

| TACTIC tool template for assessment of CCA and CCA effects |                                       | Functionality     |                       |                                        | Tool type       |                                 |                        | Intended users / user friendliness |                  |                      | Scale       | User rights and access | Extent of documentation          |                            | Relevance for TACTIC |                                      |           | Transferable to other sites? |                 |                |             |                              |                |            |            |                        |                                           |                                       |                                 |                       |                      |                                                                          |                                               |  |
|------------------------------------------------------------|---------------------------------------|-------------------|-----------------------|----------------------------------------|-----------------|---------------------------------|------------------------|------------------------------------|------------------|----------------------|-------------|------------------------|----------------------------------|----------------------------|----------------------|--------------------------------------|-----------|------------------------------|-----------------|----------------|-------------|------------------------------|----------------|------------|------------|------------------------|-------------------------------------------|---------------------------------------|---------------------------------|-----------------------|----------------------|--------------------------------------------------------------------------|-----------------------------------------------|--|
| Partner                                                    | Tool name                             | Impact assessment | Adaptation assessment | Climate projection and bias correction | Supporting tool | Physical based-integrated GW-SW | Lumped numerical model | Analytical model                   | Conceptual model | Time-series analysis | Index based | Scientists             | Professionals (e.g. consultants) | Water managers – CCA – DRR | Stakeholders         | Downstream services – General public | Catchment | Aquifer                      | Wellfield-local | Property codes | Open source | Freely accessible at no cost | Not documented | Documented | User guide | User guide and hotline | Groundwater dependent floods and droughts | Groundwater-surface water interaction | Changes in groundwater recharge | Groundwater depletion | Salt water intrusion | Generic (transferable to different sites and used in the TACTIC project) | Non-generic (not transferable to other sites) |  |
|                                                            |                                       |                   |                       |                                        |                 |                                 |                        |                                    |                  |                      |             |                        |                                  |                            |                      |                                      |           |                              |                 |                |             |                              |                |            |            |                        |                                           |                                       |                                 |                       |                      |                                                                          |                                               |  |
| BGR                                                        | AQUICLIM                              |                   |                       |                                        | 1               |                                 |                        |                                    |                  |                      | 1           |                        |                                  |                            | 1                    | 1                                    | 1         |                              |                 |                | 1           |                              | 1              |            |            |                        |                                           |                                       |                                 |                       | 1                    |                                                                          |                                               |  |
| BGS                                                        | AquiMOD                               | 1                 |                       | 1                                      |                 |                                 | 1                      |                                    |                  |                      |             | 1                      | 1                                |                            |                      |                                      |           |                              | 1               |                | 1           |                              | 1              | 1          |            |                        | 1                                         |                                       |                                 |                       |                      | 1                                                                        |                                               |  |
| BGS                                                        | IH low flow                           |                   |                       |                                        | 1               |                                 |                        |                                    |                  | 1                    |             | 1                      | 1                                |                            |                      |                                      |           |                              |                 |                | 1           |                              |                |            |            |                        | 1                                         | 1                                     |                                 |                       |                      | 1                                                                        |                                               |  |
| BGS                                                        | Thorntwaite EA <sub>p</sub>           |                   |                       |                                        | 1               |                                 | 1                      |                                    |                  |                      |             | 1                      | 1                                |                            |                      |                                      |           |                              |                 |                | 1           |                              | 1              |            |            |                        | 1                                         | 1                                     |                                 |                       |                      | 1                                                                        |                                               |  |
| BGS                                                        | Recharge spreadsheet                  | 1                 |                       |                                        |                 |                                 |                        | 1                                  |                  | 1                    |             | 1                      | 1                                |                            |                      |                                      |           |                              | 1               |                | 1           |                              |                | 1          |            | 1                      | 1                                         | 1                                     |                                 |                       |                      | 1                                                                        |                                               |  |
| BRGM                                                       | Marthe                                | 1                 | 1                     |                                        |                 | 1                               |                        |                                    |                  |                      |             | 1                      | 1                                |                            |                      |                                      | 1         | 1                            | 1               | 1              | 1           |                              | 1              |            |            | 1                      | 1                                         | 1                                     | 1                               | 1                     | 1                    | 1                                                                        |                                               |  |
| BRGM                                                       | Gardenia                              | 1                 | 1                     |                                        |                 |                                 | 1                      |                                    |                  |                      |             | 1                      | 1                                | 1                          | 1                    |                                      | 1         | 1                            | 1               | 1              | 1           |                              |                |            |            | 1                      | 1                                         | 1                                     | 1                               | 1                     | 1                    | 1                                                                        |                                               |  |
| BRGM                                                       | EROS                                  | 1                 | 1                     |                                        |                 |                                 | 1                      |                                    |                  |                      |             | 1                      | 1                                | 1                          | 1                    |                                      | 1         | 1                            | 1               | 1              | 1           |                              |                |            |            | 1                      | 1                                         | 1                                     | 1                               | 1                     | 1                    | 1                                                                        |                                               |  |
| BRGM                                                       | Esther                                |                   |                       |                                        | 1               |                                 |                        |                                    |                  | 1                    |             | 1                      | 1                                |                            |                      |                                      | 1         | 1                            | 1               | 1              | 1           |                              |                | 1          |            | 1                      | 1                                         | 1                                     | 1                               | 1                     | 1                    | 1                                                                        |                                               |  |
| BRGM                                                       | TEMPO                                 | 1                 | 1                     |                                        |                 |                                 |                        |                                    |                  |                      |             | 1                      | 1                                | 1                          |                      |                                      | 1         | 1                            | 1               | 1              | 1           |                              | 1              |            | 1          | 1                      | 1                                         | 1                                     | 1                               | 1                     | 1                    | 1                                                                        |                                               |  |
| BRGM                                                       | WTF-RISE                              |                   |                       |                                        | 1               |                                 |                        |                                    |                  | 1                    |             | 1                      | 1                                |                            |                      |                                      |           |                              | 1               | 1              | 1           |                              | 1              |            |            |                        | 1                                         | 1                                     | 1                               | 1                     | 1                    | 1                                                                        |                                               |  |
| DLT                                                        | IMOD                                  | 1                 | 1                     | 1                                      | 1               | 1                               |                        | 1                                  |                  | 1                    | 1           | 1                      | 1                                | 1                          | 1                    |                                      | 1         | 1                            | 1               | 1              | 1           |                              | 1              | 1          | 1          | 1                      | 1                                         | 1                                     | 1                               | 1                     | 1                    | 1                                                                        | 1                                             |  |
| Geoinform                                                  | ASPA                                  |                   |                       |                                        | 1               |                                 |                        |                                    |                  | 1                    |             | 1                      | 1                                | 1                          | 1                    | 1                                    | 1         |                              |                 | 1              | 1           |                              | 1              |            |            |                        |                                           |                                       |                                 | 1                     | 1                    | 1                                                                        |                                               |  |
| GEUS                                                       | NAM                                   | 1                 | 1                     |                                        |                 |                                 | 1                      |                                    |                  |                      |             | 1                      | 1                                |                            |                      |                                      | 1         |                              |                 |                |             |                              | 1              |            | 1          | 1                      |                                           |                                       |                                 |                       |                      | 1                                                                        |                                               |  |
| GEUS                                                       | Pastas                                | 1                 | 1                     |                                        |                 |                                 |                        |                                    |                  | 1                    |             | 1                      | 1                                |                            |                      |                                      |           |                              | 1               | 1              | 1           |                              |                | 1          | 1          |                        |                                           |                                       |                                 |                       |                      | 1                                                                        |                                               |  |
| GEUS                                                       | MIKESHE-DAISY                         | 1                 | 1                     | 1                                      | 1               | 1                               |                        |                                    |                  |                      |             | 1                      | 1                                |                            |                      |                                      | 1         |                              |                 |                |             |                              | 1              | 1          |            |                        |                                           |                                       |                                 |                       |                      | 1                                                                        |                                               |  |
| GEUS                                                       | MIKE SHE                              | 1                 | 1                     | 1                                      |                 | 1                               |                        |                                    |                  | 1                    |             | 1                      | 1                                | 1                          |                      |                                      | 1         | 1                            | 1               | 1              | 1           |                              |                |            | 1          | 1                      | 1                                         | 1                                     | 1                               | 1                     | 1                    | 1                                                                        |                                               |  |
| GEUS                                                       | MIKE HYDRO                            | 1                 | 1                     |                                        | 1               |                                 |                        |                                    |                  |                      |             | 1                      | 1                                | 1                          |                      |                                      | 1         |                              |                 |                |             |                              |                | 1          | 1          | 1                      |                                           |                                       |                                 |                       |                      | 1                                                                        |                                               |  |
| GEUS                                                       | EVA                                   | 1                 |                       |                                        | 1               |                                 |                        |                                    |                  | 1                    |             | 1                      | 1                                |                            |                      |                                      |           |                              | 1               | 1              |             |                              |                | 1          | 1          |                        |                                           |                                       |                                 |                       |                      | 1                                                                        |                                               |  |
| GSI                                                        | Irish method recharge                 | 1                 | 1                     |                                        | 1               |                                 |                        |                                    |                  |                      | 1           | 1                      | 1                                | 1                          | 1                    | 1                                    | 1         | 1                            | 1               | 1              | 1           |                              | 1              |            |            |                        | 1                                         | 1                                     |                                 |                       |                      | 1                                                                        |                                               |  |
| GSI                                                        | High Resolution GDHC Ireland          | 1                 |                       | 1                                      | 1               |                                 | 1                      |                                    |                  |                      |             | 1                      | 1                                | 1                          | 1                    |                                      | 1         | 1                            | 1               | 1              | 1           |                              |                |            |            | 1                      | 1                                         | 1                                     | 1                               | 1                     | 1                    | 1                                                                        | 1                                             |  |
| GSI                                                        | Irish Groundwater Flood map           |                   |                       | 1                                      | 1               |                                 | 1                      |                                    | 1                | 1                    |             | 1                      | 1                                | 1                          | 1                    | 1                                    | 1         | 1                            | 1               | 1              | 1           |                              | 1              | 1          |            | 1                      | 1                                         | 1                                     |                                 |                       |                      | 1                                                                        | 1                                             |  |
| IGME                                                       | SACRAMENTO (SRG)                      | 1                 |                       |                                        |                 |                                 |                        |                                    |                  |                      |             | 1                      | 1                                | 1                          |                      |                                      | 1         | 1                            | 1               | 1              | 1           |                              | 1              | 1          | 1          | 1                      | 1                                         |                                       |                                 |                       |                      | 1                                                                        |                                               |  |
| IGME                                                       | Temez                                 | 1                 |                       |                                        |                 |                                 | 1                      |                                    |                  |                      |             | 1                      | 1                                | 1                          |                      |                                      | 1         |                              |                 |                |             |                              |                |            |            |                        |                                           |                                       |                                 |                       |                      | 1                                                                        |                                               |  |
| IGME                                                       | CROP-WAT                              | 1                 | 1                     |                                        | 1               |                                 | 1                      | 1                                  | 1                | 1                    |             | 1                      | 1                                | 1                          |                      |                                      | 1         |                              |                 |                | 1           |                              | 1              |            | 1          |                        |                                           |                                       |                                 |                       |                      | 1                                                                        |                                               |  |
| IGME                                                       | Aquatool                              | 1                 | 1                     |                                        | 1               | 1                               | 1                      | 1                                  | 1                | 1                    |             | 1                      | 1                                | 1                          |                      |                                      | 1         |                              |                 |                | 1           |                              | 1              |            | 1          | 1                      | 1                                         | 1                                     | 1                               | 1                     | 1                    | 1                                                                        | 1                                             |  |
| IGME                                                       | Renata                                | 1                 |                       |                                        | 1               |                                 | 1                      |                                    |                  |                      |             | 1                      | 1                                | 1                          | 1                    | 1                                    | 1         | 1                            | 1               | 1              | 1           |                              |                |            | 1          |                        |                                           |                                       |                                 |                       |                      | 1                                                                        |                                               |  |
| IGME                                                       | Estimating subsidence from InSAR data | 1                 |                       |                                        | 1               |                                 |                        |                                    |                  | 1                    |             | 1                      | 1                                | 1                          |                      |                                      | 1         | 1                            | 1               |                |             |                              | 1              |            |            |                        |                                           |                                       |                                 |                       |                      | 1                                                                        |                                               |  |
| IGME                                                       | Visual MODLOW (MODFLOW, SEAWAT, etc)  | 1                 | 1                     |                                        | 1               |                                 |                        |                                    |                  |                      |             | 1                      | 1                                | 1                          | 1                    | 1                                    | 1         | 1                            | 1               | 1              | 1           |                              |                |            | 1          | 1                      | 1                                         | 1                                     | 1                               | 1                     | 1                    | 1                                                                        | 1                                             |  |
| IGME                                                       | GIS-GALDIT (vulnerability)            |                   |                       |                                        | 1               |                                 |                        |                                    |                  |                      |             | 1                      | 1                                | 1                          |                      |                                      | 1         | 1                            | 1               | 1              | 1           |                              | 1              |            |            | 1                      | 1                                         | 1                                     | 1                               | 1                     | 1                    | 1                                                                        | 1                                             |  |
| IGME                                                       | GIS-MaRT (summary of SWI)             |                   |                       |                                        | 1               |                                 |                        |                                    |                  |                      |             | 1                      | 1                                | 1                          | 1                    | 1                                    | 1         | 1                            | 1               | 1              | 1           |                              | 1              |            |            |                        |                                           |                                       |                                 |                       |                      | 1                                                                        | 1                                             |  |
| LBEG                                                       | mGROWA                                | 1                 |                       |                                        |                 |                                 | 1                      |                                    |                  |                      |             | 1                      | 1                                | 1                          | 1                    | 1                                    | 1         | 1                            | 1               | 1              | 1           |                              | 1              | 1          | 1          |                        | 1                                         |                                       |                                 |                       |                      | 1                                                                        |                                               |  |
| MBFSZ                                                      | HELP                                  |                   |                       |                                        | 1               |                                 | 1                      |                                    |                  | 1                    |             | 1                      | 1                                |                            |                      |                                      |           |                              | 1               | 1              |             |                              |                |            |            |                        |                                           |                                       |                                 |                       |                      | 1                                                                        |                                               |  |
| PGI-NRI                                                    | BI                                    |                   |                       |                                        | 1               |                                 |                        |                                    |                  | 1                    |             | 1                      | 1                                |                            |                      |                                      | 1         | 1                            | 1               | 1              | 1           |                              | 1              | 1          |            |                        |                                           |                                       |                                 |                       |                      |                                                                          | 1                                             |  |
| PGI-NRI                                                    | Platforma PHS                         |                   |                       |                                        | 1               |                                 |                        |                                    |                  | 1                    |             | 1                      | 1                                |                            |                      |                                      | 1         | 1                            | 1               | 1              | 1           |                              | 1              | 1          |            |                        |                                           |                                       |                                 |                       |                      |                                                                          | 1                                             |  |
| PGI-NRI                                                    | Statistica                            |                   |                       |                                        | 1               |                                 |                        |                                    |                  | 1                    |             | 1                      | 1                                |                            |                      |                                      | 1         | 1                            | 1               | 1              | 1           |                              | 1              | 1          |            |                        | 1                                         | 1                                     | 1                               |                       |                      |                                                                          | 1                                             |  |
| PGI-NRI                                                    | BankHydro                             |                   |                       |                                        | 1               |                                 |                        |                                    |                  |                      |             | 1                      |                                  |                            |                      |                                      | 1         |                              |                 |                |             |                              |                |            |            |                        |                                           |                                       |                                 |                       |                      |                                                                          | 1                                             |  |
| SGSS                                                       | leapfrog                              |                   |                       |                                        | 1               |                                 |                        |                                    | 1                |                      |             | 1                      | 1                                |                            |                      |                                      | 1         | 1                            | 1               | 1              | 1           |                              | 1              | 1          | 1          | 1                      | 1                                         | 1                                     | 1                               | 1                     | 1                    | 1                                                                        | 1                                             |  |
| SGU                                                        | HYPE                                  | 1                 | 1                     | 1                                      | 1               | 1                               | 1                      |                                    |                  | 1                    |             | 1                      | 1                                | 1                          |                      |                                      | 1         | 1                            | 1               | 1              | 1           |                              | 1              | 1          | 1          | 1                      | 1                                         | 1                                     | 1                               | 1                     | 1                    | 1                                                                        | 1                                             |  |
| TNO-GSN                                                    | Metran                                | 1                 |                       |                                        | 1               |                                 |                        |                                    |                  |                      |             | 1                      | 1                                | 1                          | 1                    | 1                                    | 1         | 1                            | 1               | 1              | 1           |                              | 1              |            | 1          | 1                      | 1                                         | 1                                     | 1                               | 1                     | 1                    | 1                                                                        | 1                                             |  |
| TNO-GSN                                                    | GDNisohypsen                          |                   |                       |                                        | 1               |                                 |                        | 1                                  |                  |                      |             | 1                      | 1                                | 1                          | 1                    | 1                                    | 1         | 1                            | 1               | 1              | 1           |                              | 1              |            | 1          | 1                      | 1                                         | 1                                     | 1                               | 1                     | 1                    | 1                                                                        | 1                                             |  |
| USGS                                                       | ModelMuse (MODFLOW, SUTRA, SWI2 etc.) | 1                 | 1                     |                                        | 1               | 1                               |                        |                                    |                  |                      |             | 1                      | 1                                | 1                          | 1                    | 1                                    | 1         | 1                            | 1               | 1              | 1           |                              | 1              |            | 1          | 1                      | 1                                         | 1                                     | 1                               | 1                     | 1                    | 1                                                                        | 1                                             |  |
| USGS                                                       | MODLOW/MT3D/SEAWAT                    | 1                 | 1                     |                                        | 1               | 1                               |                        |                                    |                  |                      |             | 1                      | 1                                | 1                          | 1                    | 1                                    | 1         | 1                            | 1               | 1              | 1           |                              | 1              |            | 1          | 1                      | 1                                         | 1                                     | 1                               | 1                     | 1                    | 1                                                                        | 1                                             |  |
| USGS                                                       | BFI PART                              |                   |                       |                                        |                 |                                 |                        |                                    |                  | 1                    | 1           | 1                      |                                  |                            |                      |                                      | 1         |                              |                 |                | 1           |                              | 1              | 1          |            | 1                      | 1                                         | 1                                     | 1                               | 1                     | 1                    | 1                                                                        | 1                                             |  |
| USGS                                                       | BFI RORA                              |                   |                       |                                        | 1               |                                 |                        |                                    |                  | 1                    | 1           | 1                      |                                  |                            |                      |                                      | 1         |                              |                 |                | 1           |                              | 1              | 1          |            | 1                      | 1                                         | 1                                     | 1                               | 1                     | 1                    | 1                                                                        | 1                                             |  |
| USGS                                                       | WTF MRC                               |                   |                       |                                        |                 |                                 |                        |                                    |                  | 1                    | 1           | 1                      |                                  |                            |                      |                                      | 1         |                              |                 |                | 1           |                              | 1              | 1          |            | 1                      | 1                                         | 1                                     | 1                               | 1                     | 1                    | 1                                                                        | 1                                             |  |
| -                                                          | SWAT                                  | 1                 | 1                     |                                        |                 | 1                               |                        |                                    |                  |                      |             | 1                      | 1                                |                            |                      |                                      | 1         |                              |                 | 1              | 1           |                              | 1              |            |            | 1                      |                                           |                                       |                                 |                       |                      | 1                                                                        |                                               |  |
| -                                                          | PCR-GLOBWB-MODFLOW                    | 1                 | 1                     |                                        |                 | 1                               |                        |                                    |                  |                      |             | 1                      | 1                                |                            |                      |                                      | 1         |                              |                 | 1              | 1           |                              | 1              |            | 1          |                        |                                           |                                       |                                 |                       |                      | 1                                                                        |                                               |  |
| -                                                          | HBV                                   | 1                 | 1                     |                                        |                 | 1                               |                        |                                    |                  |                      |             | 1                      | 1                                |                            |                      |                                      | 1         |                              |                 | 1              | 1           |                              | 1              |            | 1          |                        |                                           |                                       |                                 |                       |                      | 1                                                                        |                                               |  |
| -                                                          | mHM                                   | 1                 | 1                     |                                        |                 | 1                               | 1                      |                                    |                  |                      |             | 1                      | 1                                |                            |                      |                                      | 1         |                              |                 | 1              | 1           |                              | 1              |            | 1          |                        |                                           |                                       |                                 |                       |                      | 1                                                                        |                                               |  |
| -                                                          | VIC                                   | 1                 | 1                     |                                        |                 | 1                               |                        |                                    |                  |                      |             | 1                      | 1                                |                            |                      |                                      | 1         |                              |                 | 1              | 1           |                              | 1              |            | 1          |                        |                                           |                                       |                                 |                       |                      | 1                                                                        |                                               |  |
| -                                                          | SubSol - toolbox                      |                   |                       |                                        | 1               |                                 | 1                      |                                    |                  |                      |             | 1                      | 1                                |                            |                      |                                      | 1         | 1                            |                 | 1              | 1           |                              | 1              |            |            | 1                      |                                           |                                       |                                 |                       |                      | 1                                                                        |                                               |  |
| -                                                          | LISFLOOD                              | 1                 | 1                     |                                        |                 | 1                               |                        |                                    |                  |                      |             | 1                      | 1                                |                            |                      |                                      | 1         |                              |                 | 1              | 1           |                              | 1              |            |            |                        |                                           |                                       |                                 |                       |                      | 1                                                                        |                                               |  |
| -                                                          | LISVAP                                |                   |                       |                                        | 1               |                                 | 1                      |                                    |                  |                      |             | 1                      | 1                                |                            |                      |                                      | 1         |                              |                 | 1              | 1           |                              | 1              |            |            |                        |                                           |                                       |                                 |                       |                      | 1                                                                        |                                               |  |
| -                                                          | FOCUS                                 | 1                 |                       | 1                                      | 1               | 1                               |                        | 1                                  |                  |                      |             | 1                      | 1                                |                            |                      |                                      | 1         |                              |                 | 1              | 1           |                              | 1              |            | 1          | 1                      | 1                                         |                                       |                                 |                       |                      | 1                                                                        | 1                                             |  |
| -                                                          | FreeWAT                               | 1                 | 1                     |                                        | 1               | 1                               | 1                      | 1                                  | 1                | 1                    |             | 1                      | 1                                | 1                          |                      |                                      | 1         | 1                            | 1               | 1              | 1           |                              | 1              |            | 1          | 1                      |                                           |                                       |                                 |                       |                      | 1                                                                        |                                               |  |
| -                                                          | HFEMC-SUFT3D                          | 1                 | 1                     |                                        | 1               | 1                               |                        |                                    |                  |                      |             | 1                      | 1                                |                            |                      |                                      | 1         |                              |                 | 1              | 1           |                              | 1              |            |            |                        |                                           |                                       |                                 |                       |                      | 1                                                                        |                                               |  |
|                                                            |                                       | 20                | 13                    | 6                                      | 28              | 8                               | 8                      | 4                                  | 6                | 20                   | 8           | 34                     | 30                               | 17                         | 9                    | 9                                    | 21        | 19                           | 19              | 22             | 4           | 17                           | 3              | 17         | 13         | 14                     | 22                                        | 23                                    | 29                              | 25                    | 8                    | 35                                                                       | 2                                             |  |

| TACTIC tool factsheet              | AQUICLIM                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                    |   |       |    |         |   |        |   |         |   |         |   |      |   |                                |   |                   |    |                       |   |                     |     |                |        |                     |                   |           |                   |       |
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| Description of tool                | <p><b>AQUICLIM: An index-based method to evaluate aquifer vulnerability to climate change</b></p> <p>AQUICLIM comprises a weighted overlay technique of spatial information to build a vulnerability-to-climate change index for shallow aquifer systems at small observation scales (200k – 1mil) from three parameters:</p> <ul style="list-style-type: none"><li>- <b>Climate change</b> expressed as groundwater recharge difference in mm between mean annual current groundwater recharge for the period 1970 – 2000, and future annual groundwater recharge scenarios for the period 2041 – 2060,</li><li>- <b>Aquifer productivity</b> according to hydrogeological map data classified using the “Standard Legend for Hydrogeological Maps” (SLHYM, Struckmeier &amp; Margat 1995) and</li><li>- <b>Aquifer void type</b> according to hydrogeological map data classified using the “Standard Legend for Hydrogeological Maps” (SLHYM).</li></ul> <p>The index (vi) can be calculated in any raster-GIS environment involving map algebra using the following weighted linear summation:</p> <div><div><math display="block">vi = \sum_{j=1}^3 w_j \times x_{ji}</math></div><div><p><b>vi:</b> Vulnerability-to-climate change index (vi 0...10)</p><p><b>w<sub>j</sub>:</b> Weighting parameter j</p><p><b>x<sub>ji</sub>:</b> Weighting class i in parameter j</p></div></div> <p>The three parameter weights w with parameter class weights x are established using the following classification scheme:</p> <div><table><tr><th>Recharge difference [mm] (w = 0.5)</th><th>x</th></tr><tr><td>≤ -15</td><td>10</td></tr><tr><td>-15 - 0</td><td>8</td></tr><tr><td>0 - 15</td><td>6</td></tr><tr><td>15 - 30</td><td>4</td></tr><tr><td>30 - 45</td><td>2</td></tr><tr><td>≥ 45</td><td>0</td></tr></table><table><tr><th>Aquifer productivity (w = 0.1)</th><th>x</th></tr><tr><td>Highly productive</td><td>10</td></tr><tr><td>Moderately productive</td><td>5</td></tr><tr><td>Limited groundwater</td><td>2.5</td></tr><tr><td>No groundwater</td><td>nodata</td></tr></table><table><tr><th>Void type (w = 0.4)</th></tr><tr><td>Karst / fractures</td></tr><tr><td>Fractures</td></tr><tr><td>Fractures / pores</td></tr><tr><td>Pores</td></tr></table></div> <p>The index has been applied on a national level for Germany (Höbbling 2016) and on a continental level for Europe (Günther et al, 2018).</p> <p><u>References:</u></p> <ul style="list-style-type: none"><li>• Günther A, Bretthauer M P, Broda S, Clos P, Reichling J (2018): Shallow aquifer diagnostics across Europe at the overview scale. Geophysical Research Abstracts, 20, 13613.</li><li>• Höbbling, C., Broda, S., Chiffard, P., Pflanz, D., Reichling, J. (2018). Assessing Groundwater vulnerability to climate change using an index based approach. GeoBonn2018 – Living Earth, abstract book.</li><li>• Struckmeier W F, Margat J (1995): Hydrogeological maps – a guide and a standard legend. International Association of Hydrogeologists International Contribution to Hydrogeology, 17.</li></ul> | Recharge difference [mm] (w = 0.5) | x | ≤ -15 | 10 | -15 - 0 | 8 | 0 - 15 | 6 | 15 - 30 | 4 | 30 - 45 | 2 | ≥ 45 | 0 | Aquifer productivity (w = 0.1) | x | Highly productive | 10 | Moderately productive | 5 | Limited groundwater | 2.5 | No groundwater | nodata | Void type (w = 0.4) | Karst / fractures | Fractures | Fractures / pores | Pores |
| Recharge difference [mm] (w = 0.5) | x                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                    |   |       |    |         |   |        |   |         |   |         |   |      |   |                                |   |                   |    |                       |   |                     |     |                |        |                     |                   |           |                   |       |
| ≤ -15                              | 10                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                                    |   |       |    |         |   |        |   |         |   |         |   |      |   |                                |   |                   |    |                       |   |                     |     |                |        |                     |                   |           |                   |       |
| -15 - 0                            | 8                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                    |   |       |    |         |   |        |   |         |   |         |   |      |   |                                |   |                   |    |                       |   |                     |     |                |        |                     |                   |           |                   |       |
| 0 - 15                             | 6                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                    |   |       |    |         |   |        |   |         |   |         |   |      |   |                                |   |                   |    |                       |   |                     |     |                |        |                     |                   |           |                   |       |
| 15 - 30                            | 4                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                    |   |       |    |         |   |        |   |         |   |         |   |      |   |                                |   |                   |    |                       |   |                     |     |                |        |                     |                   |           |                   |       |
| 30 - 45                            | 2                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                    |   |       |    |         |   |        |   |         |   |         |   |      |   |                                |   |                   |    |                       |   |                     |     |                |        |                     |                   |           |                   |       |
| ≥ 45                               | 0                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                    |   |       |    |         |   |        |   |         |   |         |   |      |   |                                |   |                   |    |                       |   |                     |     |                |        |                     |                   |           |                   |       |
| Aquifer productivity (w = 0.1)     | x                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                    |   |       |    |         |   |        |   |         |   |         |   |      |   |                                |   |                   |    |                       |   |                     |     |                |        |                     |                   |           |                   |       |
| Highly productive                  | 10                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                                    |   |       |    |         |   |        |   |         |   |         |   |      |   |                                |   |                   |    |                       |   |                     |     |                |        |                     |                   |           |                   |       |
| Moderately productive              | 5                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                    |   |       |    |         |   |        |   |         |   |         |   |      |   |                                |   |                   |    |                       |   |                     |     |                |        |                     |                   |           |                   |       |
| Limited groundwater                | 2.5                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                    |   |       |    |         |   |        |   |         |   |         |   |      |   |                                |   |                   |    |                       |   |                     |     |                |        |                     |                   |           |                   |       |
| No groundwater                     | nodata                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                    |   |       |    |         |   |        |   |         |   |         |   |      |   |                                |   |                   |    |                       |   |                     |     |                |        |                     |                   |           |                   |       |
| Void type (w = 0.4)                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                                    |   |       |    |         |   |        |   |         |   |         |   |      |   |                                |   |                   |    |                       |   |                     |     |                |        |                     |                   |           |                   |       |
| Karst / fractures                  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                                    |   |       |    |         |   |        |   |         |   |         |   |      |   |                                |   |                   |    |                       |   |                     |     |                |        |                     |                   |           |                   |       |
| Fractures                          |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                                    |   |       |    |         |   |        |   |         |   |         |   |      |   |                                |   |                   |    |                       |   |                     |     |                |        |                     |                   |           |                   |       |
| Fractures / pores                  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                                    |   |       |    |         |   |        |   |         |   |         |   |      |   |                                |   |                   |    |                       |   |                     |     |                |        |                     |                   |           |                   |       |
| Pores                              |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                                    |   |       |    |         |   |        |   |         |   |         |   |      |   |                                |   |                   |    |                       |   |                     |     |                |        |                     |                   |           |                   |       |

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| Required data                                  | <p>Spatial information on shallow aquifer productivity and flow characteristics (void type) according to standard legend for hydrogeological maps, groundwater recharge differences for climate normal and IPCC climate scenarios. For estimation on groundwater recharge:</p> <ul style="list-style-type: none"> <li>• Distributed data on effective precipitation (monthly 30a-means)</li> <li>• Topography</li> <li>• land cover/land use</li> <li>• permafrost</li> <li>• soil texture</li> <li>• aquifer lithology</li> </ul> |
| Strength                                       | Easy to apply in any GIS                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| Weaknesses                                     | Subjective, hard to calibrate/evaluate                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| Examples of uses of tool                       | <p>Günther A, Bretthauer M P, Broda S, Clos P, Reichling J (2018): Shallow aquifer diagnostics across Europe at the overview scale. Geophysical Research Abstracts, 20, 13613.</p> <p>Höbling, C., Broda, S., Chiffard, P., Pflanz, D., Reichling, J. (2018). Assessing Groundwater vulnerability to climate change using an index based approach. GeoBonn2018 – Living Earth, abstract book.</p>                                                                                                                                  |
| Links to complement ary material and downloads | N/A                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| GSO Contacts                                   | <p>BGR</p> <p>Dorthe Pflanz (Dorthe.Pflanz@bgr.de) and Andreas Gunther (Andreas.Guenther@bgr.de)</p>                                                                                                                                                                                                                                                                                                                                                                                                                               |

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| <b>TACTIC tool factsheet</b>                  | <i>AquiMOD</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| Description of tool                           | AquiMod is a simple, lumped-catchment groundwater model. It simulates groundwater level time-series at a point by linking simple algorithms of soil drainage, unsaturated zone flow and groundwater flow. It takes time-series of rainfall and potential evapotranspiration as input, and produces a time-series of groundwater level. Hydrographs of flows through the outlets of the groundwater store are also generated, which can potentially be related to river flow measurements.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| Required data                                 | Rainfall<br><br>Potential evaporation<br><br>Groundwater level time series                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| Strength                                      | Fast simulation of groundwater level time-series.<br><br>User defined time stepping for flexibility.<br><br>Monte Carlo parameter sampling.<br><br>Modular structure with multiple process representations.<br><br>Choice of objective functions to evaluate model efficiency.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| Weaknesses                                    | Lumped (not distributed) groundwater model<br><br>Point calculation<br><br>Over all representation of catchment characteristics                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| Examples of uses of tool                      | <i>Monthly Hydrological Summary</i><br>The National Hydrological Monitoring Programme (NHMP) produces the monthly Hydrological Summary of the UK. This regular report describes the hydrological conditions during the preceding month, using the data holdings of the National River Flow Archive and National Groundwater Level Archive. <a href="https://nrfa.ceh.ac.uk/monthly-hydrological-summary-uk">https://nrfa.ceh.ac.uk/monthly-hydrological-summary-uk</a><br><i>Hydrological Outlook UK</i><br>To forecast groundwater levels the British Geological Survey uses models that simulate fluctuations in groundwater level at 25 sites across the UK. <a href="https://www.hydoutuk.net/">https://www.hydoutuk.net/</a><br><i>Historic Droughts UK</i><br>The Historic Droughts project seeks to identify the complex relationships between natural drivers and the social and economic dimensions of drought and water scarcity through the analysis of a range of historical drought episodes.<br><a href="http://historicdroughts.ceh.ac.uk/">http://historicdroughts.ceh.ac.uk/</a> |
| Links to complementary material and downloads | <a href="https://www.bgs.ac.uk/research/environmentalModelling/aquimod.html#download">https://www.bgs.ac.uk/research/environmentalModelling/aquimod.html#download</a><br>British Geological Survey<br>UK                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| GSO Contacts                                  | UKRI / British Geological Survey (BGS).<br>aquimod@bgs.ac.uk                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |

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| <b>TACTIC tool factsheet</b>                  | <i>IH low flow method (Gustard et al., 1992)</i>                                                                                                                         |
| Description of tool                           | A procedure for the calculation of two low flow measures (the flow duration and flow frequency curve) from observed data                                                 |
| Required data                                 | River flow time series.                                                                                                                                                  |
| Strength                                      | Easy to use method implemented in a spreadsheet.<br>Other procedures also included in the spreadsheet for comparison purposes.                                           |
| Weaknesses                                    | This is a model. Results are subject for interpretation.<br>Some hydrologist are sceptic about the application of this method.                                           |
| Examples of uses of tool                      | Many applications related to the calibration of surface flow models.                                                                                                     |
| Links to complementary material and downloads | <a href="http://nora.nerc.ac.uk/id/eprint/6050/1/IH_108.pdf">http://nora.nerc.ac.uk/id/eprint/6050/1/IH_108.pdf</a><br>The spreadsheet is available from BGS by request. |
| GSO Contacts                                  | UKRI / British Geological Survey (BGS).<br><br>majm@bgs.ac.uk                                                                                                            |

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| <b>TACTIC tool factsheet</b>                  | <i>Thornthwaite equation for calculation of potential evaporation (1948)</i>                                                                                                                                  |
| Description of tool                           | An empirical formula to calculate potential evaporation using temperature and the number of daylight hours                                                                                                    |
| Required data                                 | Temperature time series<br><br>Monthly adjustment factor related to hours of daylight                                                                                                                         |
| Strength                                      | Easy to use and does not require many input data.<br><br>It can be easily implemented in spreadsheet calculations                                                                                             |
| Weaknesses                                    | Does not include other factors affecting the calculation of potential evaporation such as wind speed, net radiation, soil heat index, vapour pressure, etc. and that are included in other methods.           |
| Examples of uses of tool                      | Many applications related to the calibration of surface flow models.                                                                                                                                          |
| Links to complementary material and downloads | Method very well reported in papers and text books<br><br>Thornthwaite, C. W. (1948). An approach toward a rational classification of climate. <i>Geographical Review</i> . 38 (1): 55–94. doi:10.2307/210739 |
| GSO Contacts                                  | UKRI / British Geological Survey (BGS).<br><br>majm@bgs.ac.uk                                                                                                                                                 |

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| <b>TACTIC tool factsheet</b>                  | <i>Spreadsheet of analytical methods for recharge estimation (Recharge spreadsheet)</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| Description of tool                           | <p>The spreadsheet contains a collection of analytical solutions that aims at the estimation of recharge and the simulation of groundwater flows and levels. The modelling toolbox is written in VBA and implemented in an excel spreadsheet. Methods implemented are:</p> <ul style="list-style-type: none"> <li>• Cumulated Rainfall Departure (CRD)</li> <li>• Revised CRD</li> <li>• mn CRD</li> <li>• Rainfall Infiltration Breakthrough (RIB)</li> <li>• Saturated Volume Fluctuation (SVF) adapted for individual boreholes</li> <li>• Park and Parker Groundwater model</li> <li>• Simplified Water Table Fluctuation (WTF).</li> </ul> <p>The methods in the spreadsheet estimate the groundwater recharge from rainfall and groundwater level fluctuations.</p> |
| Required data                                 | <p>Rainfall<br/>Potential evaporation<br/>Groundwater level time series<br/>Pumping rates</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| Strength                                      | <p>A collection of seven different methods that allows a comparison between the recharge values estimated using these methods.<br/>Organised approach through the implementation of the methods in a spreadsheet.<br/>Easy to use.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| Weaknesses                                    | <p>Point calculation.<br/>Spreadsheet user manual is available but not published.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Examples of uses of tool                      | <p>The spreadsheet was used on a commercial project by the British Geological Survey as part of the modelling work undertaken for the Consultancy Services for National Hydrogeological and Water Quality Mapping, Malawi.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| Links to complementary material and downloads | <p>User manual available on request from the British Geological Survey, UK.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| GSO Contacts                                  | <p>UKRI / British Geological Survey (BGS).<br/>majm@bgs.ac.uk</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |

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| <b>TACTIC tool factsheet</b>                  | <b>MARTHE</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| Description of tool                           | MARTHE is a BRGM software developed for the flow and transport modelling in three-dimensional and multilayer porous media. It is an integrated hydrological / hydrogeological model that can simulate the hydrosystem as a whole. MARTHE is designed to address underground hydrodynamic problems in various contexts: planning and management of water resources, environmental problems related to groundwater and surface water (pollution, seawater intrusion...), Civil works etc. Marthe makes it possible to take into account discontinuities such as open water bodies (lakes, gravel pits), local groundwater drying (and re-watering), including multi-layer aquifers, groundwater overflows (watercourses, sources, drains). In addition, Marthe can take into account the density effects induced by salinities and / or heterogeneous temperatures, the energy transfer, the development of vegetation, etc. MARTHE can be used for the impact studies: change in land use, water abstraction, climate change. |
| Required data                                 | <p>Climatic data (precipitation, temperature and evapotranspiration) - daily time series (or less).<br/>Parameters of soil and unsaturated zone.<br/>Geological and geophysical data needed for building a geological model (aquifers and aquitards as layers and / or lenses); DEM (Digital elevation model).<br/>Hydraulic conductivities (kx, kz) and storage coefficient for the saturated zone.<br/>Data on the volumes of water taken and injected into the aquifer and rivers for different uses.<br/>Observation data (piezometric maps, time series of groundwater level, level and flow rates of rivers, Salinity maps, logs and times series of water salinity etc.)<br/>Data on hydrographic network, including longitudinal profiles and cross-sections.</p>                                                                                                                                                                                                                                                    |
| Strength                                      | <p>MARTHE is physically based, distributed-parameter, fully integrated code for three-dimensional simulation of hydrologic systems (saturated and unsaturated continuum).<br/>Adapted to model complex aquifer systems under transient state.<br/>Capabilities for solving both simple and highly complex, integrated problems.<br/>Graphical interface (GUI) and documentation are available.<br/>Free limited version of MARTHE is available.<br/>The effects of climate change on groundwater and hydrology can be simulated.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| Weaknesses                                    | <p>Requires a dense set of input data and observations data to check the results reliability.<br/>Requires a good deal of training and a team of modellers.<br/>Calibration and validation procedure is critical.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| Examples of uses of tool                      | MARTHE is used to design and develop water resources management and prediction models in France and abroad. In France, several models of regional aquifer system were developed, during the last 20 years. Especially for the water resource management and as decision support: the north Aquitaine model for the deep Gironde aquifers management (area of 27 000 km <sup>2</sup> , 15 aquifer layers, transient simulation over 1972-2015), the Jurassic model of Poitou Charentes (area of 19600 km <sup>2</sup> , 8 layers, interaction between surface water and groundwater, transient simulation over 1999-2012). Somme model for groundwater flooding (7200 km <sup>2</sup> , transient simulation at the time of day time over 1989-2012). These models has been used for climate change assessment on groundwater and surface water. MARTHE is also used in several research projects (seawater intrusion, artificial recharge of aquifers...).                                                                   |
| Links to complementary material and downloads | <a href="http://marthe.brgm.fr">http://marthe.brgm.fr</a>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| GSO Contacts                                  | <p><a href="mailto:marthe@brgm.fr">marthe@brgm.fr</a><br/>Logiciel MARTHE<br/>BRGM, Direction D3E / GDR<br/>BP 36009<br/>45060 Orléans Cedex 2 (France)</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |

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| <b>TACTIC tool factsheet</b>                  | <i>GARDENIA</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| Description of tool                           | <p>GARDENIA is a lumped hydrological model for the simulation of relationships between series of stream or spring flow data at the outlet of a watershed, and/or groundwater level data at an observation well situated in the underlying aquifer and the rainfall received over the corresponding watershed. Withdrawals by pumping groundwater can be considered if necessary. The calibration phase of the model is done automatically by the software under control of the user.</p> <p>GARDENIA enables to set a hydrological balance for the basin: actual evapotranspiration, runoff, infiltration, recharge. The hydrological balance can be used for the evaluation of natural groundwater recharge of aquifers. GARDENIA gives the extension of river flow, groundwater level or recharge data over a long period for which precipitation and potential evaporation data are known.</p>                                          |
| Required data                                 | <p>Climate data: a continuous series of rainfall data and a continuous series of potential evapotranspiration data (PET). PET values can be calculated from sunshine duration, air temperature and relative humidity data.</p> <p>One or two series of observations: flow at the basin outlet and/or representative level in an observation well located in the basin.</p> <p>Groundwater abstraction data.</p> <p>These different series of data must at a regular time step: daily, 5 days, 10 days, or monthly.</p>                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Strength                                      | <p>Fast simulation of groundwater level time-series.</p> <p>The modelling of the relationships rainfall/flow and/or rainfall/groundwater level implies a minimum of 4 to 6 lumped parameters (soil capacity, recession times, etc...) representative for a basin or a homogeneous unit within the basin.</p> <p>This calibration of the model is done automatically by the software under control of the user.</p> <p>Choice of objective functions to evaluate model efficiency according to the different issues</p>                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Weaknesses                                    | <p>Lumped groundwater model</p> <p>Point calculation</p> <p>Over all representation of catchment characteristics</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| Examples of uses of tool                      | <ul style="list-style-type: none"> <li>- Calculation of terms of the water balance at a pre-defined time-step (varying from one day to one month); results can be helpful for water resource evaluation or as input for a discretized groundwater model.</li> <li>- Simulation of river flows or groundwater levels for exceptional climatological periods. These simulations allow the design of structures like dams for mitigation of peak floods, storage of irrigation water, building foundations, etc ...</li> <li>- Extension of series of river flow or groundwater level data over a long period using different climatological scenarios.</li> <li>- The forecasting of river flows or groundwater levels for the design of structures;</li> <li>- The study of particular phenomena like the rise of aquifer levels or the occurrence of drought and floods;</li> <li>- Studies of the influence of climate change.</li> </ul> |
| Links to complementary material and downloads | <a href="http://gardenia.brgm.fr/">http://gardenia.brgm.fr/</a>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| GSO Contacts                                  | <p>Logiciel GARDÉNIA</p> <p>BRGM</p> <p>Direction D3E / unité GDR</p> <p>BP 36009</p> <p>45060 Orléans Cedex 2 (France)</p> <p><a href="mailto:gardenia@brgm.fr">gardenia@brgm.fr</a></p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |

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| <b>TACTIC tool factsheet</b>                  | <i>EROS</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| Description of tool                           | EROS (acronym for Ensemble de Rivières Organisé en Sous bassins) is a generalised application of GARDENIA. It is used to produce models of heterogeneous catchment basins as ranked clusters of GARDENIA models, where each GARDENIA model is applied to a sub-basin. At present, EROS is not available outside the BRGM.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Required data                                 | Climate data: a continuous series of rainfall data and a continuous series of potential evapotranspiration data (PET). PET values can be calculated from sunshine duration, air temperature and relative humidity data.<br>One or two series of observations: flow at the basin outlet and/or representative level in an observation well located in the basin.<br>Groundwater abstraction data<br>These different series of data must at a regular time step: daily, 5 days, 10 days, or monthly.                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| Strength                                      | Fast simulation of groundwater level time-series.<br>The modelling of the relationships rainfall/flow and/or rainfall/groundwater level implies a minimum of 4 to 6 lumped parameters (soil capacity, recession times, etc...) representative for a basin or a homogeneous unit within the basin.<br>This calibration of the model is done automatically by the software under control of the user.<br>Choice of objective functions to evaluate model efficiency according to the different issues                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| Weaknesses                                    | Lumped groundwater model<br>Point calculation<br>Over all representation of catchment characteristics                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| Examples of uses of tool                      | <ul style="list-style-type: none"> <li>- Calculation of terms of the water balance at a pre-defined time-step (varying from one day to one month); results can be helpful for water resource evaluation or as input for a discretized groundwater model.</li> <li>- Simulation of river flows or groundwater levels for exceptional climatological periods. These simulations allow the design of structures like dams for mitigation of peak floods, storage of irrigation water, building foundations, etc ...</li> <li>- Extension of series of river flow or groundwater level data over a long period using different climatological scenarios.</li> <li>- the forecasting of river flows or groundwater levels for the design of structures;</li> <li>- the study of particular phenomena like the rise of aquifer levels or the occurrence of drought and floods;</li> <li>- Studies of the influence of climate change.</li> </ul> |
| Links to complementary material and downloads | <a href="http://gardenia.brgm.fr/">http://gardenia.brgm.fr/</a>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| GSO Contacts                                  | Logiciel GARDÉNIA<br>BRGM<br>Direction D3E / unité GDR<br>BP 36009<br>45060 Orléans Cedex 2 (France)<br><a href="mailto:gardenia@brgm.fr">gardenia@brgm.fr</a>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |

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| <b>TACTIC tool factsheet</b>                  | <i>ESTHER</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| Description of tool                           | <p>Time series analysis for ground water data (Hydraulic Head, Hydrochemistry, Flowrate, Rainfall). The tool is intended to provide a range of analysis for understanding of flow dynamics of aquifers. Computation of cross correlation, autocorrelation, drought or flood estimation and trends are possible. Those computations are based on probabilistic approaches and statistics law adjustments.</p> <p>Some 'out of the box' treatments are available: filling gap in a time series, seasonal component filtering (moving average, or first order differentiation), trends substitution, spectral analysis, wavelet analysis, classification of flow rate (base flow index), recession curves, standard piezometric index and standard precipitation index, multidimensional analysis and ascendant hierarchical classification.</p> <p>Esther is based on the 'R' software, and designed as set of functions that can be used from a main module.</p> |
| Required data                                 | <p>Piezometric level</p> <p>Hydrochemistry time series</p> <p>Flowrate</p> <p>Rainfall</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| Strength                                      | <ul style="list-style-type: none"> <li>- based on well-known statistical methods</li> <li>- highly versatile tools</li> <li>- high number of statistical tests for time series</li> <li>- suitable for various studies, even hydrochemistry</li> <li>- easy to upgrade.</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| Weaknesses                                    | <ul style="list-style-type: none"> <li>- User interface rather rough and simple</li> <li>- developed for internal use yet, and some bugs could still remains (interface mainly)</li> <li>- user interface in French language at the moment</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| Examples of uses of tool                      | <ul style="list-style-type: none"> <li>- natural disaster classification (flood)</li> <li>- drought analysis (months of occurrence)</li> <li>- thresholds determination based on various metrics (annual minimums/maximums, medians...)</li> <li>- Determination of Piezometric Survey Network for climate change impact on aquifer</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Links to complementary material and downloads | <p>User guide: <a href="http://infoterre.brgm.fr/rapports/RP-67518-FR.pdf">http://infoterre.brgm.fr/rapports/RP-67518-FR.pdf</a></p> <p>Partial functionality in the Hype tool: <a href="http://infoterre.brgm.fr/rapports/RP-63066-FR.pdf">http://infoterre.brgm.fr/rapports/RP-63066-FR.pdf</a></p> <p>Healy, Richard W., and Bridget R. Scanlon. 2010. Estimating Groundwater Recharge. <a href="http://ebooks.cambridge.org/ref/id/CBO9780511780745">http://ebooks.cambridge.org/ref/id/CBO9780511780745</a>.</p> <p>Scanlon, Bridget R., Richard W. Healy, and Peter G. Cook. 2002. "Choosing Appropriate Technique for Quantifying Groundwater Recharge." <i>Hydrogeology Journal</i> 10: 18–39.</p> <p>Seguin, Jean-Jacques et al. 2015. "BRGM/RP-65635-FR Méthodes d'Évaluation de La Recharge Des Nappes Complément d'étude Pour La Caractérisation Des Pressions et Impacts Sur Les Eaux Souterraines Rapport Final." : 219.</p>                      |
| GSO Contacts                                  | <p>BRGM</p> <p>Hélène Bessiere</p> <p><a href="mailto:h.bessiere@brgm.fr">h.bessiere@brgm.fr</a></p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |

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| <b>TACTIC tool factsheet</b>                  | <i>TEMPO</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| Description of tool                           | <p>TEMPO, an application that characterises hydrogeological functioning using transfer functions (recharge and emptying), is widely used to forecast water table levels or river flow rates from analyses of meteorological, piezometric and hydrometric time series.</p> <p>Based on a systems approach (the input, e.g. effective rainfall, is convolved by means of a transfer function to produce the output: flow rate at the catchment basin outlet). This type of model is very practical as it handles the functioning of an entire hydrosystem and thus dispenses with the need for studies of its hydrodynamic characteristics.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| Required data                                 | Meteorological (effective rainfall), piezometric and hydrometric time series.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| Strength                                      | <p>The model handles the functioning of an entire hydrosystem and thus dispenses with the need for studies of its hydrodynamic characteristics.</p> <p>Low data needs.</p> <p>Simple to handle, fast and efficient.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| Weaknesses                                    | No specialisation possible. For example, pumping volume impacts are hard to assess.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| Examples of uses of tool                      | <ul style="list-style-type: none"> <li>- For the Paris region DREAL (data from three piezometers), it is used each year in March and April to make forecasts, based on different climatic hypotheses, of seasonal trends for an intensively used chalk groundwater table (Champigny) to help anticipate abstraction management.</li> <li>- TEMPO is used for a similar purpose in Picardy, to estimate trends in water flow rates and water table levels in ten different catchment basins. In the Lez catchment basin (Hérault).</li> </ul> <p>TEMPO is used to produce more exact knowledge of water flow dynamics in a karstic environment.</p> <ul style="list-style-type: none"> <li>- Thanks to TEMPO's modular design, allowing the incorporation of additional statistical functions and input data, it is also used in fields other than hydrology. For example, with the use of two transfer functions and input data on rainfall and the speed of terrain movements, TEMPO accurately forecasted two land slips in La Réunion.</li> <li>- It also identified the origin of water from a karstic spring (rainwater vs. deep aquifer).</li> </ul> |
| Links to complementary material and downloads | <p><a href="http://www.brgm.eu/project/tempo-modelling-tool-to-support-hydrosystem-management">http://www.brgm.eu/project/tempo-modelling-tool-to-support-hydrosystem-management</a></p> <p>Seguin, Jean-Jacques et al. 2015. "BRGM/RP-65635-FR Méthodes d'Évaluation de La Recharge Des Nappes Complément d'étude Pour La Caractérisation Des Pressions et Impacts Sur Les Eaux Souterraines Rapport Final." : 219.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| GSO Contacts                                  | <a href="mailto:tempo@brgm.fr">tempo@brgm.fr</a>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |

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| <b>TACTIC tool factsheet</b>                  | <i>WTF RISE</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| Description of tool                           | <p>The computer program RORA provides estimates of groundwater recharge from the displacement he water-table fluctuation (WTF) method assumes that a water level rise in unconfined aquifers are due to recharge water arriving at the water-table multiplied by the specific yield of the aquifer.</p> <p>The simplest calculation for this method consist in summing all water-table rise and multiplying the result by the specific yield.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| Required data                                 | <p>Groundwater level time series</p> <p>Specific yield</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Strength                                      | The method is simple to apply and inexpensive if water-level records are available from existing observation wells. It should work best for wells that show a relatively rapid water-level rise in relation to the rate that water moves away from the water table.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| Weaknesses                                    | <p>Although simple in concept, the water-table fluctuation method has drawbacks in its application related to accurate estimation of specific yield and water-level rise. Other complications include water-level rises that are not associated with recharge – such as those caused by changes in atmospheric pressure, earth tides, and entrapped air.</p> <p>This simplest calculation underestimate recharge because there is no correction made from recession curves, such as in the WTF MRC method.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| Examples of uses of tool                      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| Links to complementary material and downloads | <p><a href="#">ESPERE (BRGM)</a></p> <p><a href="#">RISE (USGS)</a></p> <p><a href="http://www.brgm.eu/scientific-output/scientific-software/espere-estimating-effective-rainfall-aquifer-recharge">http://www.brgm.eu/scientific-output/scientific-software/espere-estimating-effective-rainfall-aquifer-recharge</a></p> <p><a href="https://water.usgs.gov/ogw/gwrp/methods/wtf/">https://water.usgs.gov/ogw/gwrp/methods/wtf/</a></p> <p>Delin, Geoffrey N., Richard W. Healy, David L. Lorenz, and John R. Nimmo. 2007. "Comparison of Local- to Regional-Scale Estimates of Ground-Water Recharge in Minnesota, USA." <i>Journal of Hydrology</i> 334(1–2): 231–49.</p> <p>Healy, Richard W., and Bridget R. Scanlon. 2010. Estimating Groundwater Recharge.</p> <p>Scanlon, Bridget R., Richard W. Healy, and Peter G. Cook. 2002. "Choosing Appropriate Technique for Quantifying Groundwater Recharge." <i>Hydrogeology Journal</i> 10: 18–39.</p> <p>Seguin, Jean-Jacques et al. 2015. "BRGM/RP-65635-FR Méthodes d'Évaluation de La Recharge Des Nappes Complément d'étude Pour La Caractérisation Des Pressions et Impacts Sur Les Eaux Souterraines Rapport Final." : 219.</p> |
| GSO Contacts                                  | <p>BRGM</p> <p>Hélène Bessiere</p> <p><a href="mailto:h.bessiere@brgm.fr">h.bessiere@brgm.fr</a></p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |

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| <b>TACTIC tool factsheet</b> | <i>iMOD (applied to NHI and NHI-fresh-salt)</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| Description of tool          | <p>The Dutch Hydrological Instrument (NHI) is the national integrated subsurface and surface water model of the Netherlands. Within NHI, the open source software iMOD is used. This software is based on the USGS MODFLOW-source, and adapted (iMODFLOW), to apply for (extreme) large modelling areas. Within iMOD, coupled modules for the unsaturated zone (MetaSWAP) and the regional and national surface water system (MOZART, RIBASIM) can be used, if desired.</p> <p>NHI calculates the regional groundwater flow pattern of the Netherlands for the current as well as for climate scenarios. With the instrument, for example groundwater levels, hydraulic head heights in deeper water-bearing packages, seepage and discharge fluxes and the exchange between ground and surface water can be calculated.</p> <p>With the coupled models, characteristics of the unsaturated zone can also be calculated (e.g. moisture content in the soil to simulate effects on agriculture and terrestrial nature). In combination with surface water modules, the distribution of surface water can be calculated to simulate the effect of water demand and water supply at a national and regional level.</p> <p>In addition to the water balance, the chloride balance is also calculated in the ground and surface water. Within NHI-fresh-salt, variable-density groundwater flow and coupled salt transport will be simulated, using 3D salinity distributions retrieved from the interpolation of different data types (VES, samples, borelogs) as well as Airborne EM surveys.</p>                                                                                                                                                                       |
| Required data                | <p>Geohydrological properties of the different subsoil layers (transmissivities, conductances, tops, bottoms) are required for the basis simulation of groundwater flow, as well as other input data like withdrawals and salinities. Besides information on boundary conditions (heads, fluxes, salinity concentration or combinations) are needed. A meteorological boundary (recharge) is needed, or can be derived by the coupled model for the unsaturated zone (MetaSWAP) or less complicated models for the vadose zone.</p> <p>Data on soil type, land use types, crop types and irrigation are required for the simulation of the unsaturated zone. In the modelling databases more detailed information of soils and crops is available for extended calculations of the unsaturated zone (e.g. retention curves, crop developing stages and characteristics of root development). The upper boundary condition is given by meteorological input data on a daily basis, or a smaller timestep if desired (precipitation and reference evaporation (Penman Monteith or Makkink).</p> <p>River stages and salinities (retrieved from surface water models) and stage-discharge relations are required for the river system and regional water system, respectively. Most of the required data can be given as a full-coverage grid, while other data (e.g. river flows) is required as point-data.</p> <p>If the modules for surface water are used, river discharges, distribution characteristics of the water supply network, salinities and volume/area/discharge relations are needed.</p> <p>All modelling data for the Netherlands is freely available and can be downloaded from the dataportal NHI, <a href="http://www.nhi.nu">www.nhi.nu</a>.</p> |
| Strength                     | <p>The iMOD software is very well equipped to cope with large models (enormous datasets, high resolution, high performance). If required, parallel calculations can be used to speed up the calculations even more.</p> <p>The software is free to download, open-source software (<a href="https://oss.deltares.nl/web/imod/home">https://oss.deltares.nl/web/imod/home</a>) and applicable to other regions in the world, including a user-friendly interface.</p> <p>Within the software, options can be used for a sophisticated coupling with the unsaturated zone (using share state variables, Van Walsum and Veldhuizen (2011) and the surface waters for integrated climate assessments of the whole water system.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| Weaknesses                   | <p>The options for the unsaturated zone and surface water requires a lot of data. For the Netherlands, this is not a problem since this data is all available for the whole country. But if the model will be transferred to other areas , not all required data might be available.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| Examples of uses of tool     | <p>NHI is used as operational tool for surface water management in periods with drought, like the year 2018. NHI can also be used to investigate the effect of certain measures or specific climate</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |

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|                                               | <p>circumstances. For example, an analysis has been done with NHI on the long-term effects of the very dry summer of 2018 on the groundwater levels.</p> <p>NHI-fresh-salt can be used to analyse effects of scenarios on chloride concentrations, saline seepage and volumes of fresh groundwater in the subsoil (viz. water that is used as a national strategic resources).</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| Links to complementary material and downloads | <p>Scientific article about the NHI:<br/> <a href="http://www.nhi.nu/nl/files/1014/2662/4400/publicatie_NHI_Environmental_Modelling_and_Software_2014.pdf">http://www.nhi.nu/nl/files/1014/2662/4400/publicatie_NHI_Environmental_Modelling_and_Software_2014.pdf</a></p> <p>Website NHI (currently only in Dutch):<br/> <a href="http://www.nhi.nu/nl/">http://www.nhi.nu/nl/</a></p> <p>Website iMOD:<br/> <a href="https://oss.deltares.nl/web/imod">https://oss.deltares.nl/web/imod</a></p> <p>Article:<br/> De Lange, W.J., Prinsen, G.F., Hoogewoud, J.C., Veldhuizen, A., Verkaik, J., Oude Essink, G.H.P., van Walsum, P.E.V., Delsman, J.R., Hunink, J.C., Massop, H.T.L., Kroon, T., 2014, An operational, multi-scale, multi-model system for consensus-based, integrated water management and policy analysis: The Netherlands Hydrological Instrument. Environmental Modelling &amp; Software 59, 98-108, doi: 10.1016/j.envsoft.2014.05.009</p> |
| GSO Contacts                                  | <p>Willem Jan Zaadnoordijk, TNO, <a href="mailto:willem_jan.zaadnoordijk@tno.nl">willem_jan.zaadnoordijk@tno.nl</a></p> <p>Timo Kroon, Deltares, <a href="mailto:timo.kroon@deltares.nl">timo.kroon@deltares.nl</a></p> <p>Gualbert Oude Essink, <a href="mailto:gualbert.oudeessink@deltares.nl">gualbert.oudeessink@deltares.nl</a></p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |

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| <b>TACTIC tool factsheet</b>                  | <i>ASPA</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| Description of tool                           | <p>ASPA (automatic prediction and analysis system) is a time series analysis tool. It is running on the probabilistic-statistical forecasting approaches. It involves correlation procedure – in order to estimate hydrometeorological factors influence value, extrapolation of harmonious components and autocorrelation (realized using regression equations).</p> <p>The forecasting task comprises two sequential steps:</p> <ul style="list-style-type: none"> <li>- Main elements of groundwater level fluctuations forecasting (spring maximum level, summer-autumn minimum level, average annual level and pre-spring level);</li> <li>- Preparation of validation forecast.</li> </ul> <p>Groundwater level fluctuations evaluated factors – precipitation, temperature, relative air humidity.</p> <p>The algorithm for average annual values, variance and standard deviation values calculation are totally common as for statistics.</p> <p>The result of ASPA application is a groundwater levels distribution predictive map. Groundwater levels are mapped in the form of relative position ratios, which show the amount of average long-term value deviations in percent of long-term oscillation amplitude:</p> $\lambda H_p = (H_{\min} - H_p) / (H_{\min} - H_{\max}),$ <p>where <math>\lambda H_p</math>- the coefficient of relative position of predicted level,<br/> <math>H_p</math> – depth to groundwater level on the basis of the prediction,<br/> <math>H_{\min}</math>, <math>H_{\max}</math> – depth to minimum and maximum groundwater level, respectively, during the observation period.</p> |
| Required data                                 | Time series of groundwater levels, temperature indicators, precipitation values                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| Strength                                      | Forecasts with ASPA are reliable for short-term and seasonal fluctuations evaluation. Tool is based on common and spread statistical principles.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Weaknesses                                    | The success of tool application depends on input data, that requires a certain level of the observation network density.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| Examples of uses of tool                      | Tool is used for national annual groundwater level predictions and is introduced in the report form, it is provided for hydrometeorological, water management, agricultural and geological organizations, various ministries and departments dealing with water-ecological and environmental issues, use.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| Links to complementary material and downloads | <a href="http://geoinf.kiev.ua/wp/wp-content/uploads/2018/05/prognoz_2018.pdf">http://geoinf.kiev.ua/wp/wp-content/uploads/2018/05/prognoz_2018.pdf</a>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| GSO Contacts                                  | <a href="mailto:gidrogeo@geomail.kiev.ua">gidrogeo@geomail.kiev.ua</a> ,<br>boyko_ekateruna@ukr.net                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |

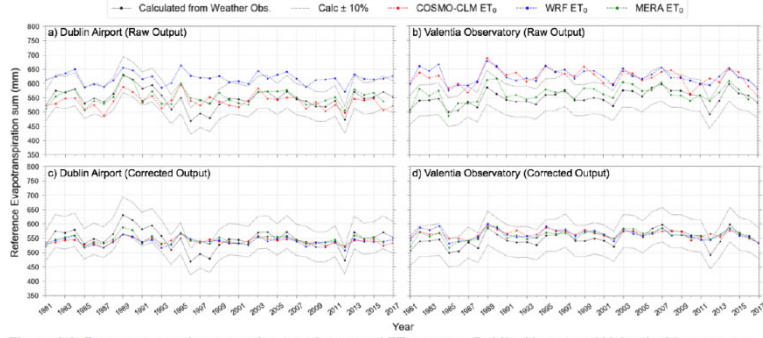
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| <b>TACTIC tool factsheet</b>                  | <b>MIKE SHE</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| Description of tool                           | MIKE SHE is an integrated hydrological modelling system for building and simulating groundwater and surface water flow. MIKE SHE can simulate the entire land phase of the hydrological cycle and allows components to be used independently and customized to local needs. MIKE SHE can be used for the analysis, planning and management of a wide range of water resources and environmental problems related to groundwater and surface water, especially surface water impact from groundwater abstraction, conjunctive use of groundwater and surface water, wetland management and restoration, river basin management and planning, impact studies for changes in land use and climate. MIKE SHE is part of the MIKE ZERO common user interface that contains several software products that can be used in water related issues, such as MIKE FLOOD, MIKE HYDRO River, MIKE URBAN MOUSE and MIKE 21. |
| Required data                                 | The MIKE SHE system is a fully distributed model developed primarily for transient modelling, and thus need system data to be fully distributed over the entire catchment (e.g. topography, soil properties for UZ and SZ, land use and vegetation, drainage, paved areas etc.), and time series for temporally varying input data (e.g. precipitation, temperature and evapotranspiration, abstraction and irrigation). As an integrated SW-GW model, it also needs descriptions of the surface water system such as river networks and point source discharge to rivers. Finally, the model requires observation data for, as a minimum, groundwater heads and river discharge for calibration and validation.                                                                                                                                                                                              |
| Strength                                      | MIKE SHE is a powerful, physically based, distributed-parameter, fully integrated code for three-dimensional simulation of hydrologic systems. It has been successfully applied at multiple scales, using spatially distributed, continuous climate data to simulate a broad range of integrated hydrologic, hydraulic, and transport problems in humid as well as semi-arid and arid areas. Capabilities for solving both simple and highly complex, integrated problems. GUI, application, output/plotting, documentation and speed are very good. Climate change effects on groundwater and hydrology can be simulated.                                                                                                                                                                                                                                                                                    |
| Weaknesses                                    | MIKE SHE requires a good deal of training and a team of modellers. A full version of MIKE SHE is expensive (property code). MIKE SHE requires a dense set of input data, model structure and parameter data and observation data. Sound model setup, calibration and validation procedures & inverse modelling is critical.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| Examples of uses of tool                      | GEUS has used MIKE SHE for National Water Resource Model ( <a href="http://www.vandmodel.dk">www.vandmodel.dk</a> ) for water resource analysis (evaluation of sustainable groundwater abstraction, quantitative status of groundwater bodies in relation to RBMP/WFD, nitrate loads and N-reduction in subsurface) since 2003.<br>The model has been used for climate change impact assessment on hydrology (extreme value analysis) and groundwater (DK portal: <a href="http://www.klimatilpasning.dk">www.klimatilpasning.dk</a> ).<br>Used by GEUS in a number of research projects. Transition into national flood risk model has been investigated, combining the model with external modules for downscaling of phreatic depth, 1D steady state river level simulation and flooding from rivers to terrain.                                                                                           |
| Links to complementary material and downloads | <a href="https://www.mikepoweredbydhi.com/download/mike-2016">https://www.mikepoweredbydhi.com/download/mike-2016</a><br>MIKE Powered by DHI Client Care<br>DHI, Agern Allé 5, Hørsholm 2970, Denmark<br>+45 45169333<br><a href="mailto:mike@dhigroup.com">mike@dhigroup.com</a>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| GSO contact                                   | Simon Stisen, <a href="mailto:sst@geus.dk">sst@geus.dk</a><br>Anker Lajer Højberg, <a href="mailto:alh@geus.dk">alh@geus.dk</a>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |

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| <b>TACTIC tool factsheet</b>                  | <i>MIKE HYDRO River</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| Description of tool                           | <p>Can be setup with MIKE SHE or as a standalone river runoff and hydrodynamic model. The MIKE HYDRO River rainfall-runoff module includes a variety of catchment runoff models. The most commonly applied models comprise:</p> <ul style="list-style-type: none"> <li>○ NAM, a lumped and conceptual catchment runoff model with continuous accounting of moisture content in sub-surface zones</li> <li>○ UHM, the standard unit hydrograph method for single storm events</li> <li>○ Urban models tailored to runoff calculations in urban environments</li> </ul> <p>Common applications of catchment runoff modelling with MIKE HYDRO River include:</p> <ul style="list-style-type: none"> <li>○ Inflow forecasting to rivers and reservoirs</li> <li>○ Runoff impact assessments for land use changes</li> <li>○ Climate change scenario analysis</li> <li>○ Long-term water resources analysis and planning</li> <li>○ Groundwater using linear reservoir groundwater calculations for basin-wide water balance and river inflow calculations</li> </ul> <p>The HD – hydrodynamic model is a powerful, flexible, robust, parallelised 1D hydrodynamic engine for rivers and open channels (successor of the world-known MIKE 11 river modelling system). Key features include:</p> <ul style="list-style-type: none"> <li>○ Fully dynamic solution to the 1D St. Venant equations</li> <li>○ Hydraulic routing options for simplified channel routing</li> <li>○ Automatic adaptation to subcritical and supercritical flow</li> <li>○ Comprehensive hydraulic structures library</li> <li>○ Extremely flexible control module for operational gates, pumps and turbines</li> </ul> <p>Hydrology features include (eventually coupled to MIKE SHE):</p> <ul style="list-style-type: none"> <li>○ Overland flow using a simplified, semi-distributed method or a 2D diffusive wave method. This enables simplified 1D/2D flood modelling with MIKE HYDRO River</li> <li>○ Unsaturated infiltration using a two-layer water balance method for infiltration losses</li> <li>○ Evapotranspiration from intercepted storage, ponded water, the root zone and groundwater</li> </ul> |
| Required data                                 | Digital Elevation Model (DEM), alignment lines, river network and catchment delineation, cross sections, chainage points, water level and discharge observations, structures (weirs, culverts, bridges, pump, gates etc.). Bed resistance. Initial conditions.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| Strength                                      | <ul style="list-style-type: none"> <li>○ Continuous and fast runoff models for effective forecast modelling</li> <li>○ Coupled runoff and hydrodynamic simulations</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| Weaknesses                                    | <ul style="list-style-type: none"> <li>○ Computational demanding for large setups</li> <li>○ Require detailed data (water levels, bed resistance)</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| Examples of uses of tool                      | <p>Stisen S, Schneider JM, Ondracek M og Henriksen HJ. 2018. Modellering af terrænnært grundvand, vandstand i vandløb og vand på terræn for Storå og Odense Å. Slutrapport (FODS 6.1 Fasttrack metodeudvikling). GEUS rapport 2018/36: <a href="https://sdfe.dk/media/2919109/36-2018-geus_endelig-rapport.pdf">https://sdfe.dk/media/2919109/36-2018-geus_endelig-rapport.pdf</a></p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Links to complementary material and downloads | <p>National Water Resource Model homepage: <a href="http://dk.vandmodel.dk/in-english/">http://dk.vandmodel.dk/in-english/</a></p> <p>Henriksen HJ, Roberts MJ, van der Keur P, Harjanne A, Egilson D and Leonardo A. 2018. Participatory early warning and monitoring systems: A Nordic framework for web-based flood risk management. IJDRR 31: 1295-1306: <a href="https://www.sciencedirect.com/science/article/pii/S2212420917301553">https://www.sciencedirect.com/science/article/pii/S2212420917301553</a></p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| GSO Contacts                                  | <p>Simon Stisen, <a href="mailto:sst@geus.dk">sst@geus.dk</a></p> <p>Anker Lajer Højberg, <a href="mailto:alh@geus.dk">alh@geus.dk</a></p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |

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| <b>TACTIC tool factsheet</b>                  | <i>EVA</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| Description of tool                           | <p>Extreme Value analysis software package developed by DHI:</p> <ul style="list-style-type: none"> <li>• Extract extreme value series (AMS, PDS, seasonal analysis)</li> <li>• Define extreme value series</li> <li>• Probability distribution and estimation method (AMS, PDS)</li> <li>• Independence and homogeneity tests</li> <li>• Goodness of fit statistics</li> <li>• Evaluation return periods</li> <li>• Analysis of MIKE dsf2 files (e.g. groundwater level return periods based on gridded timeseries)</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Required data                                 | <p>Observed or simulated time series of water level or flow at gauging stations.</p> <p>Simulated grid based time series from groundwater models (potentiometric or groundwater depth time series).</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| Strength                                      | <ul style="list-style-type: none"> <li>• Flexible choice of annual maximum series (AMS) or partial duration series (PDS e.g. Peaks over Threshold).</li> <li>• Options for many different AMS distributions: Generalised extreme value, Gumbel, Weibul, Frechet, Generalised Pareto, Gamma/Person 3, Log-Person 3, Log-normal and Square root exponential or PDF distributions: Weibul, Generalised Pareto, Gamma/Person 3, Log-Person 3, Log-normal, Exponential and Truncated Gumbel.</li> <li>• Different Estimation methods: Methods of Moments, Maximum Likelihood or Method of L-moments.</li> <li>• Independence and homogeneity tests: Run Test, Mann-Kendall test for trend and Mann-Whitney test for shift in mean. Goodness of fit statistics: Chi-squared, Kolmogorov-Smirnov, SLCS, PPCC1-2, Log-likelihood. Uncertainty calculation: Monte Carlo and/or Jackknife.</li> <li>• EVA also allows for extreme value analysis of time series in a DFS2 file.</li> </ul> |
| Weaknesses                                    | <ul style="list-style-type: none"> <li>• MIKE SHE toolbox (require MIKE SHE license)</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Examples of uses of tool                      | <p>Henriksen HJ, Pang B, Olsen M, Sonnenborg T, Refsgaard JC and Madsen H. 2014. Klimaeffekter på ekstremværdi afstrømninger. GEUS rapport 2014/38 (in Danish): <a href="https://www.klimatilpasning.dk/media/877909/Final_report_GEUS_2014_38.pdf">https://www.klimatilpasning.dk/media/877909/Final_report_GEUS_2014_38.pdf</a></p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| Links to complementary material and downloads | <p>Scientific Doc: <a href="http://manuals.mikepoweredbydhi.help/2017/General/EVA_SciDoc.pdf">http://manuals.mikepoweredbydhi.help/2017/General/EVA_SciDoc.pdf</a></p> <p>User Guide: <a href="http://manuals.mikepoweredbydhi.help/2017/General/EVA_UserGuide.pdf">http://manuals.mikepoweredbydhi.help/2017/General/EVA_UserGuide.pdf</a></p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| GSO Contacts                                  | Hans Jørgen Henriksen (hjh@geus.dk)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |

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| <b>TACTIC tool factsheet</b>                  | <i>Irish GW recharge model</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| Description of tool                           | <p><b>National groundwater recharge map (applied in Ireland)</b></p> <p>The groundwater recharge map is derived from hydrogeological and meteorological spatial datasets available in Ireland, which are combined in a GIS.</p> <p>The main hydrogeological controls on groundwater recharge include the permeability and thickness of superficial deposits (mainly tills in Ireland), the presence of saturated soils, and the ability of the underlying aquifer to accept percolating waters. Combinations of these factors are assessed, and a 'recharge coefficient' is established for different hydrogeological scenarios.</p> <p>To produce the groundwater recharge map, the GIS layer containing the recharge coefficients is multiplied by the effective rainfall (rainfall – actual evapotranspiration). The recharge map is finally modified to take into account areas where the natural recharge capacity of the underlying aquifer is less than the estimated potential groundwater recharge.</p> <p>There are a number of assumptions made in creating the groundwater recharge map (notably, only direct (diffuse) recharge is taken into account) and there are limitations of precision associated with the input datasets. For reasons of scale and generalization to a national coverage, the map is useful for giving regional estimates of recharge but these, in many cases, will need to be refined by site-specific studies.</p> <p><u>References:</u><br/> Hunter Williams, N.H., Misstear, B.D.R., Daly, D. and Lee, M. (2013) Development of a national groundwater recharge map for the Republic of Ireland <i>Quarterly Journal of Engineering Geology and Hydrogeology</i>, Vol. <b>46</b>, 2013, pp. 493–506</p> |
| Required data                                 | <ul style="list-style-type: none"> <li>• Rainfall and actual evapotranspiration (average annual, but can use daily, monthly)</li> <li>• Soil drainage ('well drained', 'poorly drained')</li> <li>• Subsoil type ('glacial till', 'sand/gravel', 'peat')</li> <li>• Subsoil permeability ('high', 'medium', 'low')</li> <li>• Subsoil thickness (embedded within the Irish groundwater vulnerability map, has &lt;1m, 1-3m, 3-5m, 5-10m and &gt;10 m categories)</li> <li>• Aquifer category</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| Strength                                      | <ul style="list-style-type: none"> <li>• The tool is very simple to use and generate within a GIS, and it should be possible to adapt it to use datasets available in different regions/countries.</li> <li>• Derived at 1:40,000, based on input data scale</li> <li>• Could use to model simple future climate change scenarios using different input meteorological data</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| Weaknesses                                    | <ul style="list-style-type: none"> <li>• Only simulates diffuse (direct) recharge. Doesn't account for point (indirect) recharge.</li> <li>• Doesn't include slope</li> <li>• Recharge coefficients based on limited data. National map uses mid-point of recharge coefficient range. Specific studies would need to modify. Subjective choice of value within the range.</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| Examples of uses of tool                      | Hunter Williams, N.H., Misstear, B.D.R., Daly, D. and Lee, M. (2013) Development of a national groundwater recharge map for the Republic of Ireland <i>Quarterly Journal of Engineering Geology and Hydrogeology</i> , Vol. <b>46</b> , 2013, pp. 493–506                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| Links to complementary material and downloads | <a href="https://www.gsi.ie/en-ie/data-and-maps/Pages/Groundwater.aspx#Recharge">https://www.gsi.ie/en-ie/data-and-maps/Pages/Groundwater.aspx#Recharge</a><br>(interactive webmapping – national Irish recharge map)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| GSO Contacts                                  | <a href="mailto:Taly.hunterwilliams@gsi.ie">Taly.hunterwilliams@gsi.ie</a>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |

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| <b>TACTIC tool factsheet</b> | <b>High-Resolution Gridded Datasets of Hydro-Climate Indices for Ireland</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| <b>Description of tool</b>   | <p>The ‘definitive’ gridded datasets of hydro-climate variables including reference and actual evapotranspiration, along with soil moisture deficits and the Standardized Precipitation Index (SPI) for Ireland for the period 1981-2016, over daily, monthly, seasonal and yearly time steps.</p> <p>The production of these datasets has been achieved by comparing the output of three downscaled ERAInterim climate simulations:</p> <ul style="list-style-type: none"> <li>• ICHEC WRF with 2-km grid spacing</li> <li>• ICHEC COSMO-CLM5 with 1.5-km grid spacings</li> <li>• Met Éireann Re-Analysis (MÉRA) with 2.5-km grid spacings</li> </ul> <p>These outputs have been compared with measurements recorded at synoptic stations across Ireland in order to quantify the uncertainties of individual climate fields. A comprehensive statistical analysis has been undertaken in order to validate the datasets and assign error estimates to the climate fields. The climate data, together with the uncertainty estimates, have been made publicly available so that researchers, policy makers, Irish industry and the general public can utilise the datasets.</p> <div> </div> <p><b>References:</b><br/> Werner, C., Nolan, P. and Naughton, O. (2018) High-Resolution Gridded Datasets of Hydro-Climate Indices for Ireland. EPA report 2016-W-DS-29.</p> |
| <b>Required data</b>         | <ul style="list-style-type: none"> <li>• ERAInterim (ECMWF and NCEP) (to produce RCMs)</li> <li>• ICHEC WRF with 2-km grid spacing</li> <li>• ICHEC COSMO-CLM5 with 1.5-km grid spacings</li> <li>• Met Éireann re-analysis (MÉRA) with 2.5-km grid spacings</li> <li>• Soil drainage map</li> <li>• Hybrid Soil Moisture Deficit Model (HSMD) (Schulte <i>et al.</i>, 2006)</li> </ul> <p>See also list of outputs from each model (appendix)</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |

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| Strengths                                     | <ul style="list-style-type: none"> <li>BIAS correction methods investigated and best applied (LSE)</li> </ul>  <p>Figure 3.2. Raw output and corrected output for annual <math>ET_0</math> sums at Dublin Airport and Valentia Observatory.</p> <ul style="list-style-type: none"> <li>High resolution (spatial, temporal) rainfall, <math>ET_0</math>, AE models for Ireland</li> <li>MÉRA best performer for <math>ET_0</math> simulation</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Weaknesses                                    | <ul style="list-style-type: none"> <li>Data output only for Ireland</li> <li>Massively computationally expensive to run the initial models</li> <li>Some soil classes missing (peat) currently</li> <li>Hindcast <math>ET_0</math>/AE/SMD only currently. Planned predictions on ensembles.</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| Examples of uses of tool                      | <p>Werner, C., Nolan, P. and Naughton, O. (2018) High-Resolution Gridded Datasets of Hydro-Climate Indices for Ireland. EPA report 2016-W-DS-29.</p> <p>The data will be used to update and expand the current Irish national recharge map</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| Links to complementary material and downloads | <p>All datasets are available for download are available through ICHEC's ERDDAP server, which can be found at <a href="https://erddap.ichec.ie/erddap/files/EPA_Hydroclimate">https://erddap.ichec.ie/erddap/files/EPA_Hydroclimate</a></p> <p>Complementary studies and datasets:</p> <ul style="list-style-type: none"> <li>High-Resolution Climate Projections for Ireland – a Multi-Model Ensemble Approach (Paul Nolan, ICHEC). Simulated climate change in Ireland at high spatial resolution using Regional Climate Models (RCMs). The periods 1975-2005 and 2020-2100 are simulated. <a href="mailto:paul.nolan@ichec.ie">paul.nolan@ichec.ie</a></li> <li>ICARUS Climate Research Centre, Maynooth University. <a href="https://www.maynoothuniversity.ie/icarus">https://www.maynoothuniversity.ie/icarus</a>. Data include climate simulations, long-term reconstructed rainfall dataset for Ireland (1700's-present) <a href="https://www.clim-past.net/14/413/2018/">https://www.clim-past.net/14/413/2018/</a>.</li> <li>Hybrid Soil Moisture Deficit Model (HSMD) (Schulte <i>et al.</i>, 2006)</li> </ul> |
| GSO Contacts                                  | <p><a href="mailto:Taly.hunterwilliams@gsi.ie">Taly.hunterwilliams@gsi.ie</a> (only for initial questions)</p> <p>Authors: Paul Nolan and Chris Werner, ICHEC (<a href="mailto:paul.nolan@ichec">paul.nolan@ichec</a>, <a href="mailto:christopher.werner@ichec">christopher.werner@ichec</a>), Owen Naughton, CIT (<a href="mailto:Owen.Naughton@itcarlow.ie">Owen.Naughton@itcarlow.ie</a>). Contributor: Keith Lambkin, Met Éireann (<a href="mailto:keith.lambkin@met.ie">keith.lambkin@met.ie</a>)</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |

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| <b>TACTIC tool factsheet</b> | <i>Irish GW flood mapping</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| Description of tool          | <p><b>National groundwater flood map (applied in Ireland)</b></p> <p>Identifying and mapping areas vulnerable to flooding is a key step in the management of flood risks. However, the nature of groundwater flooding on the lowland karst limestone plains of Ireland poses significant technical challenges in this respect. These areas are susceptible to groundwater flooding due to the combination of low soil and aquifer storage, high diffusivity and limited surface drainage. Unprecedented flooding in winter 2015/2016 reinforced the need for a greater understanding of groundwater flooding as a geohazard and improvement of our ability to quantify the location and likelihood of flood occurrence.</p> <p>Geological Survey Ireland, in collaboration with Trinity College Dublin and the Institute of Technology Carlow, have developed a novel approach to produce historic and predictive groundwater flood maps for Ireland in line with the 2nd implementation cycle of the EU Floods Directive.</p> <p>A methodology for delineating flood extents and water elevations from multi-temporal Synthetic Aperture Radar (SAR) imagery was developed to provide flood data from the 2015/2016 extreme flood event at gauged and ungauged sites. Maximum flood extents derived from SAR imagery from this event were combined with limited field observations to produce historic groundwater flood maps.</p> <p>Hydrological models capable of reproducing groundwater flooding time series from antecedent rainfall and soil moisture conditions were developed. Models for viable groundwater flooding locations were calibrated on a combination of observed and SAR hydrographs. Using long-term observational and stochastic meteorological series as input, the models have been used to construct long-term hydrological series suitable for extreme value analysis and the generation of predictive groundwater flood extents and maps.</p> <p><u>References:</u></p> <p>Naughton, O., McCormack, T., Bradford, R., McAteer, J., (2018) Monitoring Groundwater Flooding In Ireland Using Sentinel-1 SAR (2018), in NEREUS/ ESA/EC “The Ever Growing use of Copernicus across Europe’s Regions”, p174-175.</p> <p>Ted McCormack, Owen Naughton, Rebecca Bradford, James McAteer, Patrick Morrissey, Laurence Gill (2018) Improving our understanding of Turlough/Groundwater flooding. National Flood Management Conference, 15<sup>th</sup> March 2018</p> <p>Owen Naughton, Ted McCormack, Rebecca Bradford, James McAteer (2018) Groundwater Flood Mapping in Ireland using Multi-temporal Synthetic Aperture Radar Imagery. Remote Sensing &amp; Hydrology Symposium ICRS-IAHS. Cordoba, Spain. 8th – 10th May 2018</p> <p>Owen Naughton, Ted McCormack, Rebecca Bradford, James McAteer (2018) Developing Historic and Predictive Groundwater Flood Maps for Ireland. Irish National Hydrology Conference, Mullingar, Co. Westmeath, 20th November 2018</p> <p>Ted McCormack, Owen Naughton, Rebecca Bradford, James McAteer (2018) Developing a National Groundwater Flood Map using Sentinel-1 Imagery. Irish Earth Observation Symposium 2018, 6th December 2018</p> |
| Required data                | <ul style="list-style-type: none"> <li>• Sentinel-1 Earth Observation imagery (Copernicus Programme)</li> <li>• Rainfall and evapotranspiration</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |

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|                                               | <ul style="list-style-type: none"> <li>• Water level data from recurrent groundwater flooding sites (for calibration of earth observation &amp; hydraulic models)</li> <li>• High Resolution digital topography mapping (preferably Lidar)</li> </ul>                                                                                                                                                                                                 |
| Strength                                      | <ul style="list-style-type: none"> <li>• Generates hydrometric data for ungauged sites</li> <li>• Enables predictive mapping of groundwater flooding in Ireland</li> <li>• Earth Observation (EO) imagery is freely available from Copernicus Programme</li> <li>• Combining EO data with topographic mapping allows for topographic correction (i.e. mapping floods beneath heavy vegetation that interferes with the Sentinel-1 imagery)</li> </ul> |
| Weaknesses                                    | <ul style="list-style-type: none"> <li>• Methodology for topographic correction requires a flat flood surface. As such it will not be reliable on river flooding.</li> <li>• Flood delineation pixel resolution limited to 10m (limitation of Sentinel-1 imagery)</li> <li>• Some sites cannot have predictive mapping applied as hydraulic models do not calibrate (due to the inherent complexity of karst groundwater systems)</li> </ul>          |
| Examples of uses of tool                      | The data will be used to enhance the current Irish national groundwater flooding map                                                                                                                                                                                                                                                                                                                                                                  |
| Links to complementary material and downloads | <a href="https://www.gsi.ie/en-ie/programmes-and-projects/groundwater/projects/gwflood/Pages/default.aspx">https://www.gsi.ie/en-ie/programmes-and-projects/groundwater/projects/gwflood/Pages/default.aspx</a><br>(project webpage)                                                                                                                                                                                                                  |
| GSO Contacts                                  | <a href="mailto:Taly.hunterwilliams@gsi.ie">Taly.hunterwilliams@gsi.ie</a><br><br>Authors/technical contacts: Ted McCormack ( <a href="mailto:ted.mccormack@gsi.ie">ted.mccormack@gsi.ie</a> ); Owen Naughton ( <a href="mailto:owen.naughton@gsi.ie">owen.naughton@gsi.ie</a> ; <a href="mailto:owen.naughton@itcarlow.ie">owen.naughton@itcarlow.ie</a> )                                                                                           |

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| <b>TACTIC tool factsheet</b>                  | <i>Aquatoool</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| Description of tool                           | AQUATOOL is a Decision Support Systems (DSS) for the analyses of conjunctive use water resources planning and management problems at basin scale. It includes rainfall-runoff models to assess natural resources, modules to generate multiple synthetic hydrological series preserving the main statistics of the series and management optimization and simulation models at basin scale, including quantity and quality aspects. The results are summarised in terms of different variables (evolution of hydraulic head, storage in the reservoirs, flows in rivers, etc.) and indices (demand reliability, resilience, etc), which can be represented in Tables and Figures by using the graphical interface. Other DSS tools with similarities with AQUATOOL (UPV) are: WEAP (SEI-Boston); MODSIM (CSU); HEC-ResSim (HEC-USACE); MIKE-BASIN (DHI). The main singularity with respect to the other DSS is that it allows to simulate groundwater flow and stream-aquifer interaction with different approaches: Distributed numerical approaches by using eigenvalue techniques, analytical and conceptual solutions. It includes a component that helps to define distributed eigenvalue solutions equivalents to previously calibrated Finite Difference or Finite Element models. |
| Required data                                 | Historical series to calibrate rainfall-runoff models, historical inflows and demands in the system, calibration of stream-aquifer interaction models (distributed numerical approaches by using eigenvalue techniques, analytical or conceptual solutions). Quality data in the system.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Strength                                      | Flexible, Sturdiness, interactive and user friendly. Well-tested. It allows to assess in an integrated way conjunctive use operation rules (including surface and groundwater systems). It is a “shared vision” tool that help in the decision making process.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| Weaknesses                                    | You lose the flexibility that you have for research purposes when you directly develop your own codes. You cannot test options not included within the code.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| Examples of uses of tool                      | <p>The tool has been extensively applied to analyse water resources planning and management at basin scale in Spain (Júcar, Segura, Tajo) and foreign basins (in Argentina, Brazil, Italy, Mexico, Bosnia, Chile, Morocco, Algeria, Ecuador, Peru, etc.). It is a general tool that can be applied to any basin. Within the framework of TACTIC, it could be useful to assess impacts of climate change on water resources systems at basin scale, and to assess the propagation of climatic drought to operational droughts (scarcity). Examples of AQUATOOL application can be found in the next papers:</p> <p>Escriva-Bou, A., Pulido-Velazquez, M. and Pulido-Velazquez, D, 2017. The Economic Value of Adaptive Strategies to Global Change for Water Management in Spain’s Jucar Basin. Journal of Water Resources Planning and Management: 143, Number: 5, (May 2017) DOI: 10.1061/(ASCE)WR.1943-5452.0000735.</p> <p>Pulido-Velazquez, D., Garrote, L., Andreu, J., Martin-Carrasco, FJ, Iglesias, A. 2011a. A methodology to diagnose the effect of climate change and to identify adaptive strategies to reduce its impacts in conjunctive-use systems at basin scale. Journal of Hydrology 405: 110–122 doi:10.1016/j.jhydrol.2011.05.014.</p>                                |
| Links to complementary material and downloads | <a href="https://aquatool.webs.upv.es/aqt/en/aquatool-2/">https://aquatool.webs.upv.es/aqt/en/aquatool-2/</a>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| GSO contact                                   | David Pulido Velázquez, <a href="mailto:d.pulido@igme.es">d.pulido@igme.es</a>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |

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| <b>TACTIC tool factsheet</b>                  | <i>Renata</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| Description of tool                           | It is a user-friendly tool to estimate potential aquifer recharge by applying different approaches. Potential evapotranspiration can be computed from temperature data by one of the next methods: Thornwaite, Hargreaves or Blaney-Criddle. Actual evapotranspiration and effective rainfall are computed by using potential evapotranspiration and rainfall data either by applying a Thornwaite balance method, or with a modification introduced by G. Girard. |
| Required data                                 | Historical daily and/or monthly climatic series (temperature and rainfall) and irrigation supply series.                                                                                                                                                                                                                                                                                                                                                           |
| Strength                                      | It is a user friendly tool that allows to introduce, change data in an easy way and to obtain nice figures to summarize results due to its graphical capacity. It can be applied to any case study (it is a generic tool)                                                                                                                                                                                                                                          |
| Weaknesses                                    | You lose the flexibility that you have for research purposes when you directly develop you own codes. You cannot test options not included within the code.                                                                                                                                                                                                                                                                                                        |
| Examples of uses of tool                      | See in the tutorial. <a href="http://www.igme.es/productos_descargas/aplicaciones/renata.htm">http://www.igme.es/productos_descargas/aplicaciones/renata.htm</a> (in Spanish).                                                                                                                                                                                                                                                                                     |
| Links to complementary material and downloads | <a href="http://www.igme.es/productos_descargas/aplicaciones/renata.htm">http://www.igme.es/productos_descargas/aplicaciones/renata.htm</a> (in Spanish).                                                                                                                                                                                                                                                                                                          |
| GSO Contacts                                  | David Pulido Velázquez, <a href="mailto:d.pulido@igme.es">d.pulido@igme.es</a>                                                                                                                                                                                                                                                                                                                                                                                     |

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| <b>TACTIC tool factsheet</b> | <i>Estimating subsidence from InSAR data</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| Description of tool          | Interferometric Synthetic Aperture Radar (InSAR) is a space geodetic technique that exploits the phase difference (interferogram) between two SAR images to derive ground displacements with millimeter accuracy. The analysis of large stacks of SAR images, known as A-DInSAR (Advanced DInSAR) has been successfully applied to monitor different geohazards, such as volcanic activity, tectonic motions, subsidence and landslides. Currently there are several satellites acquiring SAR data suitable for InSAR, such as the European Space Agency's Sentinel-1 satellites, the Canadian Radarsat, the German TerraSAR-X, the Italian Cosmo-SkyMed and the Spanish PAZ satellites.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| Required data                | SAR (Synthetic Aperture Radar) images covering the study area acquired during the study period. Typically, for a time series analysis, at least 20 images acquired at different dates are required. A DEM of the study region is also necessary to correct the topographic phase contribution in the interferograms.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| Strength                     | The advantage of InSAR data over other in-situ techniques to measure ground deformation, such as GPS data, is that InSAR provides continuous spatial coverage of the deformation field, while GPS data consist of discrete measurements. Besides, the InSAR technique is 100% remote and low cost compared to GPS monitoring, which requires field work that is expensive and difficult to carry out in many regions of the planet. The new European Space Agency (ESA) Sentinel-1 constellation is particularly well adapted to this task, since it acquires images globally every 6–12 days, that are distributed free of charge.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| Weaknesses                   | Changes in the scattering properties of the Earth's surface with time and incidence angle limit the applicability of the technique.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| Examples of uses of tool     | <p>The tool has been extensively used to detect and monitor aquifer-related deformation (e.g., Colesanti et al., 2003; Boni et al. 2015, Mateos et al. 2017), estimate aquifer hydraulic properties (e.g., Tomás et al., 2009; Ezquerro et al., 2014) and predict water level changes (e.g., Chaussard et al., 2014; Béjar-Pizarro et al. 2017).</p> <p>Béjar-Pizarro, M. et al. (2017). Mapping groundwater level and aquifer storage variations from InSAR measurements in the Madrid aquifer, Central Spain, <i>Journal of Hydrology</i>, 547, 678–689 doi: <a href="http://dx.doi.org/10.1016/j.jhydrol.2017.02.011">http://dx.doi.org/10.1016/j.jhydrol.2017.02.011</a>.</p> <p>Boni, R. et al. (2015). Twenty-year advanced DInSAR analysis of severe land subsidence: the Alto Guadalentín Basin (Spain) case study. <i>Eng. Geol.</i> <a href="http://dx.doi.org/10.1016/j.enggeo.2015.08.014">http://dx.doi.org/10.1016/j.enggeo.2015.08.014</a>.</p> <p>Colesanti, C. et al. (2003). SAR monitoring of progressive and seasonal ground deformation using the permanent scatterers technique. <i>IEEE Trans. Geosci. Remote Sens.</i> 4, 1685–1701.</p> <p>Chaussard, E. (2014). Predictability of hydraulic head changes and characterization of aquifer-system and fault properties from InSAR-derived ground deformation. <i>J. Geophys. Res. Solid Earth</i> 119, 6572–6590. <a href="http://dx.doi.org/10.1002/2014JB011266">http://dx.doi.org/10.1002/2014JB011266</a>.</p> <p>Ezquerro, P. et al., (2014). A quasi-elastic aquifer deformational behavior: Madrid aquifer case study. <i>J. Hydrol.</i> 519, 1192–1204. <a href="http://dx.doi.org/10.1016/j.jhydrol.2014.08.040">http://dx.doi.org/10.1016/j.jhydrol.2014.08.040</a>.</p> <p>Mateos, R.M. (2017). Multiband PSInSAR and long-period monitoring of land subsidence in a strategic detrital aquifer (Vega de Granada, SE Spain): An approach to support management decisions. <i>Journal of Hydrology</i> 553, 71–87 doi:<a href="https://doi.org/10.1016/j.jhydrol.2017.07.056">https://doi.org/10.1016/j.jhydrol.2017.07.056</a>.</p> <p>Tomás, R. et al., (2009). A ground subsidence study based on DInSAR data: Calibration of soil parameters and subsidence prediction in Murcia City (Spain). <i>Eng. Geol.</i> 111, 19–30.</p> |

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| Links to complementary material and downloads | The ESA Geohazards Exploitation Platform ( <a href="https://geohazards-tep.eu/">https://geohazards-tep.eu/</a> ) |
| GSO Contacts                                  | Marta Béjar, <a href="mailto:m.bejar@igme.es">m.bejar@igme.es</a>                                                |

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| <b>TACTIC tool factsheet</b>                  | Visual MODFLOW                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| Description of tool                           | Graphical user interface that helps to design, calibrate, validate and simulate groundwater flow and transport models in porous medium. The non-density-dependent flow is approached by using the MODFLOW code developed by the USGS: <a href="https://en.wikipedia.org/wiki/MODFLOW">https://en.wikipedia.org/wiki/MODFLOW</a> . Other graphical interface employed to simulate aquifer evolution that use MODFLOW are: PMWIN, Vistas, GMS, SIMTRA, etc.                                                                                                                                                                                                                                                                                                                        |
| Required data                                 | Historical series to calibrate of stresses (recharge, pumping), boundary conditions, historical observation data about the status (hydraulic head and stream flows), others (Geometrical and geological information, hydrodynamic data [pumping tests, slug test, etc]).                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| Strength                                      | It is a user friendly tool that allows to introduce, change data in an easy way and to obtain nice figures to summarize results due to its graphical capacity.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| Weaknesses                                    | You lose the flexibility that you have for research purposes when you directly use the Open Access USGS calculation codes (MODFLOW, SEAWAT, etc), which allow you to implement changes in the algorithmic if you want to test option not included in the code. For example, it does not allow to use the sharp interface solution (swi2) included in MODFLOW 2005.                                                                                                                                                                                                                                                                                                                                                                                                               |
| Examples of uses of tool                      | <p>It is the most used tool to develop Groundwater Flow models in the world. Many examples can be found within the web. Some applications performed in IGME are included in the next papers:</p> <p>Llopis-Albert, C. and Pulido-Velazquez, D., 2015. Using MODFLOW code to approach transient hydraulic head with a sharp-interface solution. Hydrol. Process 29, Issue 8, pages 2052–2064, 15. DOI: 10.1002/hyp.10354.</p> <p>D. Pulido-Velázquez, JL García-Aróstegui, JL Molina, M. Pulido-Velázquez, 2015. Assessment of future groundwater recharge in semi-arid regions under climate change scenarios (Serral-Salinas aquifer, SE Spain). Could increased rainfall variability increase the recharge rate? Hydrol. Process. 29 (6), 828–844. DOI: 10.1002/hyp.10191.</p> |
| Links to complementary material and downloads | Link to Visual MODFLOW: <a href="https://www.waterloohydrogeologic.com/visual-modflow-flex/">https://www.waterloohydrogeologic.com/visual-modflow-flex/</a>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| GSO contact                                   | David Pulido Velázquez, <a href="mailto:d.pulido@igme.es">d.pulido@igme.es</a>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |

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| <b>TACTIC tool factsheet</b>                  | GIS-GALDIT (vulnerability)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| Description of tool                           | It is a GIS program developed to generate vulnerability maps by applying the GALDIT method (Chachadi and Lobo-Ferreira, 2005)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| Required data                                 | The GALDIT method is defined by combining the next information: Aquifer type; aquifer hydraulic conductivity; height of groundwater head above sea level; distance from the shore; impact of existing status of SWI; thickness of aquifer being mapped                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| Strength                                      | It can be applied to any case study, where enough information is available                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| Weaknesses                                    | It is not a user friendly tool                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| Examples of uses of tool                      | <p>See the papers:</p> <ul style="list-style-type: none"> <li>- Chachadi AG, Lobo-Ferreira JP (2001) Sea water intrusion vulnerability mapping of aquifers using GALDIT method. In: Proc. Workshop on Modelling in Hydrogeology (Anna University, Chennai), 143–156, and in COASTIN A Coastal Policy Research Newsletter, Number 4, March 2001. New Delhi, TERI, 7–9, cf. <a href="http://www.teriin.org/-teri-wr/coastin/newslett/coastin4.pdf">http://www.teriin.org/-teri-wr/coastin/newslett/coastin4.pdf</a></li> <li>- Chachadi AG, Lobo-Ferreira JP (2005) Assessing aquifer vulnerability to sea-water intrusion using GALDIT method: part 2 – GALDIT indicator descriptions. IAHS and LNEC, Proceedings of the 4th The Fourth Inter Celtic Colloquium on Hydrology and Management of Water Resources, held at Universidade do Minho, Guimarães, Portugal, July 11–13, 2005</li> <li>- Baena-Ruiz, L., Pulido-Velazquez, D., Collados-Lara, AJ. et al. Water Resour Manage (2018). <a href="https://doi.org/10.1007/s11269-018-1952-2">https://doi.org/10.1007/s11269-018-1952-2</a></li> <li>- Mahrez, B., Klebingat, S., Houha, B. et al., 2018. GIS-based GALDIT method for vulnerability assessment to seawater intrusion of the Quaternary coastal Collo aquifer (NE-Algeria). Arab J Geosci (2018) 11: 71. <a href="https://doi.org/10.1007/s12517-018-3400-2">https://doi.org/10.1007/s12517-018-3400-2</a></li> </ul> |
| Links to complementary material and downloads | <a href="http://www.teriin.org/-teri-wr/coastin/newslett/coastin4.pdf">http://www.teriin.org/-teri-wr/coastin/newslett/coastin4.pdf</a>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| GSO contact                                   | Leticia Baena Ruiz, <a href="mailto:l.baena@igme.es">l.baena@igme.es</a>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |

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| <b>TACTIC tool factsheet</b>                  | GIS-MaRT (summary of SWI)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| Description of tool                           | It is a GIS program developed to summary Sea Water Intrusion status and vulnerability in Groundwater Bodies at different scale. It includes steady pictures defined with maps and conceptual cross sections for specific dates or statistics (mean, minimum, maximum values) of a period, and a temporal series of an index which gives an idea of the dynamic of the intrusion (Baena-Ruiz et al., 2018).                                                                                                                                                                                                                                                                |
| Required data                                 | In order to summarize the status of intrusion within the Groundwater Bodies we will need information about the distribution of the aquifer resources and the chloride &/or salinity concentration. In order to summarize the vulnerability to the intrusion within a Groundwater Body we will need also to generate maps of vulnerability, that can be generated for example by applying the GALDIT method (see required data in the description of the GIS-GALDIT tool                                                                                                                                                                                                   |
| Strength                                      | It can be applied to any case study, where enough information is available.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| Weaknesses                                    | It is not a user friendly tool.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| Examples of uses of tool                      | See the papers:<br>- Baena-Ruiz, L., Pulido-Velazquez, D., Collados-Lara, AJ. et al. Water Resour Manage (2018). <a href="https://doi.org/10.1007/s11269-018-1952-2">https://doi.org/10.1007/s11269-018-1952-2</a><br>- Chachadi AG, Lobo-Ferreira JP (2001) Sea water intrusion vulnerability mapping of aquifers using GALDIT method. In: Proc. Workshop on Modelling in Hydrogeology (Anna University, Chennai), 143–156, and in COASTIN A Coastal Policy Research Newsletter, Number 4, March 2001. New Delhi, TERI, 7–9, cf. <a href="http://www.teriin.org/-teri-wr/coastin/newslett/coastin4.pdf">http://www.teriin.org/-teri-wr/coastin/newslett/coastin4.pdf</a> |
| Links to complementary material and downloads | Not available nowadays.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| GSO contact                                   | Leticia Baena Ruiz, <a href="mailto:l.baena@igme.es">l.baena@igme.es</a>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |

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| <b>TACTIC tool factsheet</b>                  | <i>HELP</i>                                                                                                                                                                                                                                                                                                                                                                    |
| Description of tool                           | HELP (Hydrologic Evaluation of Landfill Performance) is a hydrologic numerical model developed by the United States Environmental Protection Agency for landfills. The model uses a water-balance approach to model evapotranspiration and drainage through soil layers. The model is often used for simulating the effects of various climate scenarios.<br>.                 |
| Required data                                 | The HELP model needs several meteorological variables, such as daily and monthly average mean temperature, daily and monthly accumulated total precipitation, monthly average horizontal wind speed, daily global radiation and monthly relative humidity. Besides climate parameters the model needs well defined soil profiles with soils types, vegetation cover and slope. |
| Strength                                      | HELP provides water budget time-series based on simple soil profiles. It also has a climate generator. It provides transient water budget output at daily resolution.                                                                                                                                                                                                          |
| Weaknesses                                    | HELP is one dimensional and thus a separate model is needed for each climate zone and each soil type.                                                                                                                                                                                                                                                                          |
| Examples of uses of tool                      | Gogolev M I (2002) Assessing groundwater recharge with two unsaturated zone modeling technologies. Environmental Geology 42, 248–258.<br>Jyrkama, M I, Sykes, J F (2007) The impact of climate change on spatially varying groundwater recharge in the grand river watershed (Ontario). J. Hydrol. 338 (3–4), 237–250.JRC, 2010                                                |
| Links to complementary material and downloads | <a href="https://www.epa.gov/land-research/hydrologic-evaluation-landfill-performance-help-model">https://www.epa.gov/land-research/hydrologic-evaluation-landfill-performance-help-model</a><br><a href="https://www.nrc.gov/docs/ML1015/ML101590180.pdf">https://www.nrc.gov/docs/ML1015/ML101590180.pdf</a>                                                                 |
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| <b>TACTIC tool factsheet</b>                  | <i>Leapfrog suite</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Description of tool                           | Leapfrog suite is a commercial software based on geological 3d modelling and allow to visualise groundwater data of different surveys and interpolate them in order to obtain 3D maps in time of water level and distribution on physical (e.g. temperature) or chemical (eg. salinity) parameters. Detailed geological models point out lithological and geotechnical properties, driving zonations of aquifers useful for vulnerability assessment. It's possible to export 3d geological model in Modflow or Feflow compatible formats and import outputs of these hydrological simulations for an integrated visualization.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| Required data                                 | Geological model (..)<br>Groundwater data                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| Strength                                      | It's based on powerful tools to build regional to local (detailed) geological models. It can integrate geological and groundwater data (or hydrological simulations) and simplify the dissemination thanks to friendly outputs, helping in the decision-making process.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| Weaknesses                                    | Hydrological modelling has to be directly processed by other software.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| Examples of uses of tool                      | <p>The tool has been used to model Holocene succession and then to characterize the coastal phreatic aquifer. Another case study was the 3d modelling of Marecchia River alluvial fan where is currently active a MAR project.</p> <p>It allows to overcome previous simplifications by putting in evidence heterogeneities within geological bodies and so 3d distribution of physical parameters. It provides an extremely detailed basis for hydraulic modelling.</p> <p>It's a powerful tool to visualize 3d thematic maps as piezometric level, conductivity, temperature or chemistry of groundwater.</p> <p>It can integrate a large amount of different data allowing to compare the evolution of the aquifer with other environmental and territorial data.</p> <p>An example of application is reported in the paper:<br/>Calabrese L., Perini P., Lorito S., Luciani P., Martini A., Severi P., Correggiari A., Remia A. (2016). 3D modelling of the Holocene succession in the southern Po Delta (Italy): from geology to applications. Zeitschrift der Deutschen Gesellschaft für Geowissenschaften, 167 (4), 339-352</p> |
| Links to complementary material and downloads | <a href="https://www.leapfrog3d.com/">https://www.leapfrog3d.com/</a><br><br><a href="https://www.leapfrog3d.com/__data/assets/pdf_file/0020/25463/Po-Delta-Case-Study.pdf">https://www.leapfrog3d.com/__data/assets/pdf_file/0020/25463/Po-Delta-Case-Study.pdf</a>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| GSO Contacts                                  | Paolo Severi , <a href="mailto:Paolo.Severi@Regione.Emilia-Romagna.it">Paolo.Severi@Regione.Emilia-Romagna.it</a>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |

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| <b>TACTIC tool factsheet</b>                  | <i>HYPE</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| Description of tool                           | <p>HYPE is a lumped precipitation-runoff model developed by SMHI in Sweden. The hydrological model HYPE simulates groundwater level, surface water flow and nutrient (N,P) concentration (Arheimer et al., 2008; Lindström et al., 2009). The model is developed from HBV model.</p> <p>It can be used for catchment and divided into subbasins which in turn are divided into classes (calculation units) depending on land use, soil type and elevation (HRU). The classes can not be coupled to a geographic location within the subbasin but are given as part of its area. Typical land uses are forest, lake, open land, but also different crops, e.g. cereal and potatoes, are common. Elevation can be used to get temperature variations within a subbasin to influence the snow conditions.</p> |
| Required data                                 | <p>Forcing data:<br/>Precipitation<br/>Temperature</p> <p>Optional:<br/>Net radiation<br/>Snow depth<br/>Etc.</p> <p>Calibration data:<br/>Groundwater level or Surface water Flow</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Strength                                      | <p>Simple and fast.<br/>Flexible and stable.<br/>Standardised for applications at different scales (point, catchment, national, European, worldwide).</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Weaknesses                                    | Relative groundwater level (not absolute level).                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| Examples of uses of tool                      | <p>Current situation and prediction of groundwater level and surface water flow in Sweden. (Flood forecasting, water hydropower operation, droughts, eutrophication, etc.).</p> <p>There is also a European version and a world wide version etc.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| Links to complementary material and downloads | <p><a href="https://www.smhi.se/en/research/research-departments/hydrology/hype-1.7994">https://www.smhi.se/en/research/research-departments/hydrology/hype-1.7994</a></p> <p><a href="http://www.smhi.net/hype/wiki/doku.php?id=start">http://www.smhi.net/hype/wiki/doku.php?id=start</a></p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| GSO Contacts                                  | <a href="http://www.smhi.se">www.smhi.se</a>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |

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| <b>TACTIC tool factsheet</b>                  | <i>METRAN</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| Description of tool                           | Transfer-noise tool for time series modelling, mostly used with piezometric heads as explained variable and precipitation and reference evaporation as explanatory variables. Tool can also perform factor analysis of residuals of multiple time series models.                                                                                                                                                                                                                                                                                                       |
| Required data                                 | Time series of explained variable and one or more explanatory variables                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| Strengths                                     | Can handle irregular frequency of explained variable.<br>Simple parametrization of transfer functions, which allows spatial correlation and interpretation of the physical system.                                                                                                                                                                                                                                                                                                                                                                                     |
| Weaknesses                                    | Linear transfer functions.<br>Parameter optimization sensitive to initial parameter estimates.                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| Examples of uses of tool                      | Creation of time series models for all piezometric head series in the national database DINO ( <a href="http://www.dinoloket.nl">http://www.dinoloket.nl</a> ).<br>Trend analysis.                                                                                                                                                                                                                                                                                                                                                                                     |
| Links to complementary material and downloads | <a href="https://www.grondwatertools.nl/grondwaterdynamiek">https://www.grondwatertools.nl/grondwaterdynamiek</a><br><a href="https://www.grondwatertools.nl/grondwatertools-viewer">https://www.grondwatertools.nl/grondwatertools-viewer</a><br><a href="https://onlinelibrary.wiley.com/doi/epdf/10.1111/gwat.12819">https://onlinelibrary.wiley.com/doi/epdf/10.1111/gwat.12819</a><br><a href="https://www.sciencedirect.com/science/article/pii/S0022169416300622?via%3Dihub">https://www.sciencedirect.com/science/article/pii/S0022169416300622?via%3Dihub</a> |
| GSO Contacts                                  | willem_jan.zaadnoordijk@tno.nl<br>aris.lourens@tno.nl                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |

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| TACTIC tool factsheet                         | <i>GDNisohypsen</i>                                                                                                                                                                                                          |
| Description of tool                           | Interpolation of piezometric heads using a trend surface giving the regional shape of the piezometric surface.                                                                                                               |
| Required data                                 | Piezometric heads and preferably a trend surface (in our case from the national database DINO maintained by TNO and the Dutch National Groundwater model of NHI maintained by Deltares, respectively).                       |
| Strengths                                     | Quick visualization with decent accuracy (depending on the density of the measurements and the quality of the trend surface).                                                                                                |
| Weaknesses                                    | Linear transfer functions.<br>Parameter optimization sensitive to initial parameter estimates.                                                                                                                               |
| Examples of uses of tool                      | Interactive creation of contour maps at various depths (taken from the aquifers in the schematization of the Dutch National Groundwater model).                                                                              |
| Links to complementary material and downloads | <a href="https://www.grondwatertools.nl/isohypsen">https://www.grondwatertools.nl/isohypsen</a><br><a href="https://www.grondwatertools.nl/grondwatertools-viewer">https://www.grondwatertools.nl/grondwatertools-viewer</a> |
| GSO Contacts                                  | willem_jan.zaadnoordijk@tno.nl<br>aris.lourens@tno.nl                                                                                                                                                                        |

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| <b>TACTIC tool factsheet</b>                  | <i>ModelMuse</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| Description of tool                           | ModelMuse is a graphical user interface (GUI) that helps to design, calibrate, validate and simulate groundwater flow and transport models in porous medium. It is a GUI for the U.S. Geological Survey (USGS) models MODFLOW–2005, MODFLOW-LGR, MODFLOW-LGR2, MODFLOW-NWT, MODFLOW-CFP, MODFLOW-OWHM, MODPATH, ZONEBUDGET, PHAST, SUTRA, MT3D-USGS, SWI2 and WellFootprint and the non-USGS model MT3DMS. This software package provides a GUI for creating the flow and transport input file for PHAST and the input files for the other models. |
| Required data                                 | Historical series to calibrate of stresses (recharge, pumping), boundary conditions, historical observation data about the status (hydraulic head and stream flows), others Geometrical and geological information, hydrodynamic data, pumping tests, slug test etc.                                                                                                                                                                                                                                                                               |
| Strength                                      | It is an open source user friendly tool that allows introducing, change data in an easy. It can be applied to any case study. In ModelMuse, the spatial data for the model are independent of the grid, and the temporal data are independent of the stress periods. Being able to input these data independently allows the user to redefine the spatial and temporal discretization at will.                                                                                                                                                     |
| Weaknesses                                    | The graphical outputs are not so friendly and flexible.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| Examples of uses of tool                      | See in the ModelMuse web page, section Examples of Studies in which ModelMuse was Used <a href="https://water.usgs.gov/nrp/gwsoftware/ModelMuse/ModelMuse.html">https://water.usgs.gov/nrp/gwsoftware/ModelMuse/ModelMuse.html</a>                                                                                                                                                                                                                                                                                                                 |
| Links to complementary material and downloads | A series of videos is available that illustrate how to use ModelMuse:<br><br><a href="https://water.usgs.gov/nrp/gwsoftware/ModelMuse/ModelMuseVideos.html">https://water.usgs.gov/nrp/gwsoftware/ModelMuse/ModelMuseVideos.html</a>                                                                                                                                                                                                                                                                                                               |
| GSO Contacts                                  | IGME<br>Carolina Guardiola-Albert, <a href="mailto:c.guardiola@igme.es">c.guardiola@igme.es</a>                                                                                                                                                                                                                                                                                                                                                                                                                                                    |

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| <b>TACTIC tool factsheet</b>                  | <i>MODFLOW/MT3D/SEAWAT</i><br><i>GMS</i><br><i>Groundwater Vistas (GV)</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Description of tool                           | MODFLOW is the USGS's modular hydrologic model. MODFLOW is considered an international standard for simulating and predicting groundwater conditions and groundwater/surface-water interactions. MODFLOW's modular structure has provided a robust framework for integration of additional simulation capabilities that build on and enhance its original scope. The family of MODFLOW-related programs now includes capabilities to simulate coupled groundwater/surface-water systems, solute transport, variable-density flow (including saltwater), aquifer-system compaction and land subsidence, parameter estimation, and groundwater management. GMS is a modeling interface (GUI) for advanced three-dimensional groundwater modeling with MODFLOW/MT3D/SEAWAT including a full 3D visualization. GV is a pre- and post-processor (GUI) for MODFLOW/MT3D/SEAWAT models with focus on new technology for model calibration, optimization, and uncertainty analysis. |
| Required data                                 | Depending on the site and the problem to model data are required for the hydrostratigraphic model and parameter values, boundary conditions, sources and sinks, description of surface water systems, and observation data for model calibration and validation.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| Strength                                      | MODFLOW is relatively easy to set up and to pre/post process files. MODFLOW is an industry standard and is widely used for both research and consulting around the world. The software is free to use and GUIs are relatively inexpensive. The modular structure of MODFLOW makes it easy to develop and add new model packages.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| Weaknesses                                    | MODFLOW is command line executable programs written in FORTRAN that reads ASCII text and binary files and writes ASCII text and binary output files. Although experienced MODFLOW users may be able to create MODFLOW input files by hand, most MODFLOW users rely on a graphical user interface (GUI) like GMS and GV to prepare the input files and post-process the output files. The MODFLOW program itself does not generate contour plots or any other type of graphical output. These plots must be generated from MODFLOW results using other software programs. The USGS distributes several free pre- and post-processors for MODFLOW. Also the GUIs require some training and experience to use competently. MODFLOW uses simplified descriptions of evapotranspiration and surface water systems compared to e.g. MIKE SHE / MIKE ZERO.                                                                                                                         |
| Examples of uses of tool                      | Kidmose, J. B., Dahl, M., Engesgaard, P. K., Nilsson, B., Christensen, B. S. B., Andersen, S., & Hoffmann, C. C. (2010). Experimental and numerical study of the relation between flow paths and fate of a pesticide in a riparian wetland. <i>Journal of Hydrology</i> , 386(1-4), 67-79. <a href="https://doi.org/10.1016/j.jhydrol.2010.03.006">https://doi.org/10.1016/j.jhydrol.2010.03.006</a> .<br>Rasmussen, P., Sonnenborg, T.O., Gonsior, G., & Hinsby, K. (2013). Assessing impacts of climate change, sea level rise, and drainage canals on saltwater intrusion to coastal aquifer. <i>Hydrol. Earth Syst. Sci.</i> , 17, 421–443, 2013. <a href="http://www.hydrol-earth-syst-sci.net/17/421/2013/">www.hydrol-earth-syst-sci.net/17/421/2013/</a> doi:10.5194/hess-17-421-2013.                                                                                                                                                                              |
| Links to complementary material and downloads | MODFLOW/MT3D/SEAWAT: <a href="https://water.usgs.gov/ogw/modflow/">https://water.usgs.gov/ogw/modflow/</a><br>USGS Office of Groundwater, 411 National Center, 12201 Sunrise Valley Drive, Reston, VA 20192. Phone: (703) 648-5001. Email: <a href="mailto:ogw_webmaster@usgs.gov">ogw_webmaster@usgs.gov</a><br>GMS: <a href="https://www.aquaveo.com/">https://www.aquaveo.com/</a><br>Aquaveo, LLC. 3210 N. Canyon Road. Suite 300. Provo, Utah 84604. United States. Tel: +01 801-691-5528. Email: <a href="mailto:info@aquaveo.com">info@aquaveo.com</a><br>GV: <a href="http://groundwatermodels.com/">http://groundwatermodels.com/</a><br>Environmental Simulations, Inc. 254 Ziegler Road. Leesport, PA 19533. Tel (610) 223-5273. Email: <a href="mailto:support@groundwatermodels.com">support@groundwatermodels.com</a>                                                                                                                                         |
| GSO Contacts                                  | Jacob Kidmose, <a href="mailto:jbki@geus.dk">jbki@geus.dk</a> . Per Rasmussen, <a href="mailto:pr@geus.dk">pr@geus.dk</a>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |

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| <b>TACTIC tool factsheet</b>                  | <i>BFI PART</i>                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| Description of tool                           | The computer program PART uses streamflow partitioning to estimate a daily record of groundwater discharge under the streamflow record. The method designates groundwater discharge to be equal to streamflow on days that fit a requirement of antecedent recession, linearly interpolates groundwater discharge for other days, and is applied to a long period of record to obtain an estimate of the mean rate of groundwater discharge.                  |
| Required data                                 | Streamflow time series.<br>Amount of pumped water if possible.                                                                                                                                                                                                                                                                                                                                                                                                |
| Strength                                      | Easy to use and inexpensive.<br>Several codes and softwares available.<br>Application to a long period of streamflow record gives an estimate of long-term average groundwater recharge.                                                                                                                                                                                                                                                                      |
| Weaknesses                                    | Drawbacks are that the hydrograph separation methods are arbitrary and the base discharge may have been significantly reduced compared to the amount which recharged the aquifer.<br>Water table must be connected with the surface streamflow.<br>Storage variations must be insignificant, or must be taken into account.                                                                                                                                   |
| Examples of uses of tool                      |                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| Links to complementary material and downloads | PART (USGS)<br><a href="https://water.usgs.gov/ogw/part/">https://water.usgs.gov/ogw/part/</a><br><a href="https://pubs.usgs.gov/wri/wri984148/pdf/wri98-4148.pdf">https://pubs.usgs.gov/wri/wri984148/pdf/wri98-4148.pdf</a><br><br>Seguin, Jean-Jacques et al. 2015. "BRGM/RP-65635-FR Méthodes d'Évaluation de La Recharge Des Nappes Complément d'étude Pour La Caractérisation Des Pressions et Impacts Sur Les Eaux Souterraines Rapport Final." : 219. |
| GSO Contacts                                  | BRGM<br>Hélène Bessiere<br><a href="mailto:h.bessiere@brgm.fr">h.bessiere@brgm.fr</a>                                                                                                                                                                                                                                                                                                                                                                         |

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| <b>TACTIC tool factsheet</b>                  | <i>BFI RORA</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Description of tool                           | The computer program RORA provides estimates of groundwater recharge from the displacement of the streamflow-recession curve from equations developed by Rorabaugh (1964) and Glover (1964). RORA estimates values of recharge for individual events on a daily basis from streamflow records, but it is recommended that results be reported at no smaller than a seasonal (3-month) time scale. The method assumes that streamflow recessions represent groundwater discharge from areal precipitation on the aquifer. Snowmelt runoff, streamflow regulation, storage and release of water from wetlands or bank storage could be other sources that affect the shape of the recession curve. |
| Required data                                 | Application of RORA requires an estimate of the slope of the streamflow-recession curve (recession constant K) representing periods when all streamflow is from groundwater discharge. The recession index can be computed by constructing a master-recession curve from the streamflow record by use of the program RECESS.<br>Streamflow time series<br>Amount of pumped water if possible                                                                                                                                                                                                                                                                                                     |
| Strength                                      | Easy to use and inexpensive<br>Several codes and softwares available<br>Application to a long period of streamflow record gives an estimate of long-term average groundwater recharge.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| Weaknesses                                    | Drawbacks are that the hydrograph separation methods are arbitrary and the base discharge may have been significantly reduced compared to the amount which recharged the aquifer.<br><br>Water table must be connected with the surface streamflow<br>Storage variations must be insignificant, or must be taken into account                                                                                                                                                                                                                                                                                                                                                                    |
| Examples of uses of tool                      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Links to complementary material and downloads | RORA (USGS)<br><a href="https://water.usgs.gov/ogw/rora/">https://water.usgs.gov/ogw/rora/</a><br><a href="https://pubs.usgs.gov/wri/wri984148/pdf/wri98-4148.pdf">https://pubs.usgs.gov/wri/wri984148/pdf/wri98-4148.pdf</a><br><br>Seguin, Jean-Jacques et al. 2015. "BRGM/RP-65635-FR Méthodes d'Évaluation de La Recharge Des Nappes Complément d'étude Pour La Caractérisation Des Pressions et Impacts Sur Les Eaux Souterraines Rapport Final." : 219.                                                                                                                                                                                                                                    |
| GSO Contacts                                  | BRGM<br>Hélène Bessiere<br><a href="mailto:h.bessiere@brgm.fr">h.bessiere@brgm.fr</a>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |

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| <b>TACTIC tool factsheet</b>                  | <i>WTF MRC</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| Description of tool                           | This method, developed by the USGS, is based on the water-table fluctuation (WTF) method, and so assumes that a water level rise in unconfined aquifers are due to recharge water arriving at the water-table multiplied by the specific yield of the aquifer. This method of calculation lays on the assumption that during every water level rise, there is a hidden recession, so the rise values have to be corrected. For each individual water level rise, a master recession curve (MRC), specified as the intercept and slope of a line fitted to measured values, is calculated from the antecedent recession period time. To determine total recharge, $\Delta H$ is set equal to the difference between the peak of the rise and low point of the extrapolated recession curve.                                                                                                                                                                                  |
| Required data                                 | Groundwater level time series<br>Specific yield                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| Strength                                      | The method is simple to apply and inexpensive if water-level records are available from existing observation wells. It should work best for wells that show a relatively rapid water-level rise in relation to the rate that water moves away from the water table.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| Weaknesses                                    | Although simple in concept, the water-table fluctuation method has drawbacks in its application related to accurate estimation of specific yield and water-level rise. Other complications include water-level rises that are not associated with recharge – such as those caused by changes in atmospheric pressure, earth tides, and entrapped air.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| Examples of uses of tool                      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| Links to complementary material and downloads | <a href="https://wwwrcamnl.wr.usgs.gov/uzf/EMR_Method/EMR.method.html">https://wwwrcamnl.wr.usgs.gov/uzf/EMR_Method/EMR.method.html</a><br>Following the previous link, R codes are available to calculate recession curves and recharge.<br>Delin, Geoffrey N., Richard W. Healy, David L. Lorenz, and John R. Nimmo. 2007. "Comparison of Local- to Regional-Scale Estimates of Ground-Water Recharge in Minnesota, USA." <i>Journal of Hydrology</i> 334(1–2): 231–49.<br>Healy, Richard W., and Bridget R. Scanlon. 2010. Estimating Groundwater Recharge.<br>Scanlon, Bridget R., Richard W. Healy, and Peter G. Cook. 2002. "Choosing Appropriate Technique for Quantifying Groundwater Recharge." <i>Hydrogeology Journal</i> 10: 18–39.<br>Seguin, Jean-Jacques et al. 2015. "BRGM/RP-65635-FR Méthodes d'Évaluation de La Recharge Des Nappes Complément d'étude Pour La Caractérisation Des Pressions et Impacts Sur Les Eaux Souterraines Rapport Final." : 219. |
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| <b>TACTIC tool factsheet</b>                  | <b>Business intelligence (BI)</b>                                                                                  |
| Description of tool                           | application for data processing, analysis and visualization                                                        |
| Required data                                 | database                                                                                                           |
| Strength                                      | reporting, automatic insertion of calculation formulas                                                             |
| Weaknesses                                    | unintuitive                                                                                                        |
| Examples of uses of tool                      | Database: MWP (Groundwater Monitoring); automatic well measurements; chemical monitoring; prognosis and statements |
| Links to complementary material and downloads | license required                                                                                                   |
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| <b>TACTIC tool factsheet</b>                  | <b>Platforma PHS (Platform of Polish Hydrogeological Survey)</b>                                                                                                                                                                                                                                                                                                                                                                                 |
| Description of tool                           | Internet applications for viewing and recording of data; e-PSH map browser; pages offering WMS services (Geoserver); desktop applications for management and updating of hydrogeological databases; applications supporting the preparation and import of source data                                                                                                                                                                            |
| Required data                                 |                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Strength                                      | intuitive                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| Weaknesses                                    |                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Examples of uses of tool                      | <p>to view spatial data from hydrogeological database:</p> <ul style="list-style-type: none"> <li>- major groundwater basin (MGB)</li> <li>- Hydrogeological Maps of Poland on a scale 1:50000, – schedule of realization</li> <li>- Hydrogeological Maps of Poland on a scale 1:50000 – potential pumping yield of the well</li> <li>- groundwater body</li> <li>- Bank HYDRO – boreholes, springs</li> <li>- Groundwater monitoring</li> </ul> |
| Links to complementary material and downloads | <a href="http://spd.pgi.gov.pl/PSHv8/Psh.html">http://spd.pgi.gov.pl/PSHv8/Psh.html</a> ; ( <a href="http://epsh.pgi.gov.pl/epsh">http://epsh.pgi.gov.pl/epsh</a> )                                                                                                                                                                                                                                                                              |
| GSO Contacts                                  | <a href="mailto:www.spdpsh@pgi.gov.pl">www.spdpsh@pgi.gov.pl</a>                                                                                                                                                                                                                                                                                                                                                                                 |

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| <b>TACTIC tool factsheet</b>                  | <i>mGROWA</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Description of tool                           | The mGROWA is a conceptual area-differentiated water balance model to calculate the monthly groundwater recharge rate. It was developed at the Forschungszentrum Jülich in collaboration with LBEG. The model mGROWA simulates the water balance over the entire Federal State of Lower Saxony in two successive steps. In a first step soil moisture and the related actual evapotranspiration are simulated using a multilayer soil water balance model with a temporal resolution of one day and a spatial resolution of 100 x 100 m. In a second step the water surplus not stored in the soil layers, i.e. the total runoff, is separated into the runoff components “groundwater recharge” and “direct runoff”. Because of its relevance for the regional water balance as well as the availability and quality of water, the anthropogenically induced direct runoff from artificial drainage systems is shown separately. |
| Required data                                 | In order to simulate the water budget, mGROWA needs a digital terrain model, the distribution of type of land uses, soil types, time series for precipitation and evapotranspiration, drainage information, distance to water table, a map of the water logging tendency, the geological map of hard rocks.<br>For evaluation data from gauged catchments are needed.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| Strength                                      | The large-scale water budget is calculated monthly taking into account climate data and soil properties                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| Weaknesses                                    | For climate extremes the model simulation is under/overestimating the groundwater recharge rate.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Examples of uses of tool                      | Simulation of the water balance over the entire Federal State of Lower Saxony.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| Links to complementary material and downloads | <a href="https://www.lbeg.niedersachsen.de/boden_grundwasser/grundwasser/grundwasserneubildung/grundwasserneubildung-618.html">https://www.lbeg.niedersachsen.de/boden_grundwasser/grundwasser/grundwasserneubildung/grundwasserneubildung-618.html</a>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| GSO Contacts                                  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |

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| <b>TACTIC tool factsheet</b>                  | <b>BankHydro (The Hydro Bank)</b>                                                                                                                                                                                                                                                                                                            |
| Description of tool                           | hydrogeological database, which collects documentation data on boreholes, intakes and springs of regular, mineral and thermal groundwaters from the area of Poland                                                                                                                                                                           |
| Required data                                 | <p>The information stored in the database includes:</p> <ul style="list-style-type: none"> <li>○ location of the hydrogeological feature (borehole, spring)</li> <li>○ hydrogeological measurements and calculations</li> <li>○ basic drilling and lithostratigraphic data</li> <li>○ physicochemical data of groundwater samples</li> </ul> |
| Strength                                      | reporting, reporting, simple analyzes                                                                                                                                                                                                                                                                                                        |
| Weaknesses                                    | -                                                                                                                                                                                                                                                                                                                                            |
| Examples of uses of tool                      | all work requiring data to be obtained from wells                                                                                                                                                                                                                                                                                            |
| Links to complementary material and downloads | <a href="http://spd.pgi.gov.pl/PSHv8/Psh.html">http://spd.pgi.gov.pl/PSHv8/Psh.html</a>                                                                                                                                                                                                                                                      |
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