Hydrologic Modeling Overview

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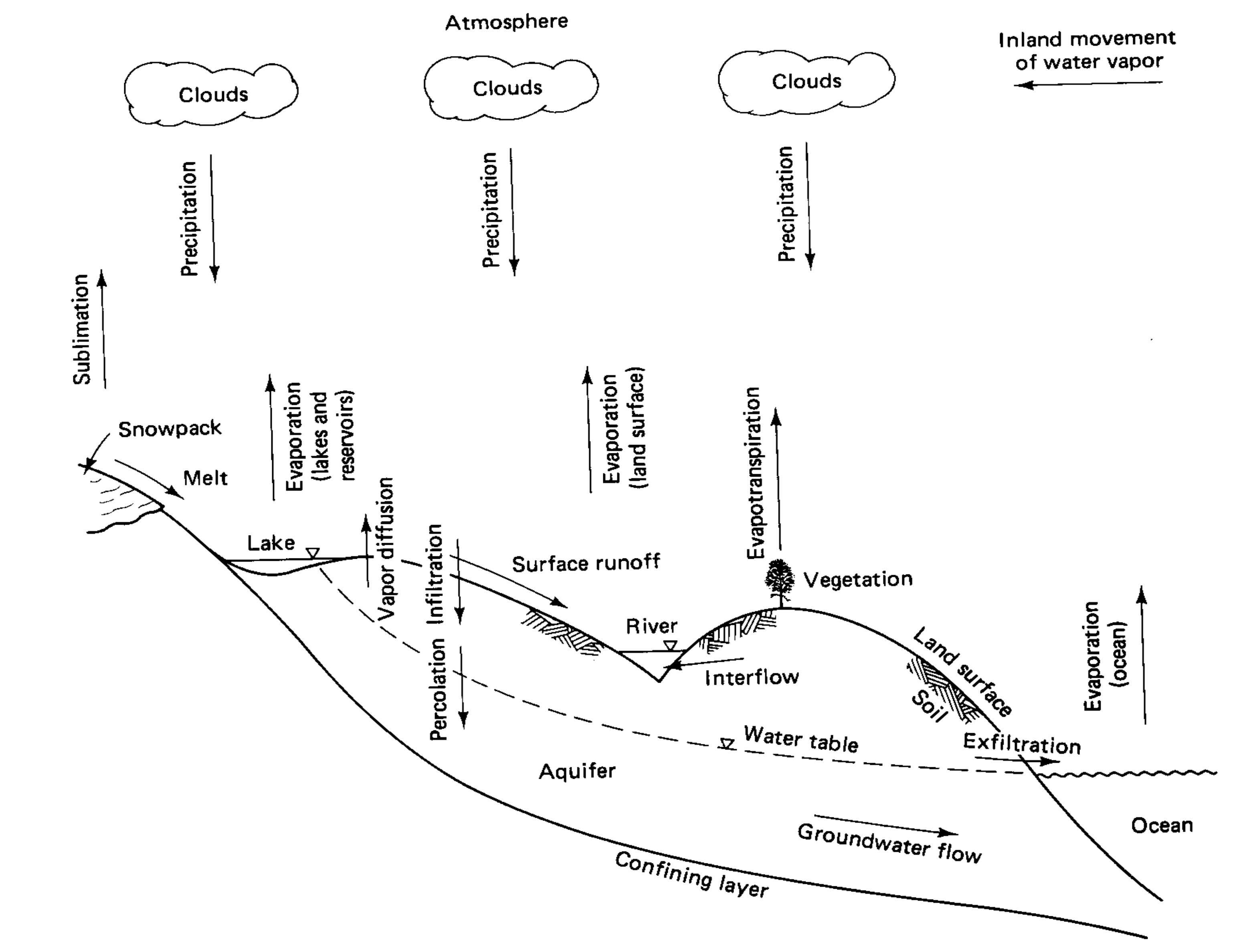
Discussion Topics

1. Hydrologic processes
2. Hydrologic modeling
3. Hydrologic modeling approaches
   - Empirical, lumped parameter models
   - Distributed, physics-based models
   - Hybrid models

1 - Hydrologic Processes

The Hydrologic Cycle



Sources of Stream Flow

- Hortonian, infiltration excess, runoff
- Saturated source areas
- Exfiltration
- Groundwater discharge to stream

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Infiltration Excess Runoff

- Infiltration excess runoff occurs when the rainfall intensity exceeds the infiltration capacity of the soil.
- Process described by Horton (1933), often referred to as Hortonian runoff.
- Dominant runoff mechanism in arid to semi-arid regions.
- Conditions conducive to infiltration excess runoff:
  - Fine texture soils
  - High intensity precipitation
  - Deep water table

Saturated Source Areas

- When the storage capacity of the soils in the unsaturated zone is filled infiltration no longer occurs, and runoff is equal to the precipitation intensity.
- Described by Dunne and Black (1970).
- Dominant runoff production mechanism in humid regions.
- Conditions conducive to saturation excess runoff
  - Permeable soils
  - Low intensity precipitation
  - High water table

Exfiltration

- When the elevation of the surface of the saturated groundwater exceeds the elevation of the land surface groundwater may discharge directly onto the land surface.
- Often called a seep or spring.
- Not typically a dominant runoff mechanism.
- Conditions conducive to seeps and springs
  - High water table
  - Breaks in slopes

Groundwater Discharge to Stream

- When the elevation of the saturated groundwater surface exceeds the free water surface elevation in the stream, groundwater may discharge directly to the stream.
- Often referred to as base flow.
- Can be a significant portion of water balance in humid areas, especially in larger basins.
- Conditions conducive to groundwater discharge to the stream
  - High water table
  - Permeable subsurface materials
  - Extended periods of rainfall

Mixed Basins

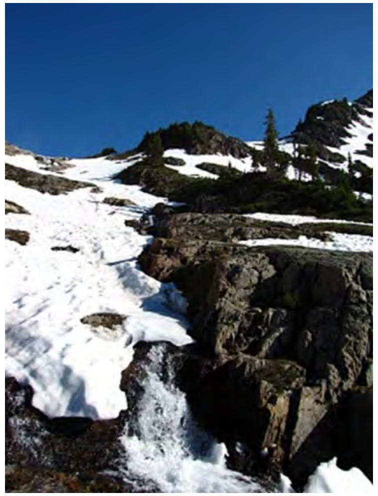
- Many basins are mixed basins
- Runoff is generated from a variety of methods
- Spikes in runoff are due to Hortonian flow
- Spikes in runoff may also occur due to saturation excess flow
- Long tails on hydrographs and base flow due to groundwater interaction with stream
- Streams gain and lose depending on location in stream and water table
- Different locations in the watershed may have different runoff mechanisms

Special Considerations

- Seasonality
- Soil layering

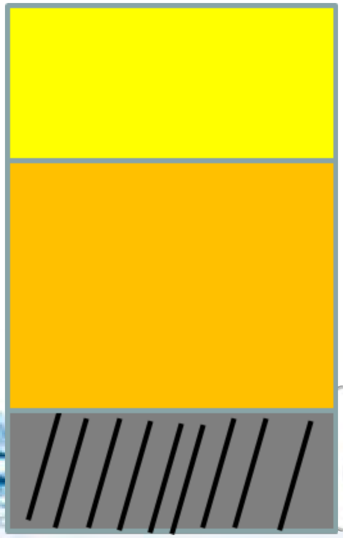
Seasonal Considerations

- Seasonal plant changes also affect vegetative interception of rainfall
- Snowfall accumulation affects, and can dominate, the timing of runoff and stream flow.
- Frozen soils can greatly inhibit infiltration and produce enhanced runoff.
- In temperate zones, seasonal plant changes change result in large changes in canopy resistance during the year
  - Inverse of leave area index
  - Controlling factor in evapo-transpiration



Soil Layering

- Soil layer can greatly affect infiltration
- Infiltration capacity, hydraulic conductivity, tends to be substantially lower in deeper layers
- Fragipans – very impermeable layers below the tilled soils, are common in agricultural areas
- Impermeable layers in the soil can cause perched water tables when ET is low
- Can result in a seasonality of the dominate runoff mechanisms
  - Hortonian for summer season
  - Saturation excess for winter/spring season



2 – Hydrologic Modeling

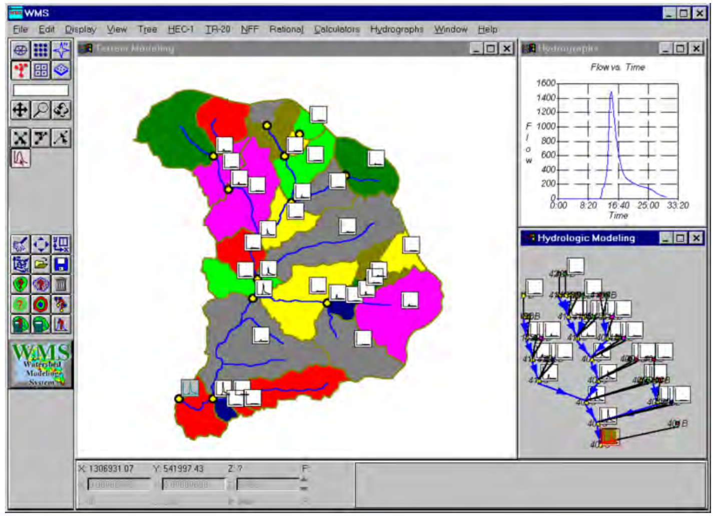
- Numerical Models
  - Represent complex natural systems with mathematical and empirical relationships.
  - System complexity is reduced, or processes are solved separately and then reassembled.
  - Provide a mechanism for analyzing project alternatives and predicting the effects of future changes, such as: urban development, land use change, or climate change.

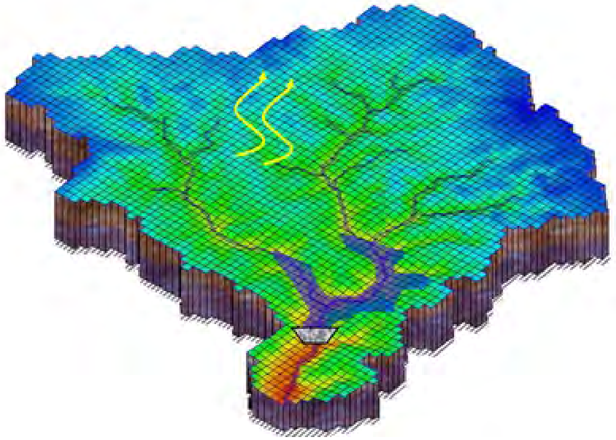
Computation Element

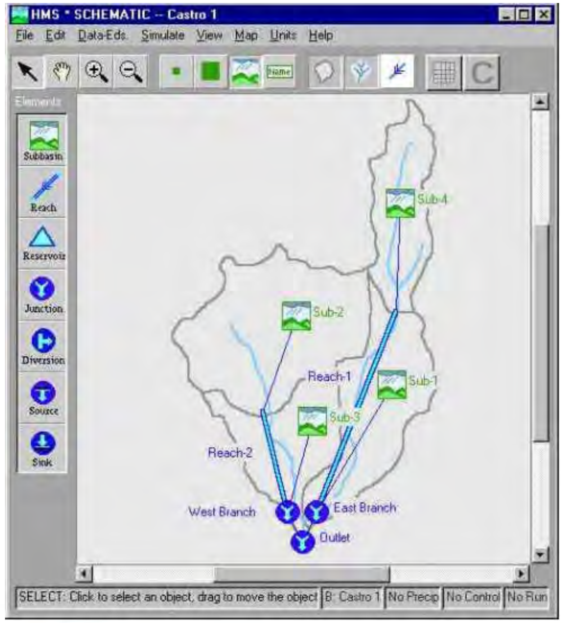
- Defined region in a model where calculations are performed
  - sub-watershed
  - grid cell
  - control volume
  - finite element node
- Physical conditions, and parameter values, are homogeneous throughout the computation element
- **Any heterogeneity within a computational element is lost, or must be implicitly included in the parameter values.**

3 - Hydrologic Modeling Approaches

- Empirically based, lumped parameter models
- Physically-based, distributed parameter models
- Hybrids – semi-distributed, quasi-physically based

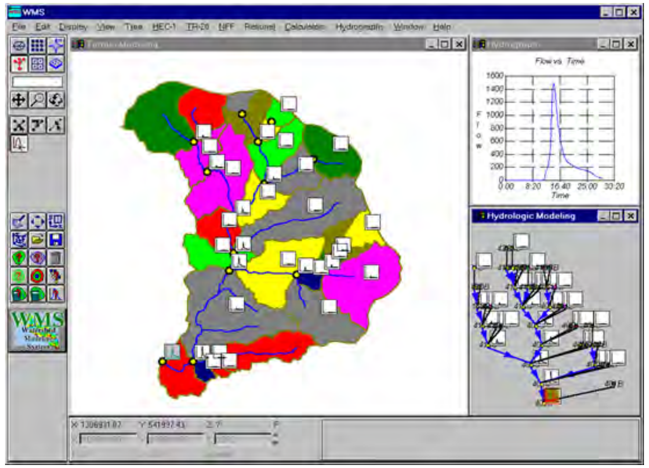


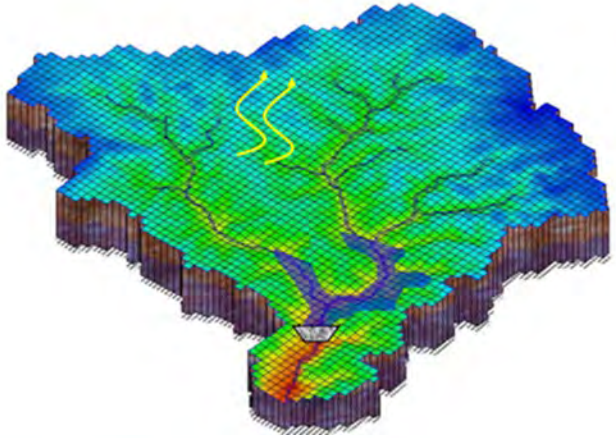




Dual Modeling Theories

- Empirically-based, lumped parameter models – integrated over large enough time and space scales, the highly non-linear response of watersheds appears linear.
- Physically-based, distributed parameter models – broken down into small enough time and space increments, the physical processes occurring in the watershed may be explicitly simulated, and then integrated to produce the watershed response.





Empirical verses Process Based Models

Empirical (lumped) Approach

- Computational element is the sub-watershed.
- Subdivide watersheds into smaller sub-watersheds.
- A single parameter value represents processes the entire sub-watershed.
- Empirical relationships relate system response to hydrologic inputs.
- Sub-basins are connected with simplified flow relationships - link/node

Process – (physics) Approach

- Computational element is the grid cell or node.
- Subdivide watersheds into cells/nodes.
- Parameter values can vary for each cell/node.
- Point physical processes (infiltration, ET, etc.) are computed at the cell/node level.
- Cell/node response is integrated to get system response (overland/subsurface flow, stream flow)

Advantages/Disadvantages

Empirical (lumped) Approach

- Simple to understand and use
- Long history of use
- Regulatory acceptance
- Short simulation times facilitate automated calibration methods
- Lumping of information
- No process information provided
- Parameters have limited physical meaning and may be difficult to estimate with changing conditions.
- Not reliable outside the range of calibration (verifiability problem)

Process – (physics) Approach

- More difficult to use
- Relatively new technology
- May need to justify use to regulatory agencies
- Long simulation times can hamper calibration efforts
- Explicitly includes spatial heterogeneity
- Model helps user understand physical processes in the system
- Parameters have physical meaning and don't change with changing conditions.
- Model can be used for new conditions

Hybrid Models

- Contain elements of lumped parameter and fully distributed, physics based models
  - Approach varies amongst models
- Mixture of empirical and physics based approaches within the model
- Semi-distributed models share many of the same advantages/disadvantages as simple lumped parameter models
  - Typically include greater spatial heterogeneity than simple lumped parameter models
  - May include more physically meaningful representation of processes than lumped models
  - Maintain the computational advantage over fully distributed, physics based models

Proper Use of Empirical, Lumped Parameter Models

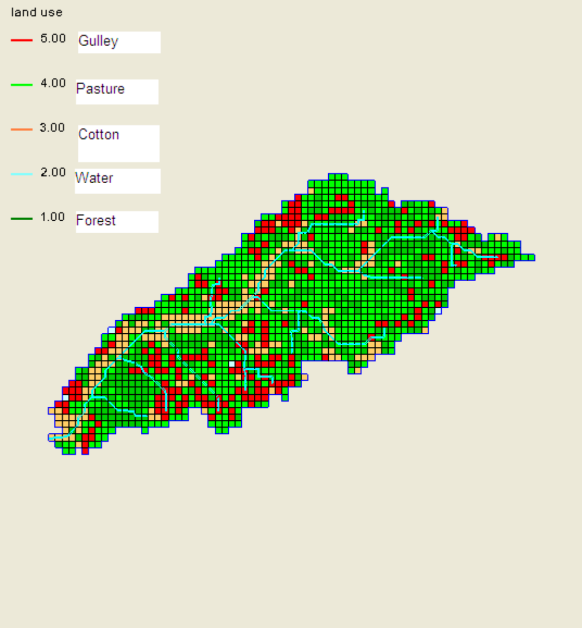
- Empirical lumped parameter models are best used for analysis of current systems.
- Can be applied to analyze very large basins
- Can be used to provide predictions within the range of calibration
- Can identify areas of concern
  - hotspots
  - source areas

Good Lumped Model Example

- National Weather Service River Forecast Centers uses the Sacramento Model for flood predictions
- The Sacramental model is a simple volumetric model with compartments representing different hydrologic regions
  - surface water
  - unsaturated zone
  - groundwater
- Model is automatically recalibrated every evening
  - extend the range of calibration
  - account for changes to the system.
- Model typically performs very well for forecast.

Distributed Modeling Example

- Goodwin Creek Experimental Watershed Erosion Modeling.
- Red and orange areas sources of sediment erosion.
- Green areas are sediment deposition areas.
- Only erosional areas near the stream contribute to the sediment load.
- The path matters!



Modeling Philosophy

- Model should account for dominant physical processes
- Model must include important physical features (both temporal and spatial)
- Model should not contain undue complexity
- Different approaches for different problems

Model representation of the physical system should be as simple as possible, but no simpler

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Conclusions

- The hydrologic cycle is complex
- Hydrologic modeling aids in understanding and analyzing hydrologic systems
- Hydrologic modeling falls into two large classes
  - empirical, lumped parameter models
  - distributed, physics based models
- Hybrid models contain elements of both
- Different types are useful for different purposes
- Lumped models are best for analysis
- Physics based models are best suited for design
- Hybrid models
  - refine analysis
  - screen design
- Physics based models range greatly in complexity
- The appropriate model depends on the application

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