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Water Distribution Modelling

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Lecture-4:
Model Calibration and Optimization

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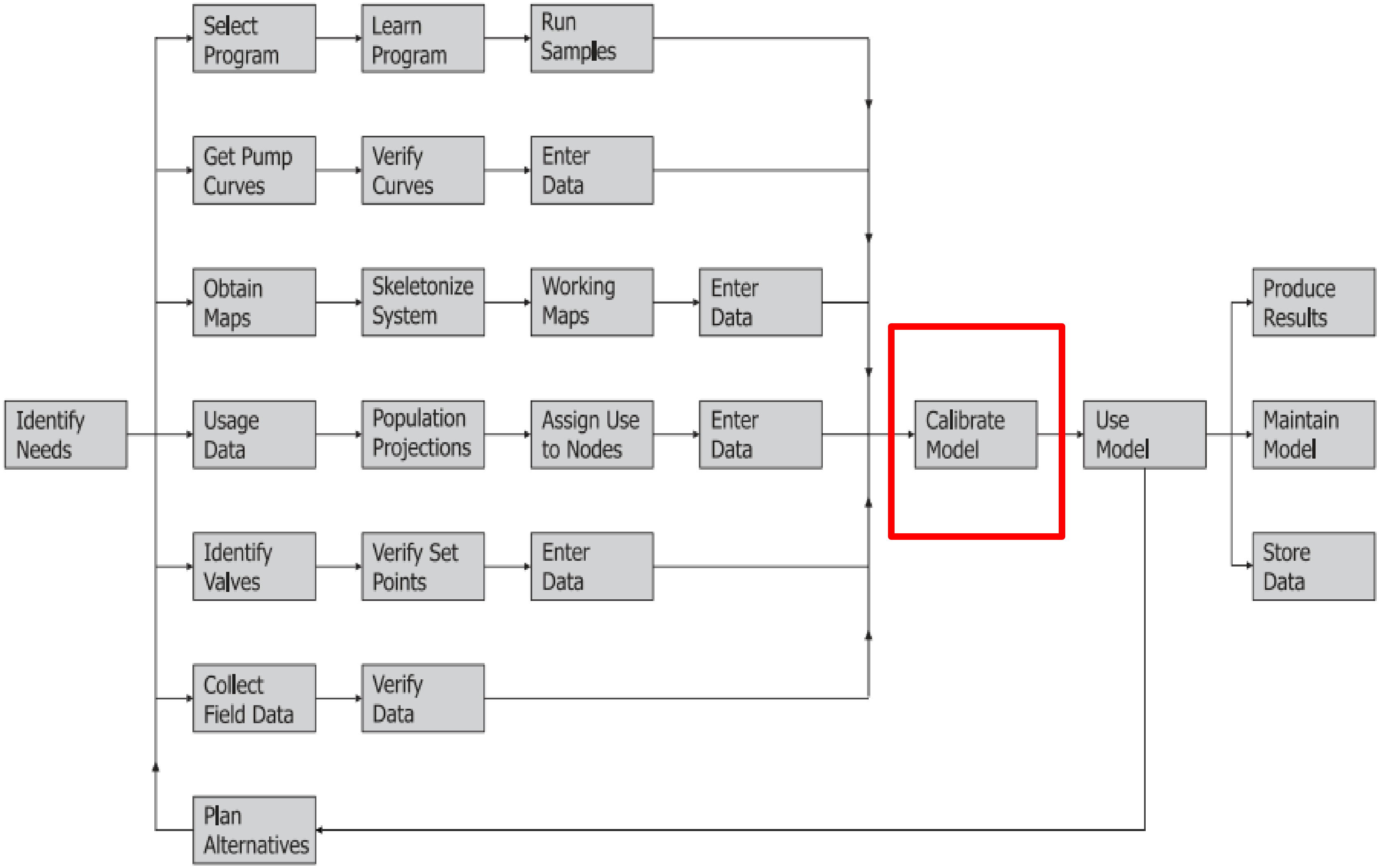
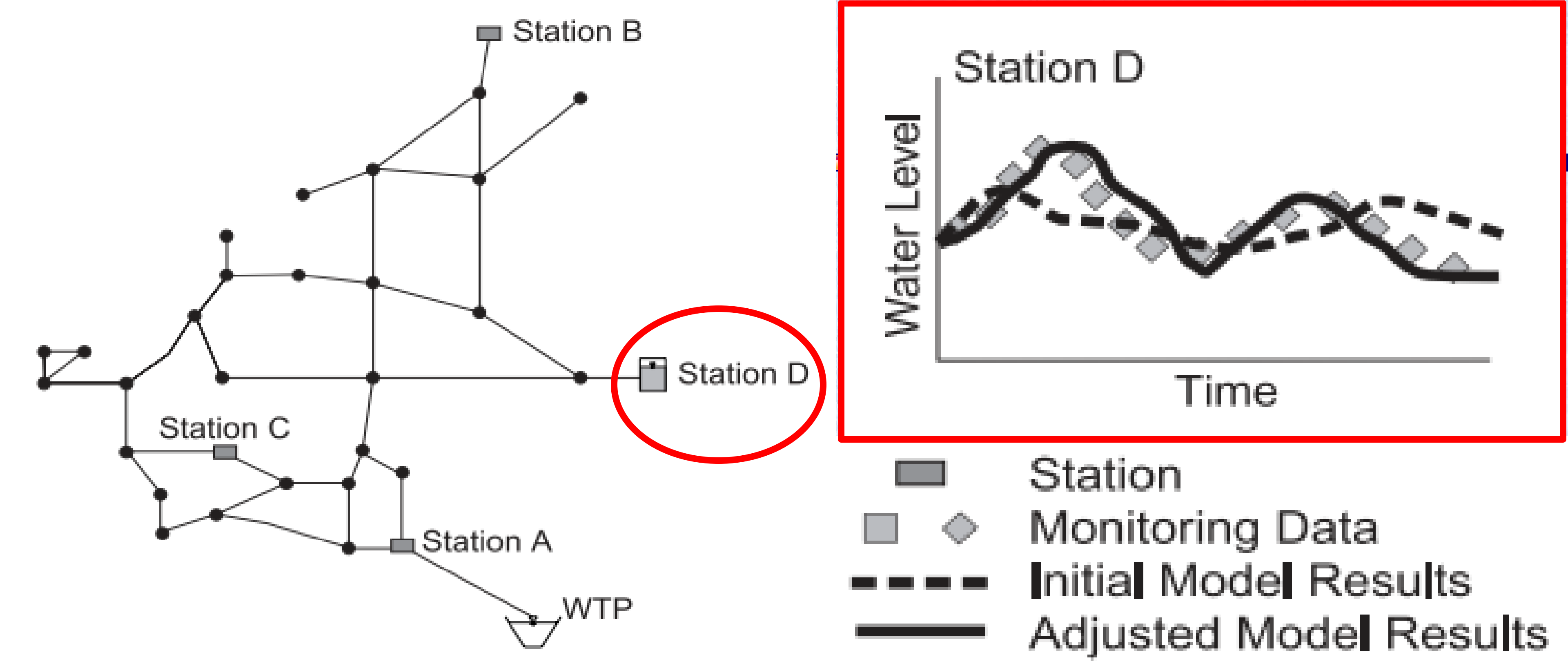
2020

Contents of the Course

The Modeling Concept…





Model Calibration

Topics

- Definition
- Calibration approaches
- Steps of Calibration
- Optimization Formulation
- Data for Calibration
  - Planning field tests
  - Flow measurements
  - Meter calibration
  - C-factor tests
  - Diurnal demands
  - Hydraulic gradient tests
  - HGL tests
  - Fire flow tests

The Modeling Process-
(Model Calibration)

- **Definition:**
  - The accuracy of a hydraulic model depends on how well it has been calibrated, so a calibration analysis should always be performed before a model is used for decision-making purposes
  - ***Calibration*** *is the process of comparing the model results to field observations and, if* necessary, adjusting the data describing the system until model-predicted performance reasonably agrees with measured system performance over a wide range of operating conditions.

The Modeling Process- (Model Calibration)

- The **Process of calibration** may include:
  - Changing system demand
  - Fine-tuning the roughness of pipes
  - Altering pump operating characteristics
  - Adjusting other model attributes that affect simulation results

The Modeling Process- (Model Calibration)

- The Calibration process is necessary for the following reasons:
  - Confidence
  - Understanding
  - Troubleshooting

The Modeling Process-
(Model Calibration)

- Calibration Approaches (Generally two stages)
  - Rough-tuning (Macro calibration)
    - Bringing predicted and observed system parameters into closer agreement with one another
  - Fine-tuning (Micro calibration)
    - Adjusting the pipe roughness values and nodal demand estimates.

Challenge in Calibration: Making judgments regarding the adjustments that must be made to the model to bring it into agreement with field results

The Modeling Process-
(Model Calibration)

- **Seven steps** to guide the model calibration:
  1. Identify the intended use of the model.
  2. Determine estimates of model parameters.
  3. Collect calibration data.
  4. Evaluate model results based on initial estimates of model parameters.
  5. Perform a rough-tuning or macro-calibration analysis.
  6. Perform a sensitivity analysis.
  7. Perform a fine-tuning or micro-calibration analysis

The Modeling Process-
(Model Calibration)

- Model Calibration Approaches:
  - Manual (trial-and-error) Calibration Approaches
    - *involves the modeler's supplying estimates of pipe roughness values and nodal demands, conducting the simulation, and comparing predicted performance to observed performance*
    - *Can be performed using one steady-state simulation but to improve results further, an EPS based calibration shall be conducted.*
    - *In EPS, calibration is performed until there is reasonable agreement between modeled and observed **pressures, flows, and tank water levels***
  - Automated Calibration Approaches

The Modeling Process- (Model Calibration)

- Model Calibration Approaches:
  - Automated Calibration Approaches
    - *Because many potential combinations of calibration parameters exist, finding the best set of parameters presents a challenge to the engineer while using manual approaches; hence, Computer-based, numerical optimization techniques are used.*
    - *Automated approaches can be grouped in* ***three*** *categories:*
      - **Iterative** procedure models
      - **Explicit** Models (or hydraulic simulation models)
      - **Implicit** Models (or Optimization models)

The Modeling Process- (Model Calibration)

- **Iterative models :**

  - Unknown parameters are updated at each trial or iteration using heads or flows obtained by running a simulation model.

  - For this group of models:
    - *Simplifying the WDM is necessary*
    - *Only small calibration problems can be effectively handled*
    - *Convergence rate of the iterative models is rather slow*

The Modeling Process- (Model Calibration)

- **Explicit models :**
  - These are based on solving an extended set of steady-state, mass-balance, and energy equations.
  - They solve for roughness or demand as well as pressure and flow.
  - Disadvantages:
    - *Calibration problem must be even-determined (i.e. number of calibration parameters must be equal to the number of measurements)*
    - *Measurement errors are not taken into account (i.e. measured heads/flows are completely accurate)*
    - *It is difficult to quantify the uncertainty of the estimated calibration parameters.*

The Modeling Process-
(Model Calibration)

- **Implicit models :**
  - These are models consists of optimization-based models.
  - The calibration problem is represented as an optimization problem by introducing an **objective function**.
  - The problem is solved **implicitly**, usually by minimizing the objective function

  - Three commonly used objective functions are:
    - *Sum of squared errors (SSE)*
    - *Sum of absolute errors (SAE)*
    - *Maximum absolute error (MAE)*

The Modeling Process- (Model Calibration)

❑ Optimization Problem Formulation:

- The optimization methods search for a solution describing the unknown calibration **parameters** that **minimizes** an **objective function**, while simultaneously satisfying **constraints** that describe the feasible solution region.

- The objective function usually minimizes the sum of the squares of differences between observed and model-predicted heads and flows

Optimization Problem Formulation…

- Assume vectors of unknown as x (i.e. roughness, demand, control status), the objective function may be given as

$$\min_{x} f(x) = \sum_{i=1}^{N} w_i [y_i^* - y_i(x)]^2$$

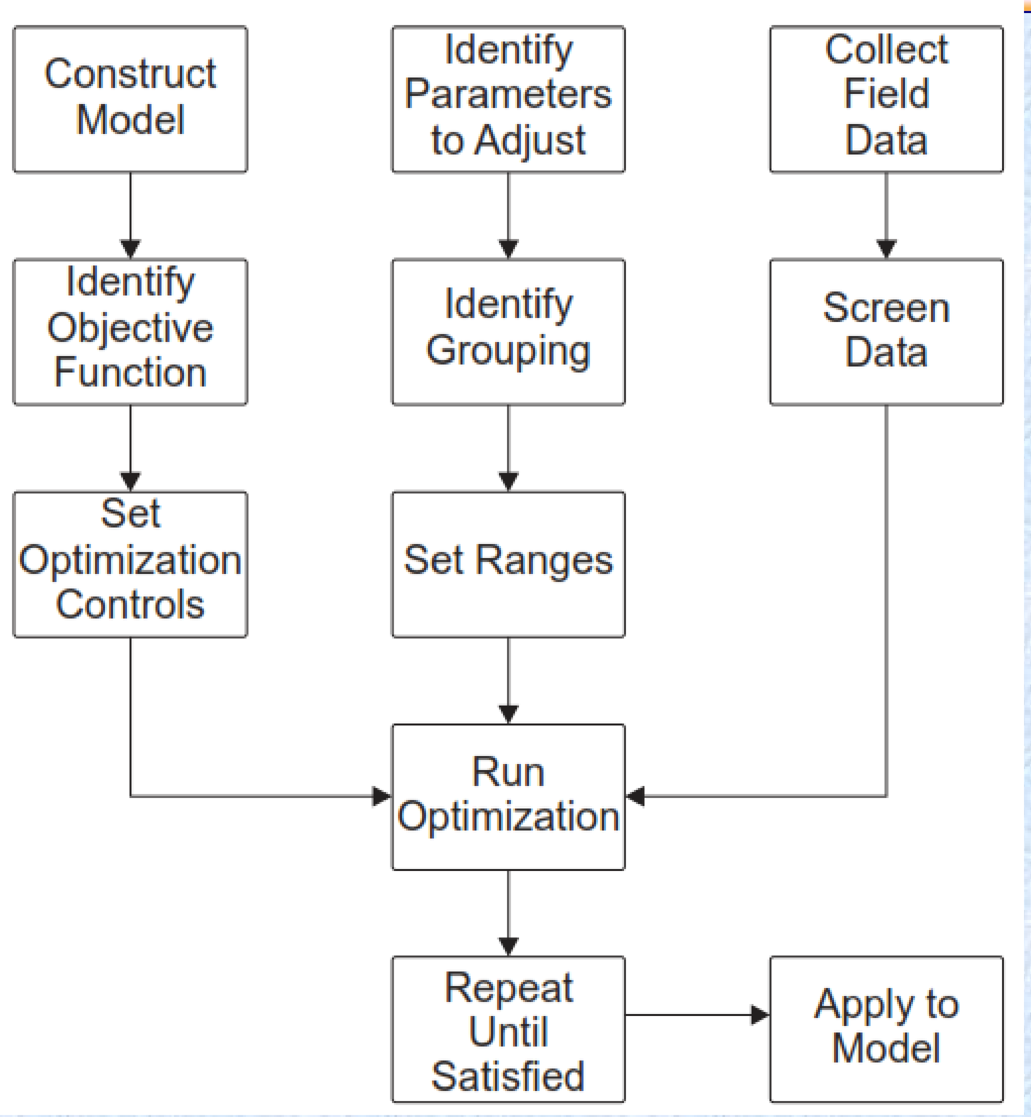
where
- f = objective function to be minimized
- x = vector of unknowns
- N = number of observations
- w_i = weighting factors
- y_i^* = observation (head, flow)
- $y_i(x)$ = model predicted system variable (head, flow)

Read Walski, Page 271-280)

The Modeling Process- (Model Calibration)

The Calibration

Optimization Process



Read Walski, Page 271-280)

The Modeling Process- (Model Calibration)

- Hydraulic Testing (**Data for Calibration**)
  - Major control points
  - Flow monitoring is done at all inlets and outlets
  - Reservoir levels, pump station flows, and pump station pressures provide valuable information during fire flow tests.

The Modeling Process-(Model Calibration)

- Flow measurements
  - Flow measurements are an integral part of meter tests, C-factor tests, diurnal demand measurements, pump tests, and fire-flow tests. Flow-measuring equipment in water supply includes hydrant pitot gauges, pitot tubes, master meters, and portable magnetic meters.

The Modeling Process- (Model Calibration)

- C- Factor tests
  - Measuring C-factors for each and every pipe is usually not practical; therefore, assumptions are made based on a sample of C-factor measurements. The sampling includes all combinations of pipe sizes and materials, and also old and new pipes. Larger pipes tend to have higher coefficients. If there are unlined cast iron pipes in the system, they should definitely be included in the sample, as C-factors vary widely from less than 25 to over 100, depending on the pipe age and water quality.

The Modeling Process- (Model Calibration)

- C- Factor tests
  - It is important to take C-factor measurements near sources where treatment processes have coated the inside of pipes.

The Modeling Process- (Model Calibration)

- Diurnal demand measurements
  - Diurnal demand is the variation in water demand over a 24-hr period
  - Knowledge of diurnal demand provides information on demand peaks, determines peaking factors, as well as the distribution of demand over time.
  - Diurnal demand measurements also allow the user to easily check for leakage. Excluding industrial use, a minimum demand flow rate over 50 percent of the average flow rate indicates the likelihood of leakage

The Modeling Process-
(Model Calibration)

- Pump Tests
  - Data from pump tests are entered into the model for simulating hydraulic performance and for calculating energy costs. Input data based strictly on design curves introduces significant errors, as true performance is sometimes quite different from design parameters caused by worn impellers, undocumented equipment changes, or trimming of impellers.

The Modeling Process- (Model Calibration)

- Pump Tests
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  - Tests usually include normal conditions, design conditions, induced flow, throttled flow, etc.

The Modeling Process-
(Model Calibration)

- Hydraulic Gradient Tests
  - Hydraulic gradient tests consist of taking simultaneous flow and pressure measurements at intervals along a pipe path, under the condition of steady flow. In large systems, the tests follow trunk mains between plants, tanks, and pump stations
  - In small systems, the tests follow pipes from sources to flowing hydrants at key locations. Pressure measurements are taken at plants, on the inlet and outlet of pump stations, at tanks and major pipe intersections, and where pipe diameters transition. At key pipe sections, the flow rate is measured.

The Modeling Process-
(Model Calibration)

- Fire Flow Tests

  - Fire flow tests are used to determine friction factors in pipes near hydrants. These tests consist of simultaneously taking flow and pressure measurements at selected locations. These simple tests are an inexpensive way of checking a model against measured values..

The Modeling Process-
(Model Calibration)

- Other Tests
  - Some models require conducting other types of tests. Modeling pressure-reducing valves requires accurate downstream pressure measurements at known elevations. Pressure and flow measurements are useful in modeling other types of control valves. Pressure and tank level measurements are necessary for checking the accuracy of data from water plant charts and SCADA systems

The Modeling Process-
(Simulation/caliberation)

- Steady state
- Extended period simulation
- Transient simulation

The Modeling Process- (Simulation/caliberation)

- Steady state
  - A steady-state model simulation predicts behavior in a water distribution system during a hypothetical condition where the effects of all changes in the operation and demands of the system have stopped. Steady-state analysis is sometimes compared with taking a snapshot picture of the distribution system.

The Modeling Process-(Simulation/calibration)

- Steady state calibration : trial and error approach and/or automatic.
- Fine-tuning a model means correcting errors and adjusting the data to within .reasonable limits. Examples of errors that are in the data include incorrect pipe sizes or interconnections that do not exist. Adjustments to the data usually involve demand distribution, friction coefficients, and controls, such as pump curves. Unreasonable adjustments, such as changing C-factors to 25 for lined pipes, may force models to match measurements without finding underlying problems, such as closed valves.

The Modeling Process-(Simulation/calibration)

- Manual method prohibitive for large networks. Genetic algorithm way out.
- The need for calibration arises because of uncertainties and assumptions in the data. Assumptions include Hazen-Williams coefficients, skeletonization, pump performance, and demand loading (Cruickshank and Long).

The Modeling Process-(Simulation/calibration)

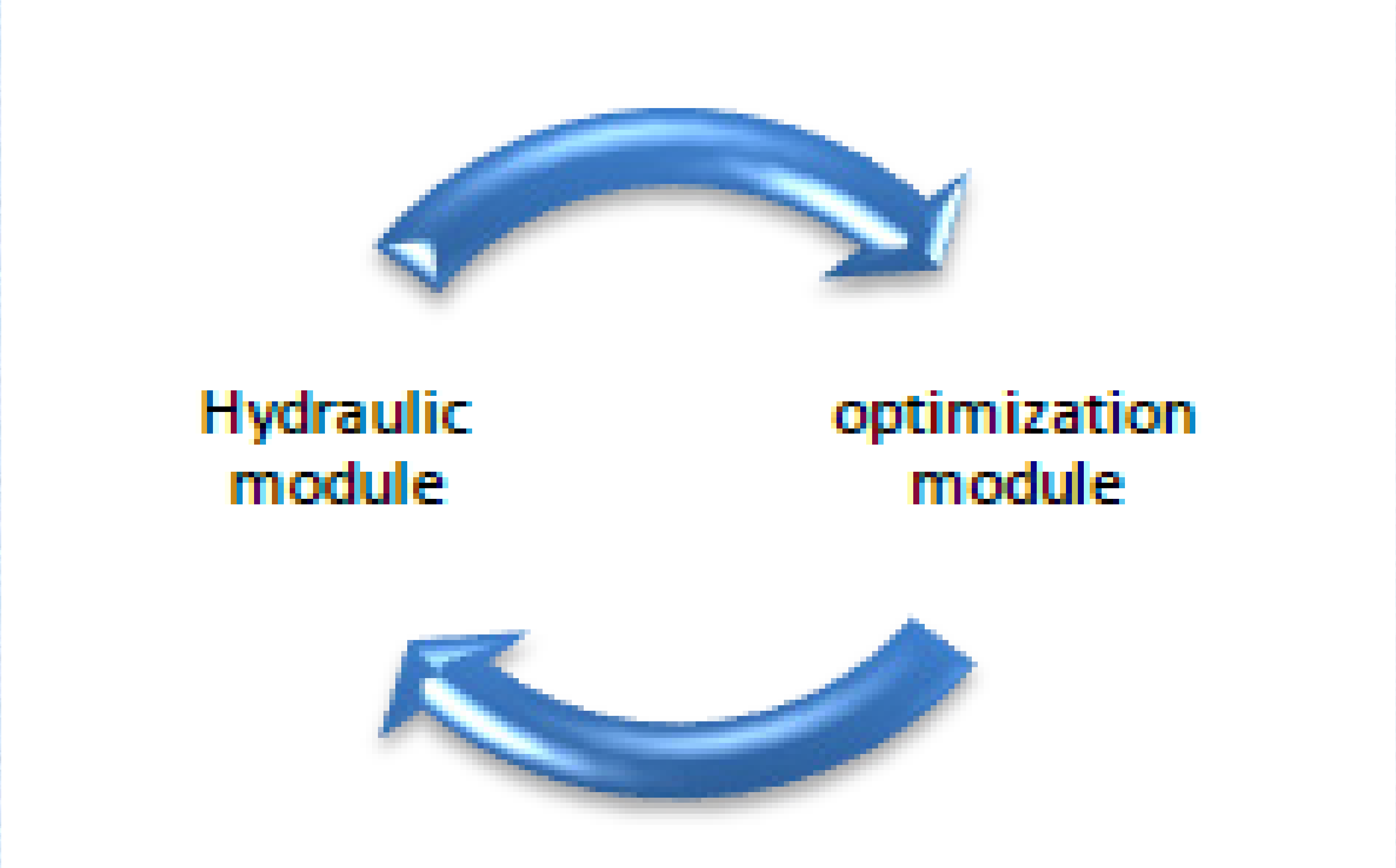
Table 4-1 Typical model scenarios

Purpose of the Analysis	Recommended Steady-State Demand Scenario
Studies of normal operation	Maximum day
Production and pumping requirements	Maximum day
Design—small systems	Maximum day plus fire flow
Design—large systems	Maximum hour of maximum day
Tank filling capabilities	Minimum hour of maximum day
System reliability during emergency or planned shutdown	Condition when the emergency or shutdown is likely to occur
Model calibration	Condition during time when measurements were collected

Advanced Design Procedures

- The design process as a function of a number of competing objectives.
- Optimal solution

Advanced Design Procedures



Advanced Design Procedures

- Objectives of
  - the hydraulic model should be framed
  - optimization model should be framed.

- The optimization model
  - estimates the cost of the network and settles with the least cost satisfying all the constraints.
  - The network cost is calculated as the sum of the pipe costs where pipe costs are expressed in terms of cost per unit length. Total network cost is computed as follows:

$$C = \sum c_k(D_k) \cdot L_k \qquad (9)$$

where, $c_k(D_k)$ = cost per unit length of the k^{th} pipe with diameter D_k,

L_k = length of the k^{th} pipe.

Advanced Design Procedures

- The optimization module keeps on checking the combination of pipe diameters satisfying the head conditions and resulting in the least cost of the network.

Research Trends

- Real time modeling for system operation
- Integrated optimization –hydraulic modeling