Assessment and Remediation of Petroleum-Impacted sites within Karst Environments – Addressing Potential Complications With Positive Solutions

Presented by Polk and Escambia County Local Programs

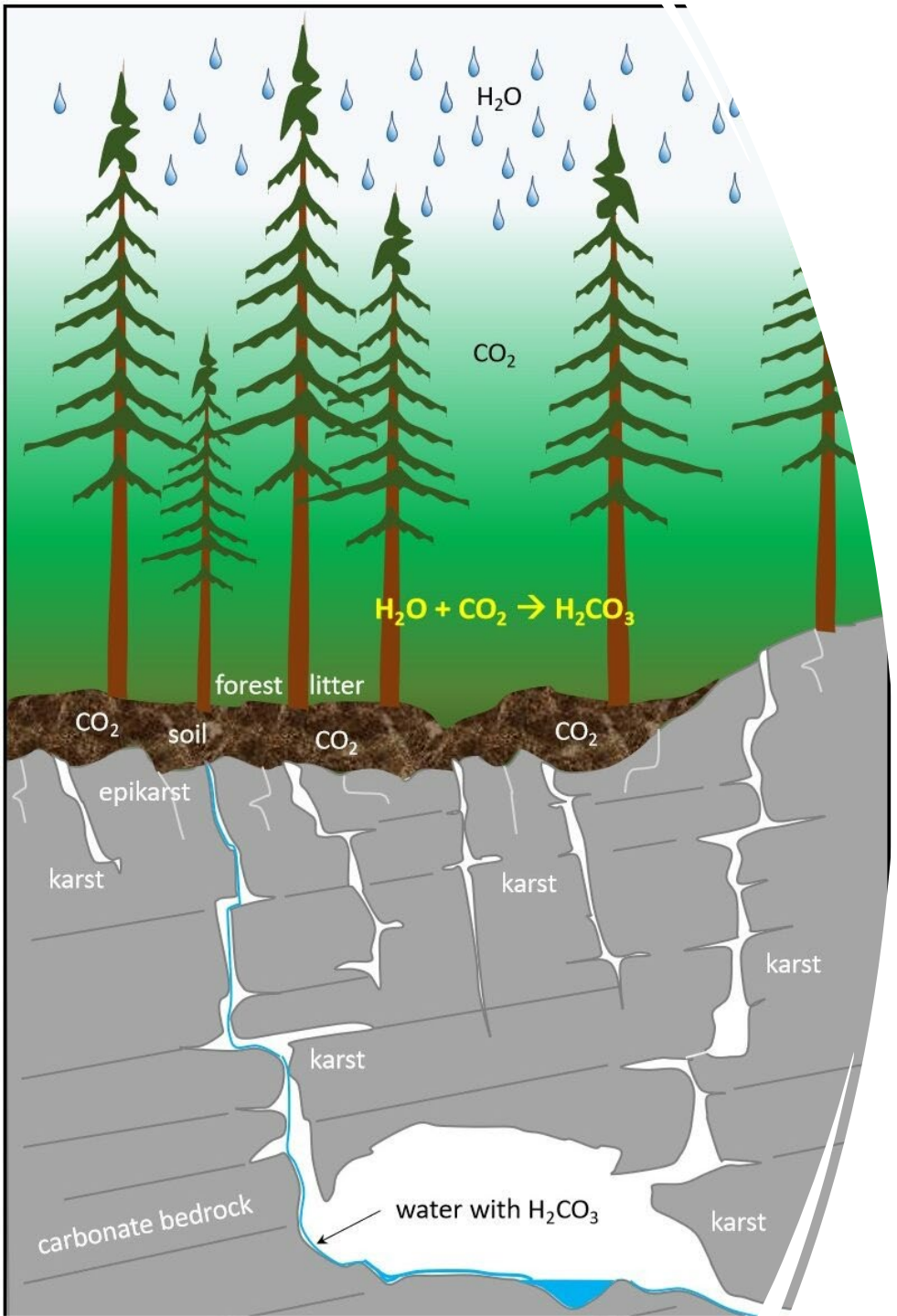
What is a karst environment?

- Karst is a topography formed from the dissolution of soluble carbonate rocks such as limestone, dolomite, and gypsum(-western U.S.). It is characterized by features like drainage systems with sinkholes and caves underground.

- Karst is also most strongly developed where the water table is relatively low, such as in uplands with entrenched valleys, and where rainfall is moderate to heavy. This contributes to rapid downward movement of groundwater, which promotes dissolution of the bedrock.

How is the limestone bedrock dissolved?

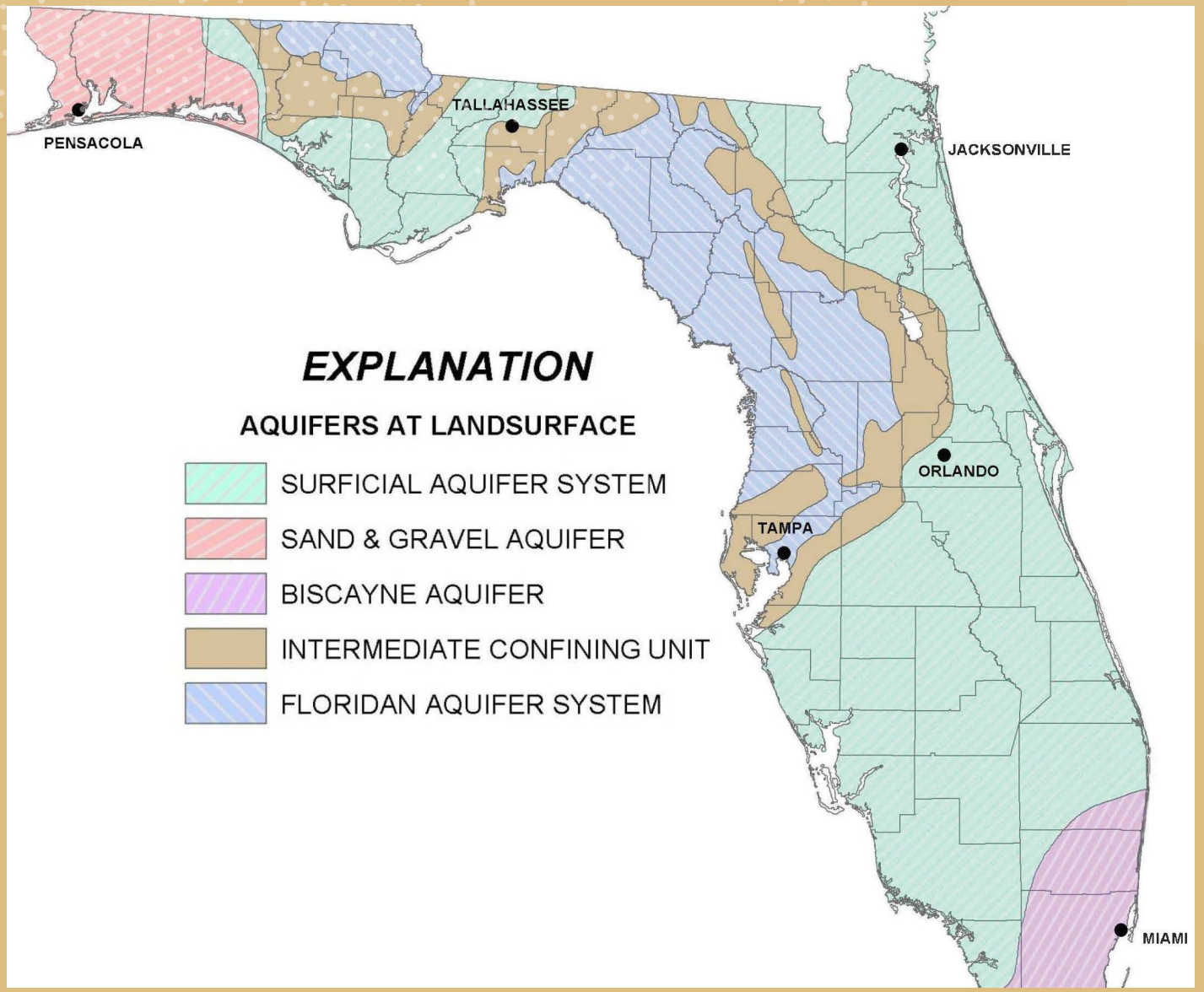
What processes occur?



Chemistry of dissolution

- The carbonic acid that causes karstic features is formed as rain passes through Earth's atmosphere picking up carbon dioxide (CO2), which readily dissolves in the water. Once the rain reaches the ground, it may pass through soil that provides additional CO2 produced by soil respiration. Some of the dissolved carbon dioxide reacts with the water to form a weak carbonic acid solution, which dissolves calcium carbonate. The primary reaction sequence in limestone dissolution is the following:

Aquifers in Florida



Sand and Gravel Aquifer

- The **Sand and Gravel Aquifer** in the far western panhandle is the main source of water for Santa Rosa and Escambia Counties. It is made up of sand and gravel interbedded with layers of silt and clay.

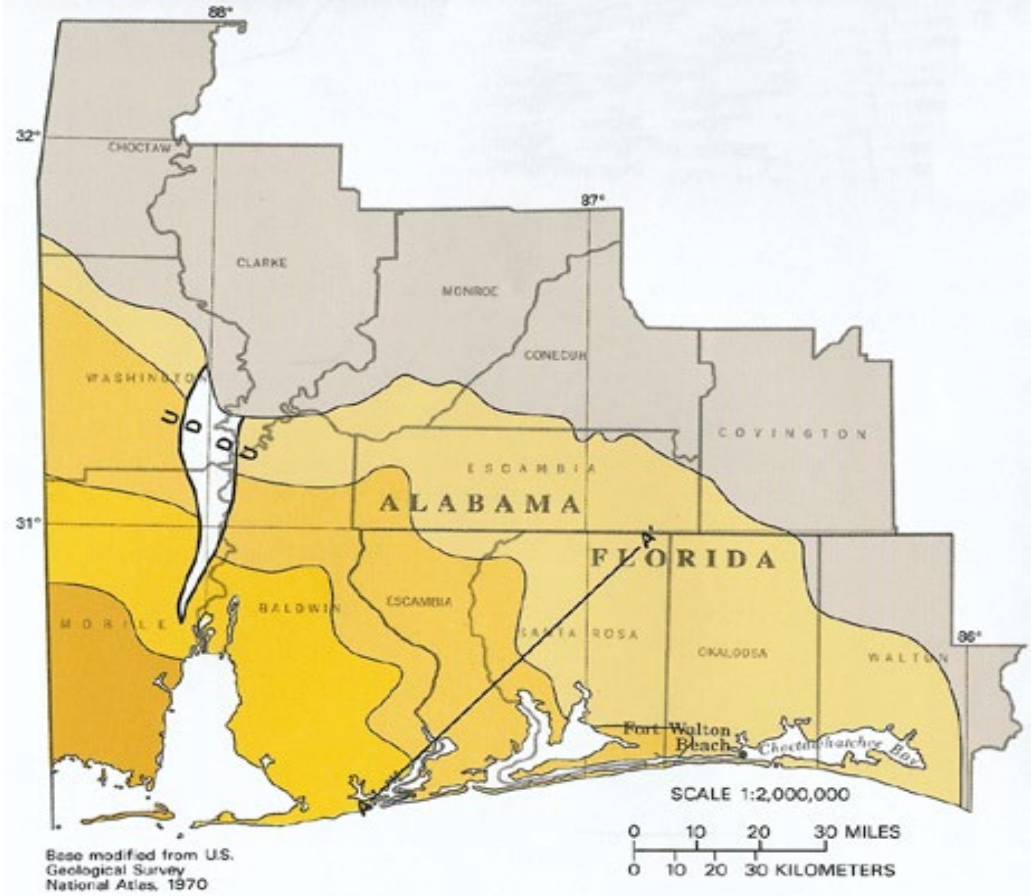
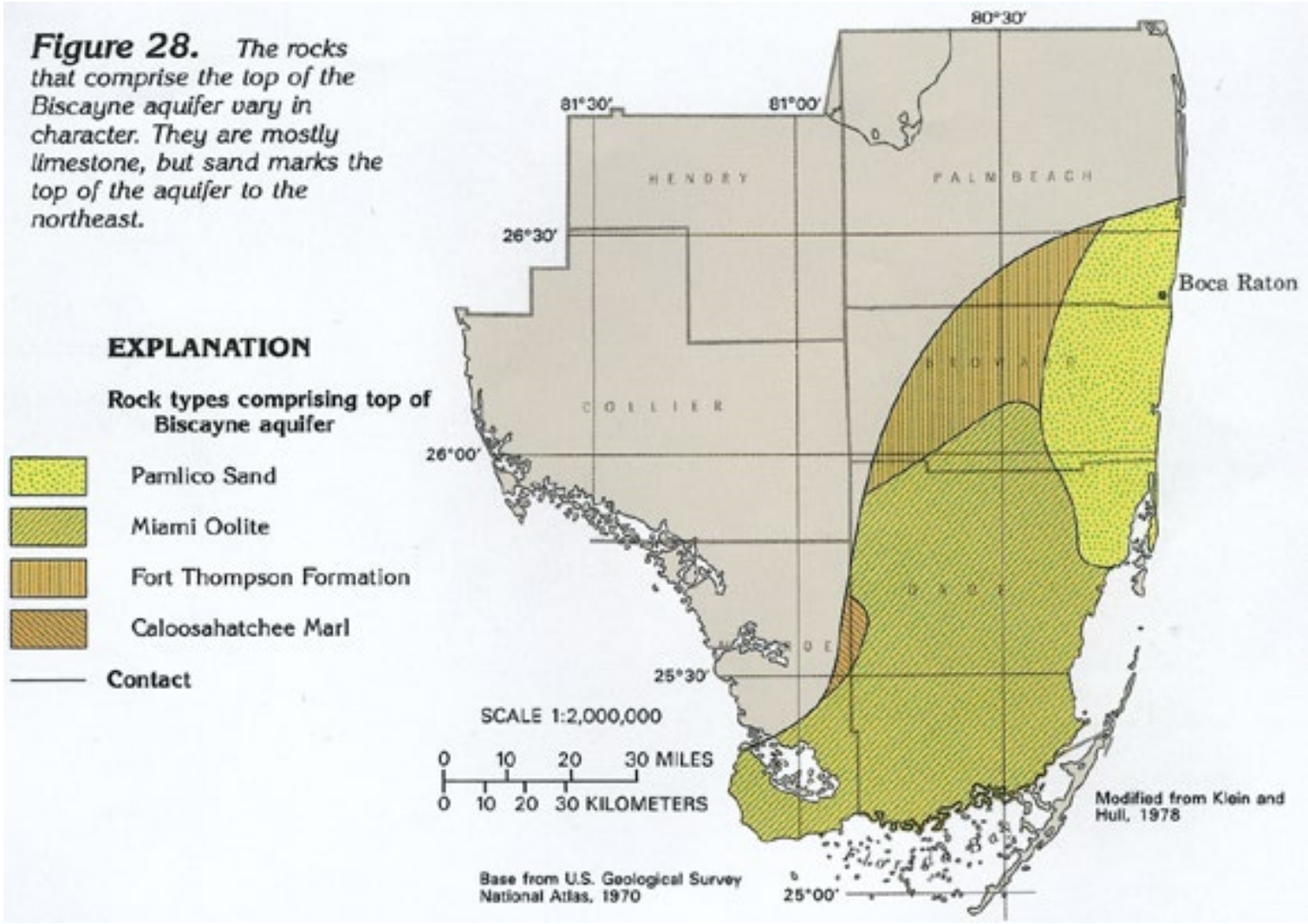


Figure 22. *The sand and gravel aquifer thickens to the southwest. In western Alabama, the aquifer is offset by a down-dropped fault block called the Mobile graben.*

Biscayne Aquifer

- The **Biscayne Aquifer** supplies water to Dade and Broward Counties and southern Palm Beach County. A pipeline also transports water from this aquifer to the Florida Keys. The aquifer is made of permeable limestone and less permeable sand and sandstone.



Surficial Aquifer System

- The **Surficial Aquifer System** is the major source of drinking water in St. Johns, Flagler and Indian River counties, as well as Titusville and Palm Bay. It is typically shallow (less than 50 ft. thick) and is often referred to as a ‘water table’ aquifer, but in Indian River and St. Lucie Counties, it can be up to 400 ft. thick.

The Surficial aquifer system extends throughout large areas in the Coastal Plain of Florida, Georgia and South Carolina. The Surficial aquifer is the uppermost aquifer in the Northern Atlantic Coastal Plains aquifer system. The surficial aquifer extends over large parts of the Delmarva Penninsula and the eastern coastal plain of North Carolina.

Intermediate Aquifer system

- A fourth aquifer, the **Intermediate Aquifer System** in southwest Florida lies at a depth between the Surficial Aquifer System and the Floridan Aquifer. It is found south and east of Tampa, in Hillsborough and Polk counties and extends south through Collier County. It is the main source of water supply for Sarasota, Charlotte and Lee counties, where the underlying Floridan Aquifer is too salty to be potable.

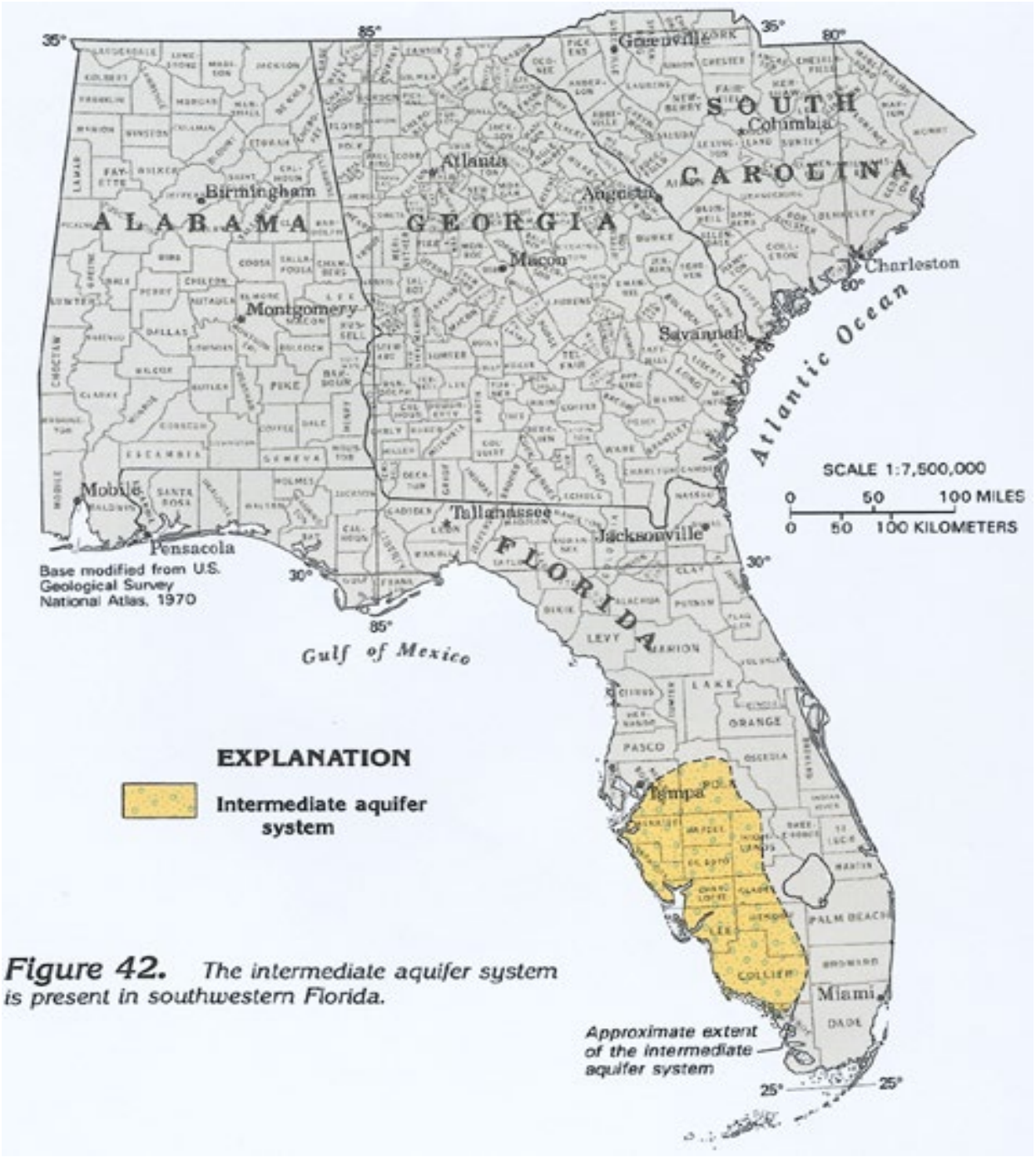
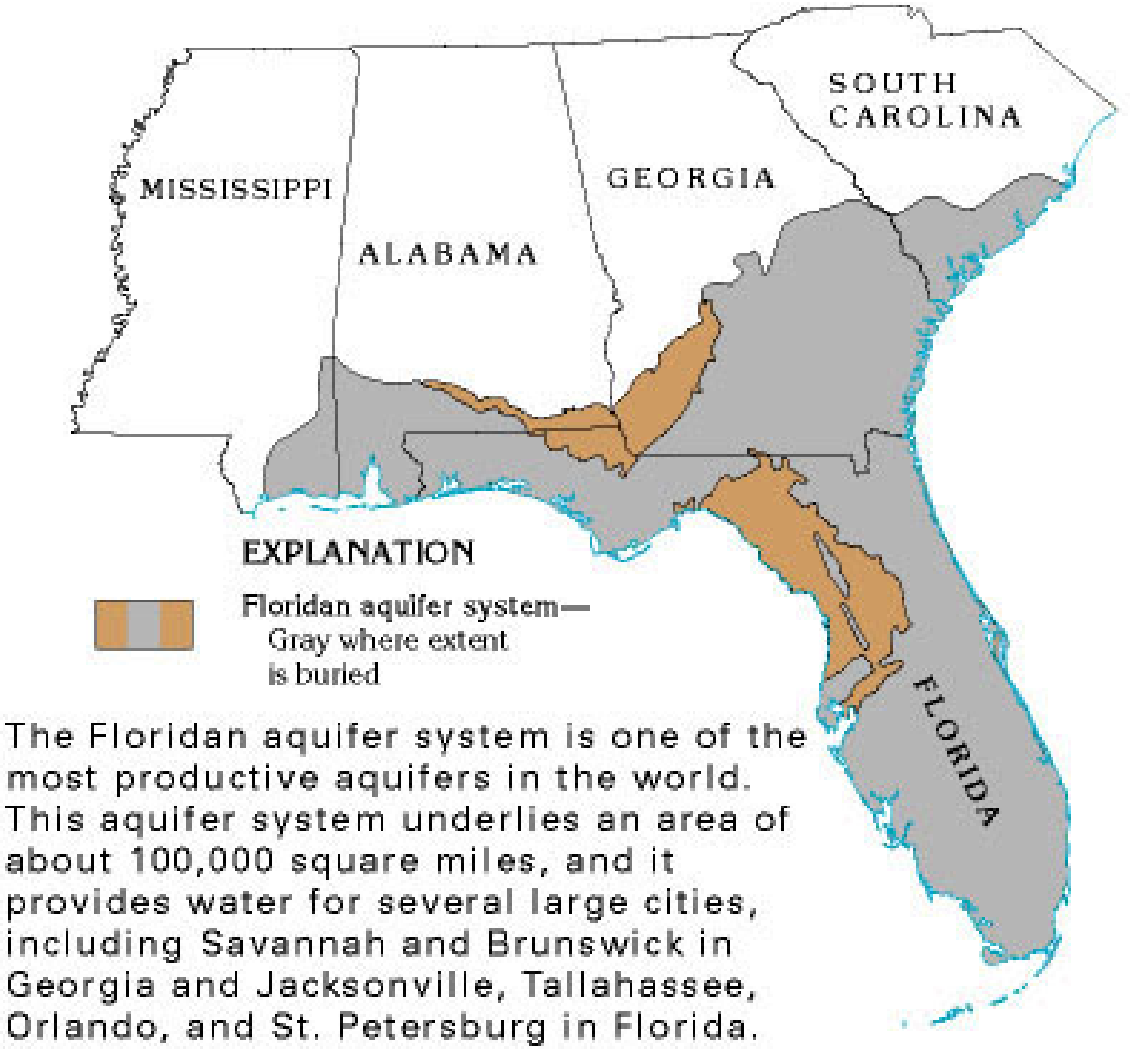


Figure 42. The intermediate aquifer system is present in southwestern Florida.

Floridan Aquifer System

- The **Floridan Aquifer System** is a principal productive artesian aquifer covering almost 100,000 sq. miles including all of Florida and parts of Georgia, Alabama, Mississippi (not used due to high salinity and depth), and South Carolina. It behaves as one aquifer over much of its extent, although rocks of lower permeability create hydrologic separation between the UFA and LFA sub-regionally. The majority of freshwater is contained in the UFA and is used for water supply and is the main source of groundwater in the Kissimmee Basin. In south Florida, the UFA is brackish and used as reverse osmosis water, blending with shallower fresh Biscayne groundwater, and aquifer storage/recovery. The LFA has fresh to brackish water in northeastern Florida and Georgia, while in south Florida it is saline and used to dispose of effluent from wastewater treatment processes.

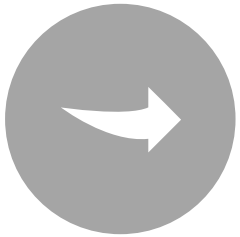


The Floridan aquifer system is one of the most productive aquifers in the world. This aquifer system underlies an area of about 100,000 square miles, and it provides water for several large cities, including Savannah and Brunswick in Georgia and Jacksonville, Tallahassee, Orlando, and St. Petersburg in Florida.

Source: *http://sr6capp.er.usgs.gov/aquiferBasics/ext_floridan.html*

Effects of Karst Hydrogeology

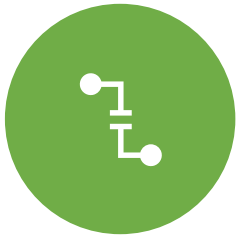
POSES POTENTIAL COMPLICATIONS FOR ASSESSMENT AND REMEDIATION OF **PETROLEUM-IMPACTED** GROUNDWATER.



CHANGE IN DEPTH AND GROUNDWATER FLOW DIRECTION.

CHANGE IN PETROLEUM PLUME DELINEATION.

POTENTIAL CONTAMINATION OF POTABLE/PUBLIC WELLS.



NOW WHAT?

Sinkholes/Underground Drainage Systems/Springs/Caverns

- Most rainwater is slightly acidic and becomes more acidic as it moves through decaying plant debris. Limestone strata in Florida is porous, allowing this water to percolate and dissolve the limestone and carry it in solution. Over time, this process creates underground voids, drainage systems and cavities in the limestone bedrock. When a large cavity enlarges to the point that its ceiling can no longer support the weight of overlying sediments, the earth collapses into the cavity, creating a sinkhole.

Sinkholes/Underground Drainage Systems/Springs/Caverns

- When groundwater discharges from an underground drainage system, it is a spring, such as Wakulla Springs, Silver Springs or Rainbow Springs. Sinkholes can occur in the beds of streams, sometimes taking all of the stream's flow, creating a disappearing stream. Leon County, (county seat of Tallahassee) in the eastern panhandle, is the location of geologically active Lake Jackson, which undergoes periodic disappearances through underlying sinkholes! This 4,000 acre lake has a history of virtually draining about every 25 years, most recently in 2006. Dry caves are parts of karst drainage systems that are above the water table, such as the Florida Caverns in Marianna.

Sediment-filled Sinkholes

- Over a considerable period of time, typical erosional and depositional processes cause sinkhole structures to fill with sediments including sand, silt, gravel and clay. Since most sedimentary formations are originally deposited horizontally, the presence and extent of these filled-in sinkholes may be determined through review of boring logs and noting the depth of contact with the limestone bedrock.
- This determination can be complicated due to the horizontal extent of certain lithologies, surface drainage structures and limited by depth constraints of assessment investigation activities.

Non-Karst Subsidence Incidents

- Other subterranean events can cause holes, depressions or subsidence of the land surface that may mimic sinkhole activity. These include subsurface expansive clay or organic layers which compress as water is removed, collapsed or broken sewer and drain pipes or broken septic tanks, improperly compacted soil after excavation work, and even buried trash, logs and other debris… Such an event is called a **"subsidence incident.**"

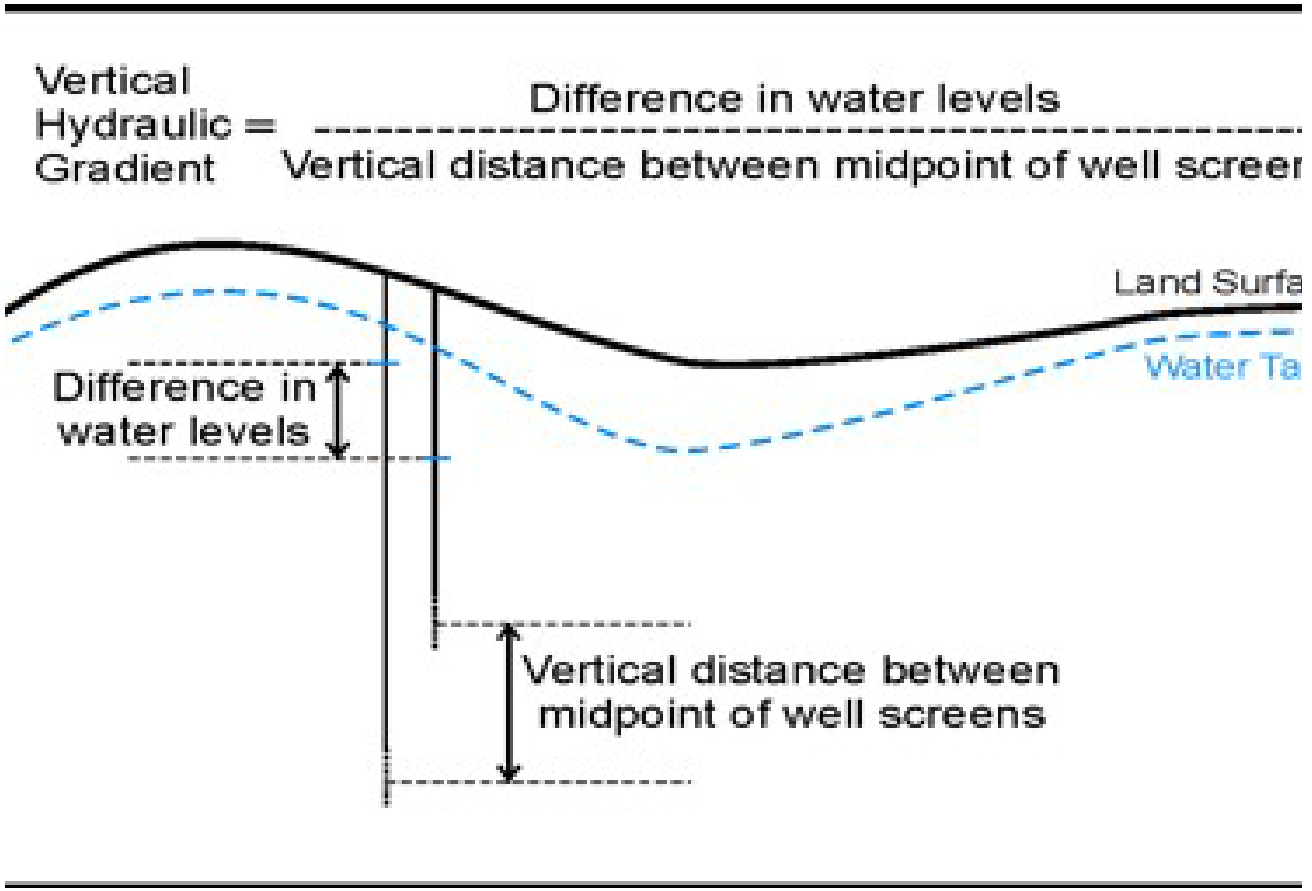
Unfortunately, at many sites where karst features may be present, these other subterranean situations exist as well, adding to the difficulty in properly assessing and remediating petroleum impacts.

Local Program 17 and PRP Sites with Karst Hydrogeology in Northwest Florida

- Local Program 17 (Escambia) oversees PRP work in seven Northwest Florida counties; Escambia, Santa Rosa, Okaloosa, Bay, Walton, Holmes and Washington. Of these, Walton, Holmes and Washington Counties exhibit the most evidence of Karst Hydrogeology and its effects on Petroleum Contaminated Site Assessment and Cleanup.
- While **Karst Hydrogeology effects** are very evident in PRP sites located throughout these 3 Counties in towns such as Westville, Bonifay, Graceville, Vernon and others, the number of sites and the difficulties encountered are **most evident in the town of Chipley**, located in the North-Central portion of Washington County, just north of the Interstate 10 East-West corridor.

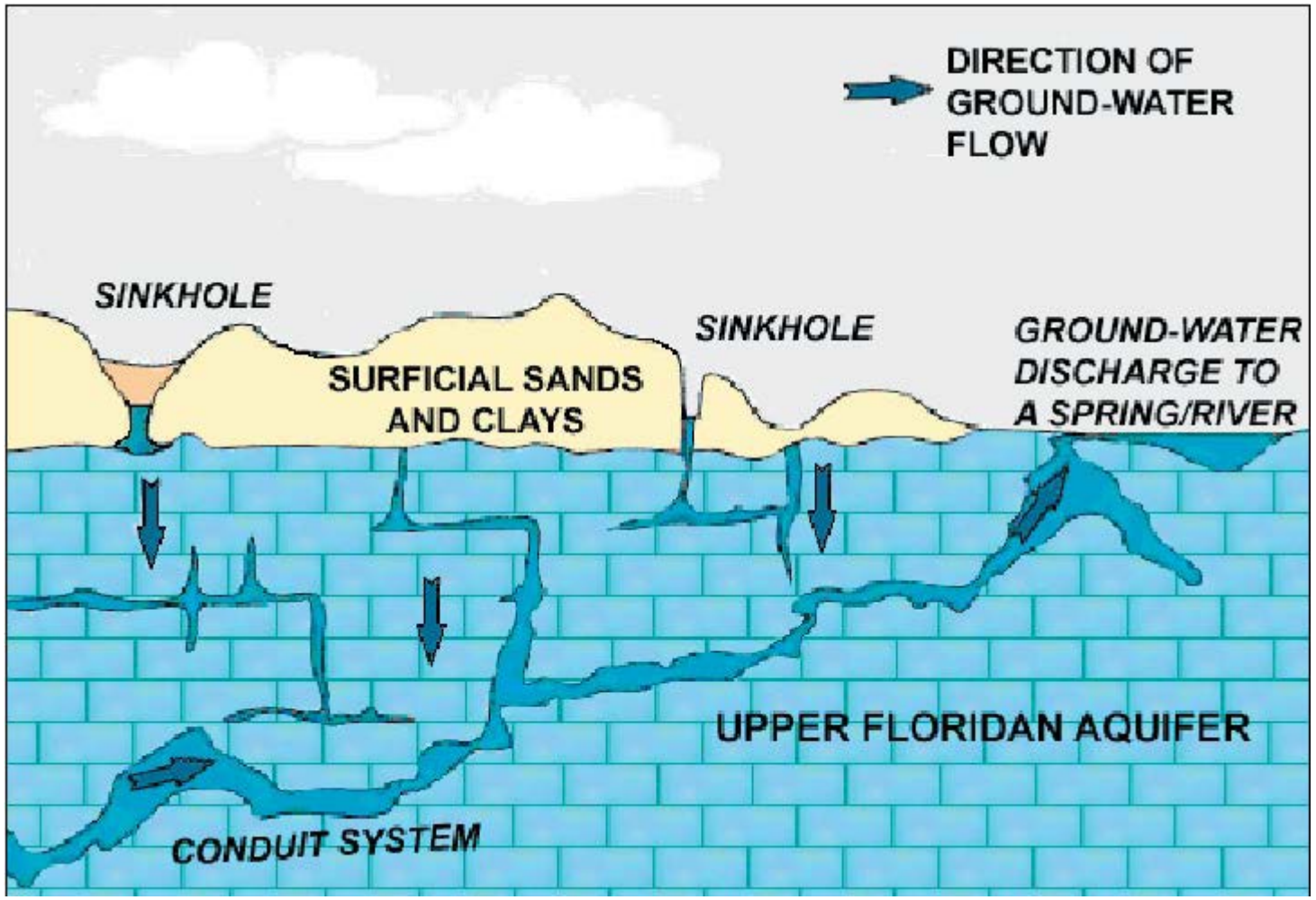
Vertical Hydraulic Gradient

- At many sites, the vertical hydraulic gradient is small in comparison to the horizontal hydraulic gradient. At karst sites with shallow Limestone, vertical hydraulic gradients may be very significant, leading to downward migration of contaminant plumes. Subtract the hydraulic head value of the deeper well from the shallower well value and divide by the vertical distance between the midpoints of the well screens.
- A quick look at the groundwater (gw) elevations of nearby-clustered wells (shallow, intermediate, deep, etc.), should provide evidence if a vertical hydraulic gradient is present with gw elevations dropping in feet as the wells get deeper. This assumes no confining layers are present.



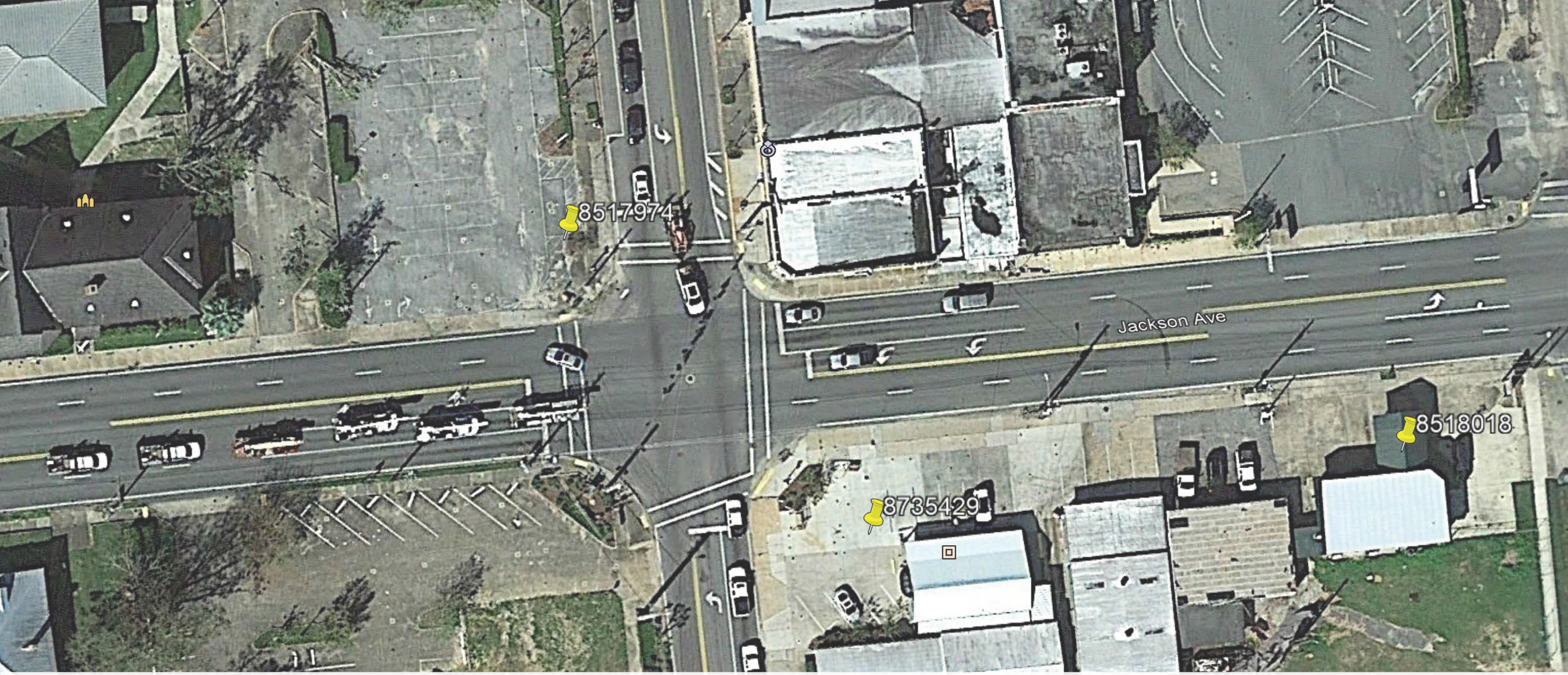
Vertical Hydraulic Gradient

- The most important mechanism that causes vertical migration of a plume is the presence of a downward vertical gradient beneath the site. A trend of increasing hydraulic conductivity with depth could induce a downward vertical potential beneath the site. A more permeable horizon may be situated below, and be hydraulically connected to, the shallower unit in which the discharge occurred. A downward hydraulic potential would develop causing the groundwater and contaminant plume to migrate towards the deeper more permeable layer.



Chipley, Washington County, Florida

- State Highway 77 runs North-South through the center of Chipley, intersecting Highway 90 running East-West through the town center. Petroleum contaminated sites are located predominately along Hwy 77 and Hwy 90, especially near the town center.
- Chipley is located in the Marianna Lowlands where Limestone is near the ground surface and consequently, the area is one of karst development with many sinkholes.
- A typical lithology encountered in Chipley is comprised of silty, slightly clayey sands from surface to approximately 8-feet below land surface (bls), followed by very impermeable clay down to a depth of approximately 30-feet bls; below this clay unit various interbedded layers of sand, silt and clay of poor to high permeability persist until a thin marl (<5-feet thick mix of clay & limestone), is encountered immediately above a chalky Limestone at approximately 48-feet bls. This typical soil column varies locally based on buried Karst sinkhole/drainage features and other variables occasionally including the presence of dolomitic, drusy and microcrystalline limestone as well as gravel. Coquina may be encountered at sites farther south in Washington County.
- An unusual feature encountered at some sites just west of the Hwy 77/Hwy 90 intersection, near the former town Courthouse, is the presence of large voids containing air under substantial pressure. One 4-inch monitoring well installed in the early days of State-funded cleanup reportedly blew air under pressure upon removal of its well cap, for more than 30 years before it was abandoned!



BP-Main Street : FAC# 678517974

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- The BP-Main Street site FAC# 678517974, at 1260 Jackson Ave. (Hwy 90), in Chipley, Washington County, FL is a former automobile service and gasoline service station starting sometime prior to WWII. The site is currently a municipal parking lot for the city.
- The site has had an EDI discharge and 3 PLIRP discharges with an initial Remedial Action limited source removal of 600 gallons of free product and petroleum contact water via vacuum truck in 1991.
- The site was deemed an Imminent Threat site due to its proximity to a primary Public Water Supply Well (open-hole production from 120 to 175-feet bls after 1993;prior to 1993, the well was only 67-feet deep!). Due to analytical results detecting the dissolved petroleum plume was impacting the water quality of the well, it was put offline and abandoned in 2018.

BP-Main Street FAC# 678517974 - Lithology

- The site lithology from surface to depth consists of silty sand (SM), clayey sand (SC), sandy clay (SC-CL) and clay (CL), with thin silt and sand stringers until the Limestone formation is encountered at approximately 48-feet bls.
- Limestone lens and fragments are encountered within the clay and sand units at depths as shallow as 30-feet bls along the southeastern perimeter of the site and interbedded lenses of sand and clay were observed from 70 to 100-feet bls at the site to the immediate southeast, consistent with sediment deposited in a collapsed sinkhole.

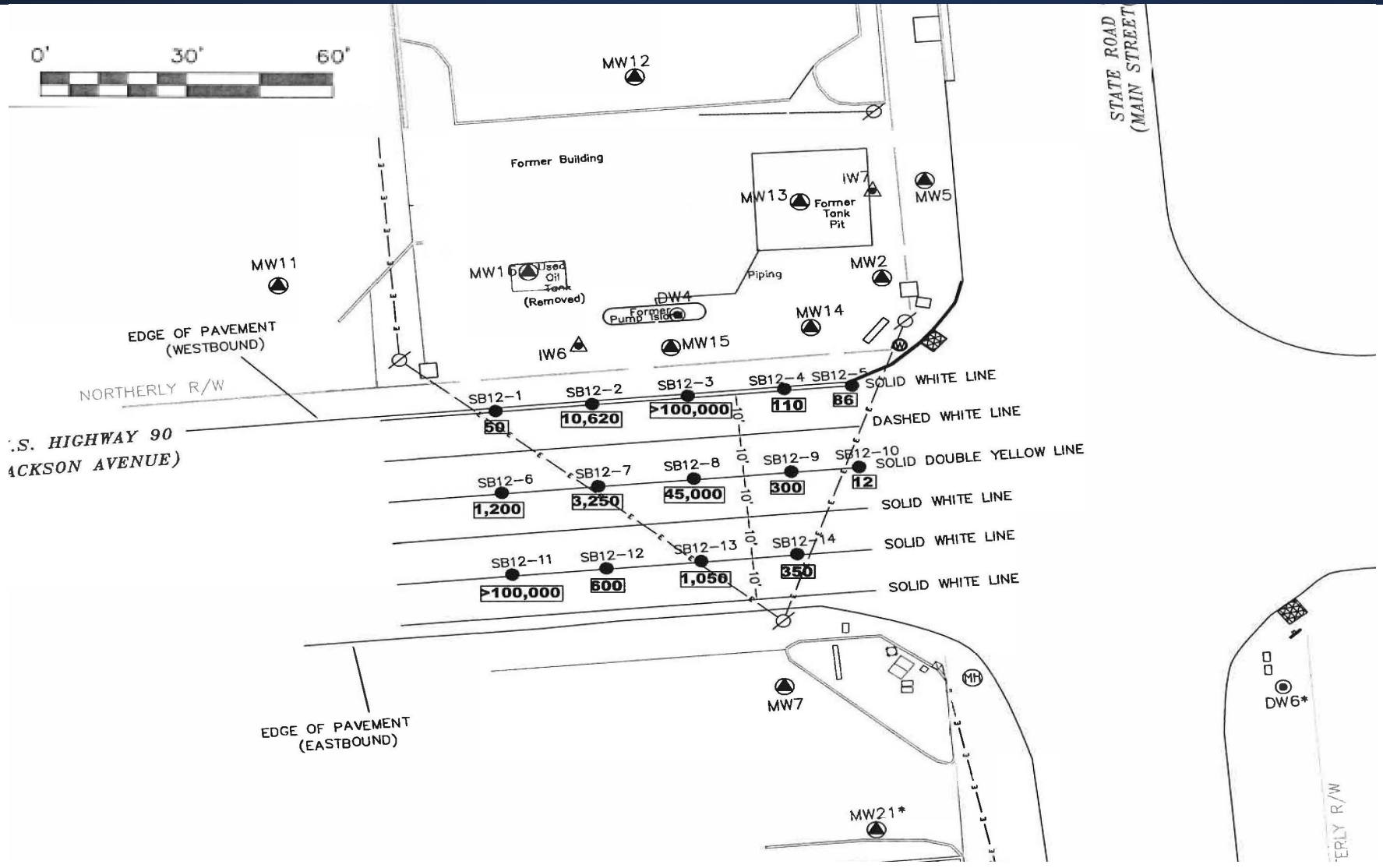
BP-Main Street : FAC# 678517974 – Site Activities

- A 2004 Pilot Test determined that although SVE had influence in the shallow perched zone (0 – 12-ft), air sparging in this zone and at deeper depths was determined to be marginal to not acceptable and AS/SVE was determined not to be a feasible remedial strategy.
- In 2007 a conventional source removal was conducted down to a maximum depth of 27-feet bls and removed 5,512-tons of impacted soil from the site. Post Source Removal monitoring and offsite soil sampling indicates that contamination is migrating back into the site from beneath Highway 90 and has impacted the offsite properties to the south and southeast.
- Vertical extent wells into the limestone aquifer at approximately 40-feet bls confirmed the impacts to the high-recharge zone of the upper Floridan Aquifer. High dissolved BTEX constituent concentrations posing potential threats to a HDPE water line (permeable to gasoline) led to discussions regarding the replacement of this water main which may have occurred recently during FDOT roadwork.

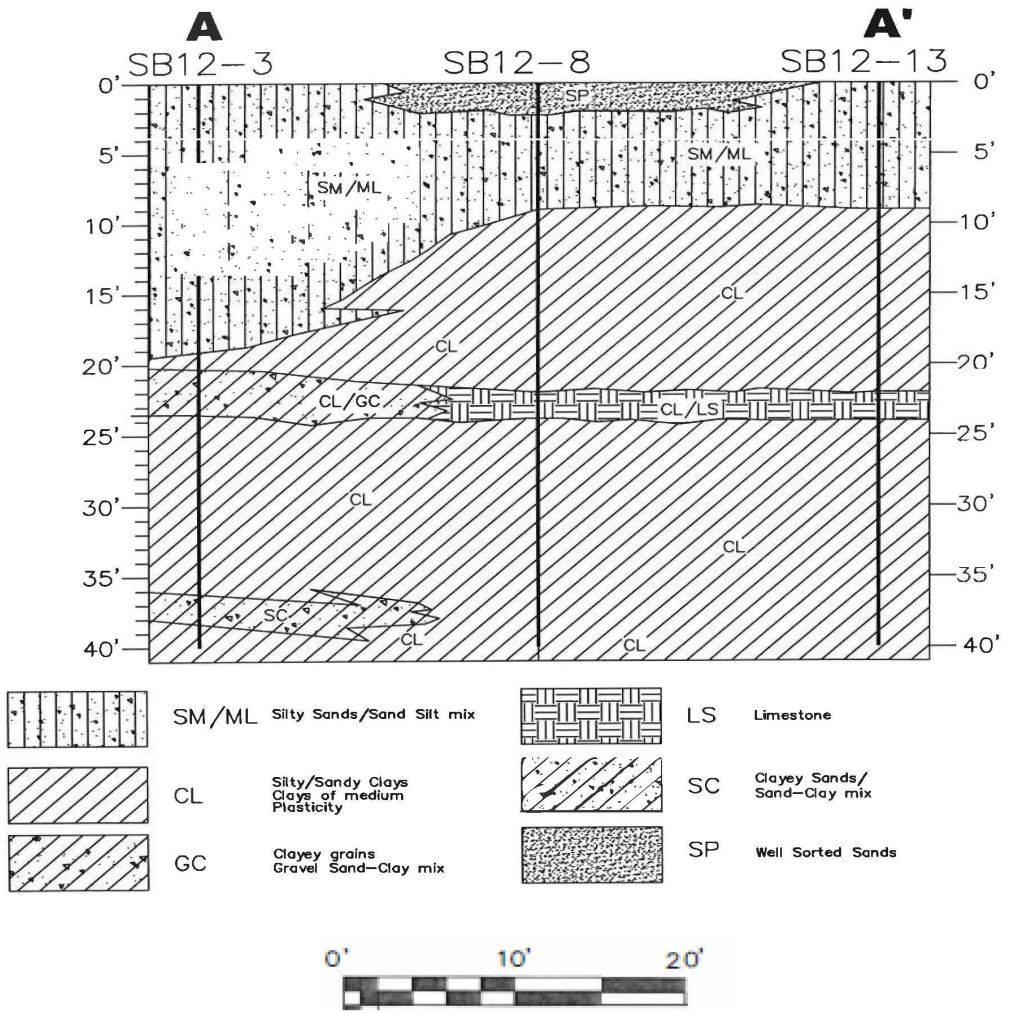
BP-Main Street : 2012 Soil Assessment Site Activities

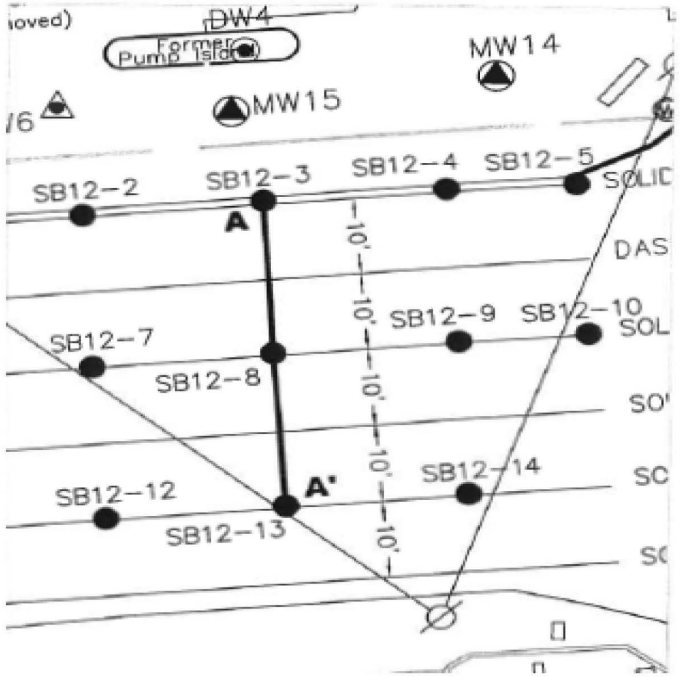
- Site activities conducted in 2012 included advancing several rows of soil borings in the Highway 90 Roadway. The work was performed at night as Highway 90 is the main East – West roadway through Northwest Florida other than Interstate I-10.
- The following slides display the soil boring locations and two cross-sections North-South and West-East beneath Hwy 90 between the BP –Main Street site and the City of Chipley property immediately to the south.

BP-Main Street : 2012 Soil boring locations/OVA max

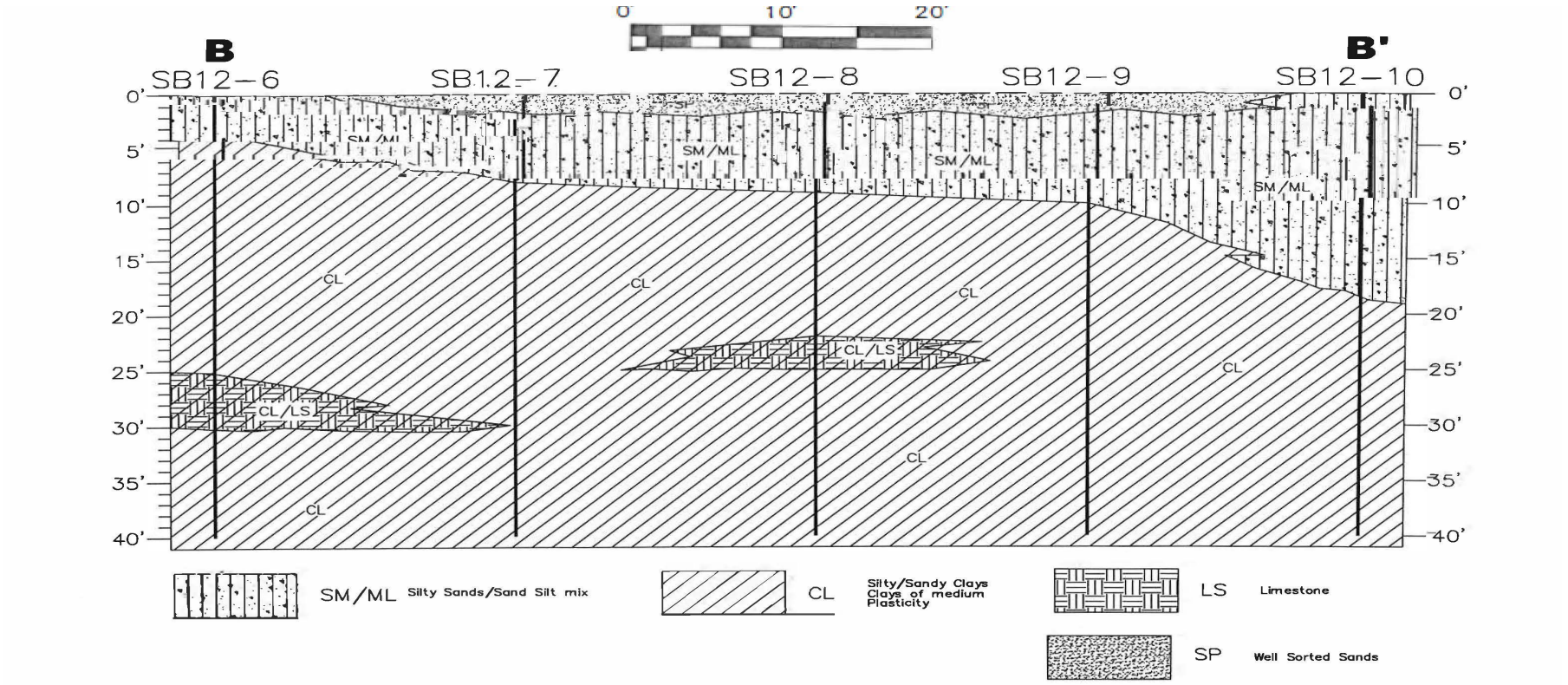


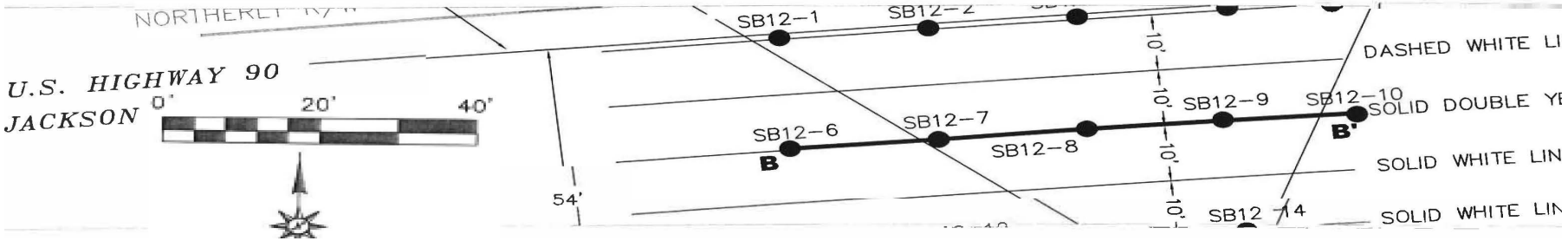
BP-Main Street : 2012 North-South X-Section





BP-Main Street : 2012 West – East X-Section





BP-Main Street : – Recent Activities

Source removal utilizing Large Diameter Augers (LDA) was conducted at the Discount Outlet 59 frmr Exprezit #759 FAC# 678735429, immediately southeast of BP-Main Street, in 2007, removing 3,125 tons of impacted soils down to 15-feet below land surface (bls) following initial manual free product removal. This site was also granted Imminent Threat status. A 2013 Injection Pilot Test determined that Injection into depth intervals deeper than the shallow perched interval (0 – 12-ft) was not feasible.

A Pilot Test Plan was approved in 2018 to evaluate the effectiveness of dual phase extraction from discrete depth intervals at the BP-Main Street site. Three depth intervals were to be investigated following the installation of three nested wells inside a three-foot diameter borehole advanced to the top of the Limestone via LDA. During LDA borehole advancement, a large void was observed after having advanced the LDA borehole less than 12-feet bls. Flowable fill was used to fill the void. No determination was made regarding the origin of the void.

BP-Main Street – Void in Parking Lot during failed LDA boring

BP-Main Street : 2023 – HRSC Investigation

Following the completion of several NAM Purchase Orders, a Scope of Work was agreed upon to determine if intervals representing high permeability and low-permeability as well as elevated contaminant concentrations were somewhat uniform throughout the BP-Main Street site and the Discount Outlet 59 frmr Exprezit #759 site utilizing High Resolution Site Characterization (HRSC) technology.

A DPT Membrane Interface Probe (MIP)/Hydraulic Profiling Tool (HPT) equipped with Photo Ionization Detector (PID) and Electrical Conductivity Dipole (ECD) were advanced to the Limestone at several locations on the BP-Main Street site, the adjacent offsite property to the south (the former location of the Public Supply Well) and at the Discount Outlet 59 frmr Exprezit #759 site.

- Two borings to 60-feet bls at BP-Main Steet site.(MIP-1, MIP2)
- Four borings to 80-feet bls at the City of Chipley property to the south of BP-Main Street. (MIP-3, MIP-4, MIP-5, MIP-6)
- Two borings to 80-feet bls at Discount Outlet 59 frmr Exprezit #759. (MIP-7, MIP-8)

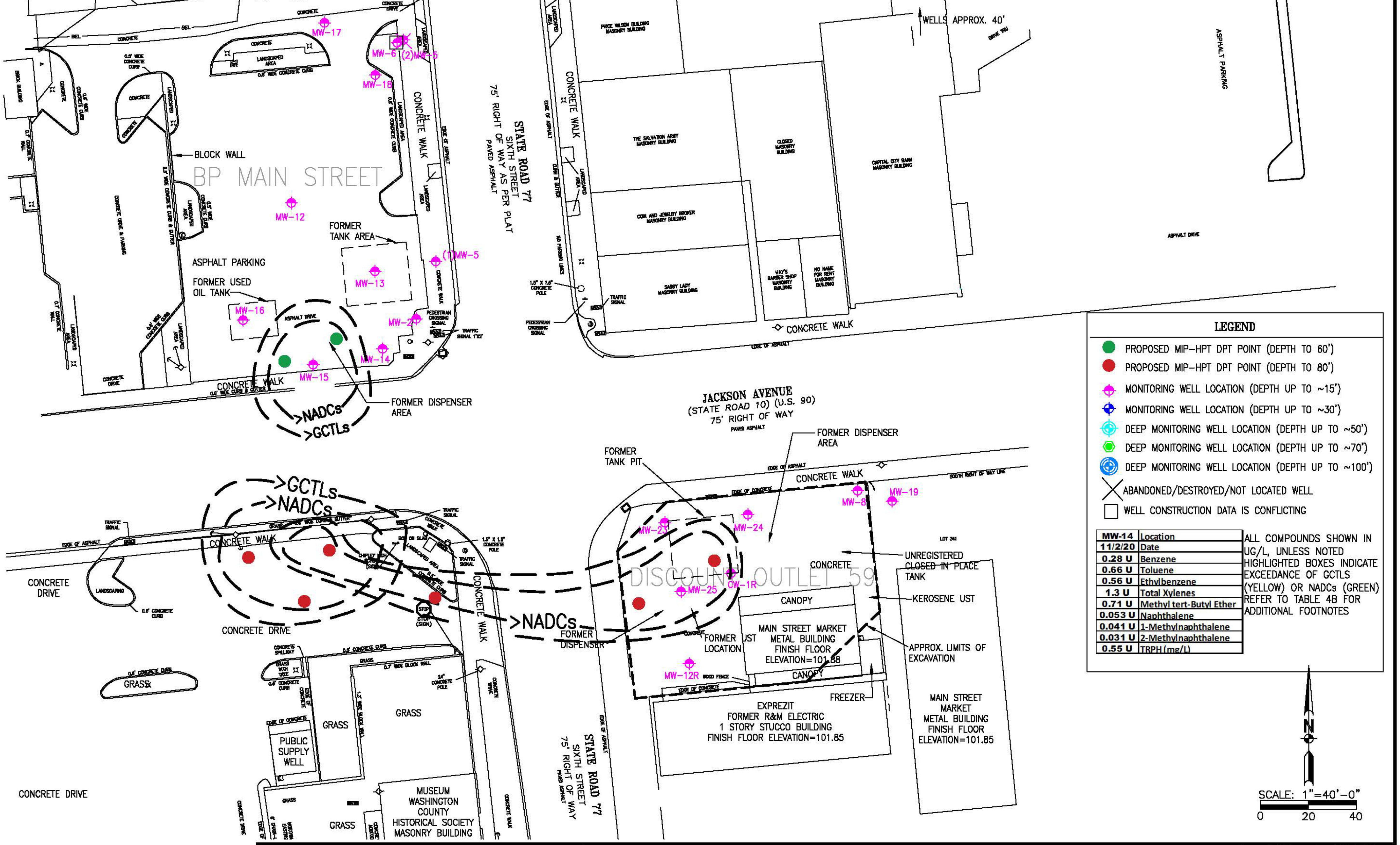


FIGURE 5 - PROPOSED DPT POINTS USING MIP-HPT

BP-MAIN STREET 1260 JACKSON AVENUE CHIPLEY, WASHINGTON COUNTY, FLORIDA	DISCOUNT OUTLET 59-FORMER EXPREZIT 759 1251 JACKSON AVENUE CHIPLEY, WASHINGTON COUNTY, FLORIDA	DATE AUG.2022	PROJ. NO. 5487
		PROJ. MGR. R.A.	REVIEWED BY K.G.
		FDEP ID. NO.	DRAWN BY

BP-Main Street : MIP/HPT Tooling & Instrumentation

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BP-Main Street : MIP/HPT Tooling & Instrumentation

BP-Main Street : MIP/HPT Tooling & Instrumentation

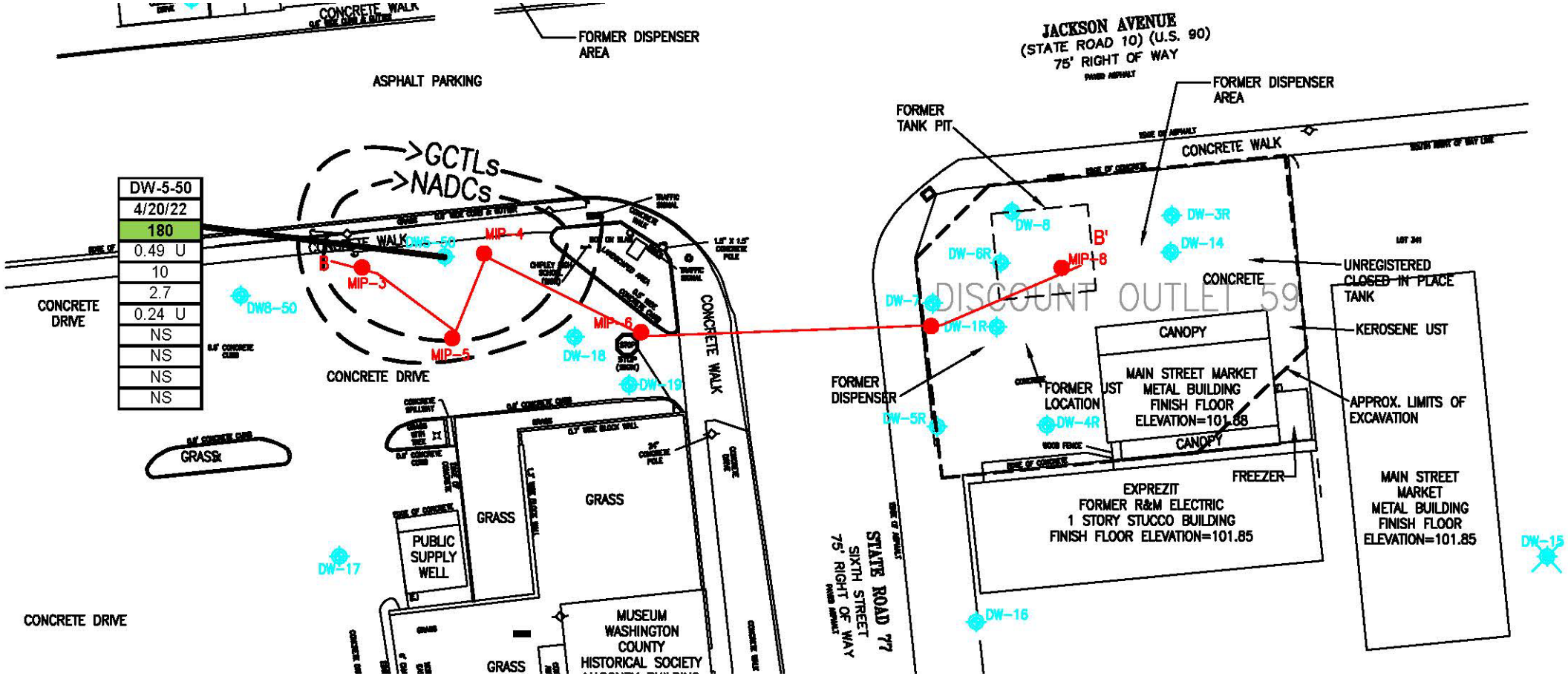
BP-Main Street : FAC# 678517974 – Results of the HRSC Investigation

FIGURE 4

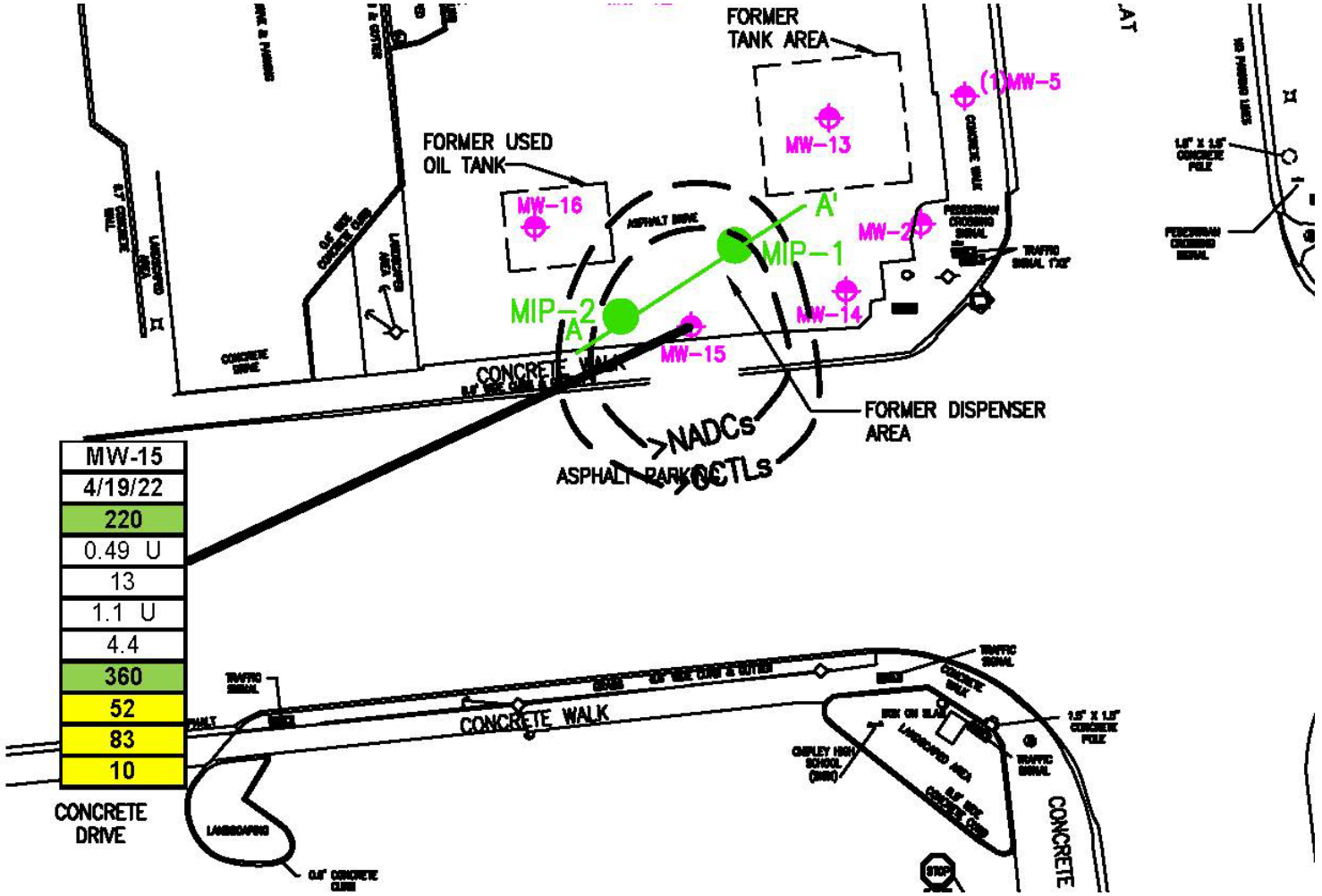
DATE 8/10/2023

PROJ. NO. 5487

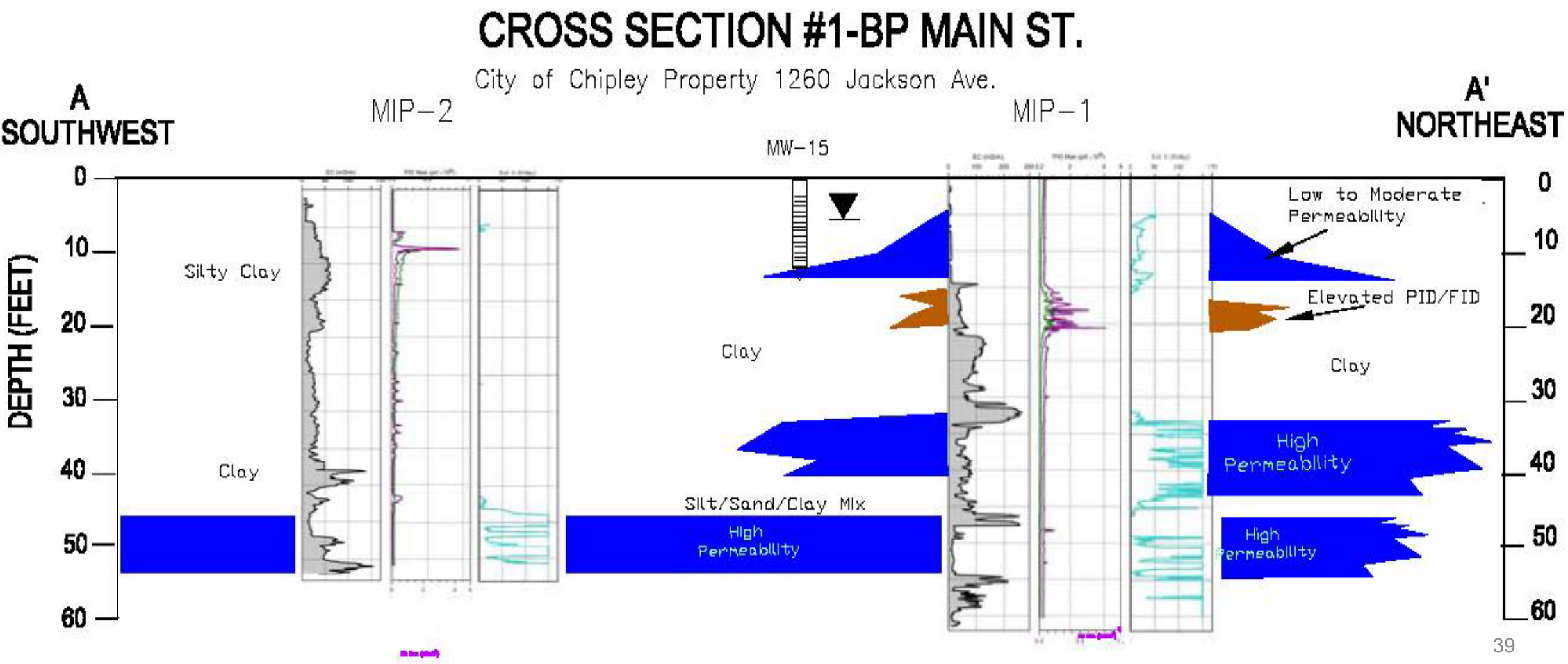
BP-Main Street : HRSC X-Section MIP-3 through MIP-8 Aerial View

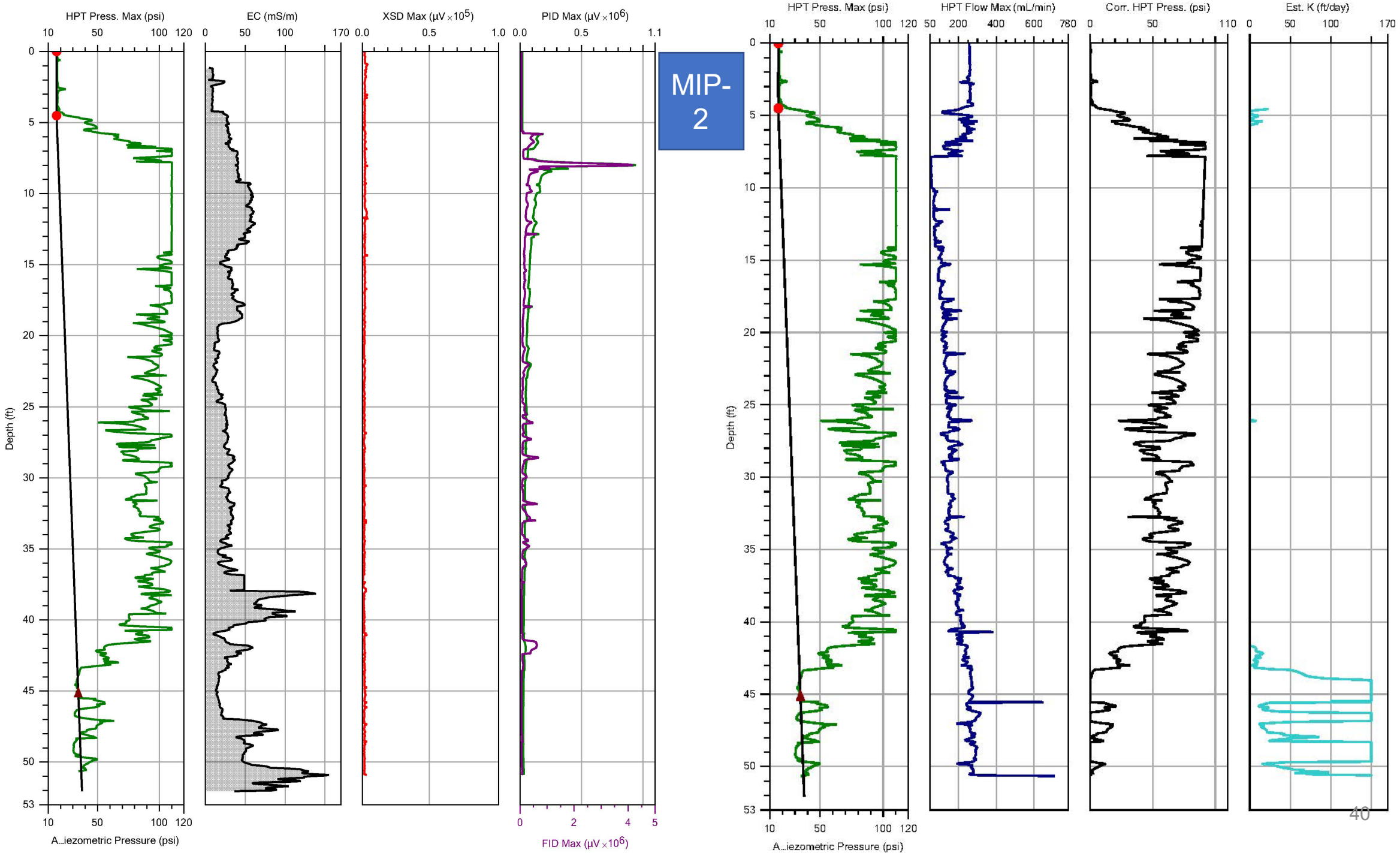


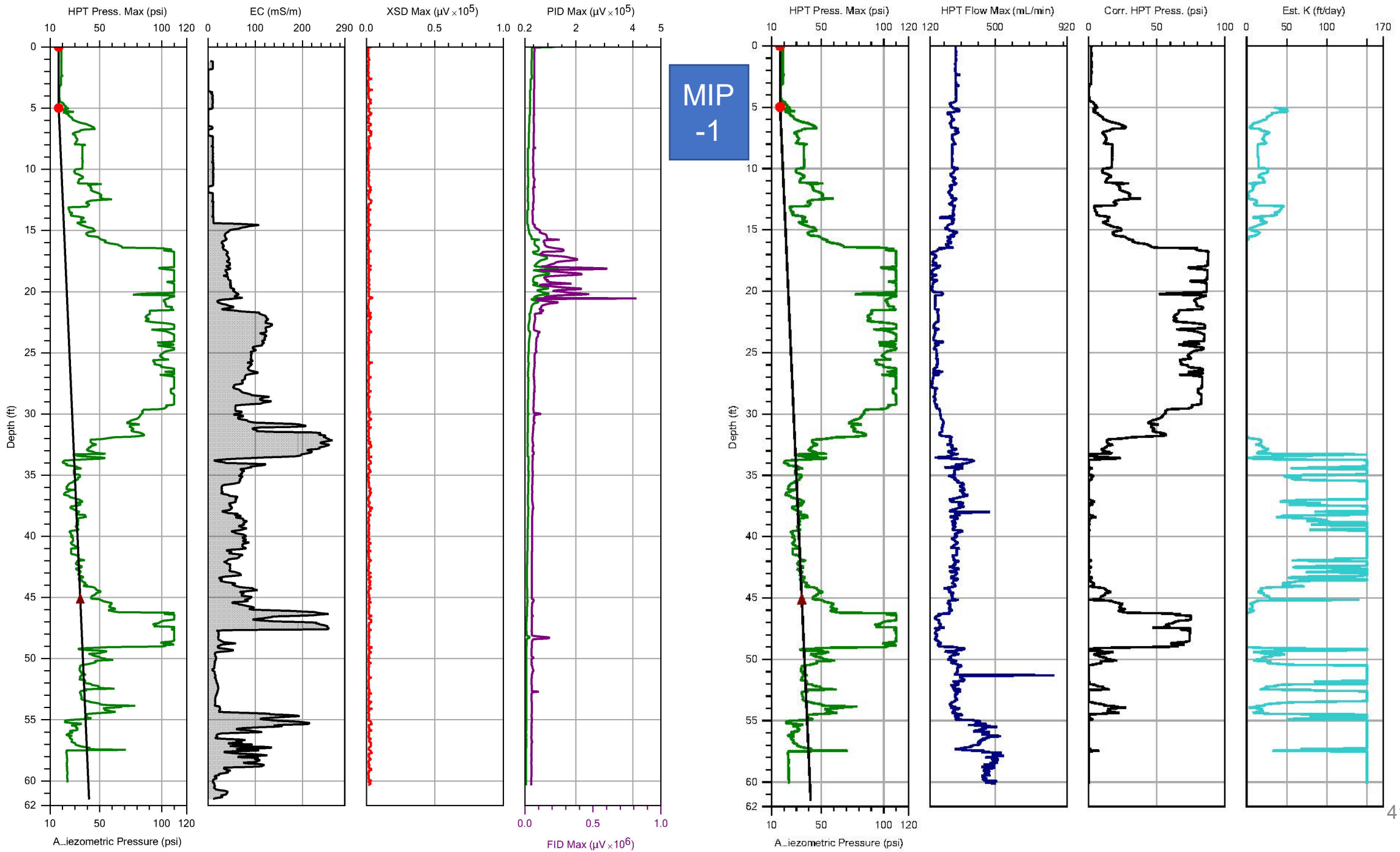
BP-Main Street : HRSC X-Section MIP-1 to MIP-2 Aerial View



BP-Main Street : HRSC X-Section MIP-1 – MIP-2




HPT Press. Max (psi)
EC (mS/m)
XSD Max (µV ×10^5)
PID Max (µV ×10^6)
Depth (ft)
A...iezometric Pressure (psi)
FID Max (µV ×10^6)
MIP-2
HPT Press. Max (psi)
HPT Flow Max (mL/min)
Corr. HPT Press. (psi)
Est. K (ft/day)
Depth (ft)
A...iezometric Pressure (psi)


HPT Press. Max (psi)
EC (mS/m)
XSD Max (µV×10^5)
PID Max (µV×10^5)
HPT Press. Max (psi)
HPT Flow Max (mL/min)
Corr. HPT Press. (psi)
Est. K (ft/day)
MIP -1
Depth (ft)
A...iezometric Pressure (psi)
FID Max (µV×10^6)
A...iezometric Pressure (psi)

BP-Main Street : FAC# 678517974 – Results of the HRSC Investigation

- MIP-1 indicated permeable layers at the 5-15 feet bls, 33-43 feet bls and at the 48-55 feet bls layers. The 48-55 feet lbs permeable zone is the only layer which correlates with MIP-2 at the BP-Main St. site. Elevated PID/FID readings were observed at the 15-20 feet bls interval in MIP-1, denoting a source area.
- Permeable layers at the City of Chipley Property were generally confined to the 55 to > 65 feet bls layer at MIP-3, MIP-4 (likely) & MIP-5. This zone of permeability somewhat correlates with the deep permeable zone located at the BP-Main St. site (48'-55'). An isolated zone of moderate to high permeability was detected at MIP-6 from 20 to 35 feet bls which does not correlate with the other borings. Minor PID/FID readings were dispersed throughout the soil column generally at the City of Chipley site above 50 feet bls.
- At the Discount Outlet 59 frmr Exprezit #759, permeability was extremely low with no correlating or apparent zones of significant permeability, likely due to a clay rich environment. PID/FID readings, however, were notable at the 20-35 feet bls depth range indicating a source area.

BP-Main Street : HRSC Investigation Takeaways

- Although Zoomed-In Logs for only the BP-Main Street Site are included in this presentation, review of the logs for all the borings at all three of the properties showed a lack of hydraulic connectivity at corresponding depths between the sites except for the deep zone 48-55 feet bls between the BP-Main Street Site and the City of Chipley Property.
- This data and historic data appears to indicate that complicated lithology is present due to collapsed sinkhole(s), high permeability sand stringers are a primary path of contaminant and that even in locations where low-permeability clays are present, contamination is present in the deep zones, most likely corresponding with the limestone aquifer.
- The Estimated K (hydraulic permeability) log (light blue graph), appeared to mark the top of the Limestone at the BP-Main Street Site and the adjacent City of Chipley Property to the south, any where from 44 to 55 feet bls, but no evidence of its presence was provided in borings MIP-6,7 & 8, on the east extent of the City of Chipley Property and at the Discount Outlet 59 site on the east side of Highway 77.

Remedial Options

Because of the low-permeability soils encountered throughout Chipley combined with the tendency for downward vertical migration of contaminants due to interbedded sand stringers and the high permeability Limestone aquifer at depth resulting in very noticeable vertical hydraulic gradients when Depth-to-Water measurements are collected from adjacent wells installed at differing depths, remedial options are limited. Conventional Air Sparge and Soil Vapor Extraction (AS/SVE) are only very rarely proposed or successful in these lithologies.

- Source Removal using conventional methods or Large Diameter Auger (LDA) is effective but **all** of the impacted soils need to be removed. Post-LDA remedial options are extremely limited by the flowable fill which is used to backfill each LDA boring.
- Ozone treatment is very destructive to Petroleum Hydrocarbons but still has limitations regarding low-permeability soils and great care must be taken to fine tune the design to treat very specific depth intervals and little information has been gathered regarding its utilization & effectiveness in vadose soils. Recent Ozone Pilot Tests have shown some potential for its use in the Chipley area.
- Electrical Heating can be very effective in low-permeability soils but it requires a robust electrical utility infrastructure and comes with a very high price tag.
- Chemical injections also encounter difficulties with low-permeability soils and should be evaluated for use only at sites where contaminant concentrations are low and its true cost-effectiveness should take into account the often-times need for multiple injection events which are usually not accounted for in the initial RAPs proposing its use.

Assessment and Remediation of Petroleum-Impacted sites within Karst Environments – Addressing Potential Complications With Positive Solutions

QUESTIONS?

Presented by Polk and Escambia County Local Programs