Apex Spectral Technology, Inc

ADF® Product Suite in support of Sustainable Aquifer Production

January 2022

Groundwater identification, monitoring and production in a sustainable way is critical worldwide.

APEX

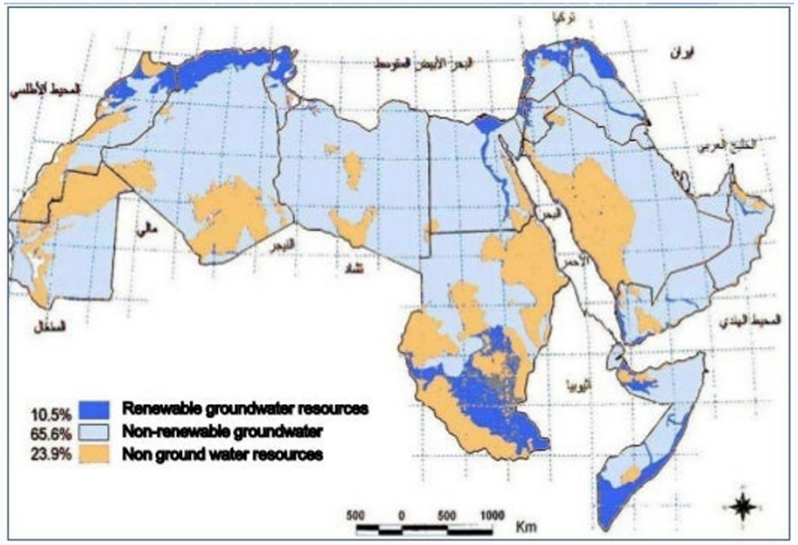
From management and optimization of agricultural and industrial regions….

…. to a life-saving and critical science in others.

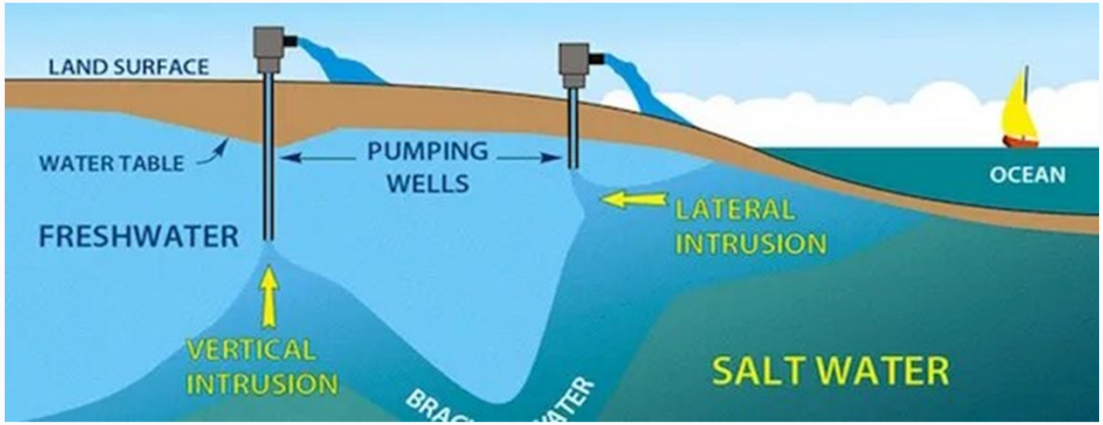
In areas where groundwater is plentiful, it still needs to be managed.
In areas where groundwater is scarce, it is usually where it is most needed.

APEX

BUT IN ALL CASES…..
…. IT IS A LIMITED RESOURCE



AND IF MISMANAGED…..
…. CAN HAVE DRAMATIC CONSEQUENCES….

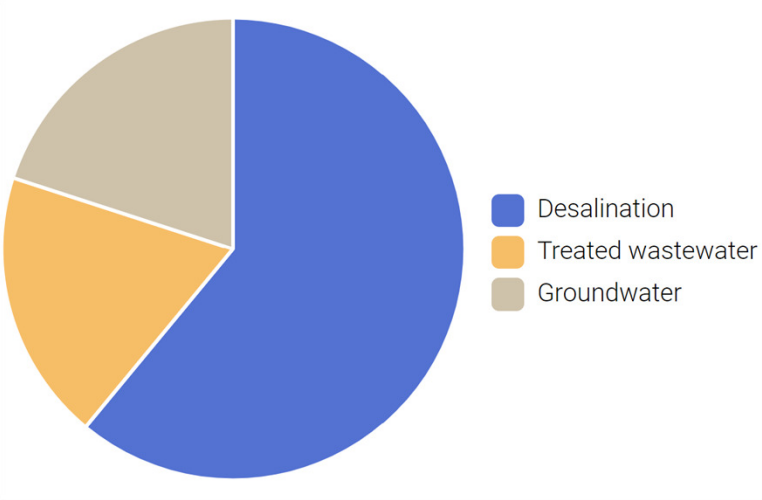


…. Both Geographic … and Political (*)

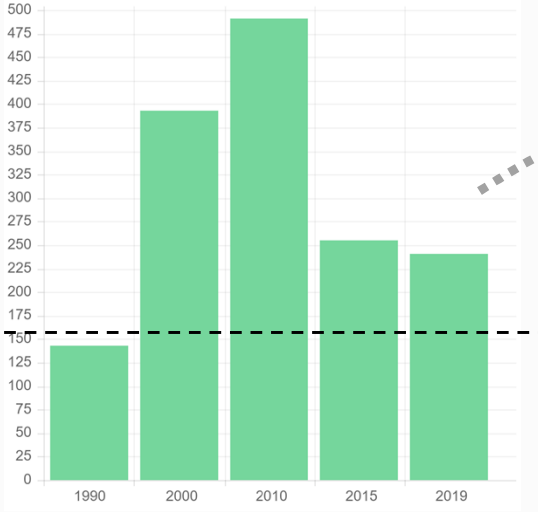
(*) Most governments have a clear Strategy and Direction for Monitoring and preserving this resource.
Apex ADF® could help produce an even clearer picture and provide an even greater unified scientific approach.

Groundwater in all countries makes up part of the total water resource profile.

Some more than others….

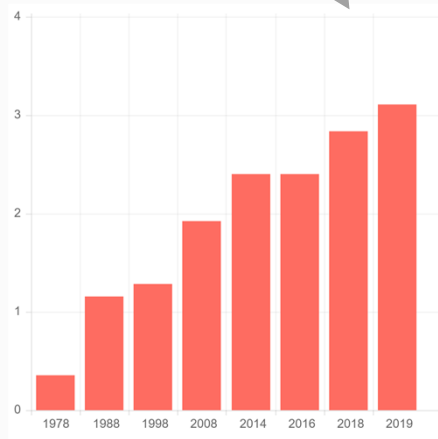


Water Resources Distribution : ME Example



Sustainable Rate

Reduction enabled by increase in desalination capacity.



(Renewable) Groundwater abstraction (MCM/Year): ME Example

Most groundwater abstraction in is from near surface aquifers 10-30M deep.
Little study, if any, has been made on deeper confined aquifer potential.

https://water.fanack.com/

The political and environmental stakes are high.

In certain areas, groundwater abstraction is already greater than the recharge level for sustainability.

It is unclear what effects global warming will have on recharge rates in a specific region, but increased temperatures, population, urbanization and industrialization will place even greater pressure to manage this resource respectfully.

Although regional aquifers are usually well known and recharge rates reasonably calculated, just balancing the equation of what is being produced verses what the recharge rate is, is NOT enough.

Vertical and lateral brackish intrusions can lead to critical salinity problems at any given pumping location.

A more detailed and better understanding of the entire subsurface aquifer (be it confined or unconfined), it's spatial variation and recharge mechanism, can significantly improve a safe, cost effective and sustainable production environment.

What more can be done?

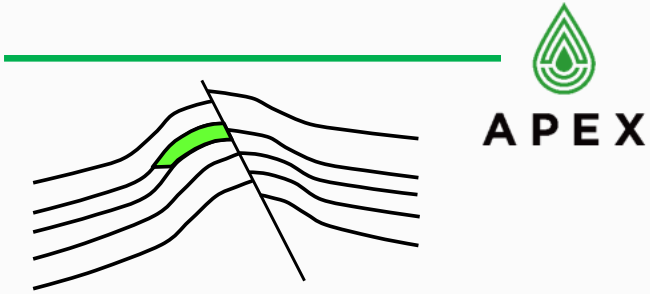
ENTER Apex and ADF®.

Apex has developed an analytical tool (ADF®) that can use existing 3D seismic data to effectively identify highly permeable formations in the subsurface. The deeper and more consolidated the subsurface, the more effective ADF® works, and for Oil and Gas identification, this is EXACTLY what is needed.

By their very nature, many deeper aquifer reservoirs are unconsolidated materials or fractured rocks (granite, carbonates or lava), which also produce anomalously large ADF® responses with respect to the surrounding impervious confining layers (confined case) [Aquafers can also be consolidated material].

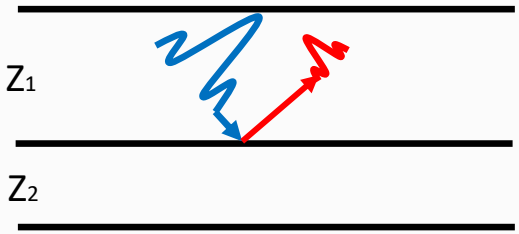
There are several tools, such as EM, ERT and seismic refraction for imaging, establishing thickness and delineating near-surface groundwater and aquifers. Standard seismic processing can provide detailed subsurface structure maps and some intrinsic properties of deeper aquifers, but ADF® (using the SAME input data) can identify areas of high permeability. Since ADF® is measuring dispersion in the sub-surface due to fluid mobility in the permeable aquifer, an integrated ADF® product can be associated with a product of permeability and groundwater column (Bulk Perm).

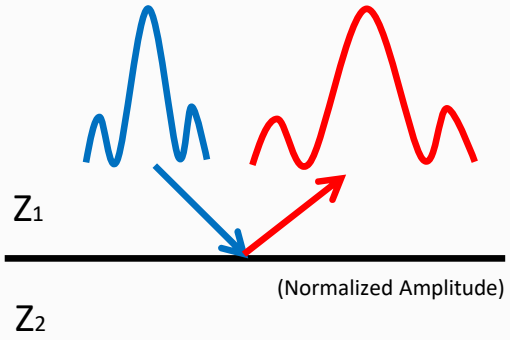
Apex and ADF®.



Standard seismic data processing (*) analyzes a series of reflections from subsurface layers and, subsequently (with a lot of math and manipulation), can build quite reliable structural images of the subsurface.

In general, the wavelet used in these analyses is considered stationary. That is, the reflected waves from the interface of two subsurface layers looks exactly like a smaller version of the incoming wave. The spread of frequencies is the same.





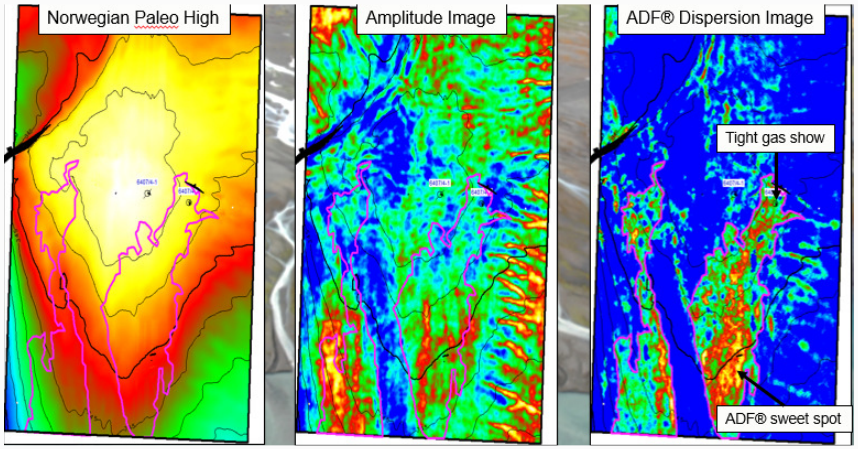
HOWEVER, in reality, when a subsurface layer is permeable and contains a fluid, the frequencies that make up the reflected wavelet travel at slightly different velocities from the frequencies that make up the incoming wavelet (each frequency component reflects away different speeds - dispersion). **The wavelet HAS changed**. The greater the fluid mobility (due to the type of fluid or the permeability of the layer), the greater the change to the reflected wavelet.

The greater these changes, the greater the ADF® response.

(*) ADF® needs non-zero reflected amplitudes from 3D seismic data to image dispersion. Hence, unless ultra high resolution shallow seismic survey has been acquired, ADF® imaging of aquifers is usually restricted to the deeper confined type.

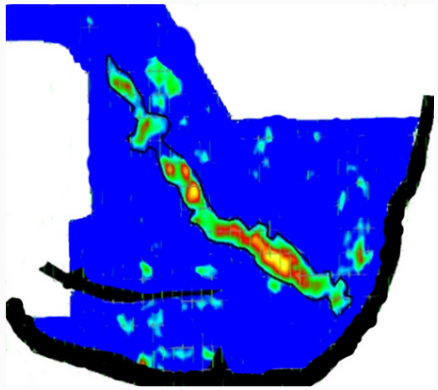
ADF® Examples

Not only can ADF® identify subsurface areas with higher permeability, it also has exceptionally high 'plan-view' resolution meaning the extent of the permeable reservoir can be better determined spatially, enabling engineers to design more efficient drilling programs.



Norwegian North Sea:
Shale filled channel with overbank deposit clearly visible. .

Nile Delta:
HC Example: HC filled channel with hottest ADF® up-dip indicating greater fluid mobility due to lower chain hydrocarbons (gas).

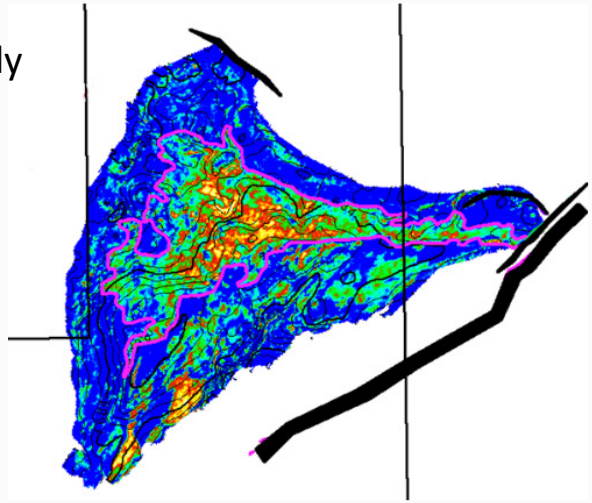


And ALL of this can be done by simply reusing existing 3D Seismic Data initially acquired for Oil and Gas exploration, giving an old industry product a new an additionally meaningful direction.

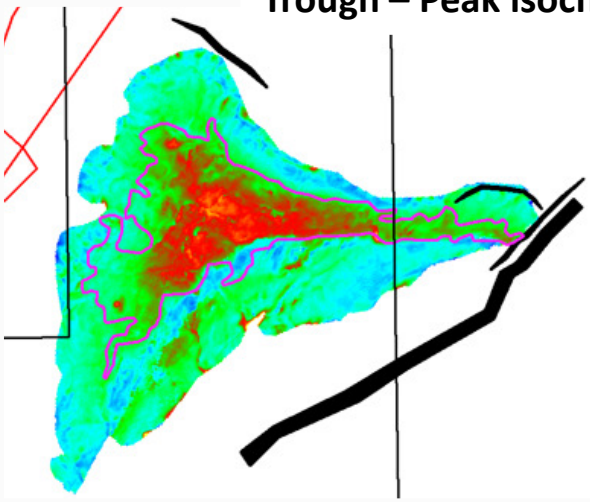
ADF® Examples – High Perm

ADF® studies the effect of fluid movement on a seismic P-wave as it passes through the earth. The more permeable, the more fluid movement and the greater the ADF® measurement. Since deeper groundwater reservoirs are enclosed by impermeable rock (Confined Groundwater), the contrasting relatively high permeable areas stand out in the ADF® results.

Perm Geo-body identified by ADF®



Trough – Peak isochron



This isochron shows there's a correlation between the ADF® and Geo-body thickness.

Areas that already have 3D-seismic can therefore be analyzed by the application of the Apex ADF® technology.

Note: Apex has examples of regional fractured layer imaging in the N. Sea and Umm er Radhuma/Rus/Dammam in Oman.

Moving Forward.

All ADF® studies are pre-empted with a simple questionnaire.
This helps Apex understand the seismic to be used for the study, the depth of primary (and secondary) targets within the seismic volume, the formation type and regional rock properties expected.

From this questionnaire, Apex staff are able to indicate if they believe it is possible to image dispersive events within the seismic.

For aquifers, this may lead to a better understanding of:

- The areal extent of the aquifer.
- Intrinsic information on the aquifer (high bulk perm areas).
- Locating the recharge course or tracking aquifer back to its source.
- Possibly assisting with understanding the rate/limitation of recharge.
- Whether regional aquifers are in communication.
- Optimum sustainable abstraction locations.

ADF® 4D.

4D seismic is the name given to the study of any two 3D seismic surveys acquired at different times over the same area. Such studies historically have helped Oil and Gas companies monitor the extraction of hydrocarbons from the subsurface. However, for standard seismic, a great deal of work has to be done in order to cross-correlate the two surveys (matching phase, frequency, time) and even then, the outcome of differences in seismic amplitude is still highly interpretable.

ADF® 4D is not as complicated and only one (or few) unaltered ADF® anomalies in the seismic are needed to calibrate one ADF® volume to another. Additionally, once this is done, the resulting ADF® difference cube can be a direct indicator of the magnitude of fluid extraction in the subsurface and how the dynamic of fluid in the reservoir has changed.

For aquifers, the situation is a little more complicated as there are several different outcomes to the abstraction process. Subsidence – thinning of aquifer, air replacement of abstracted water, brine replacement of abstracted water.

If subsidence occurs, the tuning between the top and the base of the aquifer will change. This will result in a change in the frequency content of the reflection and alter the frequency notches in Fourier space. This might appear as a change in the notch in a "Class B ADF®" event (one of three main class outcomes of ADF®). If air replaces the water, this will take on the look of a 'partially depleted aquifer' (another classic ADF® profile). If the water is completely recharged or if it is replaced by brine, we will not be able to tell the difference in 4D, suffice to say that the extraction process will turn from water to brine.

In groundwater terms, hydraulic conductivity and permeability are interchangeable. Hence, the use of ADF® can identify the aquifer boundary and delineate single hydrologic units (aquifers) of the main confined hydraulic conductive reservoir and the aquifer confining layer(s) made up of lower relative hydraulic conductivity.

For connected renewable aquifers, ADF® may further be able to identify the extent of the aquifer connections giving a better understanding of which areas could be re-charged faster than others (visa-vi, identifying the quality and size of aquifer interconnections).

SUMMARY

- Aquifers are an essential part of water supply the world over.
- In some areas, the re-charge rate is very well known.
- Abstraction rates exceeding re-charge rates can lead to serious issues.
- Understanding extent and composition of aquifers is important.
- Understanding re-charge mechanism is important to know how much to abstract at what location.

- Aquifer management depends on some intrinsic knowledge of the hydraulic unit.
- Optimization of abstraction reduces salination risks and cost of delivery.
- Apex ADF® can be used to identify hydraulic conductivity in the subsurface.
- The input to Apex ADF® is standard 3D Seismic Data.

- ADF® can identify and reveal the areal extent of the hydraulic unit.
- ADF® interpretation can, under some conditions, identify relative thickness and hence some intrinsic properties of the hydraulic unit at the time of seismic acquisition (or time lapse).
- ADF® may additionally be able to determine the hydraulic unit communication, quality of communication and source or recharge course.

ADF® is therefore an excellent tool for:

- Secondary identification of regional aquifers.
- Secondary development and optimization of regional aquifer resources.

End

For more information on Apex and ADF® visit our website at:
www.apexspectral.com