Introduction to the GWADI Modelling Workshop

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Motivation

• Widespread and routine use of models for flood design, real time flood management, water resources management, coupled modelling – flow, sediments, water quality, ecology

• Specific hydrological characteristics of arid and semi-arid areas

• Problems of data

• Important developments – in data and modelling

• Developing countries – practitioners limited access to information and tools, need to disseminate through regional centres
Aim of workshop

To produce a training package of lectures and tools that can be freely available through the web to support regional centres and individual practitioners.

This workshop is the test bed – joint activity of lecturers and participants.

We need to feed in your experience, concerns and interests....
Modelling Hydrological Processes in Arid and Semi-Arid Areas
I. Some observations on the hydrology of arid areas
Fig A4.2
Profiles of Storm Rainfall – 3 May 1981
Fig A.6-5
Representation of Wadi Adai Catchment
used in Kinematic Wave Model
Fig A6-6
Synthetic Wadi Adai Flood Hydrograph
(Kinematic Wave Model)

Peak discharge 1163 m$^3$/s
at 0315 hours
Runoff volume as a function of hydrograph peak

\[ R^2 = 0.923 \]

**Graph Details:**
- **Y-axis:** Runoff Volume (mm)
- **X-axis:** PEAKFL (cumecs)
- **Data Points:**
  - Various runoff volumes plotted against different PEAKFL values.

**Graph Analysis:**
- The relationship between runoff volume and hydrograph peak is strongly correlated, as indicated by the high \( R^2 \) value of 0.923.
Schematic of the Wadi Ghulaji Water Resource Model
Model Performance (5-6th April 1993)

Runoff (Mm^3)

- **Simulated**
- **Observed**

<table>
<thead>
<tr>
<th>Location</th>
<th>Simulated</th>
<th>Observed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al Haju</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>An Niba</td>
<td>0.8</td>
<td>0.8</td>
</tr>
<tr>
<td>Al Qabil</td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td>Scenario</td>
<td>Rainfall</td>
<td>Evaporation</td>
</tr>
<tr>
<td>----------</td>
<td>----------</td>
<td>-------------</td>
</tr>
<tr>
<td>Wet</td>
<td>87.7</td>
<td>70.9</td>
</tr>
<tr>
<td>Average</td>
<td>87.0</td>
<td>72.3</td>
</tr>
<tr>
<td>Dry</td>
<td>52.6</td>
<td>45.3</td>
</tr>
</tbody>
</table>
• Arid zone hydrology has important differences from humid zone hydrology

• Hydrological processes in arid and semi-arid areas are poorly understood

• Rainfall spatial and temporal variability and transmission losses are of particular importance for runoff and recharge processes
Appropriate models and decision support tools are needed for hydrology and water resources management; these must be based on appropriate understanding of hydrological processes.

Inappropriate models = inappropriate solutions
II. An introduction to rainfall-runoff models

setting the scene:

model strengths and weaknesses
RAINFALL- RUNOFF MODELS

• A model is a *simplified* representation of a real world system.

• A mathematical model consists of a set of simultaneous equations or a logical set of operations contained within a computer program.

• Models have *parameters* which are numerical measures of a property or characteristics that are constant under specified conditions.
Tasks for hydrological simulation models include:-

• Modelling existing catchments for which input-output data exist,
  e.g. Extension of data series, Flood design, Water resource evaluation, Operational flood forecasting, Water resource management
• Prediction of effects of catchment change
  e.g. land use change
• Runoff estimation on ungauged basins
• Coupled hydrology and geochemistry
• Coupled hydrology and meteorology
CLASSIFICATION OF MODELS

Linear/ Non-linear

Structure
black box or empirical
conceptual or grey box or parametric physically-based

Spatial representation
lumped, distributed, semi-distributed

Output Type
deterministic, stochastic

Output Frequency
event-based, continuous
Historical development of modelling methods

1930s Unit hydrograph (Metric models)
  I
  I 1960s Conceptual models
  I I
  I I 1970s Physics-based models
  I I I
  I I I 1980s Stochastic analysis
  I I I I
Metric Models
‘Letting the data speak for themselves’

Limitations of simplicity
Advantages of identifiability
Widely used for regionalisation
Important benefits for real-time forecasting
Workshop Examples

- Unit hydrograph (Al-Weshah)
- Time-series analysis (Young)
- [IHACRES (Croke, Jakeman)]
Conceptual Models

Assumed model form
In general, parameters have no direct (measurable) physical significance
Optimisation required for parameter identification
Workshop Examples

• Hughes
• Leavesley
• Sharma
• Singh
GWADI Workshop
Roorkee Feb-March 2005

- snow accumulation
  - snow water storage
- interception and surface moistening
- soil water supply
- soil surface storage
  - depression storage...
- soil moisture recharge
  - capillary water
- gravity water storage and flow
  - including macropore flow
- overland flow
- channel storage and routing
- basin discharge
- infiltration
- capillary rise
- percolation
- groundwater in upper horizons
  - shallow, perched
- deep percolation
- groundwater in deeper horizons
  - large scale aquifers...
- evapotranspiration
- precipitation
  - rain, snow

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Fitting a conceptual model

• Manual, subjective

or

• Automatic, objective
Automatic fitting of a conceptual model

• Specify performance measure(s) (objective functions OFs)
• For p model parameters pose problem of minimisation or maximisation of (p+1) dimensional response surface
• Classic optimisation methods include Rosenbrock, Simplex
• Advanced methods include Shuffled Complex Evolution (SCE-UA)
Problems in optimisation

- Multiple local optima on the objective function surface
- Interdependence of parameters gives difficulties due to production of valleys (or ridges) in objective function
- Insensitive directions in parameter space, e.g. if parameter redundant due to a threshold value
- Search hampered by boundaries in parameter values
- Saddle points
- Different scales of parameters
The reason?
Model complexity exceeds the information content of the data

The result?
Non-uniqueness:
many combinations of parameter values provide equally good fits to the data
Hence model parameters cannot be uniquely associated with physical catchment characteristics
Performance of PDM model in estimating flood magnitudes from generalised parameter estimates (after Lamb et al., 2000)

<table>
<thead>
<tr>
<th>Return period (yrs)</th>
<th>1.0</th>
<th>2.0</th>
<th>2.33</th>
<th>5.0</th>
<th>10.0</th>
<th>20.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean error (%)</td>
<td>22</td>
<td>23</td>
<td>24</td>
<td>25</td>
<td>26</td>
<td>27</td>
</tr>
<tr>
<td>S.D. (%)</td>
<td>18</td>
<td>18</td>
<td>19</td>
<td>20</td>
<td>21</td>
<td>23</td>
</tr>
</tbody>
</table>
Physics-based models

In principle based on measurable parameters, can be used to predict change.

But:
Is the right physics represented?
Do effective parameters exist at grid scale?
If so, how can they be obtained?
Limitations

‘Physical’ parameters not measurable at the scale of application (at least for the subsurface)
Hence model fitting is needed – but with a large number of parameters
The result - ambiguity of parameter values
Workshop Examples

• KINEROS (Semmens)
Physics-based model performance using prior parameter estimates
e.g. Lukey et al, 2000

SHETRAN
4 key parameters, baseline/upper/lower bound values
81 combinations; 5 years’ data

Envelope of simulations (selecting discharges above a minimum threshold) contained observed streamflow data for 64% of time.

$R^2$ value for individual years from best set 0.03 - 0.41
Conclusions?

• Model types have different strengths and limitations
• Model selection and application should be made with these in mind
• Significant progress is being made

To be continued…..