Addressing Watershed Nonpoint Source Pollution With An Integrated Environmental And Economic Computer Modeling System Using an Automated Program

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INTRODUCTION

- There is a need for a modeling system to evaluate the economic and environmental impacts of various BMPs on water quality at the field and watershed levels.
- Provides savings of resources by allowing evaluation of BMPs without necessitating costly and large-scale field testing
- This will provide decision makers a valuable tool for faster and more realistic decisions.

Modeling System

- **CEEOT**: Comprehensive Economic & Environmental Optimization Tool
  - **FEM -** Farm Economic Model
  - **APEX** – Agric. Policy/Environmental eXtender
  - **SWAT** – Soil & Water Assessment Tool

Models (Economics) FEM
Farm-level Economic Model

- A whole-farm annual model that simulates the economic impacts of a wide range of scenarios on privately owned agricultural operations
- Model is calibrated with extensive data on farm practices, budgets and other watershed information
- Includes a number of simulation and optimization routines.

Environmental Models

- Watershed-scale model:Soil and Water Assessment Tool, SWAT
- Field-scale model: Agricultural Policy/Environmental eXtender, APEX
- These process-based nonpoint source models are used to assess and evaluate various BMPs (best management practices) at field and watershed levels.

Watershed Scale Model (SWAT)

- SWAT and APEX are daily-time step models
- SWAT was developed to predict the effect of different management scenarios on water quality, sediment yields, and pollutant loading in rural watersheds
- SWAT allows data input via Geographical Information System (GIS)

Field-scale Model (APEX)

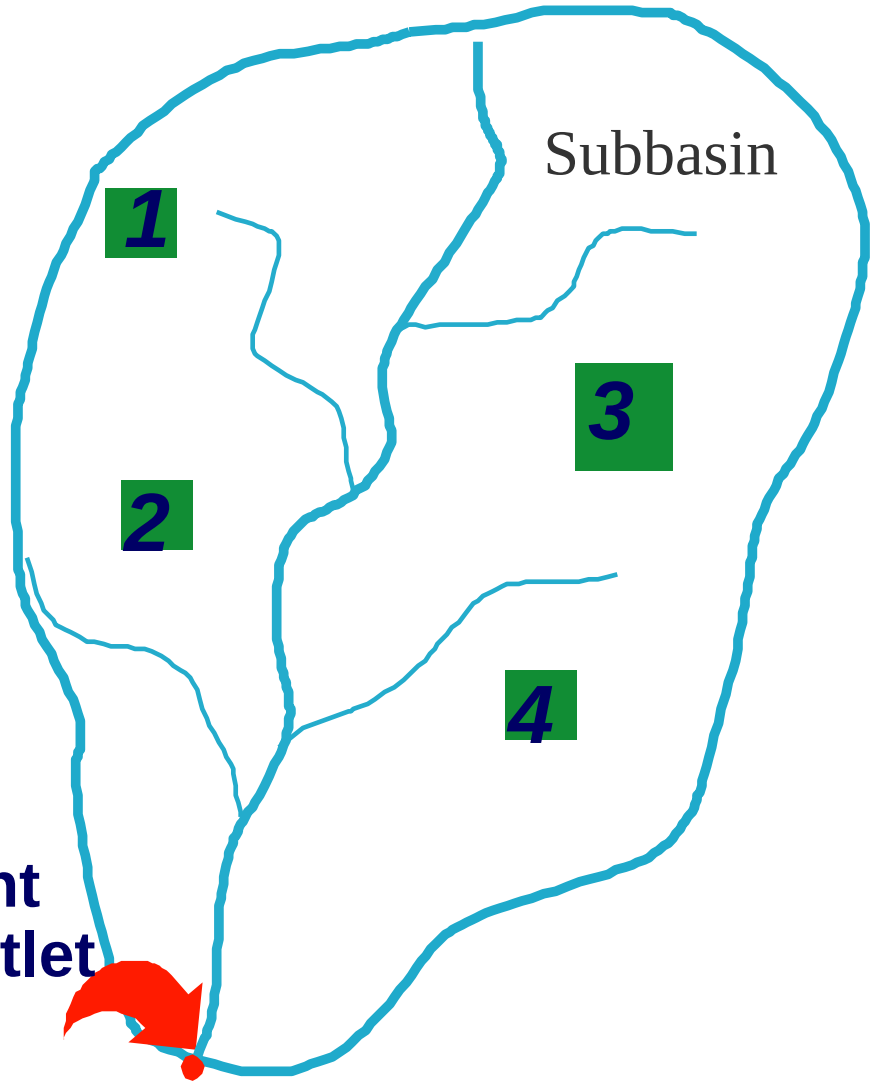
- APEX was designed to simulate the edge-of-field runoff volume, nutrients and loadings of sediment and nutrients from crop and animal producing lands
- Output from APEX for each field can be input as a point source into the SWAT model

Advantages of SWAT and APEX

- APEX
  - More precise simulation at the field level
  - Simulation of management practices (e.g., multiple cropping and filter strips)
  - Wind erosion, etc.
- SWAT
  - Generates the required data bases using AVSWAT
  - Stream routing function
  - Input from other models and point sources, etc.

APEX-SWAT Linkage

- **Simulated Landuse by APEX**



Input daily APEX edge-of-field flows, and sediment and nutrient Loadings at SWAT subbasin outlet

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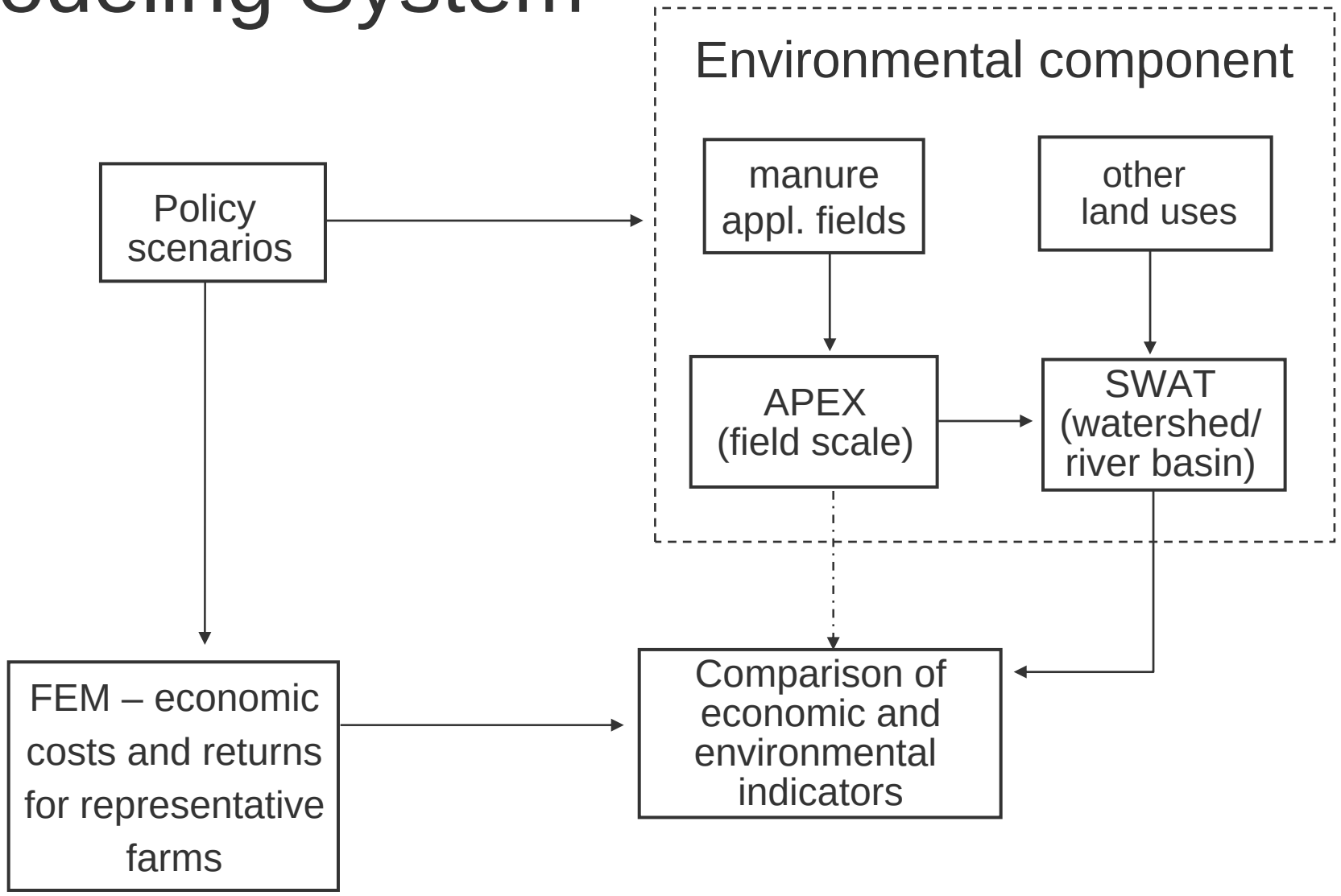
Modeling System



Examples of CEEOT Applications

- The following slides show some of the watersheds studied using CEEOT
  - Upper North Bosque River watershed, Texas
  - Lake Fork Reservoir watershed, Texas
  - Duck Creek watershed, Texas
  - Mineral Creek watershed, Iowa
  - Upper Maquoketa River watershed, Iowa
- Subsequent slides show scenarios and results for the upper Maquoketa river watershed, Iowa

An Example

Upper Maquoketa River Watershed

Northeast Iowa

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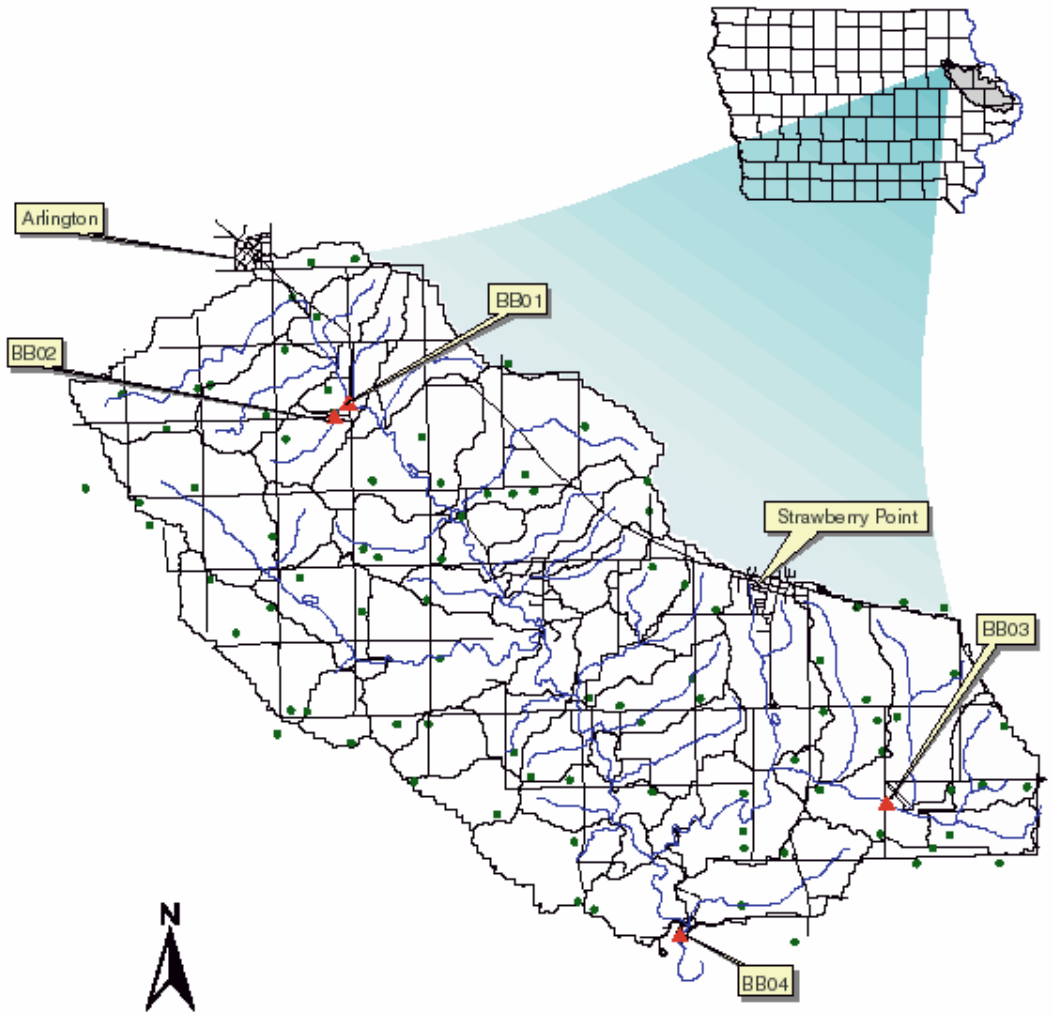
Upper Maquoketa River Watershed
Sub-basins and Producer Locations



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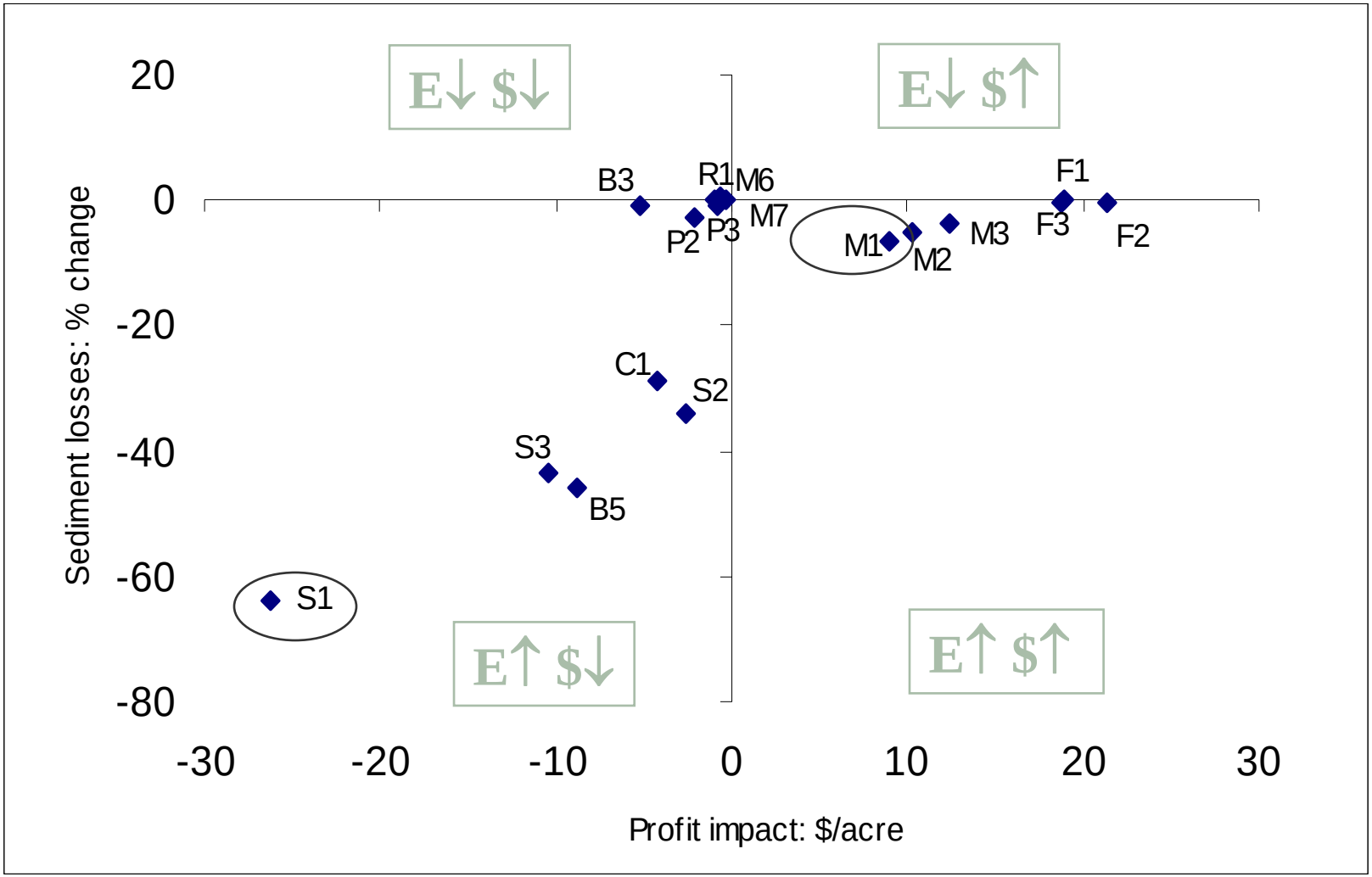
List of scenarios (1 of 2)

Scenario	Scenario Description
Manure Application (M)	
M1	Manure applied at the N rate and manure nutrient crediting
M2	Manure applied at the high P rate and manure nutrient crediting
M3	Manure applied at the low P rate and manure nutrient crediting
M6	Incorporation of solid manure
M7	Injection of liquid manure
Fertilizer Application (F)	
F1	Elimination of fall crop removal fertilizer applications on all cropland
F2	Reduced N application on all cropland
F3	Reduced and split N application on all cropland
Cropland tillage (c)	
C1	No-till on all cropland

List of scenarios (2 of 2)

Soil Management (S)	
S1	Terraces on cropland with slopes greater than 2 percent
S2	Contouring on cropland and pastureland with slopes greater than 2 percent
S3	Contour buffer strips on cropland with slopes greater than 2 percent
Ration Modifications (R)	
R1	Phytase-supplemented rations for swine farms
Structural BMPs (B)	
B3	Filter strips on manure application fields
B5	Enhancing and developing waterways for all cropland
Production System (P)	
P2	Hoop structures for all swine operations
P3	Hoop structures for open lot swine operations
Illustrative Combinations of Individual Practices	
Maquoketa 1	No-till and reduced N rate on all cropland b
Maquoketa 2	Contour buffer strips on cropland with slopes greater than 2 percent; reduced N on cropland b
Maquoketa 3	Contour crop and pastureland with slopes greater than 2 percent; reduced N on cropland b
Maquoketa 4	No-till on solid manure fields and injection of liquid manure



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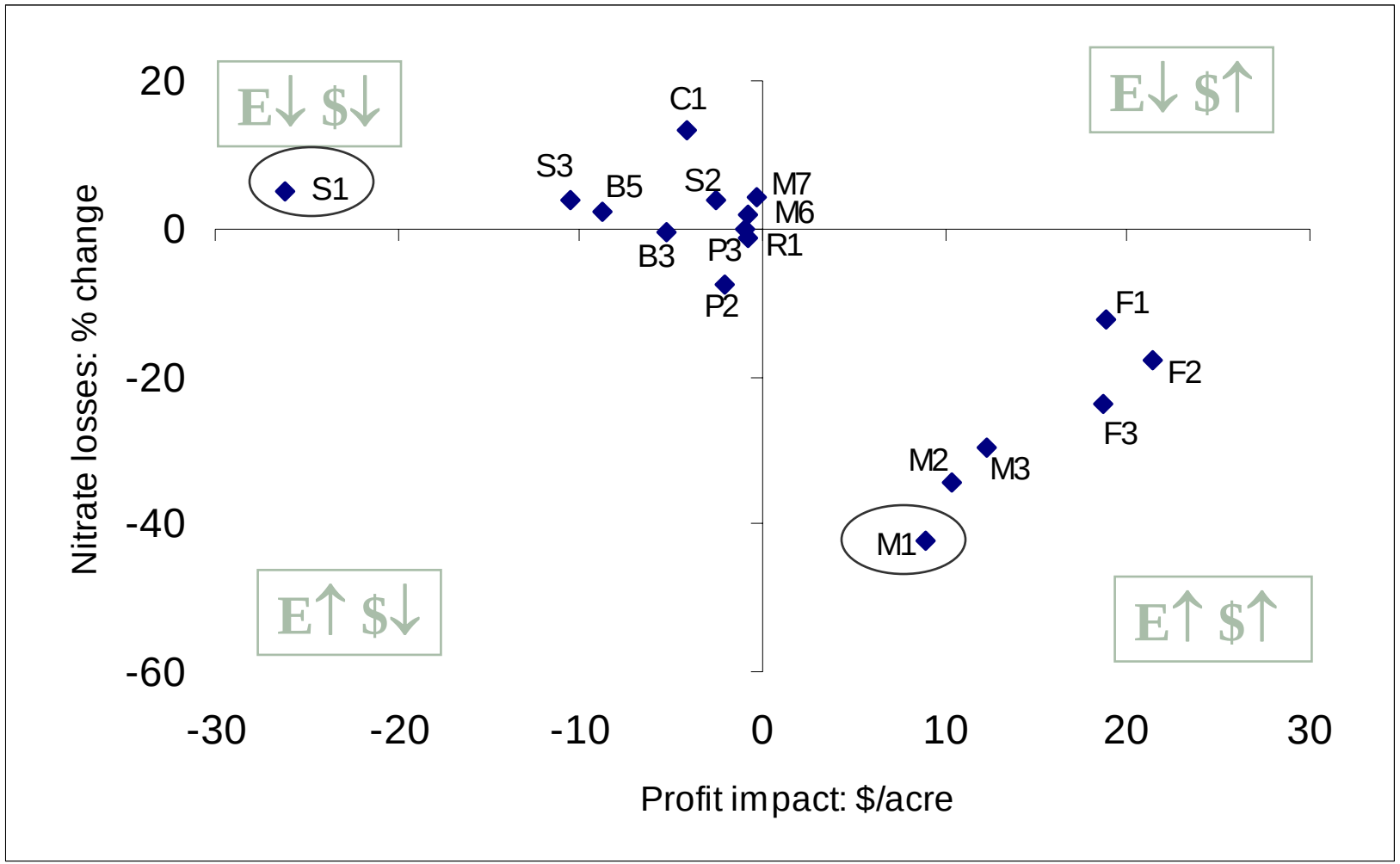

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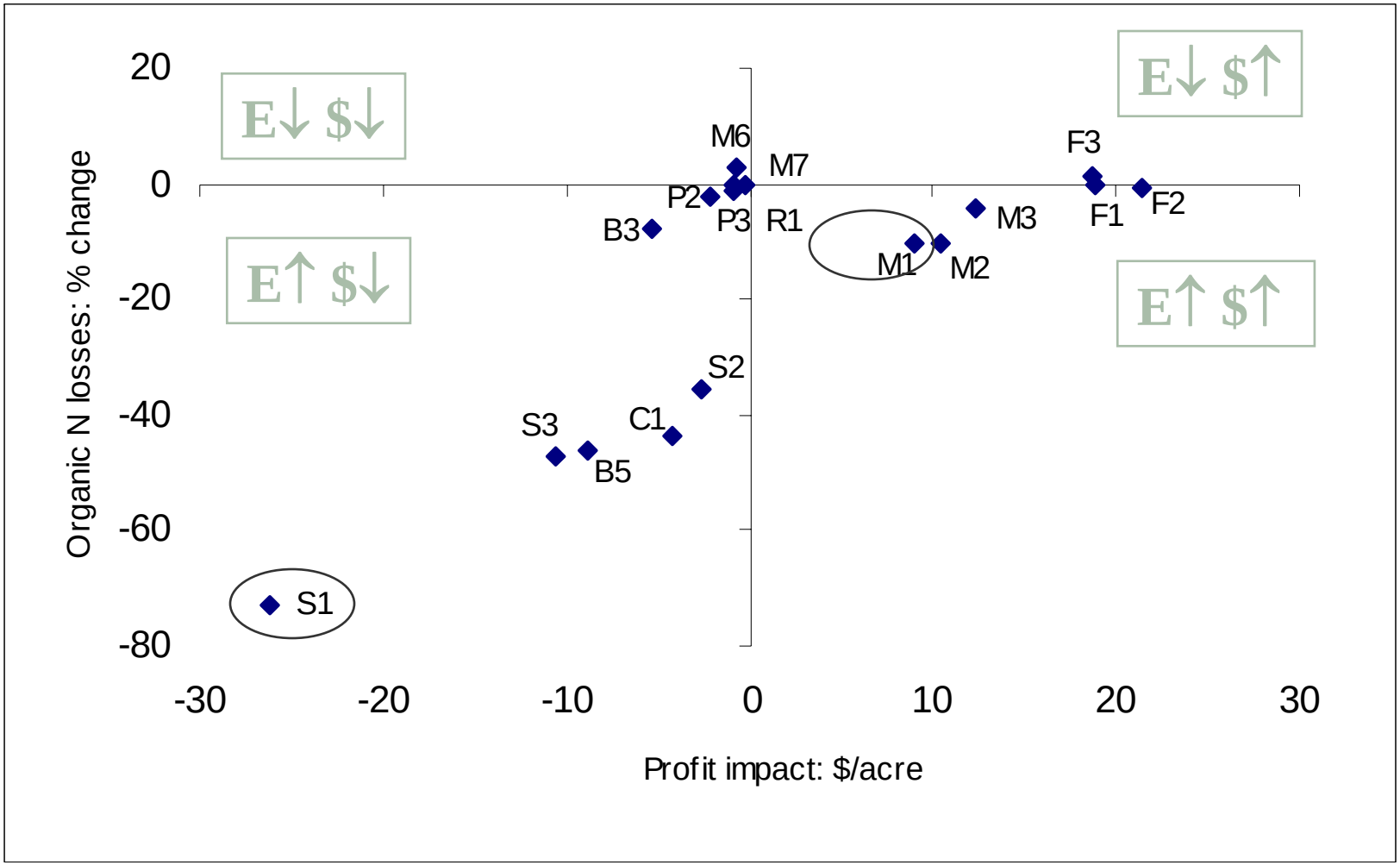

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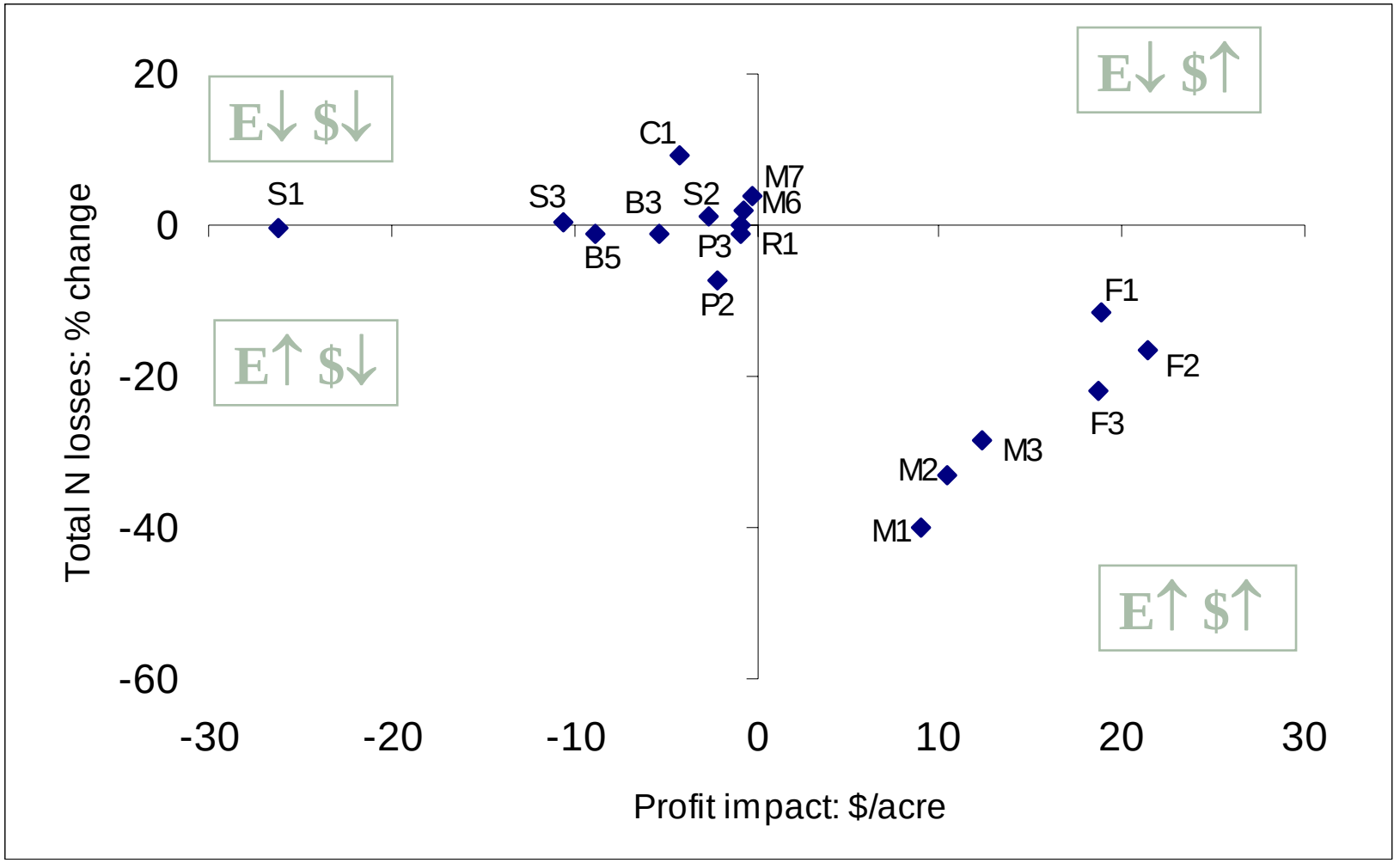

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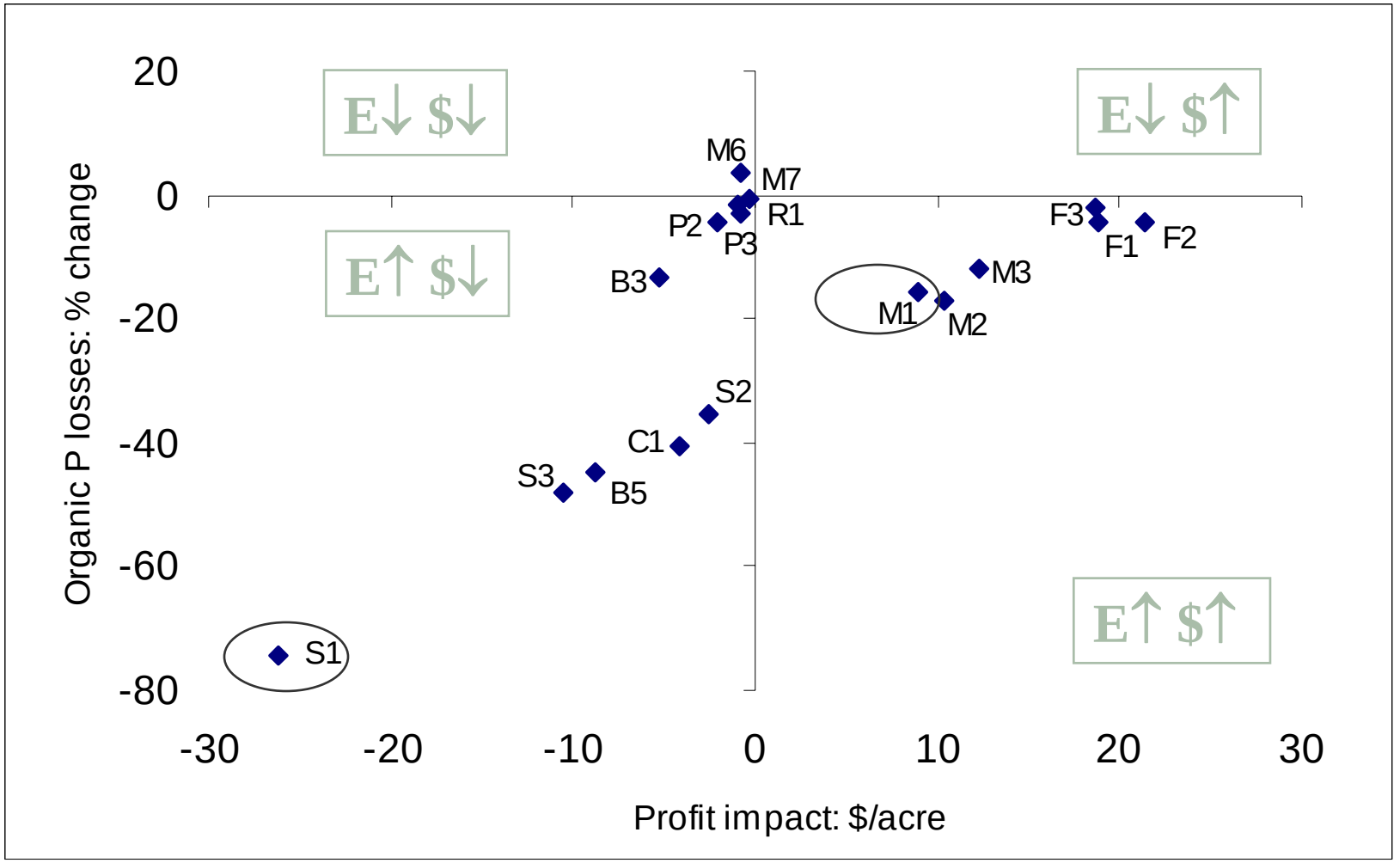
E↓ $↓
E↓ $↑
E↑ $↓
E↑ $↑
M6
M7
R1
P2
P3
F3
F1
F2
B3
M3
M1
M2
S2
C1
S3
B5
S1
20
0
-20
-40
-60
-80
-30
-20
-10
0
10
20
30
Organic P losses: % change
Profit impact: $/acre

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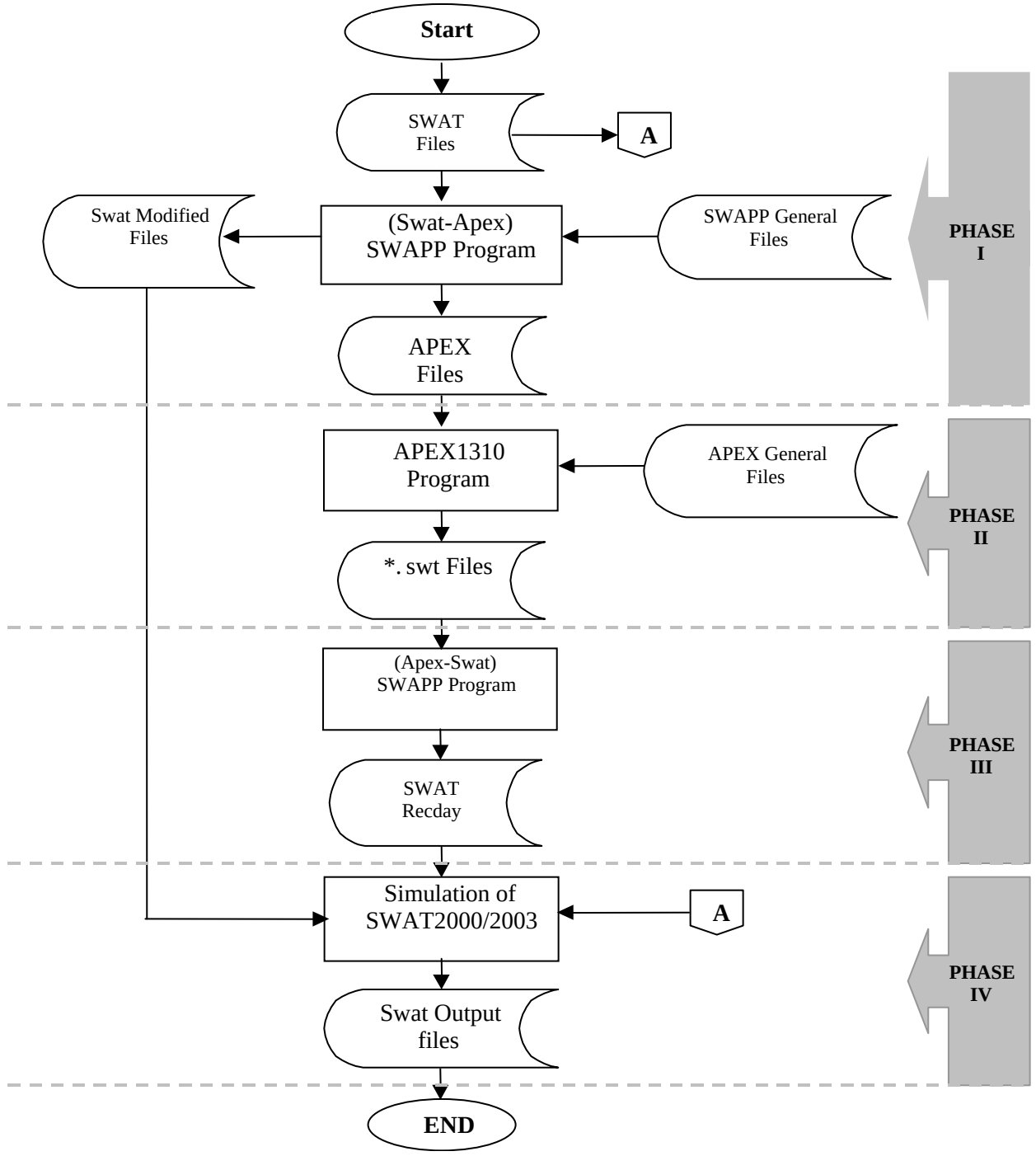
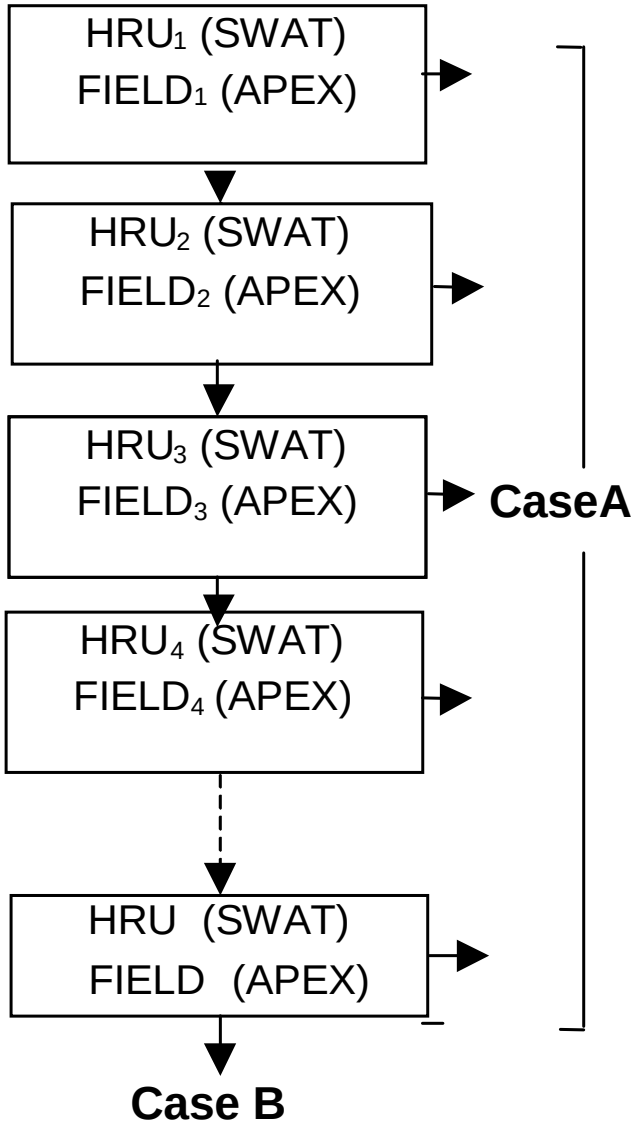
SWAT and APEX linkage Program (SWAPP)

Objective:

Develop an automated program to facilitate the simultaneous use of nested models within CEEOT program


Start
SWAT Files
A
Swat Modified Files
(Swat-Apex) SWAPP Program
SWAPP General Files
PHASE I
APEX Files
APEX1310 Program
APEX General Files
PHASE II
*. swt Files
(Apex-Swat) SWAPP Program
PHASE III
SWAT Recday
Simulation of SWAT2000/2003
A
PHASE IV
Swat Output files
END

Flow Regime in APEX



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→ Flow Direction

An Example

Upper North Bosque River Watershed (UNBRW)

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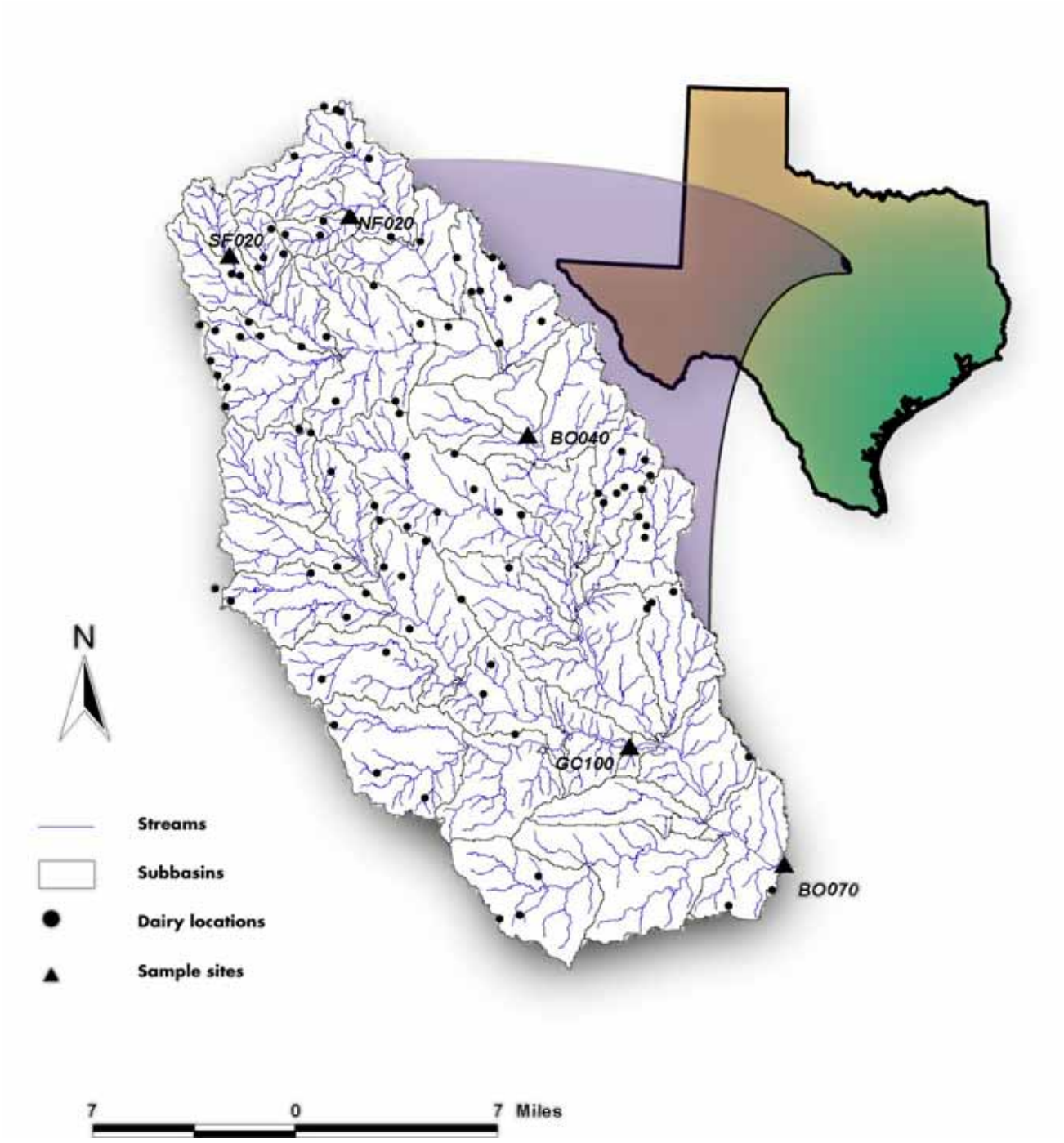
Upper North Bosque River Watershed

- 93,250 ha
- rangeland – 43%, woodland – 23%, forage fields – 23%
- dairy waste application fields – 7%
- 95 dairies; ~ 35,000 milking cows



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Land use Characteristics for drainage basin for site B040

Sampling Site	Area (km2)	Woodland (%)	Range (%)	Forage Fields (%)	Peanuts (%)	Orchard (%)	Water (%)	Urban (%)	Barren (%)	Waste Application Field (%)
BO040	**254**	**23.7**	**27.4**	**32.2**	**1.6**	**0.3**	**0.7**	**3.8**	**0.7**	**11.7**

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GIS Data Base

- Input data required by SWAT and APEX programs were generated from GIS maps using the AVSWAT program. These maps included elevation, soils, and land use/cover.

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Sampling Sites:

- Total suspended solids,
- Total nitrogen, ammonia, nitrate, nitrite,
- Total phosphorus, orthophosphate,
- A water-level measurement was obtained every five minutes at automated sampling sites and were converted to flow value through stage-discharge relationships developed for each specific site.

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LAND USE

SWAT

- PAST →
- RNGE
- FRST
- AGRR →
- URLD

APEX

- PAST
- AGRR

Simulations

- Calibration period
  - January 1,1994 to June 30, 1995
- Validation period
  - July 1, 1995 to December 30, 1998

Measure of model performance

- Nash and Sutcliff (1970) model efficiency

$$E = 1 - \frac{\sum_{i=1}^{n} (X_{mi} - X_{ci})^2}{\sum_{i=1}^{n} (X_{mi} - \overline{X}_m)^2}$$

X_{mi} = measured values, X_{ci} = predicted values, and $\overline{X}_m$ = average measured values. A value of ***E*** = 1.0 indicates a perfect match model. ***E*** is similar to a correlation coefficient obtained from linear regression; however, ***E*** compares the measured values to the 1:1 line of measured equals predicted (perfect fit) rather than to the best-fit regression line.

RESULTS
AND
DISCUSSIONS

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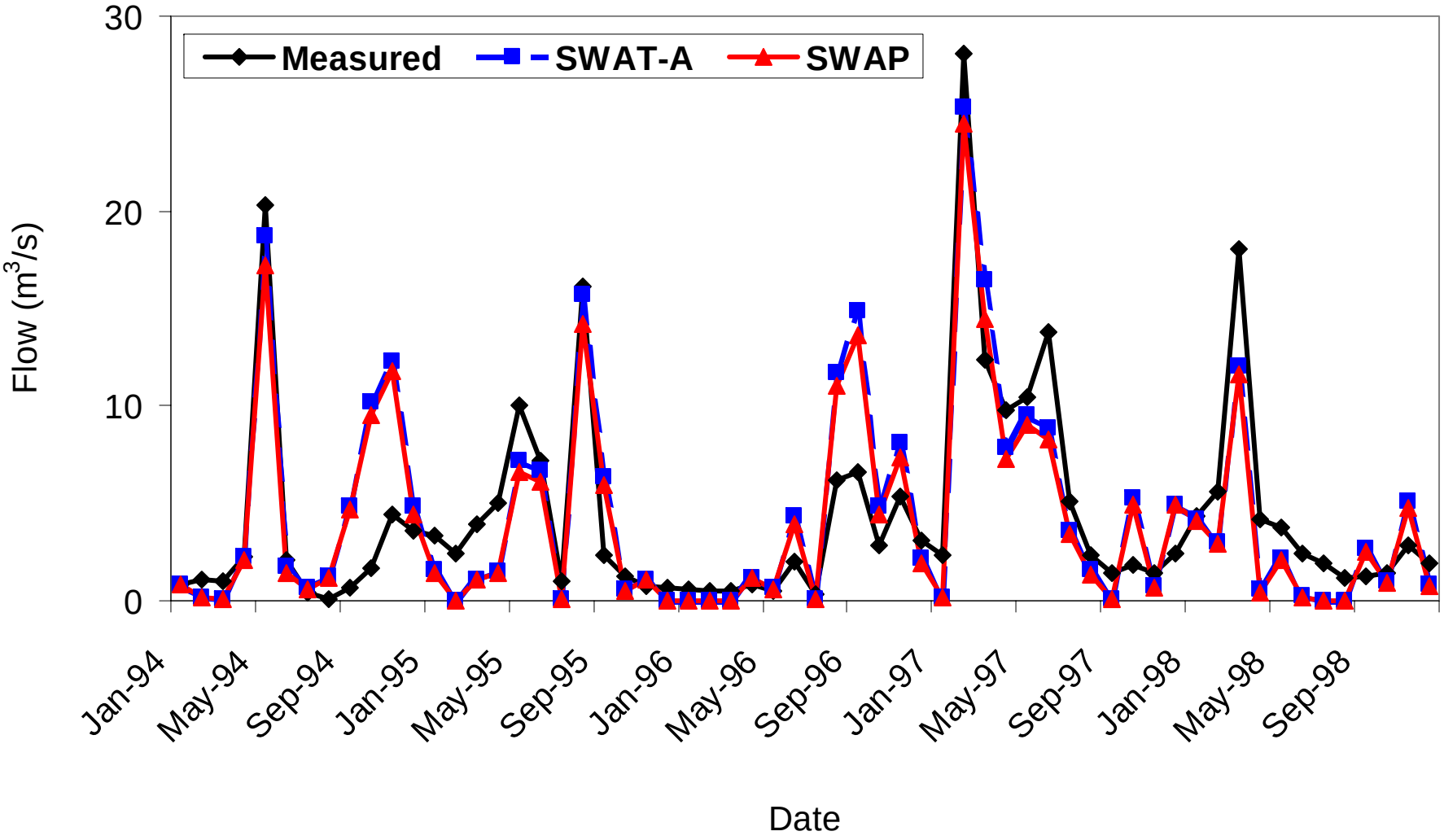
Measured and predicted monthly flow at the outlet of UNBRW (BO070)



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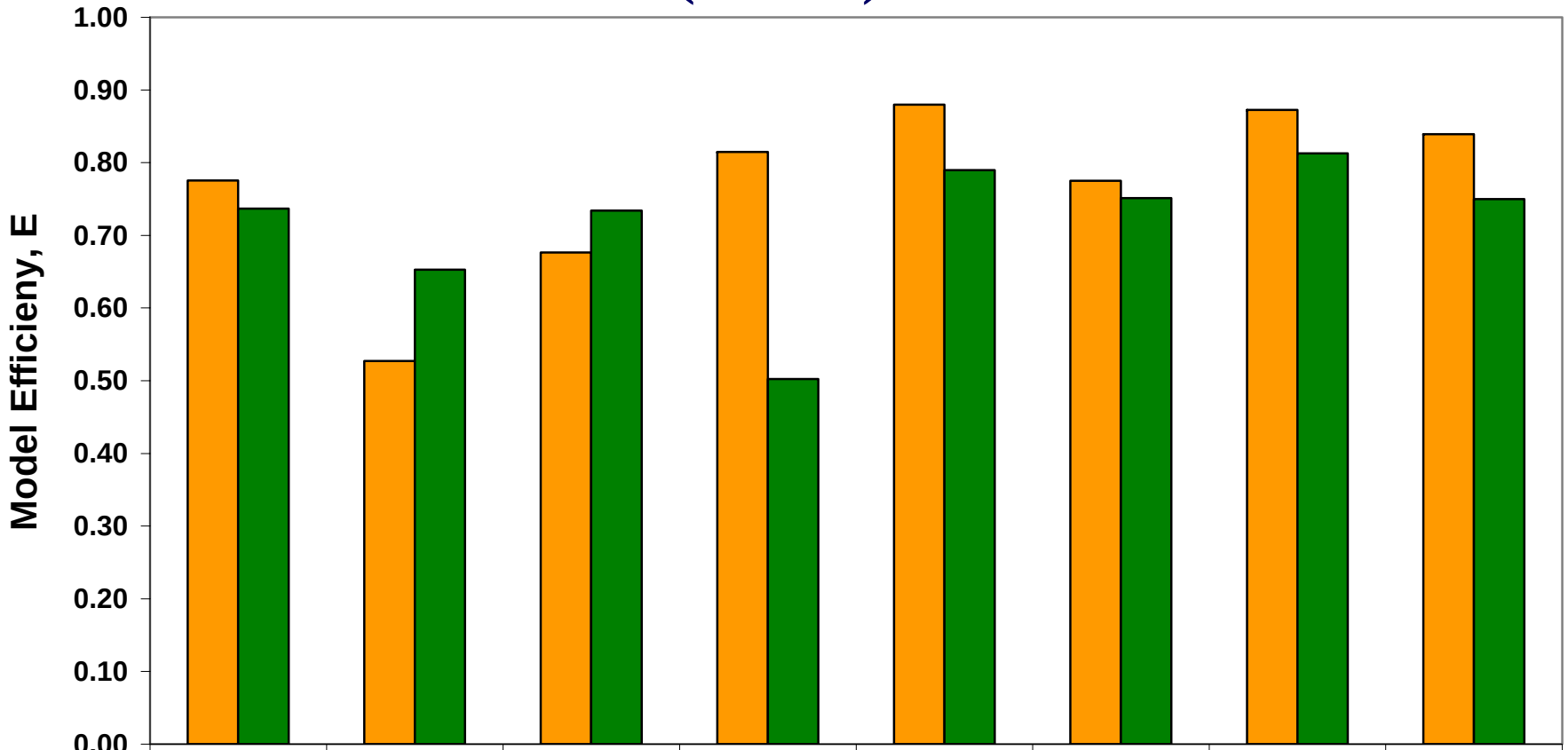
Model efficiency (E) for measured and predicted monthly flow, TSS, and nutrient loading at the outlet of UNBRW (BO070)



	Flow	TSS	NO_3-N + NO_2-N	PO_4	Organic-N	Particulate-P	Total-N	Total-P
SWAPP	0.78	0.53	0.68	0.81	0.88	0.78	0.87	0.84
SWAT-A	0.74	0.65	0.73	0.50	0.79	0.75	0.81	0.75

An Example of Filter Strip Simulation by SWAT and APEX

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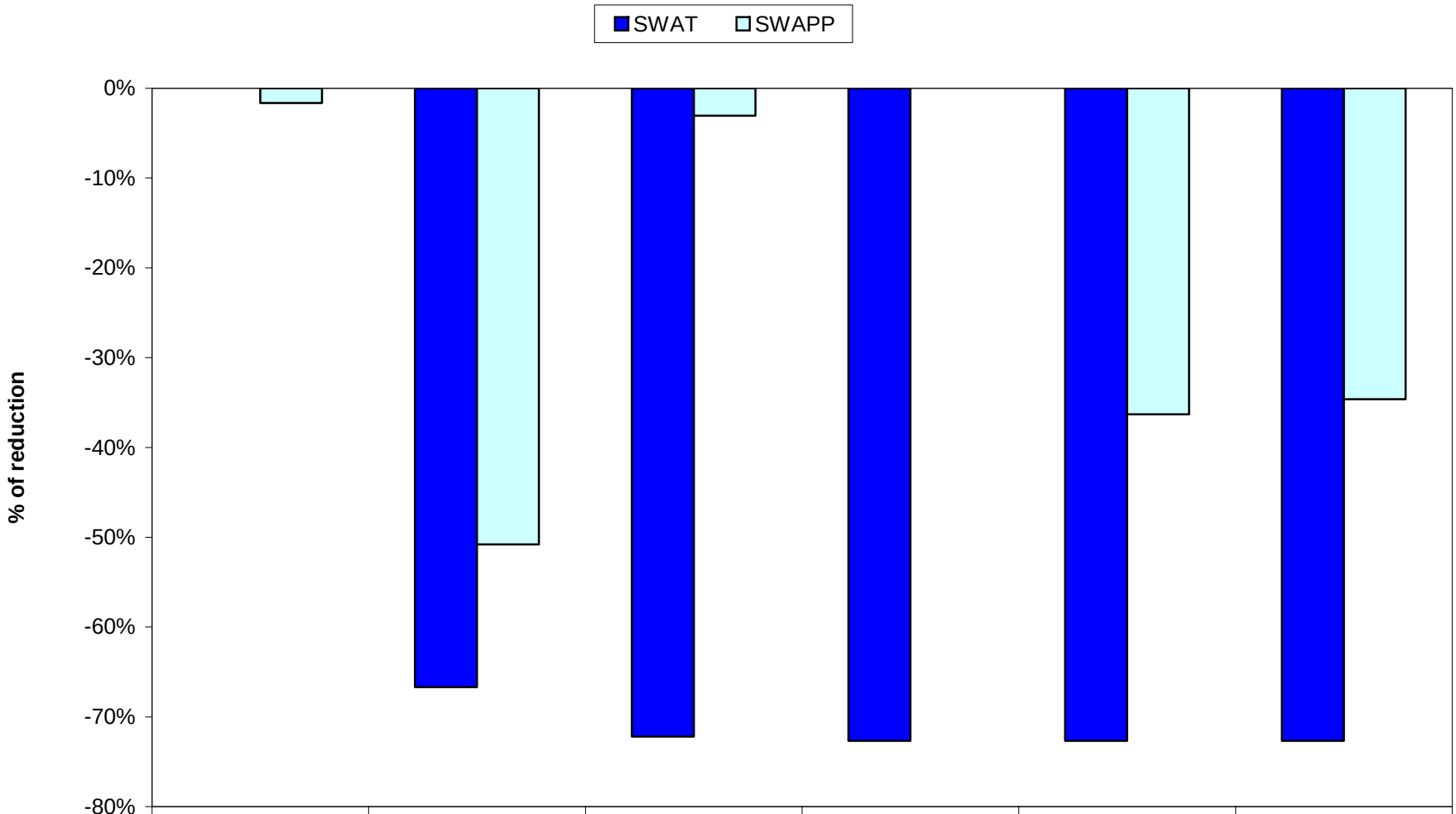
- Main Field
  - Continues corn with area of 630 ha
- Filter Strip Characteristics
  - Efficiency = 0.73 (based on SWAT calculation)
  - Width = 10 m
  - Area = 2.5 ha
  - Crop = Switch grass

SWAT and SWAPP Using Filter Strips



	Flow	TSS	NO3	PO4	Org N	Org P
SWAT	0.00%	-66.68%	-72.20%	-72.67%	-72.67%	-72.66%
SWAPP	-1.66%	-50.79%	-3.05%	0.00%	-36.31%	-34.62%

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Conclusions

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Conclusions (1 of 2)

- CEEOT program allows the simultaneous evaluation of economic and environmental impacts of BMPs on water quality
- CEEOT can be used as an important decision making tool
- CEEOT has been tested for different farming practices at various watersheds
- CEEOT and related models can be used to identify practices that are most cost effective and watersheds that are likely to see improvement

Conclusion (2 of 2)

- SWAPP development is an important addition to the CEEOT system.
- SWAPP allows the user to evaluate BMPs at the field and watershed scales more precisely
- SWAPP allows the user to simulate management practices, such as multiple cropping by APEX, which is not available in SWAT at this time.
- SWAPP is capable of generating APEX files through AVSWAT program
- The future version of SWAPP will include the FEM (economic) model

Thanks

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Acknowledgement

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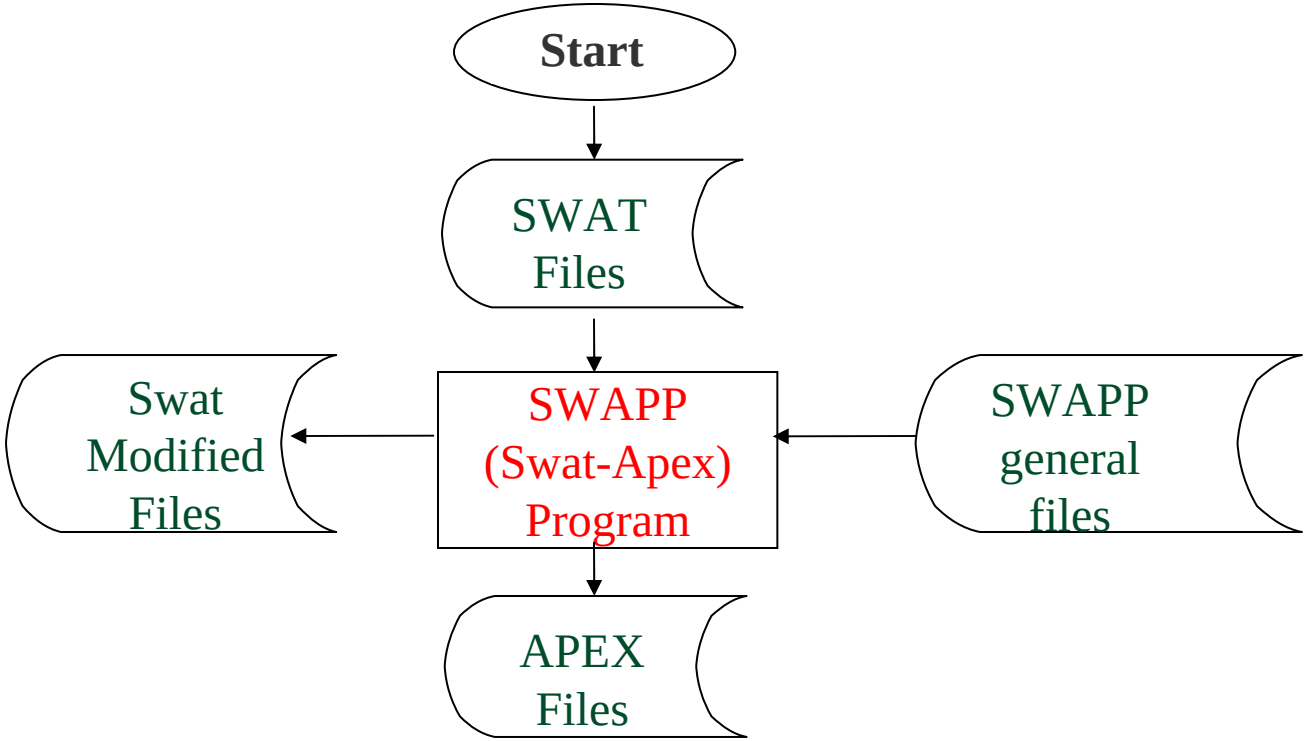
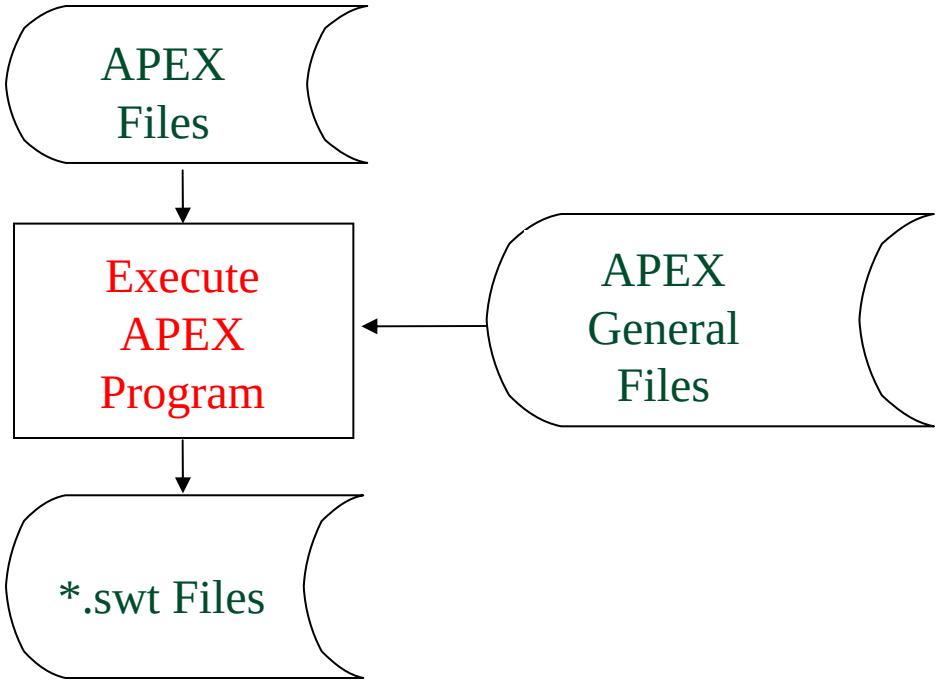
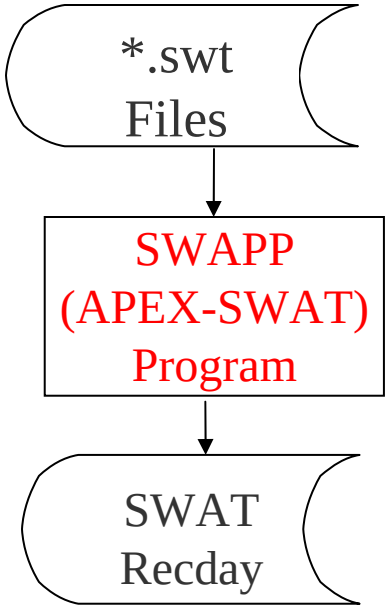
Phase I: SWAT to APEX



Phase II: APEX Simulation



Phase III: APEX to SWAT



Phase IV: SWAT Simulation