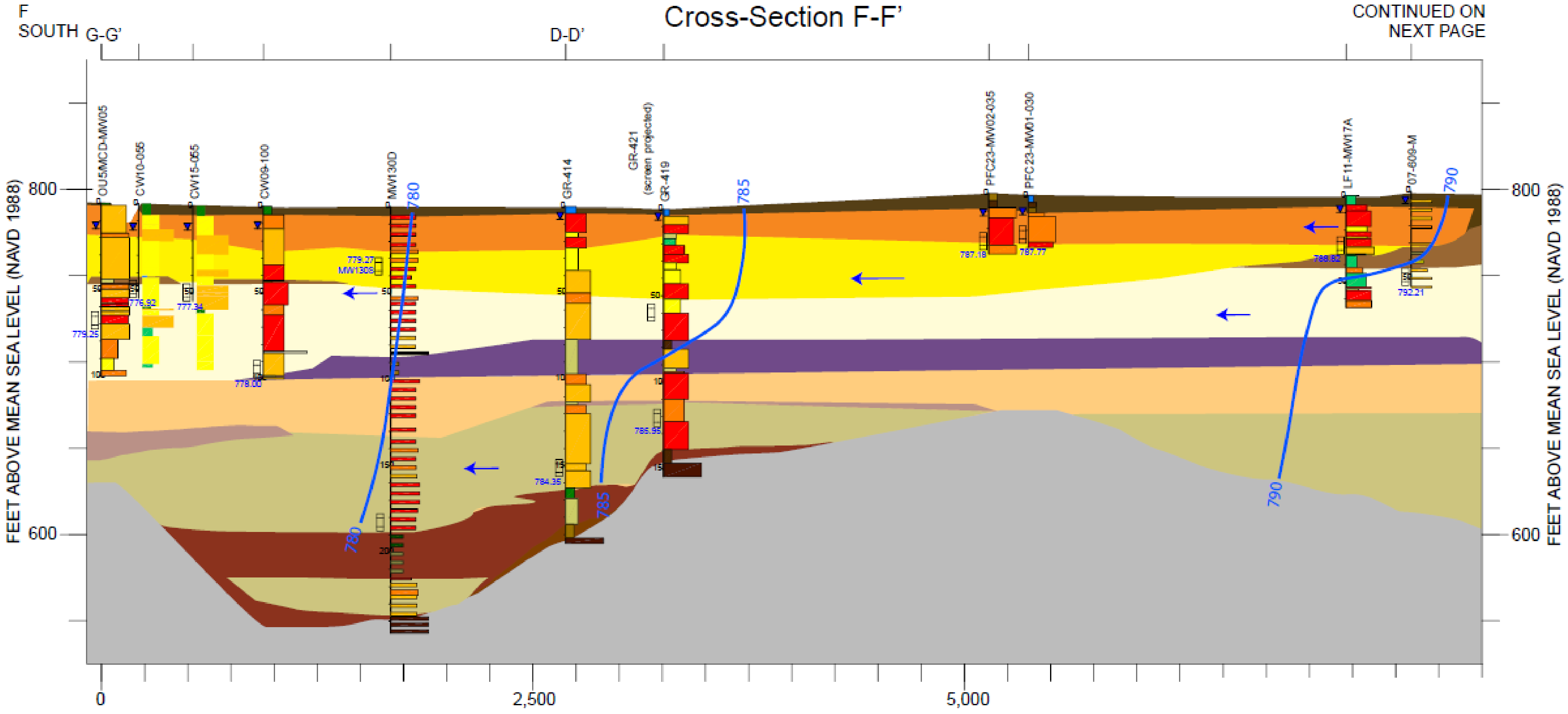
Lithologic Legend

- Mad River Alluvium (overbank).
- Mad River Alluvium (channel & bar).
- Outwash Deposit 5: sand & gravel.
- Basal Till 4: undifferentiated diamicton.
- Ice contact deposits and Outwash Deposit 4 (found in Area A).
- Basal Till 3 (diamicton).
- Outwash Deposit 3: sand & gravel.
- Basal Till 2 (diamicton) and Lacustrine Facies (silt & clay).
- Outwash Deposit 2: sand & gravel.
- Basal Till 1 (diamicton) and Lacustrine Facies (silt & clay).
- Outwash Deposit 1: sand & gravel.
- Earliest lacustrine and backwater silts; thin basal tills in Area A.
- Bedrock.
- Disturbed ground/fill.

Upland Areas Between Areas A and B

- Undifferentiated tills: generally capping bedrock highs and encompassing relative ages of all other tills.
- Undifferentiated colluvial and alluvial deposits: sand & sandy gravel.





CONTINUED ON NEXT PAGE

Notes:

1) Monitoring well screens with no groundwater elevation data noted were not measured during the synoptic round, not active, or abandoned.

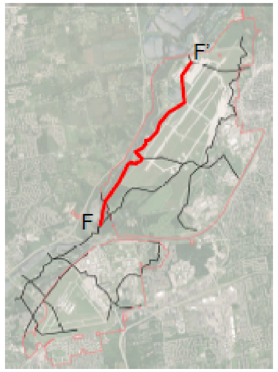
2) * - indicates monitoring well was abandoned

Lithologic Legend

- Mad River Alluvium (overbank).
- Mad River Alluvium (channel & bar).
- Outwash Deposit 5: sand & gravel.
- Basal Till 4: undifferentiated diamicton.
- Ice contact deposits and Outwash Deposit 4 (found in Area A).
- Basal Till 3 (diamicton).
- Outwash Deposit 3: sand & gravel.
- Basal Till 2 (diamicton) and Lacustrine Facies (silt & clay).
- Outwash Deposit 2: sand & gravel.
- Basal Till 1 (diamicton) and Lacustrine Facies (silt & clay).
- Outwash Deposit 1: sand & gravel.
- Earliest lacustrine and backwater silts; thin basal tills in Area A.
- Bedrock.
- Disturbed ground/fill.

Upland Areas Between Areas A and B

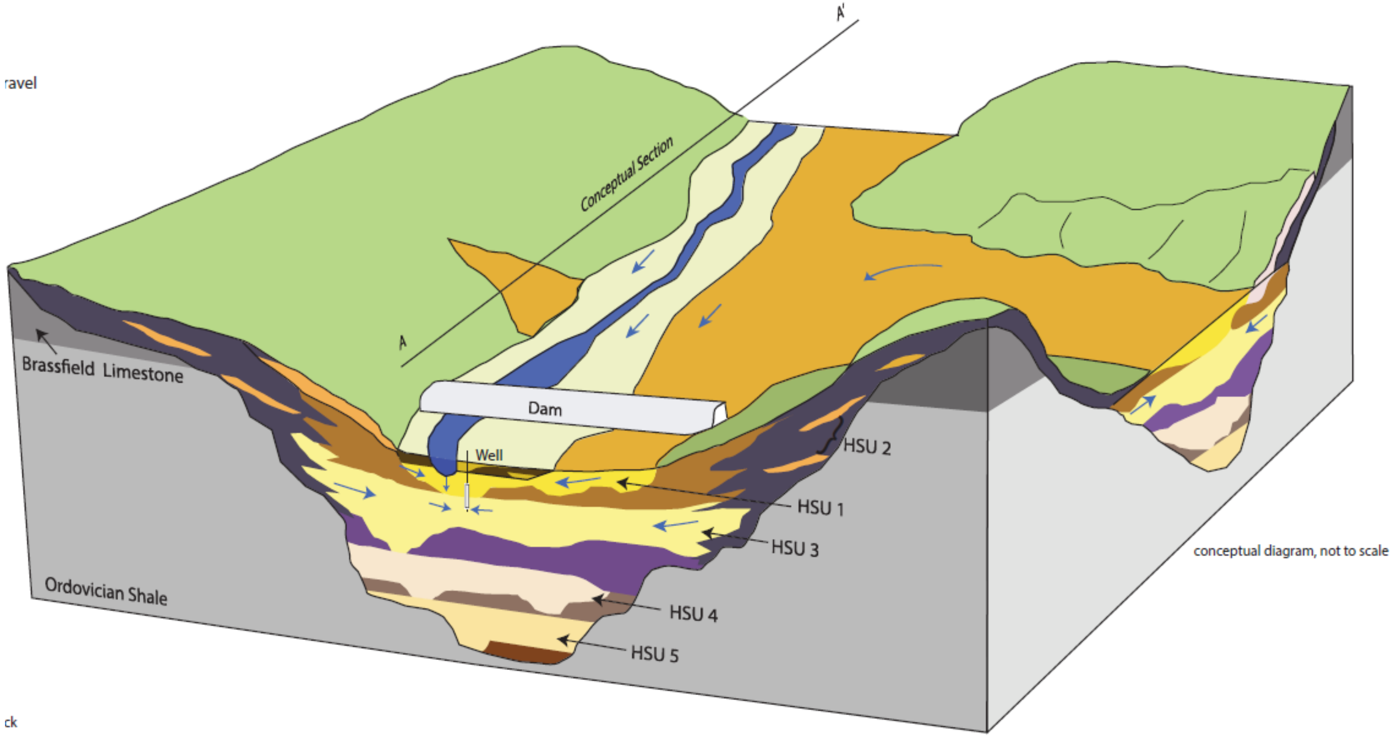
- Undifferentiated tills: generally capping bedrock highs and encompassing relative ages of all other tills.
- Undifferentiated colluvial and alluvial deposits: sand & sandy gravel.

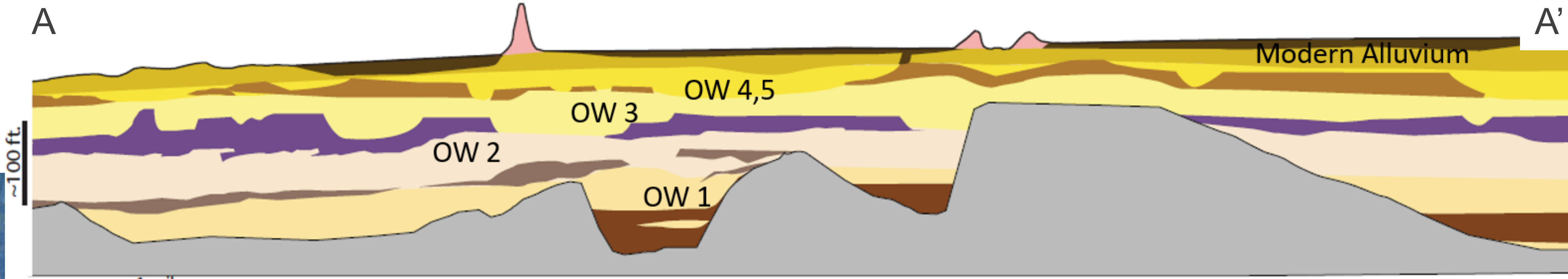


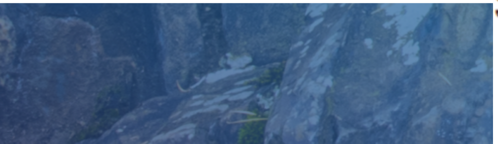
BURNS McDONNELL

Glacial Facies Model:
CSM Developed in Support of PFAS RI

- 4 till aquitards divide Dayton's Buried Valley Alluvial Aquifer into 5 hydrostratigraphic zones
- Aquitard continuity greater at margins of Mad River Valley; depositionally controlled
- CSM created context for understanding analytical data & a means for targeting PFAS transport zones







Example of Incorporation of Remediation Geology Into a PFAS RI Program

BURNS McDONNELL

United Federal Policy Quality Assurance Project Plan (UFP-QAPP)

Develop the preliminary Geology-Focused CSM used by the technical team to understand Data Gaps and Data Quality Objectives to be addressed in the Remedial Investigation Work Plan.

UFP-QAPP

- The **preliminary Geology-Focused CSM will be incorporated into the Pre-draft UFP-QAPP** and used to guide sample placement and preliminary locations for installation of monitoring wells and will continue to be executed throughout the time frame of full preparation of the UFP-QAPP (Predraft, Draft, Draft Final and Final).

Remedial Investigation (RI) Addendum

- The **revised CSM** will reflect interpretation of newly acquired borings logs and potentiometric data.


BURNS McDONNELL®