Connecting the Dots: A Unifying Theory for Water Engineering

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Water Engineering

- Water Systems: Drainage, flood control, storage (dams), water supply, hydropower, diversion, river training, etc.
- Planning, design, operation and management of water systems; policy making; environmental assessment; impacts on society
- Integration of
  - Hydrologic engineering
  - Hydraulic engineering
  - Environmental engineering
  - Ecosystems engineering
  - Water resources engineering

Hydrologic Engineering

- Key Questions
  - What is the volume of runoff for a given rainfall?
  - What is the value of peak runoff (discharge) for a given rainfall?
  - What is the runoff hydrograph for a given rainfall?
  - What is the frequency or return period of a given runoff peak or flood?
  - How can streamflow be simulated for a given time?
  - How can streamflow be forecasted ahead of time?

Application

- Runoff volume
  - Rainwater harvesting structures design, recharge basins, wetland design, etc.
- Runoff peak
  - Urban drainage design, arterial airfields, parking lots, etc.
- Runoff hydrograph
  - Hydrologic design, erosion and water quality determination, impact studies, etc.
- Runoff peak or flood frequency
  - Hydrologic design, climate change impact, assessment, flood mitigation measures, etc.
- Streamflow simulation
  - Reservoir operation, policy formulation, etc.
- Streamflow forecasting
  - Flood management and evacuation measures, etc.

Hydrologic Engineering Landscape

- Methods of Solution
  - Volume of runoff for a given rainfall
    - Empirical: Regression
    - SCS-CN method
    - Infiltration-based technique
    - Watershed simulation
  - Peak runoff for a given rainfall
    - Rational method
    - Standardized peak discharge relation
    - Unit hydrograph
    - Physically based
  - Runoff hydrograph for a given rainfall
    - Unit hydrograph
    - Kinematic wave and diffusion wave theories
    - Watershed simulation

Hydrologic Engineering Landscape (Contd.)

- Methods of Solution
  - Runoff peak or flood frequency
    - Empirical
    - Physically based
  - Streamflow simulation
    - Time series analysis (e.g., AR, ARMA, ARIMA, disaggregation, etc.)
    - Nonparametric models
  - Streamflow forecasting
    - Time series analysis (e.g. spectral analysis, etc.)
  - Nonparametric models

Hydraulic Engineering

- Key Questions
  - What is the velocity distribution in open channel flow?
  - What is the concentration of sediment in open channel flow?
  - What is the sediment discharge of a river?
  - What is the hydraulic geometry of a river?
  - What is the optimal canal design?

Application

- Velocity Distribution
  - Flow modeling
  - Scour modeling
  - Bed profiles
- Sediment Concentration and Sediment Discharge
  - Environmental pollution
  - Bed forms
  - Sedimentation
- Hydraulic Geometry
  - River training
  - Restoration
- Optimal Canal Design
  - Irrigation
  - Drainage

Hydraulic Engineering Landscape

- Methods of Solution
  - Velocity Distribution
    - Empirical
    - Quasi-physical
    - Probabilistic
  - Sediment Concentration and Sediment Discharge
    - Empirical
    - Quasi-physical
    - Probabilistic
  - Hydraulic Geometry
    - Empirical
    - Theoretical
  - Optimal Canal Design
    - Empirical
    - Quasi-theoretical

Water Supply Engineering

- Key Questions
  - How to design a water supply system?
  - What is the reliability of the water distribution system?
  - What are environmental impacts?

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Water Supply Engineering Landscape

- Methods of Solution
  - Design of a Water Supply System
    - Hydraulic
    - Optimization: deterministic and stochastic
  - Reliability of Water Distribution System
    - Hydraulic
    - Optimization
    - Stochastic

Environmental Resources

- Key Questions
  - What is environmental flow?
  - What is eco-index?

Environmental Resources Landscape

- Methods of Solution
  - Environmental Flow
    - Hydrologic indices
    - Indicators of hydrologic alterations
  - Eco-index
    - Hydrologic
    - Probabilistic

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Development of a Unifying Theory

- Entropy Theory
  - Entropy: a measure of disorder, chaos, uncertainty, surprise, or information
    - Information reduces uncertainty; more information means less uncertainty
    - Uncertainty increases need for information; more uncertainty means more information is needed.

Entropy, Information and Uncertainty

- Information is gained only if there is uncertainty about an event.
- Uncertainty suggests that the event may take on different values.
- The value that occurs with a higher probability conveys less information and vice versa.
- Shannon (1948) argued that entropy is the expected value of the probabilities of alternative values that an event may take on.
- The information gained is indirectly measured as the amount of reduction of uncertainty or of entropy.

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Types of Entropy

- Real Domain
  - Shannon Entropy
  - Tsallis Entropy
  - Exponential Entropy
  - Kapur Entropy
  - Renyi Entropy
  - Cross or relative Entropy
  - Others
- Frequency Domain
  - Burg Entropy
  - Configurational Entropy
  - Relative Entropy

Development of Entropy Theory

- Elements of Entropy Theory
  - Definition of Entropy
  - Principle of Maximum Entropy (POME)
  - Theorem of Concentration
  - Principle of Minimum Cross-Entropy (POMCE)

*Singh, V.P. (2013). Entropy Theory and its Application in Environmental and Water Engineering. 642 pp., John Wiley.
* Singh, V.P. (2014). Entropy Theory in Hydraulic Engineering. 785 pp., ASCE Press, Reston, Virginia.
* Singh, V.P. (2015). Entropy Theory in Hydrologic Science and Engineering. 824 pp., McGraw-Hill Education, New York.

Methodology for Application of Entropy Theory

- Define entropy.
- Specify constraints.
- Maximize entropy using POME.
- Use the method of Lagrange Multipliers.
- Determine Lagrange multipliers in terms of constraints.
- Probability distribution in terms of Constraints.
- Determine the maximum Shannon Entropy.
- Derive the desired result.

Conclusions

- Entropy theory provides a probabilistic description and makes a statement on uncertainty. This has important implications for sampling, model reliability, and policy making.
- The use of entropy theory leads to explicit relations with meaningful science.
- There are two fundamental issues that need to be addressed: (1) Specification of information, and (2) hypothesis on flux-concentration relation.

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