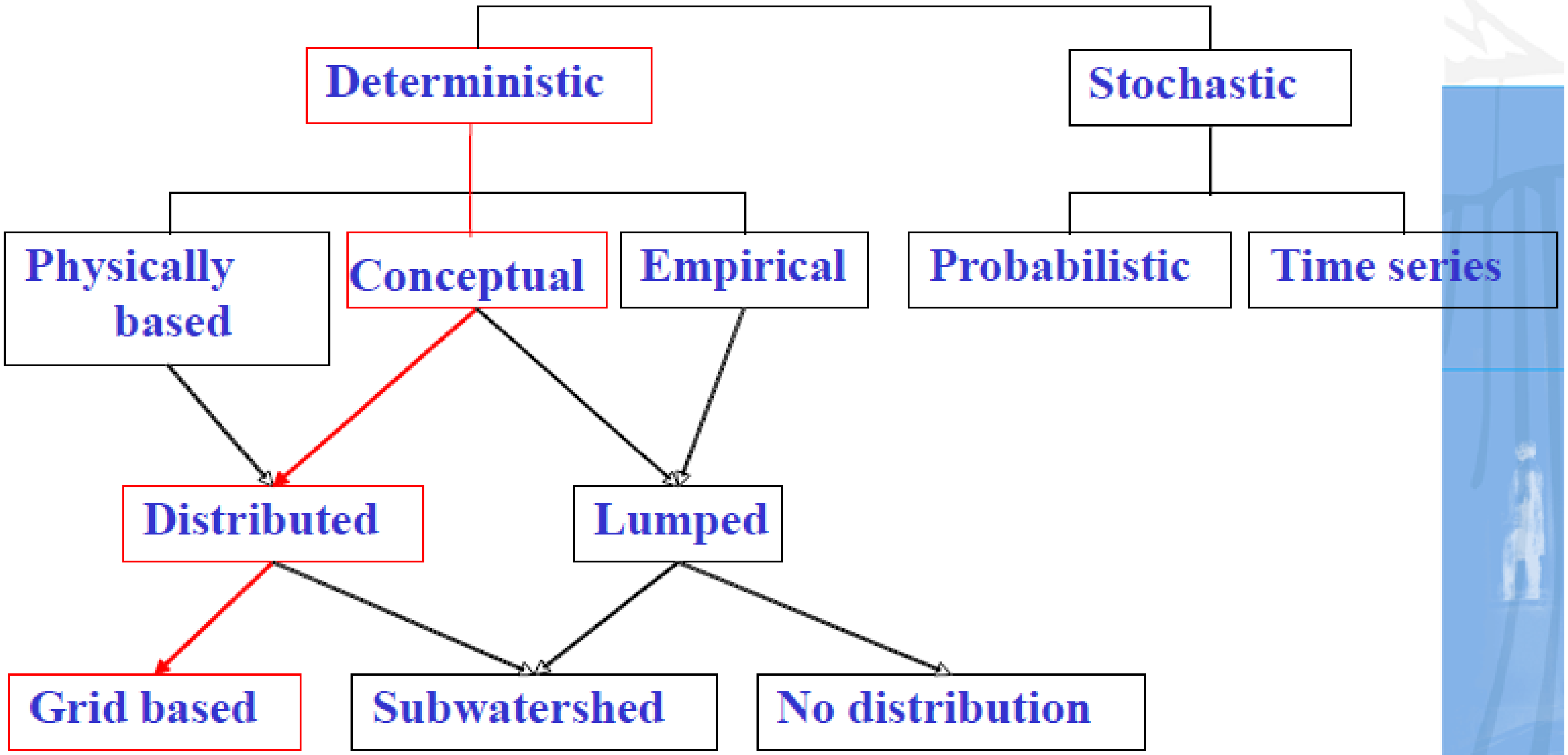
Department of Geography and Earth Sciences

WRM 625

Hydrological Modeling

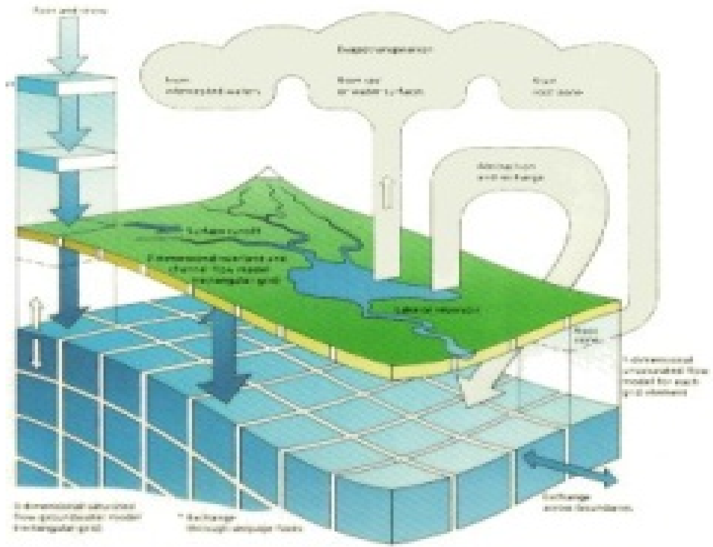
Lecture 2

Classification of Models



Physically-based Models

- White box or theoretical models
- Rigorous numerical solution of partial differential equations governing flow through porous media, overland and channel flows.
- Consequences of the most important laws governing the phenomena, measurable parameters.
- Logical structure similar to the real-world system and may be helpful under changed circumstances



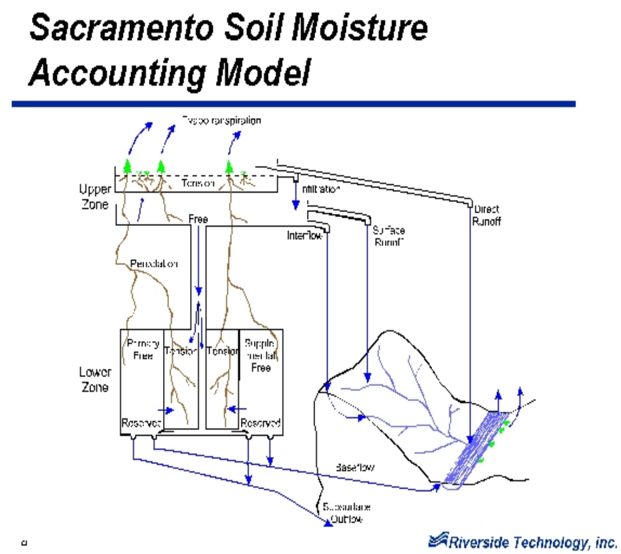
- Watershed runoff models based on St. Venant equations, infiltration models based on two phase flow theory of porous media , evaporation models based on theories of turbulence and diffusion

Empirical models

- Black-box models or input output models.
- Do not aid in physical understanding.
- Contain parameters that may have little direct physical significance and can be estimated only by using concurrent measurements of input and output
- Can yield accurate answers and can, therefore, serve a useful tool in decision-making

Conceptual Based Models

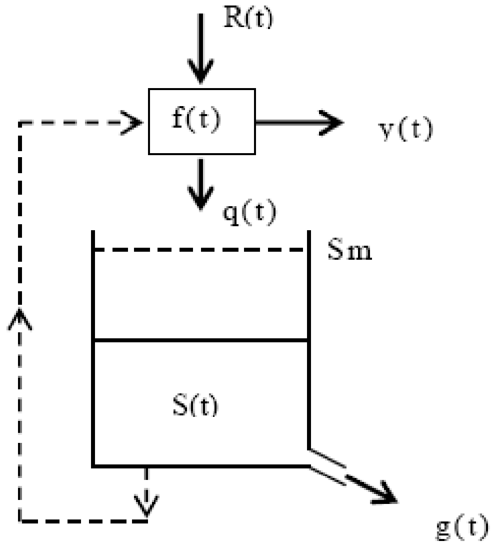
- Conceptual Models – Idealization of processes as stores, buckets, parameterizations – simplified equations representing mass, momentum, energy.
- Intermediate between theoretical and empirical models
- Conceptual models consider physical laws but in highly simplified form



Lumped Vs Distributed Models

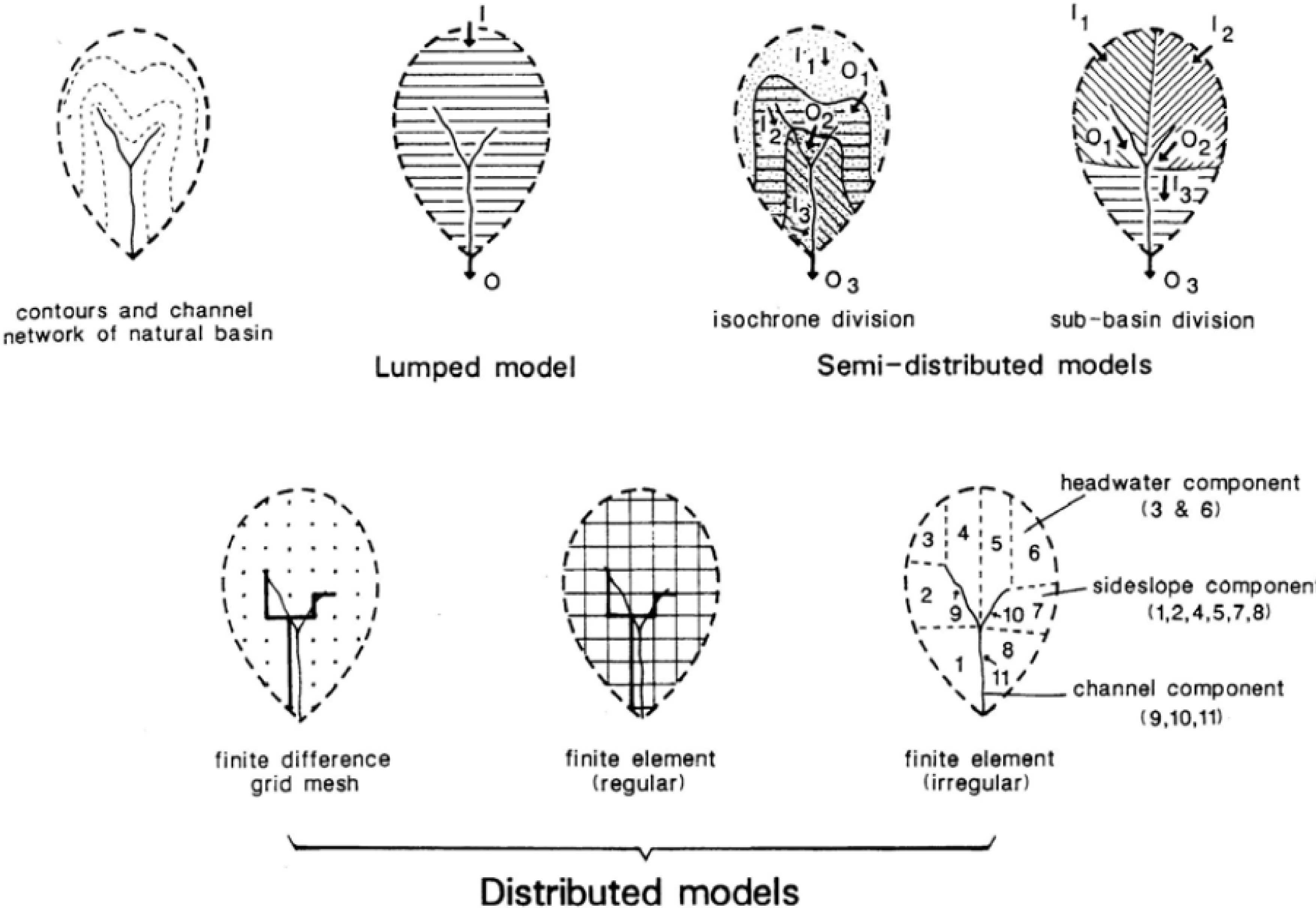
•Lumped - The spatial and temporal variation of meteorological, hydrological, geological and hydrogeological data across the model area is described as one aggregated value for input and output

!All models are lumped at the finest scale!

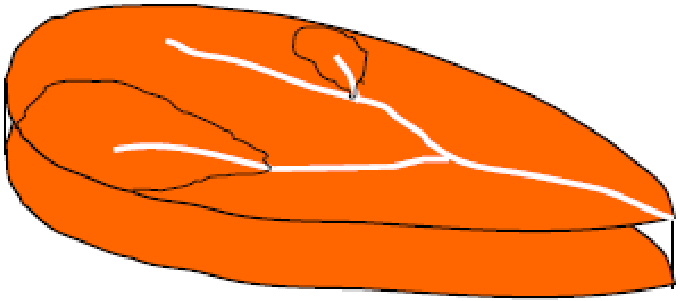


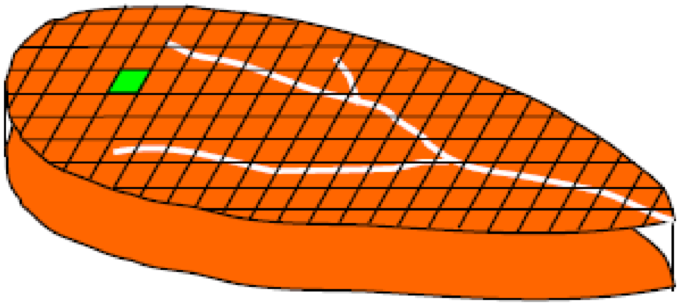
•Distributed - The spatial and temporal variation of meteorological, hydrological, geological and hydrogeological data across the model area is described in gridded form for the input as well as the output from the model

Lumped vs Distributed



Lumped vs Distributed





LUMPED SYSTEM

- Watershed averaged data
- Lumped description
- Low maintenance
- Black-box
- Highly Empirical

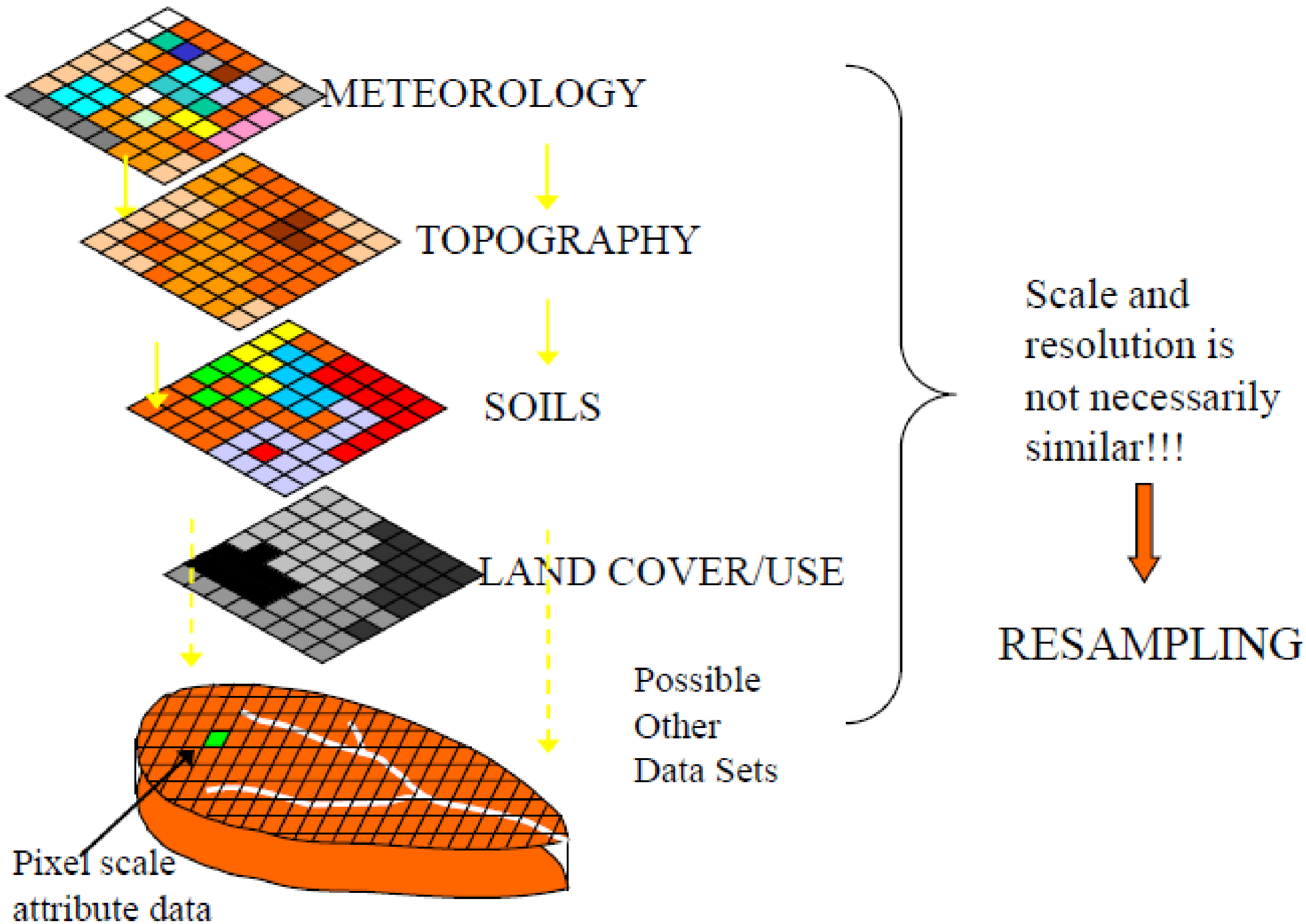
DISTRIBUTED SYSTEM

- Pixel-based data
- Distributed description
- High maintenance
- White-box
- Highly physical
- Spatial non-uniformity
- High requirements for data
- & computer resources

Lumped vs Distributed Models

- Lumped model might be used for:
  - Flood forecasting
  - Dam and reservoir design and operation
  - Water resources assessment
- Distributed model must be used for:
  - Land-use change impact assessment
  - Water quality/pollution simulation
  - Catchment management
- Data availability?

Data requirement for distributed models



Deterministic and stochastic models

- If for a given input, a model at each run with this input produces different outputs (i.e. both input and output are defined as random variables), then the model is **STOCHASTIC**.
- If for a given input, a model at each run with this input produces exactly identical outputs, then the model is **DETERMINISTIC**. (As such a deterministic model might be seen as a special case of a more general stochastic model).
- It is not a choice of either deterministic or stochastic. If uncertainty (in input variables, in state variables, in parameters) is an important issue of the problem to be solved then a stochastic model should be used.

Deterministic and stochastic models

Deterministic system:

Same input produces same output

Input → Model → Output

Stochastic system:

Same input produces different output

Input → Model →

- Probability for effect 1
- Probability for effect 2
- .
- .
- .
- Probability for effect n

Linearity vs Non-Linearity

- A model is linear in the system-theory sense (LST) if the principle of superposition holds:
  - if $y_1(t)$, $y_2(t)$ are the outputs corresponding to inputs $x_1(t)$, $x_2(t)$, a model is LST if $x_1(t)+x_2(t)$ is $y_1(t)+y_2(t)$.
- the model can also be linear in the statistical regression sense (LSR) if it is linear in the parameters to be estimated
  - if input $x(t)$ and output $y(t)$ were related by the equation $y = a + bx + cx^2$

Time-invariant and time-variant models

- Time-invariant if its input-output relationship does not change with time.
- Form of the output depends only on the form of the input and not on the time at which the input is applied.
- Most hydrologic systems are time-variant due to variations in solar activity during the day and seasonal variations during the year

General Models vs. Special Purpose Models

- **A *general model*** is one that is acceptable, without modifications, to watersheds of various types and sizes.
  - The model has parameters, either measured or calibrated, that adequately represent the effects of a wide variety of watershed characteristics.
  - In order to achieve this, it is generally necessary to use conceptual models which have parameters that require calibration.
- **A *special purpose model*** is one that is applicable to a particular type of watershed in terms of topography, geology or land use, e.g. an urban runoff model.
  - Usually, such models can be applied to watersheds of different sizes, as long as the character of the watersheds are the same.

Data Requirements for Models

- Rainfall Data (Major Input)
- Soils Data (Infiltration, Runoff)
- DEM – channel network (River routing)
- Vegetation Data (For ET)
- GWT Data (Saturated zone flow)
- Historical Rainfall-Streamflow Data (Calibration)
- Evaporation Data (ET)

More Physically-based means more data requirement

More Conceptual requires less data!

Data acquisition is an investment that needs to be commensurate with the model

Sources of Data

- Rainfall – Gage, Radar (NWS), Satellite
- Soils – STATSGO, USDA
- DEM – USGS, Topo maps, Satellites
- Vegetation – Satellites, USDA
- Streamflow – USGS

- Reliability
- Ready availability
- Cost $$$
- Resolution (space, time)

Is all data needed?

- Physically-based – Insatiable needs – but potential high returns
- Conceptual – modest needs with modest returns
- Calibration –needs historical data. What is Calibration?
- What to do in ungauged regions where there is ‘No Data’?
  - Transfer experience. PUB

What affects operational costs of a Model?

- Level of data needs – Data is expensive
- Level of physical complexity (Physically-based means qualified personnel; Rational Method – no-brainer
- Scale of the problem being addressed larger/heterogenous – more expensive

Some Models Out there

- HEC-1
- PRMS
- HSPF (Fortran)
- MIKE 11
- *Make your own survey if you wish* (Consider, DSS – Riverware, BASINS)

HEC-1

- Developed by Hydrologic Engineering Center (HEC) of US Army Corps of Engineers
- Flood Hydrograph Package – single storm even simulation. Lumped model
- Loss Function approach – SCS, Green Ampt, Holton
- Data Needs – sub-basin delineation, rainfall, runoff, routing parameters
- Based on Unit Hydrograph or kinematic for runoff routing
- Other capabilities – Snowfall/melt, dam safety, pumping, diversions
- Customer Support? – Try HEC, San Diego, CA.

PRMS – Precipitation-Runoff Modeling System

- Developed by USGS – more of an educational tool to build your own models
- Lumped/sub-basin –continuous simulation
- Data needs – (depends) precip, streamflow, DEM, minmax air temp, radiation, vegetation
- Code in F77
- Capabilities - many
- Customer Support? –USGS

HSPF Hydrological Simulation Program - Fortran

- USGS – multi-use model
- Can do water quality.
- Mainly for land-use change, reservoir operations, flow diversions etc.
- Data needs – A lot –
- Software – In Fortran 77
- Capabilities – A lot
- Customer Support? – Try USGS

MIKE 11

- Danish Hydraulic Institute DHI
- Very sophisticated – physically-based, high-end model
- Data needs – a lot (dependent of in-situ measurements
- Softwares – commercial (and expensive)
- Capabilities – Many
- Customer Support? – Try DHI or Vendors

WASMOD(WASMOD-M) or WASMOD-D)

- Available in many forms
- Daily or Monthly
- Different data requirements
- Complexity increases

What is the best Model?

- This is situational – *It All Depends!*
- Primary objectives
- $$ budget
- Level of Tolerable Accuracy/precision
- Complexity and uniqueness of the problem
- Time frame for delivery
- Data availability

It's a highly complex question whose answer is sensitive to a multiplicity of factors

METHODOLOGY FOR USING HYDROLOGIC MODELS

1. Define the problem.
2. Specify the objective.
3. Study the data available.
4. Determine the computing facilities available.
5. Specify the economic and social constraints.
6. Choose a particular class of hydrologic models.
7. Select a particular type of model from the given class.
8. Calibrate the model (that is, optimise the parameters).
9. Evaluate the performance of the model.
10. Use the model for prediction purposes.
11. Embed the model in a more general model.

Reading Assignment:

- Ngongondo et al. (2020), Multivariate Framework for the Assessment of Key Forcing to lake Malawi Level Variations in Non-Stationary Frequency Analysis, EMAS

Environ Monit Assess (2020) 192:593
https://doi.org/10.1007/s10661-020-08519-4

Multivariate framework for the assessment of key forcing to Lake Malawi level variations in non-stationary frequency analysis

Cosmo Ngongondo • Yanlai Zhou • Chong-Yu Xu

End of Lecture 2