WASH BASINS

Hydrogeological Software for Analysis of Pumping Tests and Aquifer Recharge

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ARUP

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1. Introduction

During a technical visit to India in December 2018, Arup and PSI reviewed and discussed PSI's analytical approach and a conceptual hydrogeological model of the Maseedpura Village catchment. This raised a potential issue regarding the availability and application of hydrogeological software tools. Arup has compiled a list of potential more sophisticated specialist groundwater modelling software that may be of use to WASH service delivery organisations.

1.1 Scope of the Note

In the UK, Arup hydrogeologists currently use 4 "industry standard" packages for most of their modelling projects:

- 3D numerical groundwater flow modelling – Visual MODFLOW Flex from Waterloo Hydrologic, Canada: https://www.waterloohydrogeologic.com/products/
- Water Quality Analysis & Geochemical Modelling – AQUACHEM from Waterloo Hydrologic, Canada: https://www.waterloohydrogeologic.com/products/
- Well Pumping & Slug Test Analysis & Interpretation – AQUIFERTEST from Waterloo Hydrologic, Canada: https://www.waterloohydrogeologic.com/products/
- Contouring and 3D surface mapping and data analysis for model input – SURFER from Golden Software, USA: https://www.goldensoftware.com/products/surfer

These packages are widely available, with free demonstration and tutorial webinars available on the company websites listed above. However they are very expensive and require complex licencing and maintenance agreements. Although the acquisition and use of these packages is a good long-term aspiration, in the short term they are probably too complex and expensive to be beneficial to the WASH NGOs.

As an alternative, free or open-source hydrogeological software could be more appropriate to the project. Specific areas of application include:

- Pumping test analysis
- Groundwater flow modelling
- Planning and assessing aquifer recharge

Please note that this is not a comprehensive review of all groundwater software. There are very many open source software products available online. The packages described in this note are those that Arup has some knowledge of and may best benefit the project team.

2. Pumping Test Analysis Software

2.1 Aqtesolv

Aqtesolv by Hydrosolve Inc (http://www.aqtesolv.com) is an excellent and relatively low cost commercial package (US$400). A demo can be seen here: http://www.aqtesolv.com/demo.htm

A discussion of how Aqtesolv can be used to analyse for large diameter wells can be found here: http://www.aqtesolv.com/papadopu.htm

2.2 BGSPT - Analysis software

BGSPT is designed to simulate and analyse pumping tests in large-diameter wells. It has two elements: one for analysing pumping tests (PTFIT), and the other to simulate time-drawdown behaviour for a specified set of parameters (PTSIM). The model upon which both elements are based is a well, fully-penetrating a semi-confined aquifer of infinite extent.

It is available for free download from: http://www.bgs.ac.uk/bgspt/

2.3 FC Programme (Flow Characteristic) Programme by Prof Gerrit van Tonder

The FC Programme (Flow Characteristic Programme) is an excel based tool to analyse step drawdown tests and slug tests, and includes the following methods:

- the Derivative Method;
- the Barker Fractal method; and
- the Cooper-Jacob method.

It can be downloaded free from: https://www.ufs.ac.za/natagri/departments-and-divisions/institute-for-groundwater-studies-(igs)-home/boreholes/free-pumping-test-programme .

2.4 MLU for Windows

MLU (Multi-Layer Unsteady state) can be used for drawdown calculations and inverse modelling of transient well flow (pumping tests analysis) in layered aquifer systems and stratified aquifers.

A LT-version of MLU for Windows, which is a fully functional, capacity-reduced version of MLU can be downloaded for free from: http://www.microfem.nl/products/mlu.html.

It can handle up to 2 aquifers and 3 aquitards, 2 pumping wells, 5 observation wells, while 6 parameters can be optimized in one run.

2.5 General References

Here are some useful references that discuss the technical aspects of analysis of pumping test data in large diameter wells:

- Large Diameter Wells with Well Bore Storage - Papadopulos-Cooper method of analysis can be found here: https://www.waterloohydrogeologic.com/help/aquifertest/index.html?_large_diameter_wells_with_wel.htm

- https://www.swstechnology.com/novametrix/help/aquifertest/index.html?_recovery_analysis___agarwal_s.htm – for analysis of recovery phase

- Singh V.S. & Gupta C.P. Hydrogeological parameter estimation from pump tests on a large diameter well panel: https://www.sciencedirect.com/science/article/pii/0022169486900156

- A comparison between the Slichter and & Papadopulos-Cooper methods of analysing pump tests from large diameter wells can be found here: http://shodhganga.inflibnet.ac.in/bitstream/10603/97659/12/12_chapter%207.pdf

- Rushton K. & Singh V.S. 1987, Pumping Test Analysis in Large Diameter Wells With A Seepage Face By Kernel Function Technique: available here: https://doi.org/10.1111/j.1745-6584.1987.tb02118.x

3. Groundwater Flow Modelling Software

There are many 2D & 3D numerical groundwater modelling packages available on the internet. However the recognised world standard is MODFLOW which is the U.S. Geological Survey modular finite-difference flow model, which is a computer code that solves the groundwater flow equation. The source code is free public domain software, written primarily in Fortran, and can compile and run on Microsoft Windows or Unix-like operating systems.

There are several graphical interfaces to MODFLOW, which often include the compiled MODFLOW code with modifications. These programs aid the input of data for creating MODFLOW models. Non-commercial MODFLOW versions are free, however, their licensing usually limit the use to non-profit educational or research purposes. For more information: https://water.usgs.gov/ogw/modflow/

- Model Muse is a grid-independent graphical user interface from the USGS for MODFLOW-2005, MODPATH, and PHAST. There are no license restrictions. The source code is included.

- MODFLOW-GUI – Made by the USGS: it is updated often to match the current USGS MODFLOW development. It supports MODFLOW-96, MODFLOW-2000, MODFLOW-2005, MODPATH, ZONEBUDGET, GWT, MT3DMS, SEAWAT, and GWM. Source code for MODFLOW-GUI is included. It depends on Argus ONE: a commercial interface for constructing generic models. There are no license restrictions beyond those of Argus ONE.

- PMWIN – "Processing MODFLOW" (for Windows) – powerful freeware for MODFLOW processing and visualization, provided alongside an instructional book; The license for this version is limited to non-commercial use.

- MFLAB - mflab is a MATLAB interface to MODFLOW. The user builds and analyses models by writing a set of MATLAB scripts. This results in flexible and efficient workflows, allowing a great deal of automation.

- iMOD - Free and open source interface developed by Deltares. iMOD contains an accelerated version of MODFLOW with fast, flexible and consistent sub-domain modelling techniques. Facilitating large, high resolution MODFLOW modelling and geo-editing of the subsurface

- FREEWAT (http://www.freewat.eu/) is a free and open source, QGIS-integrated modelling platform integrating MODFLOW (MODFLOW versions integrated are MODFLOW-2005 and MODFLOW-OWHM) and the following MODFLOW-related simulation codes: MT3DMS, MT3D-USGS, SEAWAT, ZONE BUDGET, MODPATH, UCODE-2014. FREEWAT has been developed in the framework of the H2020 FREEWAT project for the simulation of the hydrological cycle and hydrochemical processes. It couples the capabilities supplied by such codes with the potentialities of GIS spatial analysis tools to support model implementation.

Full list of USGS MODFLOW utilities: https://water.usgs.gov/ogw/modflow/utilities.html

4. Other Groundwater Software Tools

4.1 INOWAS Managed Aquifer Recharge (MAR) Applications

INOWAS is free, web-based software for planning and assessment of MAR applications open source INOWAS platform (https://inowas.hydro.tu-dresden.de).

The web-based toolkit contains tools grouped in three categories of various complexities based on empirical, analytical and numerical equations:

- **Low complexity**: databases and tools derived from data mining such as the global MAR portal or tools supporting GIS-based MAR suitability mapping;
- **Medium complexity**: simple tools based on analytical equations including the estimation of groundwater mounding beneath an infiltration basin, assessment of saltwater intrusion, calculation of SAT basins area, estimation of pumping-induced river drawdown etc.;
- **High complexity**: MODFLOW-based tools for setting up and calculating a groundwater flow model, including user-friendly scenarios management and analysis and model optimisation with the help of web-based genetic algorithm.