Overview of Models for Estimating Pollutant Loads & Reductions
(Handbook Chapter 8.3–8.5)

Texas Watershed Planning Short Course
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A Humorous View or a Reality Check?
Watershed Monitoring and Modeling is the Art and Science of

- Collecting data in systems we cannot adequately sample
- Using methods developed by committees of technically unqualified participants
- For organisms and pollutants we know very little about
- In order to form concepts about processes we do not fully understand
- That we represent as mathematical abstractions that we cannot precisely analyze
- To determine their responses to indeterminate stresses we cannot accurately predict now let alone in the future
- All in such a way that society at large is given no reason to suspect the extent of our ignorance.

Adapted from a slide by Dr. Thom Hardy, Texas State Univ.
Why Use Watershed Modeling?

“Models provide another approach, besides monitoring data and export coefficients, for estimating loads, providing source load estimates, and evaluating various management alternatives.”

What Are Models?

Mathematical models are analytical abstractions of the real world and as such represent an approximation of the real system.

In the context of watershed planning, mathematical models are computer based, simplified representations of landscape and water quality processes that govern the fate and transport of one or more pollutants.
Two Basic Types of Models

- Empirical Model
- Mechanistic Model

Empirical Model:

- A model where the structure is determined by the observed relationship among experimental data.
- These models can be used to develop relationships for forecasting and describing trends.
- These relationships and trends are not necessarily mechanistically relevant.

Source: EPA website, glossary of frequently used modeling terms.
An Example of an Empirical Model:

- Investigating the relationship of inflowing nutrients in a lake to algal biomass production (eutrophication).
- Most early (circa 1970) lake eutrophication models based on statistical relationships between mass loading of nutrients and average algal biomass (e.g., Vollenweider models with numerous adaptations by others)
- Applied to PL-566 reservoirs in North Bosque River Watershed

Annual mean summer chlorophyll-a concentration as a function of predicted total-P for years 1993-1998 from PL-566 reservoirs. N=25
Mechanistic Model:

- A model that has a structure that explicitly represents an understanding of biological, chemical, and/or physical processes.
- These models attempt to quantify phenomena by their underlying casual mechanisms.

Source: EPA website, glossary of frequently used modeling terms and our Handbook
Two Common Mechanistic Models Used in Watershed Modeling in Texas:

- HSPF – Hydrologic Simulation Program - FORTAN
- SWAT – Soil & Water Assessment Tool
- Both models are comprehensive watershed loading, hydrologic, water quality models.
- Both models are intensive in use of resources and skills to operate the models.
- More on these a little later.

Types of Mechanistic Models

- Steady State Model
- Dynamic Model
Steady-State Models:

A mathematical model of fate and transport of waterborne constituents using constant input parameters to predict constant values of receiving water quality concentrations (typically under low-flow conditions)

Source: Our Handbook

An Example: QUAL2K

QUAL2K is a stream water quality model. It is one-dimensional* and operates under steady-state flow. All water quality variables are simulated on a diurnal (24-hour) time scale, including dissolved oxygen.

*fully-mixed in the vertical and lateral directions
Dynamic Models:

A mathematical model of fate and transport of waterborne constituents formulated to describe the physical behavior of a system and its temporal variability.
SWAT Prediction for a Subbasin of North Bosque River (Streamflow)

**SC020 Monthly Average daily streamflow**

- **E = 0.30**
- **%E = -29.0**
- **M = 0.11**
- **P = 0.08**

SWAT Prediction for a Subbasin of North Bosque River (Total Phosphorus)

**SC020 Monthly Total TP**

- **E = -8.7**
- **%E = 199**
- **M = 88**
- **P = 263**
HSPF & SWAT – Two Dynamic Watershed Models:

- Both supported by EPA BASINS (Better Assessment Science Integrating Point & Nonpoint Sources)
- Include processes of:
  - Rainfall/runoff
  - Erosion & sediment transport
  - Pollutant loading
  - Stream transport
  - Management practices

Model efficiency (E) for measured and predicted daily (d) and monthly (m) flow, total suspended solids (TSS), and nutrient loadings during (a) calibrations and (b) verification, at the outlet of the UNBRW.
HSPF & SWAT
General Impressions by Presenter

- Both models are complete watershed and water quality models with several state variables (runoff, streamflow, bacteria, nutrients, dissolved oxygen, toxics).
- HSPF has an edge in predicting hydrology
- SWAT more user friendly
- SWAT more powerful in representing agricultural practices
- HSPF more powerful in urban environment
- HSPF has an edge with instream fate and transport processes

EPIC & APEX – Two Dynamic Field-Scale Models:

- Field-scale: application focused at the subbasin or smaller level; often on a single land use
- EPIC – Environmental Policy Integrated Climate
- APEX – Agricultural Prediction Policy/Environmental eXtender

Developer: Dr. Jimmy Williams, BREC
Field plot and rain gauge locations within the Goose Branch microwatershed.

APEX Application: Measured versus predicted storm runoff volume for a) all values and b) for values less than 50 cubic meters per hectare.
APEX Application
Comparison of measured and predicted storm loads of total nitrogen.

APEX predicted soil extractable P levels (0-15 cm) for Coastal bermudagrass field.
Load Duration Curves

• Not a model
• Method of data organization and presentation that assists in understanding and refining water quality assessments (data requirements: streamflow and pollutant data)
• Applicable to stream systems
• Explained in previous session.

Load duration curves including MOS, historical data, and flow regimes - Station 10938, West Fork Trinity River
What Questions Can Models Assist in Answering?

- Will management actions achieve desired goals?
- Which sources are the main contributors to pollutant load?
- What are the loads associated with individual sources?
- Which combination of management actions will most effectively meet identified goals?
- When does impairment occur?
- Will the loading or impairment get worse under future conditions?
- How can future growth be managed?

Examples of questions models can answer from

North Bosque River (SWAT)
Upper Oyster Creek (QUAL2K)
SWAT Model Subbasins for North Bosque River Watershed

Land Use and Soluble-P Sources North Bosque River at Clifton

**PO₄-P Source Contribution**

- Dairy Waste Appl. 49%
- Pasture 14%
- Wood/Range 22%
- Urban 6%
- Crop 5%
- WWTP 10%

**Land Uses**

- Wood/Range 71%
- Urban 2%
- Pasture 9%
- Dairy Waste Appl. 4%
- WWTP 10%
- Crop 9%
- Urban 2%
### Scenarios Evaluated

<table>
<thead>
<tr>
<th>Scen</th>
<th>Filter strip</th>
<th>WWTP 1 mg/l</th>
<th>New lagoon</th>
<th>50% manure</th>
<th>NRCS New PL-566</th>
<th>Micropy remed.</th>
<th>HWAF remed.</th>
<th>75% manure</th>
<th>WWTP 0.5 mg/l</th>
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### Exceedance Probability Graph for the North Bosque River at Valley Mills

- full-permitted baseline
- full-permitted baseline avg
- 1990s baseline
- 1990s baseline avg
- future A
- future A avg
- future G
- future G avg
Upper Oyster Creek - Lower Reach

Lower Reach Summer Critical High Temperature - Upper Oyster Cr. (Preliminary Results)

Present Permit Limits
Criteria
- BOD=5 mg/L, NH3=2 mg/L, DO=6 mg/L

Steep Bank Cr.
Hwy 6
Stafford Run
Dam 3

Location, km
Dissolved Oxygen, mg/L
Complex Watershed Modeling Systems:

- Reservoirs
- Tidal & Estuarine Systems

Integrated Modeling Approach for Watershed and Reservoir

- **The Soil and Water Assessment Tool (SWAT)**
  - applied to the Bosque River Watershed to predict In-stream PO$_4$-P (or Soluble P) concentrations
  - Used to assess various P Control Strategies
Integrated Modeling Approach

**CE-QUAL-W2**, a two-dimensional, laterally averaged, hydrodynamic and water quality model

- developed by U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, MS
- applied to Lake Waco to predict in-lake PO$_4$-P concentrations and algal response
- Used to assess various P Control Strategies

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Modeling System Linkage

**SWAT: Watershed & CE-QUAL-W2: Lake**

**Watershed Model**

- Input Data:
  - Meteorological
  - Land Use
  - Soils
  - Topographic
  - Point Sources
  - Land management practices

**Watershed Model Output:**

- Streamflow
- Loadings

**Lake Model**

**Lake Model Output:**

- Water quality conditions
- Water levels

**Additional Input Data:**

- Meteorological
- Releases
Segmentation of Lake Waco

Figure 1. Lake Waco-Bosque River watershed.
CE-QUAL-W2 Calibration

Exceedence Probability for Lake Waco
Tidal Streams & Estuaries

- Link watershed model to appropriate hydrodynamic and water quality models
- Watershed: HSPF, SWAT, etc.
- Water Quality: for example, Water Quality Analysis Simulation Program (WASP)
- Hydrodynamic model: for example, DYNHYD, RMA2, Environmental Fluid Dynamics Computer Code (EFDC; Public Domain Code)
- Complete H/WQ models: EFDC (Proprietary Code), CE-QUAL_W2

Integrated Modeling System for Watershed and Arroyo Colorado Tidal Dissolved Oxygen & Bacteria

Soil and Water Assessment Tool (SWAT)
- Watershed model with stream component
- Predicts loadings into CE-QUAL-W2
- Predicts changes in loadings from control measures

CE-QUAL-W2
- A two-dimensional model of Tidal Segment
- Predicting dissolved oxygen & bacteria
Arroyo Colorado (Tidal segment has depressed dissolved oxygen)

Source: Dr. Jaehak Jeong, BREC, Temple, TX
Agricultural BMPs Simulated with SWAT

Source: Dr. Jaehak Jeong, BREC, Temple, TX

Segmentation – Top View

ARROYO COLORADO TIDAL
Top View

164 no. of segments @ 250m
Reason for CE-QUAL-W2:
- Represent tidal influences & salt wedge
- Two-dimensional representation required
- DO variations within a day required

Urban Dominated Watersheds
- SWMM – Storm Water Management Model; hydraulic and water quality capabilities
- P8-UCM – Urban Catchment Model for evaluating nonpoint source controls
SWMM Modeling Example

Subbasins 30 & 32 at Site 8

Two Subbasin SWMM Modeling & BMP
SWMM Calibration for Stormwater Runoff

![Graph showing monitored vs. simulated runoff over time.]

Monitoring Site 8 (10/08/11 06:00 AM to 10/12/11 23:45 PM) Validation

**Measured Runoff**

**SWMM**

- Precipitation: 407.42
- Infiltration: 347.93
- Runoff: 58.01
- Surface storage: 3.08

**Total Volume (ac-ft):**

- Measured: 75.46
- Simulated: 58.01

**Typical Rain Event**

<table>
<thead>
<tr>
<th>Event Duration (yr)</th>
<th>TSS/BOD</th>
<th>TP/TN</th>
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<tr>
<td>1-yr Event</td>
<td>55%</td>
<td>29%</td>
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<tr>
<td>5-yr Event</td>
<td>62%</td>
<td>45%</td>
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<td>Load Reduction (%)</td>
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<td>(at BMP 2 System)</td>
<td>49%</td>
<td>29%</td>
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Load Reduction – BMP

<table>
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<th>Percent Removed (%) at BMP 2 System</th>
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<td>Typical Rain Event</td>
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<tr>
<td>TSS/BOD</td>
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<tr>
<td>TP/TN</td>
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Oh, No!

No Model Does Close to What Is Needed

Try load duration curve approach

or

Modify and adapt an existing model

An Example:

Modifying APEX to Better Accommodate Situations in Forestry

Work by Drs. Jimmy Williams, BREC & Ali Saleh, TIAER
Modifications of APEX for forestry conditions.

Simulated and measured sediment losses for (a) SHR and (b) CON treatments during 1980-1985 (average of three replications).
Four Considerations That Assist in Defining Your Model Application

1. **Relevance**: Is the approach appropriate to your situation?
2. **Credibility**: Has the model been shown to give valid results?
3. **Usability**: Is the model easy to learn and use? (If not, is the expertise available to apply a sophisticated model?) Are data available to support the model?
4. **Utility**: Is the model able to predict the water quality changes based on anticipated management changes?

Available Models & Model Capabilities

- See our Handbook, pages 8-18 through 8-27
- EPA’s Council on Regulatory Environmental Modeling (http://cfpub.epa.gov/crem/)
# Application Considerations

<table>
<thead>
<tr>
<th>Experience required</th>
<th>AGNPS</th>
<th>STEPL</th>
<th>GWLF</th>
<th>HSPF</th>
<th>P8-UCM</th>
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**Key:**

- **Experience:**
  - Substantial training or modeling expertise required (generally requires professional experience with advanced watershed and/or hydrodynamic and water quality models)
  - Moderate training required (assuming some experience with basic watershed and/or water quality models)
  - Limited training required (assuming some familiarity with basic environmental models)
  - Little or no training required

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**Source:** Handbook, page 8-26

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**Questions?**