Modelling Urban Drainage
Part 2
Modelling Process,
Error in modelling,
Calibration and Validation

Solomon Seyoum
Objectives

- To discuss modelling process
- To discuss error sources in modelling
- To discuss the process of model calibration
- To discuss the process of model validation
- To discuss some of model performance criteria
Modelling process

- A *mathematical model* is a set of equations that describes some physical process.
  - Example: The Manning equation
- A computer model usually contains one or more mathematical models.
  - A program such as SWMM5 can model flow in a sewage collection system.
- A *system model* consists of the computer model plus all of the data necessary for a particular system model.
  - For example, SWMM5 plus the data files describing the collection system in a particular urban area, comprise the sewer system model of that area.
- The word *modelling* is most often used to describe the process of creating and using a system model for a specific system.
Modelling Process

- Urban drainage models are used for
  - design,
  - long-range master planning,
  - water quality investigations,
  - operational analysis,
  - capacity assessments, and
  - regulatory compliance
Modelling Process

- **Long-Range Master Planning** – is the process of investigating a drainage system and its projected flows to determine which capital improvement projects are necessary to ensure quality of service for the future. It usually includes an activity to project system growth and wastewater and stormwater flows for design horizons of 5, 10, 20 years, or more.

- **Examples:**
  - Identify potential problem areas resulting from growth.
  - Determine location and capacity of new pumping stations.
  - Prepare cost estimates for alternative schemes.
Modelling Process

- **Design** - In the design of new sewer systems or the expansion of existing systems, hydraulic models simulate the performance of the individual components and the collection system as a whole. During the design process, numerous configurations, and alternatives may be evaluated to determine pipe sizes, elevations, and alignments. Checking the size of a pipe or the performance of a proposed pump under anticipated conditions are examples of how a model is used in design.

- **Examples:**
  - Determine optimum configuration of laterals, collectors, and force mains.
  - Determine required size of pipes, pumps, wet wells, and elevations.
Modelling Process

- **Rehabilitation Studies** - Hydraulic simulations can be used to aid the design of rehabilitation efforts, to assess the effects of such rehabilitation, and to determine the most economical improvements.

- **Examples:**
  - Identify causes of sewer overflows.
  - Assess the hydraulic improvements resulting from replacement or relining of pipes
Modelling Process

- **Operations** - A model can simulate different daily operation schemes to determine the effect of various actions, such as modifying pump station operation, providing the operator with better information with which to make decisions.

- **Examples:**
  - Analyze downstream flows resulting from pump-control strategies.
  - Analyze alternative wet weather flow-control schemes.
  - Analyze pump station operation effectiveness.
  - Determine sections of the sewer system prone to siltation.
Modelling Process

- **Water Quality Investigations** - Overflows must be eliminated in sanitary systems, while in combined systems they must be minimized to reduce water quality impacts. Models can help us to understand where, when, and why sewers overflow and to assess mitigation measures, which can improve water quality.

- **Examples:**
  - Determine location, frequency, and water quality of sewer overflows.
  - Determine effect of sewer flows on treatment plant operation.
  - Analyze options to reduce frequency and volume of overflows.
Modelling Process

- **Regulatory Compliance** - Models can demonstrate whether the system has adequate capacity and its effect on water quality.
- **Examples:**
  - demonstrate system has adequate capacity to convey base and peak flows.
Modelling Process

- **Types of Collection System Modelling**
  - steady-state and unsteady flow modelling.
  - *Steady-state* models assume constant flow rates at each point in the system and can be thought of as a snapshot in time of the changing conditions of the system.
    - for predicting these peak flows
    - to determine if the velocities at lower flow rates are sufficient for self-cleansing

- For larger systems or systems with widely varying flows, such that pump cycling or storage in the pipes is significant, simulation of *unsteady-flow* conditions becomes important.
- This is accomplished by routing flows through the system by solving the more complex hydrodynamic equations.
Modelling Process

1. Define Scope of Project
2. Collect calibration and verification data
   - Verify data
3. Collect input data
   - Enter input data
4. Prepare system description
   - Enter system data
5. Select modelling software
   - Learn software
6. Initial model
7. Calibrate and verify model
8. Refine alternatives
9. Apply model
10. Develop alternatives
11. Develop solutions
12. Archive model
13. Update model
14. Document results

Develop solutions

Define Scope of Project

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Error in Modelling

- Generally errors creep into the model in three ways:
  - Model error (model structure error)
  - Data error
  - Parameter error
Error in Modelling

- Model structural error
  - It can have several origins, such as
    a. incorrect representation of the processes (both in terms of physical description and of spatial and temporal discretization),
    b. disregarding of processes which are not represented and
    c. implementation errors in numerical algorithms and computer codes
Error in Modelling

- Data error
  - affects both input and observations used to evaluate the fit of the simulated outputs.
  - This error affects both the magnitude and the timing of the measurements.
Error in Modelling

- Parameter error
  - arises because of the uncertainty in determining the values of the model parameters.
  - For calibrated models, this error also accounts for the fact that the parameter set adjustment can compensate for the other types of error.
Model calibration

- Model calibration is the process of estimating the values of the model parameters so that the model responses satisfactorily simulate the behaviour of the modelled system.

- This process is also called “model optimization”, because its scope is the reduction of the model error.

- It is also defined as “inverse modelling”, since the observations of the model outputs are used to estimate the parameter values, as opposed to direct modelling, in which fixed parameter values are used to estimate the model outputs.
Calibration can be done manually or automatically

- manually by “trial-and-error” parameter adjustment, with the aim of improving the model simulations up to the desired level
- the model goodness-of-fit is judged by
  - the modeller by visual comparison of the simulated responses with the observed variables and/or
  - by using classical mathematical measures of model performance (such as the root mean squared error, the correlation coefficient and similar)
Model calibration

- Manual calibration method has the disadvantages of being
  - time consuming,
  - requiring a high degree of expert-knowledge of the model and the system

- Automatic calibration is more effective and efficient procedures and is based on numerical optimization methods.
Model validation

- The purpose is to verify that the calibrated model can perform well when it is used in conditions different than those used in calibration.

- Validation consists in generating model simulations for independent events and/or at independent locations and verifying that the model fit to the observations is comparable to that achieved in the calibration.
Goodness-of-fit

- Model performance criteria
- Efficacy of a model usually determined by comparing model outputs to the observations selected for calibration and validation
- Goodness-of-fit of a model describes how well the model fits a set of observations (it provides an objective assessment of the “closeness” of the simulated behaviour to the observed measurements)
- There are several performance criteria to test goodness-of-fit of the model to the data
- Few of them are
  - RMSE
  - NSE (COEFFICIENT OF EFFICIENCY)
  - Coefficient of Determination ($R^2$)
Goodness-of-fit

- Root mean Squared Error

\[ RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (\hat{y}_i - y_i)^2} \]

- Coefficient of determination

\[ r^2 = \left(\frac{\sum_{i=1}^{n} (y_i - \bar{y})(\hat{y}_i - \bar{\hat{y}})}{\sqrt{\sum_{i=1}^{n} (y_i - \bar{y})^2} \sqrt{\sum_{i=1}^{n} (\hat{y}_i - \bar{\hat{y}})^2}}\right)^2 \]
**Goodness-of-fit**

- Nash-Sutcliffe efficiency $E$

\[
E = 1 - \frac{\sum_{i=1}^{n} (y_i - \hat{y}_i)^2}{\sum_{i=1}^{n} (y_i - \bar{y})^2}
\]

\[
E = \frac{\text{Explained variation}}{\text{Total variation}}
\]

\[
E = \frac{\sum_{i=1}^{n} (\hat{y}_i - \bar{y})^2}{\sum_{i=1}^{n} (y_i - \bar{y})^2}
\]

**Total variation** = $\sum_{i=1}^{n} (y_i - \bar{y})^2$

**Explained variation** = $\sum_{i=1}^{n} (\hat{y}_i - \bar{y})^2$

**Unexplained variation** = $\sum_{i=1}^{n} (y_i - \hat{y}_i)^2$