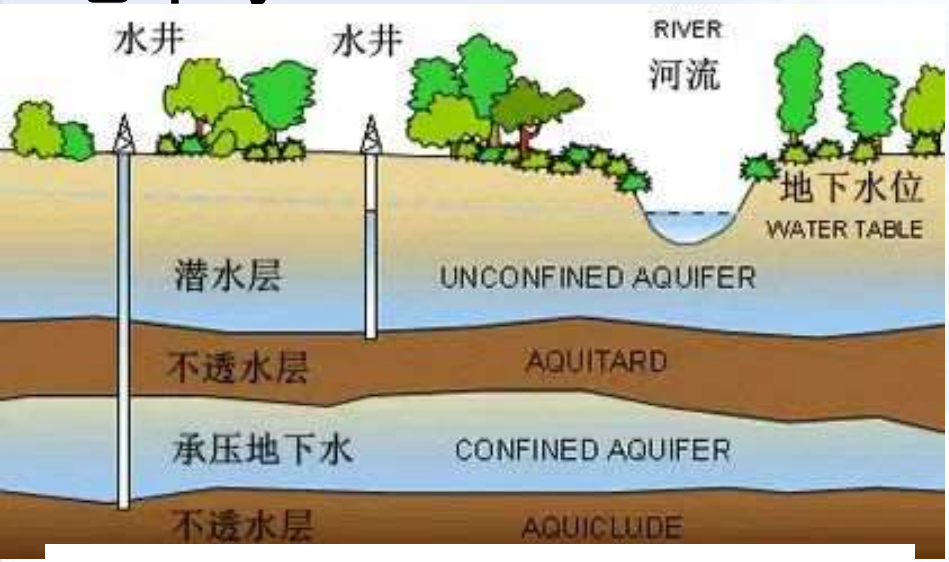
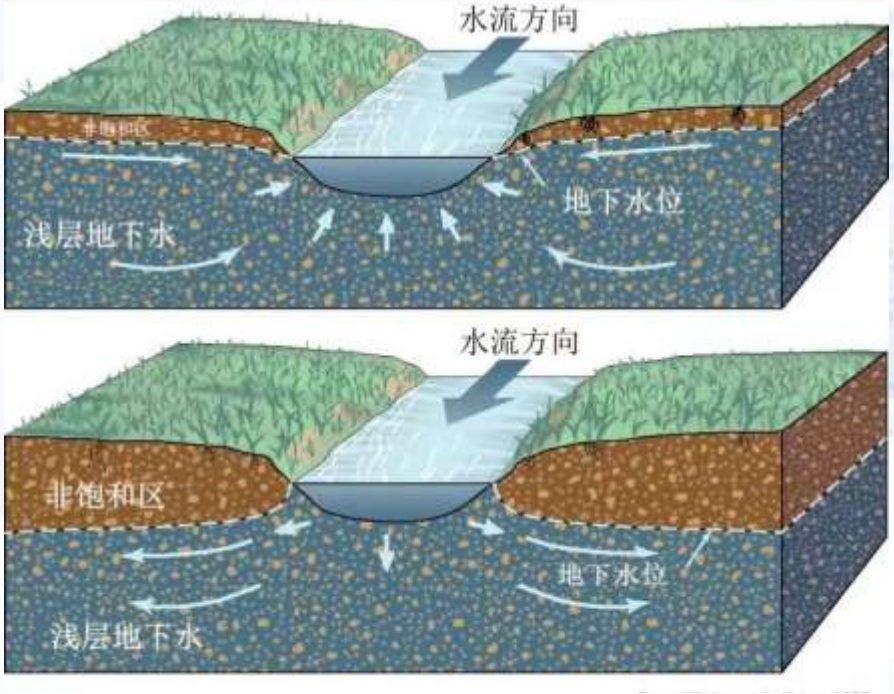
地下水模拟软件调研

Groundwater Model

李健

地下水





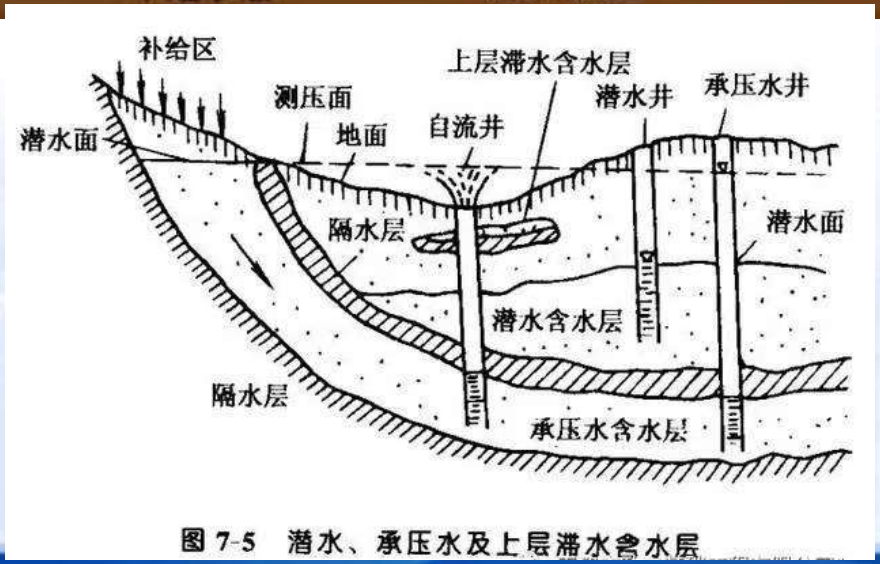
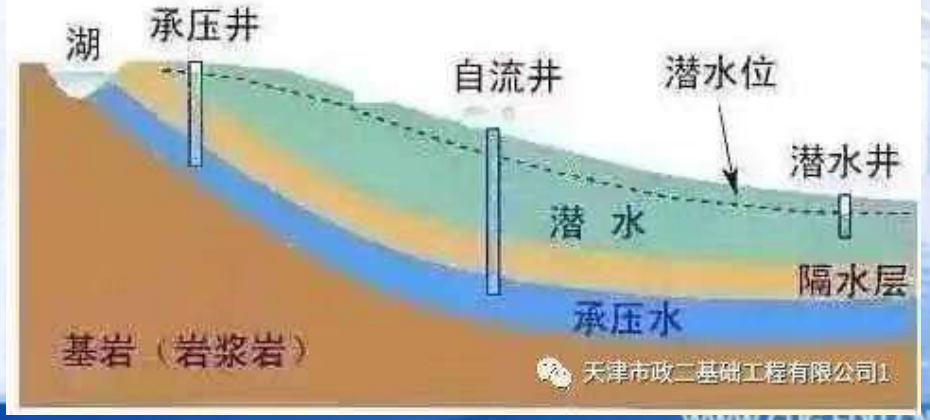


图 7-5 潜水、承压水及上层滞水含水层



MODFLOW

MODFLOW现在常用的是MODFLOW-2005（结构网格）、MODFLOW-USG(非结构网格)与MODFLOW6（统一模型框架，最新）。

MODFLOW-2005已有OpenMP与CUDA并行化的线性方程组求解器。

MODFLOW-USG只有串行版本。

MODFLOW6已实现MPI并行化。

MODFLOW-USG可使用嵌套网格(nested grid)、四叉树网格(quadtree)；而MODFLOW6可使用结构网格、MODFLOW-USG的网格以及DISV三角形网格。

Gridgen（不是Pointwise Gridgen）可作为MODFLOW-USG的quadtree网格生成程序，导出ASCII格式的MODFLOW-USG的网格输入文件。

flopy是MODFLOW系列软件的后处理程序。

Visual Modflow

Visual Modflow由加拿大Waterloo Hydrogeologic公司 开发。

Comprehensive Groundwater Modeling

With Visual MODFLOW Flex you have a comprehensive set of tools necessary for addressing water quality, groundwater supply, and source water protection initiatives, including:

MODFLOW-2000, 2005, NWT	The world standard for groundwater flow modeling
MODFLOW-USG	A finite volume version of MODFLOW that uses unstructured grids. Learn more
MODFLOW-LGR	Shared-node local grid refinement (LGR) for regional-local scale simulations
MODFLOW-SURFACT	Enhanced simulations of complex saturated/unsaturated subsurface flow and transport processes
MT3DMS	The standard package for multi-species contaminant transport simulations
SEAWAT	The model for variable-density groundwater flow coupled with multi-species solute and heat transport
RT3D	Advanced and specialized multi-species reactive contaminant transport simulations
MODPATH	The standard package for forward and reverse particle tracking
MOD-PATH3DU	An advanced package for forward and reverse particle tracking supporting unstructured grids
Zone Budget	A package for sub-regional water budget calculations
PEST v.12.3	Automated calibration and sensitivity analysis with support for pilot points

Visual Modflow

Visual MODFLOW Flex supported Grid types:

Uniform Grid

Non-Uniform Grid

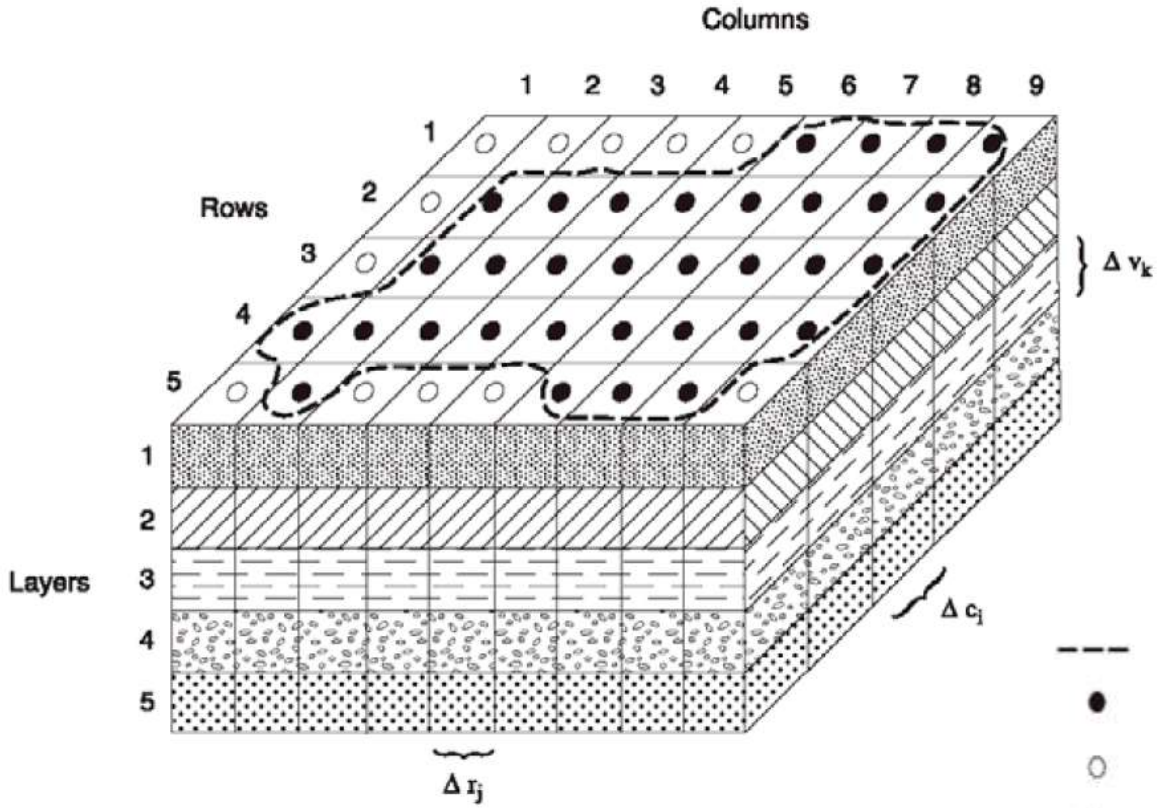
Finite Element Mesh

Localized Child Grids (MODFLOW-LGR)

Unstructured Grids (MODFLOW-USG)

MODFLOW-2005

空间离散方法见
手册P50
TM6A16.pdf



结构网格与有限差分法

EXPLANATION

AQUIFER BOUNDARY

ACTIVE CELL

INACTIVE CELL

Δr_j DIMENSION OF CELL ALONG THE ROW DIRECTION—Subscript (j) indicates the number of the column

Δc_i DIMENSION OF CELL ALONG THE COLUMN DIRECTION—Subscript (i) indicates the number of the row

Δv_k DIMENSION OF CELL ALONG THE VERTICAL DIRECTION—Subscript (k) indicates the number of the layer

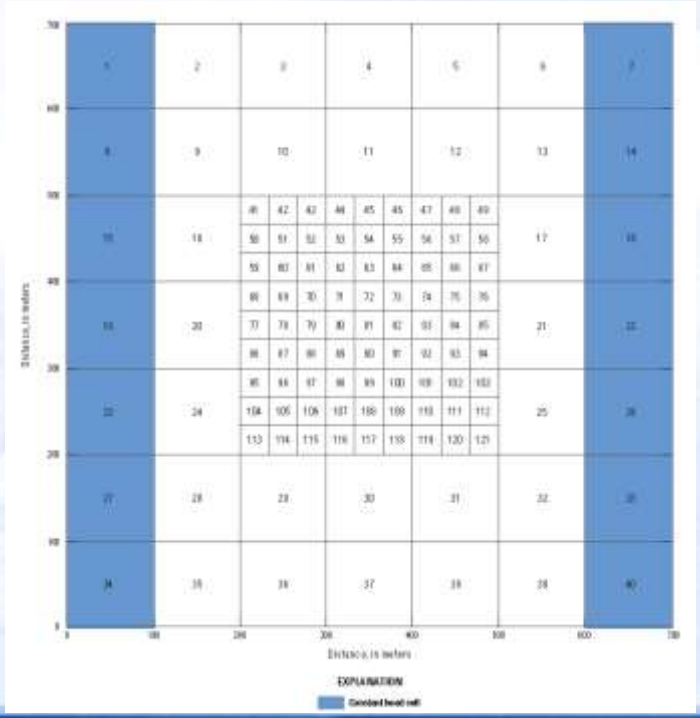
MODFLOW-USG

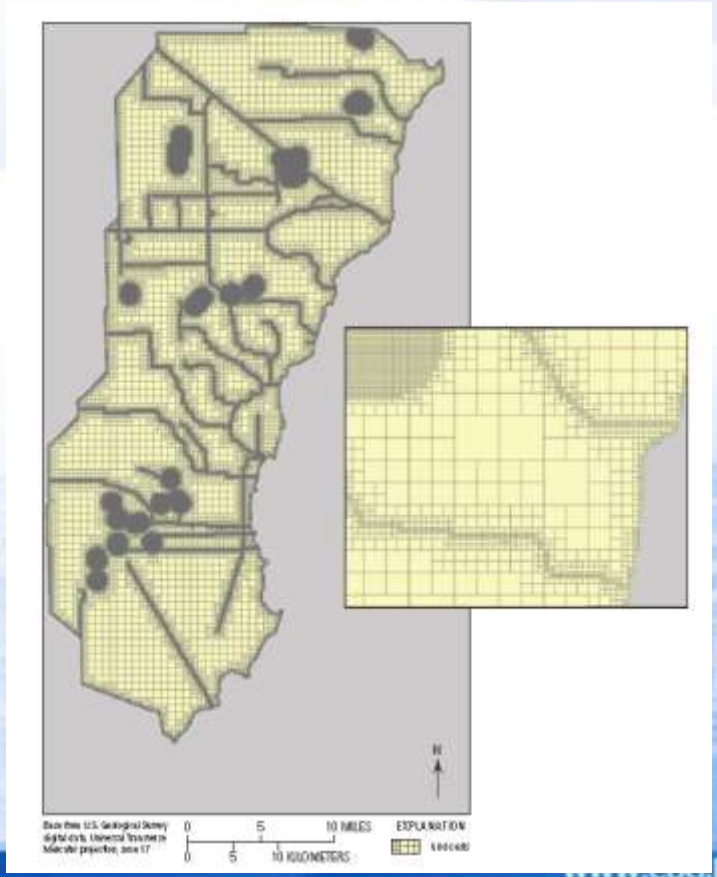
尚未见到使用DISV的三角形非结构的算例

MODFLOW-USG的水平网格，目前使用：

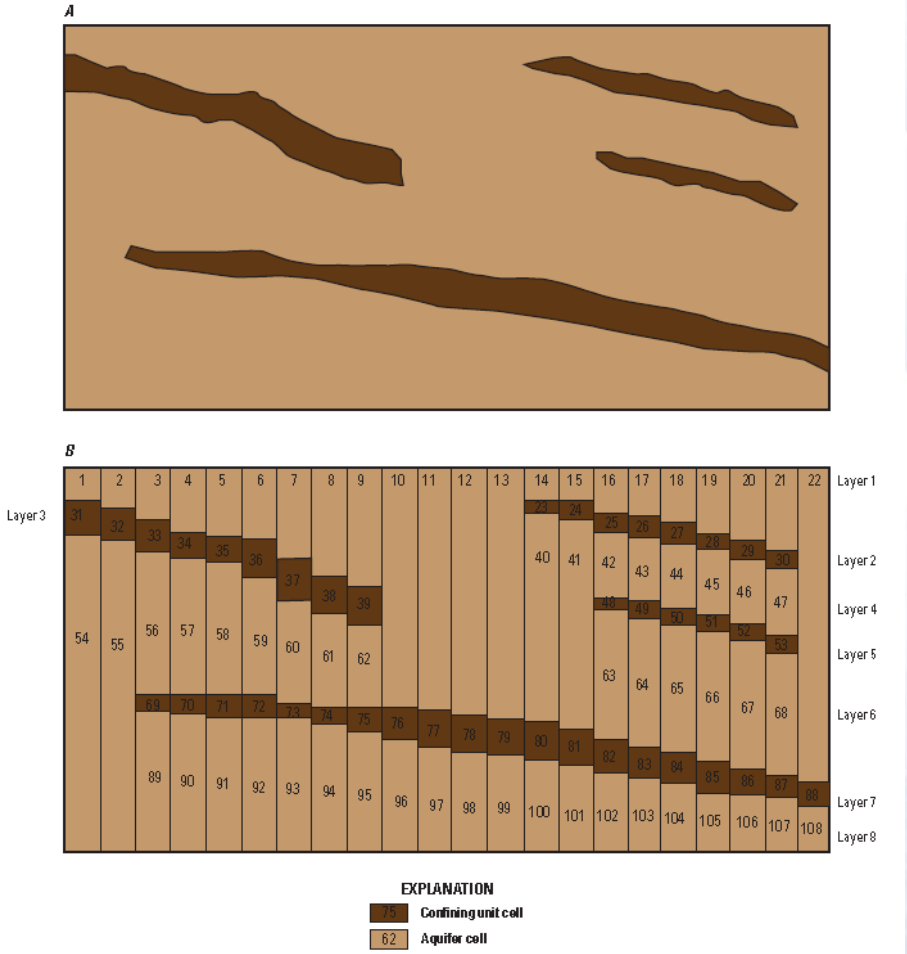
✓nested grid (LGR—Local grid refined)

✓quadtree grid

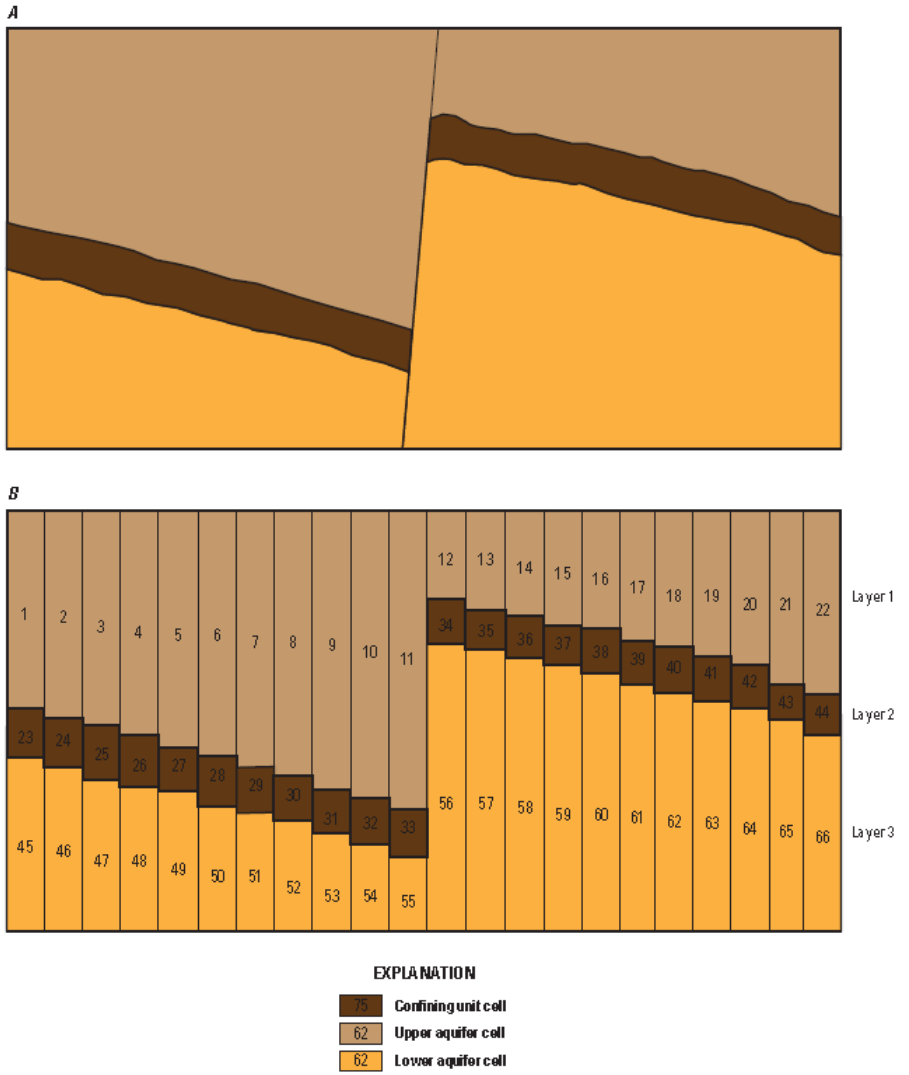




MODFLOW-USG

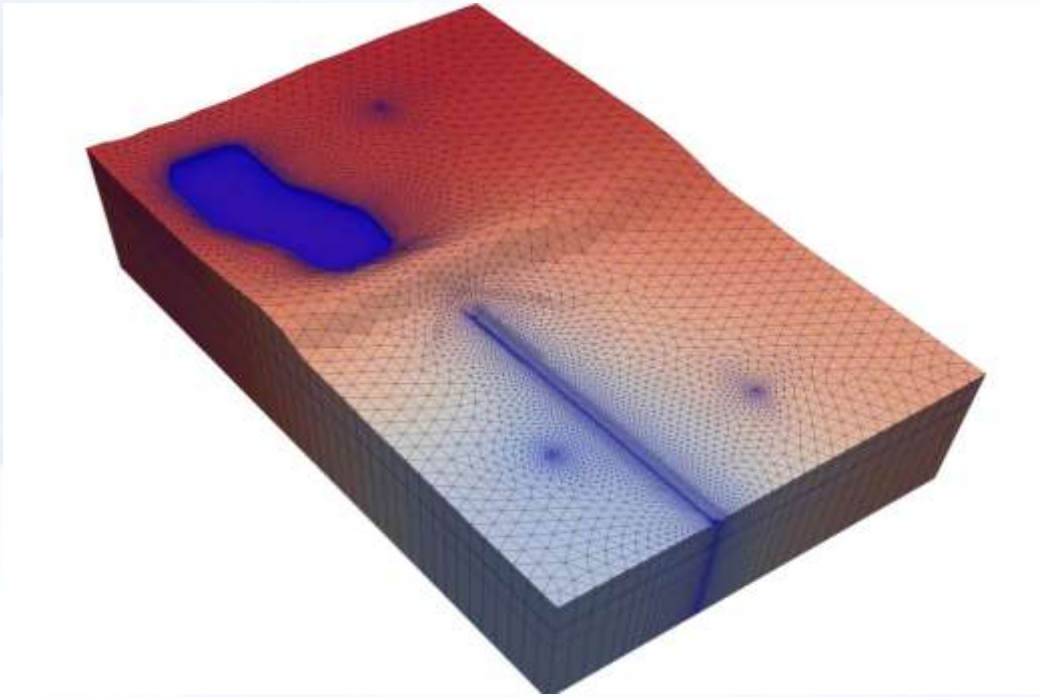


水力分层的垂向网格分层描述



断层的垂向网格分层描述

MODFLOW-6

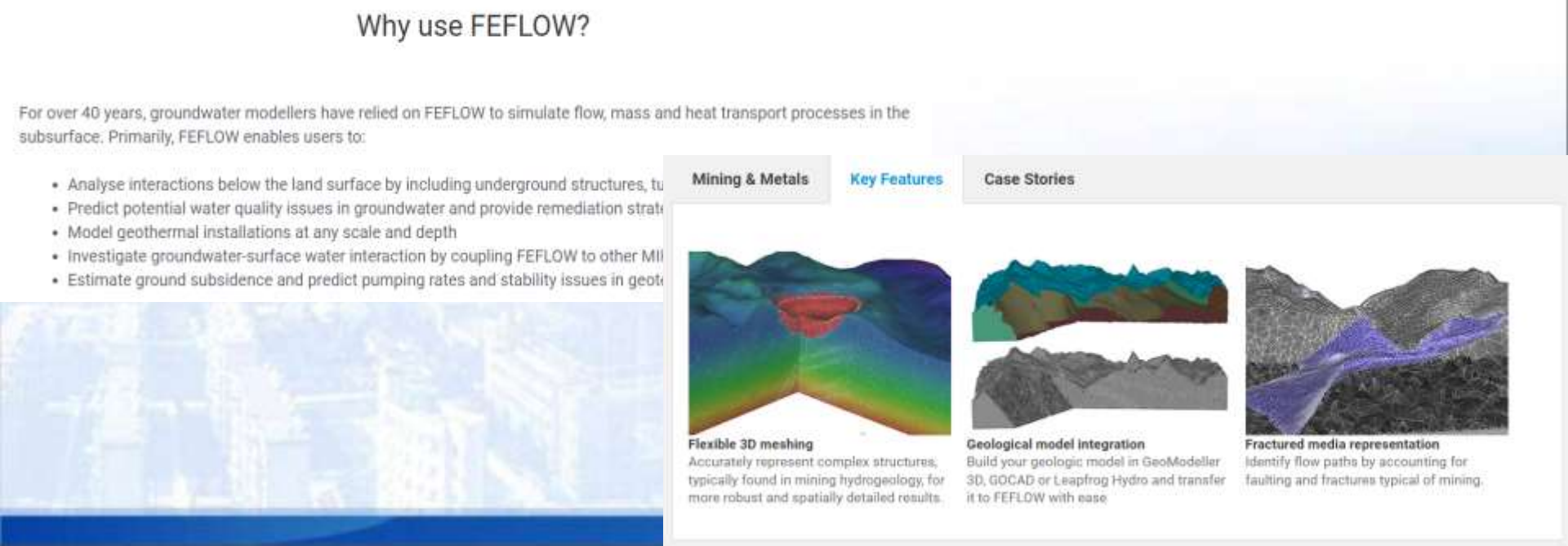


DISV水平网格

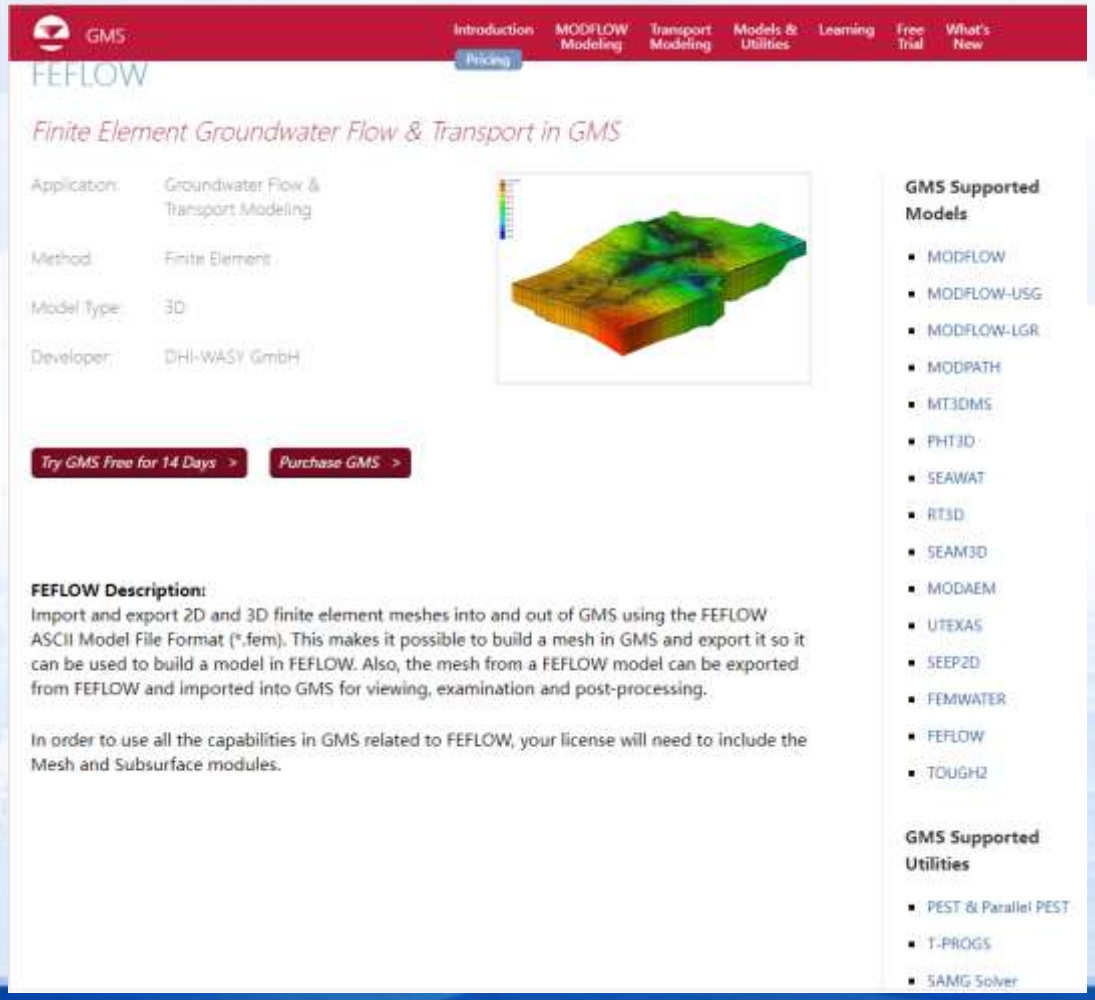
1. a regular MODFLOW grid consisting of layers, rows, and columns,
2. a layered grid defined by (x, y) vertex pairs, or
3. a general unstructured grid based on concepts developed for MODFLOW-USG.

FEFLOW-DHI

Hans-Jorg G. Diersch 在1979年开始研发，在德国柏林科学研究院，开发至1990年代。FEFLOW持续研发，拓展至一个商业模拟软件2007年，被丹麦DHI收购。



GMS（Aquavo 公司）：Groundwater Modeling System
另一个SMS(Surfacewater Modelling System)



GMS囊括了很多主流的地下水模型，包括MODFLOW, FEFLOW, TOUGH2等

界面化，交互操作

总结

1、FEFLOW, GMS 为商业软件，需要许可证；界面化很好，计算性能不足（面向工作站的HPC）。

2、MODFLOW系列，开源FORTRAN，MODFLOW6在2020年实现MPI并行化（开发中）。

3、地下水模型很多，缺少统一开发框架。DuMu^{x}基于DUNE框架开发，是一个很好的开端。