Workshop on Good Modelling Practice Guidelines for Use of Activated Sludge Models

9 September 2008
Vienna, Austria

Organised by the IWA Task Group on "Good Modelling Practice - Guidelines for Use of Activated Sludge Models in Practice"

Program

<table>
<thead>
<tr>
<th>Time</th>
<th>Topic</th>
<th>Presenter</th>
</tr>
</thead>
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<tr>
<td>09:00 - 09:10</td>
<td>Welcome</td>
<td>Günter Langergraber</td>
</tr>
<tr>
<td>09:10 - 09:30</td>
<td>Introduction – Background and purpose of the GMP Task Group</td>
<td>Imre Takács</td>
</tr>
<tr>
<td>09:30 - 09:50</td>
<td>The Unified Protocol &amp; the Application Matrix as applied for the Beenup WWTP (introduction to the case study)</td>
<td>Andrew Shaw</td>
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<tr>
<td>09:50 - 10:30</td>
<td>Walk through the GMP Guidelines:</td>
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<tr>
<td></td>
<td>• Project Definition (10min)</td>
<td>Stefan Winkler</td>
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<tr>
<td></td>
<td>• Data collection &amp; Evaluation (20min)</td>
<td>Stefan Winkler</td>
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<tr>
<td>10:30 - 11:15</td>
<td>Coffee break</td>
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<td>11:15 - 12:00</td>
<td>Walk through the GMP Guidelines (cont'd)</td>
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<tr>
<td></td>
<td>• Model Set-Up (15min)</td>
<td>Andrew Shaw</td>
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<tr>
<td></td>
<td>• Calibration/Validation (15min)</td>
<td>Andrew Shaw</td>
</tr>
<tr>
<td></td>
<td>• Simulation &amp; Results Interpretation (15min)</td>
<td>Imre Takács</td>
</tr>
<tr>
<td>12:00 - 12:45</td>
<td>Discussion on GMP guidelines and wrap-up</td>
<td>moderated by Langergraber</td>
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</tbody>
</table>
Presenter contact information

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Acknowledgments

University of Natural Resources and Applied Life Sciences, Vienna
Department of Water, Atmosphere, and Environment
Introduction

Background and purpose of the GMP Task Group

IWA GMP Task Group

Presenter: Imre Takács

IWA Task Group – The Idea

at IWA 4th World Congress in Marrakech Sept. 2004

Workshop on Modelling Protocols of

HSG, German speaking group
STOWA, The Netherlands
BIOMATH, Belgium
WERF, North America

Formation of a new IWA Task Group
Introduction

IWA Task Group on “Good Modelling Practice”
GMP workshop, 9 September 2008, Vienna, Austria

Good modelling practice using ASMs
(Structured Activated Sludge Models)

Objective based approach
(cost/benefit analysis)

Targeted towards practitioners and consultants
Focus

- The activated sludge process
- Data needs & reconciliation
- Calibration (typical defaults)

- Municipal wastewater
  (methods applicable for industrial wastewaters)

Outcome

- Internationally accepted guidelines
- Straightforward and practical
- Reference, illustrated with examples

⇒ IWA Scientific and Technical Report \( (STR) \)
We are (still) looking for input!

- Expert Groups
- Questionnaires (#1 and #2)
- Workshop and Course discussions
- Website, Forum
- Unsolicited opinions, methods

Contact
Leiv Rieger, chairman leiv.rieger@gci.ulaval.ca

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Questionnaire #1 – Quick Summary

Hélène Hauduc and the TG

- Circulated in 2007
- 96 responses
  - ASM Users: 79% (76 ASM users – 20 non-ASM users)
- International survey
Responses

Objectives of the Questionnaire

Who is using ASMs?

Which models, tools and procedures are used?

Obstacles and expectations
### ASM users: organization type

- **University & public research centres**: 58%
- **Private companies**: 34%
- **Governmental organisations**: 7%
- **WWTP**: 1%

#### Source of modelling knowledge

- **Self training**: 78%
- **University courses**: 39%
- **Software training**: 26%
- **Employee training**: 12%

**Main source**: Self training
Main modelling objectives

- Opt. for operation: 54%
- Plant modification: 30%
- Control strategies: 24%
- Opt. for wet weather: 20%
- Opt. for sewer variations: 16%
- Research/Educational: 14%
- Side streams: 13%
- Other: 3%

Consultants ➔ design
Government ➔ effluent quality control
Universities ➔ general research

Obstacles

- Reliability: 24%
- Complexity: 22%
- Inadequate model: 15%
- Data collection: 17%
- Calibration: 24%
Expectations

- Standardization: 32%
- Model limits: 17%
- Comparison of models: 5%

What’s in the STR?

- Executive Summary
- Introduction
  - We would like you to read this before you read what we think is really important
- Unified protocol and Application Matrix
  - The good stuff
- Addenda
  - Other related bits and pieces we could not cram into the important part
What’s in the STR?

Introduction
- Scope of report
- Which models are covered
- History of activated sludge modelling

Protocol and Application Matrix
- Project definition
- Data collection and reconciliation
- Model set up
- Calibration and validation
  - Sources of uncertainties and model prediction quality
- Simulation and result interpretation
  - How to run a model
  - Scenario analysis
  - Documentation and reporting
What’s in the STR?

Addenda

- Use of ASMs for industrial wastewaters
- Summary
- Future of AS modelling
- Trends
- Research needs
- FAQs
- References

- Terminology, notation
- Case studies
- Data quality evaluation tools
- Typical ratios
- Simple reliability checks
- Mass balances
- Typical sources of errors
- On-line sensors
- Analytical checks
- Statistical evaluation
- Default parameter sets

More information at

www.modelEAU.org/GMP_TG
Towards practical guidance for wastewater treatment modeling studies – Draft guidelines from the IWA GMP task group

The Unified Protocol & Application Matrix

Andrew Shaw

Black & Veatch, Kansas City, USA
Unified Protocol – Major Steps

1. Project Definition
2. Data collection & Reconciliation
3. Plant Model Set-Up
4. Calibration/Validation
5. Simulation & Results Interpretation

The Application Matrix - Development

- How the Unified Protocol is used depends on the application
- There are many applications for activated sludge models
- Choose 12 typical applications that are representative of the most common uses
- Present these applications in a matrix showing relative level of effort/importance for each Protocol step
- Users can compare their application to a similar typical application or carry out their own subjective evaluation
## The Application Matrix

### Protocol Steps

#### Applications

<table>
<thead>
<tr>
<th>Applications</th>
<th>Weightings</th>
</tr>
</thead>
<tbody>
<tr>
<td>DESIGN</td>
<td></td>
</tr>
<tr>
<td>- Calculate Sludge Production</td>
<td>1</td>
</tr>
<tr>
<td>- Design Aeration System</td>
<td>2</td>
</tr>
<tr>
<td>- Develop a Process Configuration for Nitrogen Removal</td>
<td>3</td>
</tr>
<tr>
<td>- Develop a Process Configuration for Phosphorus Removal</td>
<td>4</td>
</tr>
<tr>
<td>- Assess Plant Capacity for Nitrogen Removal</td>
<td>4</td>
</tr>
<tr>
<td>- Design a Treatment System to Meet Peak Effluent Nitrogen Limits</td>
<td>5</td>
</tr>
<tr>
<td>OPERATION</td>
<td></td>
</tr>
<tr>
<td>- Optimise Aeration Control</td>
<td>3</td>
</tr>
<tr>
<td>- Test Effect of Taking Tanks Out of Service</td>
<td>2</td>
</tr>
<tr>
<td>- Use Model to Develop Sludge Wastage Strategy</td>
<td>3</td>
</tr>
<tr>
<td>- Develop a Strategy to Handle Storm Flows</td>
<td>5</td>
</tr>
<tr>
<td>TRAINING</td>
<td></td>
</tr>
<tr>
<td>- Develop a General Model for Process Understanding</td>
<td>2</td>
</tr>
<tr>
<td>- Develop a Site Specific Model for Operator Training</td>
<td>3</td>
</tr>
</tbody>
</table>

### Subjective Scores

### Weighted Level of Effort [%]

#### Overall Effort Level

IWA Task Group on "Good Modelling Practice"
GMP workshop, 9 September 2008, Vienna, Austria

### Graphical Summary

**Overall Effort Level**
- Simulation & Results Interpretation
- Calibration & Validation
- Model Set-Up
- Data collection & Reconciliation
- Project Definition

**Weighted Level of Effort [%]**
- Calculate Sludge Production
- Design Aeration System
- Develop a Process Configuration for Nitrogen Removal
- Develop a Process Configuration for Phosphorus Removal
- Assess Plant Capacity for Nitrogen Removal
- Design a Treatment System to Meet Peak Effluent Nitrogen Limits
- Optimise Aeration Control
- Test Effect of Taking Tanks Out of Service
- Use Model to Develop Sludge Wastage Strategy
- Develop a Strategy to Handle Storm Flows
- Develop a General Model for Process Understanding
- Develop a Site Specific Model for Operator Training

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Unified Protocol & Application Matrix | Andrew Shaw
Application Matrix - Other Considerations

- Plant size/complexity
- Effluent limits
- Budget constraints
- Time constraints
- Skill level/training
- Client level of interest
- Others…?

Case Study – Beenyup WWTP

Following Slides present the UP steps and illustrate with the Beenyup WWTP model case study
Step 1: Project Definition

Stefan Winkler
Institute for Water Quality and Waste Management, Vienna Technical University, Vienna, Austria

UP diagram for Project Definition

- Problem statement
- Objectives
- Requirements (data, model accuracy, ...)
- Agreement on the objectives and budget?

From simulation and result interpretation
If objectives are not met.
Process of Project Definition

Interview
- Client’s requirements
  - Which questions to be answered?
- Client’s restrictions
  - Available data, budget, time…

Focus

Proposal
- Objectives
- Model boundary
- Acceptable preconditions
- Performance criteria (model accuracy, acceptable uncertainty)
- Responsibility
- Required data
- Fixed budget

UP guides items to be included and avoid misunderstandings and unnecessary iterations

Beenyup Wastewater Treatment Plant (WWTP)
Western Australia, Perth since 1970
Current design load is 120 ML/D
Upgrade plan to meet 137 ML/D as stage 1 in 2012
and 150 ML/D as stage 2 in 2016

GMP protocol is applied for structured, well documented and verifiable model based investigation
Background

- Engineering design report (EDR) needs assessment
- Limited budget needs rational staging of upgrade
- Pre-existing plant model was not adequate because:
  - Operational conditions changed
  - Inconsistent data identified

Objectives

- Determine **current and future capacity of individual process units**
- Identify **critical bottlenecks**
- Determine **cost-effective staging of upgrade**

- Develop a **plant-wide model** of Beenyup WWTP as a tool for current design investigation **AND** future operation support
Model boundary and preconditions

- Plant-wide modelling for bottleneck analysis

- Acceptable preconditions
  - Treatment capacity of each unit other than biological process is determined on design criteria.
  - Performance at excessive loadings beyond each unit’s design values are not considered

Performance criteria and assessment topics

- Performance criteria
  - Sludge production is important from cost aspect
    - ±10% based on annual or monthly average values.

- Target assessment topics
  - Aeration capacity (peak and average)
  - Secondary treatment capacity
  - Effluent nitrogen load
Data requirements

- Plant information database is available

- Focus
  - Data validation on flow data and conventional quality data
  - Sampling and measurement for influent characterization

Iterative aspect

- GMP helped to share the scope of project and avoid unnecessary misunderstanding and iteration
- But, even with this project,
  - re-definition of objectives happened
- Can we do this?
  
  Clear scoping helps to request budget for additional tasks
### Application matrix utilization (1)

<table>
<thead>
<tr>
<th>Objectives</th>
<th>Project Definition</th>
<th>Data collection &amp; Reconciliation</th>
<th>Model Set-Up</th>
<th>Calibration &amp; Validation</th>
<th>Simulation &amp; Results Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weightings</td>
<td>10</td>
<td>50</td>
<td>10</td>
<td>15</td>
<td>15</td>
</tr>
</tbody>
</table>

#### DESIGN

1. Calculate Sludge Production  
2. Design Aeration System  
3. Develop a Process Configuration for Nitrogen Removal  
4. Develop a Process Configuration for Phosphorus Removal  
5. Assess Plant Capacity for Nitrogen Removal  
6. Design a Treatment System to Meet Peak Effluent Nitrogen Limits

#### OPERATION

7. Optimise Aeration Control  
8. Test Effect of Taking Tanks Out of Service

#### Guideline’s use for Project Definition

- Gives guidelines on items to be considered and agreed upon during the initial project definition step.
- Application matrix can be used as background information for proposed project by clients.
Data needs, data evaluation and data reconciliation within the context of wastewater treatment modelling

INTRODUCTION

Data needs for WWTP simulation studies

► depend on the goal of the study

Quality and quantity demands will generally increase with the increasing demands concerning the accuracy and resolution of the simulation results

► will cause a collection and evaluation effort that will not necessarily correlate with the data demands

Completeness and quality of existing data sets with respect to the study goals are the decisive factor

► A simulation study cannot compensate insufficient or bad data (‘Garbage in ⇒ garbage out’)

► Approx. 50 % of the total effort of a simulation study are dedicated towards data collection and evaluation (Hauduc et al., 2008)

► should be assessed by starting from existing data sets
DATA TYPES

WWTP data classification

► Input data
  Loading data of the plant (hydraulic, organic and nutrient load)

► Physical plant data
  How the plant is built (tank sizes, pumping and aeration capacities, ..)

► Operational settings
  How the plant is operated (set points, aeration control strategy, etc.)

► Performance data
  How the plant performs; e.g. how it responds to the plant load applying the operational settings

► Effluent data

DATA COLLECTION AND RECONCILIATION

A step-wise procedure

STEP viii: Determine the influent dynamics
STEP vii: In-tank data
STEP vi: Determine the influent fractions
STEP v: Data reconciliation (assign the error)
STEP iv: Determine the WAS-production (TP-balance)
STEP iii: Analyze the flow data (balanced ?)
STEP ii: Analyze the input data (municipal ?)
STEP i: Understand the plant ‘as-is’ (plant visit)
(i): UNDERSTAND THE PLANT

Discuss with WWTP personnel

- 'as-is' / 'as-operated' vs. design documents
  - Changes of flow schemes, tank uses, intake of external streams (sludge, co-substrate, etc.)
- Routine monitoring programme
  - Sampling / probe installation locations, sampling and analysis methods, auto-sampler scheduling, processing of data in the PLC
- Operation and control concept
  - Discontinuous activities (e.g. sludge dewatering), main control loops and settings, probe signal utilization
- Instrumentation applicability
  - Installation, measurement range, measurement principle

(ii): ANALYZE THE INPUT DATA

Municipal wastewater characteristics

► Collect existing (routine plant monitoring) data
► Basic sanity checks
  - Region specific water consumption (↔ infiltration water)
  - Region specific wastewater concentrations – or better
  - (Region specific) ratios between wastewater constituents

Plant loading [PE]

Percentile [%]

0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%

3,000 4,000 5,000 6,000 7,000 8,000 9,000 10,000 11,000 12,000 13,000 14,000 15,000 16,000 17,000 18,000 19,000 20,000 21,000 22,000

Peak effluent Q_160 L/d
PE_COD_120 g/d
PE_TN_11 g/d
PE_TP_1.8 g/d
PE_TSS_70 g/d
PE_BODs_60 g/d
(iii): ANALYZE THE FLOW DATA (1)

Example: Beenyup WWTP

Flow measurements:
- 2 inlet flumes
- 4 electromagnetic flow meters in primary effluent chamber
- 2 outlet flumes (combined outlet channel)

(iii): ANALYZE THE FLOW DATA (2)

Example: Beenyup WWTP

Design studies started
TP-mass balance

► A TP-mass balance is always a closed mass balance, since P is removed in the solid phase only (waste sludge):

\[ TP_{IN} - TP_{EFF} = TP_{WAS} = Q_{WAS} \times MLSS_{WAS} \times (TP:MLSS)_{WAS} \]

► Typical (TP:MLSS)-ratios of WAS are: 1.5 - 3.0%
► If no (TP:MLSS)-data available
  ▪ Calculate ‘open balance’ and check (TP:MLSS)-ratio for plausibility
  ▪ Initiate additional monitoring
► P-precipitation sludge accounts for approx. 15 \% of the total WAS-production
► Solids loss in the effluent accounts for approx. 3-5\% of the total WAS-production

(iv): WAS-production, SRT and OC (2)

Sludge production decreases with SRT

Dold (2008):

Theoretical specific WAS-production from raw/settled sewage

vs.

Full scale data
Mass balancing

► Mass balances are a very effective tool to identify data inconsistencies and/or gross errors

► Cross linking of mass balances provides a tool for identifying the source of data inconsistencies

► Before the simulation exercise is started the applied data set needs to be reconciled, i.e. all mass balances need to be closed
  ▪ Identification of systematic measurement errors
  ▪ Engineering judgment ⇒ assign error to most probable pathway
  ▪ Advanced methods: Meijer et al. (2001), Thomann (2007)

Mass balances: AS-plant / simultaneous stabilization

All values relative to influent flow
Mass balances: AS-plant / anaerobic digestion

**Data Needs and Reconciliation I**

Stefan Winkler

IWA Task Group on "Good Modelling Practice"

GMP workshop, 9 September 2008, Vienna, Austria

**Mass balances: AS-plant / anaerobic digestion**

**LOW: PC, stabilisation**

COD: 76 %

N: 104 %

P: 91 %

**Biological treatment stage**

COD: 43 %

N: 55 %

**MORE (to be achieved): higher N:COD-ratio**

COD: 6 %

N: 30 %

P: 10 %

**ALL values relative to influent flow**

**Data Needs and Reconciliation I**

Stefan Winkler

IWA Task Group on "Good Modelling Practice"

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**(vi): INFLUENT FRACTIONS**

**Methods**

- Methods for determining influent fractions
  - WERF (2003)
  - Roeleveld and van Loosdrecht (2002: STOWA-method)
  - Apply ‘default influent fractions’ (e.g. Bornemann et al., 1998) (in case targeted investigations are not feasible)

- Fractions with direct impact on the SRT
  - Direct determination of *inert particulate COD* – instead of calculating it as the remaining fraction (typ. 15%, difference of large numbers ⇒ low accuracy)
  - *Colloidal fraction* – Membrane filtration after flocculation step
(vii): PERFORMANCE AND EFFlUENT DATA

Additional data guiding the calibration step

► Process and effluent concentrations: \( \text{O}_2, \text{NH}_4-N, \text{NO}_3-N, \text{PO}_4-P \)
  ➔ Utilising process measurement data requires a suitable plant model (number of CSTR’s ↔ modelling of mixing effects)
  ➔ Correct transfer of sampling / probe installation locations into the plant model
  ➔ Effluent data: Correct operation of auto-samplers considering the HRT within the plant / correct averaging periods of continuous measurements

► Additional process performance data
  ➔ OUR and biomass decay rates
  ➔ Not included in standard WWTP monitoring programmes
  ➔ Valuable to evaluate e.g. WWTP nitrification capacity

(viii): INFLUENT DYNAMICS

Methods

► Methods for determination of the influent dynamics
  ➔ Monitoring campaign (2h-composite samples / 2-10 days) (in case influent dynamics are essential for the goal of the simulation study)
  ➔ Continuous monitoring (existing or short term installation)
  ➔ WWTP influent generators (e.g. Langergraber et al. (2008), Gernaey et al. (2006))
SUMMARY

- Start any simulation study by talking to the WWTP personnel
- Data can be classified: physical plant, operation, influent, performance, effluent
- Data collection and evaluation should follow a step-wise approach
- Additional measurement campaigns only after analysis of existing data and identification of data needs
- Mass balances are a very effective tool for gross error detection
  Setting up a simple simulation model can support the process of ‘understanding the plant’ and detecting inconsistencies
- Advanced methods for data evaluation/reconciliation are available, but (yet) expert tools

QUESTIONS

- Consensus on step-wise data collection and reconciliation approach?
- Is it / (why is it not) possible to communicate the benefits of generating routine plant data in a meaningful way?
  Data graveyard vs. valuable resource for plant design/upgrade and/or process optimisation
- Why is an adequate instrumentation concept often lacking within the WWTP design procedure resulting in under- or over-equipped plants and/or an insufficient understanding of the WWTP personnel of the benefits/limitations of continuous monitoring?
Towards practical guidance for wastewater treatment modeling studies – Draft guidelines from the IWA GMP task group

Step 3: Model Set-up

Andrew Shaw

Black & Veatch, USA

Overview

- Step 3: Plant model set-up
- Case study WWTP Beenyup
Plant model set-up

Step 3
Plant model set-up

MODEL SET UP

Plant model building
(input specification, sub-model selection)

Functional evaluation

Sensible outputs?

yes

no

Model adequate?

yes

no

simulator (software)

real world

observations

system boundary
(x, t)

observations

input data

sub-models
(e.g. hydraulics, biochemistry, sensors, controls, operators…)

model

output data

input model

output model
Plant model set-up

Use of models

- Input to model → Prediction
- Model → Understanding
- Input to model → Communication

Plant model set-up: Boundaries

Mech. treatment → Primary clarifier → Activated sludge tank → Secondary clarifier → Sludge treatment
Plant model set-up
Plant model set-up: Real world/Modelling world

Real world (measured)

- Influent data: Flow rate, influent conc., WW characterization...
- Physical data: Process scheme, vol of tanks, lanes...
- Operational settings: Controller set points, flow rates...
- Process data: Effluent/reactor conc., flow rates, MLSS, SRT...
- Effluent/WAS data: Effluent and sludge conc., flow rates

Calibration / Validation of:
- Plant Set-up
- Operational settings
- Plant effluent
- Waste Activated Sludge (WAS)

Calibration / Validation of:
- Sub-models

Modelling world

Input Models

- Sub-models
- Plant influent

Output Models (calc. variables)
- e.g. TSS, VSS, COD, BOD, TKN, PO4, Ptot, NH4, NO3...

Plant model set-up
Plant model set-up: Sub-models
Plant model set-up
Plant model set-up: Sub-model interfaces

How to connect sub-models
- State variables
- Interfaces vs. Supermodels

Case study WWTP Beenyup
Case study WWTP Beenyup
Plant model set-up

- **Boundaries:** Whole plant model
- **Sub-models:**
  - Bio-kinetic model: ASDM (BioWin)
  - Input model: WW characterization acc. SKM
  - Hydraulic and transport model: tanks in series (CSTR)
  - Settler model: % removal with volumes
  - Aeration system model: B&V
  - Controller models: DO conc. fixed
  - Output model: BioWin package

---

Case study WWTP Beenyup
Hydraulic and Transport model
Modules 1&2

![Hydraulic and Transport model diagram]

- PE
- Anoxic 1, Anoxic 2, Aerobic 1, Aerobic 2, Aerobic 3
- ML Return
- FS Tanks

---

Modules 3&4

- PE
- Anoxic 1, Anoxic 2, Aerobic 1, Aerobic 2, Aerobic 3
- ML Return
- FS Tanks

---

Model Set-Up | Andrew Shaw
Case study WWTP Beenyup
Hydraulic and Transport model

Modules 1&2
Anoxic 1 2 CSTRs
Aerobic 1 2 CSTRs
ML Return
PE

Calculated according to Fujie et al. 1983

Modules 3&4
Anoxic 1 2 3 CSTRs
Aerobic 1 2 3 CSTRs
ML Return
PE

Aeration system

- Model prediction: air demand of 61,000 Nm³/h
- Measurement: air input 40,000 Nm³/h
- Investigation → 2 of 5 flow transmitters on blowers reading incorrectly → 30% underestimation of air input

→ Once the aeration model was set up, simulated air flows were significantly higher (>20%) than measured in plant
Case study WWTP Beenyup
Plant model set-up
Towards practical guidance for wastewater treatment modeling studies – Draft guidelines from the IWA GMP task group

Step 4: Calibration / Validation

Andrew Shaw

Black & Veatch, USA

Overview

- GMP Unified protocol (Calibration/Validation)
- Case study WWTP Beenyup
**Calibration / Validation**

**Objective:** Adjustment of selected model parameters to reach an agreement between simulated and measured values

- Define stop criteria upfront
- Parameter selected according to sensitivity analysis and expert judgement
- Validation with independent data set
Calibration / Validation

Calibration steps for activated sludge models

ASM-Models are highly over-parameterized → manual calibration with expert knowledge

1) Hydraulic model
2) Influent characterization
3) Sludge production (first COD then TSS)
4) Nitrification
5) Denitrification
6) EBPR

Iterative procedure!

Example: N-removal

<table>
<thead>
<tr>
<th>Steps</th>
<th>Related parameters</th>
<th>Confronted variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sludge production and composition (Steady state)</td>
<td>Waste sludge amount; i.e.</td>
<td>CODto in AS, MLSS; Excess sludge production;</td>
</tr>
<tr>
<td>Settling</td>
<td></td>
<td>Sludge blanket height; effluent TSS</td>
</tr>
<tr>
<td>Oxygen transfer</td>
<td>$k_d, a$</td>
<td>$[O_2]$ in tanks, oxygen presence time, airflow rates</td>
</tr>
<tr>
<td>Nitrification</td>
<td>$\mu, b_a, b_c$, affinity constants; $\eta_c$; $k_c, k_c, k_x$</td>
<td>$NH_4^+-$N and NOx-$N$ (in tanks, effluent)</td>
</tr>
<tr>
<td>Denitrification</td>
<td>$\mu : Y_A$, affinity constants; $\eta_A$; $k_s, f_A$</td>
<td>$NH_4^+-$N and NOx-$N$ (in tanks, effluent)</td>
</tr>
<tr>
<td>Validation</td>
<td></td>
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</tbody>
</table>
Case study WWTP Beenyup


Step-wise approach to calibration:

1) Sludge production (Solids balance)
2) Nitrification
3) Denitrification
Case study WWTP Beenyup
Calibration of sludge production

- Initial sludge numbers differed by > 10% from plant data
- Triggered extensive analysis of plant data to determine discrepancies

→ Continuous cross-checking of modelled data with plant data necessary

Case study WWTP Beenyup
Calibration of nitrification

- Model predictions: full nitrification
- Measurements: average effluent NH$_3$-N of 2.3 mg/L

→ No change in default nitrification kinetic parameters

(Due to uncertain data. Further evaluation required)
Case study WWTP Beenyup
Calibration of denitrification

- Model predictions: nitrate up to 20 mg N/L
- Measurements: nitrate concentration average 11 mg N/L

- Probably significant SND occurring in plant (local low-DO zones)
- Some denitrification kinetics adjusted
  - Anoxic growth factor (neta-g): 1.0 (0.5)
  - Anoxic hydrolysis factor (neta-h): 0.45 (0.28)
  - Aerobic denitrification DO switching function: 0.4 (0.05) mg/L

Case study WWTP Beenyup
Calibration / Validation: Challenges

High variability of plant data
Case study WWTP Beenyup
Calibration / Validation: Challenges

High variability of plant data
- Difficult to establish “average” operating condition for steady-state modelling
- Sensible judgement necessary

Only 5-month reliable data period for calibration – plant operating in transient state during this time
- Most important step – continuous cross-checking of model outputs with measured plant data
  ➤ Extensive, iterative process to arrive at reasonable, representative calibration

Case study WWTP Beenyup
Validation

- No validation required for particular objectives
  - Identify critical bottlenecks
  - Determine cost-effective staging of upgrade
Towards practical guidance for wastewater treatment modelling studies – Draft guidelines from the IWA GMP task group

Step 5 - Simulation and result interpretation

A. Shaw\(^1\), I. Takács\(^2\)

\(^1\) Black & Veatch, Kansas City, USA
\(^2\) EnviroSim Associates Ltd., Bordeaux, France
Step 5 – Simulation and result interpretation
The tool is ready - we have a good model
Set up and perform simulations that answer questions laid out in objectives

- Steady-state simulations
  - Overall mass balancing
  - Long term performance check

- Dynamic simulations
  - Diurnal peaks – to determine equipment limits
  - Seasonal changes – long term operating strategies
  - Storms events – optimal handling

Results
- Mass rates, operating parameters
- Effluent concentrations
- Warnings – any variable out of normal bounds?
- Tables, charts
- Visual and statistical processing
Step 5 – Simulation and result interpretation

Conclusions – Project objective
- Required equipment
- Modified operational strategy
- Pleading with authorities (strong technical justification)

Beenyup WWTP Simulations

**Steady state modelling** – Determine major process bottlenecks through direct comparison of simulated operating conditions with original design capacities and use this to prioritise upgrades

**Dynamic modelling** – Check ability of plant to deal with *peak* loads, with focus on aeration requirements
### Beenyup - Process capacity assessment criteria

<table>
<thead>
<tr>
<th>Treatment area</th>
<th>Parameter</th>
<th>Value</th>
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<th>Source</th>
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<td>L/s/centrifuge</td>
<td>On-site trials of equipment</td>
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**Benchmarking Baseline simulation – 122 ML/d**

- PSTs M1&2 HLR
- PSTs M3 HLR
- PSTs M3 HRT
- Aer.SRT M1&2
- Aer.SRT M3&4
- Sec.aeration M1&2
- Sec.aeration M3&4
- SST M1&2 HLR
- SST M1&2 SLR
- SST M3&4 HLR
- SST M3&4 SLR
- DAFs HLR
- DAFs SLR
- Centrifuge SRT
- Centrifuge HLR

0% 100%
**Beenyup - Simulation of aeration demand**

Determine peak aeration demand at 137 ML/d and 150 ML/d

Dynamic modelling used, using typical weekly diurnal flow pattern and measured diurnal influent concentrations

Maximum blower capacity in 3-blower operation 88,200 Nm³/h

Maximum blower capacity in 4-blower operation 98,000 Nm³/h

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**Beenyup - Aeration demand**

- At 122 ML/d, 3 blowers sufficient
- At 137 ML/d, peak air demand not met with 3 blowers (however BioWin shows full nitrification still achieved!)
- At 150 ML/d, 4 blowers required
 Beenyup Air flows per diffuser
- Module 1&2 at 122 ML/d

Module 1 & 2 - Maximum diffuser capacity is exceeded