Saudi Aramco
Exploration and Producing (E&P)
Dhahran
Saudi Arabia

Well Placement Optimization Using GIS

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Abstract

Determining optimal location for conventional and multilateral wells in oil and gas reservoirs is a complex process. Optimal location determination depends on a combination of geological parameters, reservoir information, and surface landcover feature data types that need to be analyzed concurrently in one software system. A Geographic Information System (GIS) can integrate and represent these many data types in a single view. It has sophisticated analysis tools that can identify the optimum well location in a reservoir. Saudi Aramco's E&P GIS application functionalities were extended to allow petroleum engineers to efficiently propose well locations where the density of wells in a field is high. Furthermore, these functionalities allow engineers to create and view fluid contact maps, formation pressure information, and well trajectory data for this complex task. This paper will provide an overview of the methodologies developed to effectively place wells in a reservoir and will highlight the GIS implementation for each methodology.

Introduction

This paper will start with an overview of Saudi Aramco and an introduction to the E&P Geographic Information System (GIS) application that integrates and represents many E&P data types in a single map view. Utilizing the petroleum engineer's workflow in the Reservoir Management Department (RMD) of E&P, various examples of the tools and processes to efficiently recommend preliminary locations for new wells in a reservoir will then be detailed. An overview of the GIS methodology and its implementation for each process will be highlighted. The paper concludes by summarizing the effectiveness of GIS in providing an integrated environment for helping to evaluate potential well locations and the GIS systems integration into the E&P workflow.

Saudi Aramco Overview

The Saudi Arabian Oil Company (Saudi Aramco) is the state-owned oil company of the Kingdom of Saudi Arabia. Saudi Aramco has evolved into a globally recognized company with fully integrated operations from the wellhead to the gas pump and holds the pre-eminent position among the world's oil companies for total reserves and annual crude oil production. Oil reserves under the company's administration amount to 259 billion barrels. The company continues to make significant investments to establish and maintain a sustainable capacity of 12 million barrels per day (bpd).

Proven gas reserves of 231 trillion standard cubic feet (tscf) signify Saudi Aramco globally as fourth in ranking of this increasingly demanding commodity, with annual gas production averaging 6.9 billion standard cubic feet (bscf) per day.

Saudi Aramco employs more than 54,000 multinational workers and is headquartered in Dhahran, Eastern Province, Saudi Arabia. Operations span the Kingdom, with production and product distribution facilities linking all markets. Major export shipping terminal are located at ports on the Arabian Gulf and Red Sea.

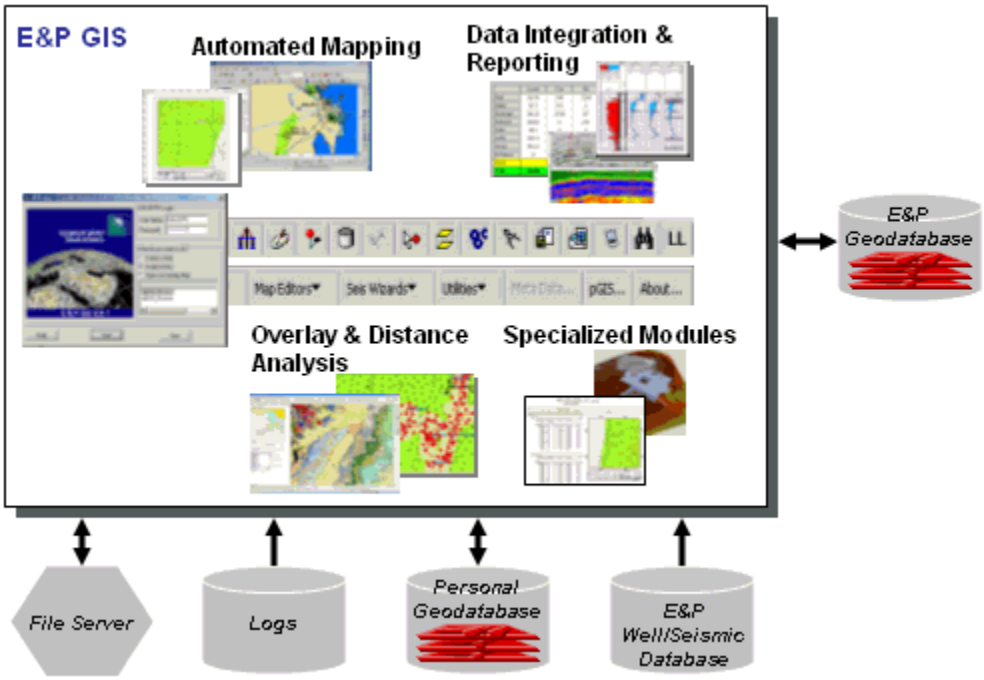
Internationally, Saudi Aramco holds substantial joint venture interest in refining and marketing activities in USA, Republic of Korea, Philippines, China and Greece. Key market services support offices are located in major cities in North America, Europe and Far East. Saudi Aramco also owns and operates a sizeable fleet of supertankers for shipping crude oil to all its customers. In keeping with the company's strategic emphasis on leveraging oil and gas resources to diversify and expand the Kingdom's economy, Saudi Aramco has signed agreements with Royal Dutch Shell and France's TOTAL for exploration, development and production of non-associated gas on more than 200,000 square kilometers of territory in Rub Al-Khali, and is a project valued at $2 billion.

Saudi Aramco E&P GIS

Saudi Aramco's E&P portfolio contains a multitude of spatial data on potential hydrocarbon accumulations. It also contains data on reserves, well locations, seismic surveys, satellite & aerial imagery, surface topography and existing infrastructure information. Major challenges in managing such a portfolio are that of ensuring data is kept up-to-date in a secure environment, a consistent evaluation with a clear audit trail is applied throughout and the data is available for integration with E&P business risk planning engines. GIS based management tools and processes have been applied to address these challenges for more than a decade.

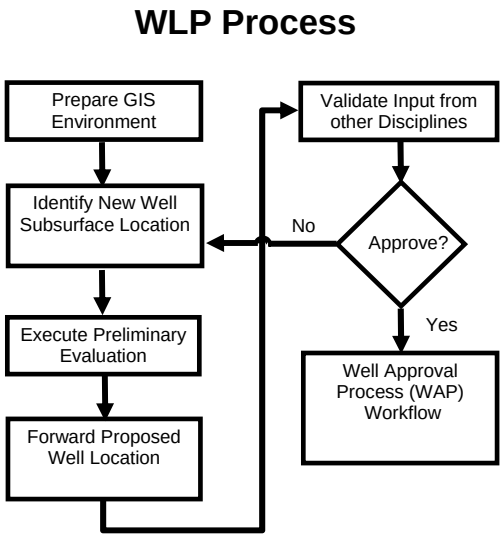
The GIS tools developed by the Expec Computer Center (ECC) of Saudi Aramco, using the ArcGIS Desktop software, support the E&P workflow from data acquisition to identification of leads that can be matured into drill ready prospects and onto facility planners that need to tie-in new well locations to existing gathering system facilities. Key to the successful implementation and adoption of this technology has been the close cooperation between the different disciplines in E&P, the GIS evaluation and development teams in ECC, and the portfolio managers.

Because data integration is one of the most powerful functions of GIS, the E&P GIS is much more than a geographic data visualization and analysis tool. It is strongly integrated with many of the E&P databases and applications. A user can, for example, select wells on a map, and access extended attributes from a wide array of tables in the well database and simultaneously display logs from the logs database. The petroleum and facility engineers, geologists and geo- physicists can now combine many pieces of information, including well profiles, surface topography, subsurface maps and other physical features, that allow them to test multiple design and selection scenarios easily and efficiently.



Well Location Planning (WLP) Process

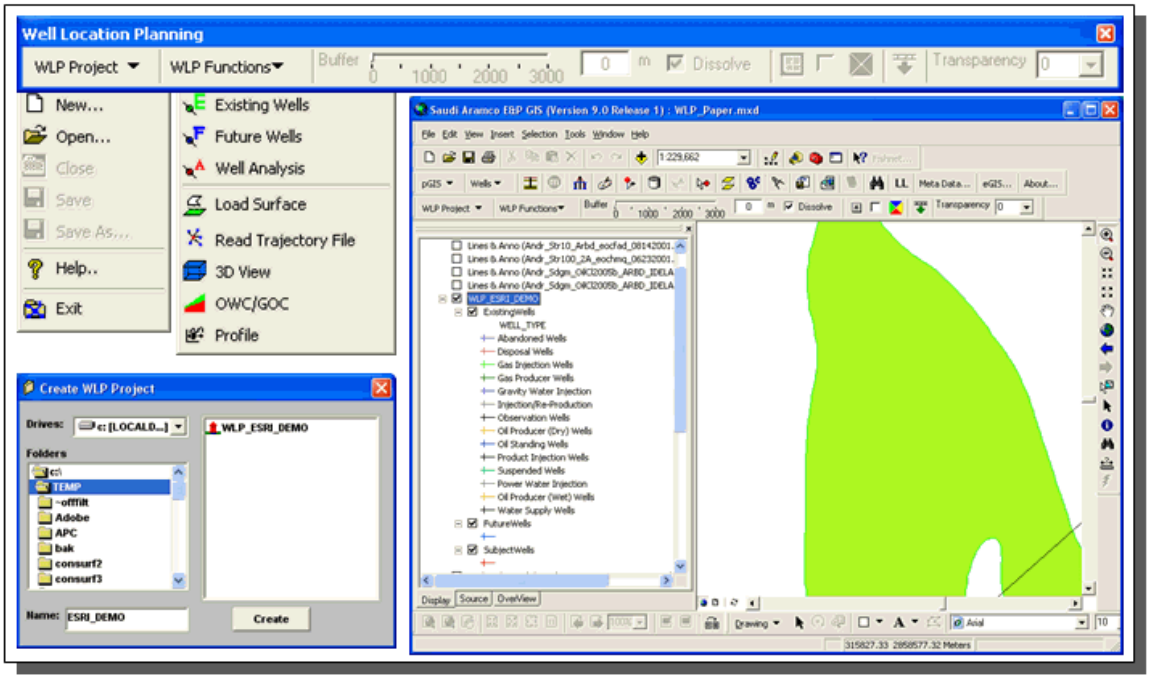
The task of planning a new well in a field with a high density of wells, complex geological features, multiple formation targets and advancing flood front or expanding gas cap is extremely challenging. The overall process can be divided into a number of tasks as highlighted in the flowchart. The Well Location Planning (WLP) program, a GIS extension (a set of tools) available in the integrated E&P GIS application, helps petroleum engineers in Reservoir Management propose subsurface locations for new wells. The program allows engineers to extract and graphically display existing well subsurface locations from the E&P well database. This information in conjunction with an array of other map displays of geological information, formation pressure or fluid data provide the engineer with the essential information to identify and select suitable subsurface location for future drilling. Moreover, the program can generate reports with results of distance analysis between the proposed well and existing wells in close proximity, accompanied by appropriate maps, for inclusion in other E&P workflow systems. The strength of the GIS, is that with limited effort (a few mouse clicks) all the critical parameters can be viewed and consider by themselves but even more importantly in relation to one another.



The set of data outlining the proposed well design is then forwarded to other disciplines namely Drilling Engineer, Facility Planner, Production Engineer and Geologist/Geophysicist for detail evaluation and design by specialized applications to meet requirements like drilling limitations and HSE. Recent developments in the WLP program allows Reservoir Management to validate the detailed design provided by the relevant parties by allowing their input to be read-in and compared with the initial proposal. The new features also include a well profiling (cross-section) interface and a 3D visualization tool.

Provided the detailed design meets the well objectives, the well proposal is finalized and the well is launched into the E&P Well Approval Process (WAP) workflow. Alternatively, it is modified or a new set of well subsurface points are selected and the process is reiterated.

The WLP program functions are available in the form of a toolbar in the E&P GIS application. The toolbar makes it easier for the user to load and work with these functions in an integrated GIS environment. The user starts by creating a new WLP project on his workstation or shared file server location. The program copies the template files from the central location to the project area and updates the ArcMap TOC (Table-of-Contents) with a group layer file representing the WLP project components. The WLP functions are now enabled to allow the user to plan for and analyze new well locations.

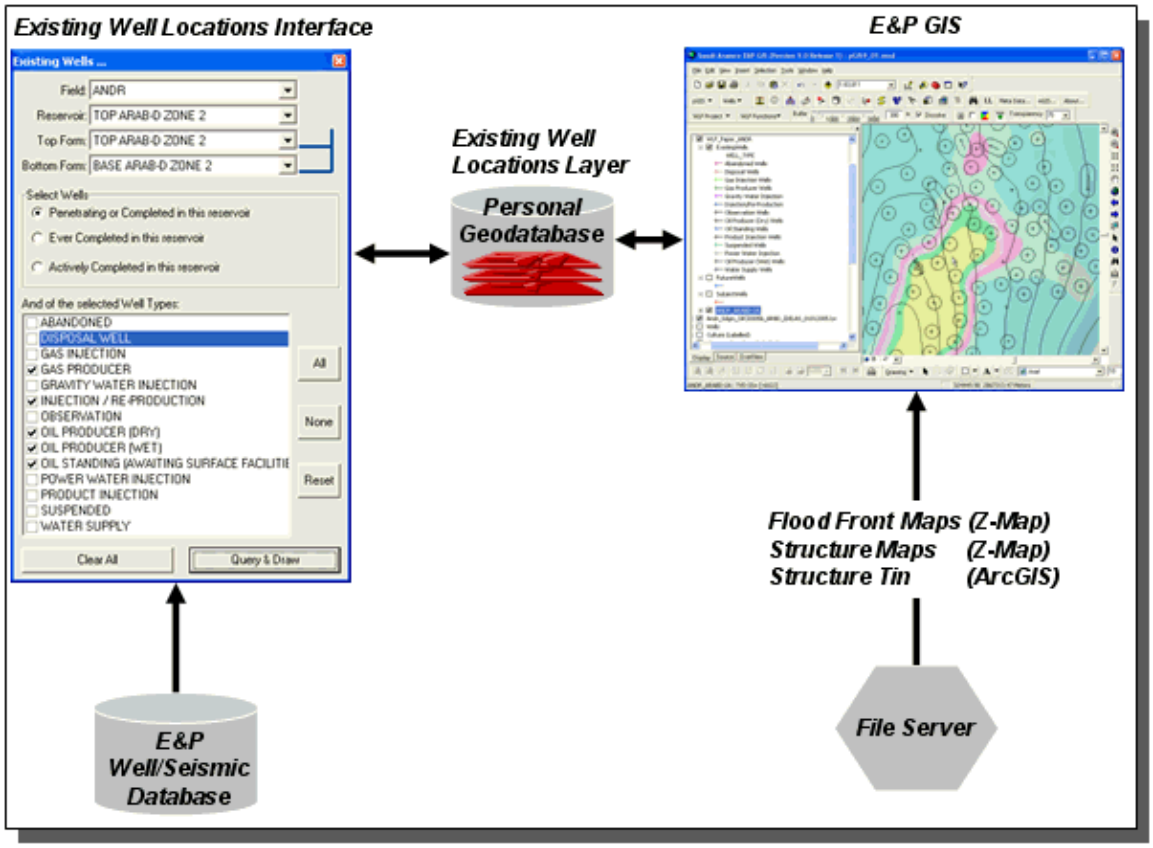


Well Location Planning Initiation Tasks

The task of planning for a well location using the WLP program begins with defining the selection and display criteria for *existing* well locations that are in close proximity to the new well location. The criterion comprises of oil/gas field reservoir parameters, completion factors and classification of well types that satisfy the requirements of petroleum engineers to propose a useable well location. These parameters are used by the program to compute from the E&P well database the estimation of the entry point (EP), i.e. the intersection of the well trajectory with the top-formation, for wells satisfying the engineer's criteria. The computed values for each well are saved in a geodatabase and are represented in GIS as line symbols. The cross-hair symbol at one end of the line signifies the EP location for the well and the end-point of the line denotes the computed bottom-hole location, total depth (TD). The WLP toolbar allows the engineer to override the default display color for each well type and draw buffers of defined distance around each well feature. This provides the engineer a better visual guide when entering data for the new well location and also identified drainage area of offset wells.

In addition to the existing well locations, supplementary geological/geophysical reservoir structure, flood front and formation mapping information, is also required for optimum

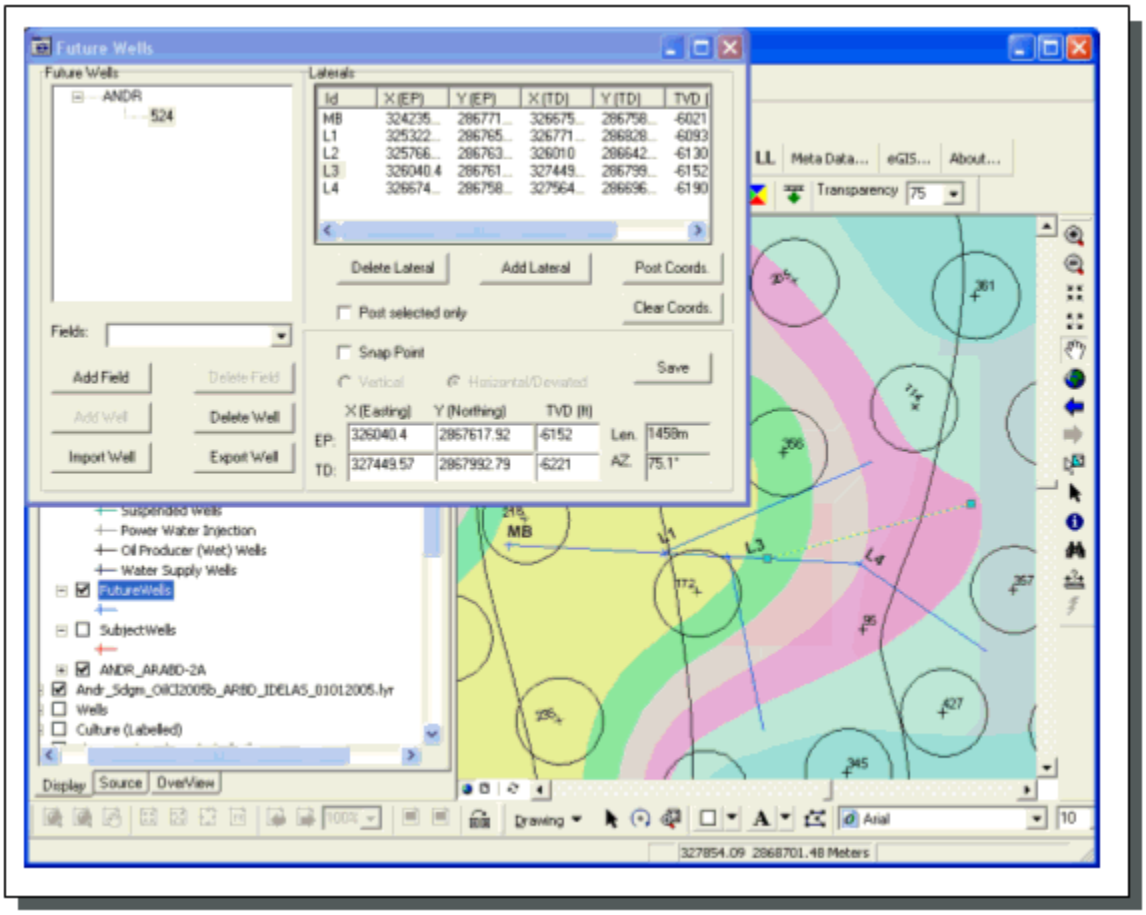
placement of the bottom of a new well. Sophisticated mapping systems in E&P, such as Z-Map Plus, enable users to create accurate reservoir models encompassing data and interpretations from geophysical, geological, petrophysical and simulation models. Visual aggregation of these models in the GIS can now be achieved through the data integration tools available in the E&P GIS application.



Well Location Planning Tools

The existing well locations, flood front/oil column maps and reservoir structure information can now be used as an effective guide to place new well locations. The *future* wells interface in the WLP toolbar allows petroleum engineers to define new well locations for vertical, horizontal, and/or multi-lateral wells. These locations are saved in the WLP project geodatabase as 3D line features. To begin the task of data entry, the engineer selects an oil/gas field name and enters a well number for the new well. The engineer can now define the entry point (EP) and total depth (TD) as X/Y coordinates for a lateral by either using coordinate input, interactively clicking on the map, or by loading an external text file that contains the new well EP/TD coordinates. The length and azimuth of the lateral are reported in the *future* wells dialog interface. The TVD (true vertical depth) of the EP/TD locations for the lateral are computed from the reservoir structure ArcGIS tin model. For multi-lateral wells, the EP/TD coordinates for more than one lateral may be specified.

Data for more that one well may be entered using this interface and saved in the WLP project geodatabase for future editing and analysis. The coordinates for these wells may also be exported so that they can be used by other E&P software systems and disciplines. The future wells are displayed in ArcMap as line symbols and their attributes, such as display colors may be modified.



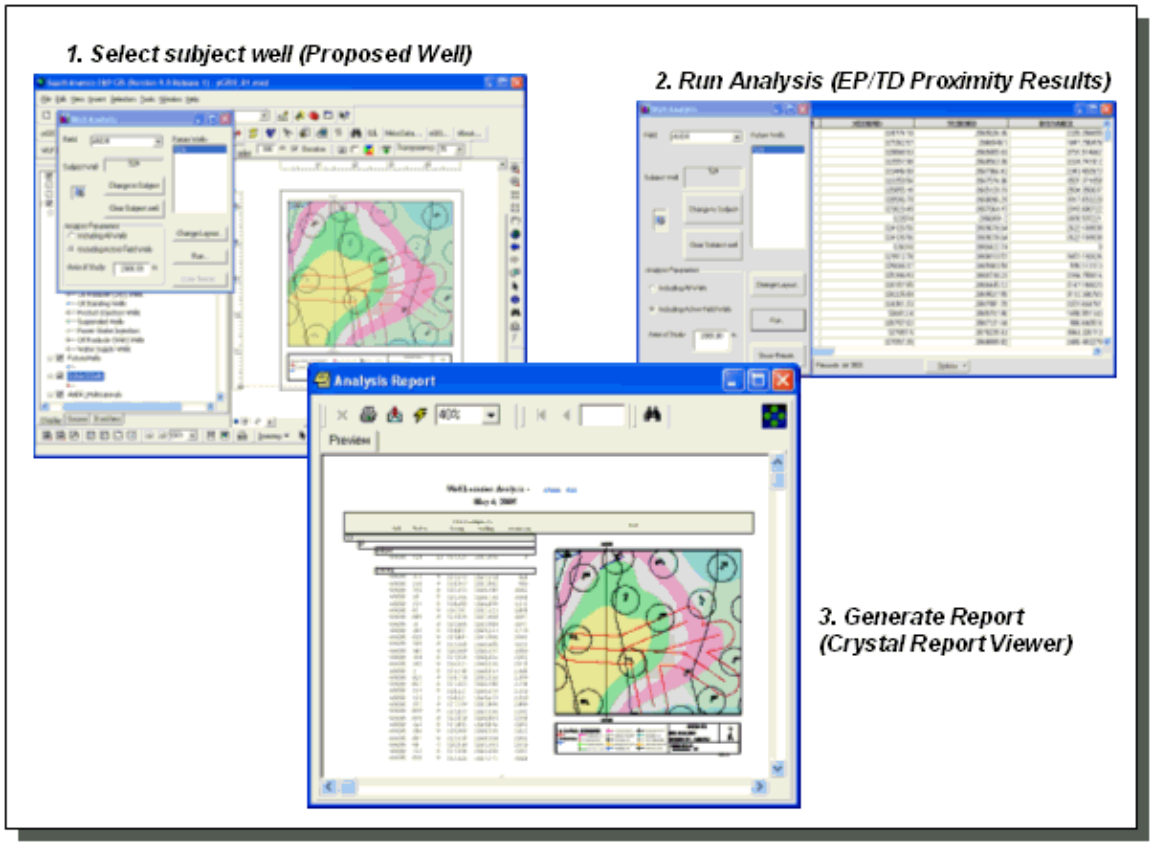
Well Location Proximity Analysis

Upon completion of the future wells data entry task, the WLP *analysis* interface allows for the proximity analysis of one well (subject well) from a list of future wells. The proximity analysis interface computes ‘EP to EP’ and ‘TD to TD’ distances between the subject well and existing well locations. The calculations can be performed against all existing well locations or existing wells that are within a user specified distance from the subject well. The computed results are saved in the project database as an access table.

The computations are first displayed in an ArcMap table window for viewing and analysis. Different scenarios can be viewed and analyzed before a final report is created. The final report includes a map of the subject area. Engineers may select a different map layout template (mxt) for the report. The report generated uses a crystal report template and receives its input data from the computed results table. The embedded map on the

report is that exported programmatically from ArcMap. The report is viewed in a crystal report viewer window where it can be printed or exported as a PDF file.

After completing the first-pass design for the new well, the set of reservoir targets are given to Drilling Engineering and their supporting service companies to complete a detailed design of the well trajectory from the reservoir back to the surface. The targets are defined as must hit data points for which the optimized well path must pass. Drilling engineering and supporting service companies generate this type of design using applications that perform torque and drag calculations and limit dogleg severity. The surface location is verified by facility planners that use the E&P GIS application to ensure the new well location takes into account aspects such as surface terrain, transportation infrastructure and safety considerations.



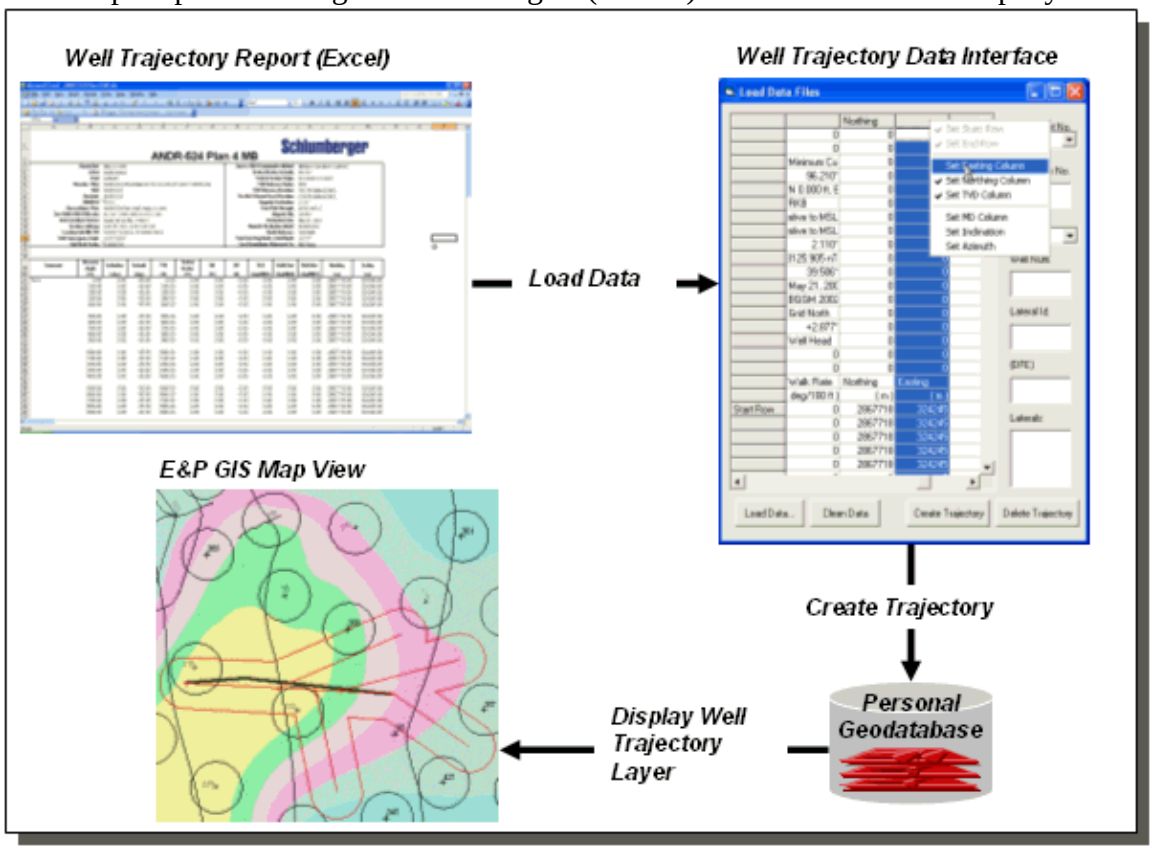
Advanced Well Location Planning (WLP) Tools

Recent developments in the WLP program focused on developing advanced features that further assist the engineer's efforts to provide optimal well placement by reducing the number of iterations as key parameters are factored in at early stages of the WLP process. These new features include an efficient way to integrate the detail well design from Drilling Engineering, a well profiling (cross-section) interface and 3D visualization tool.

Well Trajectory Data Interface

The service company's detailed design of the preliminary well trajectory is based on geometrical drilling constraints that extend from the reservoir to the surface. The petroleum engineer receives this output as an excel spreadsheet. The report provides optimized trajectory information for the first pass evaluation of the relative difficulty encountered in drilling the new well.

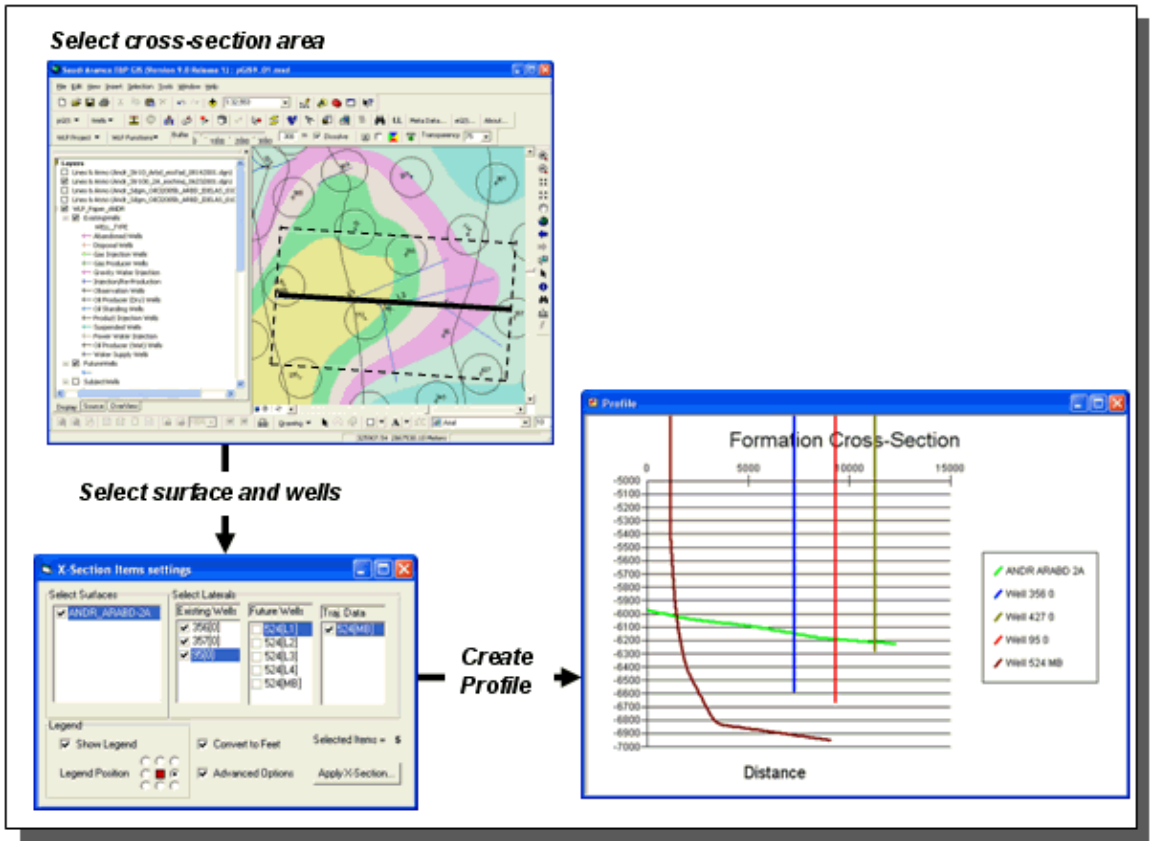
The service company report must now be verified against the set of reservoir targets computed by the WLP program. The *well trajectory* interface allows engineers to first load the excel spreadsheet into the E&P GIS system. The data from the excel spreadsheet can now be filtered to include only the rows and columns required to generate the 3D profile of the well trajectory. The profile is stored in the project geodatabase as a 3D line feature and is viewed in ArcMap where its display properties can be modified. The 3D profile of the well is now compared against the initial WLP well plan, in order to ensure the well path passes through reservoir targets (EP/TD) sent to the service company.



Well Profile (Cross-Section) Interface

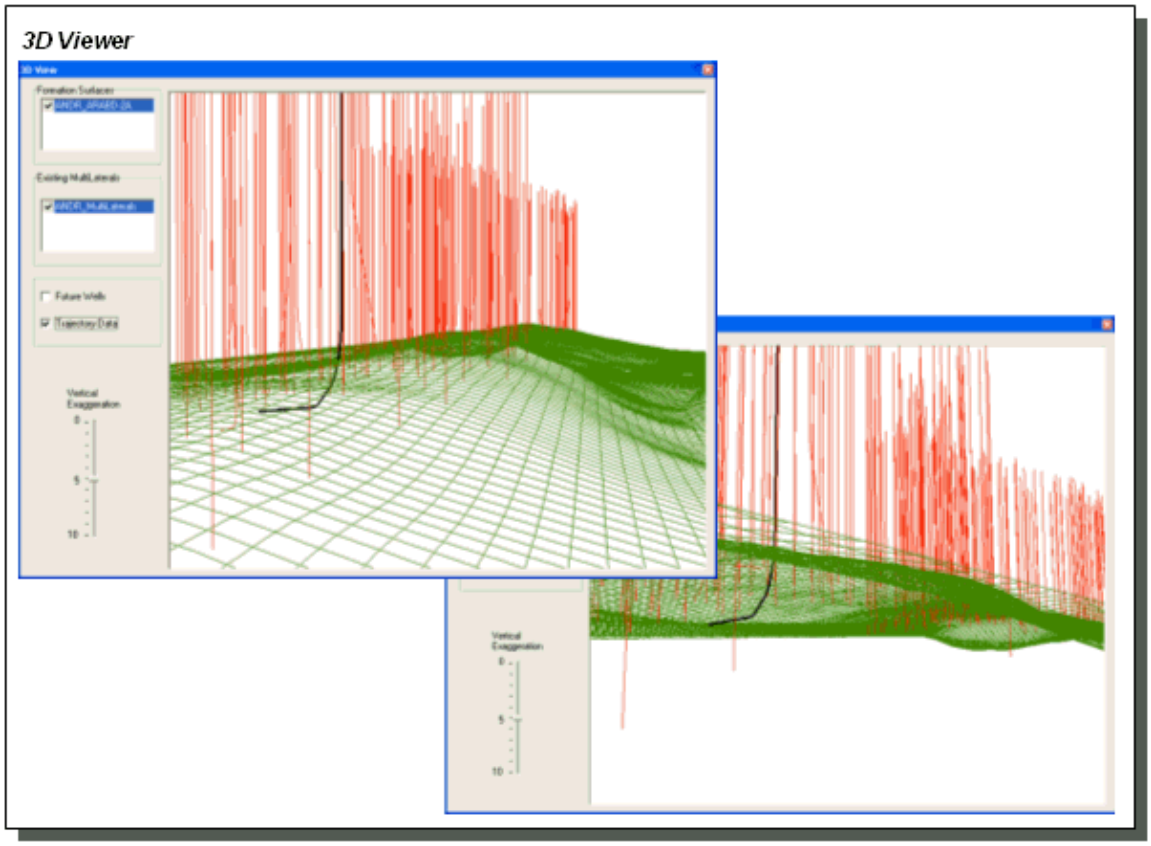
The *well profile (cross-section)* interface is a visualization and analysis aid that enables engineers to perform a quality check of the well trajectory with regards to the target formation parameters like top surface and/or reservoir fluid contacts, i.e. oil-water contact (OWC) and gas-oil contact (GOC). This assists in the vertical placement of the well as it generates a profile (cross-section) of this data versus TVD (true vertical depth) along a user specified line on the map and gives a clear indication of the thickness of the oil column to be drained if the fluid contact information is available. The first and last point of the line are used to create a cross-section plan view of the area that will determine the wells, both existing and planned, to be included automatically in the profile study. The program can generate any number of profiles in any direction to provide a better understanding of the subsurface. The resulting profiles are of good quality but more rigorous evaluations must be performed in specialized E&P geological software tools.

Using the E&P GIS's data integration tools, engineers can first create trajectory information that extends from the surface to the reservoir, for existing wells in the project area. These are 3D line features that are stored in the project geodatabase along with any future well trajectory information. After the engineer has digitized the line graphic on the map, the profile interface takes as its inputs, a surface and wells to be included on the profile graph. The resultant graph shows the well trajectories, existing and planned, penetrating the reservoir structure and fluid contact profile along the cross-section selected by the engineer.



3D Viewer

The WLP *3D viewer* interface provides the engineer a visualization tool for simultaneously viewing the reservoir structure and well trajectory information in a custom 3D viewer. Vertical exaggeration can be applied to all datasets in the viewer, enabling engineers to inspect the reservoir structure and well trajectory information, and identify relationships that were difficult to envisage in the 2D ArcMap viewing environment.



Conclusions

The Well Location Planning (WLP) extension to E&P GIS has allowed petroleum engineers involved in Reservoir Management Department to more accurately plan for and analyze complex well configurations in a single application where data from many sources can be integrated into a unified view. The application is now fully integrated into the reservoir management business workflow.

The cooperation between the different disciplines in E&P has ensured the tailoring and adoption of the E&P GIS tools to meet the business objectives of the E&P workflow. Increasingly, end-users continue to discover new ways to benefit from this technology.

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