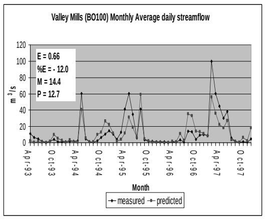
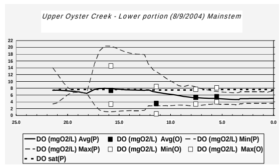


Overview of Models for Estimating Pollutant Loads & Reductions

(Handbook Chapter 8.3–8.5)

Texas Watershed Planning Short Course
Wednesday, Jan 14, 2009
Larry Hauck
hauck@tiaer.tarleton.edu



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, Utah 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:

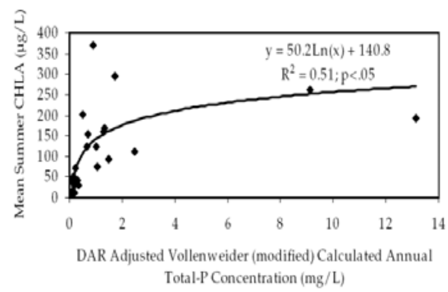
- A model where the structure is determined by the observed relationship among experimental data.
- These models can be used to develop relationships for forecasting and describing trends.
- These relationships and trends are not necessarily mechanistically relevant.

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

Presentation II 7



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

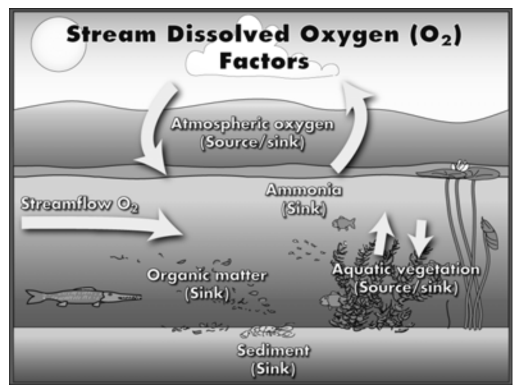
Presentation II 8

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

Presentation II 9



Presentation II 10

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.

Presentation II 11

Types of Mechanistic Models

- Steady State Model
- Dynamic Model

Presentation II 12

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

Presentation II 13

An Example: QUAL2K

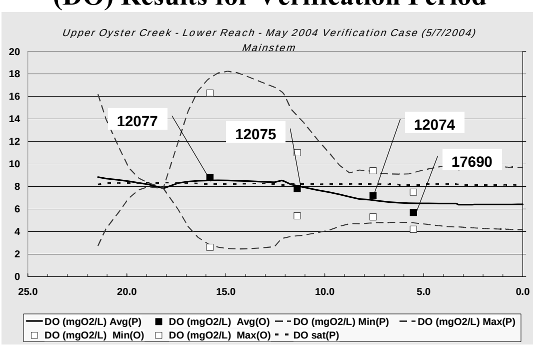
QUAL2K is a stream water quality model. It is one-dimensional* and operates under steady-state flow.

All water quality variables are simulated on a diurnal (24-hour) time scale, including dissolved oxygen.

**fully-mixed in the vertical and lateral directions*

Presentation II 14

Portion of Oyster Creek – Dissolved Oxygen (DO) Results for Verification Period



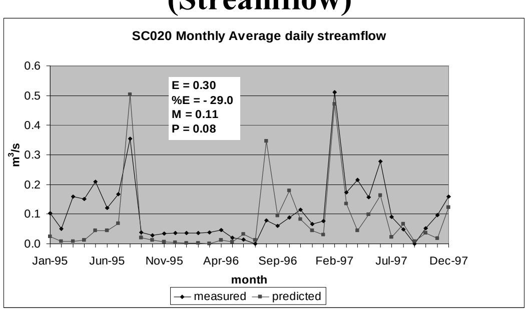
Presentation II 15

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

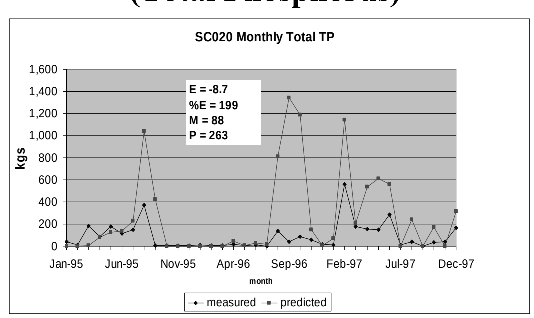
Presentation II 16

SWAT Prediction for a Subbasin of North Bosque River (Streamflow)



Presentation II 17

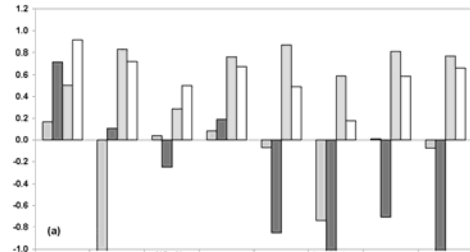
SWAT Prediction for a Subbasin of North Bosque River (Total Phosphorus)



Presentation II 18

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



	Flow	TSS	NO_3-N + NO_2-N	PO_4-P	Organic-N	Particulate-P	Total-N	Total P
SWAT(d)	0.17	-2.50	0.04	0.08	-0.07	-0.74	0.01	-0.08
HSPF(d)	0.72	0.11	-0.25	0.19	-0.85	-4.18	-0.71	-1.15
SWAT(m)	0.50	0.83	0.29	0.76	0.87	0.59	0.81	0.77
HSPF(m)	0.91	0.72	0.50	0.68	0.49	0.18	0.59	0.66

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.

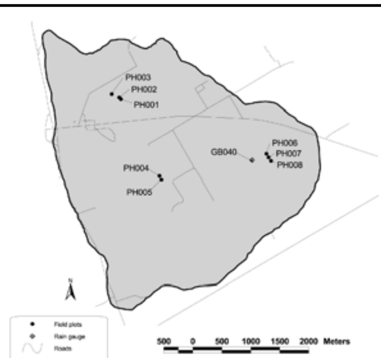
HSPF & SWAT
General Impressions by Presenter

- 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

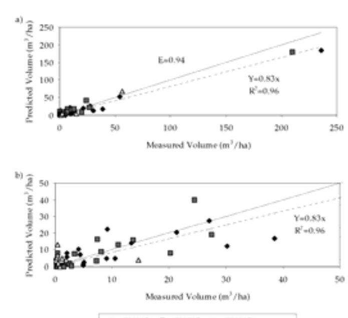
EPIC & APEX – Two Dynamic Field-Scale Models:

- 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

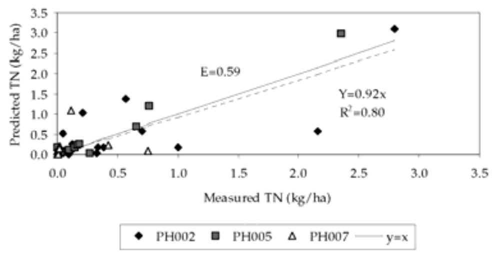
Developer: Dr. Jimmy Williams, BREC



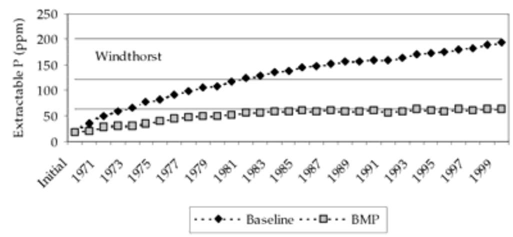
Field plot and rain gauge locations within the Goose Branch microwatershed.



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



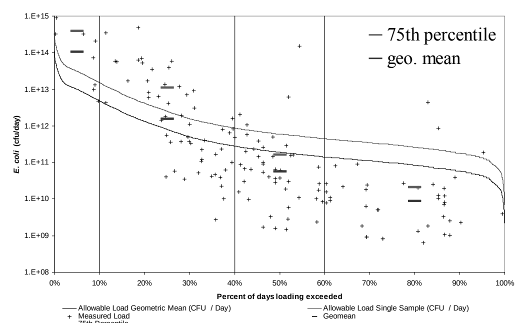
APEX Application
Comparison of measured and predicted storm loads of total nitrogen.



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?

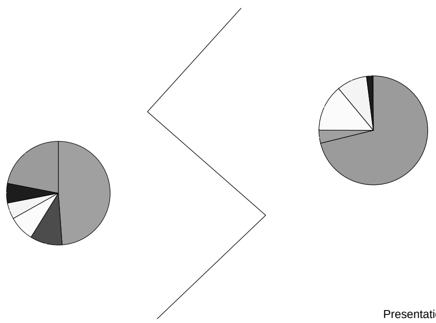
- Will management actions achieve desired goals?
- Which sources are the main contributors to pollutant load?
- What are the loads associated with individual sources?
- Which combination of management actions will most effectively meet identified goals?
- When does impairment occur?
- Will the loading 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)

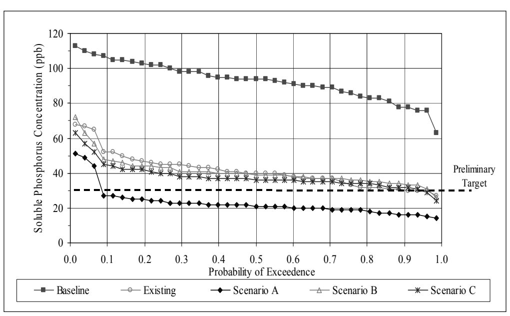
Land Use and Soluble-P Sources North Bosque River at Clifton



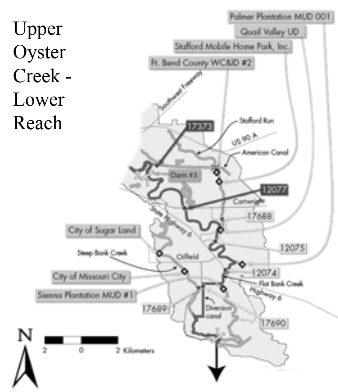
BMPs Imposed on Selected Scenarios

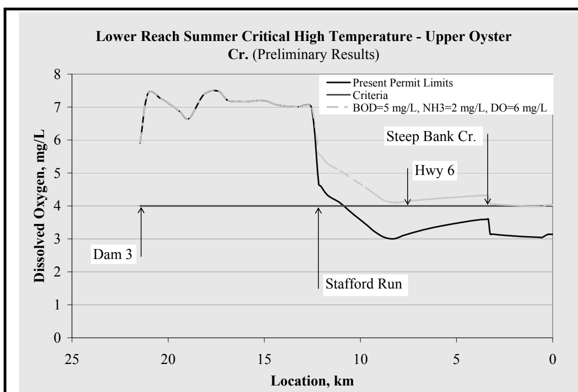
Scenario	WWTP Flow	WWTP P Limit	Dairy Manure App. Rate	Dairy Feed P Diet	Dairy Manure Haul off
Existing	1997-98	Median	Btw N&P Rate	No	No
Baseline	2020	Median	N rate	Yes	No
Scenario A	1997-98	1 mg/l	P rate	Yes	No
Scenario B	2020	1 mg/l	P rate	Yes	No
Scenario C	2020	1 mg/l	P rate	Yes	Yes

Exceedence Probability for the North Bosque River at Valley Mills



Upper Oyster Creek - Lower Reach





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 concentrations**
  - **Used to assess various P Control Strategies**

Presentation II 37

Integrated Modeling Approach

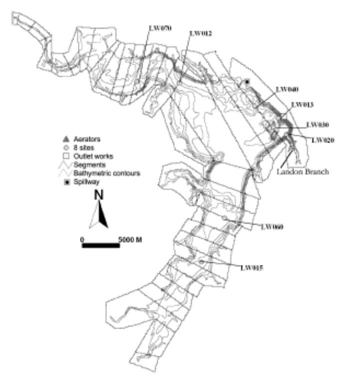
CE-QUAL-W2, a two- dimensional, laterally averaged, hydrodynamic and water quality model

- **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**

Presentation II 38

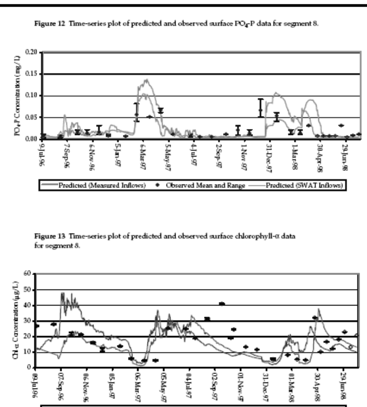
Lake Waco-Bosque River Watershed

Presentation II 39



CE-QUAL-W2 Segmentation of Lake Waco

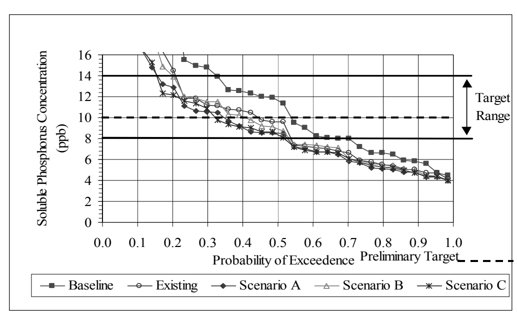
Presentation II 40



CE-QUAL-W2 Calibration

Presentation II 41

Exceedence Probability for Lake Waco



Presentation II 42

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
- Complete H / WQ models: for example, Environmental Fluid Dynamics Computer Code (EFDC)

Presentation II 43

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?

Presentation II 44

Available Models & Model Capabilities

- See our Handbook, pages 8-18 through 8-27
- EPA. 1997. Compendium of Tools for Watershed Assessment and TMDL Development. EPA841-B-97-006
- EPA's Council on Regulatory Environmental Modeling (http://cfpub.epa.gov/crem/)

Presentation II 45

Application Considerations	AGNPS	STEPL	GWLF	HSPF	P8-UCM	SWAT	SWMM
Experience required	◗	●	●	—	●	○	—
Time needed for application	◗	●	●	—	●	◗	○
Data needs	◗	●	●	○	●	◗	○
Support available Support available	◗	○	○	●	○	◗	◗
Software tools	◗	●	●	●	○	●	○
Cost to purchase	●	●	●	●	●	●	●

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

Source: Handbook, page 8-26

Presentation II 46

Oh, No!

No Model Does Close to What Is Needed

Try load duration curve approach

or

Modify and adapt an existing model

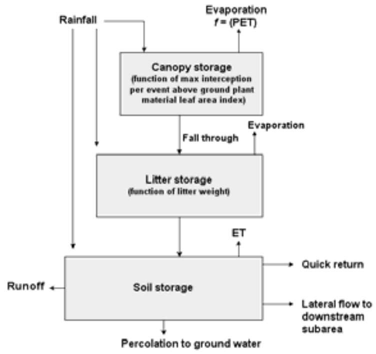
Presentation II 47

An Example:

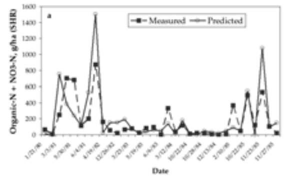
Modifying APEX to Better Accommodate Situations in Forestry

Work by Drs. Jimmy Williams, BREC & Ali Saleh, TIAER

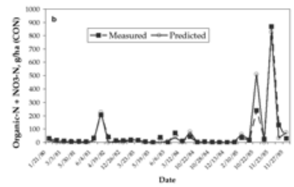
Presentation II 48



Modifications of APEX for forestry conditions.

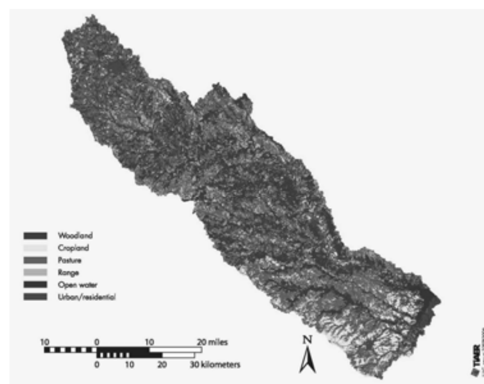


Simulated and measured sediment losses for (a) SHR and (b) CON treatments during 1980-1985 (average of three replications).



An Example Model Selection & Application

North Bosque River Watershed

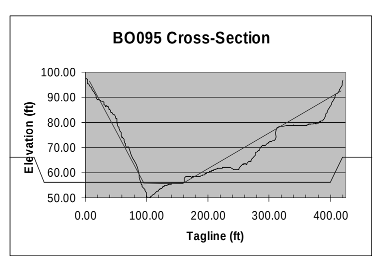


Land Use – Lake Waco Watershed

North Bosque River Watershed with SWAT subbasin delineation

Measured X-sectional Areas

X-sectional areas measured at over 10 sites along the North Bosque and its tributaries.



Model Validation

The validation process consists of model ***calibration*** and ***verification***.

Calibration - model parameters are adjusted within allowable limits until model output for a given time period matches measured output within some predetermined measure of model performance.

Verification - refers to running the calibrated model (i.e., holding adjustment parameters constant) during a different time period and comparing model output to measured values.

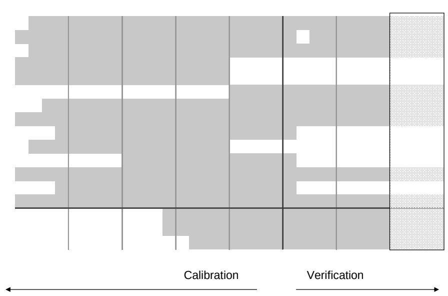
Note: Definitions & terms vary from those in Handbook.

Model Validation

Calibration and verification increases confidence that the model will accurately simulate watershed conditions for different management scenarios.

This process gives confidence that the model output during management scenarios will reasonably reflect what the true measured values would be.

Calibration and Verification Periods



Measures of Model Performance

Nash-Suttcliffe goodness of fit (E)

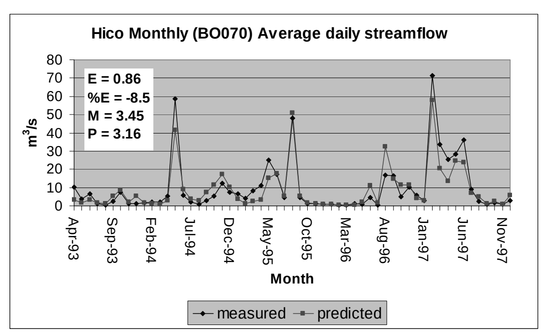
% error (% E)

Measures of Model Performance Percent Error ($\pm$ %E)

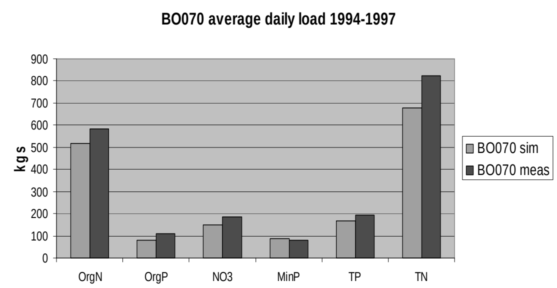
	Sediment	P, N
Very Good	< 15	< 25
Good	15 - 30	25 - 40
Satisfactory	30 - 55	40 - 70
Unsatisfactory	> 55	> 70

Moriasi et al. (2007)

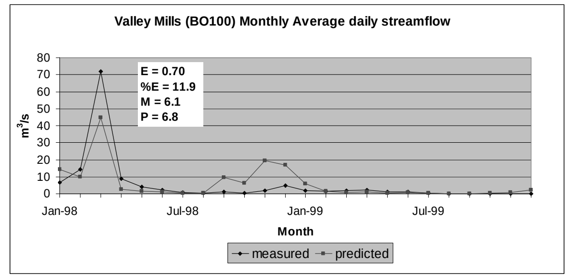
Calibration of Total Streamflow



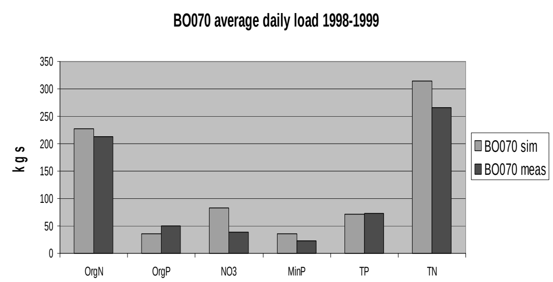
Calibration: Average daily loads



Verification Period (flow)



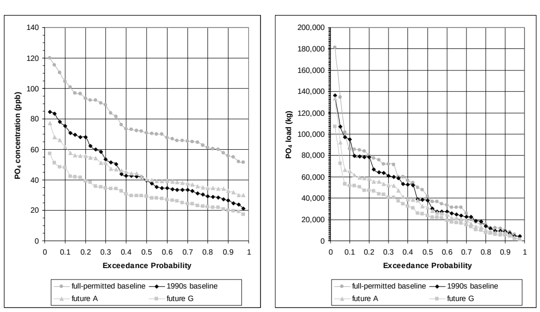
Verification: Average daily loads

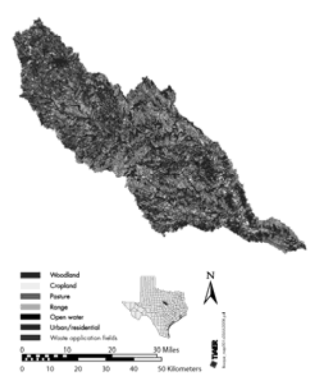


Scenarios Evaluated

	P	R	A		C	T	I	C	E	S	
Scen	Filter strip	WWTP 1 mg/l	New lagoon	50% manure	NRCS	New PL-566	Microgy remed.	HWAF remed.	75% manure	WWTP .5 mg/l	Red. graze
A	x	X	x	x	x						
B	x	x	x	x	x	x					
C	x	x	x	x	x	x	x				
D	x	x	x	x	x	x	x	x			
E	x	x	x		x	x	x	x	x		
F	x		x		x	x	x	x	x	x	
G	x		x		x	x	x	x	x	x	x

1990s and Future Baseline and Scenario A and G Annual daily-average PO_4 conc. and annual PO_4 loadings At Valley Mills (PRELIMINARY RESULTS SUBJECT TO CHANGE)





Land Uses of North Bosque River Watershed with dairy waste application fields

Questions?

Presentation II 67