POTABLE WATER DISTRIBUTION SYSTEM MODELLING USING WaterGEMS

Dr. MOHAMED DARWISH, Ph.D., P.ENG.

AGENDA

- Introduction
- Potable Water Distribution System Modeling
- Building and Preparing the Model
- Hydraulic Model Calibration
- Steady-State Simulation
- Extended-Period Simulation

INTRODUCTION

INTRODUCTION

"All models are approximations. Essentially, All Models Are Wrong, but some are useful. However, the approximate nature of the model must always be borne in mind."

George E. P. Box
One Of The Great Statistical Minds of The 20th Century

- A model is only as good as the data used to build it (garbage in garbage out)
- Be aware of your sources and the accuracy of your data
- Keeping your model up to date is as important as developing a model

POTABLE WATER DISTRIBUTION SYSTEM MODELING

POTABLE WATER DISTRIBUTION SYSTEM MODELING

- Historical Timeline
- Common Hydraulic Model Uses
- Common Challenges in Developing Hydraulic Models
- Water System Elements
  - Pipes
  - Valves
  - Pumps
  - Tanks

POTABLE WATER DISTRIBUTION SYSTEM MODELING

Pre 1970	1970 - 1990	1990s	2000s	Present
Manual Calculations and physical models (too expensive)	Programming was used to simulate small system	EPANET was introduces by USEPA	Integration with GIS was presented	Adding water quality modelling, fire flow analysis etc.

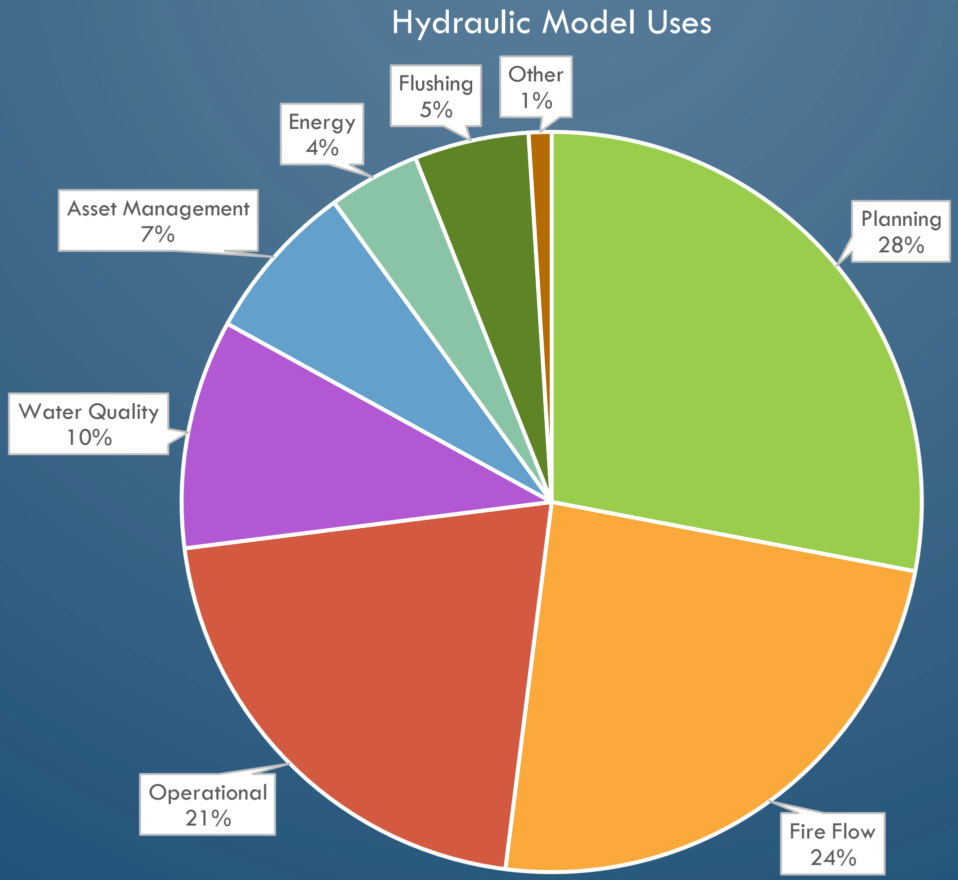
POTABLE WATER DISTRIBUTION SYSTEM MODELING

Main purposes of hydraulic modelling:

- Planning
- Design
- Operation
- Water Quality improvement

Source: Trends in water distribution system modeling, Journal AWWA, Oct. 2014.

POTABLE WATER DISTRIBUTION SYSTEM MODELING



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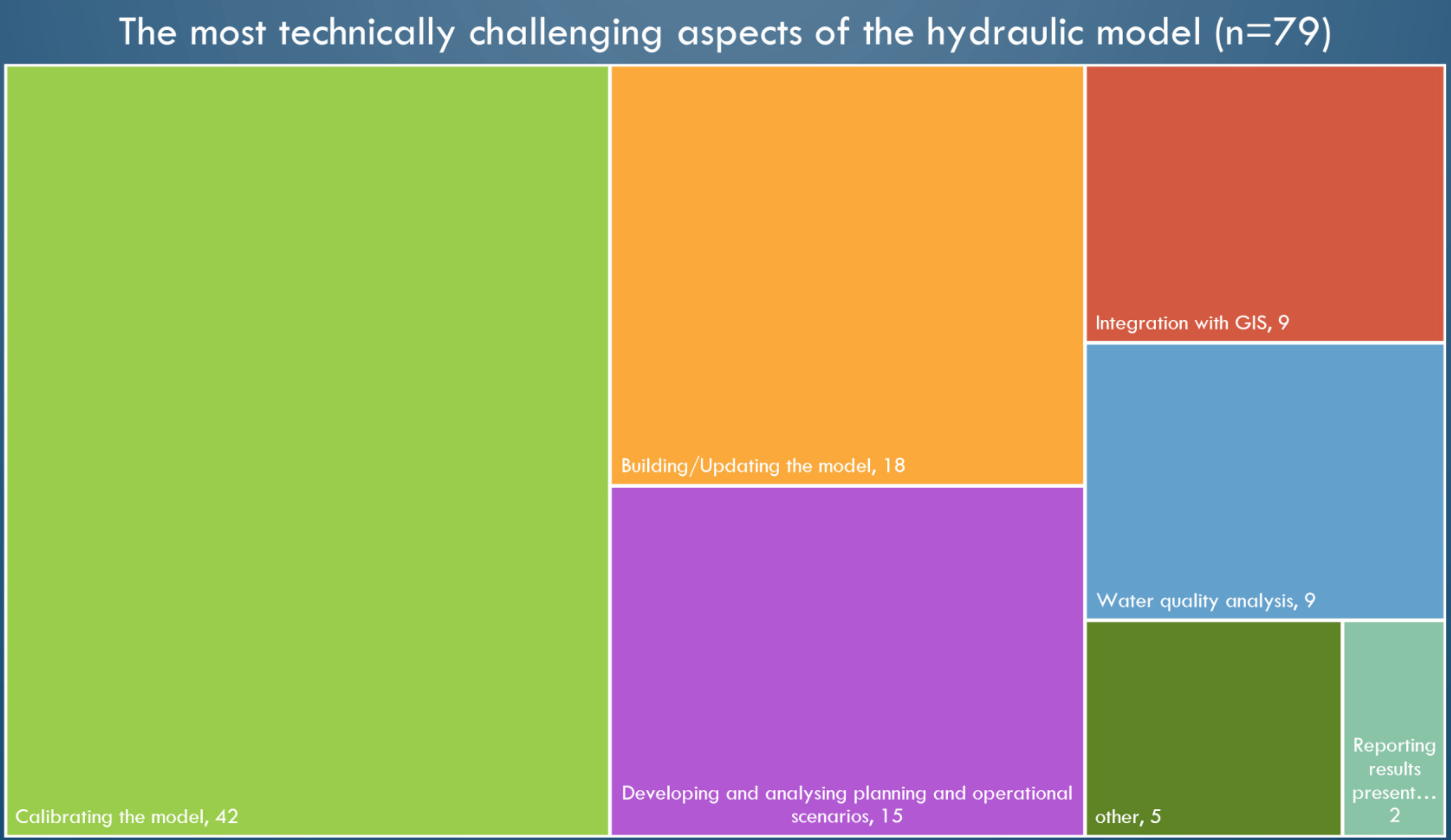
POTABLE WATER DISTRIBUTION SYSTEM MODELING



Source: Trends in water distribution system modeling, Journal AWWA, Oct. 2014.

POTABLE WATER DISTRIBUTION SYSTEM MODELING

- Water System Elements
  - Pipes
  - Pumps
  - Valves
  - Tanks

POTABLE WATER DISTRIBUTION SYSTEM MODELING

- PIPES and Fittings
  - Material
    - Polyvinyl Chloride (PVC)
    - Polyethylene (PE)
    - Asbestos Cement (AC)
    - Steel
    - Ductile Iron
    - Cast Iron
- Physical Properties
  - Diameter (Inner Diameter)
  - Roughness
- Location
  - X Coordinate
  - Y Coordinate
  - Z Coordinate (elevation)

POTABLE WATER DISTRIBUTION SYSTEM MODELING

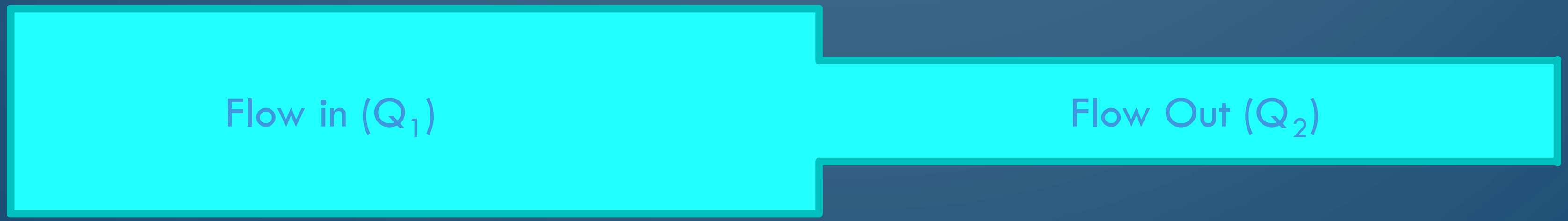
- Pipe Flow Equations
  - Continuity Equation
  - Energy Principal
  - Hazen-Williams Formula
  - Darcy-Weisbach Formula

POTABLE WATER DISTRIBUTION SYSTEM MODELING

- Flow Equations – Continuity Equation

$$Q = AV$$

Q is the flow (m^3/sec)
A is the Area of flow (m^2)
V = Flow Velocity (m/sec)



$$A_1V_1 = A_2V_2$$

POTABLE WATER DISTRIBUTION SYSTEM MODELING

- Energy Equation

$$\frac{P_1}{\gamma} + Z_1 + \frac{V_1}{2g} + H_G = \frac{P_2}{\gamma} + Z_2 + \frac{V_2}{2g} + H_L$$

Where $P =$ Pressure (N/m^2)

$\gamma =$ Specific Weight of the fluid (Water) (N/m3)

$Z =$ Elevation above the datum (m)

$V =$ Water Velocity (m/s)

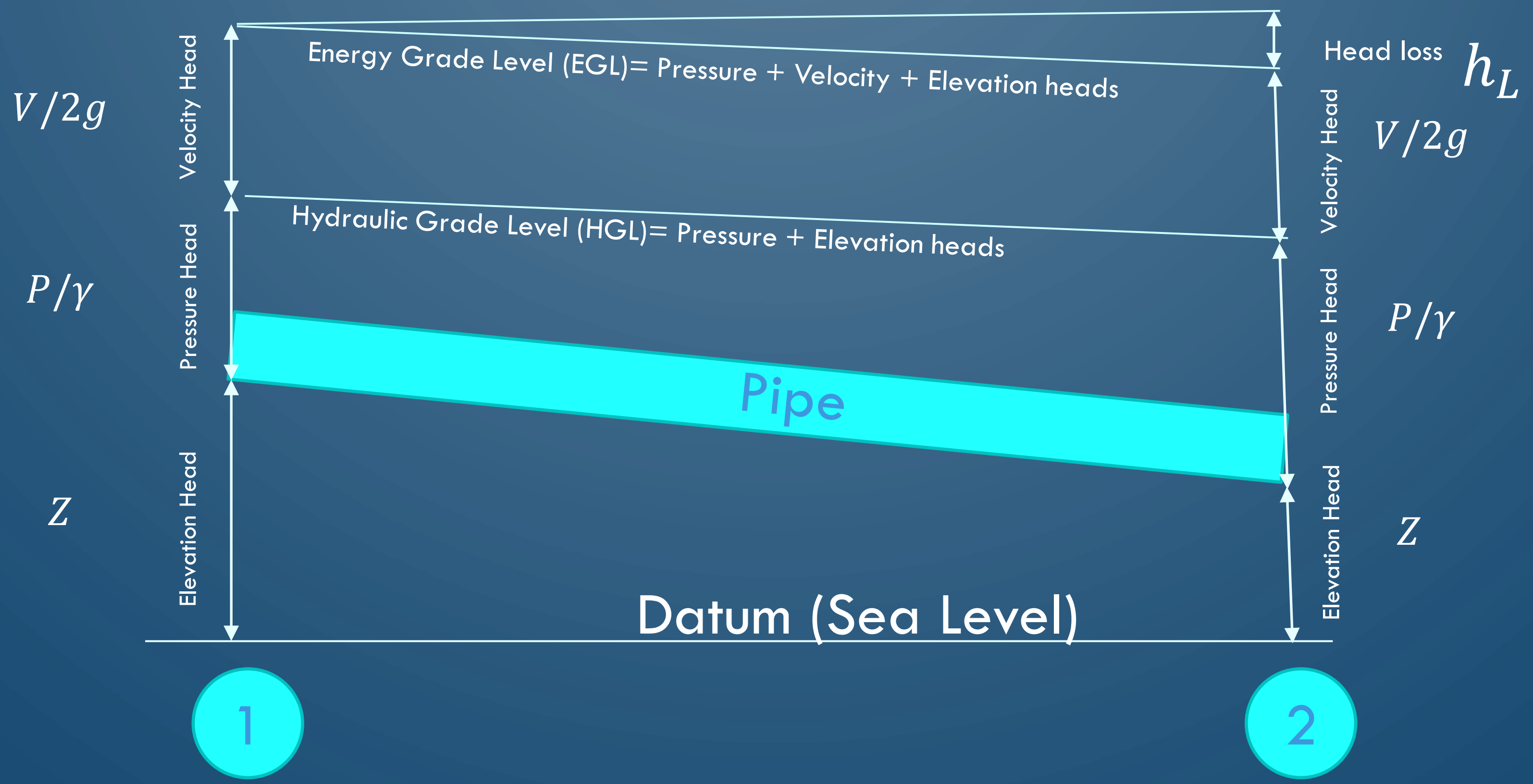
$g =$ gravitational acceleration (m/s^2)

$H_G =$ Head Gained such as from a pump (m)

$H_L =$ Head loss such as friction loss (m)

POTABLE WATER DISTRIBUTION SYSTEM MODELING

- Energy Equation



POTABLE WATER DISTRIBUTION SYSTEM MODELING

- Hazen-Williams Equation

$$V = 0.85\, C\, R^{0.63} S^{0.54}$$

Where V = Water Velocity (m/s)

C = Hazen-Williams Roughness Coefficient (unitless)

R = Hydraulic Radius (m)

= Area (m^2)/Witted Perimeter (m)

S = Slope (m/m)

POTABLE WATER DISTRIBUTION SYSTEM MODELING

- Hazen-Williams Equation – Cont.

Table 5-2. Values of the Hazen–Williams coefficient C_{HW} and Manning's n for common pipe materials

Type of Pipe	C_{HW}	n
Polyvinyl chloride (PVC) pipe	150	0.008
Very smooth pipe	140	0.011
New cast iron or welded steel	130	0.014
Wood or concrete	120	0.016
Clay or new riveted steel	120	0.017
Old cast iron or brick	100	0.020
Badly corroded cast iron or steel	80	0.035

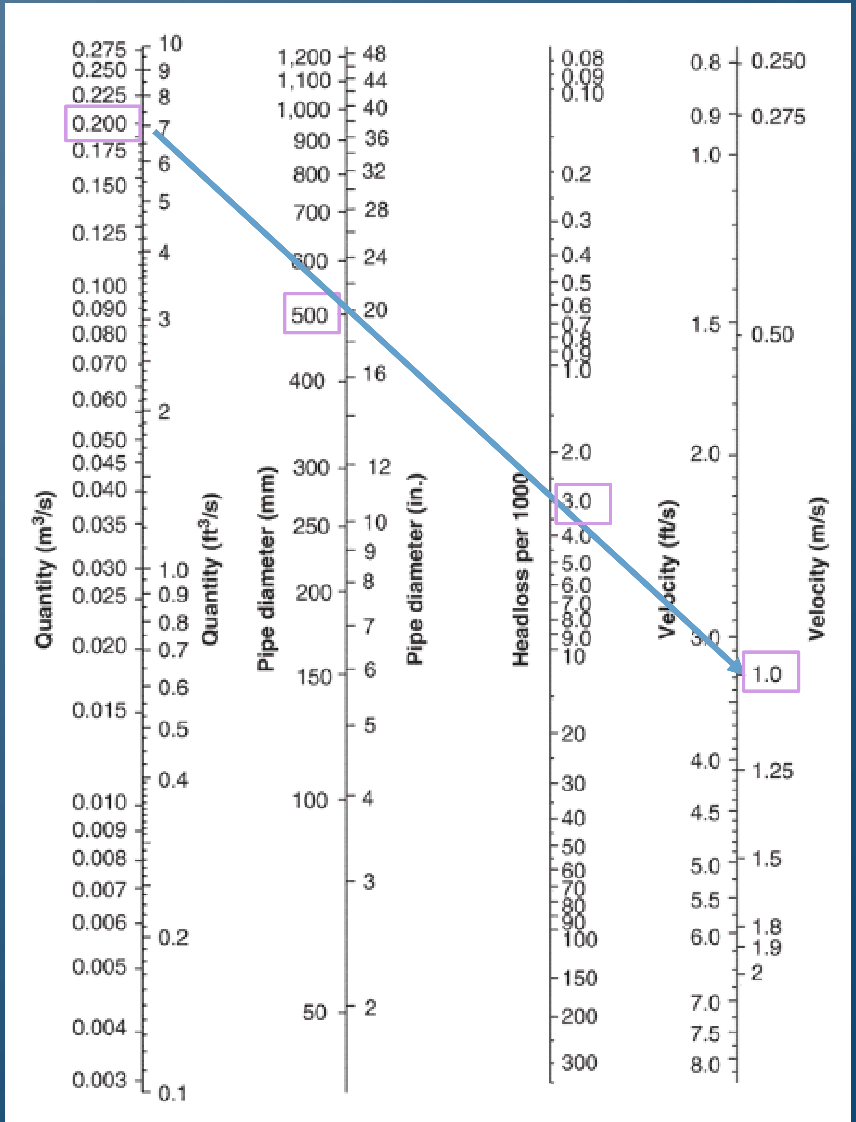
Source: Jeppson 1976.

POTABLE WATER DISTRIBUTION SYSTEM MODELING

- Hazen-Williams Equation – Cont.

Nomogram for Solving the Hazen–Williams equation

(C=100).



POTABLE WATER DISTRIBUTION SYSTEM MODELING

- Darcy-Weisbach Equation

$$V = \sqrt{\frac{8g}{f}RS}$$

Where V = Water Velocity (m/s)

f = Darcy-Wiesback friction factor (unitless)

R = Hydraulic Radius (m)

= Area (m^2)/Witted Perimeter (m)

S = Slope (m/m)

- Darcy-Weisbach Friction Factor (unitless)

$$f = \frac{1.325}{\left[log_e\left(\frac{k}{3.7D}+\frac{5.74}{Re^{0.9}}\right)\right]^2}$$

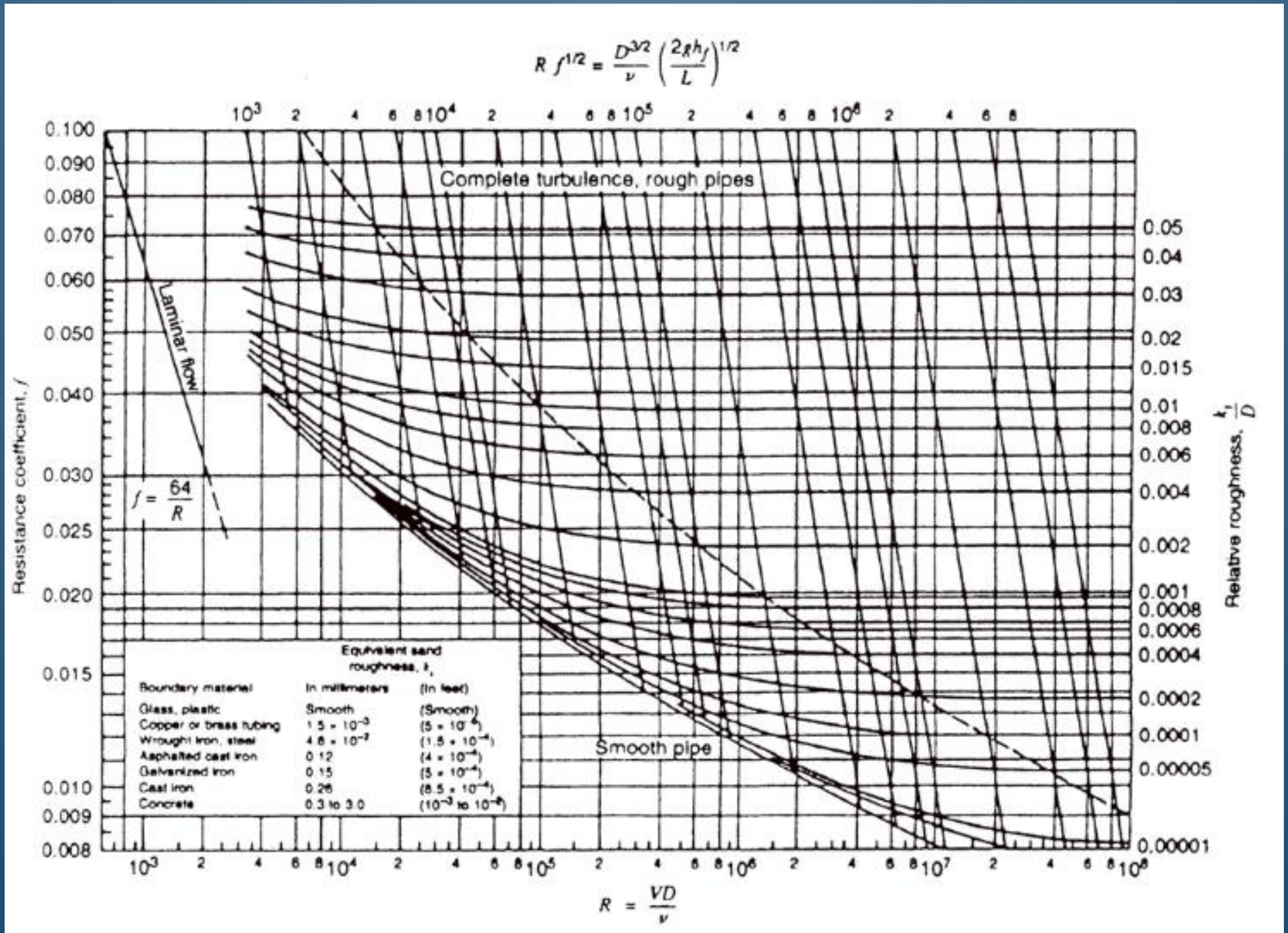
Where f = Darcy-Wiesback friction factor

k =*roughness height (m)*

D = Pipe diameter (m)

Re = Reynolds number (unitless)

POTABLE WATER DISTRIBUTION SYSTEM MODELING



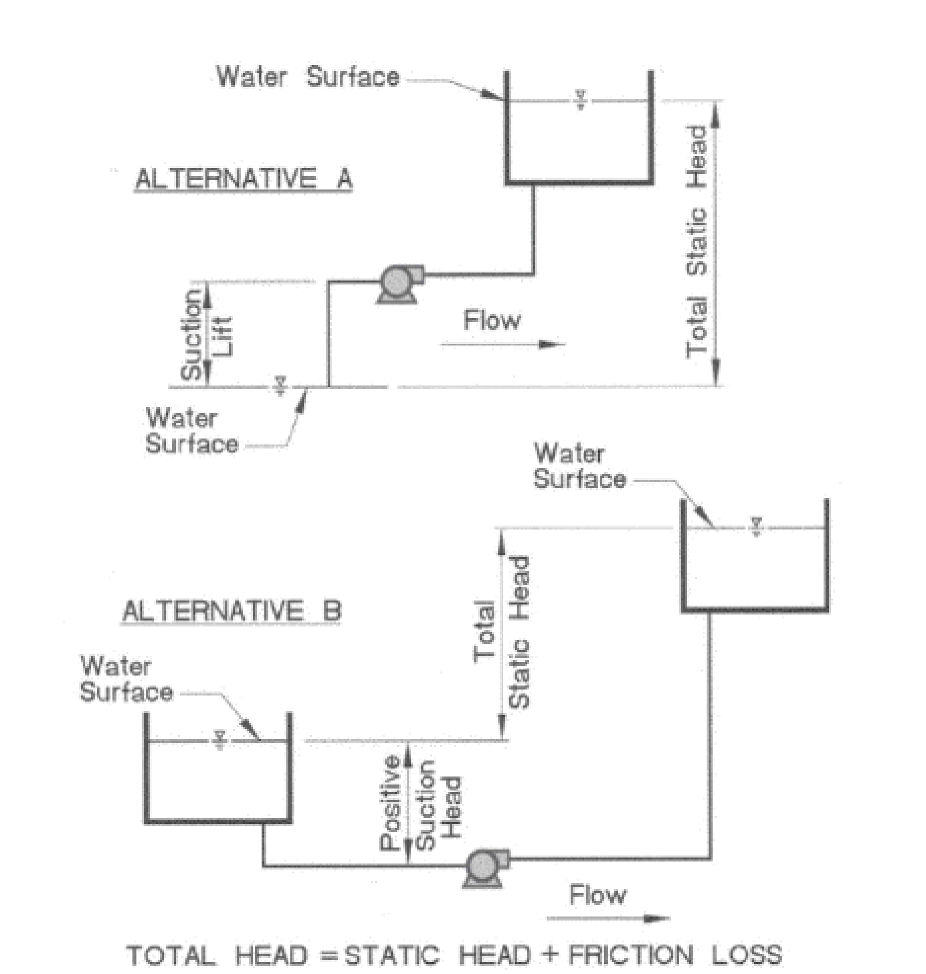
Moody diagram with the friction factor f, as a function of Reynolds number R, in Darcy–Weisbach formula for flow in conduits.

POTABLE WATER DISTRIBUTION SYSTEM MODELING

- Pumps

A water pump is a device whose main job is to increase water pressure to transfer the water, or liquid, from one place to another.

- Type of water pumps
  - Centrifugal Pumps
  - Vertical Line Shaft Turbine Pumps
  - Submersible Pumps

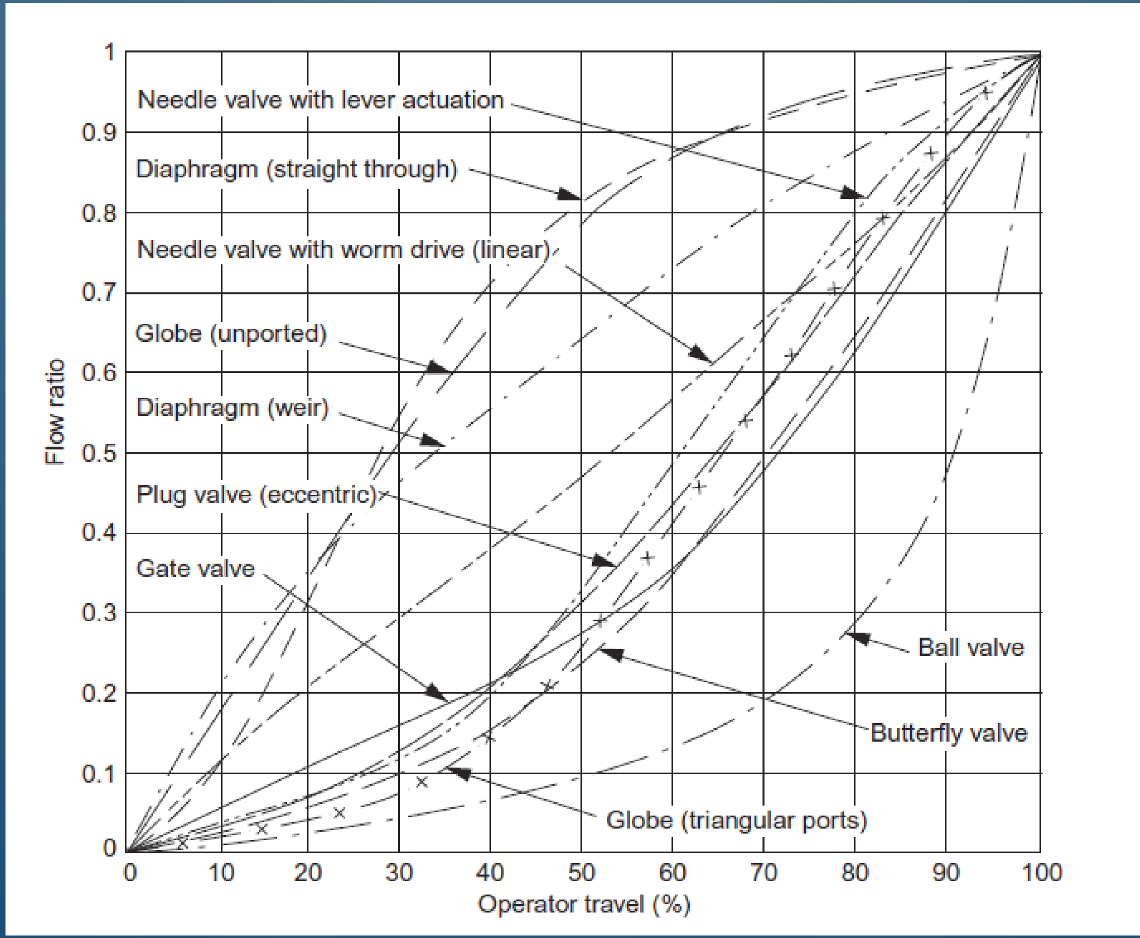


POTABLE WATER DISTRIBUTION SYSTEM MODELING

- Valves
  - Isolating Set either closed or fully open and normally not operated in flow conditions
  - Regulating Set with any degree of opening to regulate flow and capable of periodic adjustment to opening
  - Control Used with autonomous or external systems to respond to changes in flow or pressure conditions to achieve a set result which itself is capable of being reset
  - Non-return Prevents reverse flow when downstream pressure is higher
  - Venting To exhaust or admit air

POTABLE WATER DISTRIBUTION SYSTEM MODELING

- Valves – Cont.



POTABLE WATER DISTRIBUTION SYSTEM MODELING

- Valves
  - GATE VALVES
  - BUTTERFLY
  - GLOBE VALVES
  - BALL VALVES
  - DIAPHRAGM VALVES

Ball Valve Gate Valve Globe Valve Butterfly Valve Air release valve

POTABLE WATER DISTRIBUTION SYSTEM MODELING

- Tanks
  - Operational tanks

    Usually integrated within the distribution network to equalize the water flow between the low consumption and the peak hours
  - Strategic tanks

    Usually located after the water production facility or within the transamination system

BUILDING AND PREPARING THE MODEL

BUILDING AND PREPARING THE MODEL

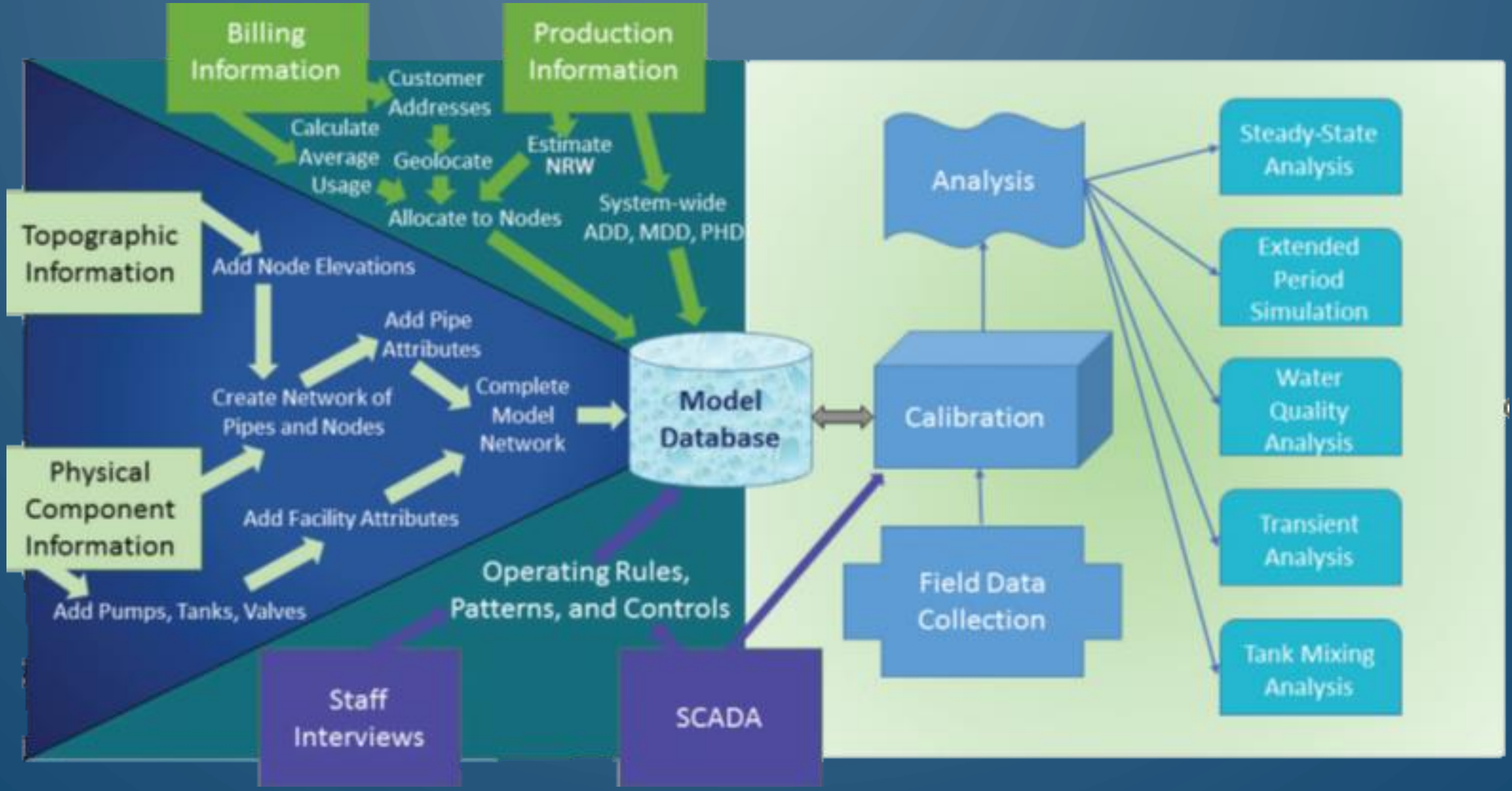
ESTABLISH THE PURPOSE AND THE NEEDS

- Planning
  - Capital Improvement Program
  - Water Main Rehabilitation Program
  - Reservoir Siting
- Design
  - Sizing the water system (mains, pump stations, PRV, tanks, etc ..)
  - Fire Flow Studies
  - Zone Boundary Selection
- Operation
  - System Trouble shouting scenarios
  - Water Loss Calculations
  - Energy Conservation scenarios

BUILDING AND PREPARING THE MODEL

- **Collect data.**
- **Develop the model.**
- **Calibrate the model.**
- **Analyze the distribution system.**

BUILDING AND PREPARING THE MODEL



Source: M32 computer modeling of water distribution systems / by James P. Cooper. Fourth edition. | Denver, CO : American Water Works Association, [2018]

BUILDING AND PREPARING THE MODEL

- Data Collection – Geographical data
  - Land use and zoning for existing and future conditions
  - Aerial photographs
  - Elevation data: digital terrain model (DTM), triangulated irregular network (TIN), contour maps, GPS, or other elevation data
  - Street maps and parcel maps: including street names, rights-of-way, and city and township boundaries

BUILDING AND PREPARING THE MODEL

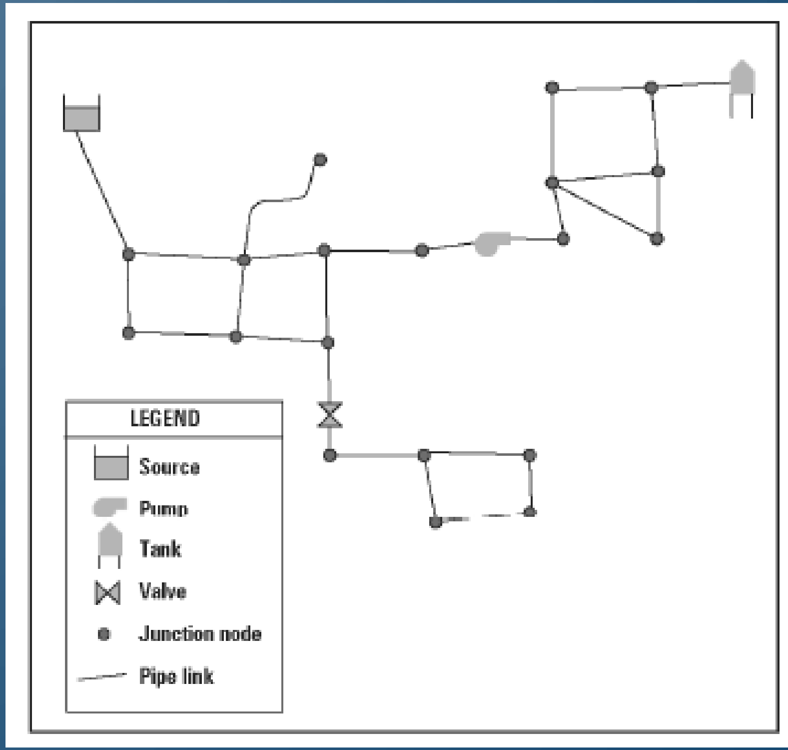
- Data Collection – Existing Facilities Inventory
  - Pipes (Location, Diameter, Length, Age, Material, Lining, connectivity)
  - Storage Facilities (Location Capacity, Dimension, base water surface level, maximum water surface level, operation hours)
  - Service Connections (location, elevations, size, etc.)
  - Pumping and booster stations (elevation, number of duty pumps, spare pumps, pumps curves, sumps elevations, on-off levels, etc.)
  - Valves (type, location, diameter, etc.)
  - Other system components as needed)

BUILDING AND PREPARING THE MODEL

- Data Collection
  - Water meter consumption
  - Production records
  - Operating records
    - Annual, seasonal, diurnal curve
  - Physical Inspection

BUILDING AND PREPARING THE MODEL

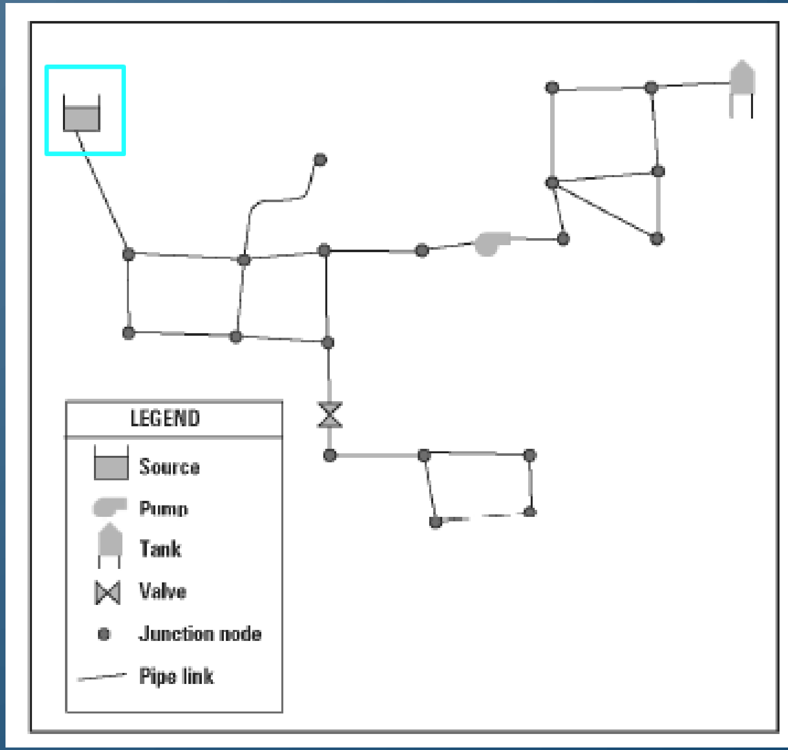
- Model Elements
  - Nodes (Junctions)
    - Storing Elevations
    - Diversion point (entrance and exist of water from the system)
    - Boundary condition (Valve, Pump, Tank)
  - Links
    - Represents the pipe



BUILDING AND PREPARING THE MODEL

- Model Elements

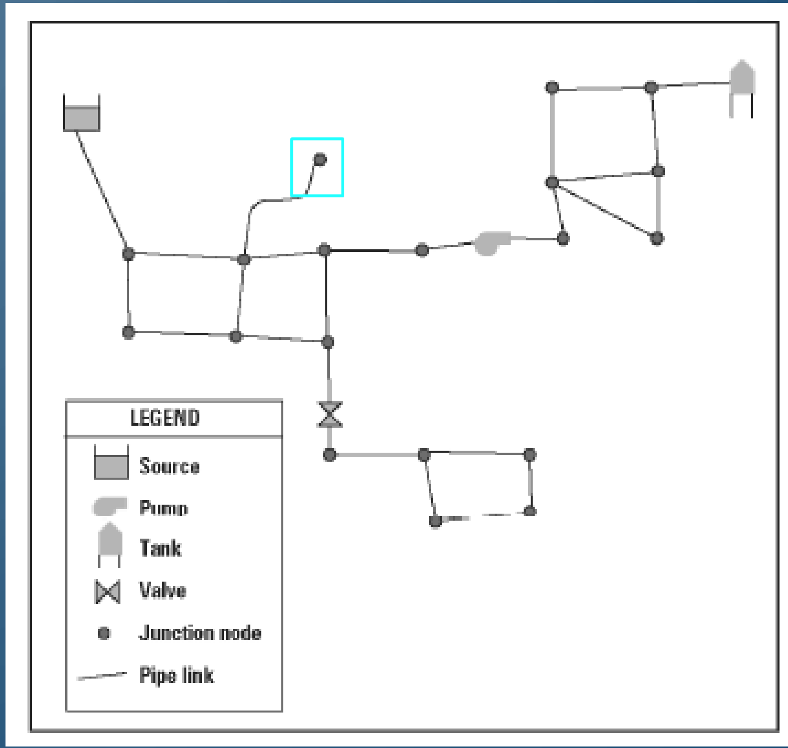
Model Element Type	Data Required
Reservoir	Location (N, W)
	Elevation (m)



BUILDING AND PREPARING THE MODEL

- Model Elements

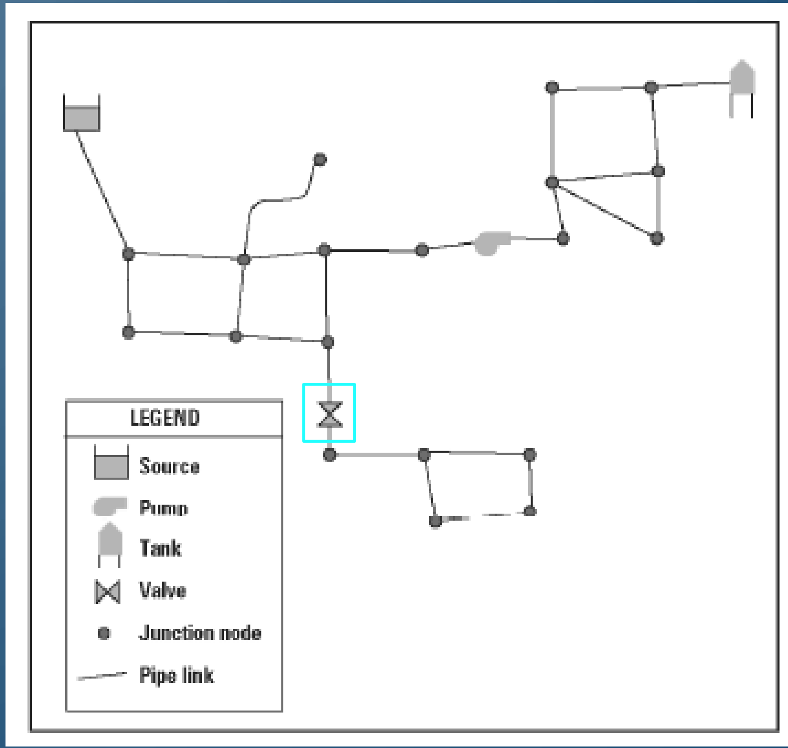
Model Element Type	Data Required
Junction	Location (N, W)
	Elevation (m)
	Demand, if exist (m^3/day)



BUILDING AND PREPARING THE MODEL

- Model Elements

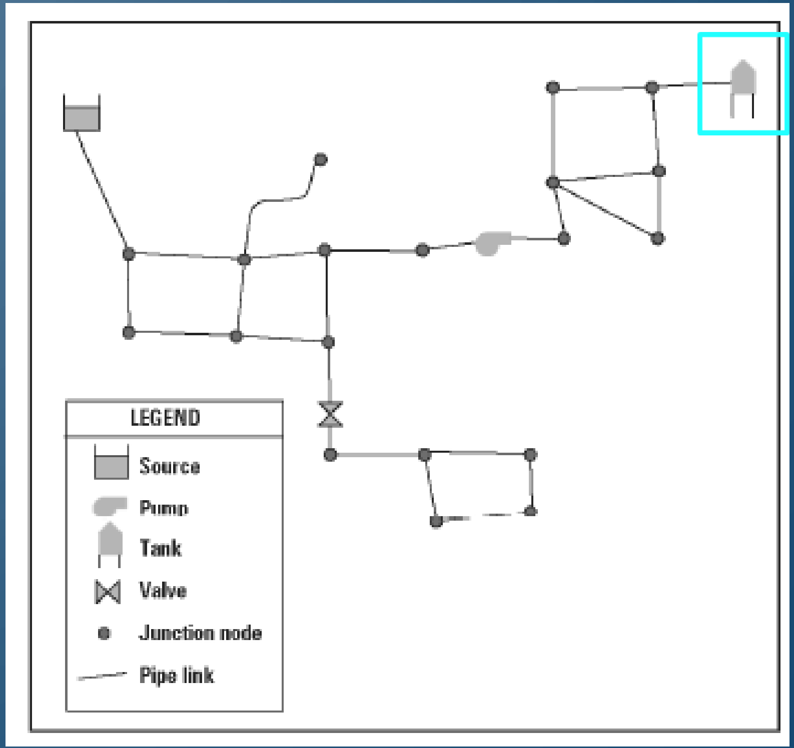
Model Element Type	Data Required
Valve	Location (N, W)
	Elevation (m)
	Status (on/off)
	Type (control, PRV, NRV, etc.)



BUILDING AND PREPARING THE MODEL

- Model Elements

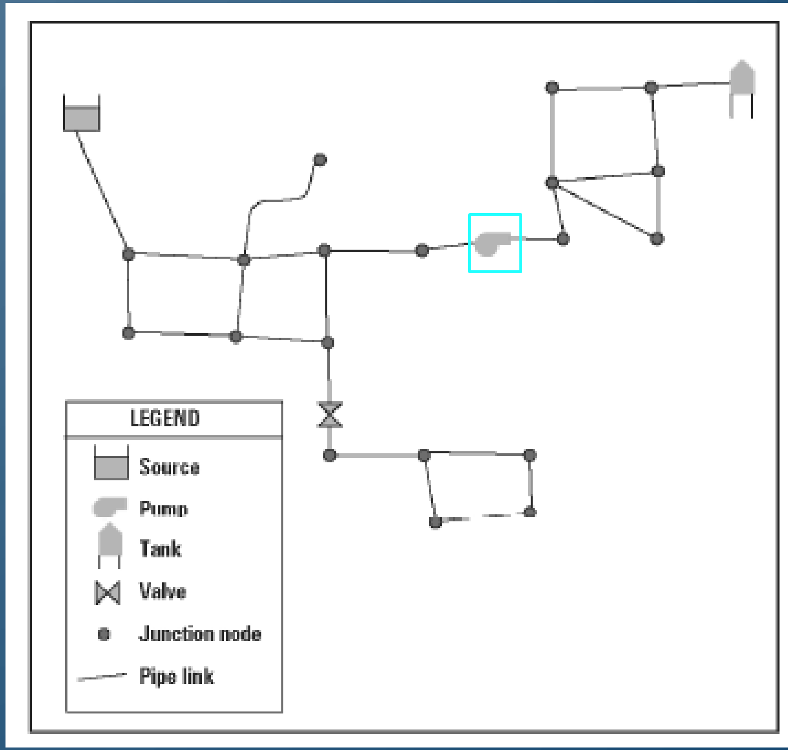
Model Element Type	Data Required
Tank	Location (N, W)
	Ground Elevation (m)
	Minimum Water Level (m)
	Maximum Water Level (m)
	Volume (m^3)
	Type



BUILDING AND PREPARING THE MODEL

- Model Elements

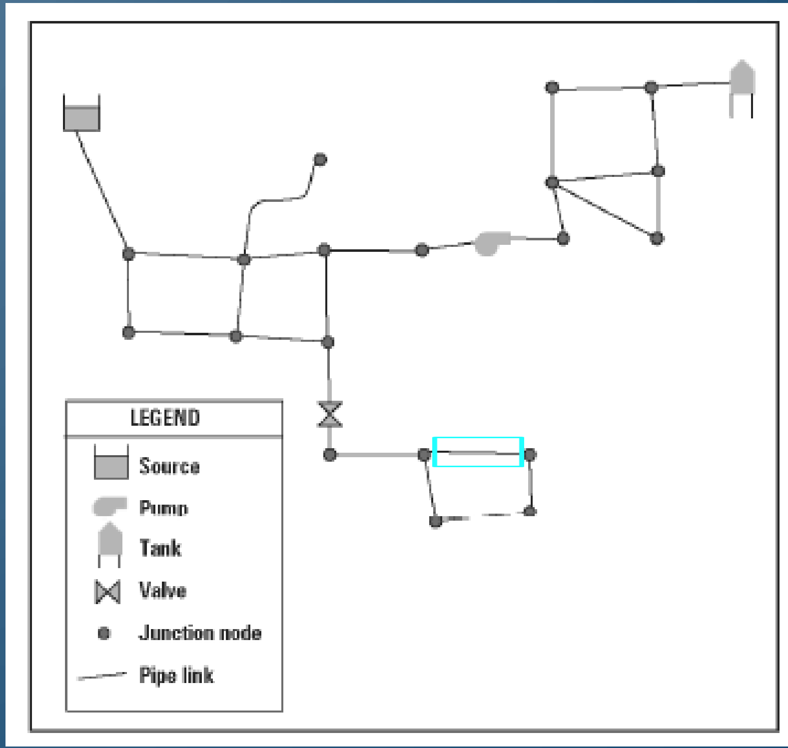
Model Element Type	Data Required
Pump	Location (N, W)
	Elevation (m)
	Operation data
	Pump Curve



BUILDING AND PREPARING THE MODEL

- Model Elements

Model Element Type	Data Required
Pipe	Location, Start, End (N, W)
	Ground Elevation, Start and End (m)
	Diameter
	Material
	Head Loss coefficient (C or ε)

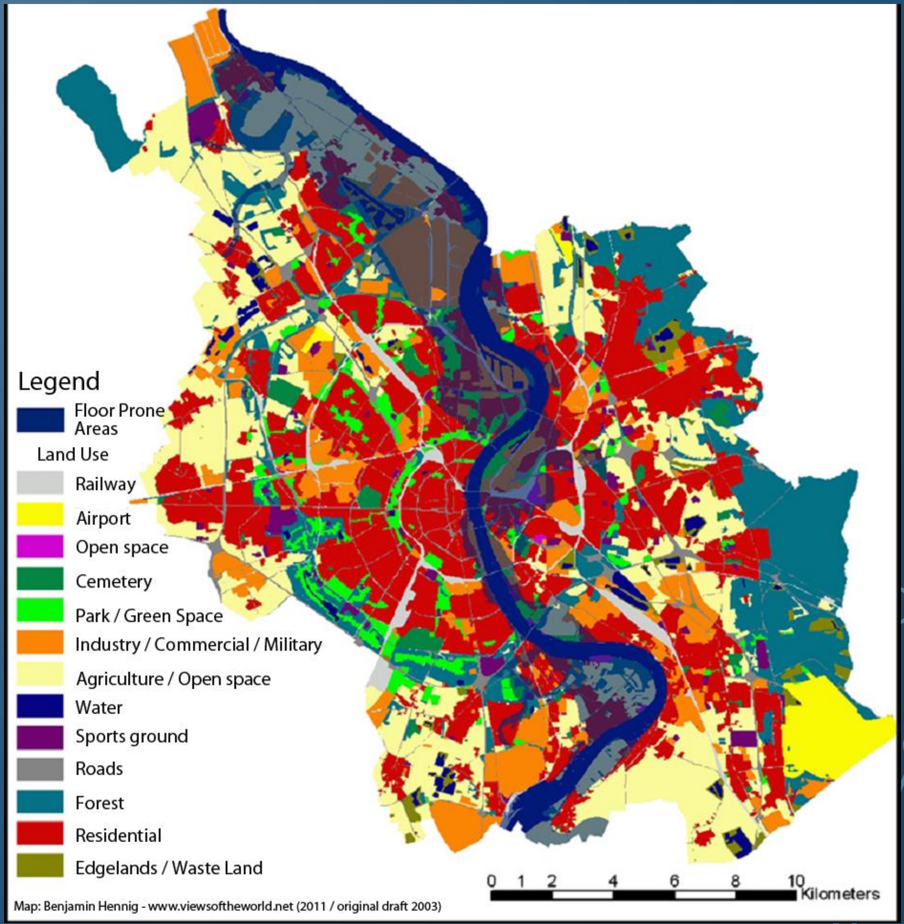


BUILDING AND PREPARING THE MODEL

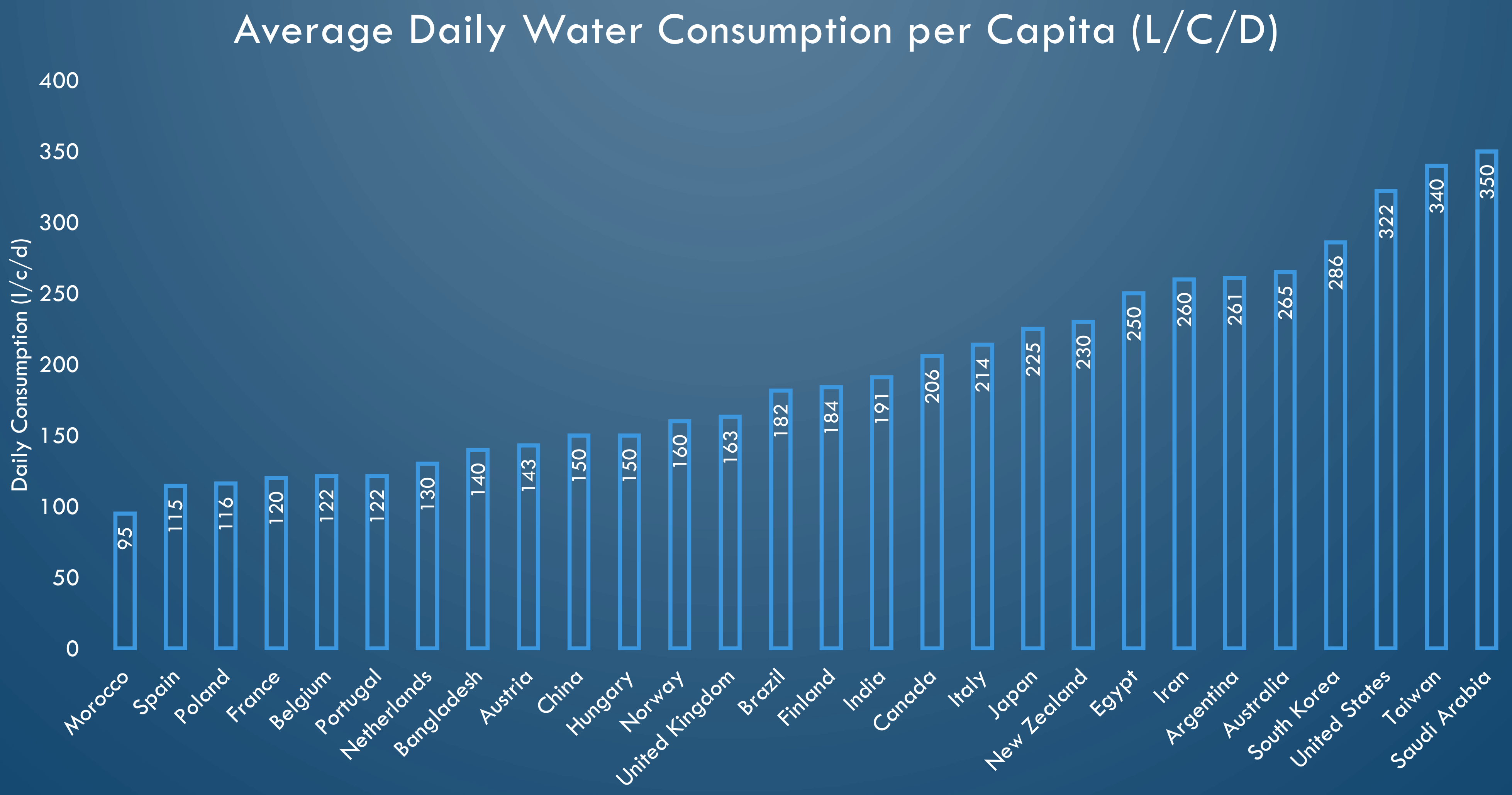
- Demand Development
  - Types of Demand (related to the land use types)
    - Residential Demands, indoor water used in flushing toilets, washing, cooking, and drinking
    - Commercial Demands, stores, restaurants, gas stations, offices.
    - Industrial Demands.

BUILDING AND PREPARING THE MODEL

- Demand Allocation Process to nodes
  - Based on land use map using GIS methodology
  - Manual process

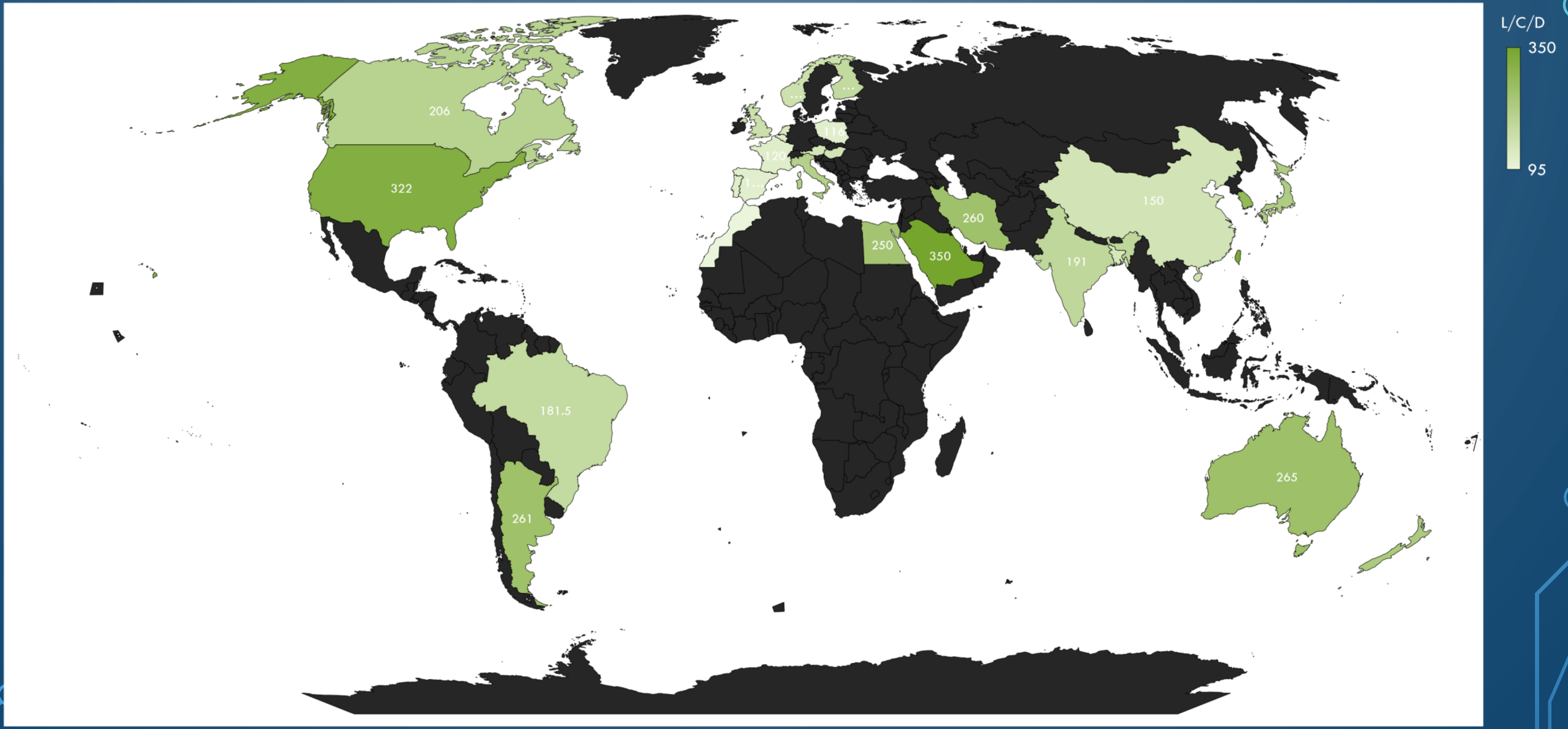


BUILDING AND PREPARING THE MODEL



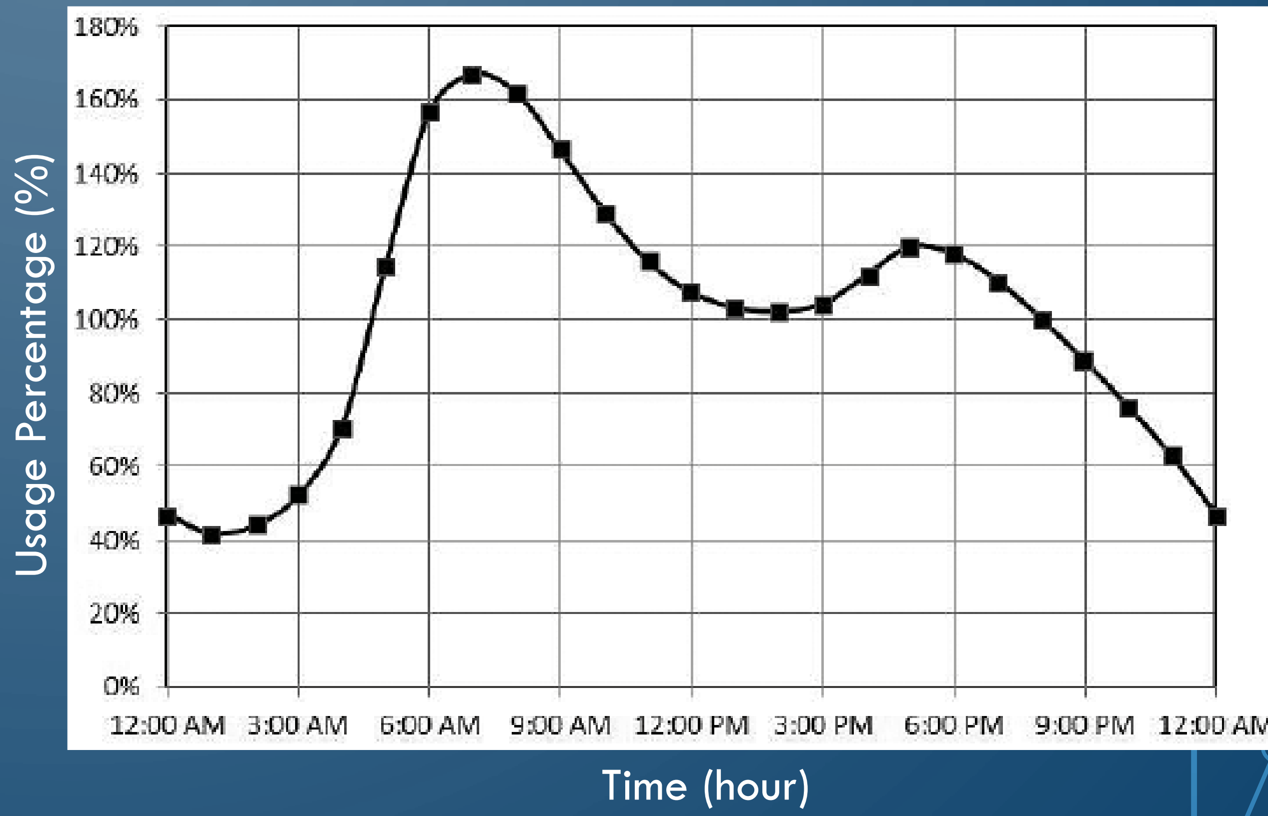
BUILDING AND PREPARING THE MODEL

Average Daily Water Consumption per Capita (L/C/D)



BUILDING AND PREPARING THE MODEL

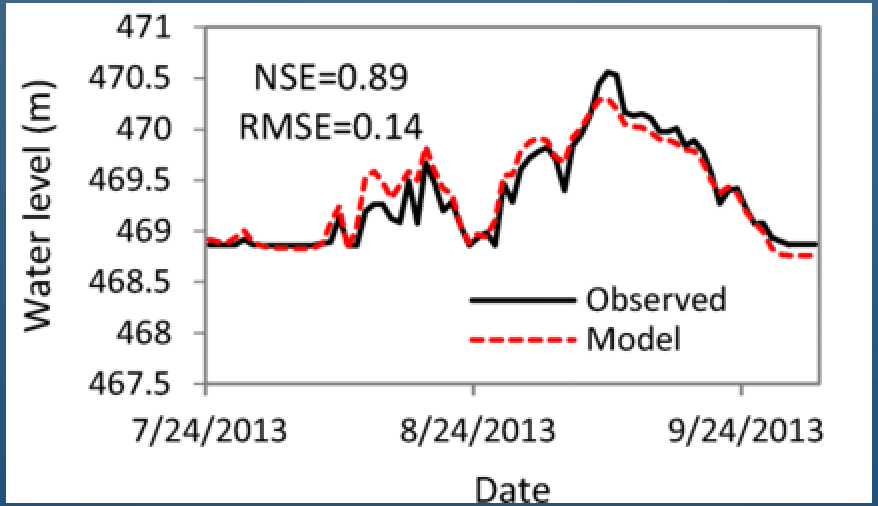
- Temporal Variation
  - Seasonal
    - Seasonal Tourism (Hajj and Omrah)
  - Daily
    - User’s behaviour (Residential)
    - Land use related variation (Offices)



HYDRAULIC MODEL CALIBRATION

HYDRAULIC MODEL CALIBRATION

Calibration is <u>comparing</u> between the developed model to the actual field data and <u>making corrections and adjustments</u> to the model to achieve close agreement between computer-predicted values and field measurements.



HYDRAULIC MODEL CALIBRATION

Calibration Goals:

- Hydraulic grade line (HGL)
  - Predicted values between ± 2.2 and 4.3 PSI of the recorded in the field
- Water Reservoir Top Water Levels
  - Predicted water levels between ± 0.9 and 1.8 m

Model Uses:

- Planning
- Pipeline sizing
- Fire flow analysis

HYDRAULIC MODEL CALIBRATION

Calibration Goals (As required by the AHJ):

- Hydraulic grade line – HGL
  - Predicted values between ± 2.2 and 4.3 PSI of the recorded in the field
- Water Reservoir Top Water Levels
  - Predicted water levels between ± 0.9 and 1.8 m
- Water Flows (UK WRc):
  - 5% of recorded flow > 10% of the total flow demand
  - 10% of recorded flow < 10% of the total flow
- Pressure (UK WRc):
  - Difference between Model and recorded measurements :
    - (5% or 0.5 m) of recorded head loss of 85% of the test measurements
    - (7.5% 0.75 m) of recorded head loss of 95% of the test measurements
    - (15% or 2.0 m) of recorded head loss of 100% of the test measurements

HYDRAULIC MODEL CALIBRATION

Data Sources and Errors:

- System maps
- Elevation Data
- SCADA system
- Pressure Recording Devices (may not be calibrated)
- Flow Recording Devices (may not be calibrated)
- Pump Curve
- Control Valve
- Non-Revenue Water (NRW)
- Unmetered flow
- Peak Factors
- Roughness Coefficients (C-factor)
- Connectivity

STEADY STATE SIMULATION

STEADY STATE SIMULATION

Steady State Simulation represents a snapshot of the system under one set of condition such as:

- Average Day Demand
- Max Day Demand
- Max Hour Demand
- Fire flow Condition

STEADY STATE SIMULATION

Purpose of the analysis	Scenario
Normal Operation Studies	Average Day, Maximum Hour
Production and pumping requirements	Maximum day
Sizing of pipelines—small systems	Maximum day plus fire flow
Sizing of pipelines—large systems	Maximum hour and 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

EXTENDED-PERIOD SIMULATION

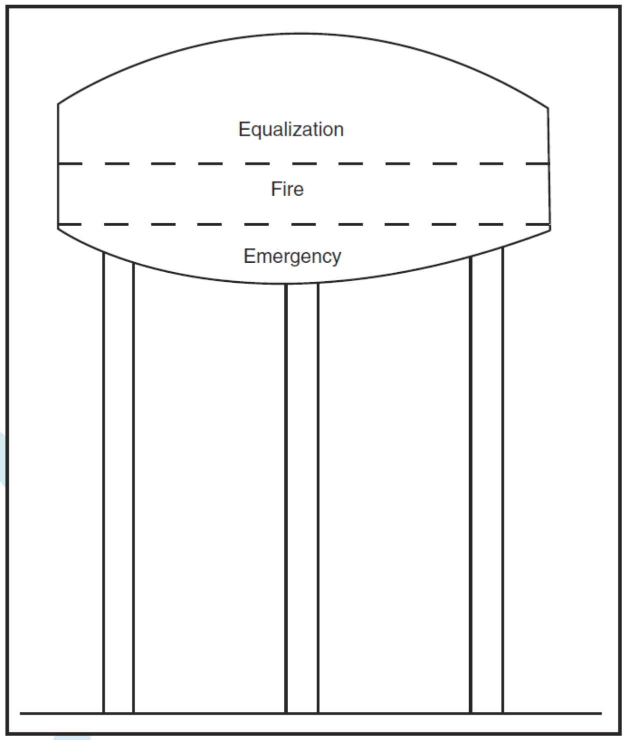
EXTENDED-PERIOD SIMULATION

Extended-period simulation (EPS) is a technique for modeling a distribution system where a <u>series of steady-state</u> simulations at <u>specified intervals</u> are performed over a <u>specified time period.</u>

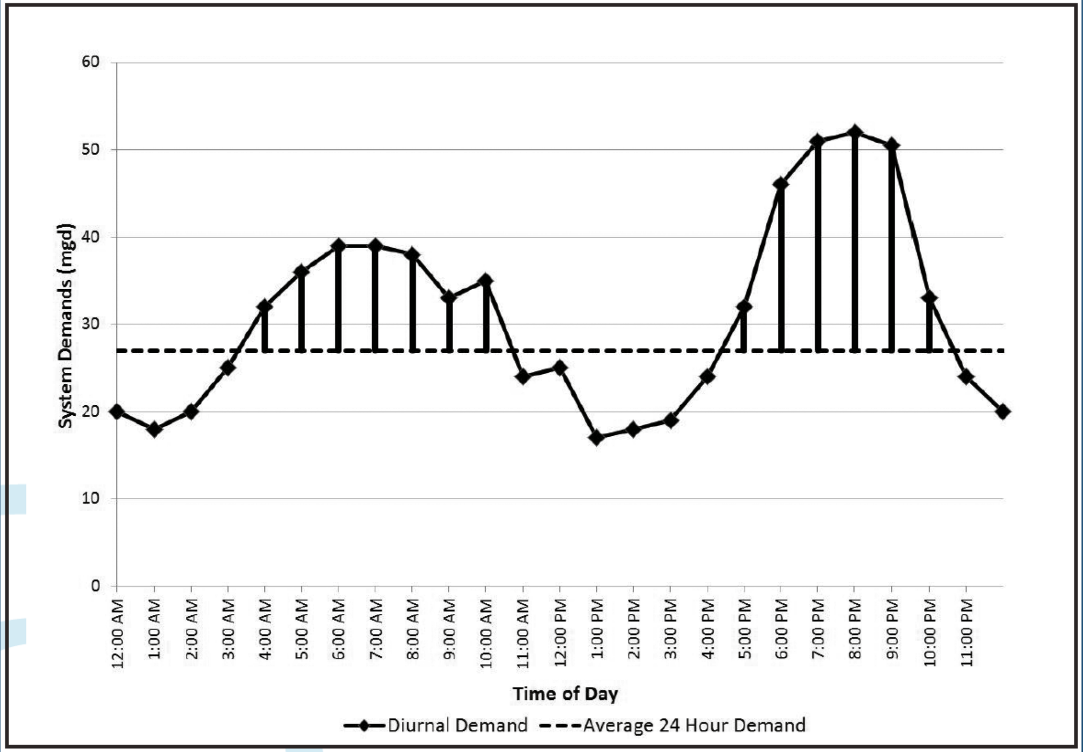
EXTENDED-PERIOD SIMULATION

- Required Information:
  - Time interval
  - Diurnal Demand Variations
  - Tanks constrains (Water high level, Water low level, fire storage ,etc..)
  - Pumps operation data and conditions (on and off controls)

EXTENDED-PERIOD SIMULATION

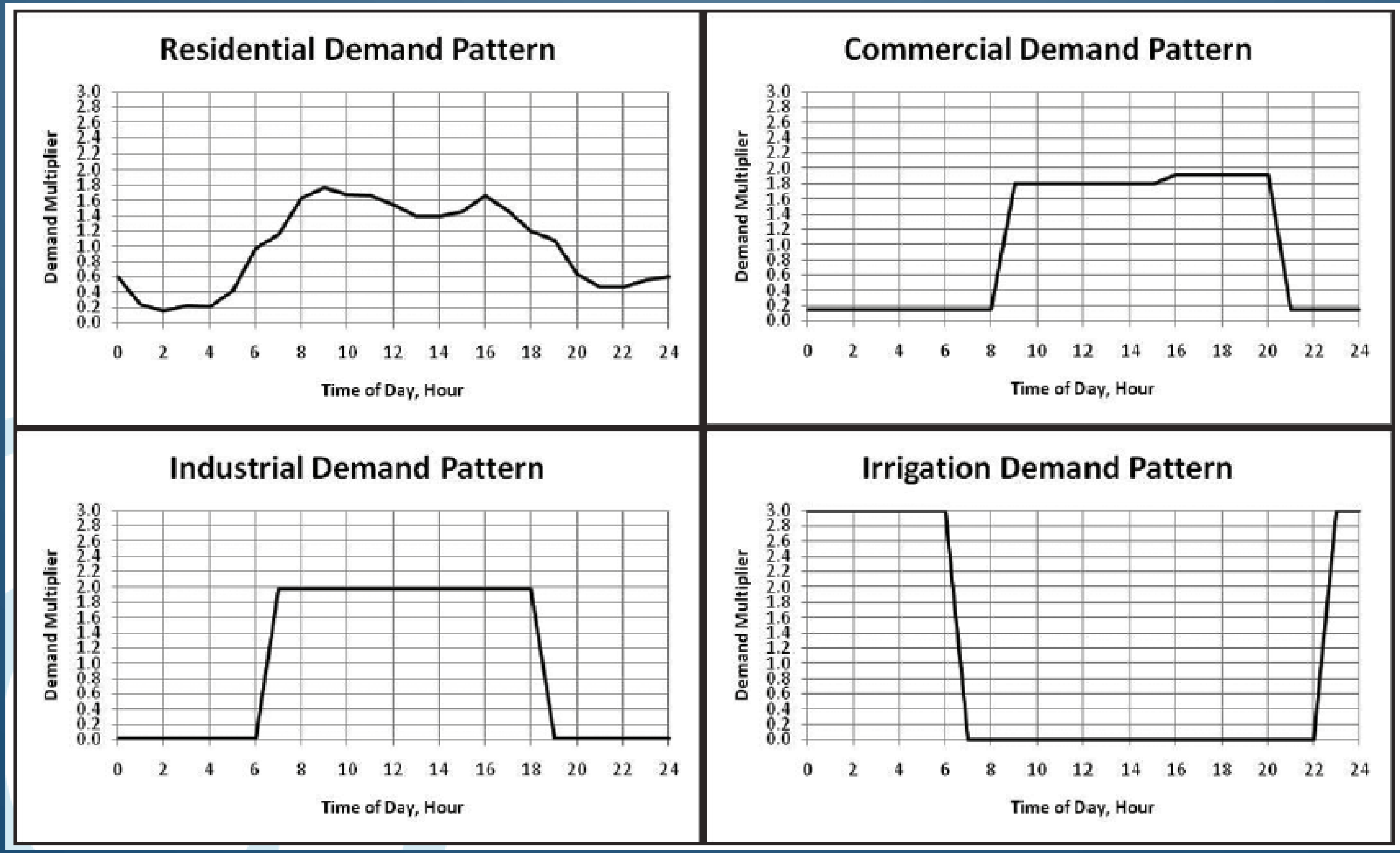


Storage Allocation



Equalization storage requirements for maximum day conditions

EXTENDED-PERIOD SIMULATION



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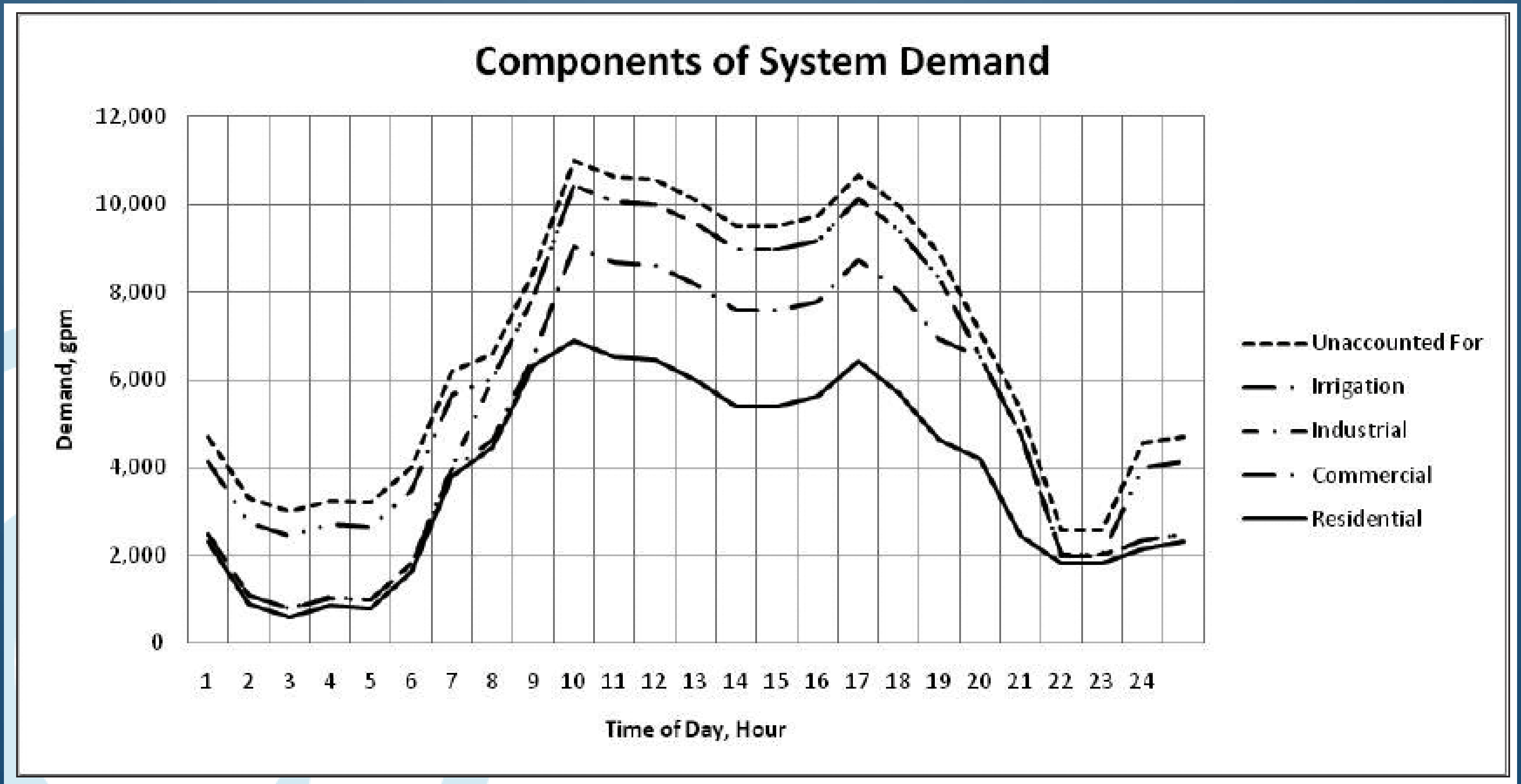

EXTENDED-PERIOD SIMULATION

Purpose of the analysis	Scenario
Sizing of storage facilities	Maximum hour
Tank filling capabilities	Minimum hour of average 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

LIVE DEMO USING WaterGEMS

REFERENCES

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QUESTIONS ?