GISpipe Turbidity Model — User Guide

1. Introduction

What does this model do?

This simulation model predicts how turbidity changes throughout a water distribution network. After running hydraulic analysis in EPANET, this MSX model tracks turbidity at every point in the network over time.

What can it predict?

- Identify high-turbidity zones in aged pipes
- Predict deposit removal rate during pipe flushing
- Forecast turbidity spikes during peak demand hours
- Assess turbidity impact from valve operations
- Trace turbidity propagation after source switching
- Estimate contamination extent and recovery time during emergencies
- Compare tank retention time effects on turbidity
- Rank long-term deposit accumulation for flushing priority

Three turbidity states tracked by the model

Name	Meaning	Field measurement
Mobile Turbidity (TURB_MOBILE)	Free-floating particles in water	✅ Direct turbidimeter reading
Bound Turbidity (TURB_BOUND)	Particles loosely held on pipe wall	❌ Not directly measurable
Deposit (DEPOSIT)	Firmly attached wall sediment	✅ Measurable during flushing

> **Note:** Bound turbidity is a virtual state used internally by the model. It separates particles that release easily at low velocity (bound) from those requiring high velocity (deposit). Initial value is typically set to 0.

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2. GISpipe Input Parameters

2.1 Basic Settings

Input	Default	Description
Headloss Formula	Hazen-Williams	Must match GISpipe [OPTIONS] Headloss setting
MSX Timestep	300 sec	Water quality calculation interval. 300 sec (5 min) or less recommended

2.2 Reaction Rate Constants

These determine how fast turbidity particles attach to walls, detach, and decay.

Input	Default	Unit	Meaning
Detachment rate	0.08	1/hr	Rate at which loosely attached particles return to water
Base resuspension rate	0.05	1/hr	Velocity-independent background resuspension of deposits
Velocity-dependent resuspension coefficient	SI: 0.10 / US: 0.03	SI: 1/hr per m/s, US: 1/hr per ft/s	How much faster deposits resuspend as velocity increases
Natural decay (mobile)	0.02	1/hr	Rate at which mobile turbidity naturally decreases
Natural decay (bound)	0.01	1/hr	Rate at which bound turbidity naturally decreases

2.3 Base Attachment & Deposition Rates

Reference values for new pipes. Automatically adjusted per pipe based on roughness.

Input	Default	Unit	Meaning
Base Attachment Rate	0.15	1/hr	Rate particles loosely attach to pipe wall (new pipe reference)
Base Deposition Rate	0.12	1/hr	Rate particles firmly deposit on pipe wall (new pipe reference)

These values are automatically scaled per pipe using EPANET roughness coefficients. Aged pipes (rougher surfaces) get higher attachment and deposition rates.

2.4 Roughness Coefficient Reference Values

Set the "new pipe" reference roughness for the selected headloss formula.

Headloss Formula	Reference Item	Default	Meaning
Hazen-Williams	Reference C	130	Higher C = smoother (new pipe)
Darcy-Weisbach	Reference ε (mm)	0.05	Lower ε = smoother (new pipe)
Chezy-Manning	Reference n	0.010	Lower n = smoother (new pipe)

> **Roughness coefficient and aging:**
> - Hazen-Williams: Low C = aged → attachment/deposition rate increases
> - Darcy-Weisbach: High ε = aged → attachment/deposition rate increases
> - Chezy-Manning: High n = aged → attachment/deposition rate increases
>
> Regardless of formula, the physical result is the same: aged pipes accumulate more deposits.

2.5 Initial Conditions

Set the network state at simulation start.

Input	Default	Unit	Meaning
Initial Mobile			

Turbidity	0.00	NTU	Residual turbidity already in the network at start
Initial Bound Turbidity	0.00	NTU	Typically left at 0 (not measurable)
Initial Deposit Scale	1.0	multiplier	Multiplier for roughness-based auto-calculation. 0=clean, 2=long neglected

> **Initial Mobile Turbidity vs Source Turbidity:**
> - Initial Mobile Turbidity = snapshot of residual turbidity in the network at simulation start
> - Source Turbidity = continuous inflow from the treatment plant (set in section 2.6)
> - These two values are independent

2.6 Source Settings

Set turbidity inflow from treatment plants. Multiple sources can be added.

Input	Description
Source Node ID	EPANET node where turbidity enters (e.g., treatment plant outlet)
Source Turbidity	Treatment plant effluent turbidity (NTU). e.g., 0.5 NTU
Use Time Pattern	Checked: hourly turbidity variation / Unchecked: constant turbidity
Time Pattern	24 multiplier values (one per hour). e.g., morning peak 1.4, night 0.7

2.7 Emergency Injection Settings

For simulating pipe breaks or contamination events.

Input	Description
Enable Emergency	Check to activate
Injection Node ID	Node where contamination enters
Injection Turbidity	Contamination turbidity (NTU). e.g., 50 NTU
Duration	Contamination duration (hours). e.g., 3 hours
Injection Mode	SETPOINT (fixes node turbidity at specified value)

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3. Scenario Guide

Scenario 1. Current Network Assessment

Purpose: Identify high-turbidity zones during normal operation.

GISpipe Settings:

Item	Value
Initial Mobile Turbidity	0.1 NTU
Initial Deposit Scale	1.0

Source	Node ID, 0.5 NTU, no pattern
Emergency	Disabled

GISpipe: No changes (current operating conditions)

Simulation: 24 hours

Results: Compare TURB_MOBILE across pipes to identify high-turbidity zones (typically aged pipes, dead ends).

Scenario 2. Pipe Flushing

Purpose: Predict deposit removal speed and downstream turbidity impact during flushing.

GISpipe Settings:

Item	Value
Initial Mobile Turbidity	0.1 NTU
Initial Deposit Scale	**2.0** (long-neglected pipe)
Source	Node ID, 0.5 NTU, no pattern
Emergency	Disabled

GISpipe changes required:
- Add high demand at downstream hydrant node (e.g., N6 at 50 LPS, 2-6 hours)
- Set demand pattern for open/close timing

Results: DEPOSIT decrease curve, TURB_MOBILE spike magnitude and duration, time to normalization.

Scenario 3. Demand Surge

Purpose: Predict turbidity spikes during morning/evening peak hours.

GISpipe Settings:

Item	Value
Initial Mobile Turbidity	0.1 NTU
Initial Deposit Scale	1.0
Source	Node ID, 0.5 NTU, **pattern enabled**
Source Pattern (24hr)	See below

Source pattern example (hourly multipliers):

00-05h	06-11h (morning peak)	12-17h	18-23h (evening peak)
0.80 0.70 0.70 0.70 0.80 0.90	1.20 **1.40** 1.30 1.10 1.00 1.00	1.00 0.90 0.90 1.00 1.10 1.30	**1.40** 1.20 1.00 0.90 0.80 0.80

Simulation: 48 hours (2-day observation)

Results: TURB_MOBILE rise timing after peak, time lag between max velocity and max turbidity.

Scenario 4. Valve Operation

Purpose: Predict turbidity events from valve closure/reopening during maintenance.

GISpipe Settings:

Item	Value
Initial Mobile Turbidity	0.1 NTU
Initial Deposit Scale	**1.5** (stagnation zones have more deposits)
Source	Node ID, 0.5 NTU, no pattern
Emergency	Disabled

GISpipe changes: Set valve schedule in [CONTROLS]

Results: DEPOSIT buildup during closure, TURB_MOBILE spike at reopening, affected downstream nodes.

Scenario 5. Pipe Aging Comparison

Purpose: Compare turbidity behavior between new and aged pipes for rehabilitation prioritization.

Method: Run **twice** with different roughness coefficients.

	Run A (New)	Run B (Aged)
Initial Deposit Scale	**0.0** (clean)	**1.0**
INP Roughness	C=130 (or ε=0.05, n=0.010)	C=80 (or ε=2.0, n=0.025)

Results: Compare TURB_MOBILE averages, DEPOSIT accumulation rates.

Scenario 6. Source Switching

Purpose: Predict turbidity propagation when switching from Plant A to Plant B.

GISpipe Settings:

Item	Value
Initial Mobile Turbidity	0.3 NTU (residual from Source A)
Source 1	Node ID-A, 0.3 NTU, pattern: [1×12hrs, 0×12hrs] (shutdown at 12h)
Source 2	Node ID-B, 0.8 NTU, pattern: [0×12hrs, 1×12hrs] (startup at 12h)

Simulation: 48 hours

Results: Propagation path of Source B (0.8 NTU) turbidity front, arrival time at network extremities.

Scenario 7. Emergency (Pipe Break / Contamination)

Purpose: Estimate contamination extent and recovery time.

GISpipe Settings:

Item	Value
Initial Mobile Turbidity	0.1 NTU
Source	Node ID, 0.5 NTU, no pattern (normal supply)
Emergency Injection	✅ Enabled
Injection Node	Node ID
Injection Turbidity	**50 NTU**
Duration	**3 hours**
Mode	SETPOINT

Simulation: 24 hours (3h contamination + 21h recovery)

Results: Number of affected nodes, max TURB_MOBILE per node, time to recovery (below 0.5 NTU).

Scenario 8. Tank Operation Optimization

Purpose: Compare turbidity effects of different tank retention times.

GISpipe Settings:

Item	Value
Initial Mobile Turbidity	**0.3 NTU** (tank residual)
Initial Bound Turbidity	**0.05 NTU**
Source	Node ID, 0.5 NTU, no pattern

Method: Same MSX, **change only GISpipe tank levels:**

Case	Tank Level Range	Retention
A	Min 2m ~ Max 8m	Long
B	Min 5m ~ Max 7m	Short

Results: Compare TURB_MOBILE time series at tank outlet node.

Scenario 9. Long-Term Deposit Accumulation (Flushing Priority)

Purpose: Predict which pipes accumulate deposits fastest over 30 days.

GISpipe Settings:

Item	Value
Initial Mobile Turbidity	0.1 NTU
Initial Deposit Scale	**0.0** (start clean)
Source	Node ID, 0.5 NTU, **pattern enabled**
Source Pattern	24-hour daily variation pattern

GISpipe changes: DURATION 720:00 (30 days), REPORT TIMESTEP 1:00

Results: Rank pipes by DEPOSIT value after 30 days = **flushing priority list**.

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4. Scenario Settings Summary

Scenario	Init. Turb.	Deposit Scale	Source	Emergency	INP Change
1. Assessment	0.1	1.0	Node ID, 0.5, constant	-	None
2. Flushing	0.1	**2.0**	Node ID, 0.5, constant	-	Hydrant demand
3. Demand Surge	0.1	1.0	Node ID, 0.5, **pattern**	-	Demand pattern
4. Valve Ops	0.1	**1.5**	Node ID, 0.5, constant	-	Valve schedule
5. Aging Compare	0.1	0.0 / 1.0	Node ID, 0.5, constant	-	Roughness
6. Source Switch	**0.3**	1.0	**Node ID-A+B, switch**	-	Pump ON/OFF
7. Emergency	0.1	1.0	Node ID, 0.5, constant	**Node ID, 50NTU, 3h**	None
8. Tank Optim.	**0.3**	1.0	Node ID, 0.5, constant	-	Tank levels
9. Long-Term	0.1	**0.0**	Node ID, 0.5, **pattern**	-	30-day sim

> **Key point:** The MSX reaction equations are identical across all 9 scenarios. Only the GISpipe input values change.

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5. Input Value Guidance

How to set Initial Deposit Scale?

Situation	Recommended Scale
Recently flushed pipe	0.0 ~ 0.5
Normal condition	1.0
Stagnation zone, near valves	1.5
Long-neglected pipe	2.0 ~ 3.0

How to set Source Turbidity?

Use actual treatment plant effluent turbidity data. Typically 0.1~1.0 NTU range. Use recent average from plant records.

Should I change reaction rate constants?

Start with defaults. Once you have flushing data or field turbidity monitoring, compare simulation vs. measured values and adjust accordingly.

Observation	Adjustment
Simulated turbidity lower than measured	Increase resuspension coefficients, decrease decay
Simulated turbidity higher than measured	Decrease resuspension coefficients, increase decay
Flushing turbidity drops slower than measured	Increase resuspension coefficients
Deposit builds up faster than measured	Decrease deposition rate

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6. Model Principles (Reference)

Turbidity Particle Cycle

```
                    Attach(k_attach)            Deposit(k_depo)
[Mobile Turb.] ──────────→ [Bound Turb.]     [Mobile Turb.] ──────────→ [Deposit]
 (free in water) ←────────── (loose wall attach) (free in water) ←────────── (firm wall deposit)
                   Detach(k_detach)            Resuspend(k_resus_base +
                                               k_resus_vel × velocity)
```

- **Attach/Detach:** Reversible loose adhesion of particles to pipe wall
- **Deposit/Resuspend:** Firm settling onto wall or velocity-driven re-release
- **Natural Decay:** Gradual removal by flocculation, settling, etc.
- **Velocity Effect:** Higher velocity = more resuspension → flushing principle

Roughness Coefficient and Aging

Headloss Formula	Roughness	Aged Pipe	Ratio Example
Hazen-Williams	C	C low (e.g., 80)	130/80 = 1.63×
Darcy-Weisbach	ε (mm)	ε high (e.g., 2.0)	2.0/0.05 = 40 → clamped to 5.0×
Chezy-Manning	n	n high (e.g., 0.025)	0.025/0.010 = 2.5×

This ratio multiplies the base attachment/deposition rates, making aged pipes accumulate more deposits.

Scientific Background

- **PODDS Model (Boxall et al., 2001):** Layered wall deposit structure and shear-stress resuspension
- **Vreeburg & Boxall (2007):** Discolouration framework for distribution networks
- **Husband & Boxall (2011):** Field validation of aging-deposit relationship
- **Furnass et al. (2014):** Surface roughness influence on deposition characteristics
- **Rossman (2000):** EPANET first-order reaction kinetics approach

Model Limitations

1. All reactions are first-order (rate proportional to concentration)
2. Tank internal deposition/resuspension not modeled (EPANET-MSX structural limitation)
3. Particle size distribution, temperature, biological growth not considered
4. Default parameters are literature-based starting values; field calibration needed